No. 141, Original Action

In the

Supreme Court of the United States

Texas v. New Mexico and Colorado

Expert Report of

Margaret Barroll, Ph.D.

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Prepared for:

State of New Mexico

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OVERVIEW OF THE QUALIFICATIONS OF DR. MARGARET (PEGGY) BARROLL

My name is Margaret ("Peggy") Barroll, Ph.D. I have been retained by the New Mexico Office of the Attorney General by and through the New Mexico Interstate Stream Commission (collectively, the "OAG") to opine on Rio Grande Project operations and accounting over time, including specifically the effects on Project allocation and operations of the 2008 Operating Agreement.

I provide consulting services specializing in hydrogeology focused primarily on my areas of expertise, the Rio Grande and Pecos River basins. Prior to my consulting work, I spent 26 years as a Senior Hydrologist for the State of New Mexico employed by the Office of the State Engineer ("NMOSE").

During my tenure at the NMOSE, I was a principal scientist in the development of MODFLOW groundwater models. Two of the models I have been deeply involved with are the Carlsbad Groundwater Model and the LRG_2007 Groundwater Model ("LRG" is an acronym for "Lower Rio Grande," as that portion of the Rio Grande river basin is known in New Mexico). Each of these models encompass large United Stated Bureau of Reclamation ("Reclamation") surface water irrigation projects: the Carlsbad Project and the Rio Grande Project. Notably, I was one of the developers of the LRG_2007 Groundwater Model, which is the basis for the groundwater model presented by Texas through their expert, Dr. William Hutchison (and as sanctioned by the U.S. through their expert Jean Moran of Stetson Engineers, Inc.).

My professional involvement with Lower Rio Grande issues within the States of New Mexico and Texas began circa 2000 and continues to the present. This work has involved the following:

- Groundwater modeling of the Lower Rio Grande aquifer system in New Mexico,
- Technical support for the development of administrative guidelines for water rights administration,
- Development of Active Water Resource Management ("AWRM") Rules,
- Analysis of groundwater level data both spatially and temporally,
- Trend analyses of groundwater pumping meter data,
- Numerous field visits to the Rio Grande Project in both New Mexico and Texas generally for the purposes of identifying and inspecting critical infrastructure and observing farm management practices,
- In-depth review of Rio Grande Project records relating to Project allocation, accounting, operations, and history,
- Quantitative analysis of Rio Grande Project allocation and accounting, compilation of Project allocation and accounting data from numerous disparate sources, and analysis of that data,
- Simulation of Rio Grande Project allocation through spreadsheet models.

My professional resume and publications from the last 10 years is attached as Section 12 to this report. Over the previous 4 years, I have not been a witness testifying as an expert at trial or by deposition. For the consulting services I am providing to the OAG, my compensation rate is $280 per hour for both expert report preparation and for any testimony I may give. My compensation is not dependent on the outcome of this litigation or the substance of my opinions.

INTRODUCTION TO REPORT

In this Report I explain the origins of the issues that have arisen over the past few decades between Reclamation, the State of New Mexico and the State of Texas over the management of the Rio Grande Project, and the practical results of actions taken by the parties involved that have led to the current litigation. Texas and the United States, through their pleadings and expert reports, make the disputed issues between the parties seem deceptively simple; they claim merely that New Mexico groundwater pumping hurts Texas. This is not the whole story, nor even the primary story of the Rio Grande Project operations and accounting issues between these three parties.

Because the actual issues involved are very complex and technical, I have arranged this Report to first generally educate the reader about how the Rio Grande Project operates, then delve more deeply into the technical issues that drive the Project and that led to dispute between New Mexico and Texas.

In Sections 1 through 5 I give overviews of the primary elements of the Rio Grande Project. Understanding how all these parts work together is necessary to comprehend the technical allocation and accounting issues I explain in Section 6. In Section 7 I describe the fundamental flaw in accounting calculations that contributes in large part to the current disputes. In Section 8 I quantify how current practices by Reclamation and Texas adversely impact New Mexico. Finally, in Section 9 I explain how the actions of Reclamation and Texas harm the Rio Grande Project as a whole, and lead to an unsustainable situation.

I have been involved in investigating and exploring these issues since 2000; I have conducted extensive research and analysis of historic and current data and I am intimately familiar with the history of Rio Grande Project operations. As described above, I was one of the developers of the computer model upon which Texas constructed the model it uses in this litigation.

Since 2000 I have been involved in discussions and negotiations with all the Reclamation, Texas, and New Mexico notable persons involved in management of the Rio Grande Project, both to understand the issues and to try to resolve problems as they arose. Some of the problems we have been able to resolve; for instance, in the early 2000s New Mexico demonstrated to the satisfaction of Reclamation and Texas that the significant salinity problems faced by the El Paso Valley were a natural phenomenon and not the result of any actions by New Mexico. Other problems remain, including problems related to present inequitable allocation of Project Supply between the New Mexico irrigation district ("EBID") and the Texas irrigation district ("EPCWID"), and the negative impacts to the groundwater systems underlying the entire Project and upon which citizens of both states rely.

Conclusions

Based upon my years of direct experience with the issues presented in this case, and the significant research and analysis I have undertaken at the request of the OAG, I have reached the conclusions below and support them with the following Report.

1. The Rio Grande Project 2008 Operating Agreement has greatly reduced the surface water supply to New Mexico farmers, to the detriment of New Mexico. Texas, however, has benefitted by the 2008 Operating Agreement through an increase in the allocation of water to its irrigation district, and because that district can now carry over large amounts of unused allocation from one year to the next.

2. The Rio Grande Project began delivering Project water in 1915. The two water Districts: Elephant Butte Irrigation District ("EBID," in New Mexico) and El Paso County Water Irrigation District No. 1 ("EPCWID," in Texas), were formed in the 1920s. The Rio Grande Compact was signed and took effect in 1938. From the beginning of Project Operations, each Project acre was entitled to the same delivery of water.

3. A 1938 Contract between the Districts sets forth a division of Project water supply between the Districts in accordance with the proportions of Project acreage: 88,000 of 155,000 Project acres (57%) to EBID, and 67,000 of 155,000 Project acres (43%) to EPCWID. From 1938 through 1978, Reclamation operated the Project so that EBID farmers were entitled to 57% of the U.S. share of Project Supply and EPCWID farmers were entitled to 43% of the U.S. share of Project Supply.

4. Starting in 1979, Reclamation explicitly allocated Project Supply to the Districts in the ratio of 57% to EBID and 43% to EPCWID. The total amounts allocated were defined using the D1/D2 Curves. The amounts of water diverted by the Districts and delivered to their farmers were consistent with this 57:43 ratio.

5. In 2008 an Operating Agreement (the "2008 OA") was reached between Reclamation, EBID, and EPCWID without the involvement or approval of New Mexico, Colorado, or the Rio Grande Compact Commission, except for the participation of the Texas Compact Commissioner as a mediator.

6. The 2008 OA adopts the D3 Allocation method which was proposed by EBID in 2006 and implemented in 2006. Under the D3 Allocation, EPCWID and Mexico are allocated Project water based on Project performance during the 1951 – 1978 period (the D1 and D2 Curves), and EBID is allocated whatever Project water is left over.

7. The 2008 OA also adopts "Carryover" (proposed in 2006 by EPCWID and partially implemented that year), so that unused allocation remaining to a District at the end of one year can be carried over intact to that same District the following year.

8. The effect of D3 Allocation, Carryover, and the 2008 OA has been to change the allocation of the U.S. share of Project water so that EPCWID is now allocated an average of 56% (not including Carryover) or 62% (including Carryover). EPCWID's actual charged diversions (that is, water actually called for, received, and charged to the District) during this period (2008-2018) have averaged 55% of total District charged diversions.

9. The D3 Allocation as initiated in 2006, has reduced EBID's full-supply allocation and the amount of water Reclamation has delivered to EBID in full-supply years by approximately one-third (1/3). EBID's full-supply allocation has dropped from 495,000 AF to less than 330,000 AF. Implementation of D3 Allocation in 2006 caused EBID's diversion in full-supply years to decrease from an average of 464,000 AF (in 1996-2002) to an average of 312,000 AF (2007-2009).

10. By contrast, the D3 Allocation and Carryover under the 2008 OA has actually increased EPCWID's full-supply allocation of water to levels not historically contemplated. EPCWID's current-year allocation (that is EPCWID's allocation apart from Carryover) in full-supply years has increased from 377,000 AF to an average of 391,500 AF. EPCWID's total allocation (including Carryover) has exceeded 500,000 AF in some years.

11. EPCWID Charged Diversions (that is, water actually called for, received, and charged to the District) in full-supply years under the 2008 OA have averaged less than 300,000 AF, leaving large amounts of unused, unneeded allocation which is "placed" in its Carryover account. One of the reasons EPCWID's Charged Diversions are as low as they are is because current Project accounting does not charge ECPWID for their diversion and use of municipal treated effluent generated in the El Paso Valley by the City of El Paso.

12. The D3 Allocation as initiated in 2006, and then set forth in the 2008 OA, reduces EBID's allocation to account for all negative departures from historical (1951 – 1978) Project performance. This allocation method is based on the assumption that all of the negative departures from historical performance are caused by New Mexico. However, a significant part of that negative departure in Project performance is caused by changes in Project accounting that have occurred since the 1951 – 1978 historical period. In addition, part of the negative departure in Project performance is caused by the effects of depletions and groundwater pumping in Texas and Mexico.

13. Since the advent of D3 Allocation and the 2008 OA, in many years EPCWID has been allocated amounts of water significantly greater than the amounts that District orders and diverts.

14. The 2008 OA has reduced EBID's share of Project supply during full-supply years below the amount needed to supply EBID's lands. As a result, EBID farmers have increased groundwater pumping.

15. The reduction in EBID's share of Project water has reduced the amount of recharge to the aquifer in the Rincon and Mesilla Valleys through canal seepage.

16. Between the increase in groundwater pumping and the decrease in recharge, the groundwater budget of the Rincon and Mesilla aquifer system has been negatively impacted by more than 100,000 AF/Y in full-supply years. Historically, shallow groundwater levels in the Rincon and Mesilla Valleys responded to surface water supply variation; groundwater levels dropped during times of low supply, and recovered in full supply years. Following implementation of D3 Allocation, shallow groundwater levels have dropped during low supply years, but have not recovered in the full supply years that follow.

17. The Project enjoyed full-supply conditions from 1979 through 2002, and EPCWID was allocated a full supply in each year. EPCWID diverted less than it was allocated in all but two of these years. Available Reclamation records do not suggest that EPCWID ordered water that it did not receive. Therefore, I conclude that EPCWID needed less water than it was allocated during this period.

18. Starting in the year 2003, EPCWID has received an allocation credit for the American Canal Extension ("ACE"). The ACE credit increases EPCWID allocation by up to approximately 20,000 AF. Under the allocation method in the 2008 OA, this same amount (up to ~20,000 AF) is subtracted from EBID's allocation, reducing EBID's total allocation and the amount EBID can order.

19. Because of the decrease in EBID's allocation under D3 Allocation, and because EPCWID is now allocated more water than it diverts in full-supply (or near full-supply) years, EPCWID makes much more use of Carryover than EBID. EPCWID has had a large Carryover account in several years.

20. EPCWID's Carryover account includes the effects of Project credits, some of which do not represent water left in reservoir storage. Carryover accounts are not reduced to account for evaporation. As a result, some amount of water in EPCWID's Carryover account is not associated with actual "wet" water. The amount of allocation carried over, and the extra water needed to deliver the Carryover, is subtracted from Usable Water before any new allocation is made. Therefore, part of the inflow to Elephant Butte is not available for allocation, but instead is used to support and fulfill EPCWID's Carryover account. This has had a significant negative effect on EBID's allocation.

21. Reclamation releases water from Caballo Reservoir in response to orders from the Districts and the Mexican delivery schedule. The amount released from Caballo is determined by combining those orders with current information on river gains and losses and on available drain flow. This calculation determines the amount of release from Caballo Reservoir which, when added to the amount of water already present at diversion headings from other sources, is equal to the District order at each heading. In full-supply years, any increase in drain flows or decrease in river losses would cause Reclamation to release less water from Caballo release in order to meet the existing orders, and there would not be any increase of flow to EPCWID. The assumption that any increase in drain flows would result in an immediate equivalent increase in the flow every year at Courchesne/El Paso is a fallacy. The reduction in Caballo release could, however, have an impact on the available supply in future low-supply years.

RIO GRANDE PROJECT ALLOCATION AND ACCOUNTING

1 OVERVIEW OF THE RIO GRANDE PROJECT

1.1 RIO GRANDE PROJECT BEGINNINGS

In 1905 Congress authorized the Bureau of Reclamation of the U.S. Department of the Interior ("Reclamation") to construct the Rio Grande Project ("Project") to provide irrigation water in southern New Mexico and western Texas, and also to address international water issues with Mexico. The first deliveries of Project water to irrigators were made by Reclamation in 1915.[1] A graphic of important Rio Grande Compact and Project Dates is in Appendix F.

In the 1920s, the Elephant Butte Irrigation District ("EBID") and the El Paso County Water Irrigation District ("EPCWID") (together, the "Districts")[2] were organized to manage water resources in their respective geographic regions and to enter into contracts to repay the United States for costs to construct the Project. In 1938, EBID and EPCWID entered into a contract (the "Inter-district Contract")[3] that allocated the Project's irrigated acreage between the two entities; this contract also assessed the District's proportional cost of repayment to the United States. The contract recognizes EBID authorized Project acreage of 88,000 acres and EPCWID authorized Project acreage of 67,000 acres for a total of 155,000 acres within the United States, and provides for each District to increase its authorized acreage by up to 3%. The Inter-district Contract states:

> *It is further agreed and understood that in the event of a shortage of water for irrigation in any year, the distribution of the available supply in such a year, shall so far as practicable, be made in the proportion of 67/155 thereof to the lands within El Paso County Water Improvement District No. 1, and 88/155 to the lands within the Elephant Butte Irrigation District.*

1.2 OVERVIEW OF GEOGRAPHY AND GROUNDWATER SYSTEM

The Project encompasses an area in southern New Mexico and west Texas that includes Elephant Butte and Caballo Reservoirs, EBID in the Rincon and Mesilla Valleys, and EPCWID in the Mesilla Valley and extending into the El Paso Valley, below Tornillo, Texas (see Figure 1.1). Downstream of EPCWID is the

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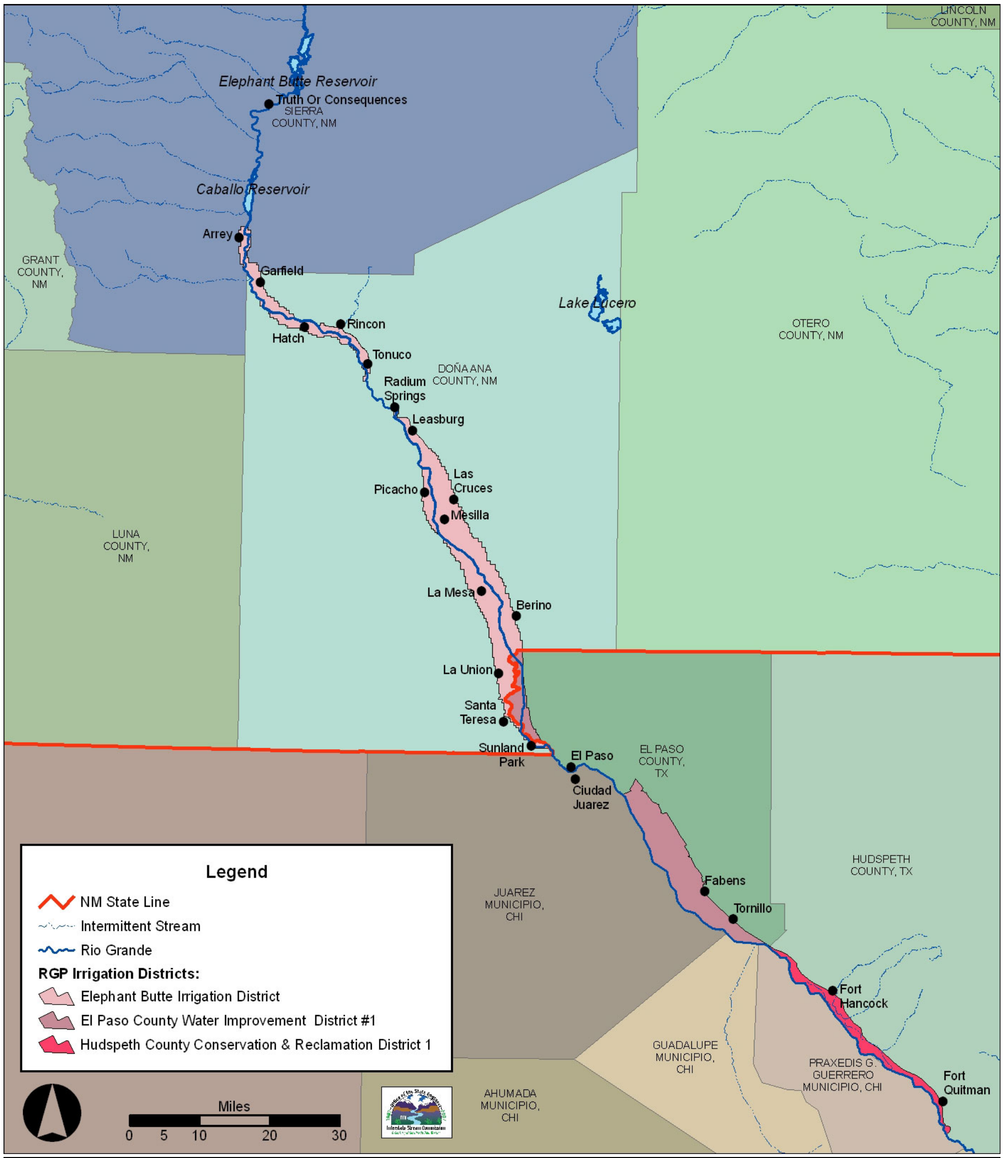
[1] *See* U.S. 33 Stat. 814, Natural Resources Committee 1938, and Autobee, Robert, *Rio Grande Project, Bureau of Reclamation,* 1994.

[2] Terms and acronyms used throughout this Report are defined in the Acronyms and Glossary, Section 10.

[3] March 18, 1938 Contract between Elephant Butte Irrigation District of New Mexico and El Paso County Water Improvement District No. 1 of Texas, signed by the U.S. Secretary of the Interior on April 11, 1938.

Hudspeth County Conservation and Reclamation District #1 ("HCCRD"), which is not part of the Project. HCCRD receives operational waste from the Project under contract.

Figure 1.1. General location of the Rio Grande Project



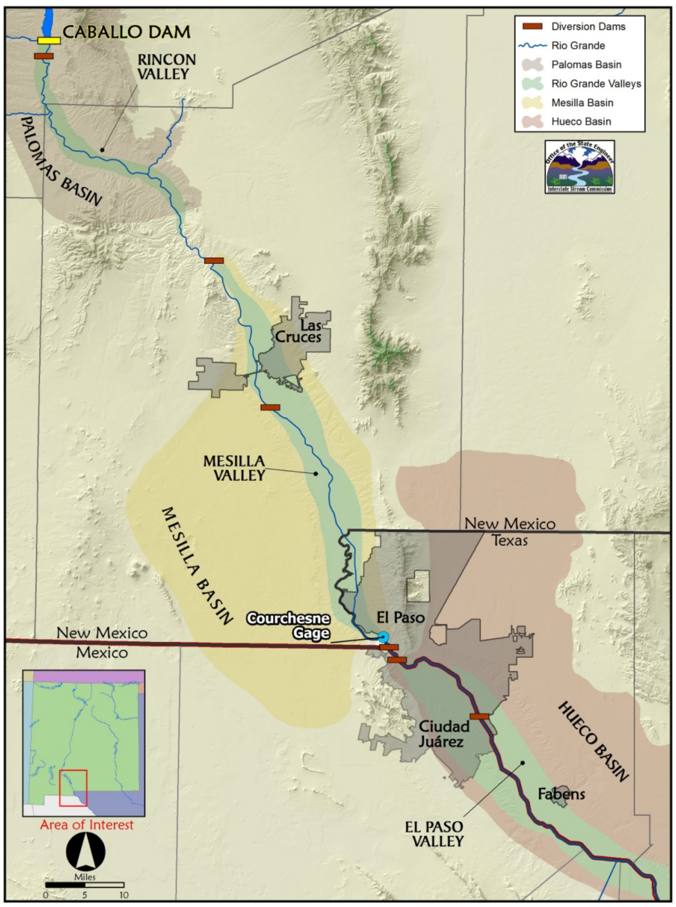
Geographically speaking, the Project area comprises portions of three river valleys along the Rio Grande (Figure 1.2):

1) The Rincon Valley extending from below Caballo Dam to Seldon Canyon,
2) The Mesilla Valley, extending from below Seldon Canyon to the El Paso Narrows, and
3) The El Paso and Juarez Valley (El Paso Valley) extending from below the El Paso Narrows to approximately Fort Quitman, downstream of EPCWID.

These river valleys are relatively narrow, often less than five miles from side to side, and are underlain by approximately 100 feet of river valley alluvial sediments, laid down by the Rio Grande itself over the last million years or so. This river valley alluvium is highly transmissive, which is to say that wells drilled into these sediments can produce large amounts of water. The river valley alluvium composes an important part of the aquifer system that supplies groundwater in the Project area.

Geographically, these river valleys are located within larger sedimentary basins, which were formed and filled with sediments over tens of millions of years. The Rincon Valley is within the much larger Palomas basin, the Mesilla Valley is within the larger Mesilla basin, and the El Paso Valley is within the larger Hueco basin (also known as the Hueco Bolson).

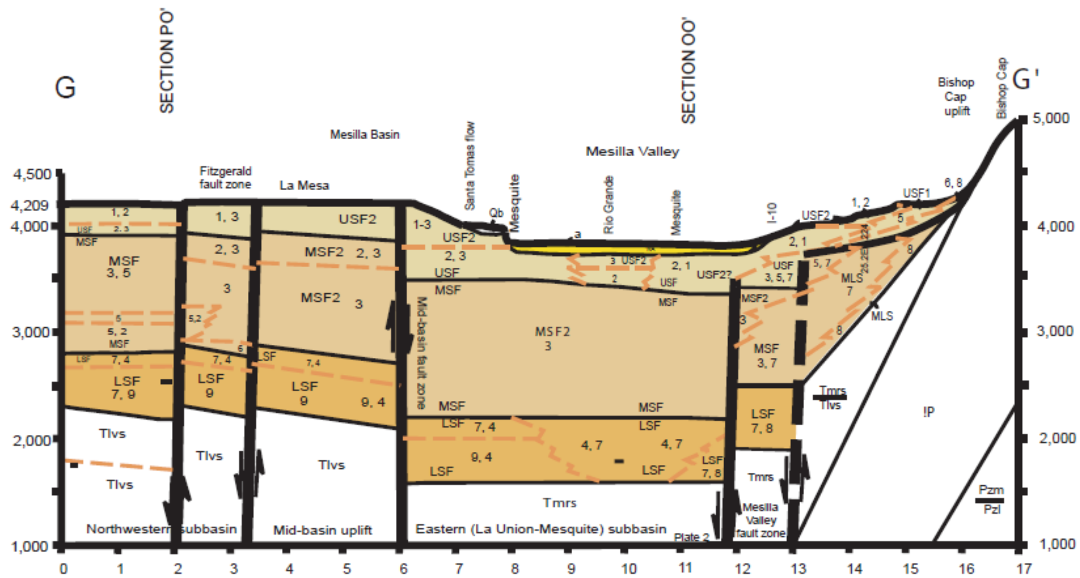
Figure 1.2. River Valleys and Sedimentary Basins within the Project Area



These basins extend over much larger geographic areas than the river valleys, and are very deep, filled with thousands of feet of sediments that are known as the Santa Fe Group. The river valley alluvium overlies the Santa Fe Group sediments within the river valleys. Both the Mesilla basin and Hueco Bolson contain very transmissive Santa Fe Group sediment, and there are deep wells (~1000 feet deep) in these basins that obtain water from the Santa Fe Group. The Santa Fe Group sediments in the Palomas basin are significantly less transmissive, and so wells in the Rincon Valley tend to be relative shallow (on the order of 100 feet deep), since they can only obtain water from the river valley alluvium.

The aquifer system is geologically and hydrologically fairly complex. Figure 1.3 is an example of an east-west cross-section of the alluvial aquifer system in the Mesilla Basin, which shows some of that complexity.

Figure 1.3. Sample East-West Cross Section of LRG alluvial aquifer system in the north-central Mesilla Basin from Hawley and Kennedy, 2004[4]



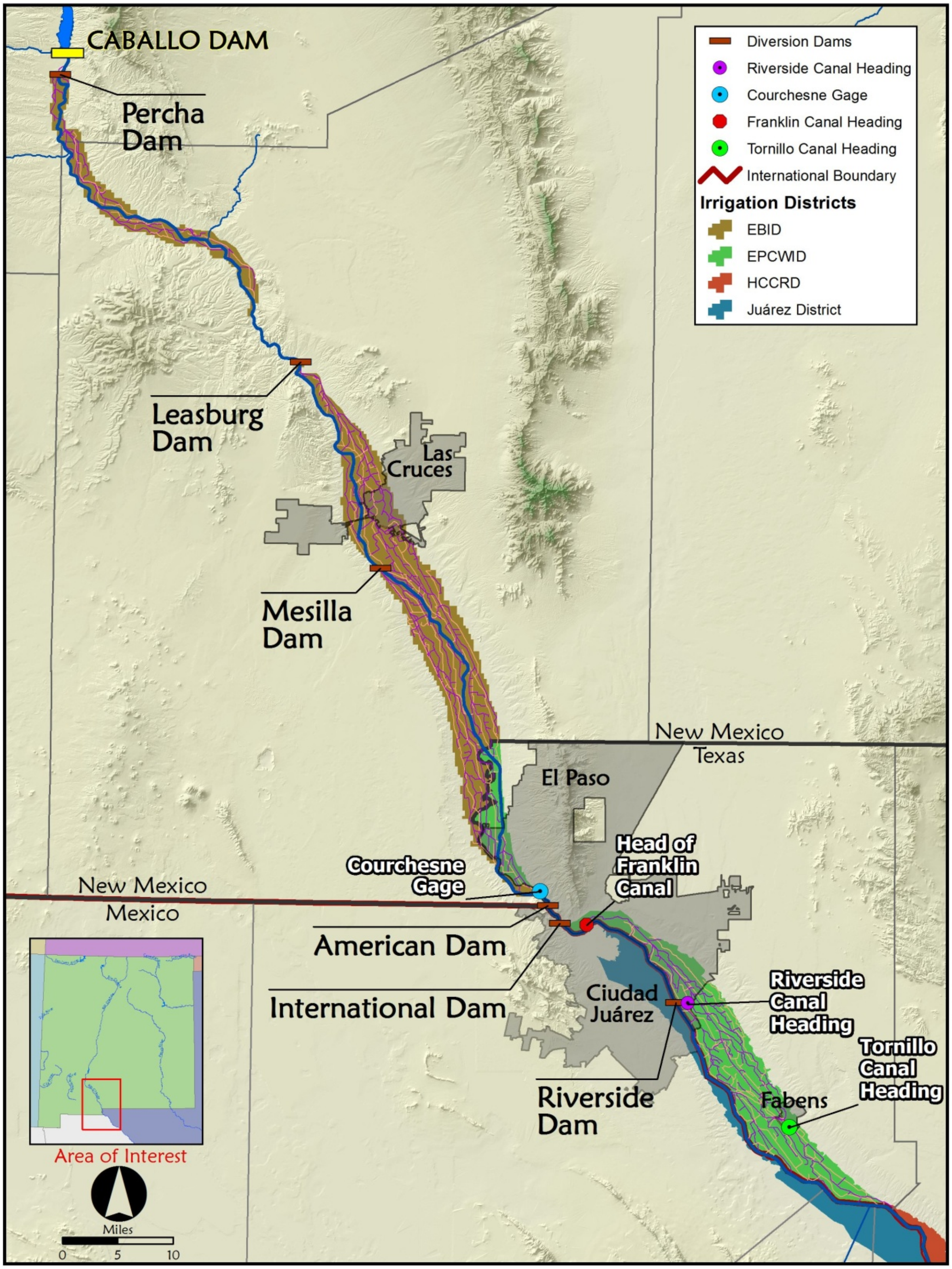
In Figure 1.3 the thin yellow area located under the "Mesilla Valley" label corresponds to the approximately 100 feet thick river valley alluvium, and the river itself is located on top of the river valley alluvium, near the center of the valley. Beige, tan and brown areas correspond to different sub-units of the Santa Fe group.

1.3 Current Description of the Rio Grande Project

The Project provides surface water for up to 155,000 acres of land in EBID and EPCWID. As recognized in the Inter-district Contract, approximately 57% (88/155) of the lands authorized to receive water directly from the Project are in New Mexico (EBID); while 43% (67/155) are in within EPCWID in Texas. Although municipal supply was not included in the original purposes of the Project, the City of El Paso now receives a substantial amount of its municipal supply from the Project through contracts with Reclamation and EPCWID. Figure 1.4 shows the general location of EBID and EPCWID, and the cities of Las Cruces, El Paso and Juarez, as well as the main diversion structures.

[4] Hawley, John and Kennedy, John, *Creation of a Digital Hydrogeologic Framework Model of the Mesilla Basin and Southern Jornada Del Muerto Basin*, WRRI Technical Report 332, New Mexico Water Resources Research Institute, June 2004. Plate 4.

Figure 1.4. Main Diversion Structures for the Project



The Project also serves as the means by which the United States provides water for diversion by Mexico to irrigate lands on the Mexican side of the El Paso Valley. Up to 60,000 acre-feet of water per year is also provided at Juarez, in accordance with the 1906 Convention between the United States and Mexico.[5]

Pursuant to Reclamation contracts, waste water from EPCWID Project lands can be used to irrigate about 18,000 acres in HCCRD, Hudspeth County, Texas.[6] The water delivered to lands in Hudspeth County is not part of the annual Rio Grande Project allocation, rather it is solely waste water and return flows from the Project.

Project water is stored in the Elephant Butte Reservoir and released at the Elephant Butte Dam (collectively, Elephant Butte) and also in the downstream Caballo Reservoir and Dam (collectively, Caballo). Once Project water is released from Caballo into the Rio Grande, it is conveyed in the bed of the Rio Grande to diversion dams along the river in New Mexico and Texas. *See* Figure 1.4. EBID diverts Project water from the Rio Grande at Percha and Leasburg dams in New Mexico to serve New Mexico farmers. EBID also diverts Project water from the Rio Grande at Mesilla Dam in New Mexico both to serve New Mexico farmers and to deliver water to EPCWID lands in the Texas part of the Mesilla Basin, north of El Paso.

The Project is naturally divided at the El Paso Narrows, which separates the El Paso Valley downstream from the Rincon and Mesilla Valleys upstream. The Courchesne stream gage ("Courchesne"; also known as the Rio Grande at El Paso stream gage) sits within the El Paso Narrows in Texas.[7] In the early decades of the Project the Project was organized in two branches: the Las Cruces Branch north of Courchesne, and the Ysleta Branch south of Courchesne.[8]

A couple of miles below Courchesne, the International Boundary and Water Commission: United States Section ("IBWC") diverts all the water in the river, except that needed to provide Mexico's water, and flood flows, at American Dam in Texas into the American Canal. EPCWID diverts water from the American Canal to deliver to farmers downstream in the El Paso Valley via the Franklin and Riverside canals. The El Paso Water Utilities ("EPWU") diverts Project water for municipal use from the American Canal and Riverside Canal. The IBWC diverts Mexico's portion of Project Supply at International Dam in accordance with an annual schedule. The water diversion and conveyance structures in El Paso area are portrayed in Figure 1.5.

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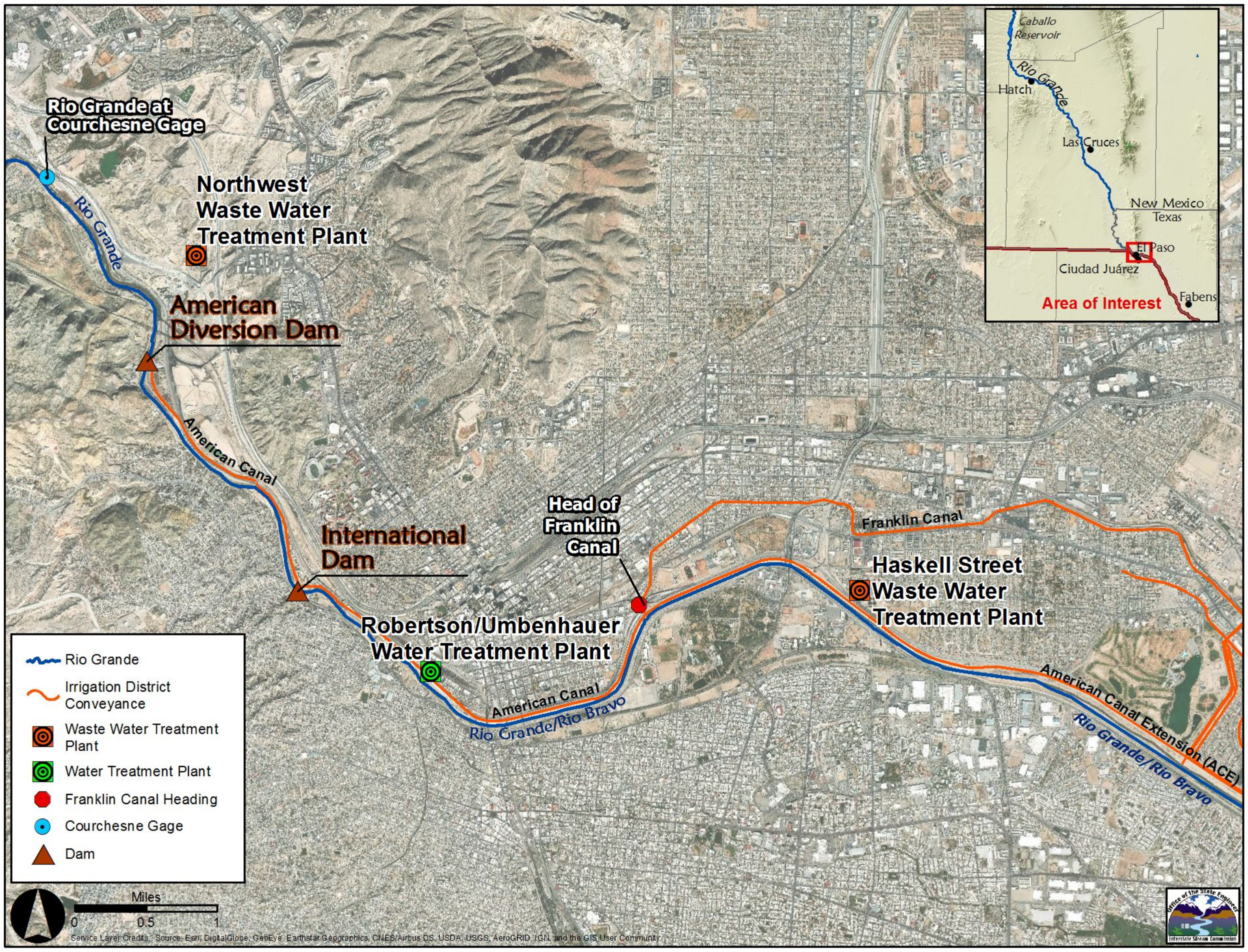
[5] *Convention between the United States and Mexico - Equitable Distribution of the Water of the Rio Grande,* Treaty, signed May 21, 1906, Washington, D.C. (the "Treaty").

[6] Supplemental Environmental Assessment, Implementation of Rio Grande Operating Procedures, June 21, 2013.

[7] A similar natural division takes place between the Rincon and Mesilla Valleys.

[8] Courchesne, depicted in Figure 1.4, is an important landmark because it generally marks the boundary between the Upper and Lower portions of the Project.

Figure 1.5. Detail Map of the El Paso Area showing Courchesne Gage, Diversion Dams, and El Paso Waterwater Treatment Plants



Reclamation's Rio Grande Project Office in El Paso, Texas, directs operation of Elephant Butte, Caballo, and Project diversion dams, and, together with EPCWID and EBID technical representatives, determines the allocation of Project Water. Current operations and maintenance of Project facilities within the EBID service area is conducted by EBID, while EPCWID operates and maintains the Project facilities within the Texas portion of the Project area.[9]

Elephant Butte and Caballo reservoirs store Project water, but not all of the water in these reservoirs is available to the Project. Only "Usable Water"[10] in Project storage, as defined by the Rio Grande Compact, is available for allocation and release by the Rio Grande Project.

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[9] 2010 Operations Manual.

[10] "Usable water" is defined in the Rio Grande Compact as "is all water, exclusive of credit water, which is in project storage and which is available for release in accordance with irrigation demands, including

2 GENERAL INTRODUCTION TO PROJECT ALLOCATION, ACCOUNTING AND OPERATIONS

2.1 PROJECT ALLOCATION AND PROJECT ACCOUNTING

A detailed discussion of Project allocation and accounting follows in Section 6 and Appendix D.[11] A graphic of Key Time Periods in Rio Grande Project Allocation and Accounting is in Appendix F. The discussion herein is intended to generally introduce the concepts to provide context for other portions of this Report.

Project allocation refers to the amount of surface water each District is entitled to order each year, and the process and methods by which Reclamation determines those allocation amounts, as well as the amount Mexico is entitled to by Treaty. Historically Project allocation was based on equal delivery of water to each Project acre, with 57% of the U.S. share of Project Supply allocated to EBID, and 43% allocated to EPCWID. The current Project allocation method is set forth in the 2008 Operating Agreement, detailed in the associated Operations Manuals,[12] and is accomplished through an allocation spreadsheet. In general, each year the allocation process starts before the beginning of the irrigation season, and is updated monthly throughout the irrigation season to address increases in Usable Water or changes in hydrologic conditions.

Project accounting, on the other hand, is the process which tracks how much of the amount allocated to each District has, in fact, been diverted by the District and thus presumably used by the District. It is a post-fact calculation involving actual diversion data. The current Project accounting system was initiated in 1979 by Reclamation and basically charges District diversions against District allocations in accordance with a set of accounting rules, which include a systems of credits. In this report I will use the term "Charged Diversion" to refer to the net amount calculated from the diversions and credits assigned to that District and charged against that District's allocation.[13]

Prior to 1979, when Reclamation operated the entire system, it allotted and delivered water directly to individual farmers in both Districts. From 1979 forward, after the Districts took over ownership of the canals and laterals, Reclamation instead allocated water to the Districts, assuming equal delivery of water to each acre of Project land via the Districts, and delivered that water to District diversion

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deliveries to Mexico", not including imported water such as water associated with the San Juan-Chama transmountain diversion." *See* Estevan Lopez Expert Report, 2019.

[11] The data underlying recitation of facts and my opinions in this Report are summarized and explained in the Appendices.

[12] Rio Grande Project Water Accounting and Operations Manual, 2008, and as amended in 2010 and 2012.

[13] Project Accounting records often refer to "Allocation Charges" which is generally equivalent to my use of "Charged Diversions."

headings when called for by the Districts. The allocation method developed for this new operational system is called the D1/D2 Allocation.

Beginning in 2006, and as formalized in the 2008 Operating Agreement between Reclamation and the Districts, Reclamation uses what is called the D3 Allocation method, which adds a component to the allocation method intended to penalize EBID for inefficiencies in the Project.

2.2 Project Operations

This section described the part of Project operations by which orders for Project water are fulfilled. The order and delivery process for the Project is described in more detail in Appendix B.

Prior to 1979 farmers ordered water directly from Reclamation, by making requests through Reclamation ditch riders for deliveries to farm headgates. Reclamation determined what releases and diversions were needed to fulfill those orders, released appropriate amounts of water from Caballo Reservoir, and then diverted water at appropriate canal headings. Reclamation ditch riders delivered the ordered water to individual farms. This process is described in detail in the Rio Grande Project Histories.[14] As part of this process, the necessary release from Caballo was calculated based on the sum of the water required at each Project diversion heading, adjusted for the estimated transit losses and "drainage flow" returns to the river above each diversion heading.

Since 1979 the order, release, diversion and delivery operational system is shared between the Districts and Reclamation. Reclamation determines Project allocations, takes orders from the Districts, releases water from the reservoir and makes deliveries to canal headings. The Districts take farm orders from their members, place orders to Reclamation for water to be delivered at canal headings, take delivery of that water and deliver to farm headgates. This operational system is generally described in a 1985 Draft Operating Agreement,[15] and also has been described by Reclamation and EBID personnel in numerous meetings.

During the irrigation season, on a regular basis, each District submits orders (in terms of cubic feet per second (cfs) at each of their canal headings)[16] to Reclamation. Reclamation releases from Caballo as much water as necessary to meet these District orders and supply the Mexican delivery schedule.

The release rate from Caballo is determined so that the sum of the return flows and other water present at each canal heading, plus water released from reservoir storage, will equal the Districts' orders at each canal heading. This is described in the 1985 Draft Operating Agreement as follows: "*The Bureau will tabulate and evaluate these orders, considering river losses or accretions … [and] notify the operating*

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[14] Rio Grande Project Histories ("RGPH") were detailed annual reports prepared by Reclamation for the years 1912 through 1988. The information cited is found in RGPH 1943 (Daily Reports of Operations Divisions), pp. 53-65/366.

[15] 1985 Draft Operating Agreement for the Rio Grande Project, between the U.S. Bureau of Reclamation, EBID, and EPCWID, January 1985. This document is discussed in more detail in Section 6 but in essence it describes the Project operations, allocation, and accounting methods employed since 1979.

[16] A flow of 1 cfs, if kept up over one entire day, provides 1.98 acre-feet (AF) of water.

official of each District of the change in the release rate at Caballo Dam." Figure 2.1 is a Project Order Sheet extracted from the 1985 Draft Operating Agreement, including terms for the river losses ("Plus River Loss") and river accretions[17] ("Less Drain Water to River") that were used to calculate the release from Caballo required to meet the sum of the orders on the Order Sheet.

Figure 2.1. Project Order Sheet extracted from 1985 Draft Operating Agreement

PROJECT WATER ORDER

Order for period from ________ to ________ Date: ________

Upper Valley Water Order EBID and EPCWID No. 1		Lower El Paso Valley EPCWID No. 1 Water Order	
Arrey Canal	____ cfs	Franklin Canal	____ cfs
Leasburg Canal	____ cfs	City of El Paso	____ cfs
California Lateral	____ cfs	Riverside Canal	____ cfs
Del Rio Lateral	____ cfs	Total Lower Valley	____ cfs
East Side Canal	____ cfs	**Total Project Water Order**	
Three Saints East Lateral	____ cfs	Upper Valley	____ cfs
West Side Canal	____ cfs	Lower Valley	____ cfs
La Union West		Mexico	____ cfs
New Mexico	____ cfs	Total Water Ordered	____ cfs
Texas	____ cfs	Less Drain Water to River	____ cfs
Total	____ cfs	Plus River Loss	____ cfs
La Union East		Release from Caballo	____ cfs
New Mexico	____ cfs	Flow Meter Setting	____ cfs
Texas	____ cfs	Time ____ Date ____	
Total	____ cfs	Ordered by ____	
Total Upper Valley	____ cfs		
		Caballo Readings	
		Date ____ Time ____	
		Hydrographer ____ (Initials)	
		Discharge	____ cfs
		Gage Height ____	
		Flow Meter CFS ____	
		East Gate ____	
		West Gate ____	
		Elevation ____	

Exhibit 4

The 2008 Operations Manual associated with the 2008 OA (both discussed in greater detail in Section 6), describes a slightly modified process for orders and deliveries, in which the release from Caballo is to be based on "the information entered into Figure 1," consisting of District orders and river gains and losses

[17] Accretions to the river include return flows, groundwater discharge into the river bed, and side inflows (in this case, arroyos with temporary influx of water due to rain), and effluent.

combined with information from the "Flow Regulation Calibration at Caballo Dam" report. Figure 1 from the 2012 Operations Manual is provided here as Figure 2.2.

Figure 2.2. Project Order Sheet extracted from 2012 Project Operations Manual

Figure 1 - Internet-Based Order Forms

RIO GRANDE PROJECT ORDER

Ord:1124	Effective Date: 7/8/2008		Prior:1123	Effective Date: 7/7/2008	
BOR	Date/Time Received: 07/08/08 15:36	Received By: IO	BOR	Date/Time Received: 07/07/08 15:09	Received By: IO
EPCWID #1	Date/Time Entered: 07/08/08 08:39	Approved By: RR	EPCWID #1	Date/Time Entered: 07/07/08 09:49	Approved By: RR
EBID	Date/Time Entered: 07/08/08 08:49	Approved By: MJN	EBID	Date/Time Entered: 07/07/08 09:51	Approved By: MJN

Upper Valley From: 7/8/2008 To: 7/9/2008

Location	Current	Prior	Change
Arrey Canal	140	140	0
(-) Bypass	0	0	0
River Pumps	0	0	0
Leasburg Canal	170	230	-60
(-) Bypass	0	0	0
California Ext.	0	0	0
Del Rio Lateral	0	0	0
Eastside Canal	110	140	-30
Westside Canal	380	400	-20
(-) Bypass WW32	-30	-70	40
Total Upper Valley	770	840	-70

State Line From: 7/8/2008 To: 7/9/2008

Location	Current	Prior	Change
La Union West TX	20	30	-10
La Union West NM	20	30	-10

Gate Settings	Current	Prior	Change
East Gate Recommended	3 98	4 41	-0 43
West Gate Recommended	3 98	4 41	-0 43

EBID Comments

-

SUMMARY

	Current	Prior	Change
RIVER BOOST	50	0	50

River Reaches/Stations	Current	Prior	Change
Caballo Release	1683	1873	-190
Flow below Percha Dam	1543	1733	-190
Gain/Loss (+/-) above Leasburg	50	0	50
Flow at Leasburg Cable	1423	1503	-80
Gain/Loss (+/-) Leasburg/Mesilla	0	0	0
Flow below Mesilla Dam	933	963	-30
Gain/Loss (+/-) Mesilla-American	0	0	0
Flow at American Dam	963	1033	-70

District Totals	Current	Prior	Change
Total for EBID	690	780	-90
Total for EPCWID #1	866	916	-50
Total for Both Districts	1556	1696	-140

Project Totals	Current	Prior	Change
Total Gains/Loss	50	0	50
Total EBID, EPCWID, Mexico	1733	1873	-140
Release	1683	1873	-190

State Line From: 7/10/2008 To: 7/12/2008

Location	Current	Prior	Change
La Union East TX	60	30	30
La Union East NM	30	20	10
3 Saints East TX	0	0	0
3 Saints East NM	0	0	0
Total State Line	130	110	20

Lower Valley From: 7/11/2008 To: 7/13/2008

Location	Current	Prior	Change
UR-WTP	56	56	0
Franklin Canal	160	130	30
JR-WTP	85	85	0
Riverside Canal	485	585	-100
Total Lower Valley	786	856	-70

Comments - EPCWID

-

Mexico From: 7/11/2008 To: 7/13/2008

Location	Current	Prior	Change
Mexico	177	177	0
Total Mexico	177	177	0

Comments - Mexico

-

Reclamation Order # 1124

Caballo Elevation	Current	Prior	Change
USBR Elevation (ft)	4148 58	4148 44	0 14
Recommended River Boost (cfs)	0.00	0.00	0
Accretions (cfs)	50 00	0.00	50

Gate Settings	Current	Prior	Change
East Gate (ft)	3 98	4 41	-0 43
West Gate (ft)	3 98	4 41	-0 43

Recommended Flow Setting	Current	Prior	Change
CFS	1683	1873	-190

Scheduled Time of Change	10:00

USBR River Measurement	Date	Time	Flow
Measured Flow (cfs)	7/8/2008	13 15	1756

USBOR Confirmation of Mexico Order	Yes

Comments

BOR recom. gate settings @ 3.86 ea.=1683 Dist. recom. gate settings @ 3.98 ea.=1735

Date/Time Received: 07/08/08 15:36	Received By: IO

The 2008 Operations Manual and the 1985 Draft Operating Agreement both include a provision that in case there is a significant shortage at EPCWID's diversion headings, water will be wasted[18] from the EBID

[18] "Waste" is defined as an operational release of water from a canal or other conveyance, typically returning unneeded water to the Rio Grande. Often waste is associated with water that was diverted in order to keep the level of water in canals high enough to allow water to flow naturally from the canal into farm headgates. If such waste is authorized and planned so that the water can be re-diverted for Project use downstream, there may be a Project accounting associated with that waste. Examples: El Paso Carriage, by which EBID diverts water for delivery to EPCWID in the El Paso Valley in very dry years, and the Ascarate Credit, whereby EPCWID used to get credit for water diverted at the Franklin heading, wasted back to the Rio Grande at the Ascarate Waste Way, and rediverted at Riverside Dam. *See* Appendix D for a further explanation of this accounting.

canal system to remedy this shortfall. This process is described in the 1985 Draft Operating Agreement as follows:

> *Flows at Riverside Heading occasionally drop below the order of the EPCWID. When this flow is 100 cfs or more below the District's order and the District cannot tolerate the shortage, the following method of sharing the shortage between EBID and EPCWID will be implemented.*
>
> *As directed by the Bureau, the EBID will release additional water through wasteways equal to one half of the amount short at Riverside. The Bureau will release an equal quantity for diversion by EBID. EBID will be given credit for the additional water released at the wasteway to help relieve the shortage.*

EBID is required to release this water for EPCWID use, and then be "reimbursed" by Reclamation, so that the needed water reaches EPCWID farmers more quickly than if the needed water were released from Caballo. In other words, EPCWID has an effective and speedy remedy in the case of a water shortfall. A similar description for remediation of a shortfall at Riverside is provided in the 2008 Operations Manual.

As the irrigation season progresses each District may continue to order surface water during the time releases are made from Caballo until its Charged Diversions equal its allocation. Significantly, New Mexico has seen no evidence that Reclamation has ever failed to deliver the amounts ordered by the Districts. It is reasonable to conclude that the amounts delivered to the Districts each year since 1979 constitute the full amounts that the Districts ordered in each year.

Understanding of Project operations is essential to understanding how any changes in the hydrologic system would impact Project deliveries. Importantly, any change in the hydrologic system that result in increased drain flows in the upper Project (that is, the Project above Courchesne) would not necessarily lead directly to an increase in the flow available downstream. In years when the Project has allocated water to ECPWID in excess of its actual irrigation season demand, any increase in upstream drain flows, or reduction in upstream river losses, would result in a decrease in the rate of release from Caballo necessary to meet demand. Caballo is operated to release only the additional amounts needed to fulfill EPCWID's orders and the Mexican delivery schedule taking into account the already existing drain flows, Project waste, and effluent existing in the Project system.

As a result, an increase in Project drain flow above Courchesne in full-supply years would not lead to increased flows at Courchesne during the irrigation season. Flows could increase during the off season (when releases are not being made from Caballo), and the decrease in Caballo releases that occurs in the full-supply years could change water supply conditions in future low-supply years. The amount of that change in future supply conditions would depend on many factors: evaporation of the extra water in storage and whether or not that water released in a reservoir spill.

For example, the years 1979 through 2002 were full-supply[19] years for the Project,[20] and the Project allocated a full supply to EPCWID every year (376,862 AF each year starting in 1991, varying full-supply

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[19] Historically, the Rio Grande Project was considered to have a full supply when the annual amount of Usable Water available to the Project was sufficient to deliver 3.024 AF/A to Project Lands, plus 60,000

amounts before 1991). There is no evidence that EPCWID did not receive all of the water that it ordered, and there is evidence that there was sufficient water in reservoir storage to have delivered more water during this time had EPCWID ordered it. I conclude that EPCWID ordered the water it needed to meet its farmers' delivery orders, as well as those for the City of El Paso.

There is no reason to believe that the existence of additional supplies of drain flow upstream of EPCWID would have caused EPCWID to order more water than it already had ordered in these full-supply years. And because Caballo releases are determined based on orders and intervening system gains and losses, I conclude that the presence of additional drain flows would have instead caused Reclamation to release less water from Caballo to meet the existing orders. The effect that reduced Caballo releases during this period would have is a complex problem, and would be impacted by the evaporation of the extra water in reservoir storage, and the reservoir spills occurring during the 1980s and 1990s.

AF to Mexico at International Dam. Reclamation and EBID recognize the years 1979 through 2002 as full-supply years, and the Districts and Mexico were allocated full-supply allocations in those years.

[20] Cortez, F., PPT: U.S. Bureau of Reclamation / Rio Grande Project, 2003 (PPT named: TCEQ_BOR_PP_121103.ppt), provided to the New Mexico ISC March 2005.

3 PROJECT INFRASTRUCTURE

Construction of the Project and Elephant Butte Dam were authorized by Congress in 1905. Construction of some Project infrastructure began shortly thereafter, and construction of Elephant Butte Dam began in 1912. Reclamation made the first deliveries of Project water in 1915.[21] Some of the information in this and other sections has been extracted from the Rio Grande Project Histories.

3.1 DIVERSION STRUCTURES IN NEW MEXICO: MESILLA AND RINCON VALLEYS

There are three main Project diversion structures in New Mexico:

- Percha Dam diverts water from the Rio Grande into Arrey Canal and Percha Lateral to supply New Mexico lands in the Rincon Valley.
- Leasburg Dam diverts water from the Rio Grande into the Leasburg Main Canal in the northern Mesilla Valley to supply New Mexico lands in the northern parts of Mesilla Valley.
- Mesilla Dam diverts water from the Rio Grande into the Eastside and Westside canals, and the Del Rio Lateral, to supply lands in the southern parts of the Mesilla Valley, including lands in both New Mexico and in Texas.

These points of diversion have remained unchanged since the early years of the Project.

Small amounts of Project water are diverted at other locations in New Mexico including the California Extension, and the Greenwood and Duran river pumps.

3.2 DIVERSION STRUCTURES IN TEXAS: EL PASO VALLEY

Diversion structures in the El Paso Valley have changed considerably through the history of Project and add complexity to the situation. These changes and their impacts are described in more detail, and illustrated, in Appendix C. Understanding these changes is important to evaluating the claims at issue in this case because changes in infrastructure in the El Paso Valley have changed Project accounting, and the way EPCWID can make use of Project Supply (return flows) generated within the El Paso Valley.

Prior to 1938, water was diverted from the Rio Grande to supply Project lands at a number of locations, including (but not limited to) major diversions at International Dam (which then supplied Franklin Canal as well as the Mexican diversion at Acequia Madre), Riverside Dam, and the Tornillo Canal heading. The Tornillo Canal, completed in 1925, was intended as "*the means to collect a large amount of recovered and developed water of the Project*"[22] and as the site of "*collection and diversion of irrigation water and return flow*."[23]

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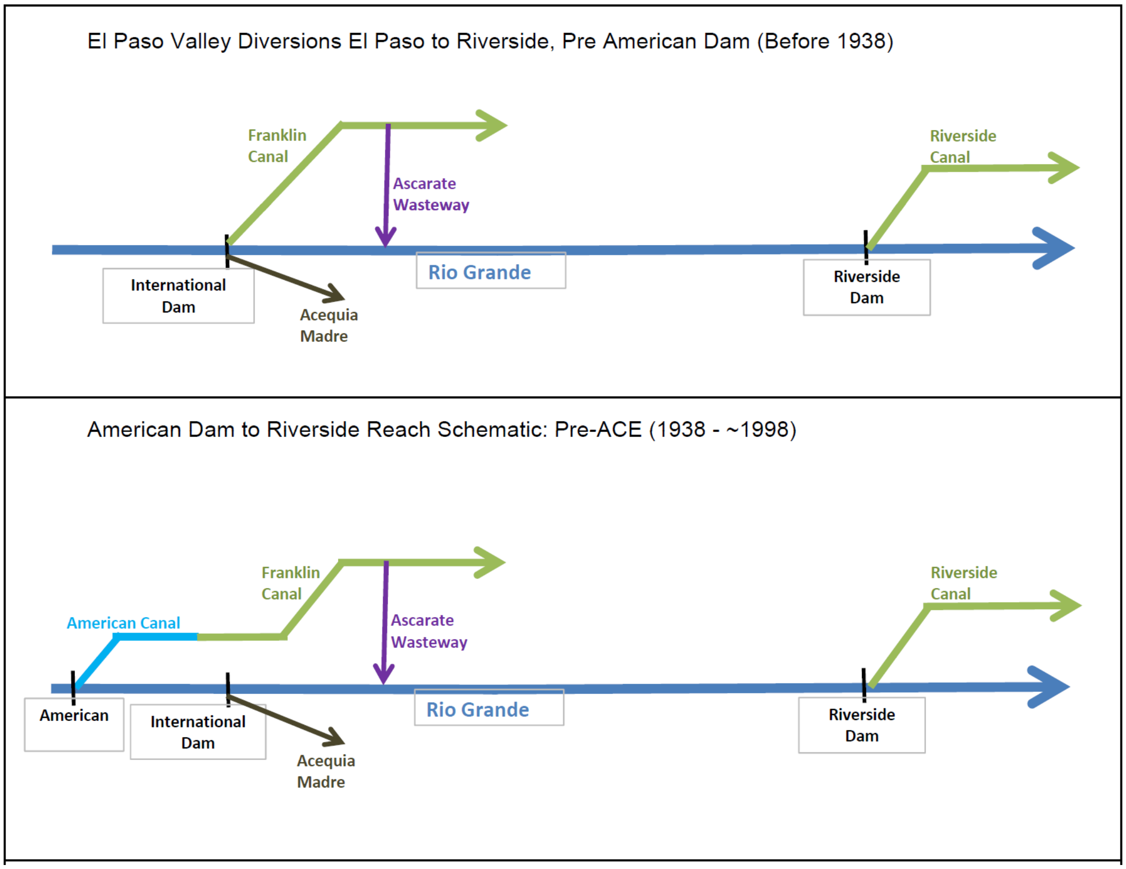
[21] Autobee, Robert, *Rio Grande Project, Bureau of Reclamation*, 1994.

[22] RGPH 1923, p. 12/416.

[23] RGPH 1926, p. 18/172.

El Paso Valley diversions and conveyances changed dramatically after the construction of the American Dam and Canal and the reconfiguration of the Rio Grande. The American Dam and Canal were completed in 1938, allowing the U.S. to divert water for the Project above International Dam.[24] This reconfiguration is illustrated in the schematic in Figure 3.1.

FIGURE 3.1. Schematic of El Paso Valley Conveyance Reconfiguration above Riverside in 1938



Riverside Canal continued to divert water from the Rio Grande at Riverside Dam. However, further downstream, the realignment of the Rio Grande (part of the Rio Grande Rectification Project) had divorced the Tornillo Canal heading from the Rio Grande as reflected in Figure 3.2. The Tornillo Canal heading could no longer divert water from the Rio Grande and was instead supplied by water that had been diverted at Riverside Dam that had been conveyed through the Riverside Canal Extension, plus diversions of flow from some El Paso Valley drains. Despite these changes, the Reclamation 1943 Project History still describes the Tornillo heading as "*the last operational* diversion of the El Paso Valley."[25]

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[24] RGPH 1938, (Hydrometry Section), starting p. 29/312.

[25] RGPH 1943, p. 57/366.

Figure 3.2. Major Changes in the Position of the Rio Grande, 1903 to Present[26]

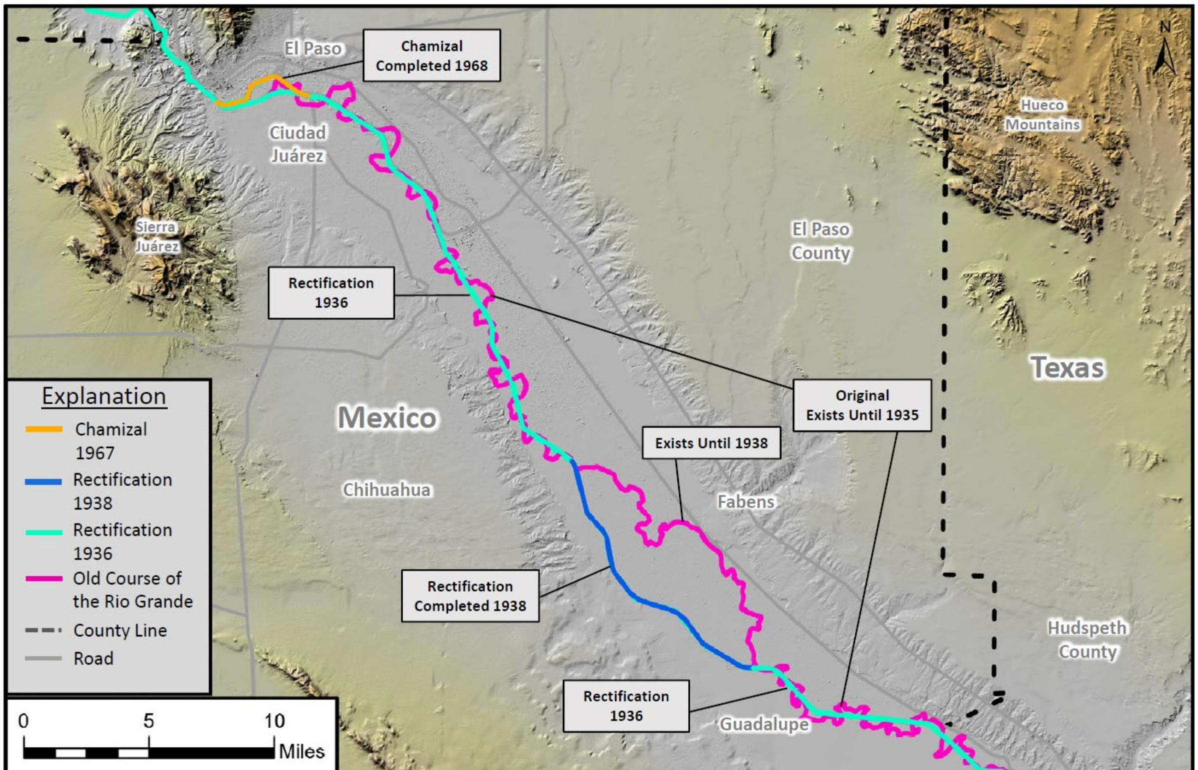

Figure 4.5a – Major changes in the position of the Rio Grande, 1903 to present.

McDonald Morrissey Associates, LLC Ground Water Hydrologists

Confidential Draft - Privileged Pursuant to Rule 26 of the Federal Rules of Civil Procedure: Prepared for Litigation

In 1998, after the failure of Riverside Dam, the American Canal Extension ("ACE") was completed; a concrete-lined canal which connected the Riverside canal heading to the American Dam and Canal. Additional concrete lining was done of the upper (pre-existing) part of the American Canal. Following the completion of the ACE, Project water could be diverted at American Dam to supply both Franklin and Riverside Canals, with water conveyed to the Riverside Canal heading through a concrete-lined canal instead of through the bed of Rio Grande.

Canal lining and drain reconfiguration have continued over time within EPCWID.[27] While the ACE, and other canal lining in the El Paso Valley, may have made the distribution to farmers in the El Paso Valley more efficient, this lining cuts off the process of seepage from the canal, thereby reducing recharge to the El Paso Valley aquifer system, further aggravating groundwater declines in this part of the Hueco Bolson aquifer system.

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[26] McDonald Morrissey & Associates Expert Report, 2019.

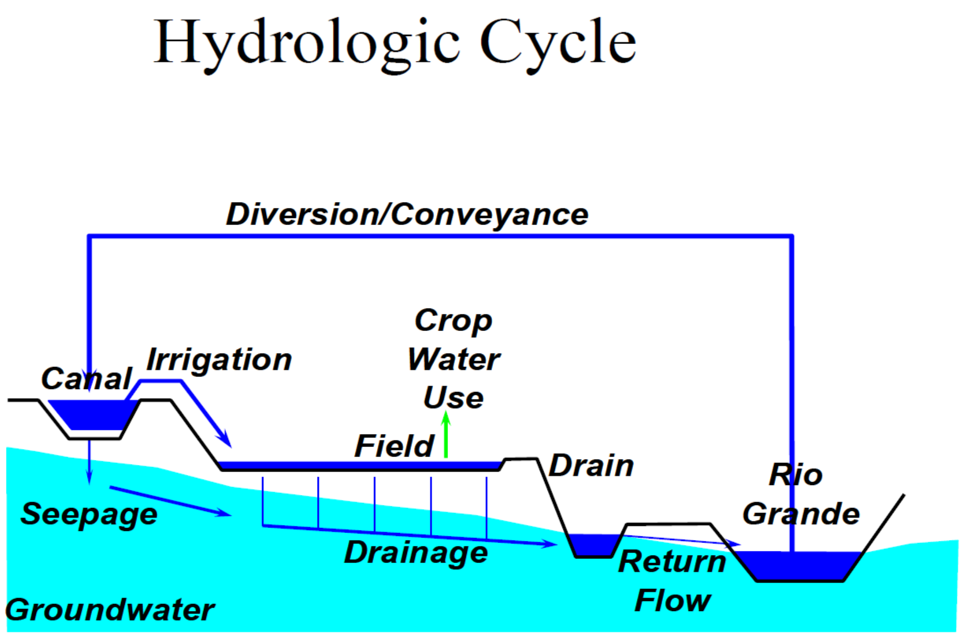
[27] McDonald Morrissey & Associates Expert Report, 2019.

3.3 Project Drains

A drain is a conveyance that has been installed to intercept the water table and convey excess groundwater away, both to prevent land from becoming water-logged and to convey return flows to the river system. Within the Project, drains convey excess groundwater into the Rio Grande or into other Project conveyances.

Most drain flow originates as water released from Project storage and diverted into Project canals. Part of the canal water seeps into the ground, where it may be captured by drains. Another part of the canal water is delivered to farms and applied to irrigated lands, and a fraction of that amount percolates into the ground below the crop root zone, where it migrates and may be captured by drains. This process is illustrated in the Hydrologic Cycle provided in Figure 3.3.

Figure 3.3. Hydrologic Cycle of the Rio Grande Project Irrigation System, Illustrating the Source of Water in Project Drains[28]



The issue of Project drainage arose early. The diversion and application of large amounts of Project water in the first years of Project operation caused a build up of groundwater under Project lands. Shallow groundwater – meaning groundwater close to the surface of the land -- in parts of the Project made lands unable to support crops because it in effect "drowned" the crop. Review of Project Histories shows that "drainage investigations" began in 1914, and lengthy "Drainage Reports" are part of Project Histories starting in 1915. According to the Rio Grande Joint Investigation, "*About 1918 the necessity for*

[28] King, J.P., 2003 EBID Drought Update, February 2003 Presentation to EBID Farmers.

drainage on the Project became apparent and by 1925 a complete system of open drains were completed."[29]

The Rincon, Mesilla and El Paso Valleys each have a separate system of drains. *See generally* Figure 1.2. Rincon Valley drains discharge into the Rio Grande at the southern end of the Rincon Valley. Mesilla Valley drains discharge into the Rio Grande in the southern half of the Mesilla Valley, above Courchesne.

However, again, the story in the El Paso Valley is complicated as more fully described and illustrated in Appendix C. Before the Rectification of the Rio Grande by IBWC, a number of the El Paso Valley drains discharged into the Rio Grande above the town of Fabens. Following Rectification, these drains were rerouted, keeping drain flow, for the most part, within the boundaries of EPCWID and HCCRD.

Associated with the Rectification of the river, El Paso Valley drains that originally discharged into the Rio Grande below Fabens were routed to the HCCRD. Some drain outfalls (where the drain empties into the river), such as that of the Fabens Waste Channel, allow for water to be wasted to the Rio Grande, or for water to be diverted from the Rio Grande for delivery to the HCCRD.

As reflected in the findings of the Rio Grande Joint Investigation, drainage accounted for a significant portion of Project water deliveries in the early years of the Project. In fact, the Joint Investigation noted that some 35% of water diverted to EPCWID at Franklin Canal was composed of drain flow and seepage, and a full 57.7% of water diverted at the Tornillo heading consisted of drain flow and seepage.[30] The increase in the percentage of drain flow diverted at Tornillo in these figures, over that diverted at Franklin, indicates that Tornillo diverted significant amounts of El Paso Valley drain flow that was unavailable at Franklin. That is, there was significant El Paso Valley return flow between Franklin and the Tornillo heading at Fabens that was used to meet Project irrigation demand. At present, the diversion of El Paso drain flow into the Tornillo Canal is either not occurring, or if it is occurring, that water is not charged to EPCWID as diversions of Project Water.

The amount and distribution of drain flow depends on a number different factors, with the amount of surface water diverted and applied to lands being a primary factor. To the extent that Project Supply is low, drain flows will be reduced and vice versa. Urbanization and permanent fallowing of lands is another factor: a drain that passes through areas in which lands have been permanently fallowed will not generate as much water as it did before the fallowing occurred. Groundwater pumping by farmers and for municipal supply and other uses would reduce the flow in nearby drains.

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[29] The Rio Grande Joint Investigation ("Joint Investigation") was a multi-agency scientific investigation in support of development of the Rio Grande Compact. It published the results of its findings in: *Rio Grand Joint Investigation in the Upper Rio Grande Basin in Colorado, New Mexico and Texas*, Regional Planning, Part VI, National Resources Committee; Volume I, Washington, D.D., Febraury 1938. The Joint Investigation is relied upon by anyone discussing the history of Rio Grande Project operations and is cited throughout this Report. This references is from p. 73.

[30] Joint Investigation, Part I,Table 90, page 100.

4 IRRIGATION WELLS

4.1 IRRIGATION WELL HISTORY

Irrigation pumping within the Rio Grande Project was minimal during the early years of the Project, until the drought of the 1950s.

Starting in the late 1940s, Reclamation warned farmers that reservoir levels were getting low and Project water supply might be inadequate, urging them to conserve and limit their application of surface water.[31]

In the June 20, 1950 Statement of Water Supply Reclamation warned farmers that "*rationing of water for 1951 will only be prevented by*" considerably above average runoff and early fall rains. The initial allotment of water to farmers in 1951 was 1.0 AF/A, rising only to 1.75 AF/A by the end of the year. Final allotments for the 1951 through 1957 irrigation seasons ranged from 0.42 AF/A to 2.5 AF/A (compared with a full-supply allotment of 3.024 AF/A.)[32]

In anticipation of low surface water supplies as predicted by Reclamation, farmers throughout the Project began to drill irrigation wells in the late 1940s. Conover[33] reports that there were only 11 irrigation wells in the Rincon and Mesilla Valleys in 1946,[34] but that by the beginning of 1948 there were 70. Irrigation well drilling increased dramatically during the 1950s. Gunaji,[35] a contemporary observer and engineering expert, states that approximately 1,200 irrigation wells were drilled within EBID during the 1950s. Gunaji's estimates of irrigation well pumping in New Mexico are provided here in Table 4.1.

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[31] This is from various sources in RGPH 1946-1950: 1946 Notice to Project Users, Project Irrigation Schedule Announcement; 1947 Statement of Water Supply Conditions May 22, 2017 –August 8, 1947; Statement on Irrigation Scheduling, Rio Grande Project, January 7, 1948, and other announcements; Statement on the Status of Water Supply Grande Project, March 24, 1949, and other announcements; 1950 Project Irrigation Water Announcement February 21, 1950 and Water Announcements through August 28, 1950.

[32] RGPH 1950 through 1960.

[33] Conover, C.S., *Groundwater Conditions in the Rincon and Mesilla Valleys and Adjacent Areas in New Mexico*, Prepared in Cooperation with the Elephant Butte Irrigation District, 1954.

[34] See Stevens Historical Research, Inc. Expert Report, 2019, for reference to earlier irrigation wells in the Project lands.

[35] Gunaji, Narendra, *Ground Water Conditions in Elephant Butte Irrigation District*, Engineering Experiment Station, NM State University, November 1961.

Table 4.1. EBID Irrigation Well Pumping Estimates from Gunaji (1961) Tables II and V

Table 4.1. EBID Irrigation Well Pumping Estimates from Gunaji 1961 Tables II and V		
Year	Surface Water Allotment (AF/A)	Estimated Quantify of Ground Water Pumped (AF)
1950	(No Limiting Allotment)	No significant pumping
1951	1.75	176,864
1952	2.50	101,388
1953	1.90	164,948
1954	0.50	286,122
1955	0.417	294,939
1956	0.392	282,732
1957	1.17	213,752
1958	4.00	No significant pumping
1959	3.50	No significant pumping
1960	3.25	No significant pumping

There was a parallel explosion of irrigation wells within EPCWID during the same time. Smith[36] reports that in the El Paso Valley in Texas "*wells were drilled to supplement the surface water supply. About 500 wells were in use in 1954, and about 120,000 acre-feet of water was pumped to irrigate approximately 45,000 acres.*" For the "Upper Valley" (Texas Mesilla Valley, but may include some lands in New Mexico) Smith reports that in 1954 "*about 40,000 acre-feet of water was pumped from approximately 250 wells to irrigate 15,000 acres of cotton and alfalfa*." Alvarez and Buckner[37] report irrigation wells pumping as high as 125,000 AF/Y in El Paso County and 26,000 AF/Y in Hudspeth County during this period.

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[36] Smith, Ralph E., *Ground-Water Resources of the El Paso District*, Texas, February 1956. p.10.

[37] Alvarez, Henry J. and Buckner, A. Wayne, *Groundwater Development in the El Paso Region, With Emphasis on the Resources of the Lower El Paso Valley*, Texas Department of Water Resources, June 1980. Table 1, p.8.

Treaty deliveries of Rio Grande water to Mexico were also greatly reduced during this period due to the drastic reduction in Rio Grande flow during that severe and prolonged drought. Data from Carreno[38] suggests a similar increase in irrigation well drilling in Mexico during the early 1950s. Irrigation well pumping estimates for Mexico's Juarez Valley for this period, as reported by the IBWC,[39] range from 26,000 AF/Y to 75,000 AF/Y.

Project Histories report on the importance of groundwater, as combined with surface water, to supply Project crops. For example, the 1953 Project History Operation and Maintenance of Irrigation System Report (O&M Report)[40] for the Ysleta Branch (El Paso Valley) states that the surface allotment of 1.90 AF "*was supplemented by water pumped from private irrigation wells, and from Project drains to the extent that the total use averaged 2.51 acre-feet per acre.*" The 1953 O&M Report for the Las Cruces Branch[41] states "*The conveyance of pumped water through the Bureau of Reclamation canals and laterals was again necessary to raise a normal crop.*"

In 1954, the O&M Report for the Ysleta Branch[42] reports "*The year of 1954 was one of the most favorable on record for growing cotton, and as a result the yields were record breaking. This was in spite of a reduction in cotton acreage, [and] a very small water allotment …This supply [0.5 ft] together with several small storm flows originating below Caballo Reservoir, during July and August, drain return flow, and water from some 418 irrigation wells, installed since 1950, was enough irrigation water for almost normal requirements."* The 1954 O&M Report for the Las Cruces Branch[43] reports "*The water users and Bureau personnel again faced a severe year from the point of available water supply, in fact the storage water carryover was so limited that even the first irrigation had to be made with a combination of water pumped from farm wells and water from the storage supply…. So, with the limited storage water, water pumped from farm wells, and conveyed in part through the project canals and laterals and the summer showers, a combination that made possible the production of one of the best yielding crops ever produced by this Branch."*

Project Histories also show that Reclamation actively promoted the use of irrigation wells during the 1950s drought. For example:

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[38] De La Carreno, Alfonso, *Preliminary Geohydrological Study of the Juarez Valley and Surrounding Areas*, State of Chihuahua, Department of Water Resources, Technical Advisory Memo No. 13.6-18, 1957, Parts 1 and 2.

[39] Ground Water Conditions and Resources in El Paso/Juarez Valley, Hydraulics Branch, Planning Division, U.S. Section, International Boundary and Water Commission, November 1989.

[40] RGPH 1953, O&M Report.

[41] RGPH 1953, O&M Report (Las Cruces Branch (Rincon and Mesilla Valleys)).

[42] RGPH 1954, O&M Report (Ysleta Branch).

[43] RGPH 1954, O&M Report (Las Cruces Branch).

> Reclamation Water Announcement of August 1, 1951[44] states "*Water users who have pumps of good capacity that will supply their needs are requested to arrange for transfer of a part of their unused allotment water to those who are in need of additional water.*"
>
> Reclamation Water Announcement of March 7, 1952[45]: *"Water users who intend to use their pumps for all or a part of their planting requirements and are willing to transfer their allotment to other water-right lands should contact the Elephant Butte Irrigation District or the Bureau of Reclamation in Las Cruces, and the El Paso County Water Improvement District in El Paso, or the Bureau of Reclamation office in Ysleta."*
>
> Reclamation Water Announcement of March 1, 1954:[46] "*Farmers with good irrigation wells are requested to use them to the greatest extent possible as a source of supply and to make available for transfer their allotment water to those farmers who do not have satisfactory wells.*"

Irrigation well pumping was not metered in New Mexico or Texas before or during the drought of the 1950s. It appears that irrigation well capacity in the Project was small until 1948, but increased rapidly in the years that followed, so that by 1955 100% of irrigation demand could be met during low-surface-supply years.

In New Mexico, a comprehensive set of irrigation well meter data is available starting in 2009, following the implementation of the New Mexico State Engineer's LRG Metering Order.[47] In Texas, irrigation wells were not and are not currently required to be metered.[48]

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[44] RGPH 1951: Reclamation Water Announcement of August 1, 1951.

[45] RGPH 1952: Reclamation Water Announcement of March 7, 1952.

[46] RGPH 1954: Reclamation Water Announcement of March 1, 1954

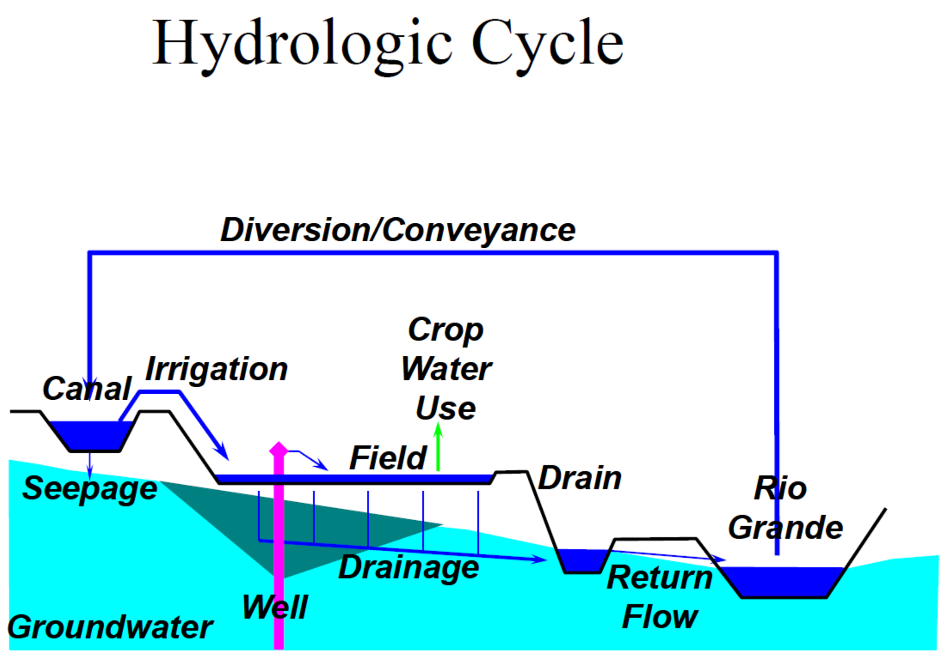
[47] New Mexico State Engineer Order #168. In the Matter of the Requirements for Metering Groundwater Withdrawals in the Lower Rio Grande Water Master District, New Mexico, December 3, 2004 (the "Metering Order"). In the New Mexico Rio Grande basin, State Engineer permits are required to replace an existing well, to supplement an inadequate well, or to drill a well to facilitate the use of an existing groundwater right on lands that have been separated from the well originally serving that right. NMSA 72.12.1 *et* seq. Most irrigation wells in the LRG supply EBID Project lands and are part of combined groundwater-surface water rights.

[48] By contrast, pursuant to NMSA 72-2-9.1, the New Mexico LRG Water Master regularly collects groundwater meter data and provides annual summaries in the LRG Water Master Annual Reports, available to the public at https://www.ose.state.nm.us/WM/WMdistrict4.php. In addition, the LRG Water Master and his staff:

- Monitor groundwater pumping by water right and enforces the groundwater diversions limits as set by permit or by the LRG Adjudication Court,
- Enforce meter installation on all active wells (unless covered by the domestic/stock exclusion),
- Enforce meter data reporting,

Irrigation well pumping (and other pumping) has an impact on the hydrologic cycle as illustrated in Figure 4.1. Well pumping can capture the water that has seeped from canals, or drained from fields, before it reaches drains and ultimately the river or other conveyance structures. Furthermore, groundwater pumping can lower groundwater levels to reduce gains and increase losses from the Rio Grande. Figure 4.1 shows the hydrologic cycle of the Project irrigation system, including the effect of irrigation well pumping.

Figure 4.1. Hydrologic Cycle of the Rio Grande Project Irrigation System, Illustrating the effect of groundwater pumping[49]



More recent data indicates that supplemental pumping for irrigation is still important in both New Mexico and Texas. A complete set of annual meter data is available for the New Mexico LRG starting in 2009. Table 4.2 provides a comparison of surface water supply to EBID and metered groundwater pumping for irrigation (including water to non-EBID lands) for the 2008-2019 period. This data shows that irrigation well pumping increases in response to low surface water supplies. The data also show

- Perform field spot checks of meter data on an ongoing basis,
- Perform field checks on meter accuracy.

The LRG Water Master reports high levels of completeness in the collection of irrigation well metering data. The 2017 LRG Water Master Report states that "98% of the actively metered irrigation wells in the LRG Water Master District have a meter reading entered into the WATERS database to close out the accounting year 2017." The efforts by the Office of the State engineer allow New Mexico to accurately determine how much groundwater is being pumped; Texas has no such mechanisms.

[49] King, J.P., 2003 EBID Drought Update, February 2003 Presentation to EBID Farmers.

that the total farm delivery per irrigated acre ranges from 3.7 to 4.4 AF/A. If this calculation is done using the entire EBID assessed acreage in the denominator, it results in a total farm delivery of 3.1 to 3.5 AF/A.

Table 4.2. Surface Water Delivery and Irrigation Well Pumping Data in New Mexico, Calculation of Total Farm Delivery per Acre

Calculation of the Total Farm Delivery to Irrigated Lands in New Mexico, 2008 - 2018								
	Surface Water Charged to EBID Canal Headings	EBID Reported Farm Delivery	Metered Irrigation Well Pumping	Total Farm Delivery of Water (GW + SW)	Irrigated Acreage	Average Farm Delivery per irrigated acre	Assessed Acreage	Average Farm Delivery per assessed acreage
Year	Reclamation Project Accounting Records	EBID Board Meeting Minutes	NM OSE Water Master Records	Calculated	Intera 2019	Calculated	EBID Total Assesssed Acreage	Calculated
	Acre-Feet	Acre-Feet	Acre-Feet	Acre-Feet	Acres	Acre-Feet /Acre	Acres	Acre-Feet /Acre
2008	329,294	187,899	**133,000**	320,899	81,061	4.0	90,640	3.5
2009	305,475	187,694	133,000	320,694	75,607	4.2	90,640	3.5
2010	282,082	155,416	137,600	293,016	79,669	3.7	90,640	3.2
2011	59,771	24,149	279,400	303,549	76,002	4.0	90,640	3.3
2012	133,060	54,002	265,000	319,002	72,524	4.4	90,640	3.5
2013	54,002	**21,818**	286,000	307,818	77,199	4.0	90,640	3.4
2014	99,007	**39,999**	252,000	291,999	76,771	3.8	90,640	3.2
2015	143,404	**57,935**	219,000	276,935	73,616	3.8	90,640	3.1
2016	175,199	**87,600**	216,000	303,600	74,884	4.1	90,640	3.3
2017	258,954	139,589	157,000	296,589	74,218	4.0	90,640	3.3
2018	130,000	67,366	244,000	311,366	73,849	4.2	90,640	3.4
Estimated Values: **2008 Irrigation Well Pumping assumed equal to metered 2009 Irrigation Well Pumping,** **EBID Farm Deliveries in 2013 - 2015 calculated assuming 40% delivery efficiency, 2016 EBID Farm delivery calculated assuming delivery efficiency of 50%.**								

Irrigation well pumping in Texas is not metered or reported. However. Texas farms are known to have and use irrigation wells, and EPCWID itself has installed 62 high-capacity District-owned wells in the El Paso Valley, which are intended to pump water directly into EPCWID canals in low-supply conditions.[50]

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[50] Reyes, J. (EPCWID General Manager), *Water Conservation and Management Projects in El Paso County Water Improvement District* (PPT also at http://www.twdb.texas.gov/waterplanning/rwp/climate/doc/13-Reyes.pdf), Symposium: Far West Texas Climate Change, June 17, 2008.

5 PROJECT SUPPLY

Project Supply refers the water that is delivered (or is available for delivery) to Project beneficiaries. Project Supply is derived from several sources, including the water released from Project storage, drain flows, Project return flows, useable tributary inflows to the stream system below Caballo Dam, and wastewater effluent from municipal sources.

5.1 WATER RELEASED FROM PROJECT STORAGE

The main source of Project Supply is water released from Project storage in Elephant Butte and Caballo. Not all water stored in these reservoirs is Usable Water available to the Project. The water stored in Elephant Butte also includes Compact Credit water[51] which is not available for Project use unless certain terms of the Rio Grande Compact are met (i.e. relinquishment),[52] and storage associated with San Juan-Chama water,[53] which is imported water reserved for use by the City of Albuquerque and, at times, the City of Santa Fe.

5.2 DRAIN FLOWS AND PROJECT RETURN FLOWS

Return flows have always been an important part of the Project Supply since drains were first installed in approximately 1919, as demonstrated in Section 3.3. As the Project has been operated, these return flows consist of drain flows, water wasted (i.e. released back to the Rio Grande) from the canal system, and surface run off of excess irrigation water.

In an irrigation system, “waste” refers to water in a canal or lateral, which is not delivered to farms, but instead is returned to the river, typically through wasteways designed for this purpose. Wasted water is often associated with extra water needed to keep canal levels high enough to allow water to flow by gravity from the canal onto farms, or water bypassed through canals to avoid losses. Some occurrences of waste are anticipated and approved Project operations, such as the waste of water from the southern end of the Mesilla Valley canal system, and conveyance and waste of EPCWID’s water through EBID canals during low supply years to reduce losses.

5.2.1 New Mexico Drain Flows

Historically all drain flow discharging from the Rincon Valley to the river entering Seldon Canyon has been available for Project diversion downstream in the Mesilla and El Paso Valleys. *See* Figure 1.2. Mesilla Valley drain flow discharging above Mesilla Dam was available for diversion into the Eastside and Westside canal. The rest of the drains in the Mesilla Valley discharge into the Rio Grande below Mesilla

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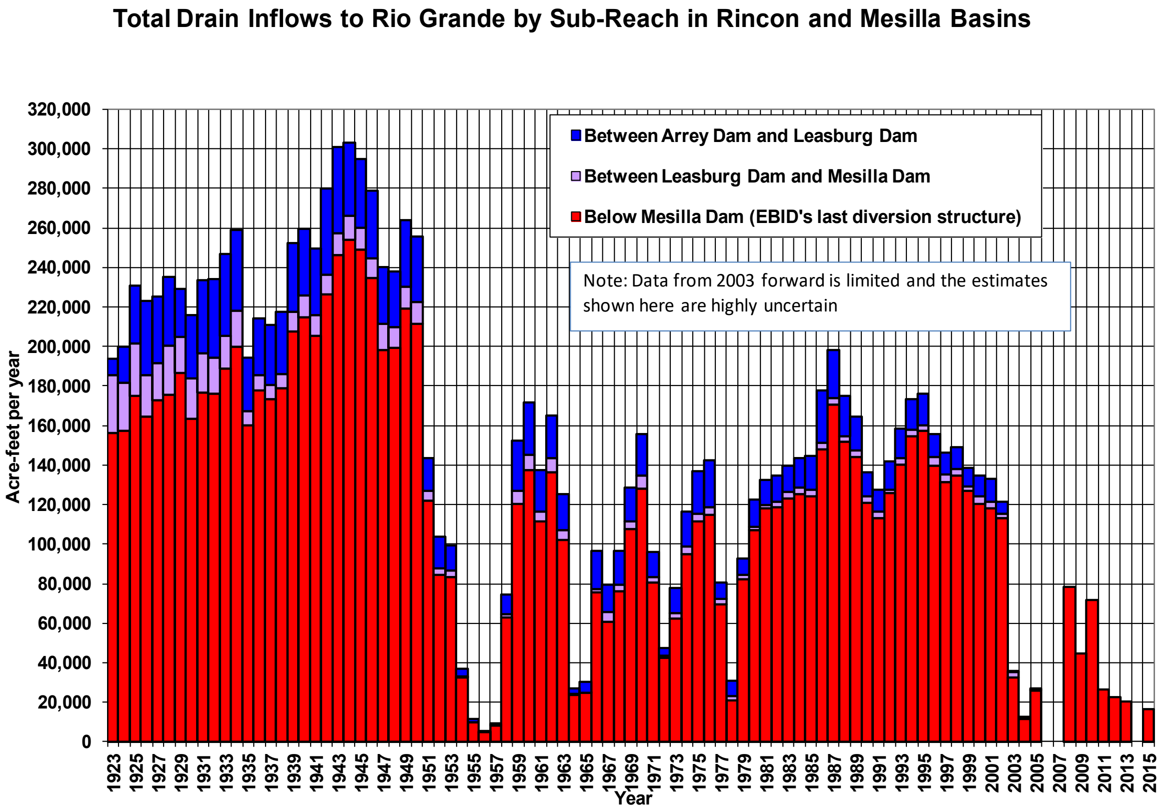
[51] Compact Credit Water, as defined in the Rio Grande Compact is that amount of water in Project storage which is equal to the accrued credit of Colorado, or New Mexico, or both.

[52] *See* Estevan Lopez Expert Report, 2019.

[53] San Juan-Chama water is water imported into the Rio Grande through a transmountain diversion. It is considered imported water, not native water subject to the Rio Grande Compact or available to the Rio Grande Project.

Dam, and the water from these drains is available for diversion in the El Paso Valley. Figure 5.1 shows the total amounts drain discharge originating in the Rincon and Mesilla Valleys, by sub-reach of the Rio Grande between major diversion headings.

Figure 5.1: Total Annual Gaged Drain Flow in the Rincon and Mesilla Valleys, Drain flows combined by reach into which drain flows discharge



5.2.2 Texas drain flows

Historically, water from some El Paso Valley drains was available to, and diverted by, Project canal headings, although, again, the situation in this region is more complex than in the Mesilla Valley. El Paso Valley drains and the issues surrounding them are fully discussed and illustrated in Appendix C.

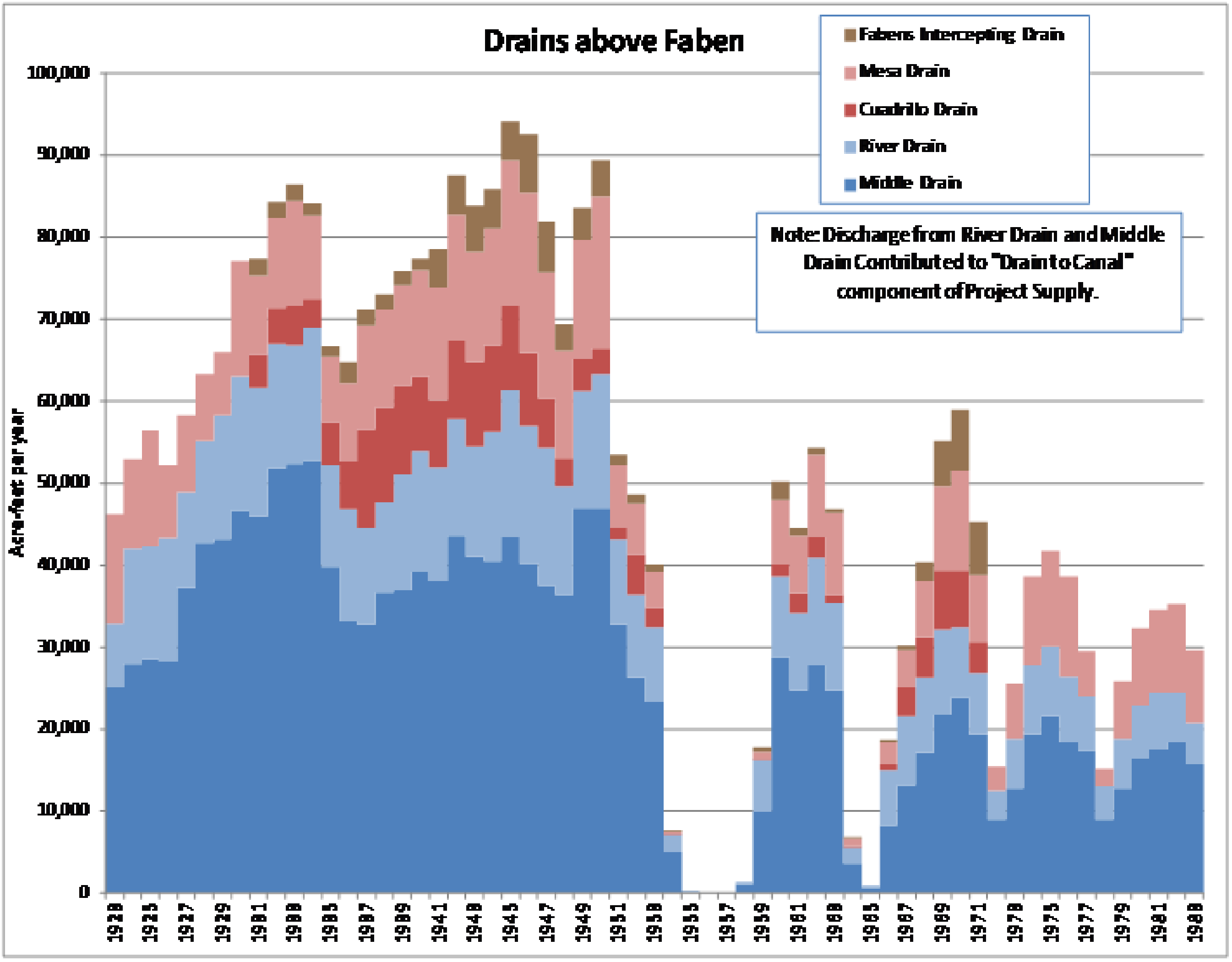
El Paso Valley drains can be divided into two groups: those discharging water into Project conveyances or the Rio Grande above Fabens (Drains Above Fabens), and those discharging into Project conveyances or the Rio Grande (Drains Below Fabens).[54]

Figure 5.2 shows the total reported discharge of the Drains Above Fabens. Data reported by Reclamation is available through 1983.[55] Prior to 1938, the entire amount plotted (65,000 AF/Y to

[54] This division is consistent with Project Drainage Reports, which starting in 1935 tabulate the "Total above Faben" as well as the "Total for [El Paso] Valley."

85,000 AF/Y) would have been available for diversion and counted as Project Supply at the Tornillo Heading. Diversion of El Paso Valley drain flow into the Tornillo Canal is consistent with the data and descriptions included in the Joint Investigation.

Figure 5.2. Total Annual Gaged Drain Flow for El Paso Valley Drains Above Fabens



After the Rectification Project realigned the Rio Grande, the amounts of drain water shown in blue in Figure 5.2 (water from the River and Middle drains) were available for diversion into the Riverside Canal Extension. Figure 5.3 is a schematic diagram showing the Rio Grande near Fabens before and after Rectification, and the resulting treatment of the Drains Above Fabens.

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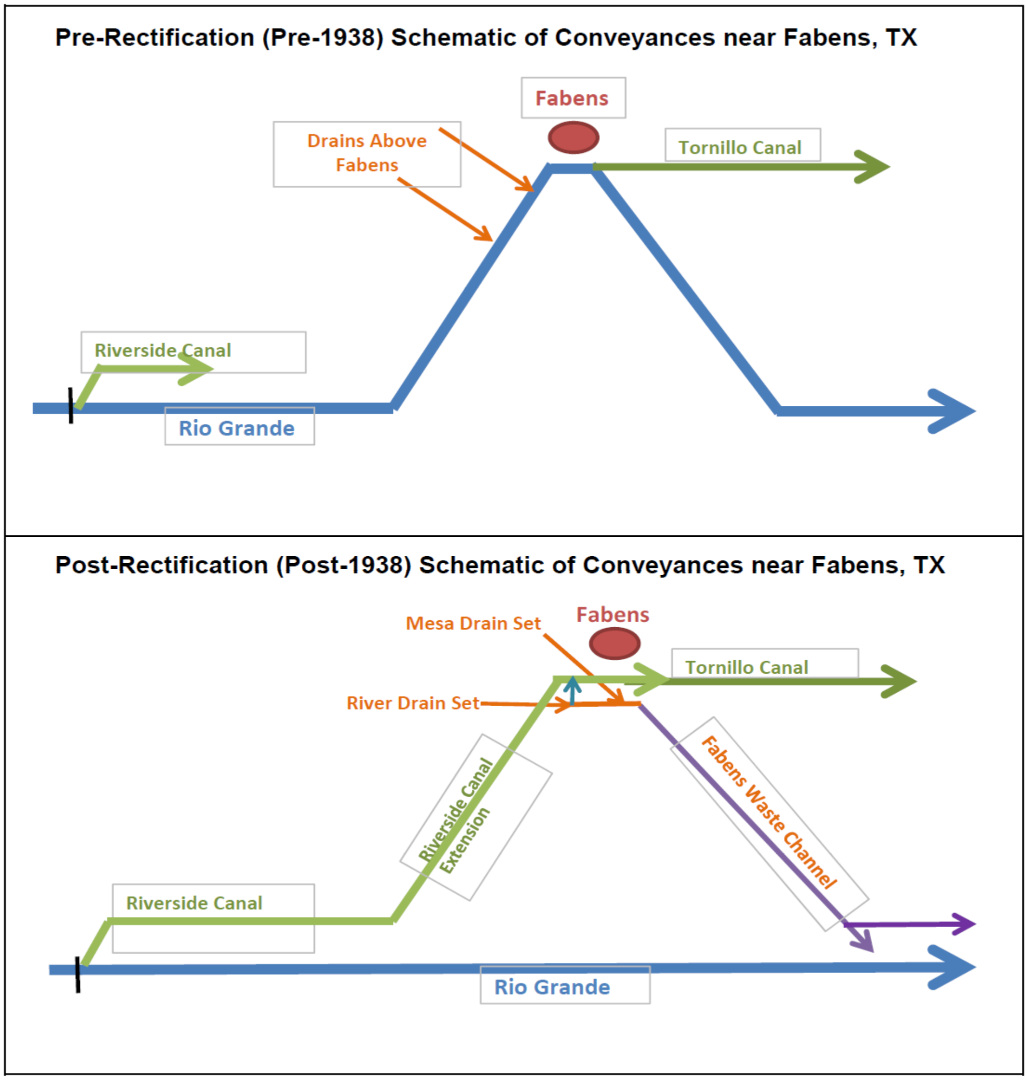
[55] RGPH 1919 – 1983; Reclamation Drainage Data Reports 1921 – 1983 as compiled by NMSU (Data Collection Effort for Flow Data from Sites along the Rio Grande between Elephant Butte Reservoir and Fort Quitman, TX. Released by NMSU in 2004).

Figure 5.3. Schematic showing Rio Grande and Project conveyances and drains before and after Rectification realignment of river



Today, however, Project accounting does not include a term for diversion of El Paso Valley drain flow at the Tornillo heading, and if any such diversion does occur, it is not considered a diversion of Project Water.

5.2.3 Historical Drain Flow Trends

The drain flow data from the Rincon, Mesilla and El Paso Valleys plotted in Figures 5.1 and 5.2 show that drain flows throughout the Project decreased substantially starting during the 1950s drought, in response to reduced Project Supply conditions and increased groundwater pumping throughout the Project during that time. Fluctuation in drain flows are observed in the 1960s and 1970s in response to intermittent low-supply condition. Afterwards, during the full-supply years of the 1980s and 1990s, drain flows largely rebounded.

5.3 Tributary Inflows

Tributary inflows within the Project consist of occasional flood flow from usually dry arroyos caused by local precipitation events. The amounts of water involved are usually small, and the amount of this water that can be used within the Project is smaller still because tributary inflows may not coincide with irrigation demands, or may be superfluous given the amount of Project Supply already available at the canal headings. Tributary inflows may also be difficult to use due to the presence of sediments in the water.

5.4 Municipal Wastewater Effluent

Treated effluent from municipal water suppliers such as Las Cruces and El Paso is used by the Project as it becomes available for diversion at downstream canal headings, or is pumped into Project canals.[56] The City of Las Cruces, and other smaller entities, discharge effluent into the Rio Grande above Courchesne. The El Paso Water Utility ("EPWU") discharges effluent into the Rio Grande upstream of American Dam from the City's Northwest Treatment Plant located along the El Paso Narrows (*see* Figure 1.5). This water is treated as Project Supply, and diversion of this water is included in Project accounting. In the El Paso Valley, EPWU discharges effluent from its Haskell R. Street Wastewater Treatment Plant ("Haskell WWTP") into the ACE canal, and from its Bustamante Wastewater Treatment Plant ("Bustamante WWTP") into EPCWID's Riverside canal. A large part of EPWU's water supply in the El Paso Valley consists of Project water,[57] and so part of their effluent is Project return flow.

However, EPCWID and Reclamation treat all EPWU effluent in the El Paso Valley as non-Project Water, and EPCWID is not charged for diversion or use of this water. Originally the effluent from the Haskell WWTP discharged into the Rio Grande above Riverside Dam and was considered to be Project Water; until 1999 EPCWID's diversion of this water was charged against its allocation. In 1999, after the completion of the American Canal Extension, Haskell WWTP effluent could be discharged to ACE, and EPCWID and Reclamation agreed that as a result, Haskell WWTP effluent was no longer Project Water.[58] This issue is discussed in more detail in Appendix D of this report. Effluent from the Bustamante WWTP discharges into the EPCWID Riverside Canal below the Riverside Canal gage, and the Project does not charge EPCWID for the use of this water, either.

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[56] To avoid confusion with Project waste, in this report I will refer to municipal treated waste water as "effluent."

[57] Project water comprises an average of 40% of El Paso Water Utility's supply in non-drought years, closer to 50% in recent years. (https://www.epwater.org/our_water/water_resources). *See* Reyes, J., Water Conservation and Management Projects in El Paso County Water Improvement District, (PPT also at http://www.twdb.texas.gov/waterplanning/rwp/climate/doc/13-Reyes.pdf) Symposium: Far West Texas Climate Change, June 17, 2008, Slide 5, in which the EPCWID General Manager describes a purpose of EPCWID to "Supply Raw Water to Water Treatment Plants."

[58] Letter from Filberto Cortez to Edd Fifer, July 8, 1999. Subject: Summary of June 25, 1999, Meeting to Discusss Water Accounting.

6 OVERVIEW OF PROJECT ALLOCATION AND ACCOUNTING

This section provides an overview of the allocation and accounting methods of the Project at different periods of time. A more detailed description and analysis of Project allocation and accounting is provided in Appendices A and D. As a result of my analysis of pertinent data and extensive years of research and involvement in Project allocation and accounting, I have concluded that:

- The 1938 Inter-district Contract sets forth a division of Project water supply between the Districts in accordance with the proportions of Project acreage: 88,000 of 155,000 Project acres (57%) to EBID, and 67,000 of 155,000 Project acres (43%) to EPCWID. From 1938 through 1978, Reclamation operated the Project so that EBID farmer were entitled to 57% of the U.S. share of Project Supply and EPCWID farmers were entitled to 43% of the U.S. share of Project Supply.

- From 1979 through 2005, Reclamation explicitly allocated the U.S. Share of Project Supply to the Districts in the ratio of 57% to EBID and 43% to EPCWID. The amounts allocated were derived from the D1 and D2 Curves. The amounts of water diverted by the Districts were consistent with this 57:43 ratio.

- In 2006 an alternative allocation procedure, "D3 Allocation," was proposed by EBID, and EPCWID demanded the right to carry over unused allocation from one year to the next. Reclamation began implementing these allocation principles in 2006.

- The 2008 Operating Agreement ("2008 OA") was reached between Reclamation, EBID, and EPCWID as part of a settlement agreement between those parties as to two different litigations, without the involvement or approval of New Mexico, Colorado, or the Rio Grande Compact Commission, except for the participation of the Texas Compact Commissioner as a mediator. The 2008 OA adopts D3 Allocation and "Carryover" of unused allocation.

- Under the D3 Allocation, and the 2008 OA, EPCWID and Mexico are allocated Project water based on Project performance during the 1951 – 1978 period (the D1 and D2 Curves), and EBID is allocated whatever Project Supply is left over.

- Before D3 Allocation as initiated in 2006, Reclamation allocated the U.S. share of Project supply 57:43 to EBID and EPCWID, respectively. Under the 2008 OA, EPCWID's allocated share has increased to an average of 56% (not including Carryover) or 62% (including Carryover). EPCWID's actual Charged Diversions (that is, water actually called for and received) during this period (2008-2018) have averaged 55% of total District diversions.

- Starting in the year 2003, EPCWID has received an allocation credit for the American Canal Extension ("ACE"). The ACE Credit increases EPCWID allocation by up to approximately 20,000 AF. Under the allocation method in the 2008 OA, this same amount (up to ~20,000 AF) is subtracted from EBID's allocation, reducing EBID's total allocation, and the amount EBID can order.

- Because of the decrease in EBID's allocation under D3 Allocation, and because EPCWID is now allocated more water than it diverts in full-supply (or near full-supply) years, EPCWID makes much more use of Carryover than EBID, and EPCWID has had a large Carryover account in several years. EPCWID's Carryover account includes the effects of Project accounting credits, which do not represent water left in reservoir storage. Carryover accounts are not reduced to account for evaporation. As a result, some amount of water in EPCWID's Carryover account is not associated with actual "wet" water. The amount of allocation carried over, and the extra water needed to deliver the Carryover, is subtracted from Usable Water before any new allocation is made. Therefore, part of the inflow to Elephant Butte is not available for allocation, but instead is used to support and fulfill EPCWID's Carryover account. This has had a significant negative effect on EBID's allocation.

6.1 Accounting and Allocation Before 1979

From the inception of the Project until about 1979, Reclamation delivered Project water to individual New Mexico and Texas farm head gates in response to farm orders. Each acre of Project land was entitled to an equal pro-rata share of Project water. The 1938 Inter-district Contract sets forth the principal that in the event of a shortage of water, "*the distribution of the available supply in such a year, shall so far as practicable, be made in the proportion of 67/155 thereof to the lands within [EPCWID], and 88/155 to the lands within [EBID]*." It is clear that the Districts and the United States agreed that the appropriate division of Project Supply was 57:43.

Until the 1940s there is no evidence that Reclamation set any limits on farm orders. During the 1940s, in some years Reclamation made restrictions on farm orders before the irrigation season began, but according to Project records those the restrictions were lifted as the season progressed.[59] Starting in 1951, at the beginning of a major drought cycle, Reclamation set a limiting allotment of Project water to individual U.S. farms each year, on an acre-feet per acre (AF/A) basis.[60] Thereafter, Reclamation announced limiting allotments before the beginning of each irrigation season, and adjusted the allotment as appropriate in response to any increase in Project Storage.

At some time during the early 1950s, Reclamation defined a "normal delivery to the Project lands" to be 3.024 AF/A[61] based upon the delivery records from 1946 through 1950; that is, presumably based on actual usage by the farms.

In the years preceding 1979, Reclamation did not provide an accounting of Project deliveries to the Districts. The closest thing to accounting records before 1979 are the Project Water Distribution Reports ("WDRs"), which tabulate diversions and deliveries by "Valley" or by "Unit," not by District. I have

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[59] RGPH 1940-1950 (Irrigation Schedule and Other Announcements).

[60] RGPH 1951 (Irrigation Schedule and Other Announcements).

[61] Friedkin, J.F. and Resch, W.F., 1906 Treaty Deliveries to Mexico, International Boundary and Water Commission, June 29, 1956.

constructed and include in Appendix A to this Report a post-fact estimate of how much water was delivered to each District during this period based on the WDRs.

From Appendix A, which fully discusses the issue, Table A.2 and Figure A.3 present the resulting annual Project diversions by District from 1931 (when consistent data of this type starts to become regularly available) through 1978. On average during the time period, EBID diverted an average of 54.5% of the U.S. share of Project Supply, and EPCWID diverted 45.5%. Table A.3 and Figure A.4 present the resulting farm deliveries by District for this same time period, 1931 – 1978. On average EBID farmers received 55.8 % of the U.S. farm deliveries, and EPCWID received 44.2%. This distribution of Project diversions and farm deliveries is generally consistent with the Project allotment by acre process which entitled EBID farmers to 57% the available supply and EPCWID farmers 43%. What amounts these Districts and farmer actually diverted and received at farm headgates is controlled both by the allotment amounts (equal for all farm acreage) and the amounts the farmers actually ordered.

6.2 Accounting and Allocation 1979 - 2006

Project operations changed after EBID and EPCWID paid off their loans to the Federal Government in 1972 and 1975. In 1979 and 1980, EBID and EPCWID signed contracts with Reclamation (the "Transfer Contracts")[62] that transferred various infrastructure (canals, etc.) to the Districts, and gave the Districts responsibility for delivering Project water to the farmers. In order to effect the goals of the Transfer Contracts, Reclamation changed its operations so that instead of allotting and delivering water to individual farms, Reclamation now allocated water to each District for delivery at the District's canal headings (i.e. Arrey, Leasburg, Mesilla, Franklin, Riverside), and the Districts became responsible for delivery to individual farms.

To support this change in operations and delivery to Mexico and the Districts, Reclamation developed a new allocation method (the "D1/D2 Allocation" method) and new accounting system. The new method and system explicitly divided the U.S. share of Project water to the Districts 88/155 (57%) to EBID and 67/155 (43%) to EPCWID. This new method and system also continued the historic process of including any unused allocation (or allotment) from one season in the pool of water available for allocation in the next year to the Districts and Mexico.

The Transfer Contracts contain language requiring that *"[a] detailed operating plan will be concluded between the United States and the District setting forth procedures for water delivery and accounting*."[63] Accordingly, during the 1980s Reclamation performed analysis of historical water distribution data as reflected in Reclamation's WDRs from 1951 to 1978, and developed allocation and operating procedures

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[62] 1980 Contract No. 0-07-54-X090, for Transfer of the Operation and Maintenance of Project Works, between Bureau of Reclamation and El Paso County Water Improvement District No. 1, March 14, 1980, and 1979 Contract No. 9-07-53-X0554, for Transfer of the Operation and Maintenance of Project Works, between Elephant Butte Irrigation District and Bureau of Reclamation, February 15, 1979 (the "Transfer Contracts").

[63] Transfer Contracts, section 6, paragraph d.

for the Project based upon that analysis. This analysis is the basis of the D1/D2 Curves and Allocation method, and this time period (1951 – 1978) shall be referred to as the "D2 Period."

In 1985 Reclamation released a Draft Operating Agreement,[64] including an early version of the D1/D2 Allocation method, and documentation of an accounting system that describes how the Districts' diversions would be accounted, or charged, against their allocations. Reclamation documented a modified version of these allocation procedures in its Water Supply Allocation Procedures document ("WSAP"),[65] which Reclamation used as the basis for Project allocation until the mid-2000s and which is relied upon extensively in this Report. These and other draft allocation procedures documents include different versions of the D2 Curve. In this report, I will work with the D2 Curve and underlying data set extracted from the WSAP document. This data is described and analyzed in Appendix E.

Throughout the 1980s and 1990s the Districts and Reclamation did not come to a full agreement concerning these proposed operating procedures, and for many years there was no signed operating agreement for the Rio Grande Project. Reclamation, however, continued to allocate Project water during the 1980s, 1990s and early 2000s in accordance with the principles and methods they had proposed: the D1/D2 Allocation.[66]

6.2.1 D1/D2 Allocation[67]

The historical water supply relationships that Reclamation developed and referred to as the "D1/D2 Curves" are shown in Figures 6.1 and 6.2.

The D1 Curve was designed to determine the amount of the Mexican Allocation as a function of Project Storage, based on the historical relationship between Project Release (from storage) and farm deliveries plus Mexican delivery. The D1 Curve is still used for this purpose in current Project allocation.

The D2 Curve was designed to determine the entire amount of Project Supply that would be available for delivery to the Districts and Mexico, as a function of Project storage. The D2 Curve is based on historical relationship between Project Release and total Project diversions, including Mexico. It is in effect an historical efficiency or Project performance relationship for Project delivery. Under D1/D2

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[64] *1985 Draft Operating Agreement* for the Rio Grande Project, between Reclamation, EBID, and EPCWID, January 1985.

[65] Bureau of Reclamation: U.S. Department of the Interior, Rio Grande Project: Water Supply Allocation Procedures (undated, circa 1990) ("WSAP"). This document was provided to New Mexico Interstate Stream Commission staff by Filberto Cortez of Reclamation in 2005.

[66] The Project allocated full-supply amounts of Project Supply to EBID and EPCWID, as defined by the sometimes-shifting D1/D2 analysis, from 1979 through 2002. In the low-supply years of 2003 and 2004, Reclamation allocated EBID and EPCWID pro-rata shares (57% and 43% respectively) of the water Reclamation estimated that it could deliver. In 2005, Reclamation again allocated EBID and EPCWID full-supply allocation amounts.

[67] A fully detailed description of the D1/D2 Curve and Allocation is in Appendix D.

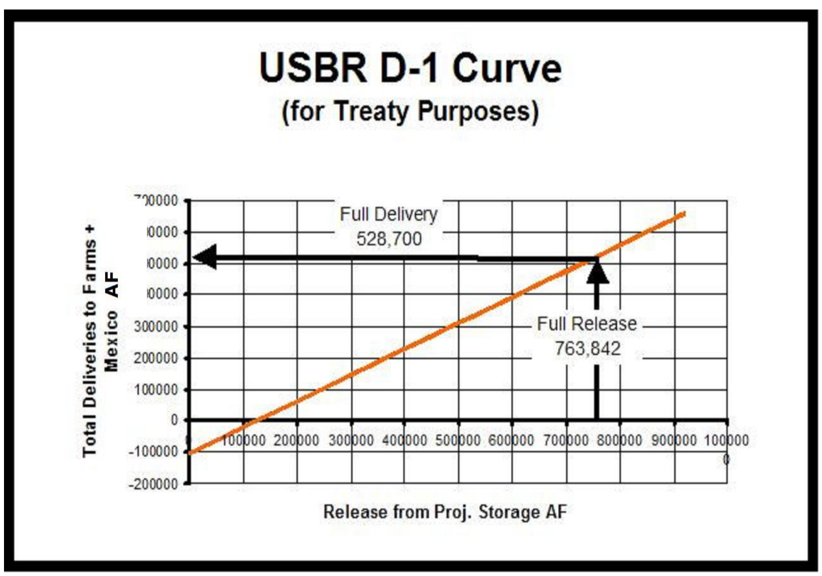
Allocation the total amount of Project Supply calculated by the D2 Curve is divided among the parties as follows: Mexico gets the share calculated using the D1 Curve, and the remainder is split 57:43 between EBID and EPCWID respectively.

Significant although largely unmeasured groundwater pumping was known to have occurred in Texas and New Mexico during the 1951 – 1978 period, and is reflected in the Project water distribution data from that period; thus the D1 and D2 Curves would have reflected the hydrologic effects of these groundwater diversions. *See* Section 4 for estimates of historical irrigation pumping throughout the Project.

The D1/D2 Allocation method explicitly divided the U.S. share of Project Supply 57:43 to EBID and EPCWID, respectively, in keeping with earlier agreements and historical practice. This division of water is illustrated in Figure 6.4, which shows the D2 Curve, with colored areas representing Mexico's, EBID's, and EPCWID's share of Project Supply. D1/D2 Allocation determined each District's annual allocation, and there was no provision for either District to "carry over" unused allocation for individual District use from one year to the next. Instead, any water associated with unused allocation was essentially put in the pool of water available for next year's allocation.

In Figure 6.3 I have plotted the underlying data from the D2 Curve (extracted from the WSAP document) and calculated a linear regression using Excel. The resulting line is identical to the D2 Curve.

Figure 6.1. Reclamation's D1 Curve from F. Cortez[68]



[68] Cortez, F., PPT: U.S. Bureau of Reclamation / Rio Grande Project, 2003 (PPT named: TCEQ_BOR_PP_121103.ppt), provided to the New Mexico ISC March 2005.

Figure 6.2. Reclamation's D2 Curve from F. Cortez[69]

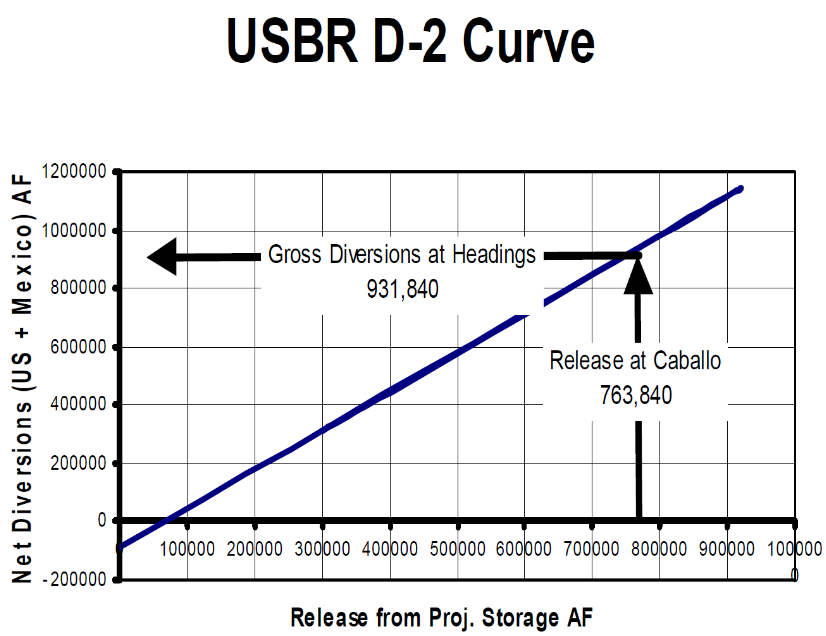
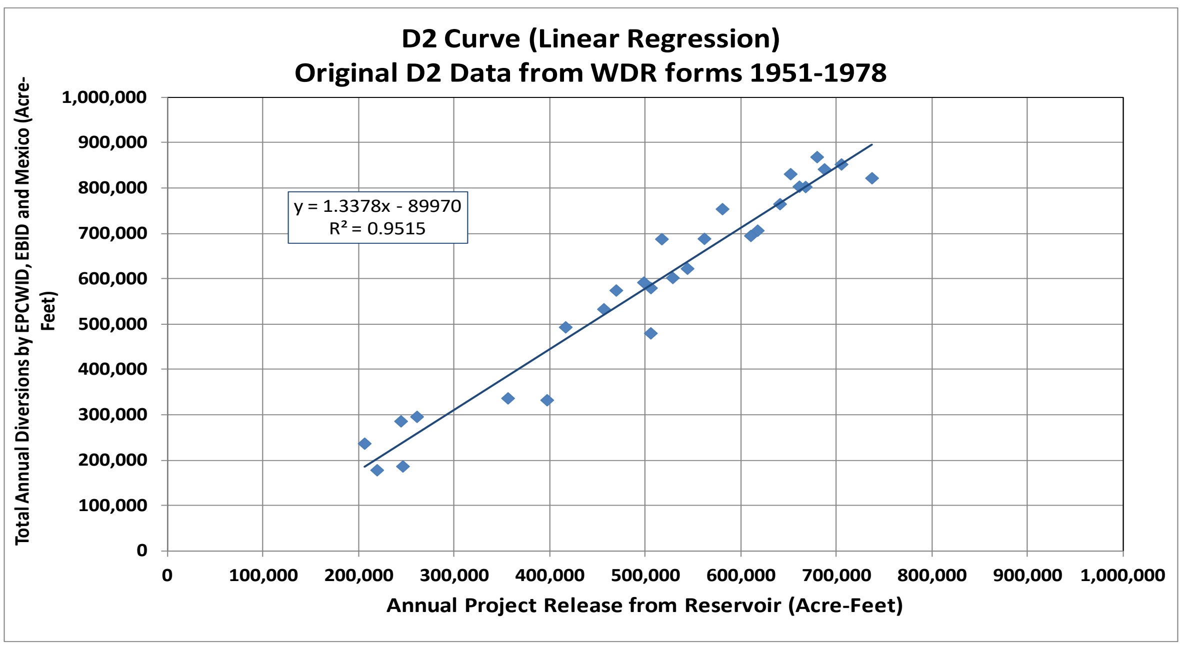


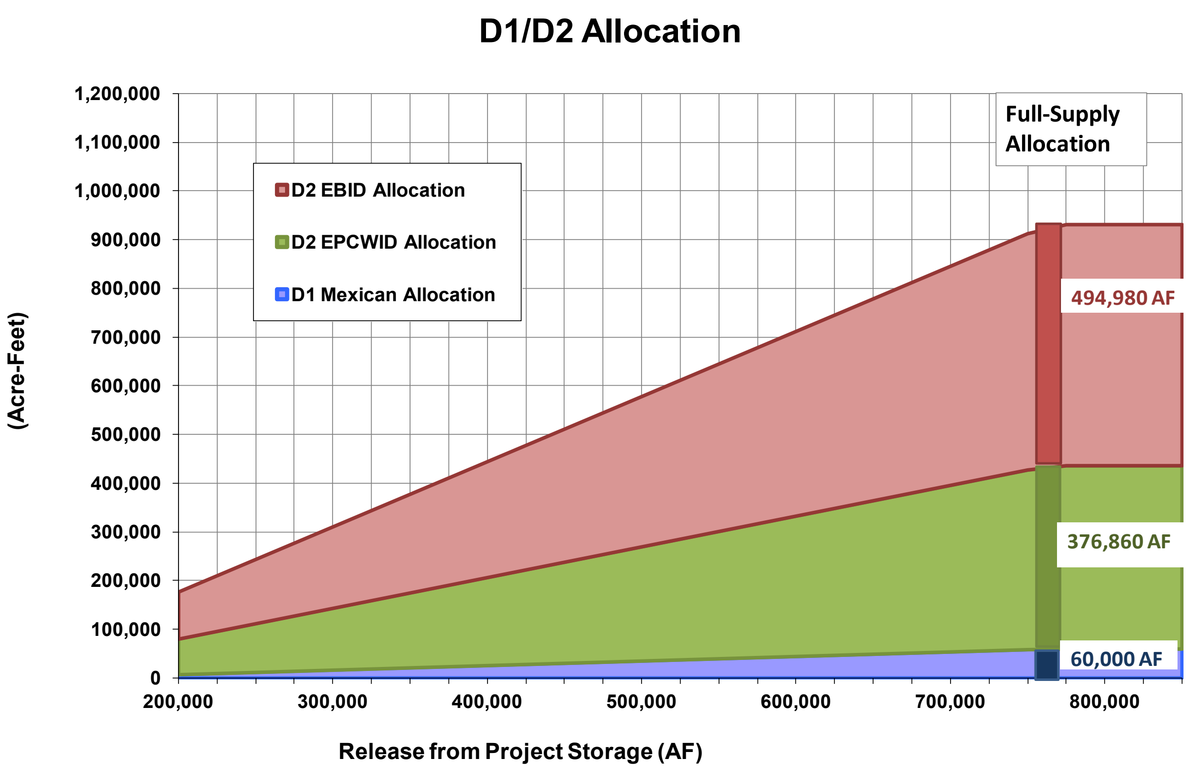
Figure 6.3. D2 Curve (or D2 Relationship) plotted with Original D2 Data from 1951-1978



69 Cortez, F., PPT: U.S. Bureau of Reclamation / Rio Grande Project, 2003 (PPT named: TCEQ_BOR_PP_121103.ppt). Figures on the Y axis are cut off in the original of this document.

Figure 6.3 shows that the D2 Curve is a good linear representation of the diversion data, although there are some significant deviations in the data. That is, Project performance during this period was generally consistent with the D2 Curve during the 1951-1978 time period.

Figure 6.4. Illustration of Project Supply based on WSAP D2 Analysis, and D1/D2 Allocation among Districts and Mexico



6.2.2 Post-1978 Accounting

Once Reclamation began allocating and delivering water to the Districts in 1979, it needed a system for charging each District's diversions against its allocation. I am not aware of any description of the accounting Reclamation used for this purpose until the 1985 Draft Operating Agreement; however, the available accounting data from 1979 through 1985 suggests that the general accounting methodology described in that 1985 document was used starting in 1979. This accounting system has been modified since it was first documented in the 1985 Draft Operating Agreement, but to a large degree this same accounting system is in place today, and will be referred to here as "Post-1978 Accounting." This accounting system includes a complex system of charges for diversion, credits and charges for deliveries to EPCWID lands within the Mesilla Basin, for excess waters diverted but not used by EPCWID, and for the operations of El Paso Water Utilities. The Post-1978 Accounting system, and the accounting credits that are part of the system, as well as the significant changes made to the processes as part of the 2008 OA, are described in more detail in Appendix D.

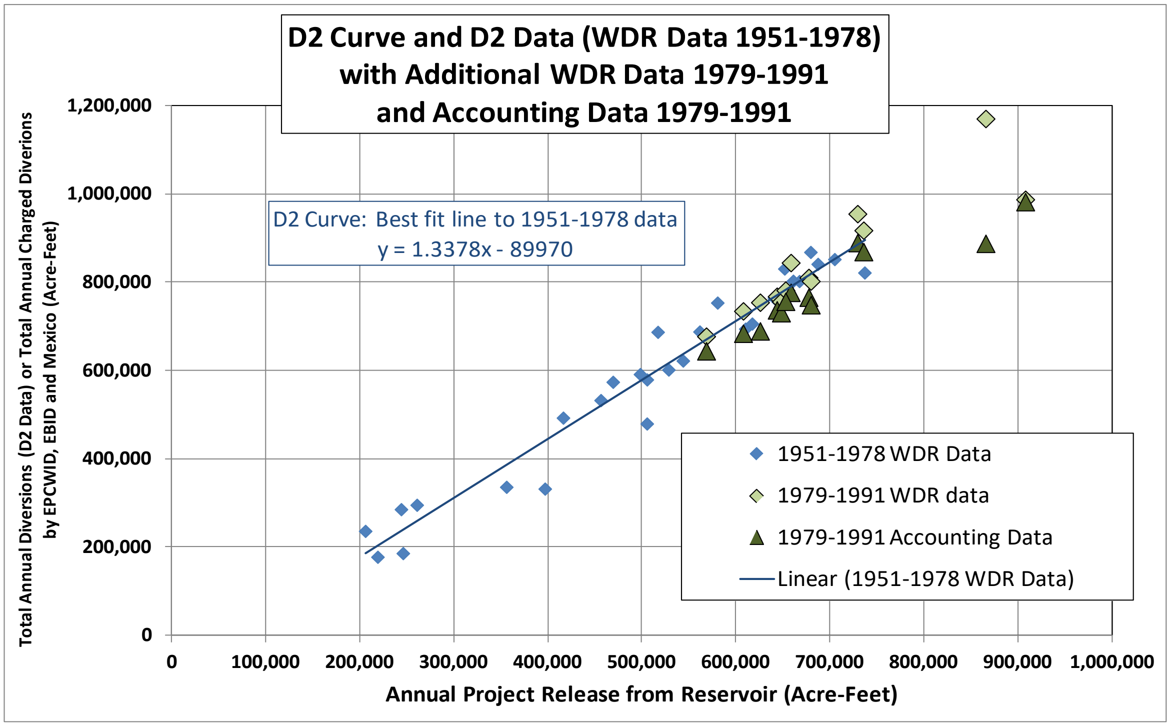
It is important to note that the Post-1978 Accounting rules are different than the way Project deliveries were tabulated and reported during the D2 Period of 1951 - 1978. The D2 data set largely consists only of actual diversion data, with some adjustment for waste. Current accounting data reflects a complex set of rules, and numerous accounting credits, that can result Charged Diversions that are less than the actual diversions that occurred in those years.

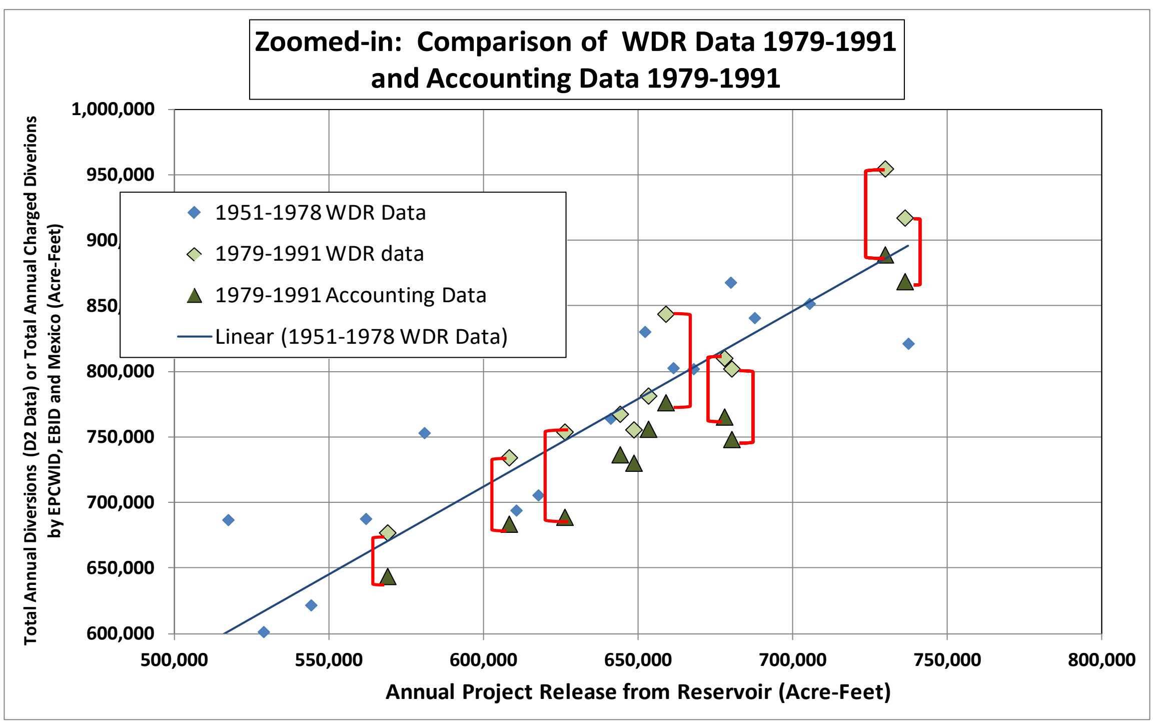
Figure 6.4 is an illustration of the D1/D2 Allocation among Mexico, EBID, and EPCWID.

The impacts theses changes in accounting rules cause is illustrated in Figure 6.5, which compares D2 Curve data (WDR Data 1951-1978), additional WDR data (from 1979 through 1991), and Project accounting data (from 1979 through 1991).

The upper graph in Figure 6.5 shows all of these data sets together, while the lower graph is focused, or zoomed-in, on the 1979 – 1991 data sets. Red brackets are included to show which two data points represent the same year. This data show that even in the 1979 through 1991 period, Project accounting data (or Charged Diversions to EBID, EPCWID and Mexico) are systematically lower than the Diversions tabulated in the WDR forms. If the accounting data is used to measure compliance with D2, there is a negative discrepancy. If the WDR data are used to measure compliance with D2, there is no apparent departure. I conclude that part of the negative departure from the D2 Curve that is observed with current accounting is caused by the effect of the accounting change itself.

Figure 6.5. Upper Graph: D2 Curve and D2 Data from WDR forms, Additional WDR Data 1979 – 1991, and Accounting Data 1979 – 1991. Lower Graph: Zoomed to Facilitate Comparison of WRD Data 1979 – 1991 and Accounting Data 1979 – 1991





US_MSJ_00000639

The practical effect of a negative departure from the D2 Curve is that more water will have to be released from Caballo to deliver a given amount of Charged Diversions to the Districts and Mexico than the D2 Curve would predict.

The allocation, charged diversion, and farm delivery data from the period 1979 through 2005 are presented in Appendix A. Table A.4 and Figure A.5 present District allocations. The split of allocation between the Districts is exactly 57:43, as provided for in the D1/D2 Allocation method, except for 2003 and 2004 in which ACE Credits were awarded to EPWCID, bringing its share of the allocation up to 45%. The District's Charged Diversions are provided in Tables A.5 and A.6, and Figure A.6. This data shows that the Charge Diversions to the Districts were divided on average 58% to EBID and 42% to ECPWID.

Other data from this period is also presented in Appendix A, such as EBID's final allotments to farms (Table A.7) and farm delivery data (Table A.8 and Figure A.7).

In Table A.9 and Figure A.8 I present a comparison of District allocations to each District's Charged Diversions. This data show that in many years EBID and EPCWID did not order or receive all of the water they were allocated.

6.3 ALLOCATION AND ACCOUNTING 2006 – 2019 (D3 ALLOCATION WITH CARRYOVER)

6.3.1 Adoption of D3 Allocation with Carryover

In 2006, after years of controversy, EBID proposed a new allocation method, "D3 Allocation," which was adopted by Reclamation in that year. The D3 Allocation method is intended to reduce EBID's allocation to account for all negative departures from the Project's historical performance. At the same time, EPCWID demanded the ability to "carry over" unused allocation from year to year for its individual use, rather than the historic practice of incorporating any water associated with that unused allocation into pool of water available for next year's allocation. Reclamation implemented D3 Allocation in 2006, and also allowed each District to carry over half (1/2) of its unused 2006 allocation into 2007. EPCWID sued Reclamation as a result of this partial implementation of what is now known as "Carryover," contending that it should be able to carry over its entire unused allocation.

6.3.2 2008 Operating Agreement

On March 10, 2008, Reclamation, EBID, and EPCWID entered into an operational plan for the Rio Grande Project referred to as the 2008 Operating Agreement ("2008 OA")[70] which incorporates both D3 Allocation and Carryover. The 2008 OA was created and adopted in confidential litigation settlement negotiations, exclusive to the aforementioned three parties, with participation by the Texas Rio Grande

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[70] *Operating Agreement for the Rio Grande Project,* Agreement between Elephant Butte Irrigation District, El Paso County Water Improvement District No, 1, and the United States through the Bureau of Reclamation, signed March 10, 2008 ("2008 OA").

Compact Commissioner as a mediator.[71] Neither New Mexico nor Colorado was a party to the associated litigation and did not participate in these negotiations.

In the months that followed adoption of the 2008 OA, Reclamation, EBID and EPCWID developed an operations manual as required by the 2008 OA providing detailed information on Project operations, equations, and methods. A large part of this 2008 Operations Manual describes Project accounting, which is similar to the Project accounting system already in use as described in the 1985 Draft Operating Agreement. The 2008 Operations Manual was updated in 2010 and 2012, as new issues arose and additional data analysis warranted.

The D3 Allocation method is described in more detail in Appendix D, but put simply: under the D3 Allocation method, Mexico and EPCWID are generally allocated water according to the D1 and D2 Curves but EBID's allocation depends on the Project Diversion Ratio, a new term in Project allocation. The Diversion Ratio for each year is calculated as the ratio of the annual Project Charged Diversions (including Mexico), divided by the annual Project release from Caballo. Under D3 Allocation, the Diversion Ratio is used to calculate Project Supply.

Roughly speaking, under the D3 Allocation method, Mexico's D1 Allocation and EPCWID's D2 Allocation are subtracted from that Project Supply (calculated using the Diversion Ratio), and whatever remains is allocated to EBID. D3 Allocation has the effect of reducing EBID's allocation by any amount by which the estimated deliverable Charged Diversions falls short of the Project Supply (or Net Diversions) calculated by the D1/D2 Allocation method.

In Figure 6.6, Project accounting data from 1979 through 2018 are plotted together with the D2 Curve and associated D2 data. The accounting data consists of annual total Charged Diversions from EBID, EPCWID and Mexico (the "Charged Diversions" for Mexico being equal to the gaged Mexican diversion at Acequia Madre.)

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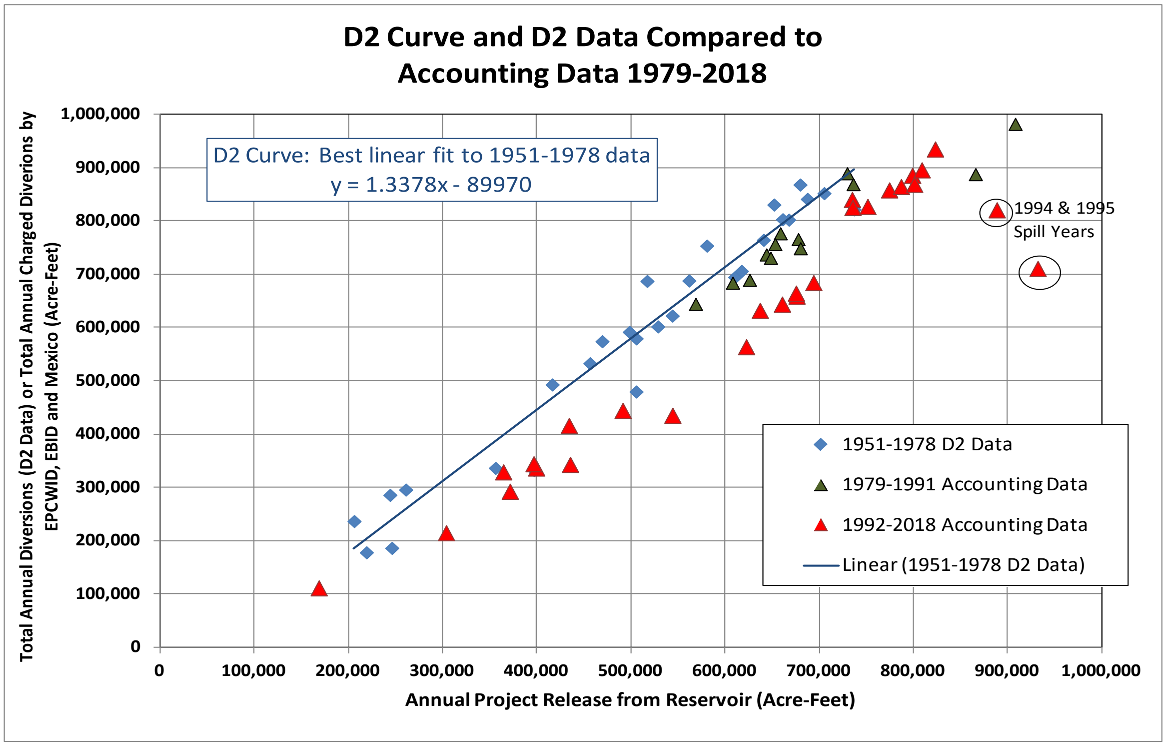
[71] 2008 Settlement Agreement, between the U.S. Bureau of Reclamation, Elephant Butte Irrigation District, and El Paso County Water Improvement District No. 1, Including the 2008 Operating Agreement, April 10, 2012.

Figure 6.6. D2 Curve and D2 data plotted together with 1979 – 2018 Charged Diversions as reported by Reclamation, calculated using Post -1978 Accounting



The 1979-2018 Charged Diversions in Figure 6.6 are systematically lower than the D2 Curve. This means that in these years, the total amount of chargeable water delivered to the Districts and Mexico was less than what would be predicted by the D2 Curve, and therefore less than what was allocated under D1/D2 Allocation

As applied, the D3 Allocation method uses the Diversion Ratio to reduce the total amount allocated each year to account for deficiencies in overall Project performance. The total D3 Allocation should, in theory, closely approximate the amount of Charged Diversions the Project can deliver to canal headings under the hydrologic conditions existing in each year. Mexico's and EPCWID's allocations, however, are still determined using the old D1/D2 method. EBID's allocation is reduced to make up the difference, or the negative departure from the D2 Curve.

D3 Allocation is illustrated for a representative full supply year (2008) in Figure 6.7, which superimposes a bar showing 2008 current-year allocations on top of a D1/D2 Allocation distribution graphic.[72] The large downward change to EBID's allocation cause by D3 Allocation is illustrated by comparing the full-supply allocation bar in Figure 6.6 to that of Figure 6.4.

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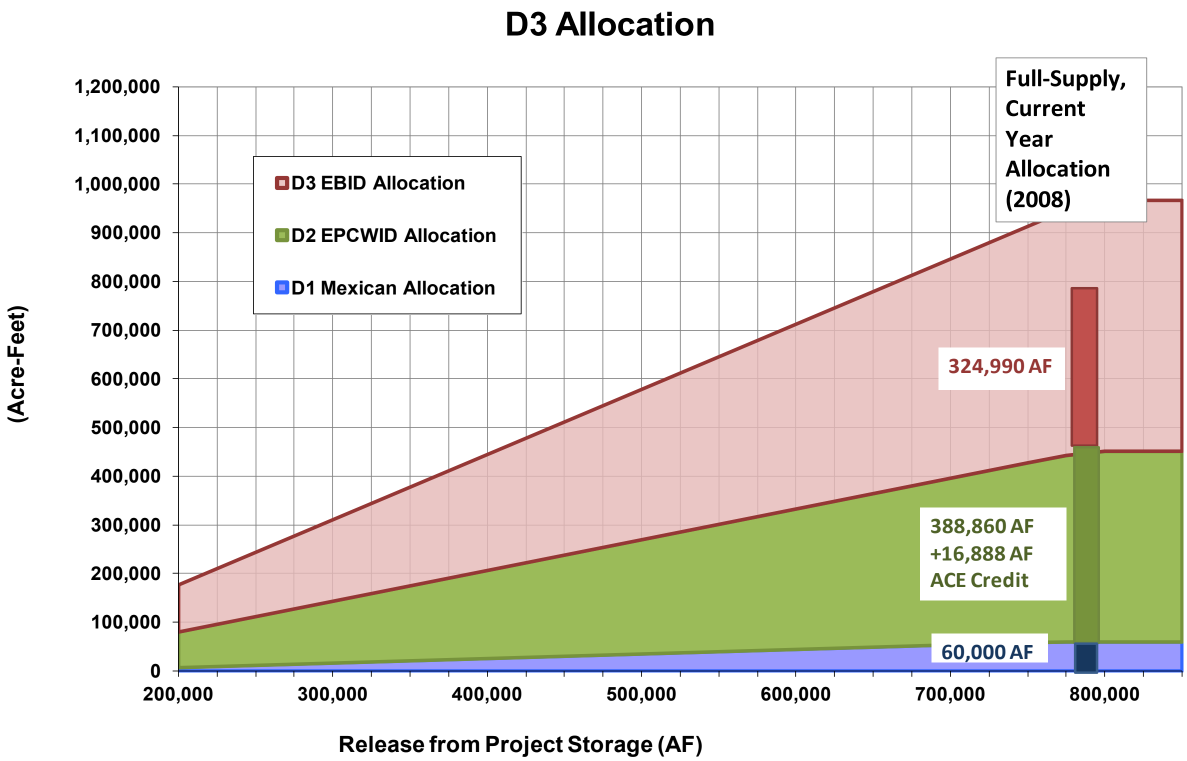
[72] The D1/D2 allocation graphic includes the "extension of the D2 curve" which increases EPCWID's full-supply, current-year allocation from 377,000 AF to 388,000 AF, not including ACE credit. This is more fully explained in Section 8.

Figure 6.7. Illustration of D3 Allocation with Current-Year Allocation Data from 2008



The D2 Curve, a plot of total water delivered to canal heading versus total release from Caballo, is in effect a historical efficiency or performance relationship for Project delivery. The D3 method is intended to reduce EBID's allocation to account for all negative departures from the Project's historical performance.[73] As described in an email by F. Cortez, June 16, 2006: "*The main points [of D3 allocation] are that the D-1/D-2 curves will be used to determine allocations and the EBID proposal stipulates that any river system losses in New Mexico that affect the deliveries in EPCWID and Mexico will be replaced from EBID allocated water.*"[74]

This result is also described in the Final Environmental Impact Statement for the Project:[75]

> *The diversion ratio provision of the OA ensures that annual allocations and deliveries to EPCWID are consistent with historical performance. Moreover, it ensures that deviations in*

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[73] In theory, EBID's allocation would be increased above their D2 allocation if Project performance is better than the D2 curve would predict, but this happened only in 2011 (*see* Appendix D).

[74] Email from Filiberto Cortez, Bureau of Reclamation to Al Blair, Gary Esslinger, EBID, Jesus Reyes, EPCWID, June 16, 2006 (underlining added).

[75] Continued Implementation of the 2008 Operating Agreement for the Rio Grande Project, New Mexico and Texas, Final Environmental Impact Statement, Bureau of Reclamation, September 30, 2016 ("2016 FEIS"), p. 7 (underlining added).

performance relative to historical conditions would be accounted for by adjusting the annual allocation to EBID.

> *Under the diversion ratio provision, the annual project allocation to EPCWID is equal to the district's historical diversion allocation, based on a regression line reflecting past delivery performance, as defined by the D-2 Curve (Appendix A, Section 2.5). The annual allocation to EBID is adjusted to reflect current year (actual) project performance, as reflected by the project diversion ratio. Again, when the diversion ratio is high relative to the baseline delivery performance defined by the D-2 Curve, EBID generally receives an increase in annual allocation compared to its diversion allocation under prior operating practices. When the diversion ratio is low relative to the D-2 Curve baseline, EBID generally receives a decrease in project allocation compared to prior operating practices.*

As described in the 2016 FEIS for the Project: "*The diversion ratio adjustment of the [2008] OA therefore mitigates potential negative effects of changes in Project performance, which result predominately from the actions of individual landowners within EBID, by ensuring that Project allocations and deliveries to EPCWID remain consistent with historical Project performance.*"[76] In fact, the D3 Allocation procedure reduces EBID's allocation to account for ***all*** negative departures from the D2 Curve (unless multi-year drought conditions apply, in which case the standard for Project performance is eased). The assumption that all negative departures from the D2 Curve are caused by New Mexico is unsupported, and as will be shown in this Report, is contradicted by fact.

Allocation and accounting data from 2006 through 2018 is contained in the third part of Appendix A. Table A.10 provides Current-Year Allocation to the Districts (exclusive of Carryover) and Table A.11 provides Total Allocation to the Districts (and Mexico). Note that the ACE Credit, which increases EPCWID's allocation, is included here as part of that District's Current-Year Allocation. The data in these Tables shows that EPCWID's Current-Year allocation is an average of 56% of District Allocation, while EBID's Current-Year Allocation is 44% of District Allocation. If Carryover is considered, EPCWID's Total Allocation is 62% of the District Allocation. EPCWID's Total Allocation includes significant amount of Carryover that has been carried over for multiple years, and does not reflect the amounts of water that EBID has actually been delivered or charged. The amounts each District were delivered and charged are provided in Table A.12, and this data shows that EPCWID's Charged Diversion are on average 55% of the District supply. This upends the decades-long 57:43 (EBID:EPCWID) distribution ratio.

Table A.13 and A.14 show a comparison of the amounts allocated and the amounts delivered and charged for each of the Districts, including unused allocations, Carryover and Carryover Transfers.

6.3.3 EBID's View of 2008 OA

The 2008 OA significantly penalizes EBID for Project-wide inefficiencies, and the question arises: why would EBID enter such an agreement? EBID made several public statements about why it found the 2008 OA necessary. EBID's Manager, Gary Esslinger, met with New Mexico's Water and Natural Resource Committee in August of 2011, and his handout indicates that key features of the 2008 OA are:

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[76] 2016 FEIS, p. 9 (underlining added).

- *Answers the question of "How much water does Texas get?" by tying the Texas allocation to storage levels in Elephant Butte and Caballo reservoir*
- *Protects Texas and Mexico from impacts of groundwater pumping in New Mexico*
- *The threat of interstate litigation over New Mexico's groundwater pumping in the LRG is eliminated*
- *New Mexico maintains flexibility to conjunctively manage surface water and groundwater without outside interference*
- *Cost to State of New Mexico: $0.00*
- *Any storm water New Mexico can capture and use, store or recharge to the aquifer does not change the Texas or New Mexico allocations.*[77]

In a 2008 copy of The Water Report[78] key points of the 2008 OA include the following:

- *With the implementation of D3, EBID/NM constituents and other ground water users in New Mexico's Lower Rio Grande basin can now plan for the most efficient and equitable use of its groundwater resources without the threat of Texas. EBID/NM users may continue to use groundwater to supplement surface water as long as the delivery requirements [based on D3 Allocation] are met.*

It appears likely that EBID was anticipating the benefits of the 2008 OA would be flexibility of ground-water use without fear of interstate litigation.

6.3.4 New Mexico's Early Concerns about 2008 OA

When EBID first proposed D3 Allocation in 2006, the New Mexico State Engineer supported its proposal, while suggesting additional study before a permanent change be adopted.[79] However, the 2008 OA was adopted by the Districts and Reclamation to "be in effect from January 1, 2008 until December 31, 2050."[80]

Following the adoption of the 2008 OA, there were a series of meetings between Reclamation and Rio Grande Compact Commission staff. In 2009, New Mexico and Colorado expressed to Texas and Reclamation their concerns about the effects of the 2008 OA, at the Rio Grande Compact Commission. These concerns were documented in letters to Reclamation from the Texas and New Mexico Rio Grande Compact Commissioners.[81] More meetings followed, in which Reclamation and District staff explained

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[77] EBID Update for the Water and Natural Resources Committee, Gary Esslinger, EBID Manager, August 4, 2008.

[78] Moon, D., Rio Grande Settlement Reached, The Water Report, Issue No. 50, April 15, 2008.

[79] Letter 2006 0605, from John D' Antonio, NM OSE to Connie Rupp, Reclamation Project Operations.

[80] 2008 OA.

[81] Concerns and Questions on the Rio Grande Operating Agreement and Operations Manual, September 2009, prepared by the Texas and New Mexico Rio Grande Compact Commissioners; Additional New

and provided information about the 2008 OA to New Mexico OSE and ISC staff (including the author), but New Mexico's primary concerns related to D3 Allocation and Carryover remained unresolved.

In 2010, the New Mexico State Engineer sent a letter to the Commissioner of Reclamation to further emphasize New Mexico's key concerns about the 2008 OA. Further correspondence and meetings failed to resolve these issues, and in 2011, after the Credit Water release, New Mexico filed suit against Reclamation, [82] citing issues related to the 2008 OA, the lack of meaningful NEPA (National Environmental Protection Act) process for the 2008 OA,[83] and Reclamation's treatment of New Mexico's Rio Grande Compact Credit Water.[84]

Since that time, Reclamation has performed two extensive NEPA processes, resulting in a supplemental Environmental Assessment (and FONSI) in 2013,[85] and a Final Environmental Impact Statement in 2016 for the "Continued Implementation of the 2008 Operating Agreement…"[86] New Mexico was not a cooperator in either of the processes, but repeatedly raised its concerns about the 2008 OA during these processes through the formal comment process.

6.3.5 Post-2008 Changes to the 2008 OA Allocation Process

The Project Allocation Committee has made modifications to 2008 OA allocation process as issues arose in the application of the 2008 OA. Three significant changes have been made since 2008. Two of these changes: the "Multiyear Extreme Drought D2 Correction Factor" and the "Estimate End of Season Adjustment of Project Water Due to Evaporation," are discussed in more detail in Appendix D.

The third important change was introduced in 2011 and is associated with the calculation of "Usable Water Available for Release." In the first years of the 2008 OA Allocations, Usable Water was calculated in accordance with the Compact, using the amounts of Compact Credit determined by the Compact Commission each March. Starting in 2011, the Project Allocation Committee started to estimate

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Mexico Operating Agreement and Manual Questions and Comments for Discussion on December 8, 2009, by the New Mexico Office of the State Engineer, Dec. 1, 2009.

[82] *State of New Mexico v United States, et al.,* Case No. CIV 11-0691 JB/ACT, in the United States District Court for the District of New Mexico.

[83] A FONSI (Finding of No Significant Impact) was issued in 2007 related to Reclamation's adoption in May of 2007 of D3 Allocation and Carryover in a ***unilateral*** document entitled "Operating Procedures for the Rio Grande Project."

[84] For a detailed discussion of Reclamation's unauthorized release of New Mexico's Rio Grande Compact Credit Water, *see* Estevan.Lopez Expert Report, 2019.

[85] 2013 Supplemental Environmental Assessment: Implementation of Rio Grande Project Operating Procedures, New Mexico and Texas, June 21, 2013, Bureau of Reclamation; 2013 Finding of No Significant Impact: Implementation of Rio Grande Project Operating Procedures, New Mexico and Texas, June 21, 1913, Bureau of Reclamation.

[86] Continued Implementation of the 2008 Operating Agreement for the Rio Grande Project, New Mexico and Texas, Final Environmental Imapact Statement, September 30, 2016, Bureau of Reclamation.

Compact Credits by other methods, reducing the Compact Commission's values for additional evaporation during the irrigation season, thus freeing up more "Usable Water" for allocation and release,[87] at the expense of New Mexico and Colorado. By reducing New Mexico's and Colorado's Compact Credits over the course of the irrigation season, and thus increasing Project Supply, Reclamation reduces the likelihood that Texas will either request or accept a relinquishment of Compact Credit Water. New Mexico objected forcefully to this change, and it has had repercussions on Compact Accounting that continue to the present time. This issue is also discussed in more detail in Appendix D and in Estevan Lopez Expert Report, 2019.

6.3.6 Post-2008 Changes to 2008 OA Project Accounting

Following the adoption of the 2008 OA, there have also been a number of modifications to the Project accounting process. These changes have taken the form of additional charges against EPCWID's allocation.

- In 2012 a charge for "Upper Valley Pumps" was added to EPCWID's accounting summary. According to Reclamation staff, this term is intended to account for the water pumped by EPCWID District-owned and operated wells in the southern Mesilla valley. The amounts of water associated with this new charge have been small (less than 500 AF/Y) and in some years this term is omitted from the accounting summary altogether. There is still no term associated with farmer-owned and operated irrigation wells in the Texas part of the Mesilla Valley, which are estimated to pump over 10,000 AF/Y in low supply years.[88]

- Another charge was added in 2016 to EPCWID's accounting summary, labeled "Proposed 2016 CWF Resolution and NWWTP Flow." This charge reappears in 2017, and in 2018 is replaced by a charge for "CWF Technical Memorandum 1/9/2019." These charges appear to be associated with the El Paso Water Utility's Canutillo Well Field. The Canutillo Well Field is located in the southern Mesilla Valley in Texas, along the Rio Grande. The Canutillo Well Field pumps 20,000 AF to 24,000 AF annually, depleting the flows of the Rio Grande. The associated annual "CWF" charges to EPCWID range from 4,500 AF to 8,000 AF. It is my understanding that the discrepancy between the amount pumped and the amount charged to EPCWID is caused by 1) an assumption that pumping effects that occur outside of the irrigation season do not have to be charged, and 2) return flow credit awarded for waste water effluent from the North West Water Treatment Plan.

  Unfortunately, the Project accounting details are not always provided in a transparent manner to the states and details of these yearly changes are not publicly documented. Based on my own modeling work and research on the effects of Canutillo Well Field pumping on the Rio Grande River, and as agreed to by the District and Reclamation members of the Project Allocation

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[87] As a result of this calculation, in 2011 Reclamation released Compact Credit water from Elephant Butte reservoir, leading to New Mexico's lawsuit against Reclamation in August of 2011. *State of New Mexico v U.S. Bureau of Reclamation, et al.*, Case No. 1-11-cv-00691-JB-KK, In the United States District Court, District of New Mexico.

[88] *See* Spronk Water Engineers, Inc. Expert Report, 2019.

Committee,[89] the actual Net Depletion to the river caused by Canutillo Well Field pumping is 95%. That is, for every 100 AF pumped by EPWU, 95 AF comes directly from the stream system (the river and drains). This actual impact to the river, and thus the Project Supply, is not adequately offset by the CWF charges in EPCWID's accounting summary.

Thus, while it appears that EPCWID is being assessed charges for some of its groundwater pumping, in fact such charges do not reflect the actual depletions to the river caused by EPCWID pumping.

6.3.7 Concerns with the 2008 OA Allocation Process

An important concern with the allocation process of the 2008 OA is that all negative departures from the D2 Curve, regardless of the actual causes of the departure, are subtracted from EBID's allocation. D3 Allocation was designed this way on the assumption that all, or almost all, of the recent departure of accounting data from the D2 Curve is caused by actions in New Mexico. This assumption has never been adequately demonstrated. Already I have presented evidence that current accounting data is not equivalent to the type of data from which the D2 Curve was derived (*see* Appendix E), which indicates that part of the negative departure from the D2 Curve is due to accounting issues unrelated to New Mexico. In Section 7, I will present evidence quantifying more of this accounting-related departure.

Another concern with the 2008 OA allocation process is related to the magnitude and the treatment of Carryover accounts. Allocation that is not used by a District in one year is now carried over into the District's allocation the following year. The limits on these Carryover accounts are high: 232,915 AF/Y for EPCWID, and 305,918 AF/Y for EBID.[90] Recall that prior to 2007, allocated water not used by either District was simply included in Usable Water for the next year.

In practice, EBID has only carried over small amounts of water from one year to the next. In fact, EBID's allocation under the D3 Curve has been insufficient to supply EBID's irrigation water needs, and typically any unused allocation EBID carries over results from late season increases by Reclamation to allocation that EBID cannot make use of in that irrigation season. EPCWID, on the other hand, has carried over large amounts of water in some years. For instance, in 2009 EPCWID reached its Carryover limit of 232,915 AF, and transferred 82,044 AF of excess Carryover to EBID.[91]

Early in the allocation process under the 2008 OA, Carryover accounts, plus additional water needed to deliver the amount carried over, are subtracted from the Usable Water in storage and effectively sequestered from the allocation process. Current-year allocation is then calculated from the remainder

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[89] December 8, 2010 Rio Grande Project – Allocation Committee Memorandum: Proposed Accounting Procedures Regarding Appendix C of the 2001 Contract.

[90] 2008 OA, p 3.

[91] Carryover Transfer data is shown in Table A.13 of Appendix A. The Carryover Limit transfer of 82,044 AF is shown in 2009. In 2010 a transfer of 10,271 AF was made from EPCWID to EBID, but this transfer appears to be associated with an attempt to address depletions to Project Supply caused by EPWU's Canutillo Well Field. The transfer associated with Canutillo impacts was not repeated; however, starting in 2016 an accounting charge averaging 6,700 AF/Y associated with Canutillo impacts was applied to EPCWID. *See* Section 6.3.5.

of Usable Water. Some part of the Carryover accounts, however, may not actually be associated with water in storage. Carryover accounts are not reduced for evaporation.[92] Since evaporation does in fact occur, inflows to the reservoir that otherwise would have been available for allocation are instead sequestered to make the Carryover accounts whole.

In addition, some of the allocation that was carried over may be associated with Project credits, such as the ACE Credit, or the accounting credits, rather than any reduction in District orders. As a result, some part of a Carryover account may consist of "paper water."[93] Despite this fact, the allocation process gives the Carryover accounts first priority in allocation, and therefore new inflows to the reservoir are first assigned to fulfill, and reserved for the delivery of, the Carryover accounts, before any of these inflows are available for current-year allocation. This results in a reduction to the current year allocation of both Districts, but the final effect is a negative impact on EBID's total allocation because EBID gets so little of the benefits of Carryover.

A clear example of this occurred in late 2010 through early 2011, as described in detail in Appendix D. In that year, 62,846 AF of the inflow to Elephant Butte occurring after the end of the 2010 irrigation season was required to fulfill Carryover obligations (mostly to EPCWID) under the 2008 OA. As a result there was 62,846 AF less water available for Current-Year Allocation. Both Districts received lower Current-Year Allocations, but EPCWID received the benefit of the addition of a large Carryover account from which no evaporative losses had been subtracted, nor had any deduction for paper water been made. As it turned out, the inflows to Elephant Butte during 2011 were very low, and EBID's Current-Year Allocation was only 67,000 AF. Presumably, if 62,846 AF of the reservoir inflows had not been sequestered to make up EPCWID's large Carryover Account and the resulting Carryover obligation, EBID's Current-Year allocation would have been considerably larger.

6.3.8 Concerns with the Current Accounting Process

One issue with current Project accounting relates to the treatment of El Paso Water Utilities ("EPWU") effluent: EPWU operates waste water treatment plants in the El Paso area which discharge water into the Project. EPCWID receives a credit for the El Paso Haskell WWTP effluent, essentially obviating any charge for its diversion of this water at Riverside and subsequent use of this water. Neither is EPCWID charged for diversion and use of effluent from the El Paso Bustamante WWTP. EPWU's effluent originated either as water diverted directly from the Rio Grande by EPWU for municipal purposes, which is Project water, or as water pumped by EPWU wells, which pumping would have impacted Project water through depletion of El Paso Valley drain flows or aggravation of the losses to the Rio Grande.[94]

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[92] By contrast, Compact accounting has a specific formula to account for evaporation, recognizing that significant amounts of Useable Water are lost through evaporation. *See* Estevan Lopez Expert Report, 2019.

[93] "Paper water" is water that ostensibly exists, based on records, but may not in fact exist as actual "wet water."

[94] The alleviation of Rio Grande seepage losses between International Dam and Riverside Dam was part of the impetus for the construction of the ACE and the rational for the ACE Credit, which increases EPCWID's allocation at the expense of EBID (*see* Section 9).

There is no reason to consider EPWU effluent as imported or non-Project water. By contrast, similar municipal effluent in New Mexico is treated as Project water, and the diversion of this water is charged in Project accounting.

It is my understanding that the reason that diversion of Haskell WWTP is not charged against EPCWID is because that water does not reach the bed of the Rio Grande, and so EPCWID and Reclamation do not consider it to be Project water. *See* Section 5.4. This position appears unreasonable both because of the source of the water, and because the Project has not used the bed of the Rio Grande as the main Project conveyance in the El Paso Valley since 1999.[95] Instead of conveying water, including the wastewater treatment plants' effluent water, to EPCWID canal headings through the Rio Grande, the Project uses a parallel conveyance system: the American Canal and ACE. Any water entering the American Canal system should certainly be considered Project Supply and charged to EPCWID accordingly.

6.4 Issues Related to American Canal Extension Allocation Credit

Starting in 1938, the American Dam and Canal were used to provide water to EPCWID's Franklin Canal heading, which previously had been supplied by the International Dam. Much of the water diverted at American Dam was then wasted back to the Rio Grande at locations below International Dam for delivery to Riverside Dam further downstream. For many years, the possibility and desirability of extending the American Canal directly to the Riverside heading had been proposed and investigated.[96] Such an extension would eliminate the need to waste so much water back to the Rio Grande, and mitigate conveyance loses associated with conveyance of that water in the bed of the Rio Grande to Riverside Dam.

In 1976, Congress approved a bill authorizing extension of the American Canal, providing that construction not be undertaken until the U.S. and EPCWID had entered into a repayment contract for the value of the 11,600 AF of "salvaged water."[97] In 1987 Riverside Dam failed, and was replaced by a temporary coffer dam, exacerbating EPCWID's delivery problems. In 1992, EPCWID and EPWU entered into a Memorandum of Understanding providing for EPWU to pay "the 'local cost share' of costs for constructing the extension of the American Canal" in exchange for more access to Project water for municipal use. [98]

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[95] Prior to 1999, Haskell WWTP effluent discharged into the bed of the Rio Grande and diversion of that water at Riverside Dam was charged to EPCWID. Since 1999, Haskell WWTP effluent is intercepted by the ACE before it reaches the bed of the Rio Grande. The ACE also conveys Project water from American Dam to the Riverside heading, bypassing the bed of the Rio Grande.

[96] IBWC, January 31, 1964, Report on Studies of Rio Grande Channel Losess from International Dam to Riverside Canal Heading.

[97] 1974 Act: Public Law 94-423, 94th Congress, S. 3283, September 28, 1974.

[98] Memorandum of Understanding between the Public Service Board of the City of El Paso and the El Paso County Water Improvement District No. 1, dated April 23, 1992. ("1992 MOU"). The Public Service Board of the City of El Paso is now known as EPWU.

As a result, in 1998 the American Canal was improved and extended to the Riverside heading. With the completion of the ACE, water could now be delivered to the heading of Riverside Canal through the ACE, entirely bypassing the bed of the Rio Grande between the American Dam and Riverside heading altogether. Citing to reports that the bed of the Rio Grande in that particular reach lost water to seepage, Al Blair of EPCWID estimated the amounts of water salvaged by conveying EPCWID's water through the ACE rather than in the Rio Grande itself.[99] Blair's calculations were based on data contained in a 1964 report by Raymond Hill,[100] and groundwater model results.[101] Blair generated a table of "Salvaged Water" for differing amounts of EPWCID diversion, with a maximum salvaged water value of 20,252 AF/Y, significantly higher than the amount contemplated in the 1976 Act of Congress (11,600 AF). Starting in 2003, Reclamation awarded EPCWID the ACE Credit as an increase in the District's allocation for "ACE Conservation." The annual amount of the ACE Credit varies depending on EPCWID's diversion, with a maximum possible value of 20,052 AF/Y.[102] The ACE Credit amounts awarded to date range from 7,485 AF to 17,998 AF (with zero in some years.)

The ACE Credit is embedded in the Allocation Spreadsheet of the 2008 OA. The effect of this Credit is to increase EPCWID's allocation by the amount of the Credit, and reduce EBID's allocation by the same amount. I have demonstrated this by testing the allocation spreadsheet itself. Figure 6.7 is a modified copy of the final allocation spreadsheet for 2009. The column labeled "Original Data" contains the final allocation calculations for 2009 as provided by the Allocation Committee to the New Mexico OSE/ISC. The column labeled "Modified: No ACE credit" contains the same data and calculations, using the equations embedded in the spreadsheet, except that the ACE Credit is set to 0. A comparison of the two columns shows that the effect of the ACE Credit is to increase EPCWID's allocation by 17,998 AF (the amount of the ACE Credit) and decrease EBID's allocation by the same amount.

In summary, the ACE Credit gives EPCWID an increase in allocation for bypassing Project conveyance inefficiencies associated with the bed of the Rio Grande. The reach of the Rio Grande between International Dam and Riverside Dam loses water to seepage. The seepage in that reach was caused by, or at least greatly enhanced by, groundwater pumping in the Hueco Bolson by Texas and Mexico. In effect, EPCWID and Texas are given a credit for mitigating a condition that they themselves caused.

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[99]October 29, 2000, Memorandum from A.W. Blair (EPCWID) to F. Cortez (Reclamation), RE: Relationship between the quantity of water salvaged by the American Canal Extension Project and EPCWID's quantify of annual diversion allocation; July 7, 2003, Memorandum from A.W. Blair to F. Cortez (Reclamation), RE: Conservation Credit for Salvage of Water by the American Canal Extension.

[100] Letter 1964 0227, from Raymond Hill, Consulting Engineer to J. Friedkin, IBWD, RE: All-American Canal in the Vicinity of El Paso

[101] Heywood, CE and Yager, RM, Simulated Groundwater Flow in the Hueco Bolson, an Alluvial-basin Aquifer System Near El Paso, Texas. USGS Water Resources Investigations Report 02-4108.

[102] Project Operations Manuals 2008, 2010, 2012.

Figure 6.8. Image of Reclamation Allocation Spreadsheet from 2009, Modified to Test Effect of ACE Credit on Allocation

TestACE_AllocationSS.xlsx 2009 Allocation-ACE

1	**Rio Grande Project Diversion Allocations (EOM OCT 2009 Project Data)**	**Original Data**		**Modified: No ACE credit**	
2	Elephant Butte Reservoir Storage	454,530		454,530	
3	Caballo Reservoir Storage	26,100		26,100	
4	Total Rio Grande Project Storage	480,630		480,630	
5	Estimated Rio Grande Compact Credit Waters	-126,600		-126,600	
6	Estimated San Juan-Chama Water	-37,298		-37,298	
7	Water Released from Storage	693,289		693,289	
8	Total Usable Water Available for Release	1,010,021		1,010,021	
9	Carryover Obligation using Estimated Diversion Ratio	235,960		235,960	
10	Total Usable Water Available for Current Year Allocation	774,061		774,061	
11	EBID Allocation Balance (Previous Year)	-4,304		-4,304	
12	EPCWID Allocation Balance (Previous Year)	232,882		232,882	
13	EBID Allocation Balance (End-of-Year)	40,343		40,343	
14	EPCWID Allocation Balance (End-of-Year)	232,915		232,915	
15	Storage for EBID and EPCWID Allocation Balance (End-of-Year)	276,869		276,869	
16	Current Usable Water	733,152		733,152	
17	End-of-Year Release for Diversion Ratio	693,289		693,289	
18	D1 Delivery	470,416		470,416	
19	Mexico's Current Diversion Allocation	53,386		53,386	
20	Gross D2 Diversion Allocation	942,117		942,117	
21	EPCWID ACE Conservation Credit	17,998		0	
22	Net D2 Diversion Allocation for EBID and EPCWID	888,731		888,731	
23	D2 Diversion Allocation for EPCWID	384,161		384,161	
24	EPCWID Diversion Allocation (w/o Conservation Credit)	617,043		617,043	
25	EPCWID Diversion (w/o Conservation Credit or 67/155ths of Row 30)	384,128		384,128	
26	Diversion Ratio	0.986956		0.987	
27	Diversion Ratio Adjustment	-9,563		-9,563	
28	Sum of Release and Diversion Ratio Adjustment	723,589		723,589	
29	EBID D2 Diversion Allocation	504,570		504,570	
30	Difference between EBID Diversion Ratio Allocation and D2 Diversion Allocation	0		0	
31	EBID Diversion Ratio Allocation	268,077		286,075	
32	EBID Diversion Allocation	268,077		286,075	
33	Total EBID Diversion Allocation (includes 88/155th of Value in Row 30)	263,773		281,771	
34	Total EPCWID Allocation (includes Row 21 and 67/155th of Value in Row 30)	635,041		617,043	
35	District to District Allocation Transfer (OA 1.11 Excess Carryover Balance)	82,044		82,044	
36	Total EBID Diversion Allocation (After Transfer)	345,817		363,815	17,998
37	Total EPCWID Allocation (After Transfer)	552,997		534,999	-17,998
38	Total EBID, EPCWID, and Mexico Allocation	952,200		952,200	
39	EPCWID 2009 Allocation Charges (calculated)	320,082		302,084	
40	EBID 2009 Allocation Charges (calculated)	305,474		323,472	
41	EPCWID 2009 Allocation Charges (actual)	320,083		320,083	
42	EBID 2009 Allocation Charges (actual)	305,475		305,475	
43	Mexico 2009 Allocation Charges (actual)	58,688		58,688	
44	Difference in Mexico's Charges and Allocation	-5,302		-5,302	
45	EPCWID Share	-2,292		-2,292	
46	EBID Share	-3,010		-3,010	

7 ANALYSIS OF THE REASONS FOR THE NEGATIVE DEPARTURE FROM THE D2 CURVE

As discussed in Section 6, D3 Allocation reduces EBID's allocation by the amount of any negative departure from the D2 Curve, regardless of the actual cause of that negative departure. In this Section I discuss the actual reasons for the negative departure from the D2 Curve, and demonstrate that a significant portion of that departure is unrelated to actions by New Mexico but is rather the result of changes in Project accounting methods.

The underlying data and support for the conclusions in this Section are in Appendices A, D, and E.

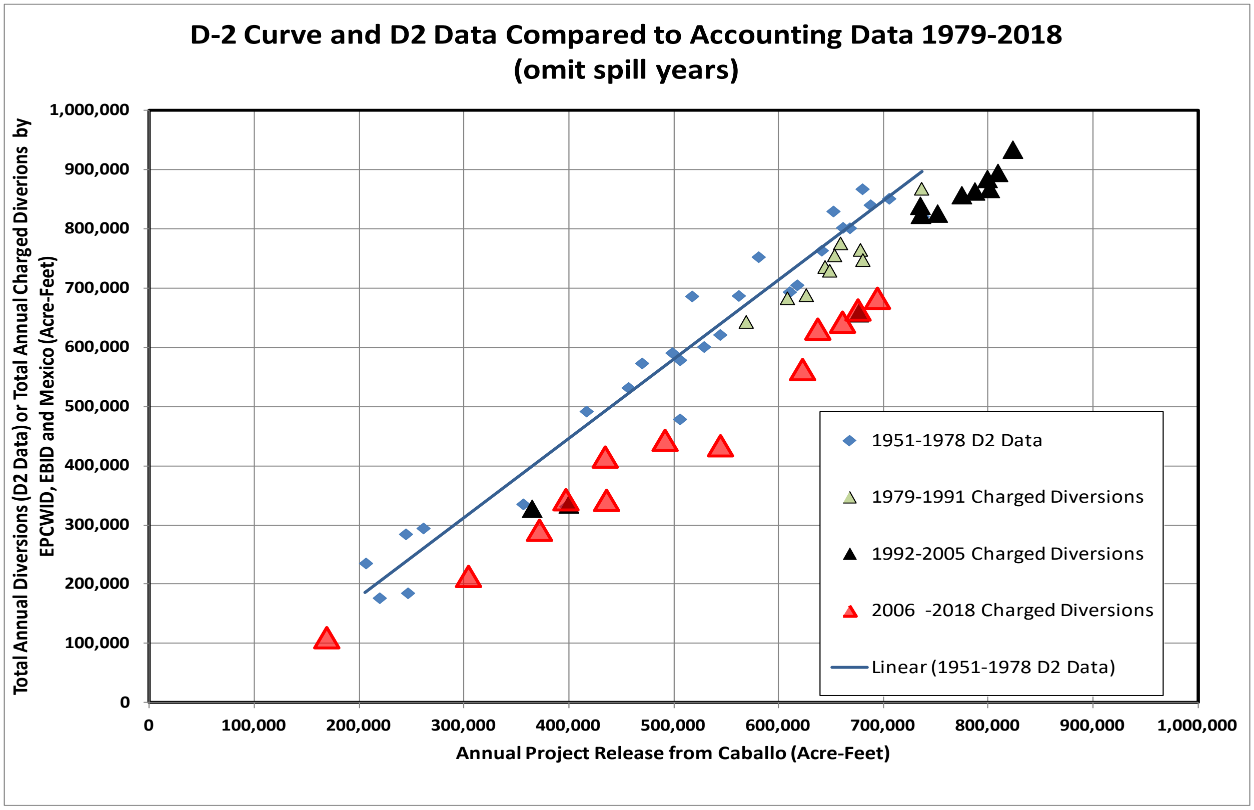
7.1 DEPARTURE DATA

Figure 7.1 shows the D2 Curve and D2 data set (1951-1978) together with Post-1978 Accounting data from 1979 through 2018. The accounting data is broken out by time periods:

1) 1979 – 1992 Accounting Data (D1/D2 Allocation)
2) 1993 – 2005 Accounting Data (D1/D2 Allocation, greater District control of records)
3) 2006 – 2018 Accounting data (D3 Allocation with Carryover)

As shown in Figure 7.1, all Post-1978 Accounting data is below the D2 Curve, to varying degrees. This can also be described as the Post-1978 Accounting data having a negative departure from D2, meaning that the Districts receive less Charged Diversion than would be predicted by the D2 Curve.

Figure 7.1. D2 Curve and D2 Data (from WDR forms) Compared with Accounting Data (Charged Diversions) from 1979 – 2018



7.2 Reasons for Negative Departure from D2

There are a number of reasons that Post-1978 Accounting data shown in Figure 7.1 show negative departures from the D2 Curve.

Accounting Differences. The data from the WDR forms used to derive the D2 Curve (that is, the D2 data set) are systematically different than the Post-1978 Accounting data. *See* Appendix E for a complete discussion. Of prime importance, the data in the 1951 – 1978 WDR forms includes off-season diversions, and diversion of El Paso Valley drain flows. Post-1978 Accounting omits these terms. In addition, Post-1978 Accounting includes credits that did not exist during the 1951-1978 D2 Period. As a result, Post-1978 Accounting data are systematically low compared with the D2 data set. D3 Allocation is built upon a comparison of these two different kinds of data, and EBID's allocation is reduced for any discrepancy between the data sets, even though there are fundamental accounting discrepancies between these two methods. In other words, even if Project efficiency in a given post-1978 year were the same as during the 1951-1978 period, the Charged Diversions for that year would ***still*** show a negative departure from the D2 Curve simply as a matter of the accounting changes.

Decreased Recharge and Increased Depletions. It is likely that there has been a net increase in irrigation depletions above Courchesne caused by increases in agricultural efficiency and increased acreage of more productive and more water-intensive crops such as pecans and alfalfa. These increases are offset to some extent by a reduction in the total amount of irrigated acreage.
Furthermore, groundwater pumping in both New Mexico and in Texas tends to lower groundwater levels in the Rincon, Mesilla and El Paso Valleys. Lower groundwater levels impact surface water flows in the Rio Grande by reducing gains to the Rio Grande from groundwater, and/or increasing seepage losses from the Rio Grande. Lower groundwater levels also reduce the discharge of groundwater into drains which discharge into the river. Both of these changes reduce the amount of water available for diversion within the Project and would tend to increase any negative departure from the D2 Curve already taking place by the changes through accounting differences.

Other Unexplored or Un-quantified Causes. These causes may include other physical changes within the Project, such as river bed aggradation, or causes related to Project operations such as deliveries to the HCCRD, or the effects of growing municipal use of Project water in Texas.

Increases in depletions and decreased recharge occurring above Courchesne would have the effect of decreasing the amount of water available for diversion at American Dam. Project operations, described in Section 2, would compensate for these depletions by increasing the release from Caballo in order to meet District orders. The net result of this operation would be to reduce the Project Diversion Ratio.

Increasing depletions in the El Paso Valley have already increased losses to the Rio Grande mainstem, and depleted El Paso Valley drain flows that used to contribute to Project Supply.

7.3 Issues Related to Post-1978 Project Accounting

There are three accounting issues which can be readily quantified that impact the negative departure between current total Charged Diversions and the D2 Curve.

7.3.1 Off-Season Diversions

The data from which the D2 Curve was developed is found in Project WDR sheets from 1951 through 1978 (the D2 Period). I have analyzed this data, and found that it includes diversions that occurred when no water was being released from Caballo Dam (i.e. the "Off Season"). I present this analysis in Appendices A and C. The water diverted at such times includes drain flows, effluent, and any gains to the Rio Grande below Caballo, and the lion's share of these diversions were made by EPCWID.

Post-1978 Accounting, and therefore recent accounting data, does not include any charge to the Districts for diversions made outside of the release season.[103]

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[103] 1985 Draft Operating Agreement, p.3: "All diversions made by the Districts during the nonirrigation season utilizing return flow waters shall not be charged against the Districts' respective allocations"; 2008 Operations Manual, p.3: "All diversions made by the Districts during the non-irrigation season utilizing return flow waters shall not be charged against the District's respective allocations."

The fact that current accounting practices do not count a component of flow that was part of the D2 data set, and therefore incorporated into the D2 Curve, causes a discrepancy between current accounting data and the D2 Curve.

It is not known how much water is currently being diverted outside of the irrigation season. However, successive years of low Project Supply, exacerbated by the even lower EBID allocations, have greatly reduced drain flows in the upper Project (above Courchesne). It is likely the amounts of water available for diversion outside of the irrigation season are currently low, but would become larger if groundwater conditions in the Rincon and Mesilla Valleys were allowed to recover. Such recovery is unlikely if current allocation procedures remain unchanged, and even if such recovery did occur, 2008 OA accounting rules mean that EPCWID could continue to divert off-season flow at no charge.

I calculate the amounts of off-season diversion occurring during the D2 period in Appendix C by comparing WDR monthly data with daily Caballo release data. In general, I considered monthly WDR diversions to be off-season when the gaged flow below Caballo was less than 100 cfs for at least a week before the beginning of that month. The amounts so derived range from about 5,000 AF/Y in low-supply years such as 1954 and 1955, to approximately 40,000 in high-supply years such as 1962 and 1969. That is, the D2 data set contains 5,000-40,000 AF each year that would not be charged against the Districts' allocation under current accounting rules.

7.3.2 El Paso Valley Drain Flows

The WDR data that forms the basis of the D2 Curve explicitly includes diversions of drain flows at Fabens as I have demonstrated in Appendices C and D of this report. Post-1978 Accounting has no term for the diversion of El Paso Valley drain flows, so if such drain flows are now diverted, they are not being charged. El Paso Valley drains flow have probably been smaller than in past years, depleted by the large amount of municipal and irrigation pumping that has occurred in the Hueco Bolson, and by the effect of urbanization on aquifer recharge. The absence of these drain flows, either as accounting terms or as physical flows, is responsible for part of the negative departure of current accounting data from the D2 Curve, and also for a reduction in supply compared to the conditions obtaining at the time of the Joint Investigation.

The reported amounts of El Paso Valley drain flow diverted in the El Paso Valley are tabulated in Appendix C. Drain flow ranged from approximately 20,000 AF to 40,000 AF during the 1940s and early 1950s. Diversions of El Paso Valley drain flow decrease to zero during the mid-1950s, presumably because of the immediate effects of low-supply conditions, and the effects of the resulting irrigation pumping in the El Paso Valley. As described in Section 5 and shown in Figure 5.2, El Paso Valley drain flows decreased substantially when extensive groundwater pumping for supplemental irrigation began in the El Paso Valley in the 1950s. Increasing groundwater pumping for municipal use by El Paso and Juarez in Mexico have also contributed to the decline in El Paso Valley drain flows.

7.3.3 Project Accounting Credits

The D2 data set forming the basis of the D2 Curve do not include the complex accounting associated with the delivery of water to EPCWID lands from Mesilla Dam that is a part of Post-1978 Accounting. These complex calculations cause the total Charged Diversion associated with Mesilla Dam to be systematically less than that amount diverted at Mesilla Dam. The D2 data set do not include other credits that are applied as part of Post-1978 Accounting with the exception of the Ascarate Credit. The net effect of these current credits in high-supply years is to reduce the total Charged Diversions below the amounts actually diverted,[104] which increases the negative departure from the D2 Curve, thereby decreasing the Diversion Ratio, which then decreases EBID's allocation.

7.3.4 Combined Effect of These Accounting Issues

The three accounting issues described above cause Charged Diversions to be systematically lower than the total diversions used to create the D2 Curve, especially in high-supply years. The result of this systematic discrepancy is that allocations made using the D2 Curve are already systematically high compared with the associated Charged Diversions. I have attempted to quantify this effect for one of the years in the D2 Period by breaking out different components of the actual diversion: off-season diversions, diverted El Paso Valley drain flows, and estimates of the amounts of credit that would be applied to Districts under Post-1978 Accounting. I have selected the year 1969 for this analysis for two reasons: 1) the 1969 point falls almost directly on the D2 curve, and 2) there is a recent year, 2008, which has almost exactly the same release from storage, and therefore I can use the accounting data from 2008 as an estimate of how accounting would be applied in 1969.

Figure 7.2 shows the D2 data set, highlighting the 1969 data point.

In Table 7.1 I provide the amount of diversion in 1969 that occurred outside of the irrigation season, from the analysis in Appendix E, and the amount of El Paso Valley drain flow that was included in the WDR data for 1969 from the compilation in Appendix A.

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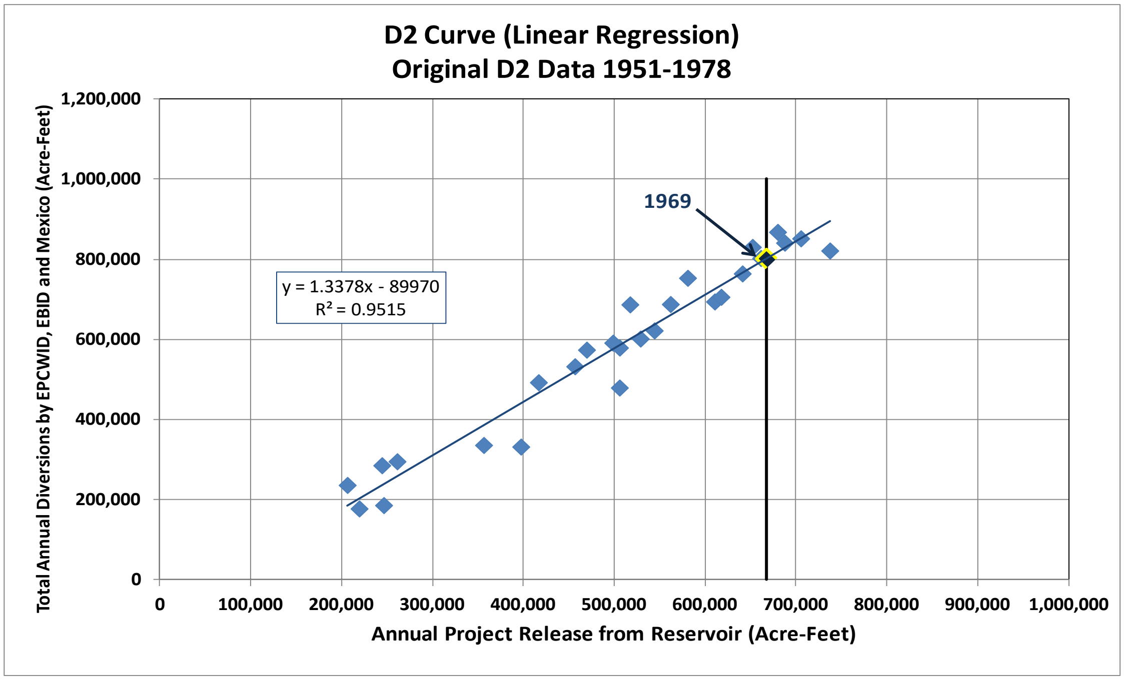
[104] Post-1978 Accounting rules provide for a District to be charged for the full release from Caballo during times when that District is the only one ordering water. Under these circumstances charged diversions may exceed total diversions. The effect of this provision was not significant during the period from 1979 through 2005, but has become very important during recent post-2005 years in which EPCWID has had a much larger allocation than EBID, and has diverted water over a much longer time period.

Figure 7.2. D2 Curve and D2 Data, Highlighting the 1969 data point



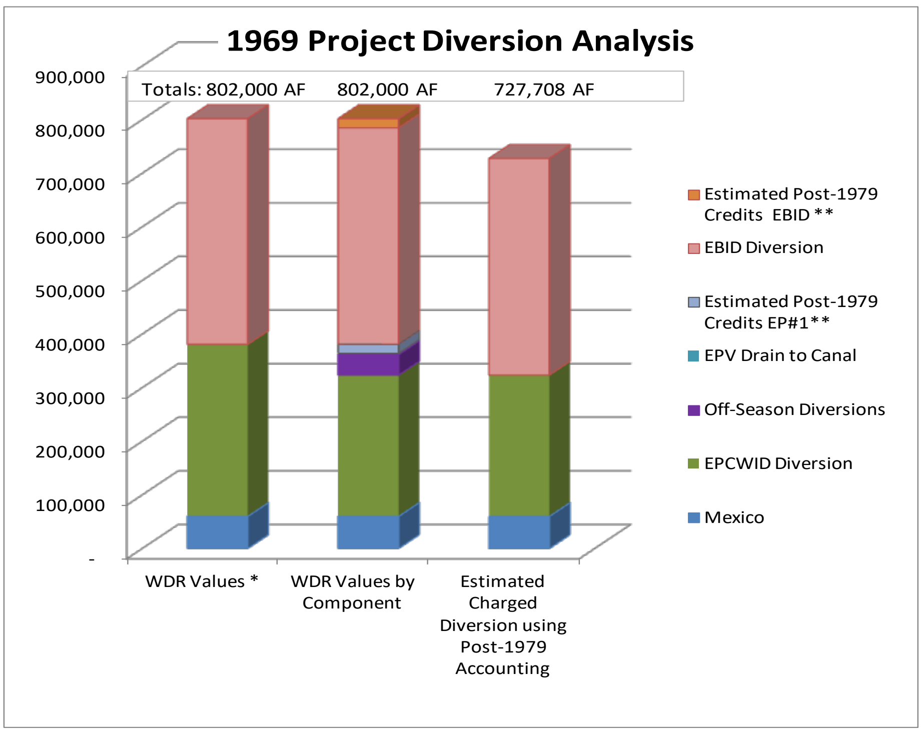
I constructed estimates of the accounting credits that would have been applied to 1968 using Post-1978 Accounting by looking at a post-1978 year with modern accounting and a similar Caballo release amount. In 1969 the release from Caballo was 668,000 AF, and the comparable year I chose is 2008, in which the Caballo release was 675,000 AF. In 2008 the total diversion (calculated using diversion data extracted from detailed District accounting records) is 699,000 AF, while the total Charged Diversion is 665,000 AF. The difference between those two numbers, 34,000 AF, is the net effect of the accounting credits in 2008, and in my analysis I split that amount 50/50 between the Districts.

These resulting diversion analysis for 1969 is tabulated in Table 7.1 and plotted in Figure 7.3.

Table 7.1. Analysis of 1968 Diversions as reported in Reclamation WRD forms

Analysis of 1969 WDR Diversions			
	WDR Values*	WDR Values by Component	Estimated Charged Diversion using Post-1978 Accounting
EBID Diversion	421,000	404,000	404,000
EPCWID Diversion	321,000	263,708	263,708
Mexico	60,000	60,000	60,000
Off-Season Diversions		38,000	
EPV Drain to Canal		2,292	
Estimated Post-1978 Credits EBID **		17,000	
Estimated Post-1978 Credits EP#1**		17,000	
Total	802,000	802,000	727,708
* WDR Values adjusted so that Mesilla Dam Diversions are split between the Districts Pro-Rata			
** Total Estimated Post-1978 Credits calculated as the difference between total diversions and Charged Diversion in a year of similar water supply to 1969. This total was split 50:50 between EBID and EPCWID			

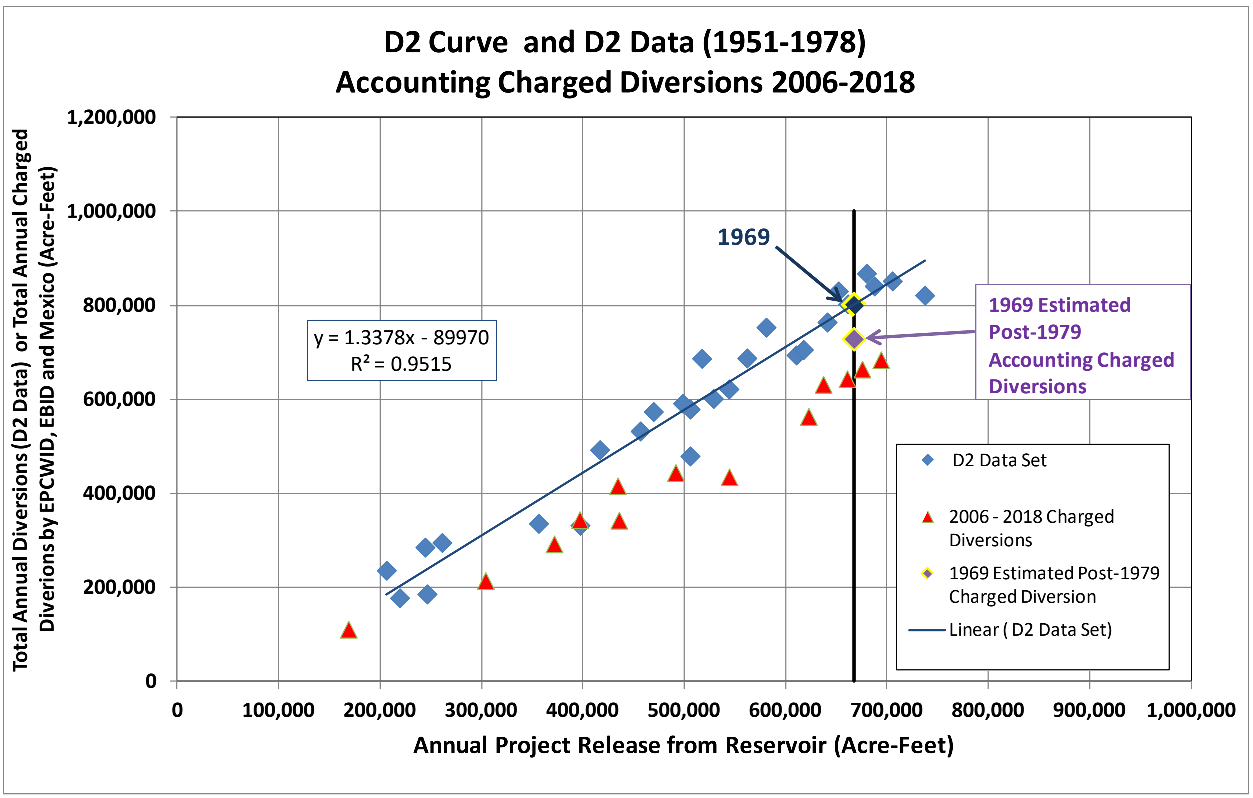
Figure 7.3. 1969 Project Diversion Analysis



The results shown in Figure 7.3 and Table 7.1 suggest that if Post-1978 Accounting rules were applied in 1969, the total Charged Diversions would have been 727,000 AF instead of the 802,000 AF actually diverted. The D1/D2 Allocation method allocates water based on actual diversion, and so for a release of 668,000 AF, would have allocated a total of 802,000 AF. The Charged Diversions associated with that release would only have totaled 727,000 AF, and so under Post-1978 Accounting, 1969 would have been 74,000 AF below the D2 Curve, as shown in Figure 7.4. I have attempted this analysis for other years and have achieved similar results.

For comparison, Charged Diversions for 2006 through 2018 are also shown on Figure 7.4. The data from my example years, 1969, suggests that a significant part of the negative discrepancy from the D2 Curve is the result of the difference in accounting between the D2 Period (1951-1978) and current accounting methods, and not related to New Mexico pumping and depletions.

Figure 7.4. D2 Curve and D2 Data, Accounting Data from 2006-2018, Illustrating effect of Post-1978 Accounting on 1969 Diversion Data



7.4 Decreased Recharge and Increased Depletions

Changes in depletion and recharge, including changes associated with the 2008 OA, are likely responsible for part of the negative departure from the D2 Curve. Increased depletions are associated with increased consumption of water for irrigation and municipal purposes, and increased pumping of groundwater for those purposes in New Mexico and Texas. Decreases in recharge are associated with increased irrigation efficiencies throughout the Project, and changes in Project allocation starting in 2006 which reduce the allocation of Project water to the upper part of the Project (above Courchesne).

Between 1979 and 2002 the Project enjoyed full-supply conditions, and Districts were allocated full supply amounts. As a result, irrigation well pumping was probably relatively low in both Districts until 2003, especially compared with the pumping levels during the preceding drought years. Both Districts, however, increased their acreages of high-demand crops, such as pecans, and worked to increase their irrigation efficiency, thus reducing return flow to the valley aquifer system, and reducing drain flows.[105] Furthermore, there was some increase in municipal groundwater pumping in both New Mexico and Texas. These changing conditions probably contribute to part of the negative departure from the D2 Curve during the 1979 through 2005 time period.

From 2006 through 2018, these factors (increased agricultural and municipal depletions) are aggravated by the change in water distribution caused by D3 Allocation. The water supply in EBID was sharply reduced to below irrigation demand, leading to a decrease in aquifer recharge from irrigation water and an increase in irrigation well pumping. As a result, drain flows above Courchesne were further depleted and the seepage from the Rio Grande was increased, leading to a decrease in Project performance and increased negative departure from the D2 Curve.

Agricultural and municipal depletions have increased throughout the Project, as farmers have improved irrigation efficiency, changed the crops they grow to adapt to market conditions, and worked to improve crop yield. This has occurred in the Rincon and Mesilla Valleys in New Mexico, and the Mesilla Valley of Texas. The changes in cropping and irrigation methods above Courchesne would impact drains and river losses above Courchesne, impacting Project performance. Changes in the El Paso Valley in Texas would have similar effects, and despite the changes in Project conveyance that have been made to mitigate losses, these changes may have, and may continue, to effect Project performance. It is my opinion that increases in irrigation efficiency, and associated increases in irrigation depletions, throughout the Project contributed to the departure from the D2 Curve observed since the mid-1990s.

Extensive groundwater pumping by Mexico and Texas in the Hueco Bolson have also contributed to reduction in drain flow and increased river losses in the El Paso Valley, impairing Project performance. Currently the Project diverts water from the Rio Grande in the El Paso Valley at American Dam, and not further downstream. While eliminating the EPCWID diversions from the Rio Grande further downstream may mitigate some of the negative effect of this groundwater pumping, it also eliminates past sources of supply, such as the El Paso Valley Drains. *See* Appendix C.

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[105] For the impact of changes in agricultural practices on consumptive use of Project water, *see* David's Engineering Expert Report, 2019.

8 COMPARISON OF PROJECT ALLOCATION AND DELIVERY AMOUNTS UNDER D1/D2 ALLOCATION AND D3 ALLOCATION METHODS

In this section I will quantify the effects of the change in allocation methods from the 2006 change from D1/D2 Allocation to D3 Allocation, summarizing the allocation and delivery amounts starting in 1996 through 2018. I will show that:

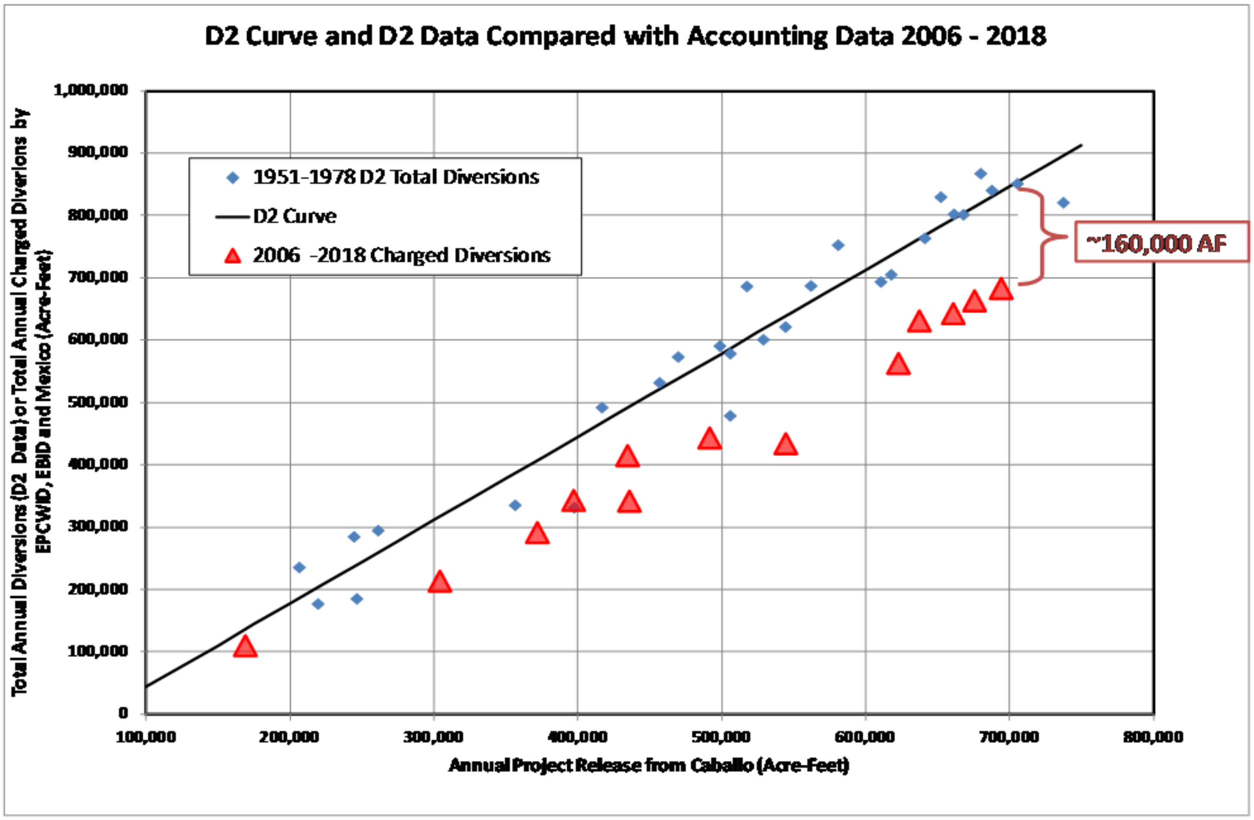
- Under D3 Allocation, EPCWID's current-year allocation (allocation apart from Carryover) in full-supply years has increased from 377,000 AF to an average of 391,500 AF. Including Carryover, EPWID's total annual allocation has exceeded 500,000 AF in some years. EPCWID Charged Diversions (water actually called for and received) in full-supply years under the 2008 OA have averaged less than 300,000 AF, leaving large amounts of unused, unneeded allocation which is "placed" in its Carryover account for its exclusive use the following year.

- By contrast, the D3 Allocation has reduced EBID's full-supply allocation and the amount of water Reclamation has diverted to EBID in full-supply years by approximately one-third (1/3). EBID's full-supply allocation has dropped from 495,000 AF to less than 330,000 AF; EBID's diversion in full-supply years decreased from an average of 464,000 AF (in 1996-2002) to an average of 312,000 AF (2007-2009).

In order to compare the allocation and delivery amounts under the different allocation methods, it is necessary to eliminate the effects of variation in water supply. Allocations and deliveries are always smaller under low-supply conditions than under full-supply conditions, regardless of allocation method. In order to eliminate supply-caused variability, I compare years in which the Project had a full supply available.

Figure 8.1 shows the D2 Curve and D2 data plotted together with Charged Diversion data from the D3 Allocation period (2006-2018). These data indicate that in years of relatively high supply (that is, when Caballo release is ~700,000 AF), the accounting data show a negative departure of approximately 160,000 AF from the D2 Curve. In the following section I compare actual allocation and diversion data from full-supply years.

Figure 8.1. Project Accounting Data 2006 – 2018 (Charged deliveries to EBID and EPCWID plus the delivery to Mexico) Plotted together with the D2 Curve



8.1 SELECTION OF FULL-SUPPLY YEARS FOR COMPARISON

Prior to the implementation of D3 Allocation in 2006, full-supply years and full-supply allocation amounts are easy to determine. The D1/D2 method, as documented in the WSAP, defines a full supply allocation to EBID as 494,979 AF and to EPCWID as 376,862 AF, and those amounts were allocated to those Districts from 1990 through 2002, and in 2005.[106] Furthermore, Mexico's full-supply allocation is 60,000 AF in full-supply years, and Mexico was allocated that amount from 1979 through 2002, and in 2005.

Following the adoption of D3 Allocation, allocation becomes more complex. The 2008 OA extended the D2 Curve, and EPCWID's full-supply allocation is now about 388,000 AF.[107] Each District has both a "Current-year Allocation" which does not include Carryover, and a "Total Allocation" which is the sum of Current-year Allocation plus Carryover. On paper, a District's Total Allocation under the 2008 OA can

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[106] 1979 – 1989 are described by Reclamation as full supply years also, but the amounts allocated to the Districts are slightly different, reflecting the evolution of the D1/D2 methodology before the adoption of the WSAP.

[107] EBID's full-supply allocation is now considered to be approximately 510,000 AF, but this is irrelevant to the current discussion because EBID's allocation has come nowhere near this amount since 2006.

exceed that District's full-supply allocation, even in years for which Project storage cannot support a full-supply release. Furthermore, because Carryover is sequestered out of Usable Water before calculating Current-year Allocation, it is possible for those Current-year Allocations to be lower than full-supply even when the Project has a full supply available to it.

In order to define full-supply years from 2006 through 2018, I choose years in which EPCWID's Current-year Allocation exceeds 360,000 AF. Based on this criterion, the years tabulated in Table 8.1 constitute the full-supply years for the time period in which D3 Allocation has been applied.[108]

Table 8.1. Reported Usable Water, EPCWID Current-Year Allocation and Mexican Allocation for Years Designated "Full-Supply" Under D3 Allocation

Year	Total Usable Water Available for Release (Allocation Spreadsheet, Row 8)	EPCWID's current-year allocation	Mexican Allocation
2007	Unknown	367,291 AF	58,769 AF
2008	1,118,436 AF	405,073 AF	60,000 AF
2009	1,010,021 AF	402,159 AF	53,386 AF
2017	876,901 AF	401,842 AF	60,000 AF

For comparison, in the following section, I show Project allocation and delivery data for the 10 years before the initiation of D3 Allocation: 1996 through 2005, along with the allocation and delivery data generated by D3 Allocation from 2006-2018.

To quantify this comparison, I have calculated the averages of the allocation and delivery for full-supply years 1996-2002 (pre-D3 Allocation full-supply years) and years 2007-2010 (D3 Allocation full-supply years).

8.2 Comparison of Current-Year Allocation 1996 – 2018

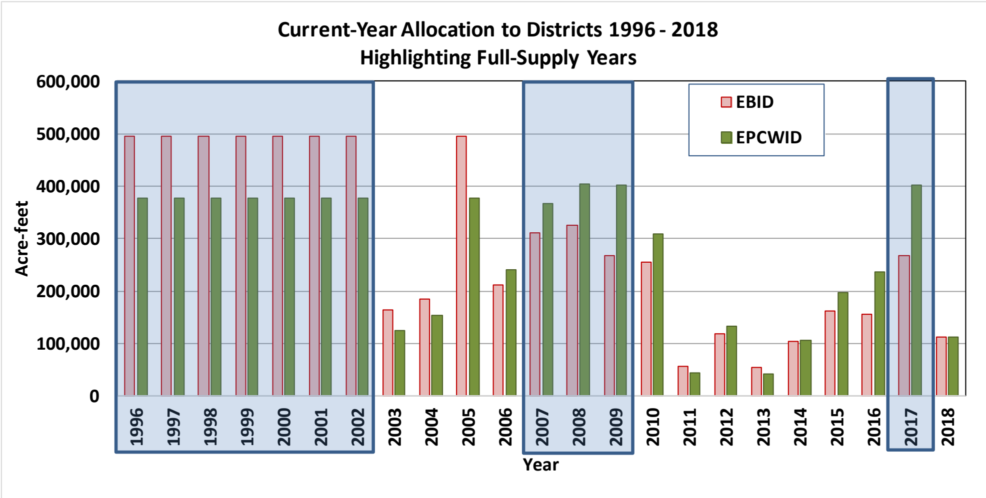
Figure 8.2 shows Current-year Allocation for the years 1996 through 2018 from Reclamation allocation and accounting records. Current-year Allocation is calculated as the total annual District allocation for each year, minus any allocation carried over from the previous years. Prior to the initiation of Carryover in 2007, Current-year Allocation was equal to Total Allocation.

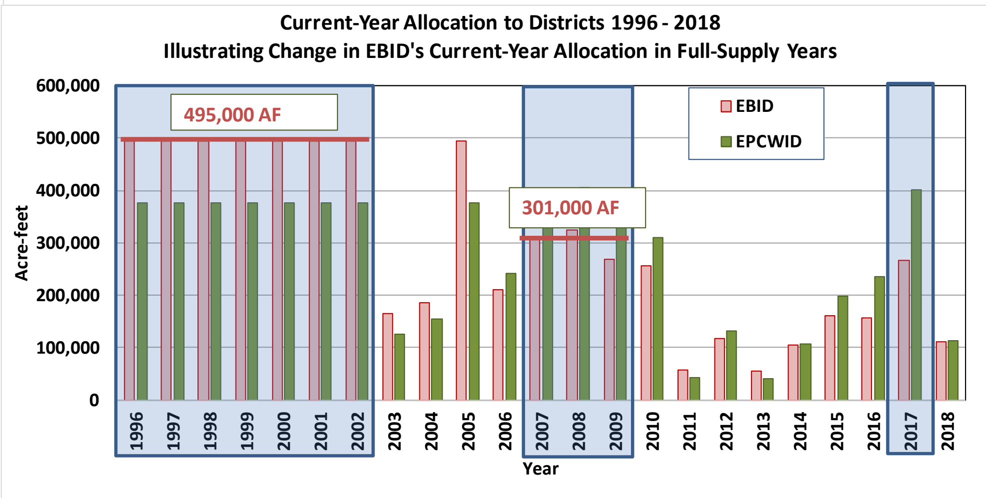
[108] Arguably, 2010 could be considered a full-supply year as well, since according to the Project allocation report for that year the amount of Usable Water Available for Release was 888,423 AF. Because EPCWID's large Carryover allocation (232,915 AF) took up a substantial amount of the Usable Water, there was not enough remaining Usable Water available for a full-supply allocation. As a result, EPCWID's 2010 Current-year Allocation was only 309,515 AF (or 291,905 AF excluding ACE Credit), which was significantly less than a full supply allocation. However, EPCWID was able to supplement this allocation with the full value of its Carryover account, 232,914 AF, for a Total Allocation in 2010 of 532,158 AF. By contrast, EBID's Total Allocation for the same year was 305,870 AF.

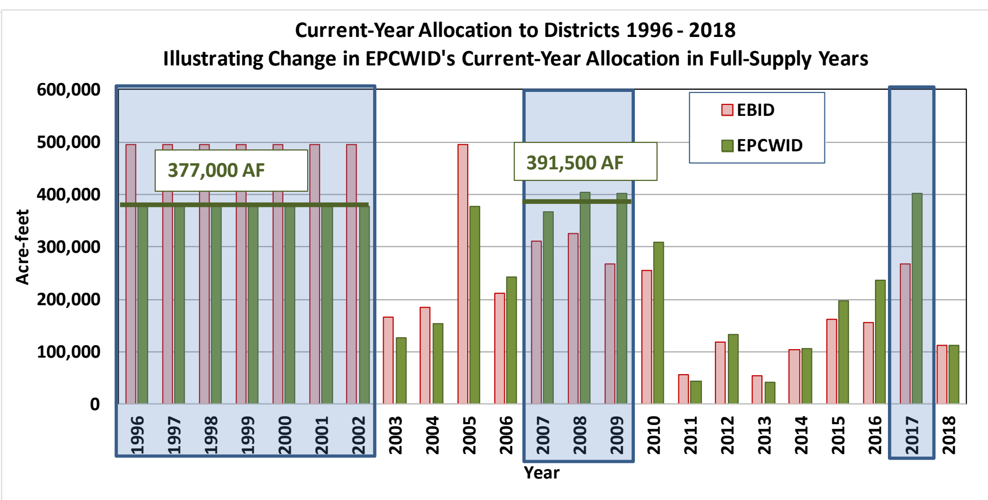
Figure 8.2 has three parts: The upper graph shows the Current-year Allocation data with full-supply years highlighted. The middle graph shows the same data, with the average of EBID's Current-year Allocations shown for the periods 1996 through 2002 and for 2007 through 2009. The lower graph in Figure 8.2 shows the same data, with the average of EPCWID's Current-year Allocation shown for the periods 1996 through 2002 and for 2007 through 2009. (Figures 8.3 and 8.4 are similarly organized for Total Allocation and Charged Diversions).

- The middle graph in Figure 8.2 shows that in full-supply years EBID's Current-year Allocation has decreased from 495,000 AF to an average of 301,000 AF under D3 Allocation. This decrease is a result of using the Diversion Ratio to calculate EBID's allocation.
- The lower graph in Figure 8.2 shows that in full-supply years EPCWID's Current-year Allocation has increased from 377,000 AF to 391,500 AF under D3 Allocation. This increase is the effect of two factors: 1) the extension of the D2 Curve, increasing the amount of a full-supply allocation under the modified D2 Curve, and 2) application of the ACE Credit, which had not been awarded to EPWID prior to 2003.

Figure 8.2. Current-Year Allocation Data for EBID and EPCWID, 1990 – 2018





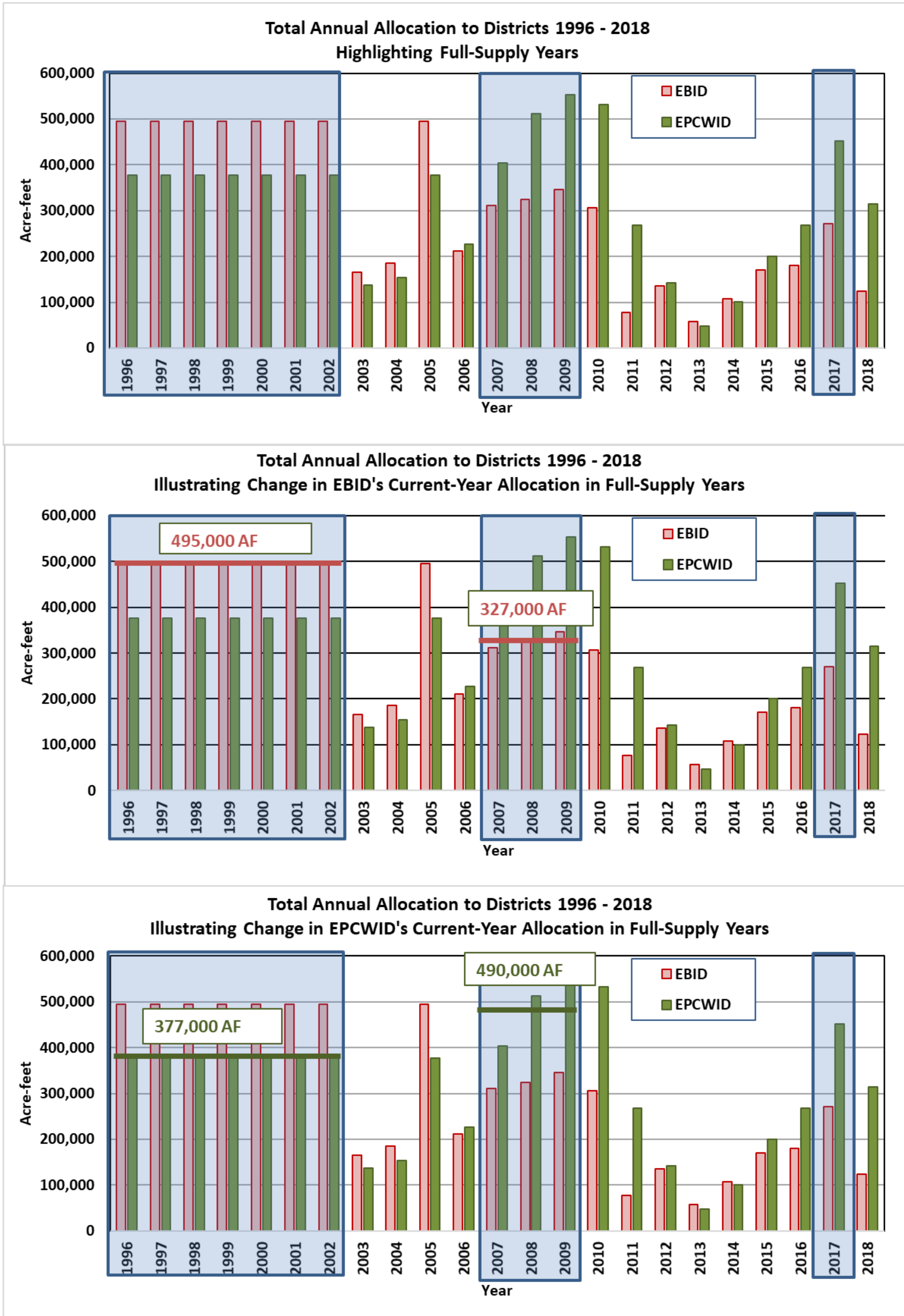


8.3 Comparison of Total Allocation: 1996 – 2018

The graphs in Figure 8.3 show Total Allocation (including Carryover) for the years 1996 through 2018 from Reclamation allocation and accounting records. Total Allocation included the Current-year Allocation of supply, the ACE Credit (for EPCWID) and any allocation carried over from the previous year.

- The middle graph in Figure 8.3 shows that in full-supply years, EBID's Total Allocation has decreased from 495,000 AF to an average of 327,000 AF under D3 Allocation. This decrease is a result of using the Diversion Ratio to calculate EBID's allocation under D3 Allocation. Comparison of the middle graphs of Figures 8.3 and 8.2 suggests that the benefit of Carryover to EBID in full-supply years has been an average of 26,000 AF.
- The lower graph in Figure 8.3 shows that in full-supply years, EPCWID's allocation has increased from 377,000 AF to an average of 490,000 AF. This large increase is the benefit of Carryover to EPCWID. A significant amount of EPCWID's large Total Allocation represents water that has been carried over for multiple years, and as such, does not reflect the amounts of water that EPCWID has actually been delivered or has diverted. The amounts the Districts were actually delivered are shown in the following section.

Figure 8.3. Total Allocation Data (including Carryover) for EBID and EPCWID 1990 – 2018



8.4 COMPARISON OF AMOUNTS DELIVERED (CHARGED DIVERSIONS) TO DISTRICTS 1996 – 2018

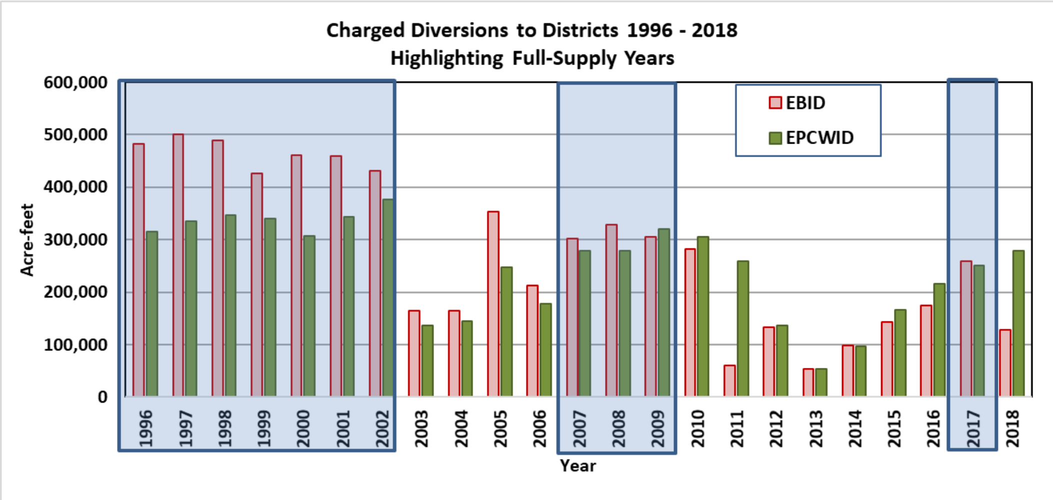
The graphs in Figure 8.4 show the Charged Diversions to each District for the years 1996 through 2018 from Reclamation allocation and accounting records. Charged Diversions (or allocation charges) reflect the amounts of water actually delivered to and diverted by the District, accounted for in accordance with the Project operations manual or operational procedures, including accounting credits.

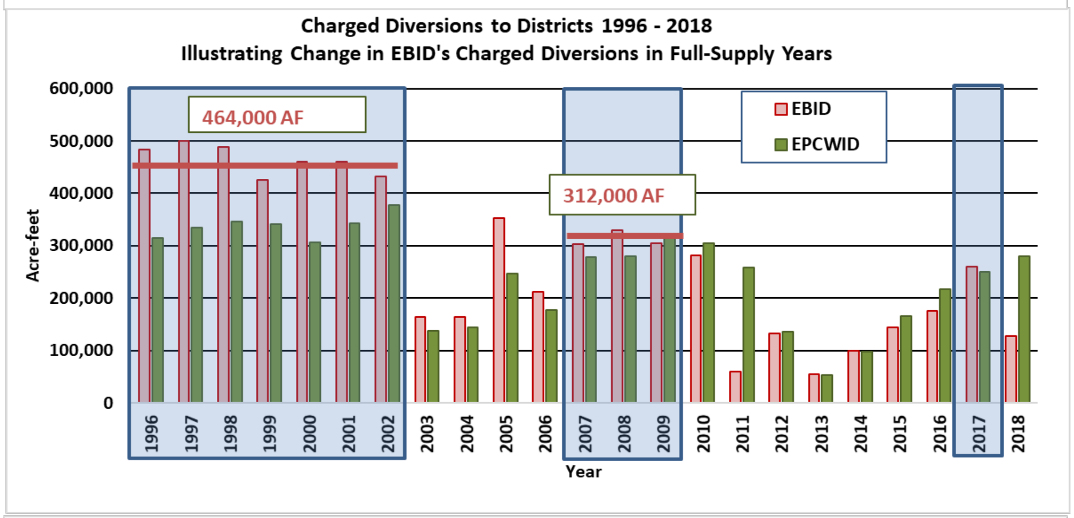
- The middle graph in Figure 8.4 shows that the average annual amount that EBID has received (its Charged Diversions) has decreased from 464,000 AF to 312,000 AF under D3 Allocation. This decrease in EBID's Charged Diversion reflects the decrease in EBID's allocation. For the time period 2007-2009, EBID's average total allocation was 327,000 AF. In some years, EBID's final allocation amount was not determined until after that District had ceased to distribute surface water, and therefore some part of EBIDs' allocation could not be ordered or used during that year.

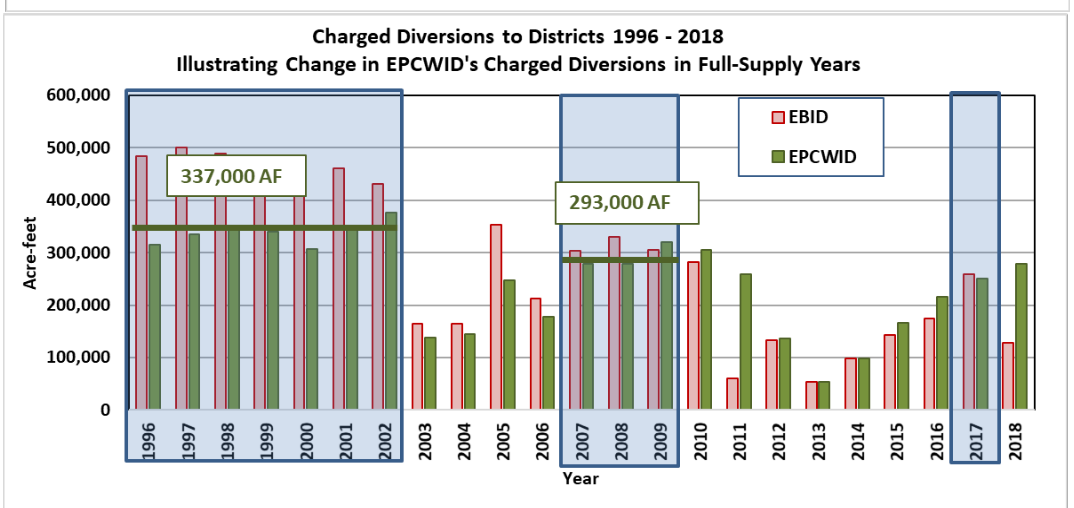
- The lower graph in Figure 8.4 shows that the average annual amount that EPCWID has received (its Charged Diversion) has also decreased from 337,000 AF to 292,000 AF. EPCWID's low Charged Diversions may reflect decreased demand for water within EPCWID, or the use of treated effluent for which EPCWID is not charged in Project accounting. Alternatively, EPCWID's Charged Diversion amounts may reflect conservation of water so that EPCWID can make use of its Carryover account to improve its supply during drought and thus provide a more reliable municipal supply to El Paso Water Utility.

  Note that even prior to the initiation of D3 Allocation in 2006 and Carryover in 2007, EPCWID's Charged Diversion in full supply years only averaged 337,000 AF out of a total allocation of 377,000 AF. Given Reclamation's operating procedures described in Section 2.2 of this report, EPCWID was entitled to order Project water as long as it had allocation remaining. Furthermore, Reclamation's procedure is, and has been historically, to adjust the gates of Caballo as necessary (given current flow conditions at each diversion heading) to ensure that all water ordered is delivered. Therefore, EPCWID's failure to divert its entire allocation in these years indicates that EPCWID's demand was significantly less than their full-supply allocation.

Figure 8.4. Delivery Data (Total Charged Diversions) for EBID and EPCWID 1990 – 2018







9 EFFECTS OF 2008 OA REDUCTION IN EBID ALLOCATION

In this Section, I demonstrate that because the 2008 OA has reduced EBID's share of Project supply during full-supply years below the amount needed to supply EBID's lands, EBID farmers have increased groundwater pumping. In addition, the reduction in EBID's share of Project water has reduced the amount of recharge to the aquifer in the Rincon and Mesilla Valleys. As a result, following implementation of D3 Allocation, shallow groundwater levels have dropped during low supply years but have not recovered in the full-supply years that follow. The combined effect of reduced recharge and increased groundwater pumping under the 2008 OA is that the groundwater budget of the Rincon and Mesilla aquifer system has been reduced by more than 100,000 AF in full-supply years. Thus, while shallow groundwater levels in the Rincon and Mesilla Valleys historically responded to surface water supply variation and recovered losses in full supply years, they no longer have the ability to recover, to the detriment of the aquifer and the Project as a whole.

9.1 EBID SURFACE WATER SUPPLY IS INSUFFICIENT TO MEET DEMAND

As previously discussed, D3 Allocation plus Carryover has resulted in a decrease in EBID's full-supply year allocation from 495,000 AF to an average of approximately 330,000 AF. As a direct result of this loss of Project water, EBID's full-supply year diversions have decreased from an average of 464,000 AF/Y to an average of 312,000 AF/Y (*see* Figure 8.4). Furthermore, EBID's farm deliveries in full-supply years decreased from approximately 250,000 AF before 2006, to less than 190,000 AF in 2008 and 2009, and 140,000 in 2017 (the difference between EBID's total diversion and its total farm delivery represents canal losses and canal waste).

EBID's diversions and farm deliveries in the full-supply years before 2006 constitute a rough estimate of EBID's irrigation demand. It is reasonable to conclude that the amounts of Project water allocated under the 2008 OA is insufficient to supply EBID's irrigation demand, even in full-supply years. Under the 2008 OA, a full-supply year for the Project is no longer a full-supply year for EBID.

9.2 EBID GROUNDWATER IRRIGATION PUMPING INCREASE

Because EBID's share of Project water is no longer adequate to meet EBID's irrigation demands, EBID farmers have become increasingly dependent on groundwater pumping. Estimates of irrigation pumping prior to 2009 have been made based on irrigation demands. These estimates suggest that New Mexico's irrigation well pumping in full-supply years of the 1980s and early 1990s averaged 60,000 AF/Y.[109] By contrast, New Mexico irrigation well meter data since 2009 shows irrigation well pumping of 131,000 AF to 157,000 AF in recent years of full Project Supply.

9.3 DECREASE IN AQUIFER RECHARGE FROM CANAL SEEPAGE

The EBID conveyance system is still largely unlined, and seepage from these canals is one of the main sources of recharge to the alluvial aquifer of the Rincon and Mesilla Valleys. Analysis of Project delivery

[109] *See* Spronk Water Engineers, Inc. Expert Report, 2019.

records, and modeling studies, suggest that, on average, aquifer recharge from canal seepage is equal to about 30% to 40% of the water diverted at EBID canal headings.

Since EBID's average diversion in full-supply years has dropped from 464,000 AF/Y to 312,000 AF/Y, this represents a decrease in canal seepage recharge of 46,000 AF/Y to 61,000 AF/Y; this amount of water previously recharged the aquifer and the impact of that loss is described below.

9.4 Groundwater Budget in Mesilla and Rincon Basins

The change in allocation procedures associated with the 2008 OA have led to a decrease of aquifer recharge (from canal seepage) and an increase in irrigation well pumping. These factors have caused a substantial change in the water budget of the Rincon and Mesilla aquifer system. I estimate, based on my experience modeling the Rincon and Mesilla aquifer system, that these factors combine to negatively impact the aquifer's water budget by well over 100,000 AF in each full-supply year (corresponding to a decrease in canal-seepage recharge of about 50,000 AF/Y and an increase in irrigation well pumping of more than 50,000 AF/Y).

A water budget of an aquifer can, in some ways, be compared to a person's financial budget. The decrease in aquifer recharge is comparable to a decrease in salary, while the increase in groundwater pumping is comparable to an increase in rent.

Based on my experience modeling the Rincon and Mesilla aquifer systems, before 2006 the aquifer budget of the Rincon and Mesilla basins was positive in full-supply years (more recharge than pumping) and negative in low-supply years (more pumping than recharge). Large amount of recharge from canal seepage and on-farm return flow (deep percolation) in full-supply years far exceeded groundwater pumping, allowing the aquifer to recover after periods of low supply, and supplying water to drains.[110] However, the introduction of D3 Allocation, and the adoption of the 2008 OA, has reduced the aquifer budget in full-supply years by more than 100,000 AF, greatly reducing the opportunity for aquifer recovery after drought.

Under the 2008 OA, it is possible that even in full-supply years groundwater pumping in the Rincon and Mesilla Basins will exceed the recharge to these basins. As a result, the aquifer system cannot recover in the full-supply years that follow times of drought. There is evidence that this has, in fact, occurred. The groundwater level plots shown in Section 9.5 show that since D3 Allocation was implemented in 2006 groundwater levels no longer rebound in full-supply years.

The equivalent financial comparison would be if a person's rent and other expenses always exceed their income. If that happens, their bank account would show a continual decrease. In the case of the Rio Grande aquifer system, groundwater levels will continue to decrease under current Project operations conditions.

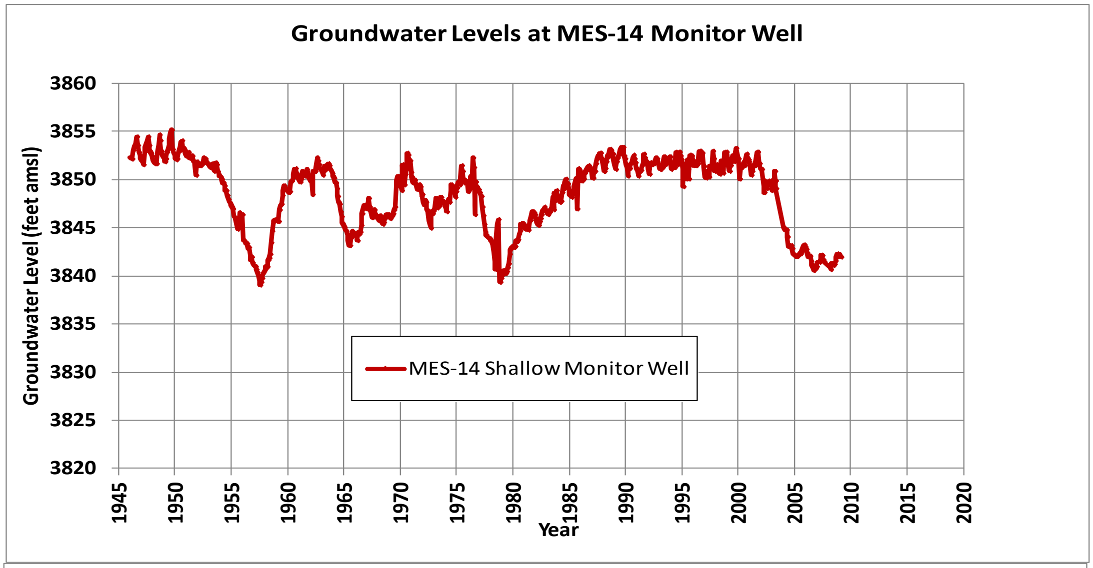
[110] S.S. Papadopulos & Associates, Inc., Summary Documentation of the Calibrated Groundwater Flow Model for the Lower Rio Grande Basin, LRG_2007.

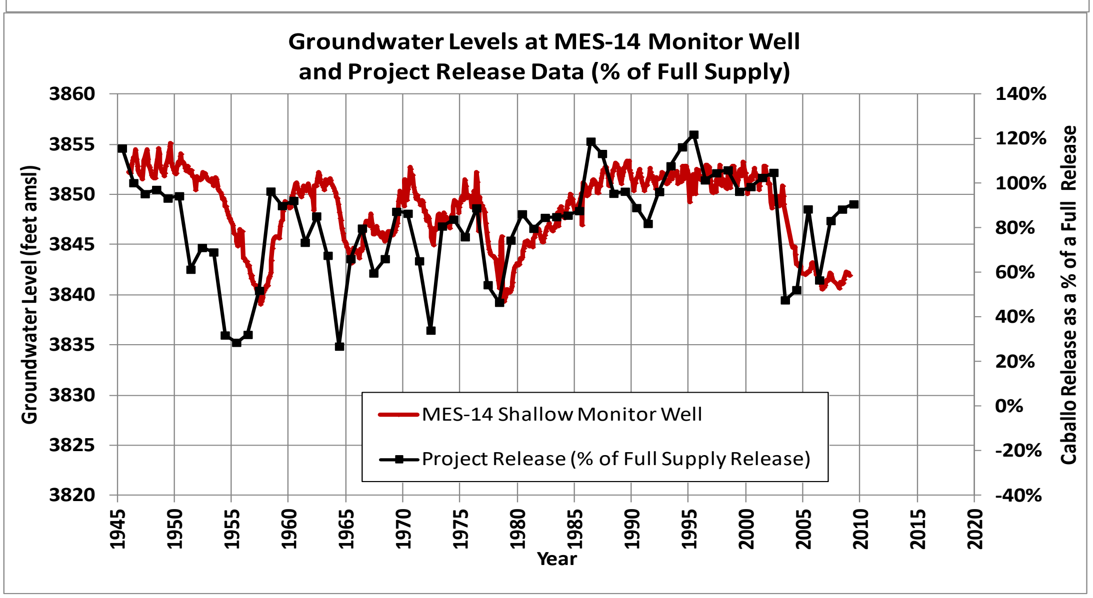
9.5 GROUNDWATER LEVELS IN MESILLA BASIN

As demonstrated in Figures 9.1 and 9.3, the historical response of groundwater levels in the 1950s, 1960s, and 1970s to changing Project water supply was that during times of low Project release, groundwater levels declined, and when the Project released full-supply amounts, groundwater levels would recover. The data I analyze herein suggest that the water budget of the Mesilla Valley aquifer has been changed by D3 Allocation. Now even when the Project has a full supply, groundwater pumping in the Mesilla Basin, by both New Mexico and Texas, may exceed the recharge to the aquifer, so that groundwater levels cannot recover following drought.

This response can be observed during the variable supply conditions of the 1950s, 1960s and 1970s as change in groundwater levels tracking Project releases. During the extended full-supply period of the 1980s and 1990s, groundwater levels recovered, and remained high until the first year of reduced supply in 2003. Groundwater levels dropped in 2003 and 2004, responding to low-supply conditions. Project releases in 2007 through 2009 were relatively high, exceeding 80% of a full-supply release, but groundwater levels do not recover from the lower levels they had reached in 2004.

Figure 9.1. Groundwater Levels at EBID Shallow Monitor Well, 1945-2009. Upper Plot: Historical Groundwater Levels; Lower Plot: Groundwater Levels plotted with Project Release % of a Full-Supply Release (763,842 AF)[111]





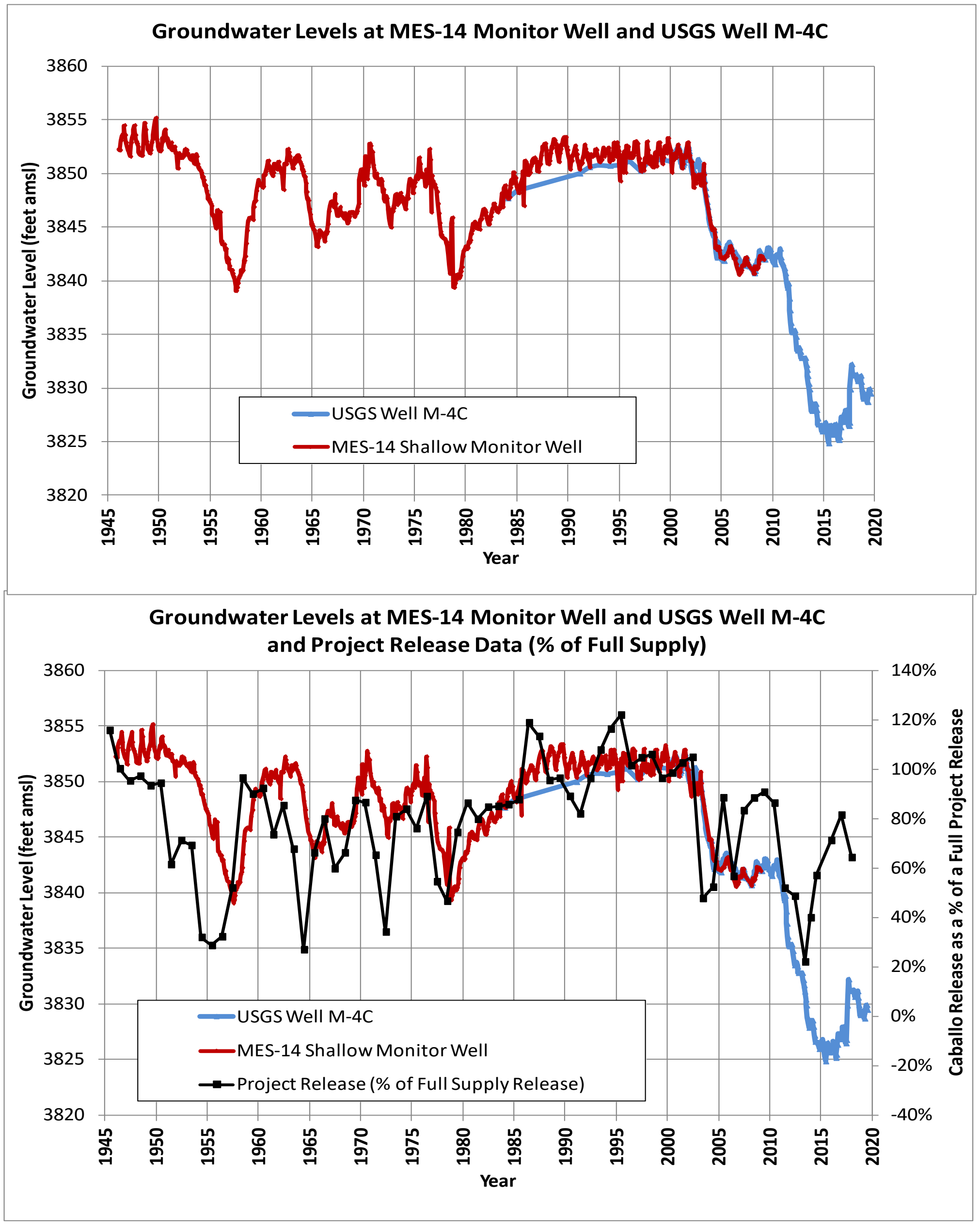
[111] Figure 9.1 is a water level plot from a Reclamation/EBID shallow groundwater monitor well (MES-14 (T24S R02E Section 09.433)) in the central Mesilla Valley, located south of Las Cruces (location indicated in Figure 9.2). This well was plugged in 2009, which is the end of the period of record. The lower graph in Figure 9.1 shows this groundwater level data plotted together with the annual Project release from Caballo, expressed as a percentage of a full-supply release (763, 842 AF).

Figure 9.2. Location Map for Shallow Monitor Wells/Piezometers MES-14 and M-4C (wells referenced in Figures 9.1 and 9.3)

While MES-14 (the well used for the Figure 9.1 data) was taken out of service in 2009, it is located very close to a shallow USGS monitor well: M-4C, which can be used to extend its record.[112] In Figure 9.3 I have combined the data from these monitor wells with Project release data, as before, including data through 2018. Data from both monitor wells shows the same response to low supply conditions in 2003 and 2004, and both show a failure to recover in 2007-2009. Groundwater levels in the USGS well, M-4C, remain low in 2010, despite a relatively high release from Caballo. In 2011, 2012 and 2013, Project releases are below 50%, and groundwater levels drop even more, below the levels observed in 2004. Higher releases in 2016 and 2017 correspond with some level of groundwater recovery, but levels still remain below the lows of 2004, and far below the groundwater levels obtaining in full-supply years prior to D3 Allocation.

[112] The M-4C USGS well has a shorter period of record, having been installed in the early 1980s, but it continues to be used as monitor well today. When the data from these two wells (MES-14 and M-4C) are plotted together, the groundwater levels coincide during the period of overlap, indicating that both wells provide compatible data.

Figure 9.3. Groundwater Levels at EBID Shallow Monitor Wells. Upper Plot: Historical Groundwater Levels; Lower Plot: Groundwater Levels plotted with Project Release % of a Full-Supply Release (763,800 AF)



The wells plotted in Figure 9.3 (MES-14 and M-4C) provide one of the most complete, long-term, high-quality sets of groundwater level data available for the LRG. These wells are located in an area of heavy agricultural water use, where the highest levels of observed groundwater level decline have occurred. Groundwater level data from a number of other Mesilla Valley wells show a similar trend, although the magnitude of groundwater level declines may be smaller. That is, groundwater levels track Project releases until about 2005, and then groundwater levels drop in response to low supply releases but do not recover in subsequent years of near-full supply release.

These data (and data from other monitor wells in the Mesilla Valley) suggest that the water budget of the Mesilla Valley aquifer has been changed by D3 Allocation. Now even when the Project has a full supply, groundwater pumping in the Mesilla Basin, by both New Mexico and Texas, exceeds the recharge to the aquifer so that groundwater levels cannot recover following drought.

In some areas of the Mesilla Valley, monitor wells show a much more muted response to Project Supply conditions, both historically and in recent years. These wells are generally at the northern end of the Mesilla Valley, or west of the Rio Grande, separated from the largest parts of the irrigated lands. The main agricultural area of the Mesilla Valley, from near the town of Dona Ana in the north to the town Mesquite in the south, show a strong response to low supply conditions, and a lack of any groundwater level recovery after 2006 and the implementation of D3 Allocation.

Data from some of the monitor wells in the Rincon Valley show similar trends to those plotted in Figures 9.1 and 9.3 but most Rincon Valley monitor wells show much smaller responses both to past low supply conditions, and to recent variations in supply. The different level of groundwater level response in the Rincon may relate to differences in water use or a difference in aquifer properties.

9.6 Effects of 2008 OA on Surface Water

9.6.1 Rio Grande Seepage

Recent declines in groundwater levels in the Rincon and Mesilla Valleys can impact the flows in the Rio Grande itself. In general, where groundwater levels are extremely shallow, groundwater may discharge into a river (sometimes in the form of springs), creating a "gaining reach" in that river. See, e.g., Figure 3.3. If those groundwater levels decline, the process reverses and results in seepage losses from the river into the groundwater. Further groundwater declines will increase seepage losses from the river, although it is likely that at some point the seepage rate reaches a maximum value, and does not increase further even if groundwater levels continue to decline.

The Rio Grande in the Rincon and Mesilla Valleys has historically been a losing reach, meaning water seeps from the river into the groundwater, although some sub-reaches have been observed to gain water. The southernmost reach of the Rio Grande in the Mesilla Valley, south of Canutillo, has historically been a gaining reach, probably because the aquifer system itself becomes very thin near the El Paso Narrows, and groundwater that had been flowing south at depth is forced upward toward the surface.

USGS seepage studies of the Rio Grande show that seepage losses in the Rio Grande have increased in recent years, and the length of the gaining reach has decreased.[113] This increase in Rio Grande seepage

[113] Briody, A.C., Robertson, A.J. and N. Thomas. *Seepage Investigation of the Rio Grande from below Leasburg Dam, Leasburg, NM, to above American Dam, El Paso, Texas*, 2015. USGS SIR 2016-5011.

makes it more difficult to transport Project water to the lower end of the Project, reducing Project performance, and reducing the Diversion Ratio. The changes in the groundwater budget in the Rincon and Mesilla basins caused by D3 Allocation, and the resulting declines in groundwater levels is most likely contributing to this increase in river losses, and resulting decrease in Project performance.

9.6.2 Drain Flows

The declining groundwater levels in the Rincon and Mesilla Valleys also negatively impact the flows in Project drains. LRG drains were constructed in order to intersect the groundwater table and convey excess groundwater away to the Rio Grande. (*See* Sections 3.3, 5.2 and Appendix C.) As groundwater levels have declined, drain flows have decreased, and in some cases stopped altogether. All of the drains in the Rincon Valley have been largely dry since 2003. Some drains in the Mesilla Valley are also dry, and others have been flowing at greatly reduced levels in recent years. Similar conditions with respect to drain flow obtain in the El Paso Valley, where large amount of municipal groundwater pumping, combined with irrigation well pumping have reduced groundwater levels and depleted drain flows. (*See* Appendix C.) This decrease in drain flow makes it necessary to release more water from storage to fill orders in the lower end of the Project, reducing Project performance, and reducing the Project Diversion Ratio from which the EBID allocation is derived under the 2008 OA.

9.7 Effect of 2008 OA on Project Performance

The net effect of the 2008 OA is to reduce the supply of Project water within EBID, leading to a decrease in aquifer recharge, and to increase in the amounts of groundwater pumping necessary to supply Project lands. These changes negatively impact the aquifer system in the Rincon and Mesilla basins, leading to a decline in groundwater levels, increased losses from the Rio Grande, and decreased drain flows. As a result, increasing amounts of water must be released from Caballo in order to fulfill orders for Project water in the lower end of the Project, thus reducing Project performance and reducing the Project Diversion Ratio.

This reduction in Diversion Ratio then causes a further reduction in EBID's allocation under D3 Allocation. In effect, D3 Allocation and the 2008 OA have created a "vicious cycle", in which the response to reduced Project performance (i.e. reductions in EBID's allocation) causes further degradation of Project performance.

Gunn, M.A. and Roark, D.M.. *Seepage Investigation on the Rio Grande from below Caballo Reservoir, NM, to El Paso, Texas*, 2012. United States Geological Survey, prepared in Cooperation with the New Mexico Interstate Stream Commission, USGS SIR 2014-5197.

Crilley, D.M. Matherne, A.M., Thomas, N. and Falk, S.E., *Seepage Investigation of the Rio Grande from below Leasburg Dam, Leasburg, NM, to above American Dam, El Paso, Texas, 2006 – 2013*. United States Geological Survey, 2006.

Assorted USGS Seepage Study results reported in Annual Water Resources of New Mexico.

Nickerson, Edward. USGS *Seepage Investigation of the Lower Rio Grande in the Mesilla Valley*, in Water Challenges on the LRG 43rd Annual New Mexico Water Conference Proceedings, p 59-65.

10 ACRONYMS AND GLOSSARY

<u>Note:</u> This Glossary and Acronyms appendix is intended solely as an aid and reference for the purpose of understanding the complex terms contained in this Report and is not intended to have a separate legal effect.

ACRONYMS

AF	Acre foot
AF/acre OR AF/A	Acre feet per acre
BOR	U. S. Bureau of Reclamation
COE	U.S. Army Corps of Engineers
EBID	Elephant Butte Irrigation District
EBR	Elephant Butte Reservoir
EP#1	El Paso County Water Improvement District #1
EPA	U.S. Environmental Protection Agency
EPCWID	El Paso County Water Improvement District #1
EPWU	El Paso Water Utility
ET	Evapotranspiration
GIS	Geographic Information Systems
HCCRD	Hudspeth County Conservation and Reclamation District #1
IBWC	International Boundary and Water Commission
ISC	(New Mexico) Interstate Stream Commission
Juarez	Juarez Valley Irrigation District (Mexico)
LRG	Lower Rio Grande River (for NM, this is the Rio Grande below Elephant Butte; for TX, this is the Rio Grande much further south near the Gulf of Mexico)
LUTA	Land Use Trend Analysis
MRG	Middle Rio Grande
MRGCD	Middle Rio Grande Conservancy District
NEXRAD	NEXt Generation Weather RADar System
NMISC	New Mexico Interstate Stream Commission
NMOSE	New Mexico Office of the State Engineer
NRCS	Natural Resources Conservation Service
OSE	(New Mexico) Office of the State Engineer
RGC	Rio Grande Compact
RGCC	Rio Grande Compact Commission
RGP	Rio Grande Project
TEQCEQ	Texas Commission on Environmental Quality Commission

URG	Upper Rio Grande (for NM, this is the Rio Grande above the Otowi Gage; for TX, this is the Rio Grande within the Texas area of the RGP)
URGWOM	Upper Rio Grande Water Operations Model
USBR	U. S. Bureau of Reclamation
USGS	U. S. Geological Survey
WDR	Water Distribution Report

GLOSSARY

57:43 - The historic delivery ratio of Project water to EBID and EPCWID, respectively, from 1915 to 2006.

A

Acre Feet (AF) - A standard volumetric measurement of water (1 acre of area covered in water 1 foot deep); this comprises 325,851 gallons.

Accounting: Compact: A system of post-fact records summarizing and tabulations of the annual credits and debits of Colorado and New Mexico, and releases and spill from Project Storage under the Compact.

Accounting: Project: A system of post-fact records and tabulations of the amount of Project water diverted by EBID and EPCWID in accordance with established procedures.

Acre feet per year (AF/Y) - The flow or diversion of 1 Acre Foot of water over the course of a year; a measurement of the rate of flow of water, and allocation amount or a diversion amount.

Actual Release - The amount of Usable Water released in any calendar year from Project Storage. (Use: COMPACT and PROJECT accounting term.)

Allocation Process- Prospective /advance determination of the amount of water (in AF) each District (and Mexico) is entitled to each year. Note that each year not all water allocated is actually ordered or delivered. (Use: PROJECT allocation term.)

Allotment: The amount of water, in terms of AF/acre, that Reclamation or the Districts determine that each authorized Project acre is entitled to each year.

Annual Allocated Water – The volume of Project water (in AF) that is determined by Reclamation, in consultation with the Districts, to be allocated each calendar year for delivery to EBID and EPCWID, and for delivery to Mexico. (Use: PROJECT allocation term.)

Alluvium - Unconsolidated clay, silt, sand, or gravel deposited by running water in the bed of a stream or on its floodplain.

Aquifer - A saturated water-bearing geologic formation, or group of formations, which stores, transmits, and yields water in sufficient quantity to be a source of supply. See also Santa Fe Group Aquifer.

B

Beneficial Use - Under New Mexico law, the direct use or storage and use of water by man for a beneficial purpose including, but not limited to, agricultural, municipal, commercial, industrial, domestic, livestock, fish and wildlife, and recreational uses. Beneficial use shall be the basis, the measure, and the limit of a water right.

C

Canalization Project - A project authorized by Congress in 1936 and constructed from 1938-43 in the Rincon and Mesilla Valleys consisting of 106 miles of rectified river channel and levees to add and fortify canals for flood protection and for Project use.

Carryover Water – In the 2008 OA, the amount of a District's Annual Allocation that is unused the end of a given calendar year, and carried over into the next year. (Use: PROJECT allocation and accounting term.)

Carryover Water/Carryover Limit - In the 2008 OA, Carryover Water may be accumulated in an account for each District to a maximum of sixty percent (60%) of each District's respective full yearly allocation (or an amount of Actual Carryover Water equal to 232,915 acre-feet for EPCWID and 305,918 for EBID). (Use: PROJECT allocation and accounting term.)

Carryover Water/Carryover Obligation – In the 2008 OA, the amount of Usable Water that is sequestered from the calculation of Current-Year Allocations for the delivery of Carryover Water. The amount of the Carryover Obligation is the total amount of Carryover Water from both Districts, divided by the Diversion Ratio.

Carryover Water/Carryover Transfer – The amount of Water transferred from one District to the other District as a result of the exceedance of the first District's Carryover Limit, or for other reasons. (Use: PROJECT allocation term.)

Charged Diversion – In Rio Grande Project Accounting, the net amount deducted from a District's Allocation representing the delivery and diversion of Project Supply over the course of an irrigation season (or other shorter period, if specified), calculated in accordance with specific Project Accounting rules. Charged Diversion is the net result of all charges and credits associated with a District's diversions and other operations over the course of an irrigation season. As opposed to Actual or Physical Diversion (Use: PROJECT accounting term.)

Cone of Depression - The cone-shaped depression in the groundwater table caused by the drawdown of a pumping well.

Conjunctive Use - Use of a combination of water sources for supply, i.e. use of both surface and groundwater.

Conservation Storage – Water stored in a reservoir during times of high flows to meet authorized purposes during times of lower flows.

Consumptive Irrigation Requirement (CIR) - The amount of applied water needed to support the growth of a healthy crop. Each type of crop may have a different CIR. Note that the CIR is a component of the Farm Delivery Requirement.

Consumptive Use (CU) - That part of water withdrawn from the stream system that is evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise removed from the immediate water environment (also referred to as water consumed). As opposed to Return Flow.

Conveyance Loss (AKA Transit Loss) - The amount of water lost between two defined points along a stream, canal, or ditch under natural conditions without interceding diversions or tributary surface water inflow. Conveyance loss can occur through seepage into the subsurface, evaporation and transpiration from vegetation.

Credits and Debits: Compact - The excess, or shortage, of surface water actually delivered by one state to another, compared to the obligation according to the Compact. (Use: COMPACT accounting term.)

Credits and Charges: Project - Positive or negative adjustments to the accounting of a District's diversions in determining a District's Charged Diversions, that is: how much of its allocation that District has been delivered. (Use: PROJECT accounting term.)

Credits and Debits/Accrued Credits - The amounts by which the sum of all Annual Credits exceeds the sum of all Annual Debits over any common time period. (Use: COMPACT accounting term.)

Credits and Debits/Annual Credits or Debits - The amounts by which actual deliveries in any calendar year exceed (or fall below) scheduled deliveries. (Use: COMPACT accounting term.)

Credits and Debits/Credit/Debit Balance - The end-of-the- year balance of credits and debits accrued under the Rio Grande Compact. (Use: COMPACT accounting term.)

Credits and Debits/Credit Water - That amount of water in Project Storage which is equal to the Accrued Credit of Colorado or New Mexico, or both. (Use: COMPACT accounting term.)

Current-Year Allocation- The amount of water annually allocated to a District under the 2008 Operating Agreement, exclusive of Carryover Water or Carryover Transfer. As opposed to Total Allocation which includes both Current-Year Allocation and Carryover Water. (Use: Project allocation term.)

D

D-1 Equation or Curve - The correlation between releases from Project Storage and delivery to farms in the Districts (and to the heading of the Acequia Madre for delivery to Mexico). The correlation was based on historical Rio Grande Project data for the period of 1951 through 1978. The D-1 Curve is now used primarily to determine the allocation to Mexico. (USE: PROJECT allocation term.)

D-2 Equation or Curve - The correlation between releases from Project Storage with corresponding annual deliveries to Rio Grande Project diversions from the Rio Grande for EBID, EPCWID, and Mexico. The correlation was based on historical Rio Grande Project data for the period of 1951 through 1978. The D2 Curve is now used primarily to determine allocation to EPCWID. (USE: PROJECT allocation term.)

D-3 Allocation Method or Procedure - A Project Allocation method first implemented in 2006, and adopted by the 2008 OA, which calculates Mexico's allocation using the D1 Curve, EPCWID's allocation using the D2 Curve, and allocates the remainder of Project Supply to EBID. (USE: PROJECT allocation term.)

Debit Storage - Water retained in storage in reservoirs constructed after 1937 in Colorado above Lobatos and in reservoirs constructed after 1929 in New Mexico equal to or less than the Accrued Debits of either state, respectively**.** (Use: COMPACT accounting term.)

Delivery: Compact - Amount of water delivered on an annual basis under the Compact as crossing the Colorado-New Mexico stateline and/or the change in volumetric content within Elephant Butte Reservoir plus the amount of water released from the reservoir downstream. (USE: COMPACT accounting term.)

Delivery: Project - The deliveries of Project water to canal headings (including water already at the canal) and the delivery of canal water to farmers. Before 1978, Reclamation made delivery both to canal headings and to farmers. Since 1978, Reclamation makes delivery to canal headings, while EBID and EPCWID make the final delivery to the farmers. (USE: PROJECT accounting term.)

Depletion - Net rate of water use consumed from a stream or groundwater aquifer for agricultural, domestic, riparian use, or evaporation from open water surfaces. Water gets "depleted."

Discharge – The flow of water, typically from one conveyance to another, or from groundwater into a surface water body.

District - In the Rio Grande Project, either EBID or EPCWID. See Irrigation District.

Diversion, Actual Diversion or Physical Diversion- The physical removal of surface water from a channel. This can be done by a dam or headgate or other means of "diverting" water from the channel. It also means the act of bringing water under control by means of a well, pump, or other device for delivery and distribution for use.

Diversion Ratio – A new term developed for D3 Allocation and the 2008 OA. The Diversion Ratio is equal to the ratio of Charged Diversions (including the Mexican diversion) and the Release from Caballo. The Diversion Ratio is used in the determination of the annual allocation to EBID. (USE: PROJECT accounting term.)

Drain, Drainage - Channels installed to intercept the water table in a shallow aquifer, removing excess groundwater and lowering the water table. In the LRG, the drains were installed after early Project irrigation return flows overloaded the aquifer, "subbing out" farm fields. LRG drains historically discharged large amounts of Project return flow throughout the Project, and that water used to comprise a significant amount of Project supply.

E

Effective Precipitation / Rainfall - Precipitation available for use by plants; the portion of the rainfall event that does not flow overland into an arroyo or stream, infiltrate to the water table and contribute to aquifer recharge or become lost to immediate evaporation from soils.

Effluent - Treated municipal wastewater.

Elevation - Physical height of a spot above mean sea level. For instance, water levels in reservoirs are often based on their elevation – that is, height above sea level. AKA Stage.

Elephant Butte Effective Index Supply (AKA Elephant Butte Scheduled Delivery) - The delivery obligation at Elephant Butte Reservoir according to the Compact. The value of this delivery obligation is determined based on inflow conditions at the Otowi Gage. USE: COMPACT accounting term.)

Engineer Advisor (EA) - Each State's technical advisor to its Compact Commissioner.

Ephemeral Flow - Water flow in a stream channel that occurs only after precipitation.

Ephemeral Tributaries - Rivers or streams that only flow during certain times of the year or under certain hydrologic conditions (versus perennial tributaries).

Evaporation (E) - The physical process by which a liquid or solid is transformed to the gaseous state which, in irrigation, usually is restricted to the change of water from liquid to gas. Water is lost to the atmosphere as a result of this process.

Evapotranspiration (ET) - The combined processes of evaporation and plant transpiration through which liquid water is converted to water vapor and lost to the atmosphere.

F

Farm Delivery Requirement (FDR) - The amount of water that must be delivered to a farm so that the CIR can be met. To account for farm losses including the deep percolation of return flow, this amount will be higher than the actual CIR requirement.

Full-Supply Conditions – Historically, the Rio Grande Project was considered to have a full supply when the annual amount of Usable Water available to the Project was sufficient to deliver 3.024 AF/A to Project Lands, plus 60,000 AF to Mexico at International Dam. Full-supply conditions largely obtained prior to 1951, pertained intermittently from 1951 through 1978, pertained from 1979 through 2002, and have occasionally occurred from 2003 until the present time. Since the adoption of the D3 Allocation method in 2006, Full-Supply Conditions can be defined either based on the annual amount of Usable Water available to the Project, or based on the Current-Year Allocation to EPCWID.

G

Gage / Gaging Stations - A surface water instrument station or structure that measures Stage (Elevation) of the water surface or flow. Within the Project, the USGS and the IBWC have gaging stations to monitor the Rio Grande level and flow rate.

Gains - Increases in the water supply within a system or "reach" of a river. For example, gains to streamflow may occur due to precipitation, snowmelt, groundwater discharge, wastewater discharge, or agricultural return flow. Roughly the opposite of Seepage.

Groundwater - Water occurring within underground geologic units of sand, gravel, fractured rock, etc. It is reached for use through drilling wells.

Groundwater Model - A computer program and input files that simulate groundwater flow and groundwater levels.

H

Head gate or Heading - The structure through which water is delivered to a canal or to a farm.

Hudspeth or HCCRD - The irrigation district located directly downstream of EPCWID. Hudspeth is not a Project beneficiary, but it receives and buys water from the Project. Many EPCWID farmers own land in Hudspeth as well, and the irrigation systems of the two districts are closely integrated.

Hydraulically Connected - A condition in which groundwater or surface water moves relatively easily between aquifers that are in direct contact, or between groundwater and a surface water body.

Hydrology - The branch of science concerned with the properties of the earth's water, and especially its movement in relation to land. The study of groundwater and its relationship to geology, the flow of surface water in rivers and conveyances, and the interaction between groundwater and surface water.

Hydrogeology - The study of groundwater and its relationship to geology.

Hydrograph - A graph showing the Stage (or Elevation), flow, velocity or other characteristics of water with respect to time. A stream hydrograph commonly shows the elevation or water flow; a groundwater hydrograph shows the water level.

Hydrologic Budget / Balance - Accounting of the inflow to, outflow from, and storage in a hydrologic unit such as a drainage basin, aquifer, soil zone, lake or reservoir; the relationship between evaporation, precipitation, runoff, consumptive use and the change in water storage, expressed by the hydrologic equation.

Hydrologic Cycle - The complete cycle that water can pass through, beginning as atmospheric water vapor, turning into precipitation and falling to the earth's surface, moving into aquifers or surface water, and then returning to the atmosphere via evapotranspiration.

I

Infiltration - The downward entry of water through the soil surface into the soil or into an aquifer.

Instream Use - The use of water that does not require withdrawal or diversion from its natural watercourse; for example, the use of water for navigation, recreation, and support of fish and wildlife.

Inter-district Contract - The contract between EBID and EPCWID executed in 1938 establishing, among other things, the agreed 57/43 division of water between the Districts.

Irrigation District - A legal entity, with definite geographic boundaries, created by statute to develop and manage large irrigation projects. In the Project, the two Districts are EBID and EPCWID.

Irrigation Water Requirements (WR) - The quantity of applied irrigation water that is required for various uses, particularly evapotranspiration (CIR, FDR, PDR).

J

Junior Appropriator - The holder of a surface or groundwater right that was acquired subsequent in time to other water rights (Senior Appropriator) on the same stream or aquifer.

M

Mainstem - The principal watercourse in a water basin system. The Rio Grande River is the mainstem of the Rio Grande River Basin.

N

Native Water - Surface water originating in the Rio Grande basin. In the Rio Grande stream system, San Juan Chama is not Native Water.

Non-Allocated Water – From the 2008 OA, Project water diverted from the Rio Grande by EBID or EPCWID that is not charged by Reclamation against any allocation account. (USE: PROJECT allocation term.) Compare to Annual Allowed / Allocated Water.

Non-Consumptive - That part of water withdrawn that is not evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise removed from the immediate water environment environment and which eventually returns to the aquifer or stream. It can include carriage water, end up as tail water, deep percolation, or operational waste.

O

Operating Agreement of 2008 (2008 OA) - The Operating Agreement for the Rio Grande Project entered into by the United State of America, by and through the Burreau of Reclamation, Elephant Butte Irrigation District, and El Paso County Water Improvement District No. 1 on March 10, 2008.

Operations Manual - The Rio Grande Project Water Accounting and Operations Manual created by Reclamation, EBID, and EPCWID that contains information regarding the methods, equations, and procedures used by EBID, EPCWID, and Reclamation to account for all water charges and operating procedures for the Rio Grande Project as required by the 2008 OA, and as periodically amended.

Order - A request to Reclamation by a District for the delivery of a quantity of Project water to the District's delivery and accounting stations at a specific flow rate (cubic feet per second) and at a specified delivery time and day. Or a request by a Farmer for delivery of a certain amount of water at the farm head gate. (USE: PROJECT Accounting and Operations term.)

Otowi Gage - The gage at Otowi on the Rio Grande, north of Santa Fe, which measures flow at that point and from which the delivery obligations of New Mexico to Elephant Butte Reservoir are determined. (USE: COMPACT accounting term.)

Otowi Index Supply - The recorded flow of the Rio Grande at Otowi Gage, adjusted for storage in reservoirs in New Mexico constructed after 1929 and for Trans-mountain Diversions. (USE: COMPACT accounting term.)

P

Perennial Tributaries - Rivers or streams that flow continuously throughout the year (versus Ephemeral Tributaries).

Permeability - The property of a material to transmit fluids (water) through its pores when subjected to pressure or a difference in Head.

Phreatophyte - A plant with roots that generally extend downward to the water table and customarily utilizes water from the capillary fringe. Phreatophytes are commonly referred to as "water-loving" plants and are common in riparian habitats.

Piezometer – A device, often consisting of pipe casing perforated near the terminal point only, or a well which is screened only over a specific depth interval, which indicates the water-pressure hydraulic head at a "point" in an aquifer.

Porosity - The ratio of void volume within the bulk volume of a material. Porosity determines the capacity of a rock formation to absorb and store groundwater.

Primary Irrigation Season - The period of a year when water is being released from Caballo Reservoir for irrigation purposes (generally early spring through about September). (USE: PROJECT accounting term.)

Priority Date - The seniority date or placement of a water right in perspective of its relative standing to other water rights within a common stream system or aquifer. This method of determining water rights is specific to the western United States (see Junior and Senior Appropriator).

Project Storage - The combined capacity of Elephant Butte Reservoir and all other reservoirs actually available for storage of Usable Water below Elephant Butte and above the first diversion to land of the Rio Grande Project, but not more than a total of 2,638,860 AF. (USE: COMPACT accounting term; PROJECT allocation term.)

Project Supply- Water that is delivered or available for delivery to Project beneficiaries, derived from several sources including Usable Water released from Project Storage, Drain flows, Return Flows, Tributary inflow, and Effluent. (USE: PROJECT allocation term.)

R

Reach - The geographic area of a river between any two points.

Recharge - The replenishment of groundwater in an aquifer. Recharge can occur from the infiltration of precipitation, seepage from a stream or irrigation conveyance, or seepage of the unconsumed part of the water applied to cropland.

Rectification Project - A project in the late 1930s-early 1940s in the El Paso Valley to straighten and fortify the Rio Grande river channel and clearly define the border with Mexico.

Release - The water released from Project Storage express either in terms of a flow rate (cubic feet per second) or a volumetric amount (acre-feet).

Relinquishment - The administrative process by which one state gives up part of its Accrued Credits, allowing that water to become Usable Water available to the Project, in exchange for the benefit of storing water upstream in reservoirs constructed after 1929 when the storage prohibition of Article VII of the Compact is in effect. (USE: COMPACT accounting term.)

Return Flow - That portion of water returning to the river or groundwater after diversion into irrigation canals, including tail water from farms, drainflow or applied irrigation water seeping past the root zone to groundwater. As opposed to Consumptive Use.

Rio Grande Compact or the Compact (RGC) - The interstate river compact that was ratified by the States of Colorado, New Mexico and Texas, approved by the United States Congress and signed by the President in 1939 (53 Stat. 785) to equitably apportion waters in the Rio Grande Basin from its headwaters in Colorado to Fort Quitman, Texas.

Rio Grande Compact Commission or the Commission (RGCC) - The agency created by the Rio Grande Compact for its administration thereof. It is comprised of one voting representative from each of the States of Colorado, New Mexico, and Texas. The United States is represented by one non-voting federal representative who acts as Chairman of the Commission.

Rio Grande Project or the Project (RGP) - The facilities, works, and appurtenant lands authorized by an Act of Congress on February 25, 1905, 33 Stat. 814 in compliance with the Reclamation Act of 1902, 32 Stat. 390. The major facilities and works include Elephant Butte Dam and Reservoir, Caballo Dam and Reservoir, a power generation plant, and six diversion dams (Percha, Leasburg, Mesilla, American, International, and Riverside) on the Rio Grande in New Mexico and Texas serving lands and service area authorized by the 1905 Act.

Riparian - Relating to or situated on the banks of a river.

Root Zone - The layer of soil that plant roots readily penetrate and in which the predominant root activity and water extraction occurs.

S

San Juan-Chama Project Water (SJC Water) - Transmountain surface water from the Colorado River system delivered through a series of diversion works and tunnels to the Rio Chama and thence to the Rio Grande. (USE: COMPACT accounting term.)

Santa Fe Group Aquifer System - A deep complex of unconsolidated alluvial sediments along the Rio Grande that form an aquifer that is hydraulically connected with the Rio Grande.

Seepage - The loss of water through the wetted perimeter beneath a reservoir, lake, ditch, canal or other open-channel water body. Roughly the opposite of Gains.

Senior Appropriator - The owner of a surface water right whose right was acquired earlier or prior to other right holders (Junior Appropriators) on the same stream.

Spill Year - A year during which there is flow over the spillway at the Elephant Butte Reservoir

Stage - Physical height of a spot above mean sea level. For instance, water levels in reservoirs are often based on their stage – that is, height above sea level AKA Elevation.

Storage - Either 1) the amount of water in a reservoir, or 2) the amount of water existing in the interstices of a geologic medium as part of a groundwater system.

Stream Connected Aquifer - An aquifer with hydraulic connection with a surface water system.

Surface Water- Water that is available on top of ground, versus groundwater.

T

Tail Water - Excess surface water flowing off a field under cultivation or excess water at the bottom of an irrigation system.

Transfer Contracts - The contracts executed between Reclamation / EBID (Feb. 15. 1979) and Reclamation / EPCWID (March 14, 1980) after the Districts had paid off their loans to the federal government, transferring certain Project infrastructure and responsibilities to the Districts.

Transit Loss - See Conveyance Loss.

Trans-Mountain Diversions - Water imported into the drainage system of the Rio Grande from a drainage system outside of the Rio Grande Basin (i.e., San Juan-Chama Project water) (USE: COMPACT accounting term.)

Transpiration (T) - The process by which water in plants is transferred as water vapor to the atmosphere.

Tributary - Any stream which naturally contributes to the flow of the Rio Grande.

U

Usable Water - All water, exclusive of Credit Water and San Juan-Chama water, which is in Project Storage. Usable Water is available for release in accordance with irrigation demands, including deliveries to Mexico. (USE: COMPACT accounting term; PROJECT allocation term.)

W

Waste - Water diverted into Project conveyances then returned to the river through wasteways.

Wasteway - A conveyance for the specific purpose of dumping water from irrigation conveyances back into a river. As opposed to canals and lateral whose purpose is to convey water to fields and other use points.

Water Balance / Water Budget - A mathematical construction that shows the amount of water leaving and entering a given watershed or aquifer (Inflow versus outflow).

Water Distribution Report (WDR) - Reports prepared by Reclamation which tabulate diversion and deliveries by “Project”, “valley”, or “unit”; these are the only accounting records of Project Deliveries prior to 1979.

Water Supply - The amount of water potentially available for use within a study area; this must account for both the hydrologic supply and the legal limitations imposed by State law and water allocation agreements such as the Rio Grande Compact.

Water Table - A fluctuating demarcation line between the unsaturated (vadose) zone and the saturated zone that forms the upper layer of an aquifer. It may rise or fall, depending upon precipitation, recharge, and withdrawals.

Well Permit - The granting of permission by the government (in New Mexico, the Office of the State Engineer) allowing the construction of a groundwater well and the application of water to beneficial use.

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12 Dr. Margaret Barroll CV and List of Publications

Margaret (Peggy) Barroll, Ph.D.
Senior Water Resource Hydrologist

Professional Resume

Peggy Barroll
691 East Zia Rd
Santa Fe, NM 8750

Phone: (505) 660 8079
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Education:

Ph.D. Geophysics, with concentration in groundwater hydrology, 1989, New Mexico Tech, Socorro, New Mexico. Dissertation: "Analysis of the Socorro Hydrothermal System, Central New Mexico"
M.S. Geophysics, 1984, New Mexico Tech, Socorro, New Mexico
B.A. Physics, Honors, 1980, Swarthmore College, Swarthmore Pennsylvania

Employment:

Fall 2017 to Current:	Balleau Groundwater Inc. and West Consultants Inc. -- Senior Water Resource Hydrologist
1991 – 2017:	New Mexico Office of the State Engineer -- Senior Water Resource Hydrologist
1988-1991:	D.B. Stephens and Associates -- Hydrologist (part-time)

Relevant Expertise:

1) **Computer model development and effective model use for scientific evaluation of hydrogeologic systems**
    a. New Mexico Administration: Lower Rio Grande Basin
        i. Principal scientist in the development of multiple MODFLOW groundwater models for the Lower Rio Grande (LRG) aquifers
            1. Development of farm budgets and groundwater pumping inputs for these groundwater models
            2. Committee member of modeling experts for 2007 LRG Groundwater Model
        ii. Completed in depth analysis of irrigation water demand and water use through
            1. Analysis of well meter data
            2. Calculation of irrigation well pumping for periods prior to well metering

      iii. Provided hydrogeologic consultation to developers of models to simulate Rio Grande Project operations
      iv. Provided hydrogeologic consultation to developers of salinity models
      v. Created compilations of hydrologic data: groundwater pumping, groundwater levels, surface water flows, etc.
      vi. Testifying Expert in the Consumptive Irrigation Requirement Determination in the Lower Rio Grande adjudication
         1. Prepared technical exhibits for Adjudication Court related to irrigation water use
   b. New Mexico Administrative Middle Rio Grande Basin
      i. Principal scientist in the revision of the pre-existing USGS Middle Rio Grande groundwater MODFLOW model for determination of impairment in Office of the State Engineer (OSE) water right application proceedings
      ii. Collaborated with the United States Geological Survey (USGS) in development of updated groundwater MODFLOW model of Middle Rio Grande Basin
   c. Taos Valley
      i. Principal scientist for the OSE in the development and refinement of the Taos Valley MODFLOW groundwater model
      ii. Collaborated with multi-agency Technical Committee (Federal, State and local representatives) on the creation and calibration of the Taos Valley MODFLOW groundwater model and associated processing tools
      iii. Technically sound consultation and work product for assistance in the Taos adjudication settlement negotiations
   d. Pecos River Basin
      i. Principal scientist for the OSE in the development, calibration, application and update of the Carlsbad Area Groundwater MODFLOW model and associated creation of preprocessing software necessary to initiate model runs
      ii. Senior scientist for the OSE collaborating in the development, application and update of the Roswell-Artesian Basin Groundwater MODFLOW model
      iii. Senior scientist for the OSE collaborating in the development of RiverWare model of the Pecos River
      iv. Senior scientist for the OSE in the development, support and technical management the Pecos Decision Support System (PDSS). The PDSS is comprised of four independent models, the Carlsbad Area Groundwater MODFLOW model, the Roswell-Artesian Basin Groundwater MODFLOW model, the Pecos River RiverWare Model, and a water balance model of the Pecos River from Carlsbad, NM to the New Mexico-Texas state line. The PDSS was developed to inform negotiators of the Pecos River Settlement Agreement of the impacts of various proposals for New Mexico's compliance with the United States Supreme Court's Amended Decree from Original Action No. 65

2) Groundwater resources development, management and protection

   a. Lower Rio Grande

i. Analysis of Rio Grande Project Operations, historical and present, within New Mexico and Texas
ii. Utilized the application of models to provide the SE information on historic and proposed Lower Rio Grande water management issues
iii. Provided technically sound consultation and work product in the development of administrative guidelines, and proposed rules for the Lower Rio Grande within the OSE's jurisdiction
iv. As the Principal scientist, provided technical evaluation and input on District Specific Rules developed under the OSE's framework rule set for the State of New Mexico's Active Water Resource Management
v. Engaged with stakeholders from the Lower Rio Grande region on the development of rules for alternative administration of water rights in the OSE's jurisdiction and provided multiple presentations on the 2008 Operating Agreement and associated Operations Manuals

b. Middle Rio Grande
   i. Development of State Engineer Water Right Application Guidelines for the Middle Rio Grande Administrative area
   ii. Guideline technical basis stemmed from groundwater water modeling
   iii. Determined Critical Management Areas where groundwater pumping is constrained to ensure limits of aquifer drawdown

c. Miscellaneous assignments as Principal scientist for New Mexico Office of the State Engineer
   i. Hydrologic assessments for pending water right applications.
   ii. Hydrologic assessments for adjudications, subdivision water availability determinations
   iii. Technically sound consultation and work product for SE consideration in water resource management and supervision
   iv. Technically sound consultation and work product for the Office of the State Engineer litigation activities, including interrogatory questions and responses, technical memoranda, exhibits and expert reports, written and oral testimony

List of Publications (10 years)

2019, Water Availability for the Industrial Diversion at Harroun Canal, Eddy County, NM. Technical Report for the NM ISC

2015, Historical Irrigation Well Pumping and Pumping Capacity in the Rincon, Mesilla and El Paso/Juarez valleys, in New Mexico, Texas, and Mexico, Barroll, Report

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2011, State Exh. No. 16. 2009 Lower Rio Grande Groundwater Pumping Data Summary, Barroll Report

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February 2011, Hydrology of Mesilla-Rincon Basins in New Mexico, Barroll CLE Written Materials

January 2011, 2009 Lower Rio Grande Groundwater Pumping Data Summery, NMOSE Hydrology Bureau Report 11-2

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May 2011, Superposition Version of the Taos Groundwater Model (T17sup.0), Memorandum, NMOSE Hydrology Bureau

June 2010, Technical Summary of Issues Related to CP-722, Memorandum, NMOSE Hydrology Bureau

June 2010, State of New Mexico Issues and Concerns about the 2008 Rio Grande Project Operating Agreement, Barroll, CLE Written Materials

August 2010, Rio Grande Project Operating Agreement – A State of New Mexico Perspective, Barroll, CLE Presentation

2009, Review of LRG Irrigation Well Meter Data from 2008, Barroll Report

2009, LRG_2007 Groundwater Flow Model for the Rincon and Mesilla Bolsons, Barroll and SSPA WRRI Presentation

September 2009, Hydrologic evaluation of application LRG-4755 into LRG 7644, Memorandum, NMOSE Hydrology Bureau

September 2009, State v. Abeyta, 69-CV-07896: Statement of Claims to Springs: "Spring Ditich Springs", Memorandum, NMOSE Hydrology Bureau

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APPENDIX A

HISTORICAL ALLOCATION AND DIVERSION DATA

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APPENDIX A - HISTORICAL ALLOCATION AND DIVERSION DATA

This Appendix presents historical Project allocation and diversion data in order to document the changes in the distribution of Project water between the Districts associated with the 2008 OA. My analyses of the raw data as set forth in this Appendix underlies other analyses and conclusions throughout this Report. The back-up raw data for this Appendix is provided with this Report in the form of WDRs, District accounting workbooks, scanned allocation spreadsheets, scanned accounting summaries, and random allocation data sources. The data sets analyzed herein are divided into three periods:

- 1931 – 1978: Unified Project Operations under Reclamation
- 1979 – 2005: D1/D2 Allocation of Project Supply to Districts
- 2006 – 2018: D3 Allocation with Carryover, 2008 OA Allocation to Districts

For convenience, key data from this Appendix are compiled by the author as Total Allocation and Delivery of Project Water to Districts and Mexico, 1930-2018, produced contemporaneously.

1 1931-1978: PROJECT ALLOTMENT, DIVERSION AND DELIVERY DATA

In this section Reclamation allotment, diversion and farm delivery data from the period 1931[1] through 1978 is summarized in tables and graphical form. During this time period (and prior to this time) Reclamation treated the Project as one entity, allotting water to all Project acreage in terms of acre-feet per acre ("AF/A"), diverting water at Project canal headings and delivering water to Project farmers.

1.1 1931-1978 PROJECT ALLOTMENT DATA

As set forth above, prior to 1979, Reclamation allotted water to all Project farms on an equal AF/A basis. The resulting allocation shares were thus equal to the shares authorized acreage: ~57% to EBID and ~43% to EPCWID (the 57:43 split).

Before 1940, it appears that Reclamation did not set a limiting allotment for Project lands. Project Histories from the 1940's indicate that in some years Reclamation was concerned about water shortages, and set a limiting allotment, although during the 1940s these limiting allotments were lifted at some point during the irrigation season. Starting in 1951, limiting allotments were set, and while these allotments were modified as water supply conditions changed, they remained in force throughout the irrigation season. Table A.1 and Figure A.1 provides Reclamation allotment data extracted from the Project Histories for various years, and from Reclamation's "Project Annual Operating Plan 1984 Operations, 1985 Outlook."[2]

[1] 1931 is the beginning of a relatively complete sequence of legible Project delivery data.

[2] *Annual Operating Plan*: *1984 Operations, 1985 Outlook*, Bureau of Reclamation, Rio Grande Project, 1985.

Figure A.1. Project Allotments Set by Reclamation 1951-1978

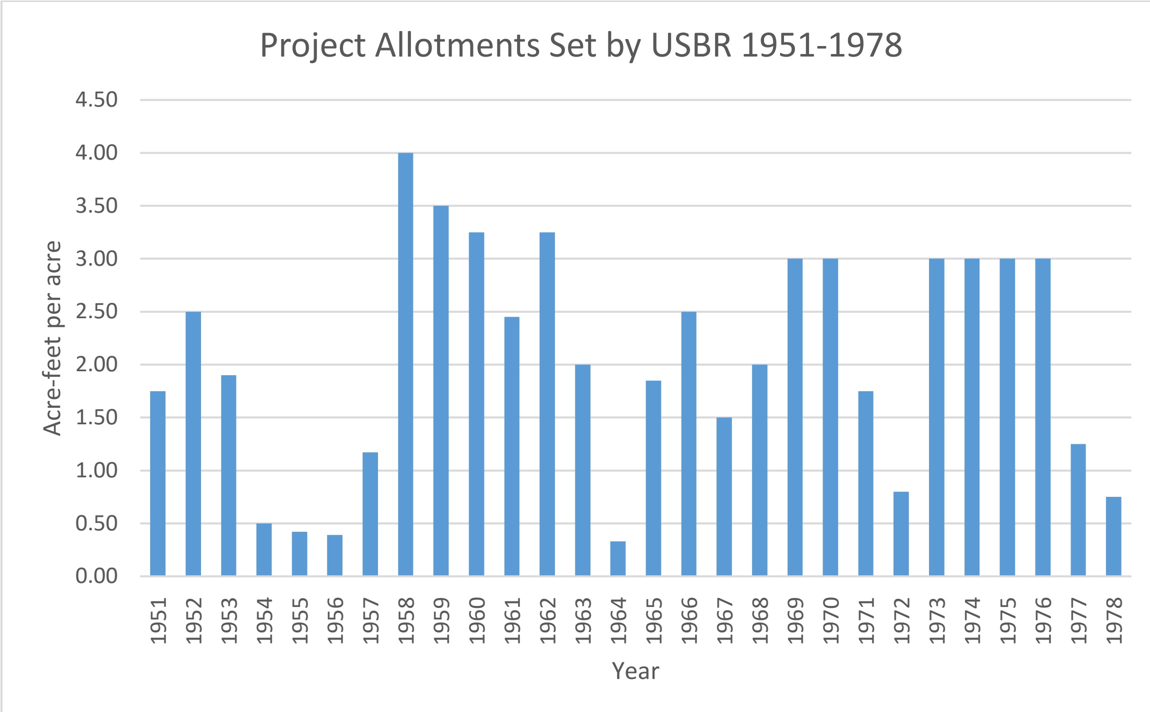


Table A.1. Project Allotments Set by Reclamation 1951-1978

Historical USBR Allotments to RGP Lands (NLA = No Limiting Allotment Set)		
	Initial Allotment to Project Lands	Final Allotment to Project Lands/EBID Lands
1940	NLA	NLA
1941	2.00	NLA
1942	NLA	NLA
1943	NLA	NLA
1944	NLA	NLA
1945	NLA	NLA
1946	NLA	NLA
1947	NLA	NLA
1948	2.00	3.00
1949	NLA	NLA
1950	NLA	NLA
1951	1.00	1.75
1952	0.21	2.50
1953	1.00	1.90
1954	0.42	0.50
1955	0.21	0.42
1956	0.33	0.39
1957	0.10	1.17
1958	1.75	4.00
1959	3.00	3.50
1960	2.25	3.25
1961	1.25	2.45
1962	1.75	3.25
1963	1.85	2.00
1964	0.25	0.33
1965	0.17	1.85
1966	1.75	2.50
1967	1.25	1.50
1968	1.00	2.00
1969	1.33	3.00
1970	2.00	3.00
1971	1.50	1.75
1972	0.60	0.80
1973	1.00	3.00
1974	3.00	3.00
1975	1.00	3.00
1976	2.50	3.00
1977	1.00	1.25
1978	0.25	0.75

1.2 1931-1978 District Diversion Data

Diversion and farm delivery data for the Project prior to 1979 is available from Project Water Distribution Reports (WDRs). During this time, diversions at canal headings were not reported on a District basis. Instead, diversions were reported by "Unit" (Rincon Valley Unit, Leasburg Unit and Mesilla Unit) or "Valley" (Mesilla Valley and El Paso Valley), with the diversions tabulated in the Mesilla Unit and Mesilla Valley supplying both EBID and EPCWID lands. An example of one of these reports is provided as Figure A.2.

Figure A.2. Water Distribution Report (WDR) for the Mesilla Unit, 1958:

Form 7-329 (May 1937)

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

MONTHLY WATER DISTRIBUTION

Project Rio Grande, New Mexico-Texas
Mesilla Unit
(East Side and West Side Canal System)
Area Irrigated 48,911
Year 1958

QUANTITIES IN ACRE-FEET

MONTH	Diverted from Stream[1]	Inflow from— Reservoirs[2]	Inflow from— Leasburg Canal	Delivered to Reservoirs[2]	Net Supply[3]	Total Waste to River	Total Losses	Delivered to Laterals[4]	Lateral Waste	Lateral Losses	Charged to Farms[5] Total	Charged to Farms[5] Per Acre
January,	0		0		0	0	0				0	-
February,	0		0		0	0	0				0	-
March,	29,019		0		29,019	2,980	15,449				10,590	0.22
April,	26,994		167		27,161	1,450	4,578				21,[illegible]33	0.43
May,	26,067		60		26,127	1,310	11,774				13,[illegible]43	0.27
June,	40,346		214		40,560	1,820	15,913				22,[illegible]27	0.47
July,	49,164		216		49,380	2,010	17,682				29,[illegible]88	0.60
August,	43,322		296		43,618	3,320	13,822				26,476	0.54
September,	19,569		381		19,950	4,090	4,443				11,417	0.24
October,	2,626		1,750		4,376	2,790	1,442				[illegible]44	-
November,	0		1,550		1,550	311	1,192				[illegible]7	-
December,	0		444		444	61	365				[illegible]8	-
Total,	237,107		5,078		242,185	20,142	66,660				135,3[illegible]3	2.77
Acre ft. per acre,	4.85		0.10		4.95	0.41	1.77				2.[illegible]7	-
Per cent Net Supply,	97.9		2.1		100	8.3	35.8				55.[illegible]	-

[1] Diversion amount exclusive of waste at head gates for sand sluicing, etc.
[2] Reservoirs connected with distributing system only.
[3] Diversions plus inflow from reservoirs and other sources less delivery to reservoirs.
[4] Measured at
[5] Measured at

I calculated the amounts diverted by each District based on data from Reclamation Unit and Valley WDRs. Net Diversions for each unit are calculated by subtracting El Paso Valley Carriage (if any) from the Diverted from Stream values. EBID's diversion is calculated as the sum of the Net Diversion from the Rincon and Leasburg units, plus 80% of the Mesilla Unit Net Diversion, plus diversions at through Percha Private Lateral, plus water pumped from EBID District wells (1976-1978). EPCWID's diversion is calculated as the sum of the El Paso Valley Diverted from Stream values, plus 20% of the Mesilla Unit Net Diversion. The resulting calculated District diversions are provided in Table A.2.

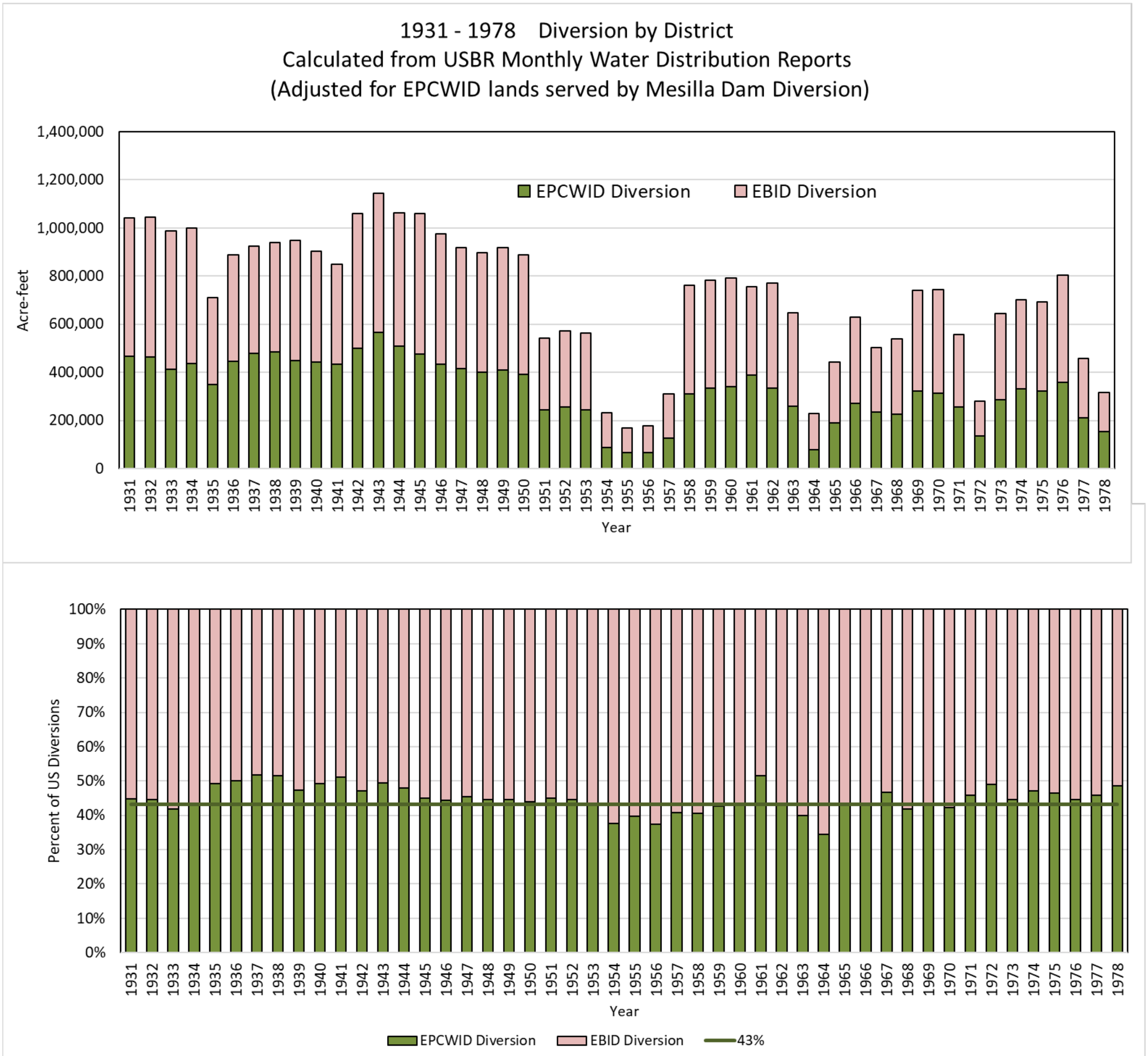
Table A.2. District Diversions 1931 - 1978

Year	EBID Diversion		EPCWID Diversion	
	AF	% of US Diversion	AF	% of US Diversion
1931	576,170	55.3%	465,745	44.7%
1932	579,603	55.5%	464,387	44.5%
1933	574,740	58.2%	413,280	41.8%
1934	563,596	56.4%	435,549	43.6%
1935	361,249	50.7%	351,076	49.3%
1936	443,168	49.9%	445,786	50.1%
1937	445,084	48.2%	478,116	51.8%
1938	455,382	48.5%	483,282	51.5%
1939	499,116	52.6%	449,602	47.4%
1940	458,687	50.9%	442,991	49.1%
1941	416,074	49.0%	433,885	51.0%
1942	560,187	52.8%	500,363	47.2%
1943	577,619	50.5%	565,512	49.5%
1944	552,802	52.0%	509,641	48.0%
1945	583,718	55.1%	475,622	44.9%
1946	542,043	55.5%	433,967	44.5%
1947	501,052	54.6%	416,298	45.4%
1948	497,826	55.5%	399,604	44.5%
1949	509,707	55.5%	408,263	44.5%
1950	497,407	56.1%	390,001	43.9%
1951	297,156	54.9%	244,015	45.1%
1952	317,204	55.4%	255,226	44.6%
1953	320,359	56.8%	243,850	43.2%
1954	144,840	62.4%	87,451	37.6%
1955	102,423	60.3%	67,395	39.7%
1956	111,812	62.7%	66,596	37.3%
1957	183,276	59.3%	125,941	40.7%
1958	452,182	59.4%	309,530	40.6%
1959	448,460	57.4%	332,788	42.6%
1960	452,520	57.1%	339,341	42.9%
1961	365,828	48.5%	388,830	51.5%
1962	435,501	56.5%	335,200	43.5%
1963	389,295	60.1%	258,360	39.9%
1964	150,923	65.6%	79,087	34.4%
1965	253,713	57.2%	189,703	42.8%
1966	359,166	57.1%	269,681	42.9%
1967	268,909	53.4%	234,693	46.6%
1968	313,758	58.1%	226,120	41.9%

1969	422,170	56.8%	320,686	43.2%
1970	430,298	57.9%	312,858	42.1%
1971	302,296	54.3%	254,586	45.7%
1972	142,290	51.0%	136,926	49.0%
1973	358,265	55.5%	287,327	44.5%
1974	372,939	53.0%	331,156	47.0%
1975	371,360	53.6%	321,615	46.4%
1976	449,660	55.7%	357,981	44.3%
1977	259,775	55.3%	209,634	44.7%
1978	168,694	52.4%	153,081	47.6%
Average 1931-1978	392,506	54.5%	327,138	45.5%
Average 1951-1978	308,753	56.2%	240,702	43.8%

Figure A.3 is a graphical representation of the data from Table A.2, both in terms of AF diverted by each District, and in terms of the percentage share diverted by each District. A line denoting the 57:43 split between EBID and EPCWID is shown for reference.

Figure A.3. District Diversions 1931 - 1978



1.3 1931-1978 District Farm Delivery Data

Farm delivery data (or "Charged to Farms" entries) from Project WDRs for the Project Units and Valleys has been similarly adjusted to obtain estimated District farm deliveries. I have assigned farm delivery data from the Mesilla Unit to EBID and EPCWID based on the amount of irrigated acreage belonging to each District within the Mesilla Unit: 80% to EBID and 20% to EPCWID. The resulting farm delivery data is provided in Table A.3 and Figure A.4.

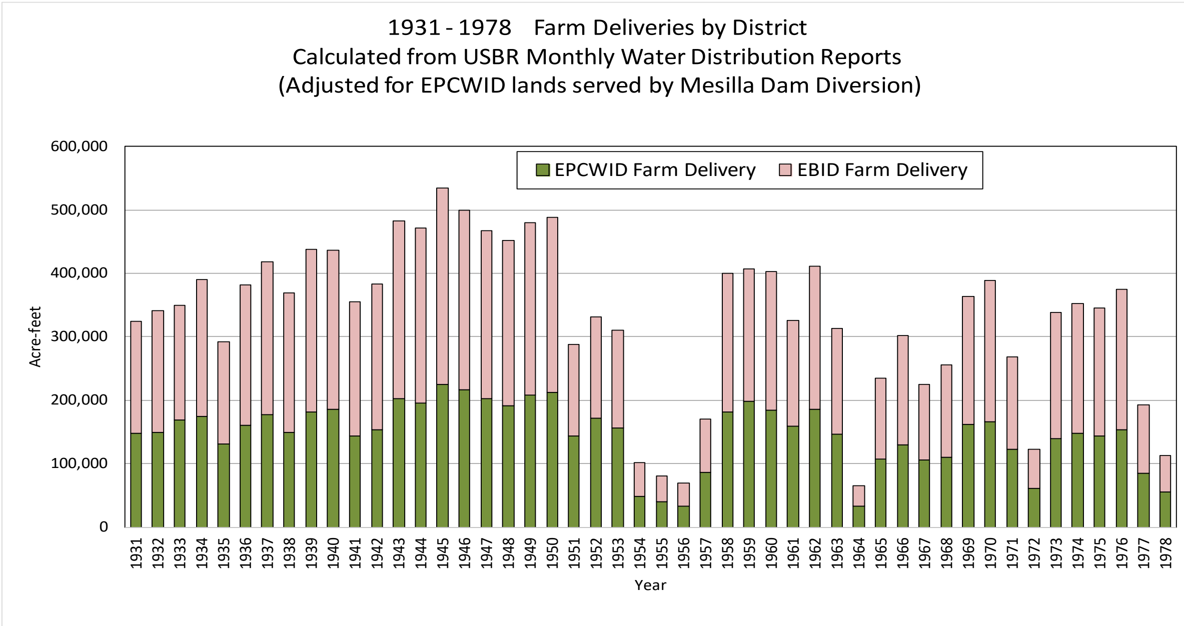
Table A.3. Farm Delivery Data from Project WDR forms, adjusted for EPCWID lands in Mesilla Unit

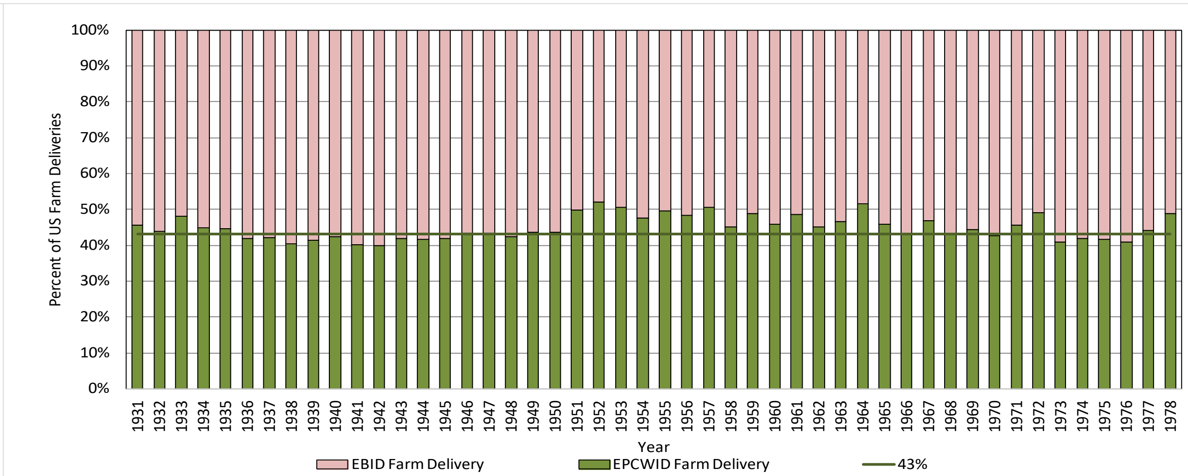
Year	EBID Farm Delivery		EPCWID Farm Delivery	
	AF	% of US Diversion	AF	% of US Diversion
1931	176,158	54.3%	148,463	45.7%
1932	191,784	56.1%	149,778	43.9%
1933	181,564	51.9%	168,470	48.1%
1934	215,780	55.2%	175,076	44.8%
1935	161,722	55.3%	130,904	44.7%
1936	221,690	58.0%	160,631	42.0%
1937	241,916	57.7%	177,069	42.3%
1938	220,463	59.7%	149,067	40.3%
1939	257,014	58.7%	180,855	41.3%
1940	250,792	57.5%	185,481	42.5%
1941	212,421	59.7%	143,343	40.3%
1942	230,294	60.0%	153,263	40.0%
1943	280,757	58.1%	202,399	41.9%
1944	275,601	58.4%	196,212	41.6%
1945	310,434	58.0%	224,816	42.0%
1946	282,868	56.7%	216,092	43.3%
1947	264,126	56.6%	202,774	43.4%
1948	260,632	57.7%	191,118	42.3%
1949	270,740	56.5%	208,850	43.5%
1950	275,318	56.4%	212,705	43.6%
1951	144,378	50.2%	143,240	49.8%
1952	159,437	48.0%	172,409	52.0%
1953	153,729	49.5%	156,711	50.5%
1954	53,492	52.3%	48,778	47.7%
1955	40,578	50.4%	39,885	49.6%
1956	35,794	51.5%	33,664	48.5%
1957	83,937	49.4%	86,047	50.6%
1958	219,768	54.8%	180,999	45.2%
1959	208,296	51.2%	198,693	48.8%
1960	217,585	54.1%	184,815	45.9%
1961	167,441	51.4%	158,540	48.6%
1962	225,253	54.8%	186,167	45.2%
1963	167,068	53.4%	145,938	46.6%
1964	31,493	48.5%	33,475	51.5%
1965	126,893	54.1%	107,707	45.9%
1966	171,516	56.9%	129,952	43.1%
1967	119,803	53.2%	105,466	46.8%
1968	145,137	56.8%	110,584	43.2%

1969	202,407	55.6%	161,661	44.4%
1970	222,715	57.3%	165,834	42.7%
1971	146,098	54.3%	122,992	45.7%
1972	62,288	50.8%	60,364	49.2%
1973	199,720	59.0%	139,049	41.0%
1974	204,430	58.1%	147,474	41.9%
1975	201,428	58.3%	144,258	41.7%
1976	221,216	59.0%	153,854	41.0%
1977	107,746	55.8%	85,475	44.2%
1978	57,328	51.0%	55,021	49.0%
Average 1938-1978	182,645	55.8%	144,537	44.2%

Average 1951-1978	146,321	54.2%	123,538	45.8%

Figure A.4. Farm Delivery Data from Project WDR forms, adjusted for EPCWID lands in Mesilla Unit





2 1979 – 2005: District Allocation Data

This section provides Project allocation, diversion and delivery data for the period 1979 through 2005. Starting in 1979, Reclamation allocated water (on a volumetric basis, in terms of acre-feet (AF)) to the Districts for diversion at canal headings. The Districts were then responsible for delivering this water to their farmers.

2.1 1979 – 2005 District Allocation Data

There was some variation in the allocation process over this period of time. During the early 1980s the D2 method was under development, and different draft versions of this method were created. In approximately 1990, Reclamation adopted the Project Water Supply Allocation Procedures[3] document ("WSAP"), and followed the procedures documented therein. The Project had a full supply every year from 1979 through 2002, and therefore EBID, EPCWID and Mexico were each allocated a full supply (although in the early part of this period, there were changes in what constituted a full supply). In 2003 and 2004, the Project has a very limited supply. Rather than implement the D2 Curve procedures for determining allocation, Reclamation implemented an ad hoc procedure, allocating an amount equal to the Usable Supply in storage, and increasing the allocation only when inflows allowed.

Throughout this time period, the allocation process involved dividing the U.S. share of Project Supply 88/155 and 67/155 between EBID and EPCWID respectively (57:43). In 2003 and 2004, EPCWID's allocation included an addition of 12,127 AF and 13,025 AF (respectively) for the ACE Credit.

Note that from 1979 forward, Reclamation no longer determined the allotment of water to farms (that is, the amount each Project acre was entitled to order, in terms of acre-feet per acre (AF/A)). Instead, each District would issue an allotment to its own farmers. EBID's allotment process is based on the annual allocation from Reclamation, and a full-supply allotment is 3.0 AF/A.[4] ECPWID's allotment process may include both its allocation from Reclamation and assorted other sources of water considered to be "non-Project water."[5] A full supply allotment for EPCWID appears to be 4.0 AF/A[6] based upon language in the Implementing Third-Party Contract between EPWU, EPCWID and US, as well as my general understanding.

This allocation data is compiled in Table A.4 and is plotted in Figure A.5.

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[3] Water Supply Allocation Procedures, Bureau of Reclamation: U.S. Department of the Interior, Rio Grande Project, circa 1990.

[4] DeMouche, L., Interpreting the Elephant Butte Irrigation District for Water Users, New Mexico State University, Circular 590, Cooperative Extension Service, undated (circa 2004); King, J.P. and Maitland, J., Water for River Restoration: Potential for Collaboration between Agricultural and Environmental Water Users in the Rio Grande Project Area, World Wildlife Fund, Prepared for Chihuahuan Desert Program, June 2003.

[5] New Mexico historically and today disagrees with some of EPCWID's characterizations of "non-Project" water. See, e.g. EPCWID treatment of effluent, discussed in Appendix D, part 3.

[6] Contract 2001 0611, No. 01-WC-40-6760 2001 0611, Implementing 3rd-Party Contract among U.S., EPCWID, and for Conversion of Rio Grande Project Water to Municipal Use (especially EXH D).

Table A.4. Total Allocation to Districts and Mexico: D1/D2 Allocation (1979-2005)

Table A.4. Total Allocation of Project Water to Districts and Mexico 1979-2005 (D1/D2 Allocation)					
	57% Allocation to EBID	43% Allocation to EPCWID	ACE Credit to EPCWID	Total Allocation to EPCWID	Mexico
	Acre-feet	Acre-feet			Acre-feet
1979	414,448	315,548		315,548	60,000
1980	414,448	315,548		315,548	60,000
1981	393,300	296,700		296,700	60,000
1982	414,448	315,548		315,548	60,000
1983	414,448	315,548		315,548	60,000
1984	478,037	363,963		363,963	60,000
1985	478,037	363,963		363,963	60,000
1986	478,037	363,963		363,963	60,000
1987	478,037	363,963		363,963	60,000
1988	478,037	363,963		363,963	60,000
1989	471,735	359,165		359,165	60,000
1990	471,735	359,165		359,165	60,000
1991	494,979	376,862		376,862	60,000
1992	494,979	376,862		376,862	60,000
1993	494,979	376,862		376,862	60,000
1994	494,979	376,862		376,862	60,000
1995	494,979	376,862		376,862	60,000
1996	494,979	376,862		376,862	60,000
1997	494,979	376,862		376,862	60,000
1998	494,979	376,862		376,862	60,000
1999	494,979	376,862		376,862	60,000
2000	494,979	376,862		376,862	60,000
2001	494,979	376,862		376,862	60,000
2002	494,979	376,862		376,862	60,000
2003	165,144	125,735	12,127	137,862	26,616
2004	185,507	141,240	13,025	154,265	27,197
2005	494,979	376,862		376,862	60,000

Figure A.5. Total Allocation to Districts and Mexico: D1/D2 Allocation (1979-2005)

US_MSJ_00000726

2.2 1979-2005 District Charged Diversion (Post-1978 Accounting Data)

Starting in 1979, Reclamation implemented accounting procedures designed to allow diversion amounts to be assigned to each District, incorporating a complex scheme of charges and credits. This accounting method is described in the 1985 Draft Operating Agreement and this description appears to have formed the basis for the current accounting methods as documented in the Operations Manuals associated with the 2008 OA. In Table A.5 below, the total charged diversions for each District and Mexico (Mexico's diversion is still measured as the gaged discharge into Acequia Madre) are provided. Table A.6 provides the distribution of the charged diversions between the Districts. The data in Tables A.5 and A.6 is plotted in Figure A.6.

WDRs continued to be generated for the Project, but no longer by Unit or Valley. Instead, a WDR was generated for each District and one for the Project as a whole. The values in the District WDRs are not the same as the charged diversions generated using the new Project accounting reflecting a discrepancy between the D2 Curve and Post-1978 Accounting, which is discussed more fully in Appendix E.

Table A.5. Total Charged Diversions for Each District and Mexico (1979-2005)

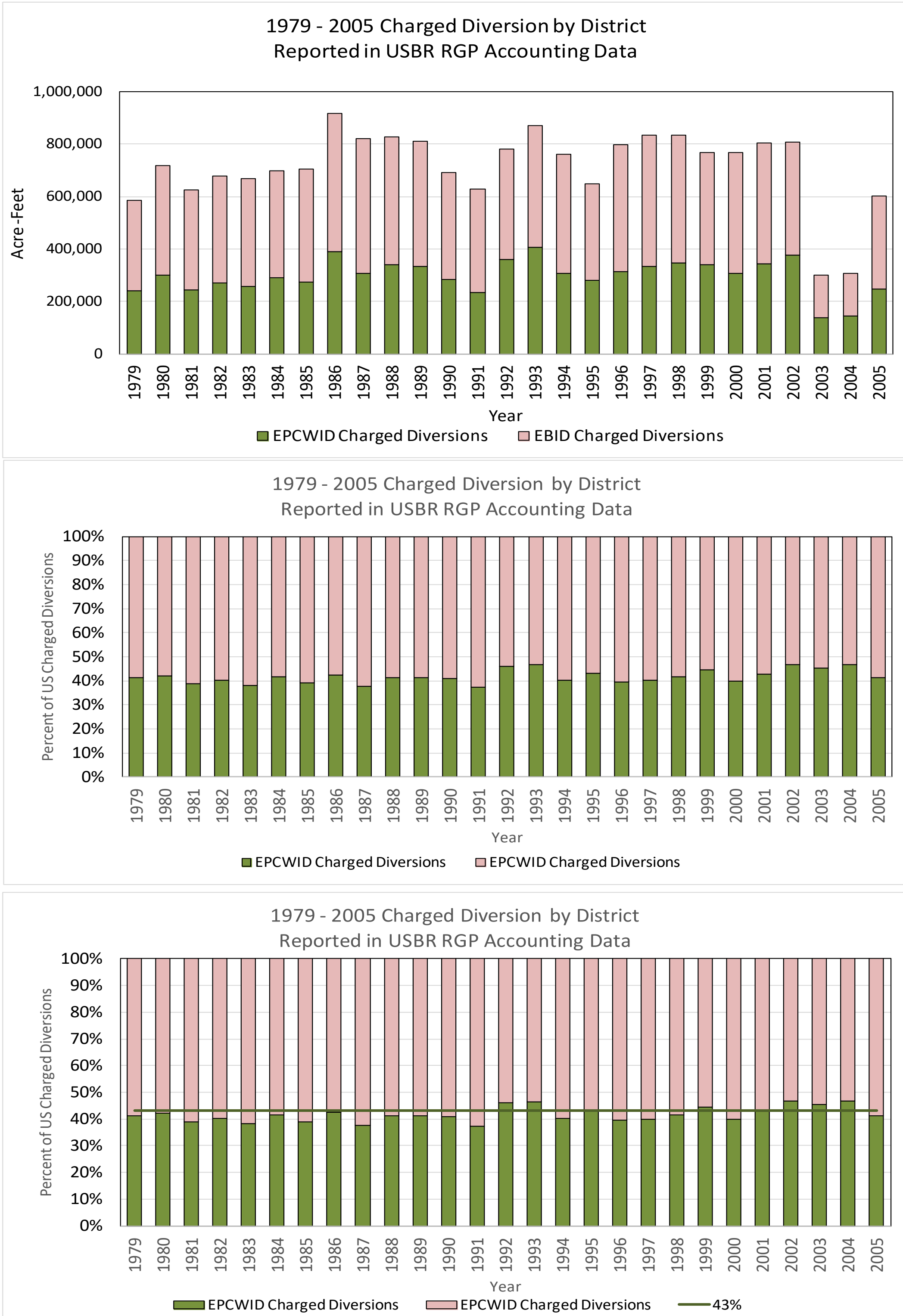
Project Release, Charged Diversion of Project Water by Districts, and Mexican Delivery 1979 - 2005				
	Release from Caballo	EBID Charged Diveersions	EPCWID Charged Diveersions	Mexican Delivery
	Acre-feet	Acre-feet	Acre-feet	Acre-feet
1979	568,689	343,811	240,471	60,055
1980	658,680	414,452	302,339	60,033
1981	608,002	381,211	242,754	60,262
1982	643,877	406,059	271,797	59,257
1983	648,335	414,069	256,034	60,621
1984	653,046	408,028	289,976	58,588
1985	677,648	430,098	275,540	60,276
1986	1,396,122	526,325	389,740	66,163
1987	1,376,204	513,174	308,850	65,866
1988	837,001	487,021	340,574	61,935
1989	736,005	477,083	333,183	58,854
1990	679,995	407,662	282,749	58,353
1991	626,007	395,933	234,303	59,242
1992	734,866	421,533	360,712	58,080
1993	823,085	465,666	405,681	63,763
1994	888,564	454,492	306,247	60,167
1995	1,095,934	367,520	279,723	63,618
1996	774,392	483,214	315,001	60,063
1997	798,814	500,483	334,751	50,442
1998	808,861	488,516	346,782	60,626
1999	735,415	426,132	340,727	58,306
2000	751,294	460,278	306,375	60,611
2001	786,889	460,182	343,365	61,037
2002	800,935	431,521	376,926	60,324
2003	364,528	164,740	137,250	26,948
2004	399,519	164,572	144,005	27,613
2005	676,031	353,261	247,607	58,091

Average 1979 - 2002	440,186	311,858	
Average 1979 - 2005	416,557	296,795	

Table A.6. Charged Diversions of Project Water to Districts (1979-2005)

Charged Diversions of Project Water, Diverted at Canal Headings, from Project Accounting Records				
	EBID Charged Diversions		EPCWID Charged Diversions	
	Acre-feet	% of US Charged Diversions	Acre-feet	% of US Charged Diversions
1979	343,811	59%	240,471	41%
1980	414,452	58%	302,339	42%
1981	381,211	61%	242,754	39%
1982	406,059	60%	271,797	40%
1983	414,069	62%	256,034	38%
1984	408,028	58%	289,976	42%
1985	430,098	61%	275,540	39%
1986	526,325	57%	389,740	43%
1987	513,174	62%	308,850	38%
1988	487,021	59%	340,574	41%
1989	477,083	59%	333,183	41%
1990	407,662	59%	282,749	41%
1991	395,933	63%	234,303	37%
1992	421,533	54%	360,712	46%
1993	465,666	53%	405,681	47%
1994	454,492	60%	306,247	40%
1995	367,520	57%	279,723	43%
1996	483,214	61%	315,001	39%
1997	500,483	60%	334,751	40%
1998	488,516	58%	346,782	42%
1999	426,132	56%	340,727	44%
2000	460,278	60%	306,375	40%
2001	460,182	57%	343,365	43%
2002	431,521	53%	376,926	47%
2003	164,740	55%	137,250	45%
2004	164,572	53%	144,005	47%
2005	353,261	59%	247,607	41%
Average	416,557	58%	296,795	42%

Figure A.6. Charged Diversions of Project Water to Districts (1979-2005)



2.3 1979 – 2005 EBID Allotment to Farmers

Starting in 1979, Reclamation allocated water to the Districts on a volumetric basis (acre-feet (AF)), and then the Districts allotted water to their farmers in terms of acre-feet per acre (AF/A). Table A.7 is a compilation of EBID allotment data from the period 1979 through 2005. I do not have a comparable set of allotment data for EPCWID.

Table A.7. Final EBID Allotment (1979 - 2005)

Table A.7 Final EBID Allotment (1979 – 2005)	
Year	Allotment (AF/A)
1979	3.00
1980	3.00
1981	3.00
1982	3.00
1983	3.00
1984	3.00
1985	3.00
1986	3.00
1987	3.00
1988	3.00
1989	3.00
1990	3.00
1991	3.00
1992	3.00
1993	3.00
1994	3.00
1995	3.00
1996	3.00
1997	3.00
1998	3.00
1999	3.00
2000	3.00
2001	3.00
2002	3.00
2003	0.67
2004	0.67
2005	3.00

2.4 1979-2005 District Farm Delivery Data

District farm delivery data, extracted from WDRs or from Project Crop and Water Data reports, is compiled in Table A.8, along with EPCWID's deliveries to EPWU for municipal purposes. This data is plotted in Figure A.7.

Table A.8. Reported Deliveries to Districts' Farm Headgates and EPWU (1979-2005)

Reported Deliveries to Farm Headgates, and to EPWU for Municipal Purposes 1979 - 2005			
Year	EBID	EPCWID	
	Farm Delivery	Farm Delivery	Delivery to EPWU
Year	Acre-feet	Acre-feet	Acre-feet
1979	169,378	126,825	13,518
1980	223,709	139,704	19,937
1981	208,862	138,574	20,018
1982	226,723	167,336	17,388
1983	227,976	136,781	20,993
1984	222,445	129,391	17,988
1985	255,215	134,335	19,651
1986	263,583	133,007	21,846
1987	263,906	133,471	17,682
1988	250,674	132,791	21,541
1989	244,326	134,528	22,918
1990	NA	123,626	26,714
1991	227,403	161,801	24,390
1992	NA	108,630	31,475
1993	241,891	140,713	45,663
1994	274,025	171,690	55,721
1995	254,849	169,591	56,603
1996	247,373	210,064	46,248
1997	260,531	140,505	53,820
1998	263,725	151,315	52,470
1999	221,255	233,024	54,611
2000	245,283	155,935	41,916
2001	243,890	187,351	47,677
2002	234,619	245,015	57,843
2003	55,719	NA	24,862
2004	55,644	NA	29,357
2005	180,359	NA	50,723

Figure A.7. Reported Deliveries to Districts' Farm Headgates and EPWU (1979-2005)

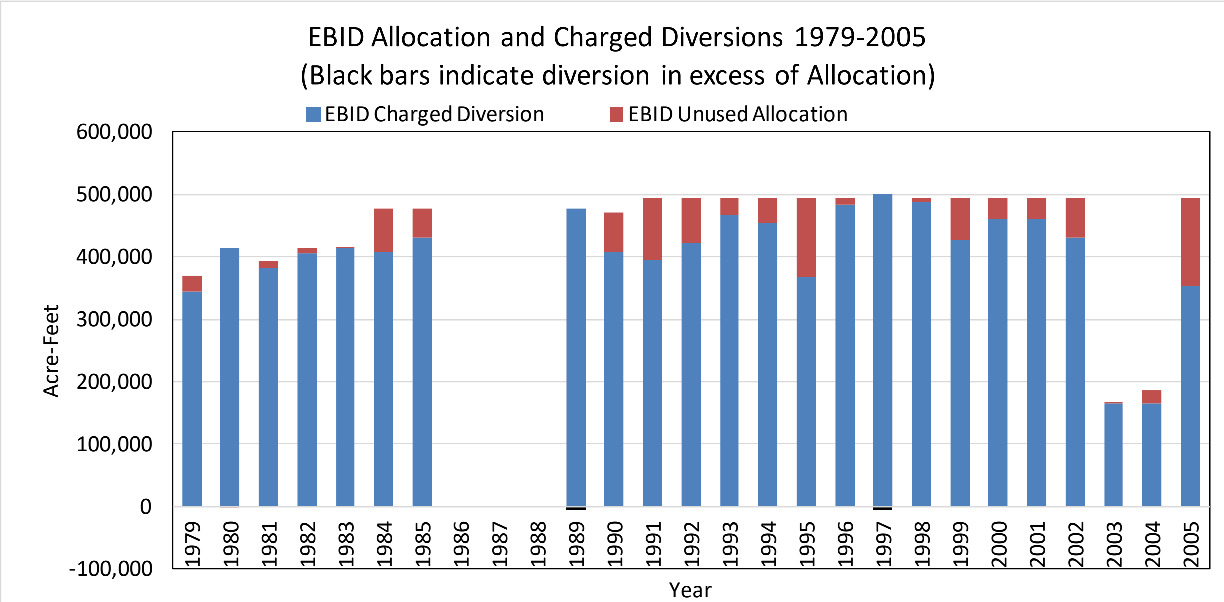
2.5 1979 – 2005 Comparison of Allocation and Charged Diversions

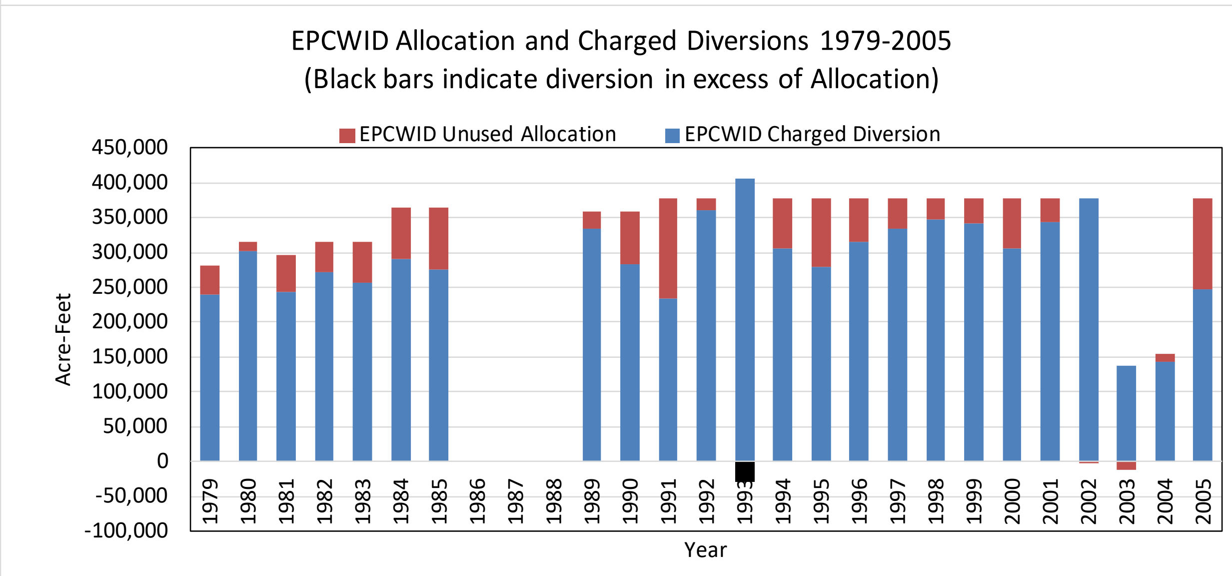
I have compared each District's charged diversions to its total allocation during the time period 1979 through 2005. This data is tabulated and Table A.9, and plotted in Figure A.8. High-flow spill years during the 1980s have been omitted; due to very high flow conditions obtaining at that time, uncharged non-Project diversions may have occurred.

Table A.9. Comparison of District Allocation and Charged Diversions, 1979-2005

Comparison of Allocation and Charged Diversions 1979 - 2005 (Omitting 1986, 1987 and 1988, due to high-flow conditions)						
	EBID Allocation	EBID Charged Diversion	EBID Unused Allocation	EPCWID Allocation	EPCWID Charged Diversion	EPCWID Unused Allocation
	Acre-feet	Acre-feet	Acre-feet	Acre-feet	Acre-feet	Acre-feet
1979	369,939	343,811	26,128	281,660	240,471	41,189
1980	414,448	414,452	(4)	315,548	302,339	13,209
1981	393,300	381,211	12,089	296,700	242,754	53,946
1982	414,448	406,059	8,389	315,548	271,797	43,751
1983	414,448	414,069	379	315,548	256,034	59,514
1984	478,037	408,028	70,009	363,963	289,976	73,987
1985	478,037	430,098	47,939	363,963	275,540	88,423
1986	478,037	526,325		363,963	389,740	
1987	478,037	513,174		363,963	308,850	
1988	478,037	487,021		363,963	340,574	
1989	471,735	477,083	(5,348)	359,165	333,183	25,982
1990	471,735	407,662	64,073	359,165	282,749	76,416
1991	494,979	395,933	99,046	376,862	234,303	142,559
1992	494,979	421,533	73,446	376,862	360,712	16,150
1993	494,979	465,666	29,313	376,862	405,681	(28,819)
1994	494,979	454,492	40,487	376,862	306,247	70,615
1995	494,979	367,520	127,459	376,862	279,723	97,139
1996	494,979	483,214	11,765	376,862	315,001	61,861
1997	494,979	500,483	(5,504)	376,862	334,751	42,111
1998	494,979	488,516	6,463	376,862	346,782	30,080
1999	494,979	426,132	68,847	376,862	340,727	36,135
2000	494,979	460,278	34,701	376,862	306,375	70,487
2001	494,979	460,182	34,797	376,862	343,365	33,497
2002	494,979	431,521	63,458	376,862	376,926	(64)
2003	165,144	164,740	404	125,735	137,250	(11,515)
2004	185,507	164,572	20,935	154,265	144,005	10,260
2005	494,979	353,261	141,718	376,862	247,607	129,255

Figure A.8. Comparison of District Allocation and Charged Diversions, 1979-2005





3 2006-2018: ALLOCATION AND ACCOUNTING DATA

This section provides tabulations and graphs summarizing annual Project allocation and charged diversions under D3 Allocation and the 2008 OA, for the time period 2006 through 2018.

3.1 2006-2018 ALLOCATION DATA

I have compiled allocation data from 2006 forward from a variety of Reclamation sources, including final Project allocation spreadsheets provided by Reclamation to the Compact Commission, Project allocation spreadsheets obtained from Allocation Committee members, Reclamation presentations obtained from the Project website, and Project accounting summary data provided to New Mexico by Reclamation staff.

Table A.10 is a summary of Current-Year Allocations, including ACE Credits, for EBID and EPCWID. This data does not include allocation carried over from the previous year by either District. Figure A.9 is graphical representation of this data.

Table A.10. Current-Year Allocation to Districts (2006-2018)

Current-Year Project Allocation to Districts 2006 -2018 (D3 Allocation)							
	EBID	EBID % of US Share	EPCWID	EPCWID ACE Credit	EPCWID (Including ACE Credit)	EPCWID % of US Share
Year	AF		AF	AF	AF	
2006	211,385	47%	227,146	14,511	241,657	53%
2007	310,894	46%	353,905	13,386	367,291	54%
2008	324,990	45%	388,192	16,881	405,073	55%
2009	268,077	40%	384,161	17,998	402,159	60%
2010	255,257	45%	291,905	17,610	309,515	55%
2011	57,090	57%	43,466	-	43,466	43%
2012	118,300	47%	132,935	-	132,935	53%
2013	54,438	57%	41,446	-	41,446	43%
2014	104,651	50%	99,105	7,485	106,590	50%
2015	161,940	45%	185,978	11,651	197,629	55%
2016	156,310	40%	235,908	-	235,908	60%
2017	267,523	40%	388,192	13,650	401,842	60%
2018	112,076	50%	112,418	-	112,418	50%
Average	184,889	44%			230,610	56%

Figure A.9. Current-Year Allocation to Districts (2006-2018)

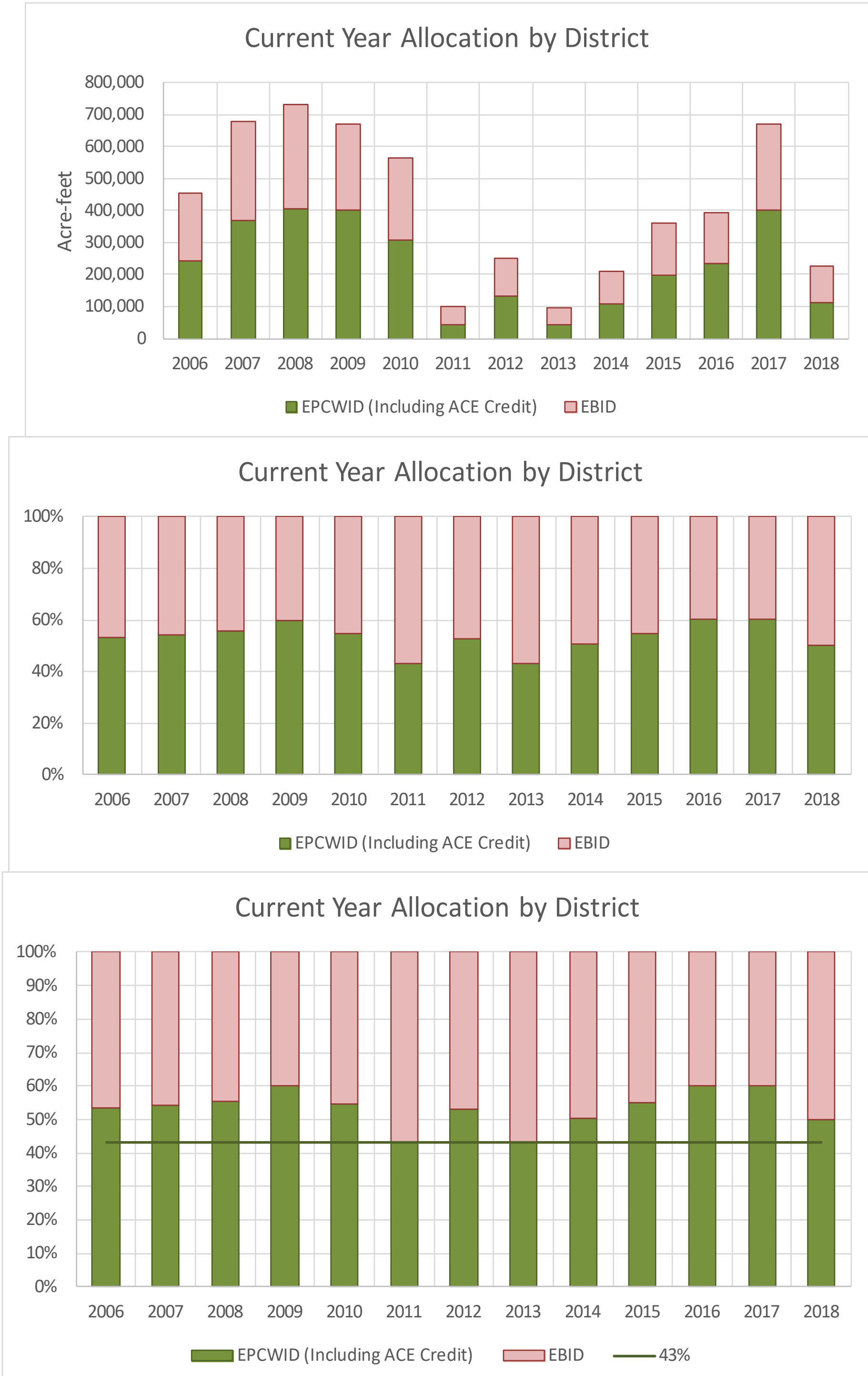
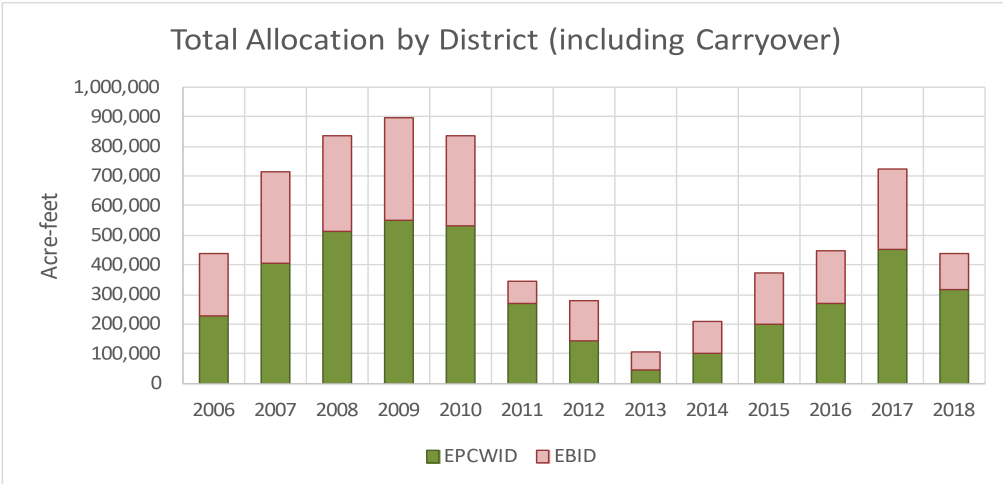


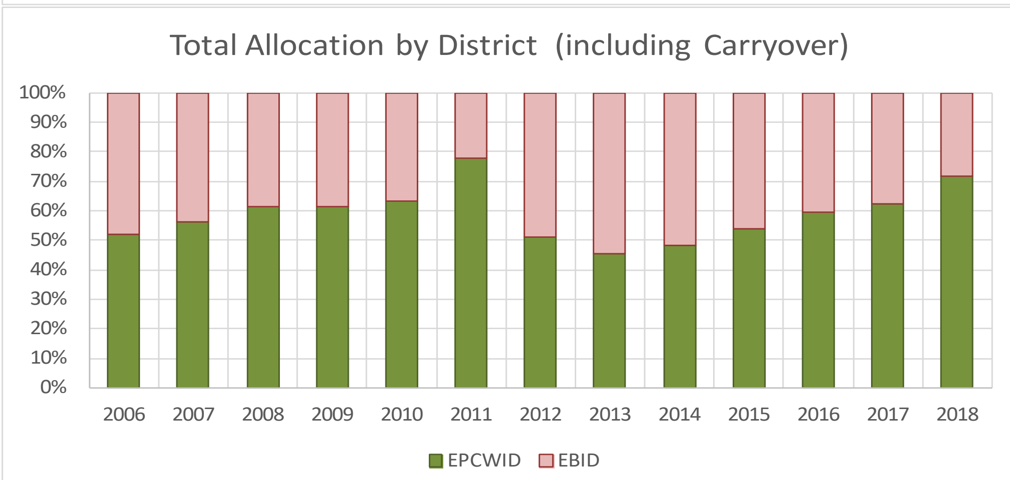
Table A.11 is a summary of Total Allocation data for EBID, EPCWID, and Mexico. Total Allocation data for the Districts include Carryover of unused allocation from the previous year. Figure A.10 is a graphical presentation of the data.

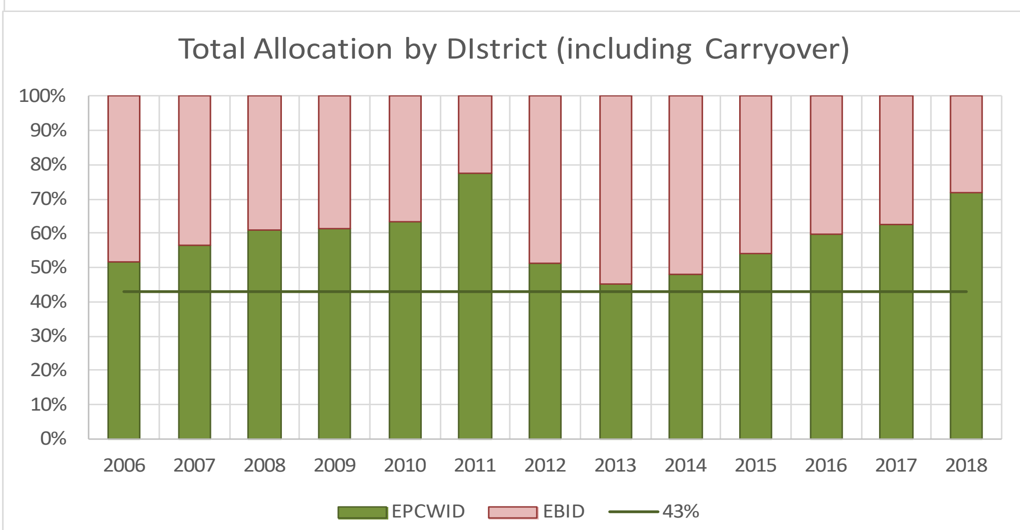
Table A.11. Total Project Allocation to Districts and Mexico (2006-2018)

Total Project Allocation to Districts and Mexico 2006 - 2018 (D3 Allocation)					
	EBID	EBID % of US Share	EPCWID	EPCWID % of US Share	Mexico
Year	AF		AF		AF
2006	211,385	47%	241,657	53%	33,895
2007	311,517	44%	403,491	56%	58,769
2008	324,990	39%	512,055	61%	60,000
2009	345,817	38%	552,997	62%	53,386
2010	305,870	36%	532,158	64%	50,235
2011	77,104	22%	267,813	78%	25,649
2012	135,633	49%	141,977	51%	23,196
2013	57,011	55%	47,043	45%	3,665
2014	107,659	52%	100,103	48%	18,216
2015	170,593	46%	200,314	54%	35,355
2016	180,912	40%	268,381	60%	46,497
2017	270,749	37%	452,021	63%	60,000
2018	123,315	28%	314,520	72%	37,670
Average	190,878	38%	308,126	62%	

Figure A.10. Total Project Allocation to Districts and Mexico (2006-2018)







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3.2 2006-2018 Charged Diversions to Districts

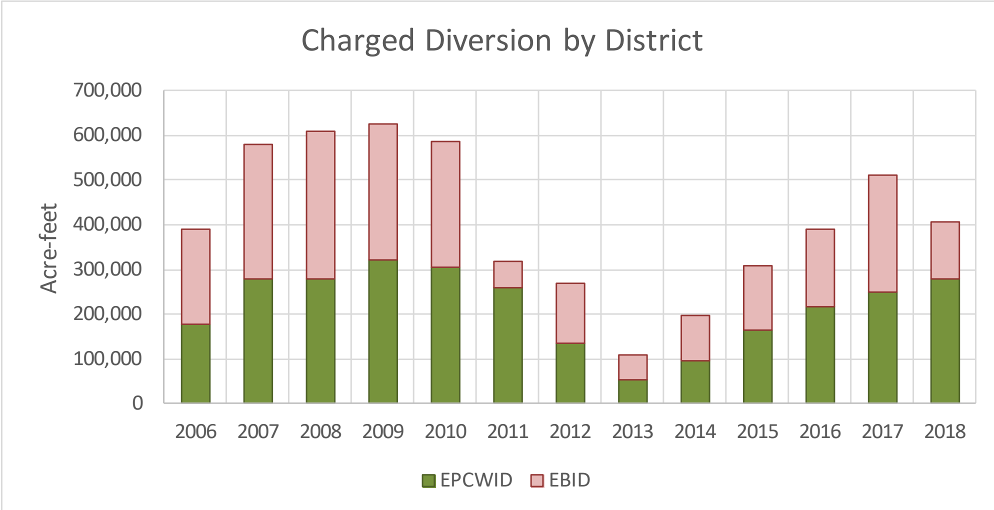
District Charged Diversions (also described as Allocation Charges or Allotment) are summarized in Table A.10 and presented in graphical form in Figure A.11, together with the gaged diversion by Mexico at Acequia Madre. I extracted annual charged diversion data for the Districts from final Reclamation accounting spreadsheets for each year from 2010 through 2018, and from accounting data summaries provided by Reclamation for earlier years.

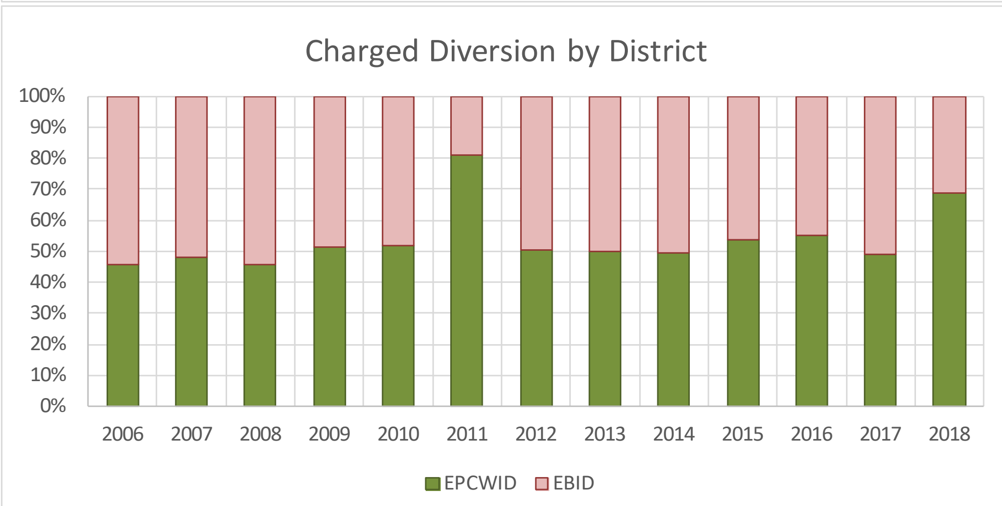
Table A.12. Charged Districts' Diversions and Delivery to Mexico (2006-2018)

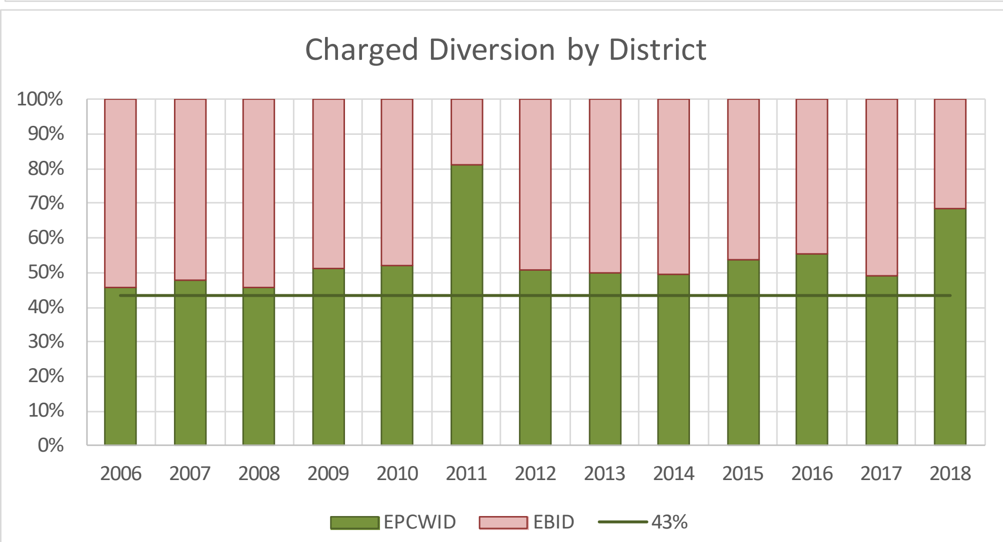
Table A.12. Charged Districts Diversions and Delivery to Mexico 2006 - 2018 (D3 Allocation)

	Release from Caballo	EBID	EBID % of US Share	EPCWID	EPCWID % of US Share	Mexico
Year	AF	AF		AF		AF
2006	434,228	211,841	54%	177,183	46%	27,112
2007	636,993	302,665	52%	278,252	48%	51,245
2008	674,724	329,294	54%	279,173	46%	56,048
2009	693,289	305,475	49%	320,083	51%	58,688
2010	659,679	282,082	48%	304,937	52%	56,883
2011	396,444	59,771	19%	258,772	81%	25,650
2012	371,271	133,060	49%	136,380	51%	23,187
2013	168,201	54,002	50%	53,530	50%	3,709
2014	306,900	99,007	50%	97,418	50%	18,261
2015	435,483	143,404	46%	165,872	54%	33,772
2016	544,181	175,199	45%	216,309	55%	43,787
2017	622,467	259,510	51%	249,919	49%	54,506
2018	491,305	127,487	31%	279,211	69%	37,735
Average		178,936	45%	214,691	55%	

Figure A.11. Charged Districts' Diversions and Deliveries to Mexico (2006-2018)







3.3 ALLOCATION, DIVERSIONS AND CARRYOVER (2006 – 2018)

Tables A.13 and A.14 below provide a summary of the allocation, Carryover, and charged diversion for EBID and EPCWID for the time period in which D3 Allocation has been implemented (2006 – 2018).

Table A.13. EBID Allocation and Charged Delivery Summary (2006-2018)

	EBID Allocation and Charged Delivery Summary 2006 - 2018							
	Current-Year Allocation	Carryover from Previous Year	Transfer from EPCWID	Total Allocation	Total Charged Diversions	Unused Allocation	Mexican Adjust-ment	Potential Carryover to Next Year
Year	AF	AF	AF	AF	AF	AF	AF	AF
2006	211,385	0	0	211,385	211,841	-456	0	-456
2007	310,894	623	0	311,517	302,665	8,852	0	8,852
2008	324,990	0	0	324,990	329,294	-4,304	0	-4,304
2009	268,077	-4,304	82,044	345,817	305,475	40,342	0	40,342
2010	255,257	40,342	10,271	305,870	282,082	23,788	-3,774	20,014
2011	57,090	20,014	0	77,104	59,771	17,333	-1	17,332
2012	118,300	17,333	0	135,633	133,060	2,573	0	2,573
2013	54,438	2,573	0	57,011	54,002	3,009	0	3,009
2014	104,651	3,009	0	107,659	99,007	8,652	0	8,652
2015	161,940	8,653	0	170,593	143,404	27,189	-2,586	24,603
2016	156,310	24,602	0	180,912	175,199	5,713	-2,487	3,226
2017	267,523	3,226	0	270,749	259,510	11,239	0	11,239
2018	112,076	11,239	0	123,315	127,487	-4,172	-1,865	-6,037

Table A.14. Allocation and Charged Delivery Summary (2006-2018)

	EPCWID Allocation and Charged Delivery Summary 2006 - 2018							
	Current-Year Allocation + ACE Credit	Carryover from Previous Year	Transfer to EBID	Total Allocation	Total Charged Diversions	Unused Allocation	Mexican Adjust-ment	Potential Carryover to Next Year
Year	AF	AF	AF	AF	AF	AF	AF	AF
2006	241,657	0		241,657	177,183	64,474	0	64,474
2007	367,291	36,200		403,491	278,252	125,239	0	125,239
2008	405,073	106,982		512,055	279,173	232,882	0	232,882
2009	402,159	232,882	-82,044	552,997	320,083	232,914	0	232,914
2010	309,515	232,914	-10,271	532,158	304,937	227,221	-2,874	224,347
2011	43,466	224,347		267,813	258,772	9,041	-1	9,040
2012	132,935	9,042		141,977	136,380	5,597	0	5,597
2013	41,446	5,597		47,043	53,530	-6,487	0	-6,487
2014	106,590	-6,487		100,103	97,418	2,685	0	2,685
2015	197,629	2,685		200,314	165,872	34,442	-1,969	32,473
2016	235,908	32,473		268,381	216,309	52,072	-1,893	50,179
2017	401,842	50,179		452,021	249,919	202,102	0	202,102
2018	112,418	202,102		314,520	279,211	35,309	-1,420	33,889

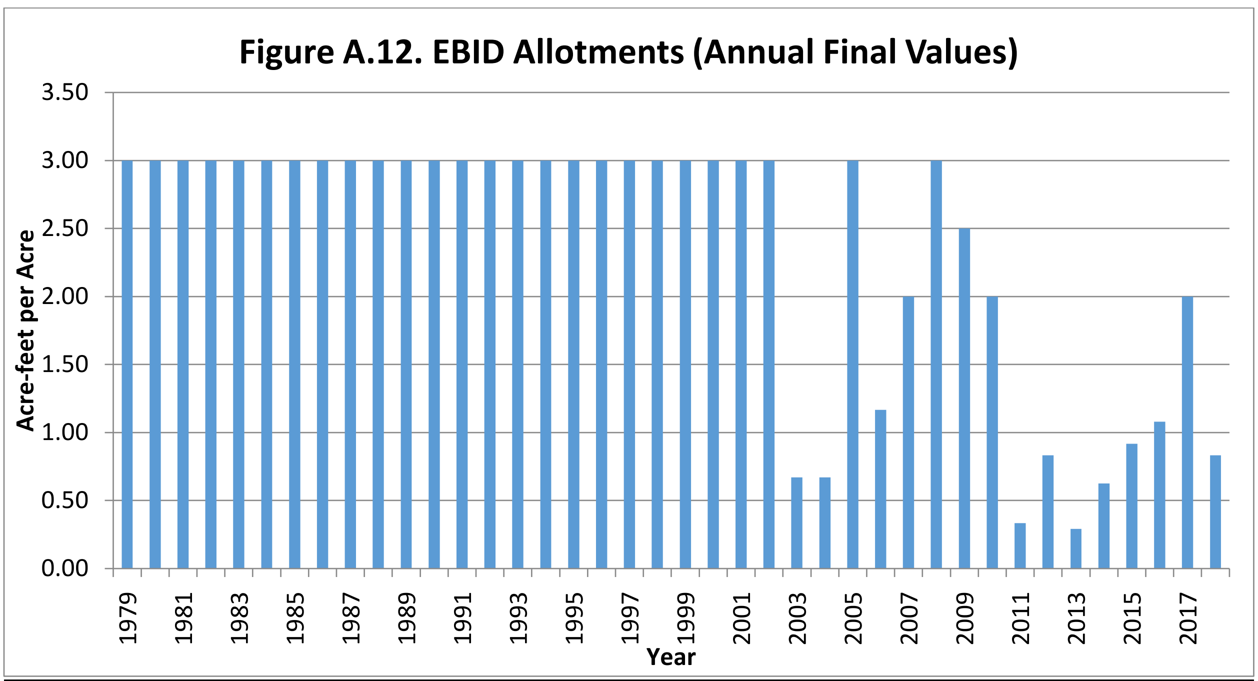
3.4 2006-2018 EBID ALLOTMENT

EBID Allotment data from 2006 through 2018 is provided in Table A.15. EBID allotment data from 1979 through 2018 is provided graphically in Figure A.12. I do not have any comparable data set for EPCWID.

Table A.15. EBID Final Allotment (2006-2018)

Table A.15. Final EBID Allotment (2006 - 2018)	
Year	Allotment (AF/A)
2006	1.17
2007	2.00
2008	3.00
2009	2.50
2010	2.00
2011	0.33
2012	0.83
2013	0.29
2014	0.63
2015	0.92
2016	1.08
2017	2.00
2018	0.83
2019	0.50

Figure A.12. EBID Final Allotment (1979-2018)



APPENDIX B

PROJECT OPERATIONS: RELATIONSHIP BETWEEN CABALLO RELEASES, ORDERS, AND INSTREAM WATER SUPPLY

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APPENDIX B - PROJECT OPERATIONS: RELATIONSHIP BETWEEN CABALLO RELEASES, ORDERS, AND INSTREAM WATER SUPPLY

This Appendix describes the current and historical procedures used to determine Caballo releases, and provides a description of a spreadsheet I developed to simulate this procedure. I demonstrate that in full-supply years the amount of water delivered to Texas is controlled by EPCWID orders for water and not by the variation in drain flows or losses in the Rincon or Mesilla Valleys upstream in New Mexico.

The procedures reviewed and relied upon are:

1) Project Order and Release procedures from the 1943 Rio Grande Project History,

2) Project Water Order description and forms from the 1985 Draft Operating Agreement, and

3) forms and description in the 2012 Operations Manual associated with the 2008 OA.

1 PROJECT ORDER AND CABALLO RELEASE PROCEDURE DESCRIBED IN THE 1943 PROJECT HISTORY

The 1943 Project History has a long section titled "Rio Grande Project – Daily Reports of Operation Divisions."[1] This Project History section provides detailed descriptions of how Reclamation ditchriders and water masters compiled and tabulated Farm Orders and translated those Farm Orders into the amount of diversion required at each main canal heading (the main canal headings discussed in this appendix are Arrey, Leasburg, Eastside, Westside, Franklin, and Riverside).

Once the necessary diversion amounts at main canal headings were determined, they were sent to the Project office where the calculation of the required Caballo release was performed by Reclamation staff. This calculation was based on the required main canal heading diversions, with adjustments made to:

- increase the release by the amount of estimated transmission loss, and
- decrease the release for the amounts of drain and waste inflows above the main canal diversion headings (i.e. an adjustment for instream flow between Caballo and the main canal headings).

These adjustments were based on observations along the Rio Grande between Caballo and Riverside Dam. Figure B1 shows a sample calculation from the 1943 Project History.

[1] RGPH 1943, pp. 53-65.

Figure B.1. Sample Calculation of Necessary Caballo Release from 1943 Project History

Desired at El Paso (El Paso Valley order and Mexican Canal)	1,111	second	feet
Estimated waste return to river from Mesilla Division	-60	"	"
Drainage flow to river from Mesilla Division	-425	"	"
Subtotal	626	"	"
Add estimate of transmission losses between Mesilla Dam and El Paso (This will vary during year from 20 CFS minimum to 85 CFS maximum)	+85	"	"
Necessary flow below Mesilla Dam	711	"	"
Add East Side and West Side Order	+800	"	"
Subtract drain flow Leasburg Division	-19	"	"
Add estimate of losses Leasburg to Mesilla (This will vary from 20 CFS minimum to 60 CFS maximum)	+ 40	"	"
Subtotal	1,532	"	"
Necessary flow below Leasburg Dam			
Add Leasburg Canal Order	+565	"	"
Subtract drainage flow to river from Rincon Valley	-80	"	"
Subtract estimated waste from Rincon Valley	35	"	"
Add estimate of river losses Caballo Dam to Leasburg Dam (This will vary from 40 to 70 CFS)	40	"	"
Add order for Arrey Canal	250		
Total necessary release from Caballo Dam	2,272	Second	Feet

2 Caballo Release Procedure Described in 1985 Draft Operating Agreement

Figure B.2 is a copy of the Project Water Order Form from the 1985 Draft Operating Agreement. The form has a section for the orders from the "Upper Valley" (above Courchesne), and a section for the "Lower El Paso Valley." As sometimes used historically, and throughout this Appendix, the Upper Valley is the part of the Project that is upstream of Courchesne, which includes the Rincon and Mesilla Valleys. The Lower Valley consists of the part of the Project that is below Rio Courchesne in the El Paso Valley.

On the order form, below the Lower El Paso Valley section, there is a section titled "Total Project Order" in which all orders are summed along with the water needed for Mexico. This form calculates the Release from Caballo based on the Total Water Ordered, minus (or "Less") the amount of "Drain Water to River," plus "River Loss." Thus, the Caballo Release was calculated based on orders, then adjusted upward if necessary to account for river losses, and downward to account for usable flows already in the Rio Grande.

Figure B.2. Project Water Order Form from 1985 Draft Operating Agreement

PROJECT WATER ORDER

Order for period from ________ to ________ Date: ________

Upper Valley Water Order EBID and EPCWID No. 1	Lower El Paso Valley EPCWID No. 1 Water Order
Arrey Canal ________ cfs	Franklin Canal ________ cfs
Leasburg Canal ________ cfs	City of El Paso ________ cfs
California Lateral ________ cfs	Riverside Canal ________ cfs
Del Rio Lateral ________ cfs	Total Lower Valley ________ cfs
East Side Canal ________ cfs	**Total Project Water Order**
Three Saints East Lateral ________ cfs	Upper Valley ________ cfs
West Side Canal ________ cfs	Lower Valley ________ cfs
La Union West	Mexico ________ cfs
New Mexico ________ cfs	Total Water Ordered ________ cfs
Texas ________ cfs	Less Drain Water to River ________ cfs
Total ________ cfs	Plus River Loss ________ cfs
La Union East	Release from Caballo ________ cfs
New Mexico ________ cfs	Flow Meter Setting ________ cfs
Texas ________ cfs	Time ________ Date ________
Total ________ cfs	Ordered by ________
Total Upper Valley ________ cfs	
	Caballo Readings
	Date ________ Time ________
	Hydrographer ________ (Initials)
	Discharge ________ cfs
	Gage Height ________
	Flow Meter CFS ________
	East Gate ________
	West Gate ________
	Elevation ________

3 CABALLO RELEASE PROCEDURE DESCRIBED IN 2008 OPERATING AGREEMENT

Figure B.3 is an image of an Excel spreadsheet I have created based on the Rio Grande Project Internet-Based Order Sheet provided in the 2012 Operations Manual of the 2008 OA (using data from the "Current" columns).[2] On the left hand side of Figure B3, the column labeled "Orders" shows the amounts (in cfs) ordered at each main canal heading from the Reclamation Order Form under "Current" (for the purpose of this Appendix, the sub-orders within the Eastside and Westside main canal headings from El Paso Water Utility have been omitted for simplicity; this does not impact the analysis). In accordance with Reclamation's Order Form, these orders are organized by Upper Valley and Lower Valley.

In the column labeled "Gains/Losses" are the Rio Grande gains or losses copied from the Reclamation Order Sheet. As indicated in the 2012 Operations Manual, and from numerous discussions with Reclamation and EBID personnel, the gains refer to any net gain to the specified reach of the Rio Grande from groundwater, from drain flows and from any other source of water that can be used by Project beneficiaries. Similarly, losses refer any net loss to seepage or evaporation occurring in a specified reach. The reaches for which gains/losses are tabulated in the Order form are:

1) The reach from Caballo Dam to Leasburg Dam ("above Leasburg"),
2) The reach from Leasburg Dam to Mesilla Dam ("Leasburg/Mesilla"), and
3) The reach from Mesilla Dam to American Dam ("Mesilla/American").

On the right hand side of Figure B.3, in the column labeled "Estimated Flow in the Rio Grande," the values from the Reclamation Order Sheet are entered. The difference between the "Estimated Flow" in the Rio Grande at each location is equal to the net effect of gains, losses and diversion of orders in the intervening reach.

[2] 2012 Operations Manual, p. 6

Figure B.3. Excel Version of Rio Grande Project Internet Order Sheet

	Rio Grande Project Order Sheet Calculations, from Figure 1 of The 2012 Operations Manual from the 2008 OA				
	Orders and Gains/Losses to Rio Grande			Estimated Flow in Rio Grande	
		Orders	Gains/Losses	Location	
		cfs	cfs	cfs	
				1683	Caballo Release
	Arrey Canal	140			
				1543	Below Percha Dam
	above Leasburg		50		
Upper Valley	Leasburg Canal	170			
				1423	Below Leasburg Dam
	Leasburg/Mesilla		0		
	Eastside Canal	110			
	Westside Canal	380			
				933	Below Mesilla Dam
	(-) Bypass WW32	-30			
	Mesilla/American		0		
				963	At American Dam
	Franklin	160			
Lower Valley	Riverside	485			
	EPWU	141			
	Mexico	177			
	Total Lower Valley Orders	963			
	plus Mexico				

Development of a spreadsheet to simulate the Caballo Release Procedure

I then created a functional Excel spreadsheet which simulates the procedures discussed above, where the Caballo release is calculated from the data (Orders and Gains), ensuring that the flow at American Dam equals the Lower Valley Orders plus the Mexican Delivery. Functions were added to the Excel spreadsheet as follows:

1) Estimated Flow at American Dam was set equal to the total Lower Valley Orders plus Mexico.
2) Estimated Flow Below Mesilla Dam was set equal to the Estimated Flow at American Dam, minus the amount of Bypass from WW32 (this is provided as a negative number, so Excel adds it to the Estimated Flow at American Dam).
3) Estimated Flow below Leasburg Dam was set equal to the Estimated Flow below Mesilla Dam plus (assumed diversion of) the Eastside and Westside Canal orders, minus any gains (or plus any losses) in the Leasburg/Mesilla reach.

4) Estimated Flow Below Percha Dam are set equal to the Estimated Flow below Leasburg Dam plus (assumed diversion of) the order at Leasburg Canal, minus any gains (or plus any losses) in the reach above Leasburg.
5) Caballo Release set equal to the Estimated Flow below Percha Dam, plus (assumed diversion of) the order at Arrey Canal.

When these functions are activated in Excel to calculate the values in the right-hand column, these resulting values of Estimated Flow in the Rio Grande were identical to those in the Figure B.2, replicating the results in the sample Order Sheet provided in the 2012 Operations Manual. This means that the Order Sheet is designed to calculate the Release from Caballo so that resulting Flow at American Dam equals the sum of the Lower Valley Orders plus the water required for the Mexican Delivery. American Dam is 1.5 miles downstream from the gage at Rio Grande at El Paso, also known as the Courchesne gage, with no Project diversion or return structures in between, so the estimated Flow at American Dam is roughly equivalent to the flow at Rio Grande at Courchesne gage.

The result is a simplified but functional spreadsheet of a Project Order Sheet, which has been tested against the Order Sheet provided in the 2012 Operations Manual as set forth above.

With this simplified spreadsheet Order Sheet, I performed a test to change the Gain/Loss to the Rio Grande between Leasburg Dam and Mesilla Dam and between Mesilla Dam and American Dam in order to test the effect of a range of gains or losses to the river. I added a gain of 30 cfs to the Rio Grande in each of these subreaches; this change represents an increase in drain flow (or other net increase in instream flows) in the Mesilla Valley. The result of this change is shown in Figure B4. The increase in total gains by 60 cfs resulted in a decrease in Caballo release of 60 cfs.

Note that in this test case, the flow “At American Dam” does not change and equals the amount of water required for Lower Valley Orders and the required Mexican Delivery. That is, the flow to EPCWID at El Paso does not change; only the Release from Caballo changes.

These results numerically demonstrate that, based on long standing Caballo Release Procedures, increasing the amount of drain flow in the Rio Grande system above Rio Grande at El Paso would not necessarily increase the flow at Rio Grande at El Paso. Instead, during the irrigation season the flow at Rio Grande at El Paso is controlled by the amount of water ordered by EPCWID and required for Mexico.

It is possible for years in which the Project does not have a full supply, increased instream flow (drain flow, etc.) between Caballo and Courchesne could result in additional water available for allocation, and thus higher allocations, and perhaps higher orders. Therefore, in years in which the Project does not have a full supply available, an increase in instream flow could result in increased flows at El Paso. However, in full-supply years, EPCWID would have been allocated a full supply, and would have ordered the water needed to supply the orders of its water users, unconstrained by supply limitations. Under such conditions, increased instream flow between Caballo and Courchesne would result in reduced releases from Caballo necessary to meet those orders. During full-supply years, I conclude that increases in instream flow (drain flow, etc.) between Caballo and El Paso would not lead to a direct increase in the flow at El Paso during the irrigation season. Instead, increases in instream flow in such years would lead to reduced releases from Caballo, which could translate to increased water availability in future low-supply years, unless that water was spilled from the reservoir before such time occurred.

Figure B.4. Functional Excel Version of Project Internet Order Form

	Rio Grande Project Order Sheet Calculations, Modified from Figure 1of the 2012 Operations Manual from the 2008 OA (Functional Version)				
	Orders and Gains/Losses to Rio Grande			Estimated Flow in Rio Grande	
		Orders	Gains/Losses		
		cfs	cfs	cfs	Location
	Caballo Release			1623	Caballo Release
Upper Valley	**Arrey Canal**	**140**			
Upper Valley				1483	Below Percha Dam
Upper Valley	above Leasburg		50		
Upper Valley	**Leasburg Canal**	**170**			
Upper Valley				1363	Below Leasburg Dam
Upper Valley	Leasburg/Mesilla		30		
Upper Valley	**Eastside Canal**	**110**			
Upper Valley	**Westside Canal**	**380**			
				903	Below Mesilla Dam
	(-) Bypass WW32	-30			
	Mesilla/American		30		
				963	At American Dam
Lower Valley	**Franklin**	**160**			
Lower Valley	**Riverside**	**485**			
Lower Valley	**EPWU**	**141**			
	Mexico	**177**			
	Total Lower Valley Orders plus Mexico	**963**			

APPENDIX C

CHANGES IN PROJECT DIVERSION AND CONVEYANCE IN THE EL PASO VALLEY AND ASSOCIATED PROJECT IMPACTS

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Appendix C

Changes in Project Diversion and Conveyance in the El Paso Valley and Associated Project Impacts

This Appendix will demonstrate that return flow from El Paso Valley drains was historically an important part of Project Supply. Significant changes in the El Paso Valley, including dramatic infrastructure changes as well as changes in groundwater conditions due to groundwater pumping in the Hueco Bolson by Texas and Mexico, and the effects of drought, have substantially reduced this source of Project Supply. Notably, Post-1978 Accounting[1] does not have a term to account for diversion of El Paso Valley drain flows; therefore, this historical source of Project Supply is not counted even if EPCWID continues to divert these waters.

In this Appendix I will first describe the infrastructure changes, then I will quantify the decrease in El Paso Valley drain flows as a source of Project Supply.

1 Description of the El Paso Valley Diversion and Conveyance Systems and Changes Thereto

Water discharged from a system of drains in the El Paso Valley has historically provided irrigation water to Project lands and to Hudspeth County ("HCCRD"), which is not a Project beneficiary. Drains collect seepage and excess water from the river, from conveyance structures, and from irrigated lands, and returns or discharges that water to the Project system for further delivery and use. Diversion structures in the El Paso Valley have changed considerably through the history of Project and add complexity to any understanding of how the drainage system initially worked and was relied upon as an important source of Project Supply, and the current situation where drainage serves as a negligible source of Project Supply or aquifer recharge.

The El Paso Valley drains can be divided into two groups: those discharging into the Rio Grande (or Project conveyances) above the town of Fabens, Texas (Drains Above Fabens), which is about two-thirds of the way down the El Paso Valley, and those discharging into the Rio Grande (or Project or HCCRD conveyances) below the town of Fabens (Drains Below Fabens).[2] This method of description will be used in this Appendix.

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[1] In approximately 1979 Reclamation implemented a new Project accounting system which determines the charged diversions (AKA allocation charges) for each District ("Post-1978 Accounting"); *see* Appendix D for a detailed discussion.

2 Starting in the early 1920s through 1983, Reclamation records subdivide the El Paso Valley drains in to "Above Fabens" and "Below Fabens," and identify cases in which the gaged flow of a tributary gage are included in the flow gaged in the combined drain downstream.

1.1 EARLY DIVERSION AND CONVEYANCE IN THE EL PASO VALLEY

Before the Rectification of the Rio Grande in 1938:

- Water was diverted from the Rio Grande at International (or Mexican) Dam into both Acequia Madre (for Mexico) and Franklin Canal (to supply U.S. Project lands (that is, the Districts)).
- Water was also diverted from the Rio Grande at Riverside Dam, to supply lands within EPCWID.
- Water supplying Project lands was also diverted from the Rio Grande at the Tornillo Canal heading, at the town of Fabens.
- Two other small U.S. diversions downstream of the International Dam are mentioned in Rio Grande Project Histories: Hansen and Guadalupe (little information is available about these diversions and I believe them to be of negligible import).

The Drains Above Fabens include the River Drain, its main tributary the Middle Drain, and the Mesa, Cuadrilla, and Fabens Intercepting Drains. Before 1938, these drains discharged into the Rio Grande, and water from these drains would then be diverted at the Tornillo Canal heading. This configuration is illustrated in Plate 21 of the Joint Investigation; an excerpt from this plate is included as Figure C.1.[3] The important conveyances in this area are more clearly illustrated in a Reclamation map from the papers of Raymond Hill[4] apparently created at the time of the Joint Investigation, included herein as Figure C.2.

Tornillo Canal at Fabens was completed in 1925. It was described In the Project Histories as "*the means to collect a large amount of recovered and developed water of the Project*"[5] and as the site of "*collection and diversion of irrigation water and return flow.*"[6] That is, return flow was plentiful enough at this location that it required a means to move it back into directed Project use.

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[3] Joint Investigation, Plate 21.

[4] El Paso Valley Main Canals and Drainage System maps from the papers of Raymond Hill, circa 1936.

[5] RJPH 1923, p. 12/416.

[6] RGPH 1926, p. 18/172.

Figure C.1. Excerpt from Joint Investigation illustrating the configuration of Project conveyances near Fabens, Texas

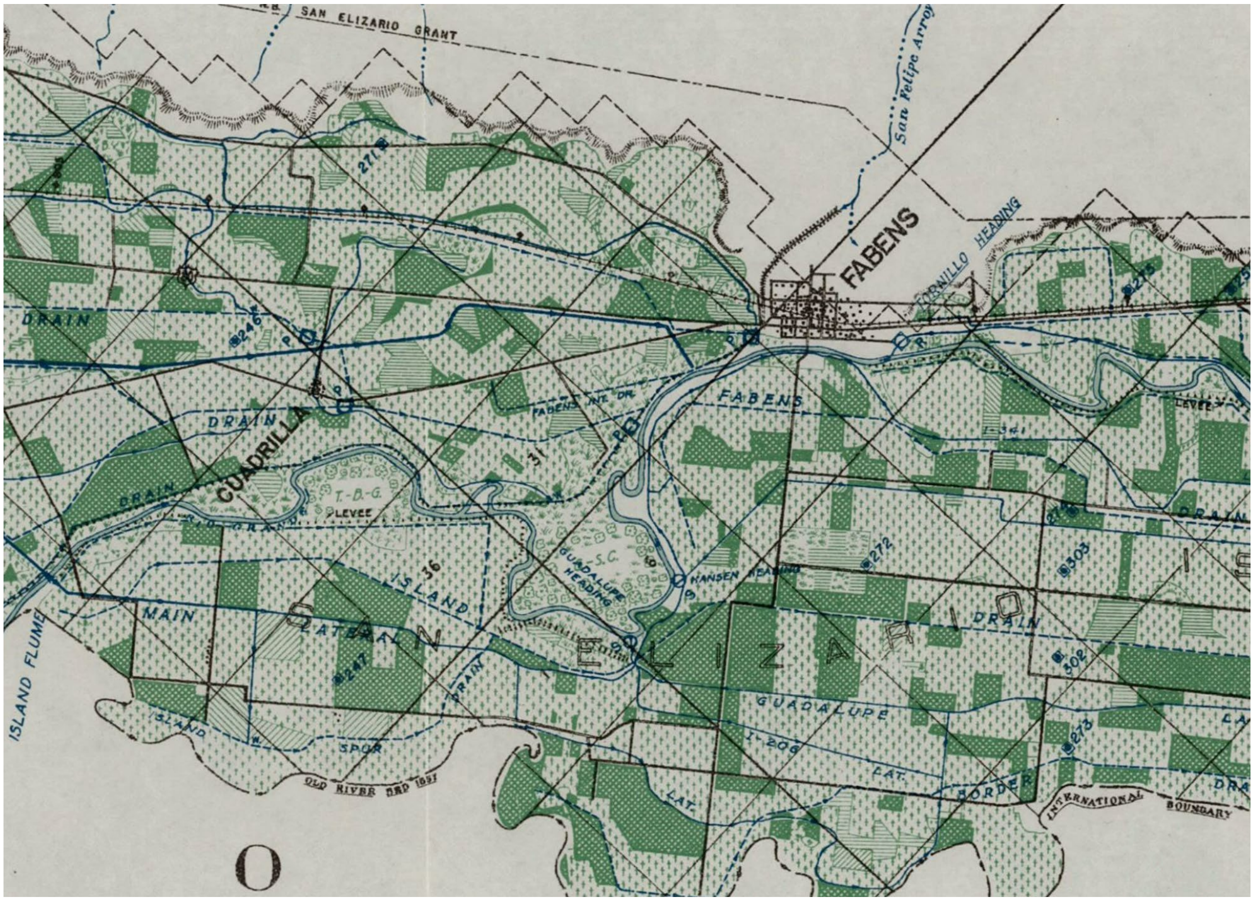
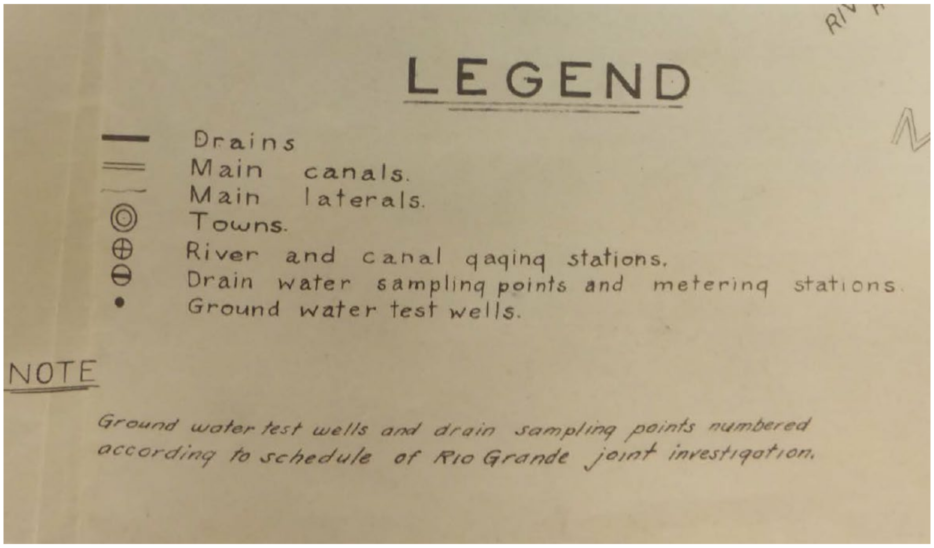
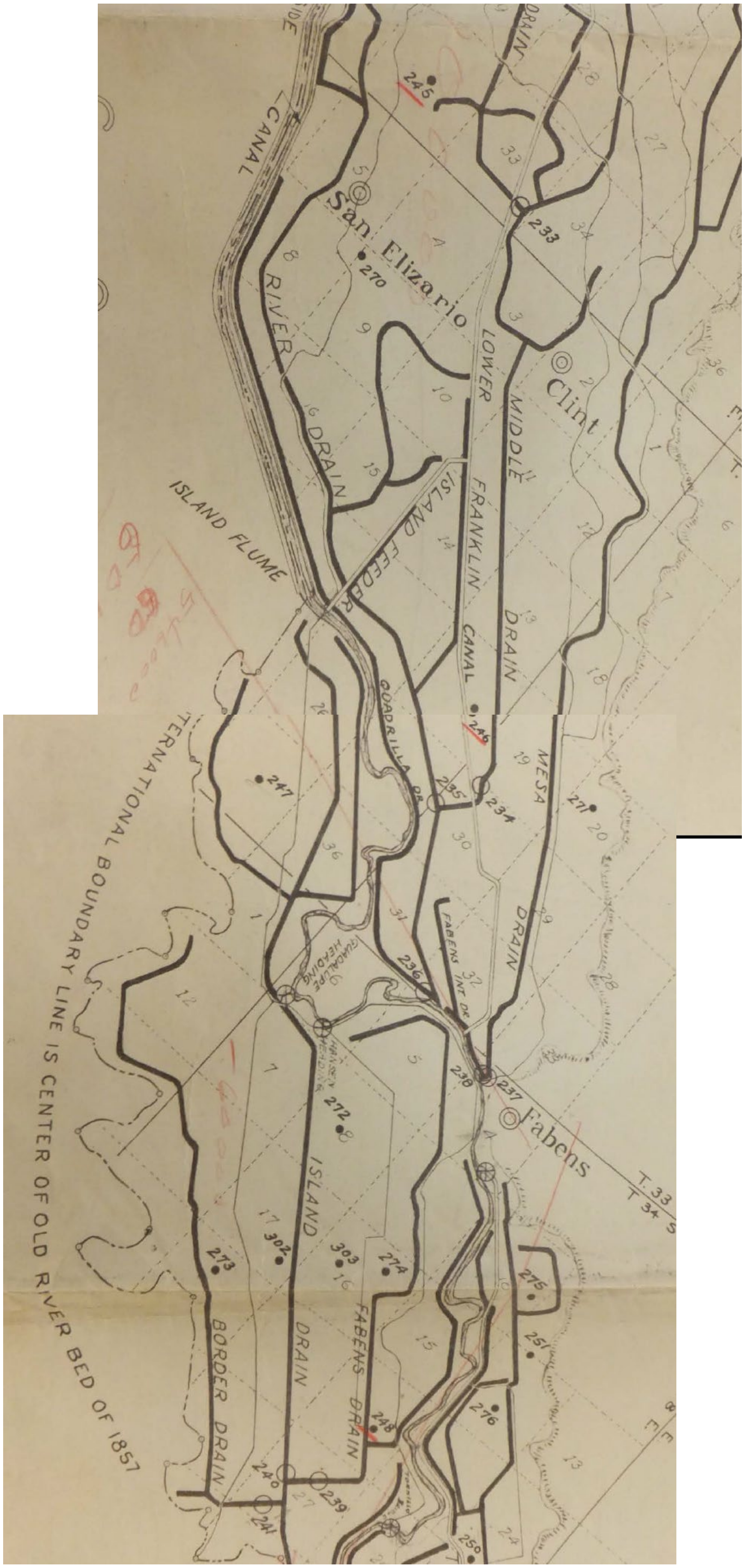


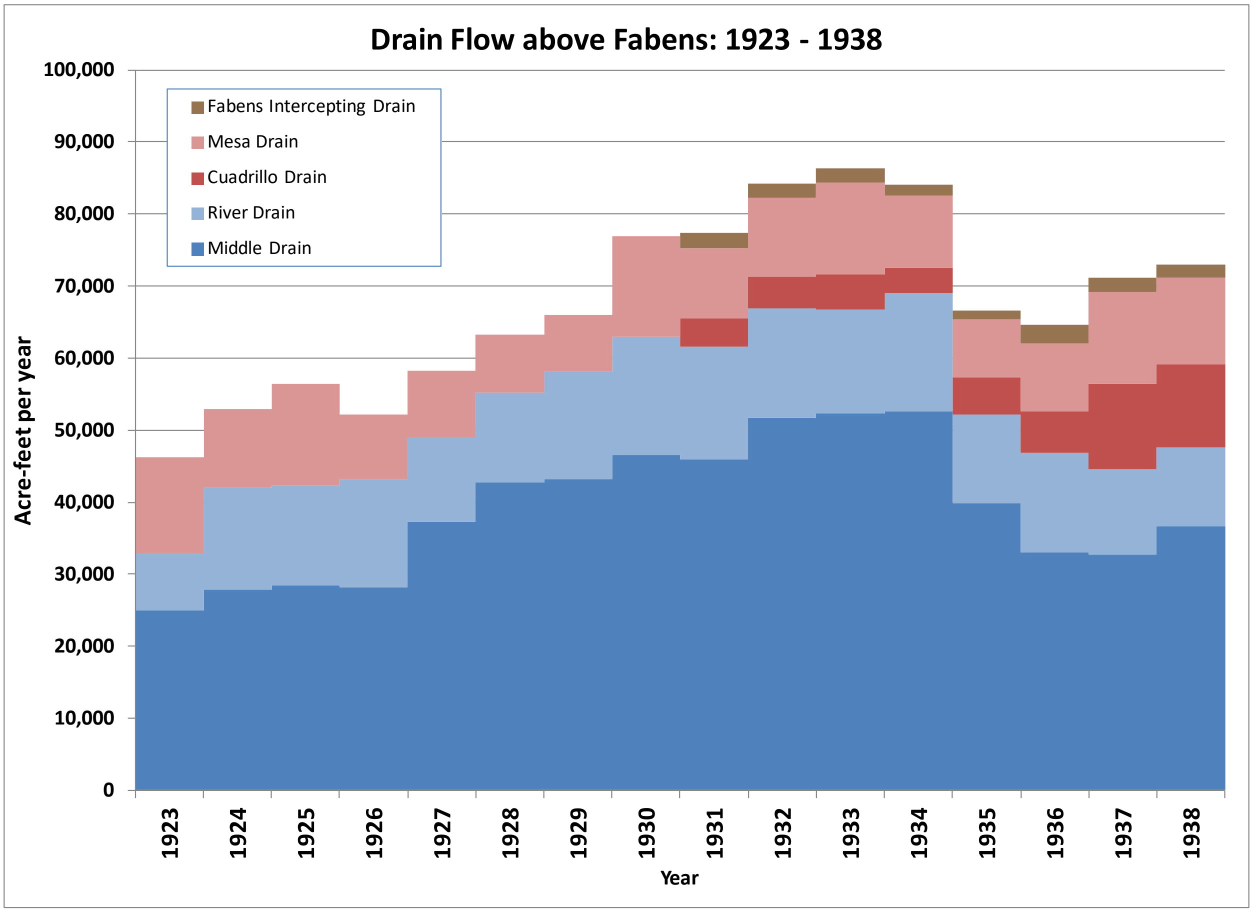
Figure C.2. Excerpts from a Reclamation map contemporaneous with the Joint Investigation illustrating the Project conveyance system near Fabens, TX




CANAL
San Elizario
RIVER
DRAIN
ISLAND FLUME
ISLAND FEEDER
LOWER
FRANKLIN
CANAL
MIDDLE
DRAIN
Clint
MESA
DRAIN
GUADRILLA DR.
FABENS INT. DR.
GUADALUPE HEADING
Fabens
T. 33
T. 34 S
INTERNATIONAL BOUNDARY LINE IS CENTER OF OLD RIVER BED OF 1857
BORDER DRAIN
ISLAND
DRAIN
FABENS DRAIN

In Figure C.3, I plotted the discharge data from the Drains Above Fabens from the time period before the Rio Grande Rectification.[7] These data show that during the 1930s between 60,000 AF/Y and 80,000 AF/Y of drain flow was available for diversion at the Tornillo heading for further delivery to EPCWID lands.

<u>Figure C.3. Gaged Discharge of El Paso Valley Drains Above Fabens</u>



[7] Reclamation Drainage Data Reports, 1923-1938.

1.2 Significant Changes to the Infrastructure of the El Paso Valley

In 1938 two major changes structural changes occurred in the El Paso Valley: completion of the American Dam, and the realignment of the Rio Grande near Fabens. Another impactful infrastructure change was the construction of the American Canal Extension ("ACE") in 1998.

1.2.1 Construction of the American Dam and American Canal

The American Dam and American Canal were completed in 1938, allowing the US to divert water for the Project above International Dam.[8] Starting in 1938, American Canal delivered water to EPCWID's Franklin Canal heading, which previously had been supplied by the International Dam. In addition, much of the water diverted at American Dam was wasted back to the Rio Grande at locations below International Dam, for delivery to Riverside Dam further downstream. This reconfiguration is illustrated in the schematic in Figure C.4.

The 1938 Project History describes the operations in this area as follows:

> *The manner of operation of the American Dam and Canal is that the water allotted to Mexico is passed through the dam into the old river channel, while the remaining total flow of the river is carried through the American Canal to the Franklin Canal settling basin. The net diversion for the Franklin is made several miles below the settling basin after sluicing operations have returned to the river all of the water not desired for the Franklin Canal net diversions. This water returned to the river, of course, is for later diversion by Riverside Canal... Incidentally, the old International Diversion Dam, which formerly served both the Franklin Canal and the Acequia Madre is now only used by the Acequia Madre, since under the new setup the diversion for the Franklin Canal is now made at the American Dam.*[9]

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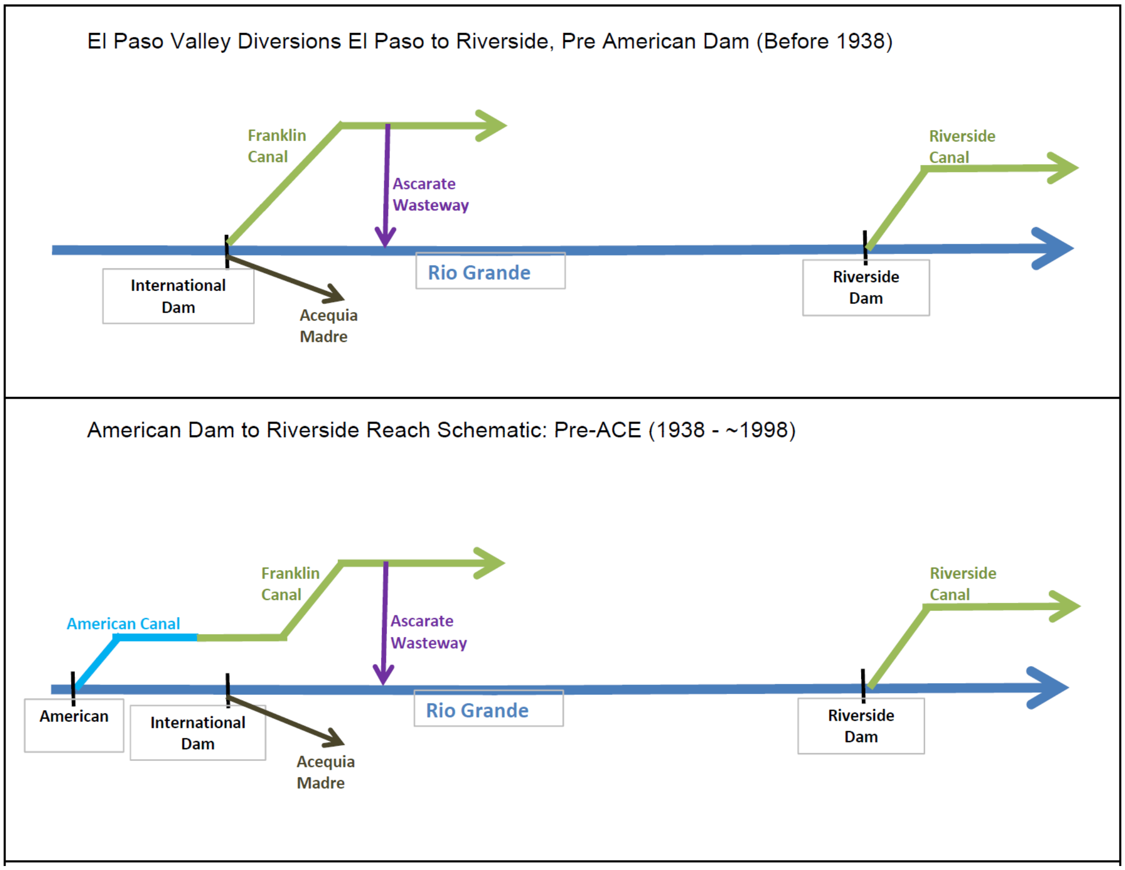
[8] RGPH 1938, (Hydrometry Section), starting p. 29/312.

[9] RGPH 1938, p. 31/312.

Figure C.4. Schematic of El Paso Valley Conveyance Reconfiguration above Riverside in 1938



1.2.2 Realignment of the Rio Grande

Prior to Rectification, the bed of the Rio Grande had passed through the town of Fabens where water, including discharge from several El Paso Valley drains, was diverted into the Tornillo Canal. Rectification moved the bed of the Rio Grande approximately 3 miles south to coincide with the international border, causing Fabens to be divorced from the river.[10] This move effectively disconnected the Project heading at Tornillo from the Rio Grande and constituted a significant change in the course of the river in the Fabens area, as illustrated in Figure C.5 showing the major changes in the position of the Rio Grande in the El Paso Valley since 1903.

[10] RGPH 1938.

Figure C.5. Major Changes in the Position of the Rio Grande, 1903 to Present[11]

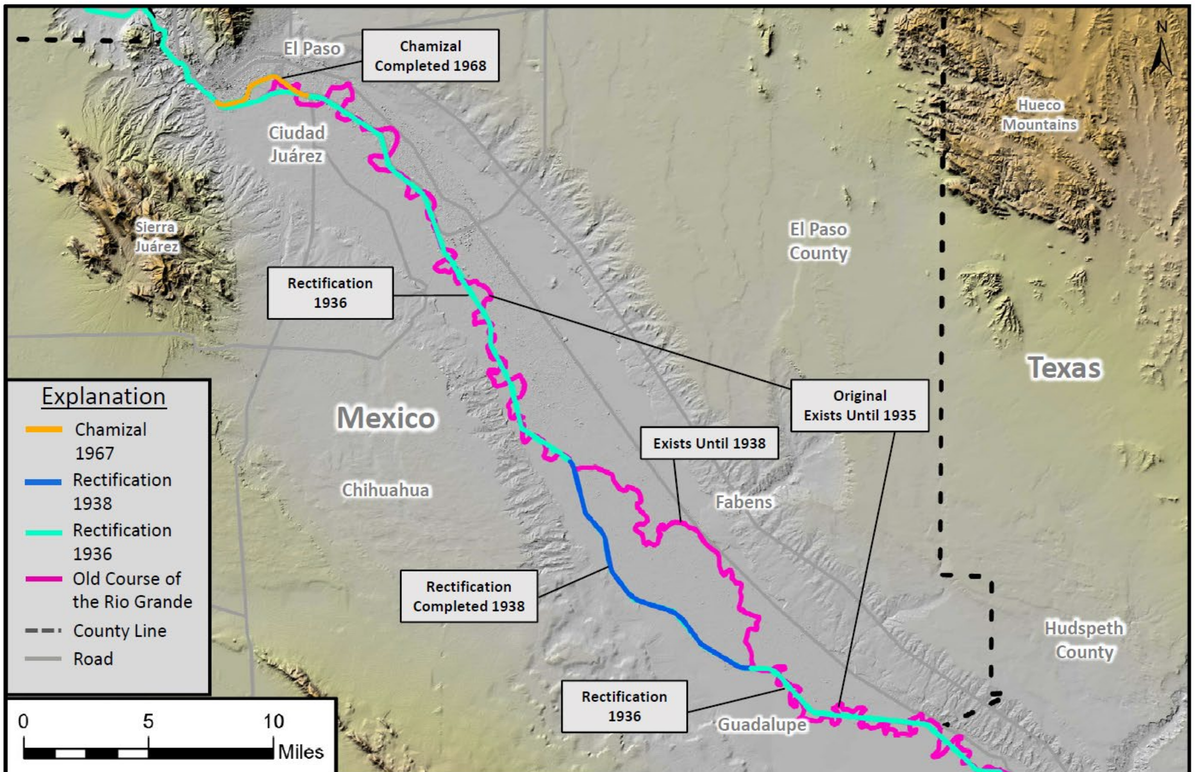


Figure 4.5a – Major changes in the position of the Rio Grande, 1903 to present.

McDonald Morrissey Associates, LLC Ground Water Hydrologists

Confidential Draft - Privileged Pursuant to Rule 26 of the Federal Rules of Civil Procedure: Prepared for Litigation

This realignment is described in the 1938 Project History: "*The river channel was relocated on July 1, 1938 … the old river channel … had run along the north and east side of the San Elizario Island through the town of Fabens … as a result of this change the old river was used merely as a feeder for the Hansen and Tornillo Canals after July 1*."[12]

In the years that followed, Reclamation used the now-dry bed of the Rio Grande above Fabens as a feeder for the Tornillo Canal, and then built an extension of the Riverside Canal along the old river bed to convey water to the Tornillo heading.[13] Reclamation also constructed the Fabens Waste Drain south of Fabens, to collect discharge from the Drains Above Fabens, and the Fabens Waste Channel along the course of the old river bed below Fabens, to convey waste and drain waters to HCCRD.

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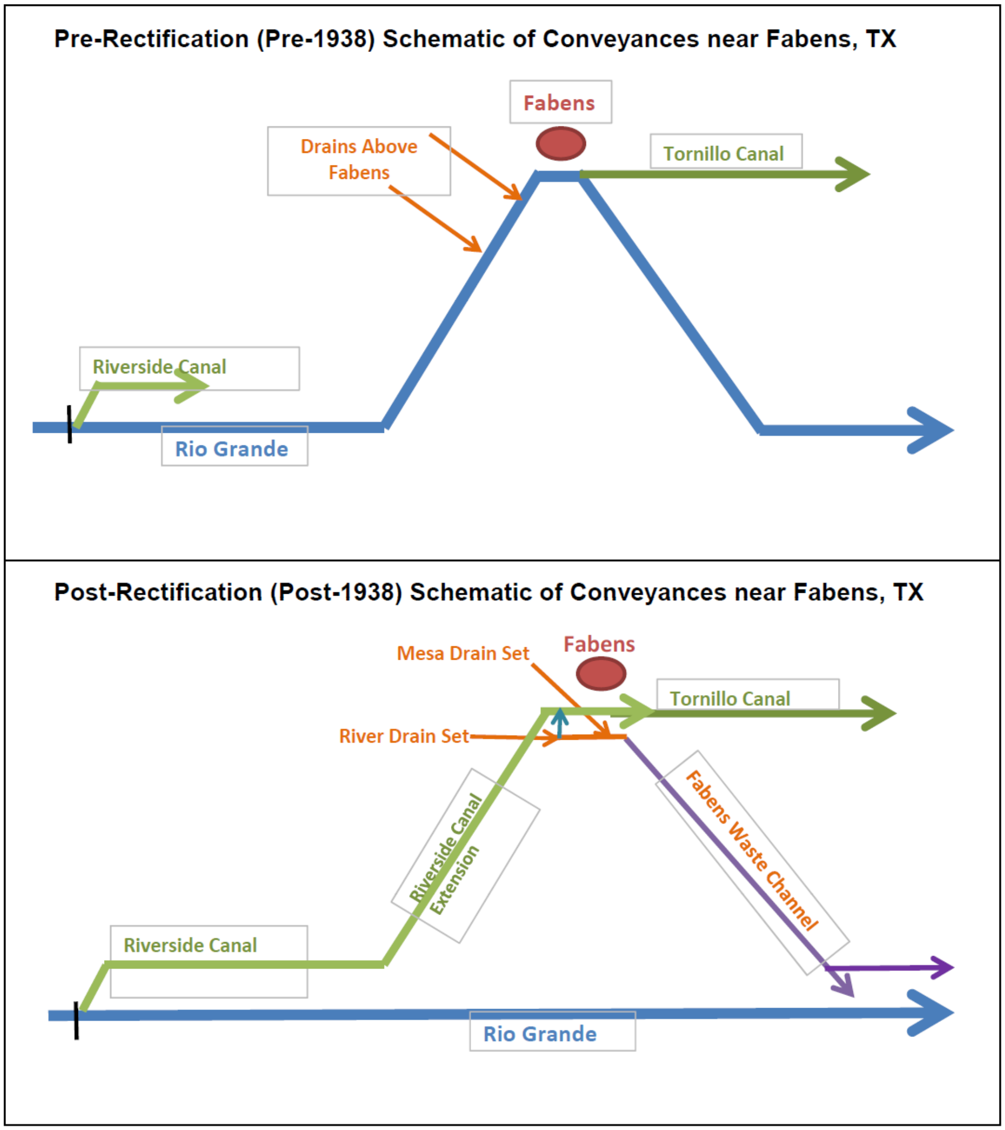
[11] McDonald & Morrissey & Associates Expert Report, 2019.

[12] RGPH 1938.

[13] RGPH,1939, 1940, 1941 (Chapter II Construction).

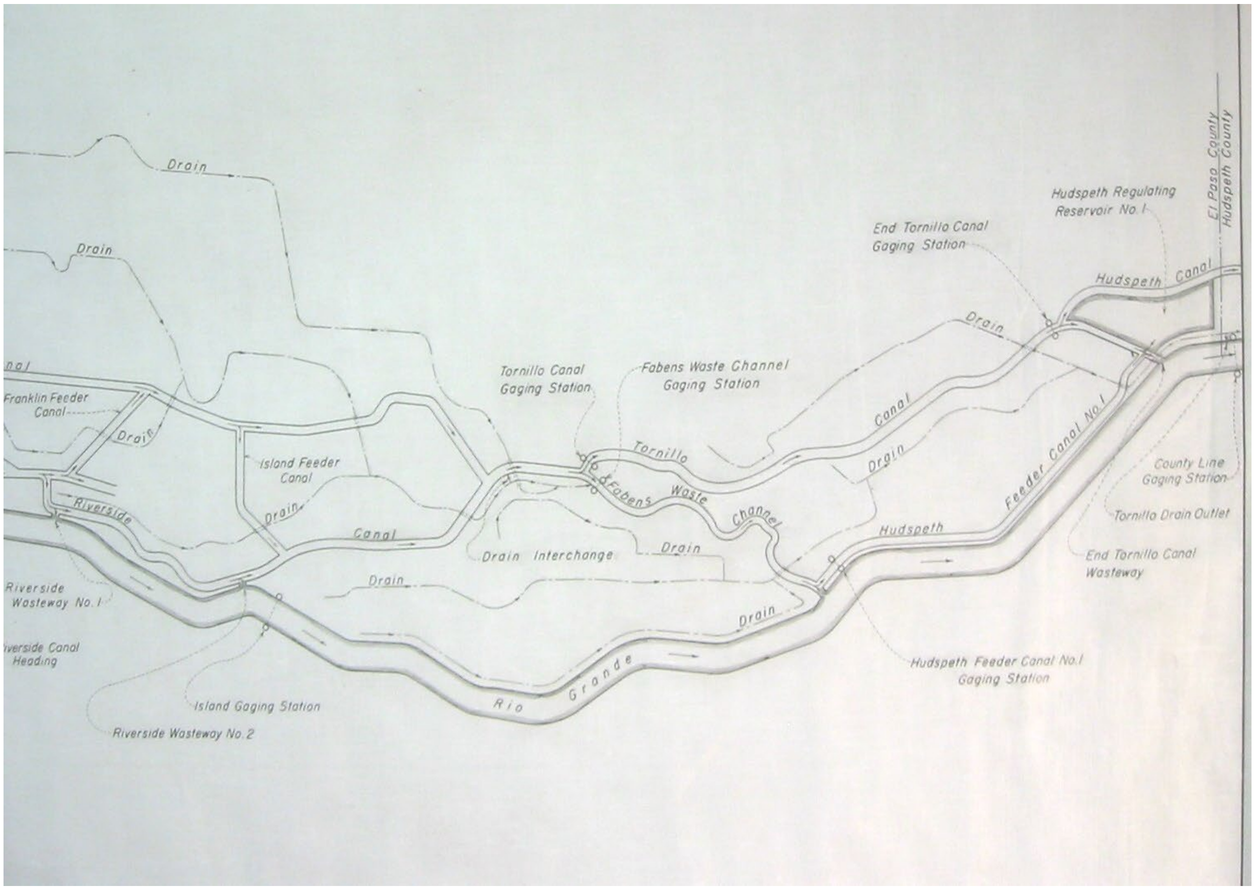
The pre-existing Tornillo Canal now received water from the new Riverside Canal Extension. This change in conveyances is illustrated in Figure C.6 (created by author), and the later configuration is illustrated by Reclamation in Figure C.7, showing the extended Riverside Canal and the heading of the Tornillo Canal.[14]

Figure C.6. Schematic of 1938 Change in Conveyances near Fabens, TX



[14] Cortez, F., PPT: U.S. Bureau of Reclamation / Rio Grande Project, 2003 (PPT named: TCEQ_BOR_PP_121103.ppt,), Slide 30.

Figure C.7. Reclamation Project Map, Fabens Area, Post-Rectification



As a result of these significant infrastructure modifications, starting in 1938 the main Project diversions in the El Paso Valley changed to:

- The Franklin Canal which now diverted water from the American Canal, and
- Riverside Dam which continued to divert water from the Rio Grande to supply the EPCWID lands it had already supplied, and to deliver water to the now land-locked Tornillo heading.

Reclamation's reconstruction of Project conveyances following Rectification did segregate the discharge from the Drains Above Fabens by conveying this water under the Riverside Canal Extension to the Fabens Waste Drain. Specifically:

- Water from Mesa Drain, Cuadrillo Drain, and the Fabens Intercepting Drain was routed directly to the Fabens Waste Channel for delivery to HCCRD.
- The River Drain, however, was configured so that water from this drain could be diverted into the Riverside Canal Extension above the Tornillo heading. As a result, the flows of the River Drain and the flows of its main tributary, the Middle Drain (which discharges into the River Drain below the River Drain gage) were available for diversion at the Tornillo heading, and evidence

(as described below) demonstrates that a "Drain to Canal" diversion formed part of Project Supply.

Contemporaneous Project documents state that one of the benefits of the Rio Grande Rectification to the Project was that poor-quality drain flow could be segregated out of Project Supply at Fabens. A 1937 letter by Fiock (then manager of the Project) states:

> "*Probably most outstanding in the way of advantages accruing to the irrigation project through the removal of the river to the international boundary line would be the possibility of keeping irrigation water for the lower end of the project separated from drain water at Fabens, thus holding the salt content to a safe dilution…"*[15]

A 1940 letter by Fiock states:

> "*The first and most important item of this work was the separation of the irrigation and drain water in the vicinity of Fabens, that is, carrying the drain discharge from the valley above Fabens under the canal and returning to the old river bed below the Tornillo Canal heading.*"[16]

Despite these clear statements, when the drain system near Fabens was reconstructed after the realignment of the Rio Grande ***only some*** of the drains were routed directly into the Waste Drain and to the Waste Canal for conveyance to HCCRD. The River Drain was plumbed differently so that water from the River Drain (which included the flow from its main tributary the Middle Drain) could be conveyed to the Tornillo heading.

The fact that Reclamation treated these two drain systems differently indicates that Reclamation preferred to continue using water from the River Drains within the Project, but not the water from the other drains which it sent to HCCRD, presumably because of water quality issues.

The connection of the drain system to the canal and waste system is illustrated in schematics obtained from Reclamation.[17] The schematic at Figure C.8 shows that the River Drain is connected to the Riverside Extension by means of a feature labeled "Drain to Canal." Based on my field inspection, this connection appears to be a subterranean tunnel between the two conveyances, which are parallel and close together at that location. Figure C.9 is a diagram I drew based on my observations of the Project conveyance system near Fabens.

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[15] Letter 1940 1012 from L.R. Fiock, Superintendent to Chief Engineer, CO, RE: Investigation for elimination of Mexican interference with water supply.

[16] Letter 1937 0826 from L.R. Fiock, Superintendent to Chief Engineer, CO, RE: River Certification Project, IBWC, San Elizerio Island.

[17] Cortez, F., PPT: U.S. Bureau of Reclamation / Rio Grande Project, 2003 (PPT named: TCEQ_BOR_PP_121103.ppt,), Slide 32.

Figure C.8. Schematic of the Project conveyance system in part of the El Paso Valley

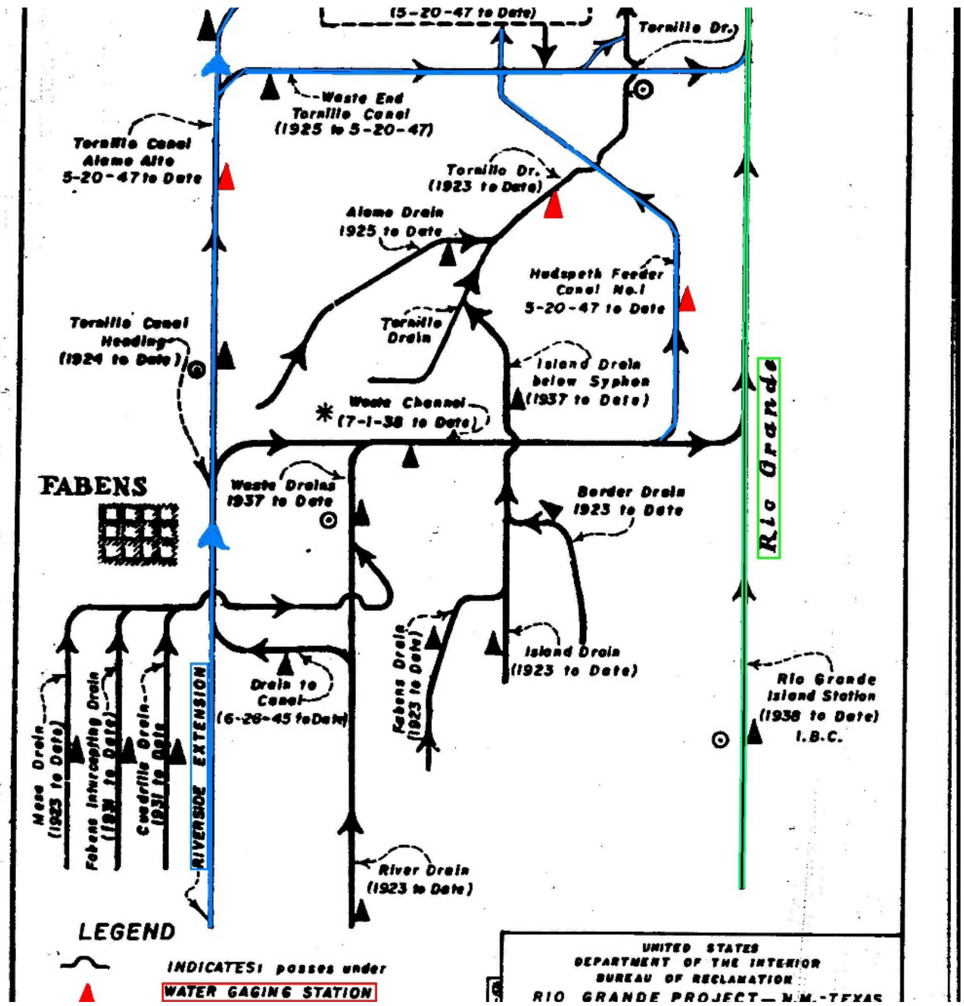
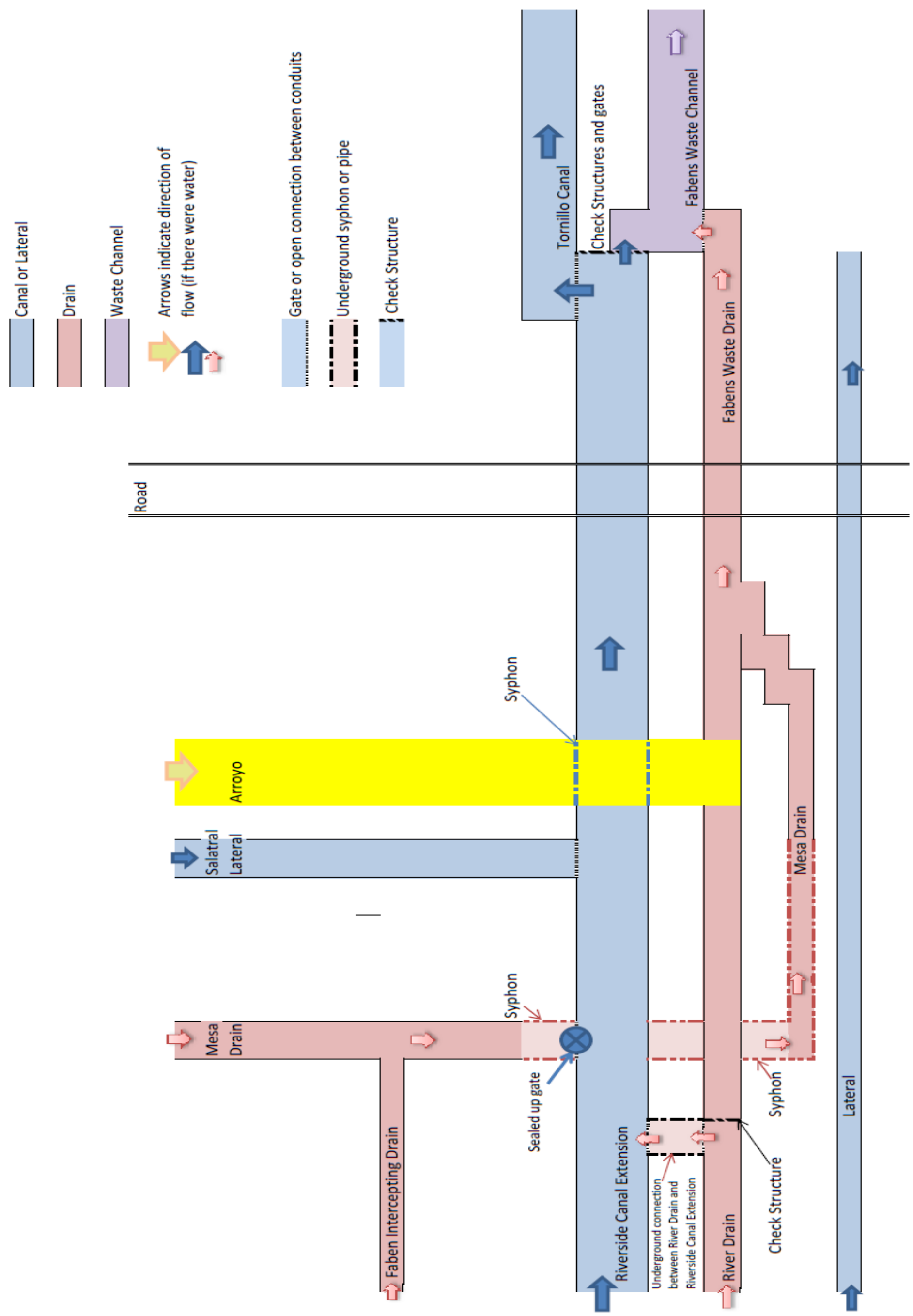


Figure C.9. Diagram by Dr Peggy Barroll of Project conveyances near Fabens, based on 2014 field visit and consultation with Rolf Schmidt-Peterson and Charles Spalding III



This same connection is also shown by Lloyd and Marston,[18] provided here as Figure C.10; I have added a red circle showing the location of the Drain to Canal diversion from the River Drain into the Riverside Canal Extension.

Figure C.10. From Lloyd and Marston

RIVER BUDGET FOR THE RIO GRANDE 113

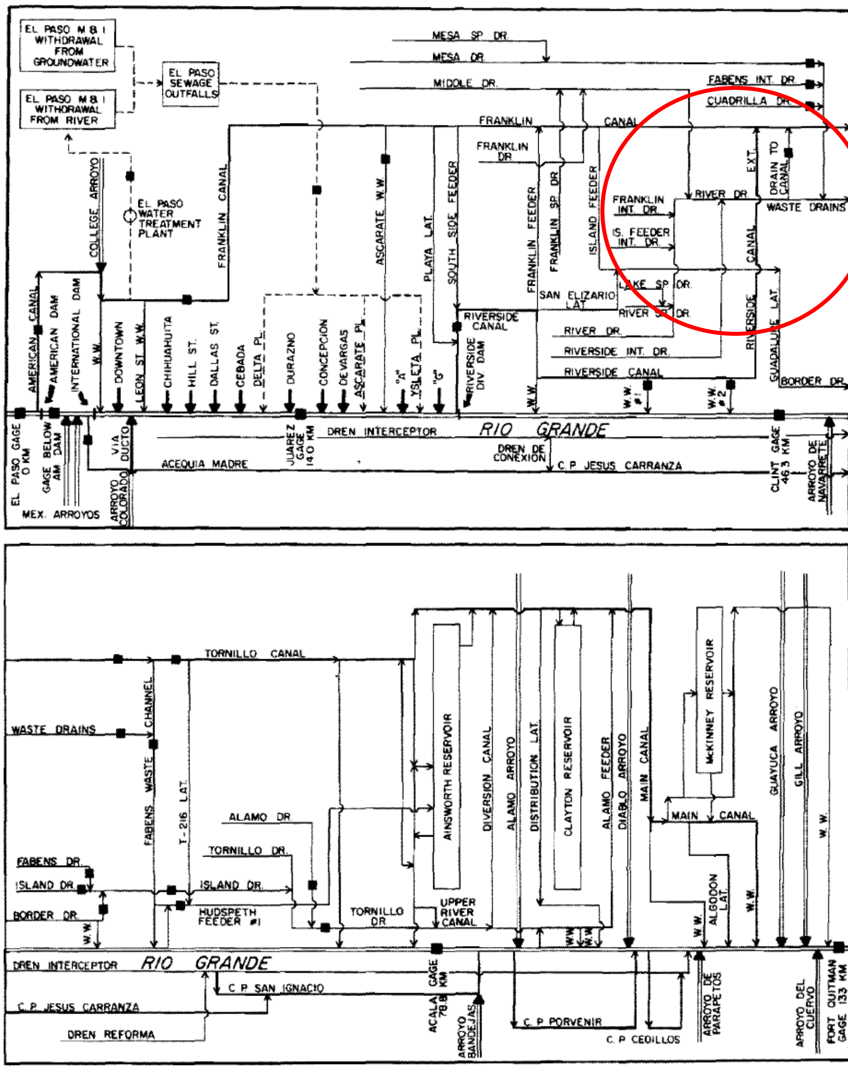
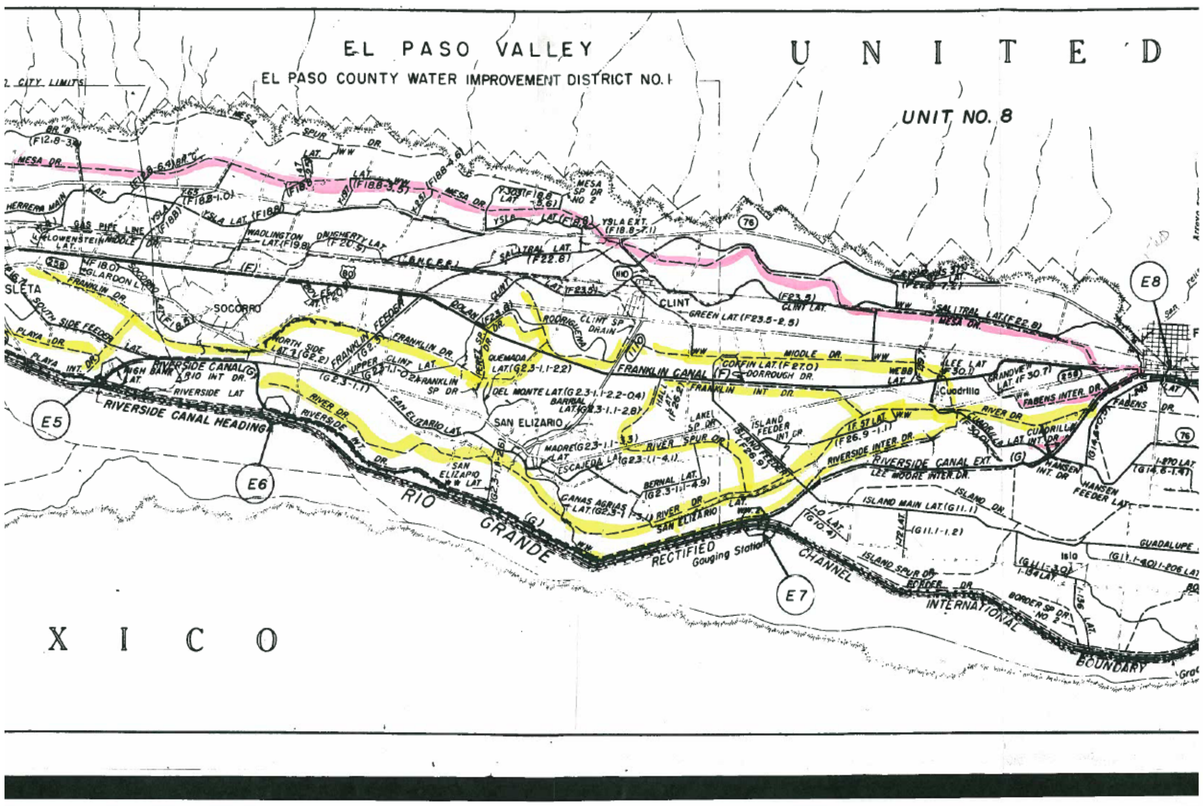


Figure 3. Schematic diagrams of present-day inflows and outflows to the Rio Grande and routing of river water through the El Paso–Juarez Valley. The bottom diagram is a continuation of the upper diagram. Solid boxes represent gages; solid triangles represent arroyo inflows to river; bold arrows represent urban runoff inflows to river; dashed arrows represent El Paso sewage inflows to river; other arrows represent irrigation transfers.

[18] Marston, R.A. and Lloyd, W.J., *River Budget for the Rio Grande, El Paso-Juarez Valley*, Journal of Arid Environments, (1985) 8, 109-119, September 30, 1983.

Figure C.11 is an excerpt from a strip map of the Project's El Paso Valley area from the 1985 Draft Operating Agreement and illustrates the two different sets of Drains Above Fabens. I modified this map by highlighting the River Drain and its tributaries in yellow, and the other Drains Above Fabens in pink. Figure C.11 clearly illustrates the large source area of the River and Middle Drain system.

Figure C.11. Excerpt of Reclamation Project strip map of the El Paso Valley



1.2.3 Construction of the American Canal Extension

In 1987 Riverside Dam was damaged by high flows. Following the failure of Riverside Dam, the Riverside Canal was supplied by a temporary coffer dam installed by EPCWID near the location of Riverside Dam until the completion of the American Canal Extension ("ACE") in 1998.[19] With the completion of the ACE, Project water could be diverted at American Dam to supply both Franklin and Riverside Canals, with water conveyed to the Riverside Canal heading through the newly built ACE instead of through the bed of Rio Grande. This is shown in schematic form in Figure C.12 (drawn by the author), and also in Figure C.13, a Project diagram obtained from Reclamation.[20]

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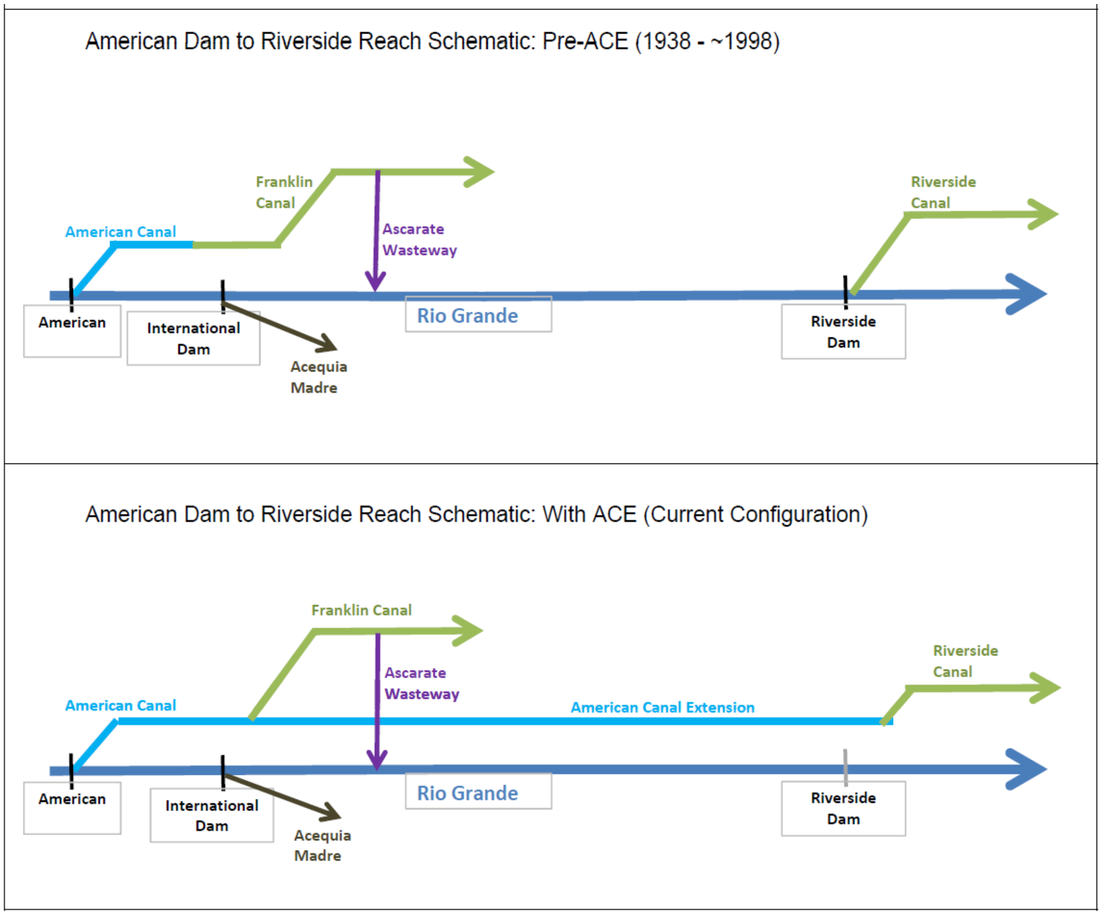
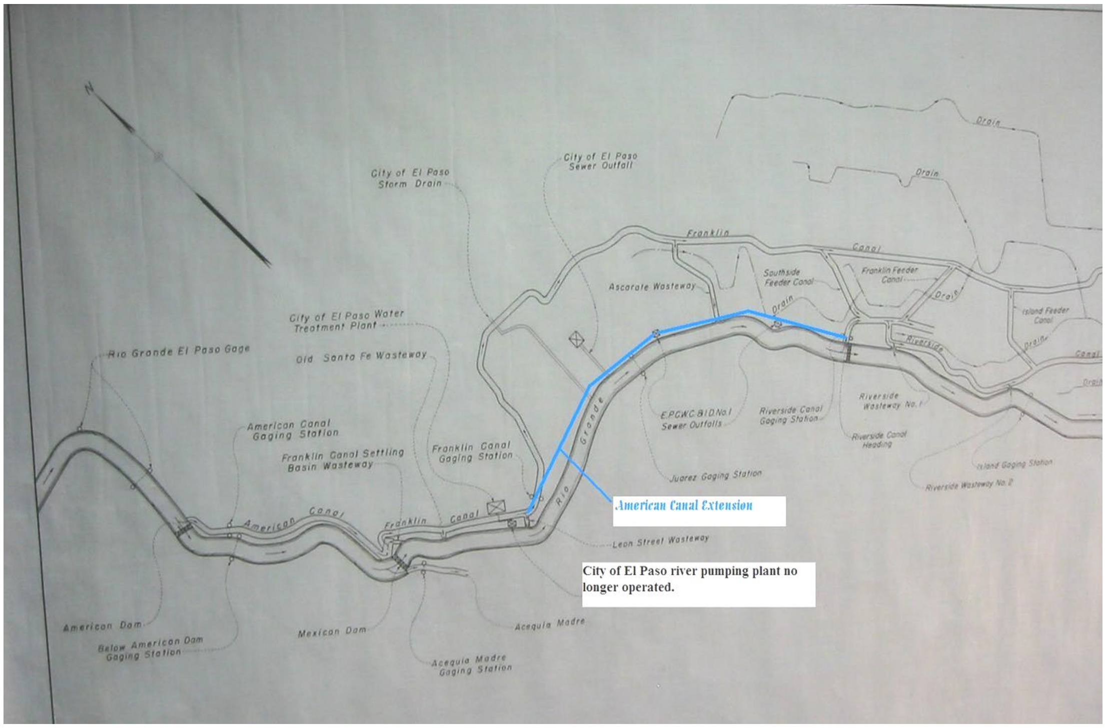
[19] 2001 Final Environmental Assessment for "Replacement of the Old American Canal" Located in El Paso, Texas. prepared for U.S. IBWC by ENCON International, Inc., December 6, 2001 (2001 FEIS).

[20] Cortez, F., PPT: U.S. Bureau of Reclamation / Rio Grande Project, 2003 (PPT named: TCEQ_BOR_PP_121103.ppt,), Slide 29.

Figure C.12. Schematic of Project: American Dam to Riverside, before and after completion of the American Canal Extension (ACE)



<u>Figure C.13. Reclamation Illustration of Project from Courchesne Gage to Riverside Dam, showing planned location of ACE</u>



The impact on Project operations of the ACE is improve the conveyance efficiency of the Project in the El Paso Valley, but at the same time recharge to the groundwater system in the El Paso Valley has been decreased because of less seepage from ACE and other concrete-lined canals, and less seepage from the bed of the Rio Grande.

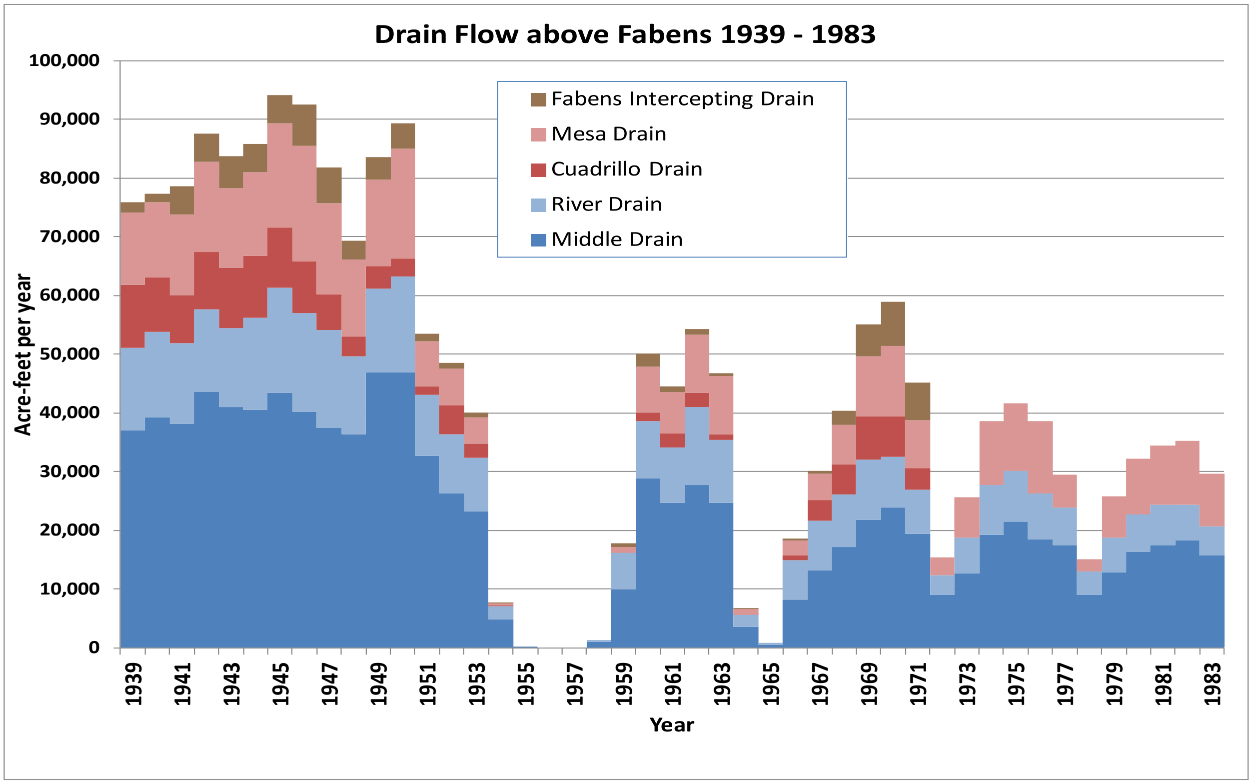
2 QUANTIFICATION OF THE IMPACTS OF EL PASO VALLEY INFRASTRUCTURE CHANGES

I have conducted a great deal of research to determine what, if any, these El Paso Valley infrastructure changes have had on Project operations and Project Supply. The results follow.

2.1 Drain Flow Availability

I plotted discharge data from the Drains Above Fabens from the time period 1939 through 1983 (post-Rectification) in Figure C.14.[21] The blue bars, representing drain flow from the River and Middle drains, would have been available to supply to the Riverside Canal Extension. Comparison of the bar charts in Figures C.3 and C.14 show a substantial decrease in El Paso Valley drain flows starting during the drought of the 1950s and continuing through the rest of the period of record. (I am not aware of any post-1983 discharge records for these El Paso Valley drains).

Figure C.14. Gaged Discharge of El Paso Valley Drains Above Fabens, 1939-1983



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21 Compiled from Reclamation Drainage Data Reports, 1923-1983.

What this plotted data clearly shows is that drain flows in the El Paso Valley have decreased substantially since extensive groundwater pumping for irrigation in the El Paso Valley began during the 1950s. Municipal groundwater pumping by both El Paso and Juarez also increased during this time.

2.2 Drain to Canal Diversion Records

The diversion from the River Drain into the Riverside Canal Extension was historically gaged, and this diversion data is available from a number of sources:

1) Reclamation Drainage Data reports from the years 1945 through 1982 include notations of the annual totals of Drain to Canal diversions, typically denoted as the amount "diverted from River Drain to Riverside Ext. – Tornillo Canal." An example excerpt from one of the Drainage Data Reports is in Figure C.15a.[22]
2) The "Report on Annual Flow Data" (circa 1956) from the New Mexico College of Agriculture and Mechanical Arts (now New Mexico State University or NMSU) includes a table of "Drain Water Diverted at Fabens" that is populated with data from 1945 through 1955.[23] This table is in Figure C.15b.
3) NMSU's 2003 compilation of Project flow data included a large set of scanned Reclamation data sheets that include annual discharge data reports for Drain to Canal at Fabens for the years 1945 through 1983.[24] An example of one of these annual discharge reports is in Figure C.15c.

Figure C.15a. Excerpt from Reclamation Drainage Data Report, 1948

* Of which 33,440 A.F. was diverted from River Drain to Riverside Ext. - Tornillo Canal.
° Beginning in 1948 Border Drain carries waste from end of Guadalupe Lateral.

DRAINS (Length of drains are above gaging stations)	Length in miles Jan 1st, 1947	Length in miles Jan 1st, 1948	January: Maximum C.F.S	Minimum C.F.S	Mean C.F.S	Total Acre Ft.	C.F.S per mile
GARFIELD	12.1	12.1	5.2	.57	4.7	290	0.4
HATCH	11.6	11.6	7.9	3.9	5.5	340	0.5
ANGOSTURA	4.0	4.0	0.5	0.4	0.4	20	0.1
RINCON	14.4	14.4	7.0	1.8	3.8	230	0.3
TOTAL FOR VALLEY	41.9	41.9			14.3	880	0.3
SELDEN	4.6	4.6	2.0	1.3	1.7	100	0.4
LEASBURG	12.1	12.1	2.4	2.3	2.4	150	0.2
PICACHO	7.3	7.3	7.5	6.3	6.7	410	0.9
MESILLA	17.5	17.5	5.3	3.3	4.3	260	0.2
DEL RIO (Includes Leasburg and Mesilla)	75.2	75.2	77.2	64.0	67.7	4160	0.9
CHAMBERINO	5.1	5.1	1.6	1.8	1.7	100	0.3
LA MESA	27.3	27.3	14.2	11.4	12.8	790	0.5
EAST	22.7	22.7	10.0	7.2	8.4	520	0.4
ANTHONY	7.9	7.9	1.2	1.0	1.1	70	0.
NEMEXAS	17.7	17.7	11.5	10.5	11.0	680	0.6
WEST	37.1	37.1	30.9	28.6	29.7	1830	0.8
MONTOYA (Includes Nemexas and West)	67.6	67.6	50.6	43.9	46.4	2850	0.7
TOTAL FOR VALLEY (Santo Tomas & Montoya intercepting drains not incl.)	277.7	277.7			146.6	[illegible]	0.7
PLAYA	22.3	22.3	20.2	20.2	20.2	1240	0.9
FRANKLIN	33.7	33.7	25.9	23.2	24.6	1510	0.7
MIDDLE (Includes Playa and Franklin)	52.9	52.9	34.1	28.5	31.3	1920	0.6
RIVER	18.9	18.9	11.3	10.2	10.8	660	0.6
CUADRILLA	13.5	13.5	1.9	1.7	1.8	110	0.1
MESA	28.4	28.4	10.8	10.5	10.6	650	0.4
FABENS INTERCEPTING	4.2	4.2	1.6	1.5	1.6	100	0.4
TOTAL ABOVE FABENS	117.9	117.9	70.0	57.0	63.7	3920	0.5
BORDER °	14.5	14.5	13.5	13.4	13.4	820	0.9
ISLAND	16.3	16.3	7.9	7.6	7.8	480	0.5
FABENS	9.1	9.1	3.7	3.6	3.6	220	0.4
ISLAND SYPHON	43.8	43.8	31.5	28.4	30.0	1840	0.7
ALAMO	21.2	21.2	6.6	5.1	5.8	360	0.
TORNILLO (Includes Alamo, Island, Border & Fabens)	81.6	81.6	40.7	37.4	40.3	2480	0.
TOTAL FOR VALLEY	177.5	177.5			104.1	6400	0.
TOTAL PROJECT	459.1	459.1			264.8	16280	0.6

[22] Reclamation Drainage Data Reports, 1948.

[23] New Mexico College of A & MA, 1956 Reports to Elephant Butte Irrigation District, *Report on Annual Flow Data*, Volume 3, 1935-1965.

[24] Drain to Canal, Intersection Point, Annual Discharge Year Sheet, Rio Grande Project, 1945 - 1983.

Figure C.15b. Excerpt from NMA&MA Reports to EBID

DRAIN WATER DIVERTED AT FABENS

SOURCE: Letters from Resch to Gregg 11/17/52

Year	Discharge - A. F.	Remarks
1945	6,660	Started July 26
1946	38,760	
1947	28,250	
1948	33,440	
1949	16,580	
1950	20,900	
1951	29,600	
1952	23,690	
1953	19,350	
1954	4,586	
1955	0	
1956		
1957		
1958		
1959		
1960		
1961		
1962		
1963		
1964		
1965		

Figure C.15c. Reclamation Daily Discharge Record for Drain to Canal at Fabens

7-212
(January 1937)

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

DAILY GAGE HEIGHT OR DISCHARGE—YEAR SHEET

Note: River Drain at point of diversion to Tornillo Canal includes flow of River Drain and Middle Drain.

DAILY ~~gage height, in feet,~~ discharge, in second-feet, of Drain to Canal at Fabens (River Drain Water diverted to Tornillo Canal) for 1948 , Observer)

Note - Flow held in Tornillo Canal in Jan. and part of February at the request of the I.B.&W.C. to facilitate construction of Hudspeth Reservoir. Not for irrigation use.

DAY	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
1	51	42	39	78	84	85	109	60	42	82	0	0
2	51	41	42	75	90	46	84	101	108	69		0
3	51	41	41	74	98	13	54	31	108	70		0
4	51	40	40	75	94	20	20	0	114	82		0
5	51	42	40	78	25	41	0	79	110	79		17
6	51	42	40	89	0	30	58	111	93	61		57
7	51	42	40	86	0	35	115	111	108	79		53
8	49	42	40	86	33	8	112	111	62	76	0	67
9	49	26	41	81	83	0	106	115	0	68	21	30
10	49	0	38	87	92	0	118	123	0	75	41	0
11	47		37	85	87	0	110	123	0	80	0	
12	45		38	76	78	0	121	112	0	86		
13	47		37	77	87	0	105	71	0	74		
14	47		38	85	80	53	118	7	0	77		
15	47		40	82	92	87	93	0	0	43		
16	47		33	86	66	80	113	0	41	0		
17	47		36	82	60	83	123	0	28			
18	46		38	85	59	80	51	0	81			
19	45		38	79	70	87	0	0	69			
20	45		40	82	73	80		43	51			
21	45		40	80	79	60		100	65			
22	45		43	86	82	80		110	94			
23	44	0	50	89	84	93		111	96			
24	44	29	51	95	69	96		97	99			
25	44	38	49	95	49	92		113	92			
26	44	38	56	90	32	83		114	93			
27	44	38	51	83	50	10		118	88			
28	44	35	54	85	46	0		118	88			
29	44	38	65	87	51	76		115	79			
30	43	—	62	88	77	99	0	108	86		0	
31	43	—	78	—	90	—	60	121	—	0	—	0
S.F.D.	1451	574	1375	2506	2060	1517	1670	2423	1895	1101	62	224
A.F.	2880	1140	2730	4970	4090	3010	3310	4810	3760	2180	120	440

Total A.F. 33440

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Where these data sets overlap, they are consistent with each other. I created a summary of the data from these sources as tabulated in Table C.1. The average annual reported Drain to Canal diversion over the period of record is 9,850 AF/Y. While this diversion is significant, it is far less than the 60,000 AF/Y to 80,000 AF/Y of Drain Flow above Fabens available for diversion at Tornillo heading at the time of the Joint Investigation.

Table C.1. Tabulation of the Annual Diversions from the River Drain into Riverside Extension

Tabulation of the Annual Diversions from the River Drain into Riverside Extension from Annual Reclamation Discharge Records				
Year	Drain to Canal Diversions		Year	Drain to Canal Diversions
	(acre-feet)			(acre-feet)
1945	6,660 (partial year)		1965	44
1946	38,760		1966	6,842
1947	28,250		1967	16,106
1948	33,440		1968	14,099
1949	16,580		1969	2,292
1950	20,900		1970	150
1951	29,600		1971	12,318
1952	23,690		1972	10,382
1953	19,350		1973	6,171
1954	4,586		1974	5,761
1955	0		1975	0
1956	0		1976	0
1957	0		1977	9,229
1958	0		1978	7,453
1959	5,727		1979	3,415
1960	9,781		1980	438
1961	18,874		1981	696
1962	12,212		1982	155
1963	17,470		1983	0
1964	2,758			

This summary table demonstrates the large amount of diverted El Paso Valley drain flow through the 1940s, the dramatic decrease in such diversions during the drought of the 1950s, the resumption of significant amounts of diverted El Paso Valley drain flows through most of the 1960s, and the sporadic and decreasing amounts of diverted El Paso Valley drain flows after about 1972. I have no information on available or diverted amounts of El Paso Valley drain flows after 1983 but believe, based on my observations and my understanding of groundwater conditions caused by recent years of low surface water supply, urbanization, reductions in recharge caused by canal lining and Texas and Mexico pumping, there is little drain water available in the El Paso Valley.

2.3 El Paso Valley Drain Flows as a Source of Project Supply

As reflected in the findings of the Joint Investigation, diverted El Paso Valley drain flow accounted for a significant portion of Project water deliveries in the early years of the Project. In fact, the Joint Investigation noted that some 35% of water diverted to EPCWID at Franklin Canal was composed of "drain flow and seepage," while a full 57.7% of water diverted at Tornillo was composed of "drain flow and seepage."[25] The difference between these two numbers: 35% and 57%, represents the amount of El Paso Valley drain flow diverted at Tornillo that would not have been available further upstream at Franklin, meaning that between these two points the Project received considerable drain flow for Project use.

Prior to Rio Grande Rectification, the discharge of all the Drains Above Fabens was available at Tornillo heading for diversion and was thus available to the Project.

After Rectification, there is evidence from Reclamation records that the Drain to Canal diversion of El Paso Valley drain flow formed part of Project Supply. The only comprehensive tabulations of Project diversions prior to 1979 are the Project Water Diversion Records (WDRs). The WDRs provide annual tabulation of water distribution for the Project as a whole, and for various subdivision of the Project, including the El Paso Valley. The data set from which the D2 Curve was derived (see Appendices A and E) included annual Project-wide diversion data from these WDRs for the period 1951 through 1978, which included the severe drought years of the 1950s.

Some of the pre-1979 WDRs available for the El Paso Valley indicate that the diversions tabulated on the forms are the result of a calculation involving various diversions and wasteway discharges. Figure C.16 is a sample WDR for the El Paso Valley for 1951 extracted from the Project History (Reclamation Form 7-322). The notations on the back of this sheet indicate that the El Paso Valley diversion is calculated from the diversions into Franklin and Riverside canals plus Drain to Canal.[26] This indicates that El Paso Valley drain flows diverted at the Drain to Canal conveyance were part of Project Supply after the Rio Grande Rectification. Another source of this data is in the 1956 New Mexico Agriculture and Mechanical Arts "Report on Annual Flow Data."[27] The tabulation of "El Paso – Diversions", which is consistent with the WDR El Paso Valley Diversions, has a description field which reads: "Includes drain water diverted at Fabens."

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[25] Joint Investigation, Part I, page 100, Table 90.

[26] Other terms are then subtracted including Ascarate waste way discharge, which at that time would have been rediverted at the Riverside Dam, discharge from Riverside waste ways #1 and #2, and Playa Lateral waste to Riverside Canal.

[27] New Mexico College of A & MA, 1956 Reports to Elephant Butte Irrigation District, *Report on Annual Flow Data*, Volume 3, 1935-1965.

Figure C.16. Sample Reclamation Monthly Project Water Distribution for the El Paso Valley

Form 7-322 (May 1937)

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

MONTHLY WATER DISTRIBUTION

Project Rio Grande, New Mexico-Texas Area Irrigated 166) 55,730) 55,896 Year 1951

El Paso Valley Unit (Ysleta Branch)

QUANTITIES IN ACRE-FEET

MONTH	Diverted from Stream[1]	INFLOW FROM— Reservoirs[2]	Other Sources	Delivered to Reservoirs[2]	Net Supply[3]	Total ~~Main Canal~~ Waste	Total ~~Main Canal~~ Losses	Delivered to Laterals[4]	Lateral Waste	Lateral Losses	DELIVERED TO FARMS[5] Total	Per Acre
January,	341)					(190)					0	0
February,	5,946)					(231)	2,628				3,238	0.06
March,	24,693					672	14,271				9,750	0.18
April,	31,911					937	7,574				23,400	0.42
May,	13,059					1,236	430				11,393	0.20
June,	25,905					983	11,030				13,892	0.25
July,	35,948					1,451	13,448				21,049	0.38
August,	36,794					2,260	8,630				25,904	0.46
September,	17,198					2,704	3,936				10,558	0.19
October,	6,217					1,277	1,922				3,018	0.05
November,	5,621					1,445	2,281				1,895	0.03
December,	4,737					1,737	1,390				1,610	0.03
Total,	208,370					15,123	67,540				125,707	2.25
Acre ft. per acre,	3.73					0.27	1.21				2.25	
Per cent Net Supply,	100					7	33				60	

[1] Diversion amount exclusive of waste at head gates for sand sluicing, etc.
[2] Reservoirs connected with distributing system only.
[3] Diversions plus inflow from reservoirs and other sources less delivery to reservoirs.
[4] Measured at
[5] Measured at

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NOTE: Tabulation does not include water delivered to City of El Paso Water Treatment Plant.

(OVER)

(A) Diversions

(1) Franklin Canal
(2) Riverside Canal
(3) Drain to Canal
(4) Less Ascarate W.W.
(5) Less Riverside W.W. 1 & 2
(6) Less Playa Lateral Waste to Riverside Canal

(B) Waste

(1) Total from Island
(2) Tornillo No. 1
(3) Tornillo No. 2
(4) T - 131
(5) T - 216
(6) T-520
(7) Residual Waste at Tabens

The inclusion of Drain to Canal diversion in Reclamation's Project WDRs indicates that El Paso Valley drain flow formed part of the data set calculated to derive the D2 Curve.[28] The average amount of Drain to Canal diversion during the D2 Period (1951 – 1978) is 8,400 AF/Y.

2.4 Current Accounting for and Diversion of El Paso Valley Drain Flows

The Post-1978 Accounting rules and procedures as set forth in the 1985 Draft Project Operating Agreement are similar to those described in the 2008 Operations Manual, which is operative today. In neither the 1985 Draft Operating Agreement nor the 2008 Operations Manual is there any term for "Drain to Canal" nor any term representing the diversion of El Paso Valley drain flow, nor any term representing a diversion at Tornillo, meaning these drain flows have not been counted as Project Supply since at least 1979 through today, although before that time records reflect these drain flows were counted. Field visits by myself and other New Mexico experts indicate that the Canal to Drain diversion structure remains in place. During my recent visits there has been no flow in the River Drain at that location, which probably results from recent low-supply Project conditions and high levels of groundwater pumping in the Hueco Bolson (the Rio Grande groundwater basin below Courchesne). Given the current Project accounting, even if such flow existed and were diverted, this diversion would not be charged to EPCWID.

3 Conclusions

Based upon the data and analysis provided below, I conclude the following:

- El Paso Valley drain flows have historically been available for diversion at the Tornillo heading for Project Supply.
- Prior to the 1938 Rectification of the Rio Grande, drain flow from all the El Paso Valley Drains Above Fabens (including the River Drain system, and the Mesa, Cuadrillo and Fabens Intercepting Drains) were discharged into the Rio Grande and were available for diversion at Tornillo heading. The total discharge of these drains ranged from 60,000 AF to 85,000 AF during the 1930s
- Tornillo heading was intended to collect and then deliver Project return flows, including drain flow.
- The Rio Grande Joint Investigation indicates that El Paso Valley drain flows were a significant source of the water diverted at the Tornillo heading during the period 1930-1936.
- Following the 1938 Rectification, water was diverted from the River Drain into the Riverside Canal Extension for delivery to the Tornillo heading. Drain flow from the Mesa, Cuadrillo and Fabens Intercepting Drains was conveyed directly to the Fabens Waste Drain and Waste Channel for delivery to HDDRC.
- The reported amounts of water diverted from the River Drain into the Riverside Canal Extension from 1945 through 1983 period of record ranged from zero to 38,000 AF/Y.

[28] See Appendix E for a discussion of the other diversion terms in Figure C.16.

- The flows in the Drains Above Fabens declined significantly during the 1950s drought from what they had been previously. The recorded flows in the Drains Above Fabens remained relatively low throughout the remainder of the period of record (until 1983). It is likely that the relatively low flows in these drains since the early 1950s is caused by a number of factors including low supply, urbanization and increased irrigation and municipal groundwater pumping in the Hueco Bolson.
- Recent field visits by me and other New Mexico staff and experts indicate that a structure to divert water from the River Drain to Riverside Canal Extension is still in place.
- My analysis of current Project accounting procedures indicates that when there is water in the River Drain, and when that water is diverted, that diversion will not be charged to EPCWID.

APPENDIX D

PROJECT ALLOCATION AND ACCOUNTING

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APPENDIX D
PROJECT ALLOCATION AND ACCOUNTING

In this Appendix, I discuss in detail and provide support for the facts and conclusions summarized in Section 6 of the Report.

1 PROJECT ALLOCATION AND PROJECT ACCOUNTING 1979-2005

1.1 D1/D2 ALLOCATION

Beginning in 1979, and as a result of the Districts and Reclamation executing the Transfer Contracts, Reclamation significantly changed its delivery operations. Heretofore, Reclamation had allotted water to farmers on a pro-rata basis by acreage, and delivered water to farmers at their individual farm head gates. To effect the mandates of the Transfer Contracts, Reclamation instead agreed to allocate water to the Districts and deliver this water to EBID and EPCWID canal headings; the Districts then to oversee delivery of the water to individual Project beneficiaries.

The Transfer Contracts contain language requiring that "[a] detailed operating plan will be concluded between the United States and the District setting forth procedures for water delivery and accounting."[1] Reclamation was charged with developing a means of allocating water to the Districts, instead of to farmers, that would maintain the equities of the Project. Accordingly, during the 1980s Reclamation performed analysis of historical water distribution data and developed the "D1 Curve" and the "D2 Curve", which are linear regression fits of Project water distribution data from 1951-1978. Figures D.1 and D.2 were obtained from Reclamation,[2] and reflect the D1 and D2 Curves. These Curves form the basis of the "D1/D2 Allocation."

Note that significant although largely unmeasured groundwater pumping was known to have occurred throughout the Project during the D2 Period (1951 – 1978). Reclamation reports (and other sources) indicate that farmers in EBID and EPCWID pumped large amounts of groundwater during years of low Project supply during this period (*see* Report section 4). Increased groundwater pumping, combined with the drought conditions that gave rise to increased pumping, caused decreased drain flows in the Rincon, Mesilla and El Paso Valleys during this time period, and probably increased seepage losses from the Rio Grande as well. Project water distribution data from that period would have reflected these hydrologic effects.

In 1985 Reclamation released its 1985 Draft Operating Agreement, including an early version of the D1/D2 Allocation method, and documentation of an accounting system that describes how the Districts' diversions would be accounted, or charged, against their allocations. A cover letter addressed to the New Mexico State Engineer indicates that the 1985 Draft Operating Agreement "has been implemented

[1] Transfer Contracts, section 6, paragraph d.

[2] Cortez, F., PPT: U.S. Bureau of Reclamation / Rio Grande Project, 2003 (PPT named: TCEQ_BOR_PP_121103.ppt), provided to the New Mexico ISC March 2005.

in 1985."[3] Thereafter, Reclamation produced a document for the Project entitled "Annual Operating Plan, Actual Operations 1984, Forecast Operations 1985"[4] which documented the implementation of the allocation and accounting described in the 1985 Draft Operating Agreement.

Reclamation officially documented the D1/D2 Allocation method (with a modified version of the D2 curve) in its Water Supply Allocation Procedures ("WSAP") document. The WSAP was provided to NM State Engineer Office staff by F. Cortez of Reclamation's El Paso Office in 2005. The WSAP document presents the D1 and D2 Curves which have been used for allocation since 1991,[5] and are incorporated into the 2008 OA.

The D1/D2 Allocation method explicitly divided the U.S. share of Project supply 88/155 (57%) to EBID and 67/155 (43%) to EPCWID, on an annual basis, in keeping with earlier agreements and historical practice. The new method and system further retained the historic practice of including any unused allocation from one season as part of pool of water available for allocation to the Districts and Mexico the next year.

In general, the D1 Curve was (and still is) used to determine Mexico's share of Project Supply, and the D2 Curve was used to determine the total amount of Project Supply available for allocation to both the Districts from Project Storage.

- The D1 Curve was derived from a plot of the annual delivery to U.S. farms plus the delivery to Mexico at Acequia Madre versus the annual release of Project water from Caballo. The farm delivery data in the D1 data set are equal to the reported farm deliveries from Reclamation's annual Water Distribution Reports (WDRs), and thus presumably originated from those reports (Appendix E to this Report describes the D1 data set).
- The D2 Curve was derived from a plot Project Net Supply plus the delivery to Mexico at Acequia Madre versus the annual release of Project water from Caballo. The Project Net Supply data are equal to the reported "Net Supply" or "Diverted from Stream" values from Reclamation's annual WDRs, and thus presumably originated from these reports (Appendix E to this Report describes the D2 data set).

In Figure D.3 I have plotted the D2 data provided in the WSAP report, together with a linear regression of that data (calculated in Excel), which is identical to the D2 Curve presented in the WSAP report. In Figure D.4 I illustrate how the amount water allocated by the D2 Curve is distributed among Mexico, EBID and EPCWID under D1/D2 Allocation.

The D2 Curve is used to calculate the total amount of water available for diversion by the Districts and Mexico at canal headings (or Project Supply), based on the amount of Usable Water in storage available

[3] Letter 1985 0129 from R.K. Patterson, USBR, to Steve Reynolds, New Mexico State Engineer, RE Implementation of 1985 Draft Operating Agreement.

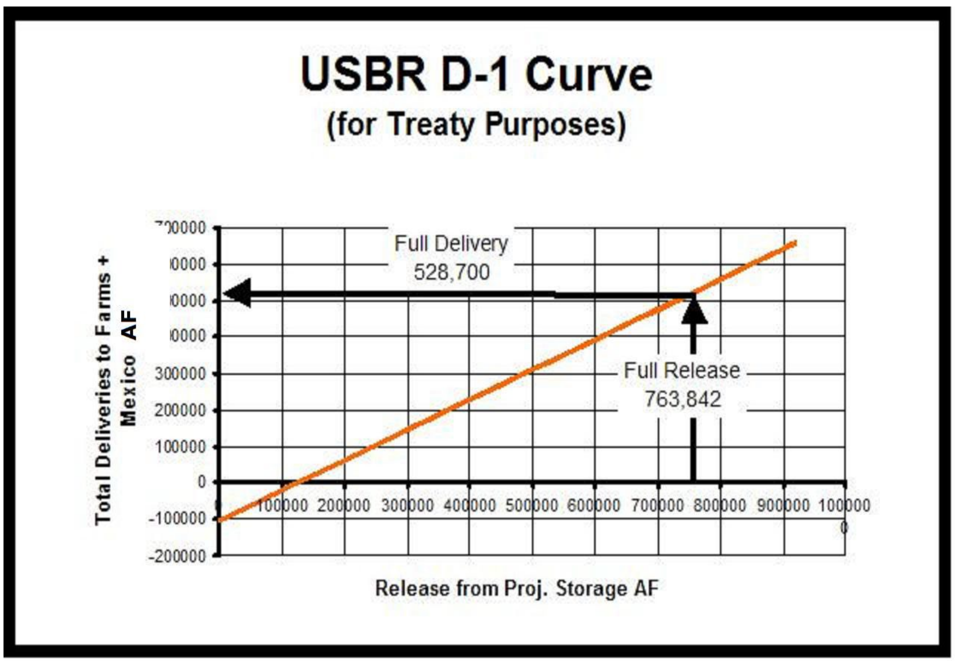
[4] Annual Operating Plan: 1984 Operations, 1985 Outlook, Bureau of Reclamation, Rio Grande Project, 1985.

[5] Full-Supply Allocation amounts for the year 1991-2002 and 2005 are consistent with the D2 Curve in the WSAP document.

for release. Historically, the total amount of water thus calculated was then divided up between Mexico, EBID and EPWCID. Mexico's allocation (determined using the D1 Curve) was first subtracted from the total Usable Water available for diversion, and the remainder was split 57:43 between EBID and EPCWID respectively. This division between the Districts is based upon each District's proportion of the Project authorized acreage as set forth in the 1938 Inter-district Contract and applied historically.

The D2 Curve is, in effect, a measure of the Project performance, or Project delivery efficiency, during the 1951 through 1978 period. It describes how much water the Project delivered to canal heading for a given amount released from Project Storage.

Figure D.1. Reclamation's D1 Curve from Cortez[6]



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[6] Cortez, F., PPT: U.S. Bureau of Reclamation / Rio Grande Project, 2003 (PPT named: TCEQ_BOR_PP_121103.ppt), provided to the New Mexico ISC March 2005. Filberto "Bert" Cortez is the long-time Manager of Rio Grande Project at the El Paso Office of U.S. Bureau of Reclamation.

Figure D.2. Reclamation's D2 Curve from Cortez[7]

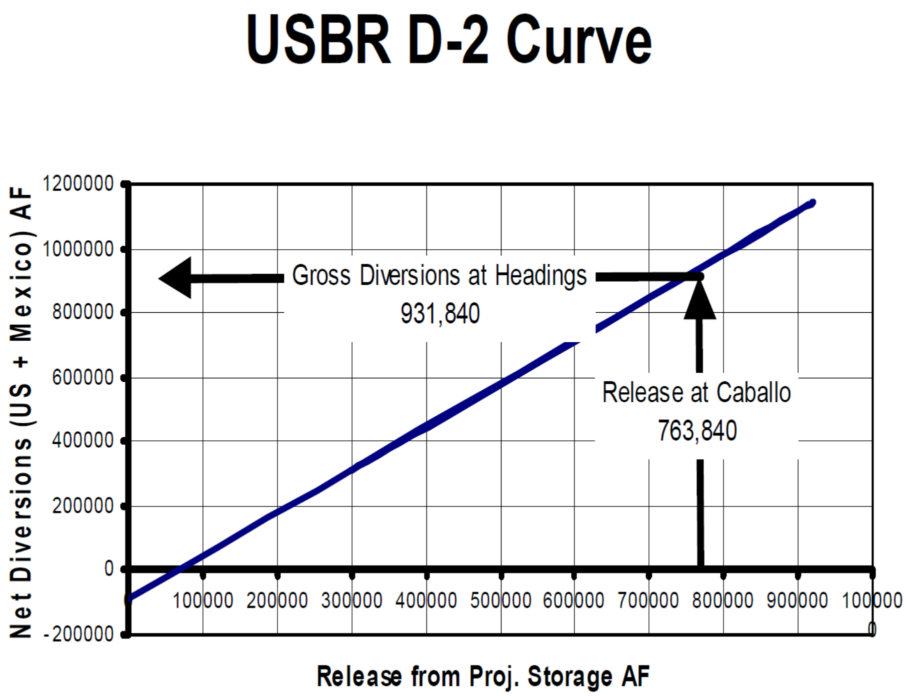
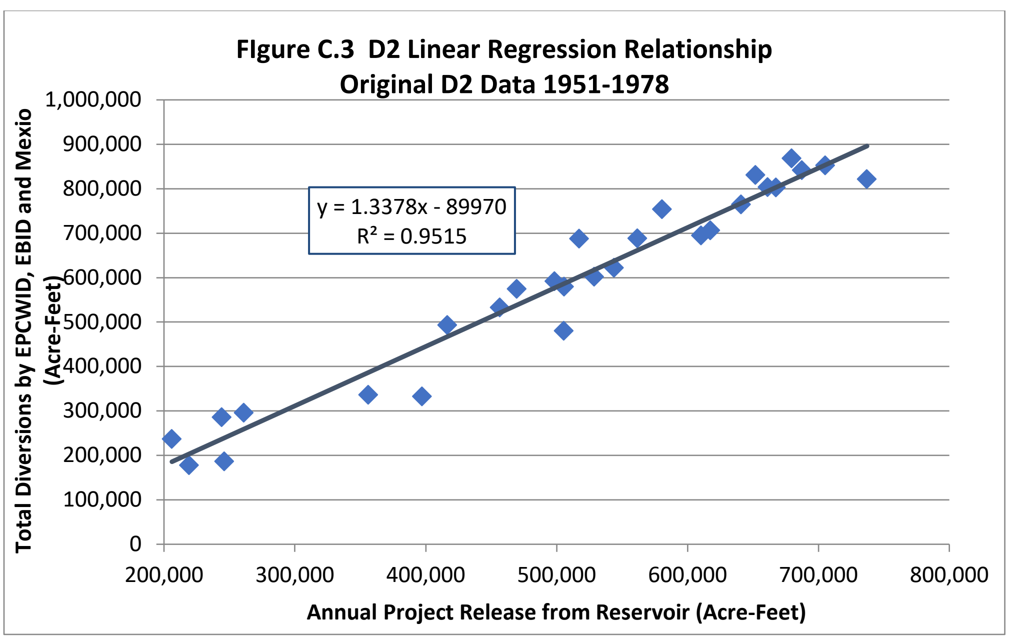
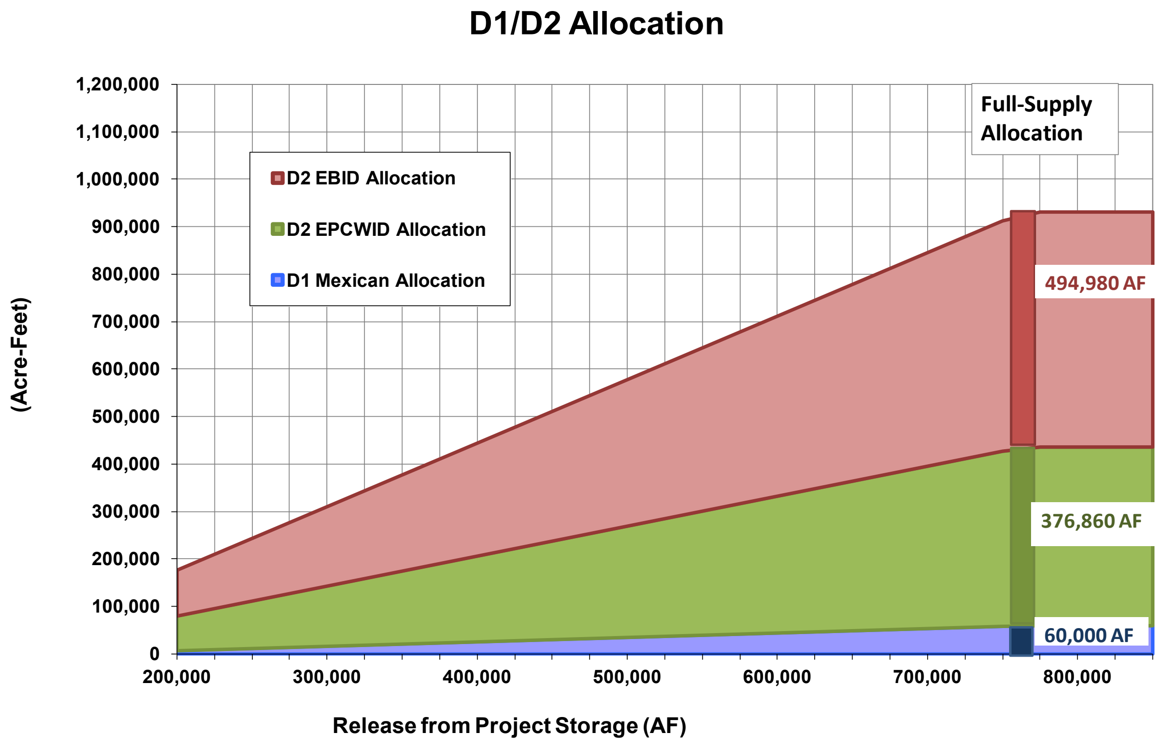


Figure D.3. D2 Curve plotted with Original D2 Data from 1951-1978



[7] Cortez, F., PPT: U.S. Bureau of Reclamation / Rio Grande Project, 2003 (PPT named: TCEQ_BOR_PP_121103.ppt), provided to the New Mexico ISC March 2005.

Figure D.4. Illustration of D1/D2 Allocation among Districts and Mexico



The D1/D2 analysis provided in the WSAP document determines full-supply allocation[8] amounts for Mexico, EBID and EPCWID as shown in Table D.1. These amounts differ from the full-supply allocations amounts provided in the 1985 Draft Operating Agreement which were based on somewhat different D2 Curve, and also from the reported allocations for full-supply years from 1979 - 1990, suggesting that the allocation method had not been completely finalized until 1990.

The D1/D2 analysis in the WSAP determined that a release from reservoir storage of 763,842 AF would provide a full supply to the Districts and Mexico.

[8] A "full-supply" allocation is the amount each District is allocated in a year during which the Project experiences a full supply of water, and was defined based on the canal heading diversions necessary to deliver a normal supply of 3.024 AF/A to all District lands.

Table D.1. D1/D2 Rio Grande Project Allocations for Full Water Supply from WSAP

Allocations for a Full Water Supply[1] (acre-feet)						
Release Requirement[2]	Net Diversions at Headings[3]	Mexico Allocation	EBID Allocation	EBID Percentage[4]	EPCWID Allocation	EPCWID Percentage[4]
763,842	931,841	60,000	494,979	56.77%	376,860	43.23%

1. Full water supply is 468,700 acre-feet to farm head gates of US lands (3.024 AF/A for 155,000 authorized acres) and 60,000 acre-feet to Mexico at the International Dam
2. Release from Caballo Reservoir necessary to meet full water supply at diversion headings
3. Net Diversion at Headings determined from Curve D2 (includes US and Mexico)
4. Percentage is based upon the net amount remaining to U.S., after deducting Mexico's allocation

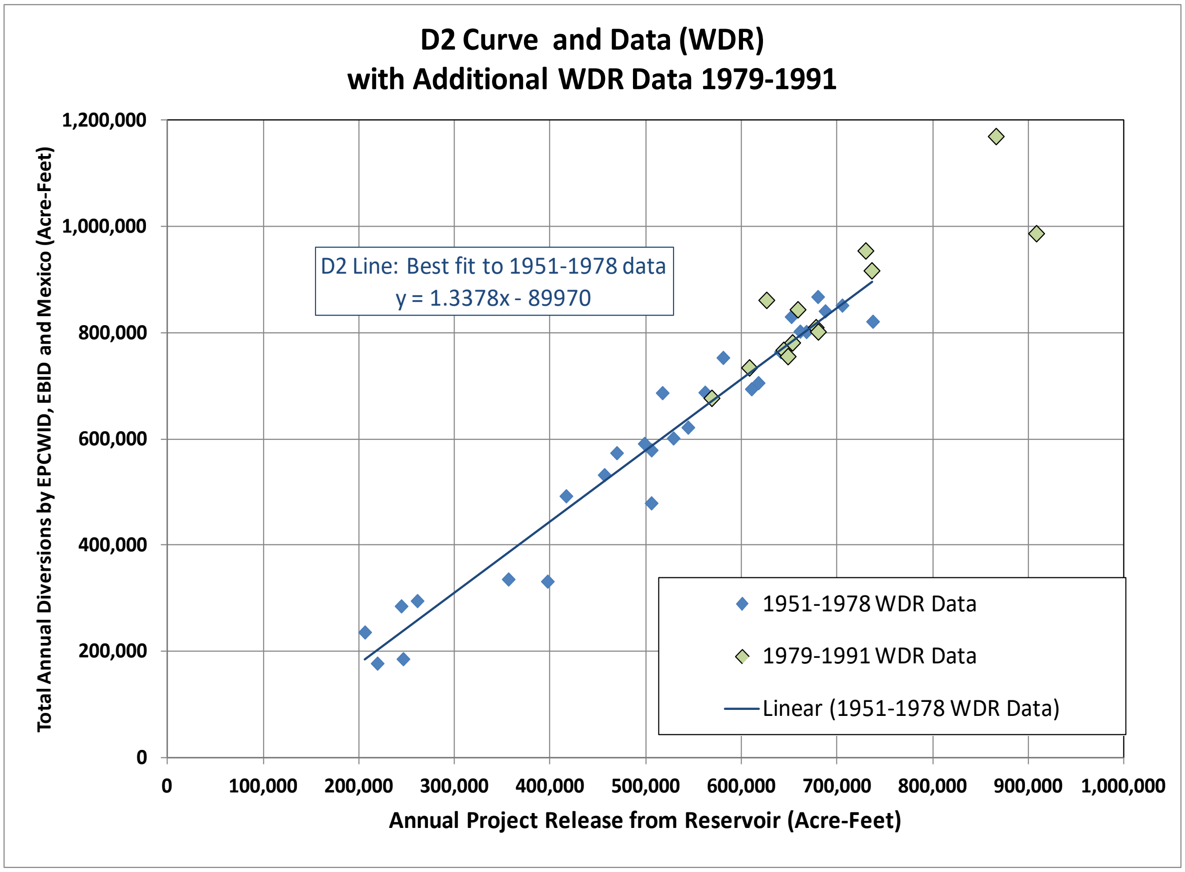
Full-supply conditions obtained for 24 years, from 1979 up to and including 2002. During this period, each District was allocated a full supply, but it was unusual for either District to divert all of the water allocated to it.

During the water-short years of 2003 and 2004, Reclamation employed an ad hoc allocation method in which the allocation to EBID and EPCWID was based upon the historic 57:43 division of an amount based on the Usable Water in storage, without reference to the D2 Curve. This change recognized the fact under the conditions existing at that time, an allocation made using the D2 Curve would be greater than the amount that could actually be delivered.

Project record keeping changed over the 1979 – 2005 period. It is my understanding that Reclamation continued to report this data through 1991 with some changes in format,[9] but starting in 1992 or 1993 more of the responsibility for cropping and water distribution reports fell to the Districts, and it is likely that the Districts were responsible for the data on these forms starting at that time. Figure D.6 is a plot of the D2 Curve and the D2 data set (with additional total diversion data from these other WDR sources from 1979 through 1991).

[9] Until 1978, this data was collected on "Monthly Water Distribution" form 7-322. From 1979 – 1981 this type of data appears on computer printout titled "Monthly Water Distribution and Operation and Maintenance Costs." Starting in 1982, this data was reported on "Crop Production and Water Utilization Data" form 7-2045 (3-79).

Figure D.6. D2 Curve and D2 Data (WDR), with additional 1979 – 1991 data from Project WDR sheets



The WDR diversion data from 1979 through 1991 are well aligned with the D2 Curve suggesting that Project performance during this period was consistent with the Project performance during the 1951 through 1978 period. That is, the D2 Curve was a good predictor for water available to be diverted at the main canal headings through 1991, as tabulated by Reclamation on WDR forms.

1.2 Post-1978 Accounting

Once Reclamation began allocating and delivering water to the Districts in 1979, it needed a system for assigning Project diversions to each District so that each District's diversions could be charged against its allocation. I am not aware of any description available of the accounting Reclamation used for this purpose until the 1985 Draft Operating Agreement; however, the available accounting data from 1979 through 1985 suggests that the general accounting methodology described in the 1985 Draft Operating Agreement was used starting in 1979. This accounting system has been modified since it was first documented in the 1985 Draft Operating Agreement, but to a large degree this same accounting system is in place today and will be referred to here as "Post-1978 Accounting."

Post-1978 Accounting is described here based on the 1985 Draft Operating Agreement. The significant changes made to the accounting process as part of the 2008 OA will be described in a later section.

In general, Post-1978 Accounting is based on the amounts diverted at Project diversion headings:

- EBID diversions from the Rio Grande at the Arrey, Leasburg, and Eastside and Westside canal headings, plus a number of minor diversions.
- EPCWID diversions at the Franklin and Riverside canal headings (which currently divert water from the American Canal), two diversion headings for the El Paso Water Utility ("EPWU"), and a number of other minor diversion locations.

An important feature of Post-1978 Accounting is a process for dealing with the diversions at Mesilla Dam to the Eastside and Westside Canals, which supply lands in both EBID and in EPCWID. Post-1978 Accounting assigns charges to EPCWID, and credits to EBID, for deliveries of Project water to EPCWID lands in the Mesilla Basin.

In addition, there is a provision in the 1985 Draft Operating Agreement called "Early Water Order by One District" for the case when one District starts ordering water earlier in the year than the other District. During such a time, charges are based on the release from Caballo "plus drain and sewage effluent," if that amount is greater than the amounts diverted at the District's diversion headings.[10] This provision is similar to current Project accounting practices applied when only one District is ordering water.

Post-1978 Accounting includes a number of credits, not part of the prior accounting method, which reduce the amount of each District's total charged diversions. These credits will be discussed in more detail in Section 3 of this Appendix.

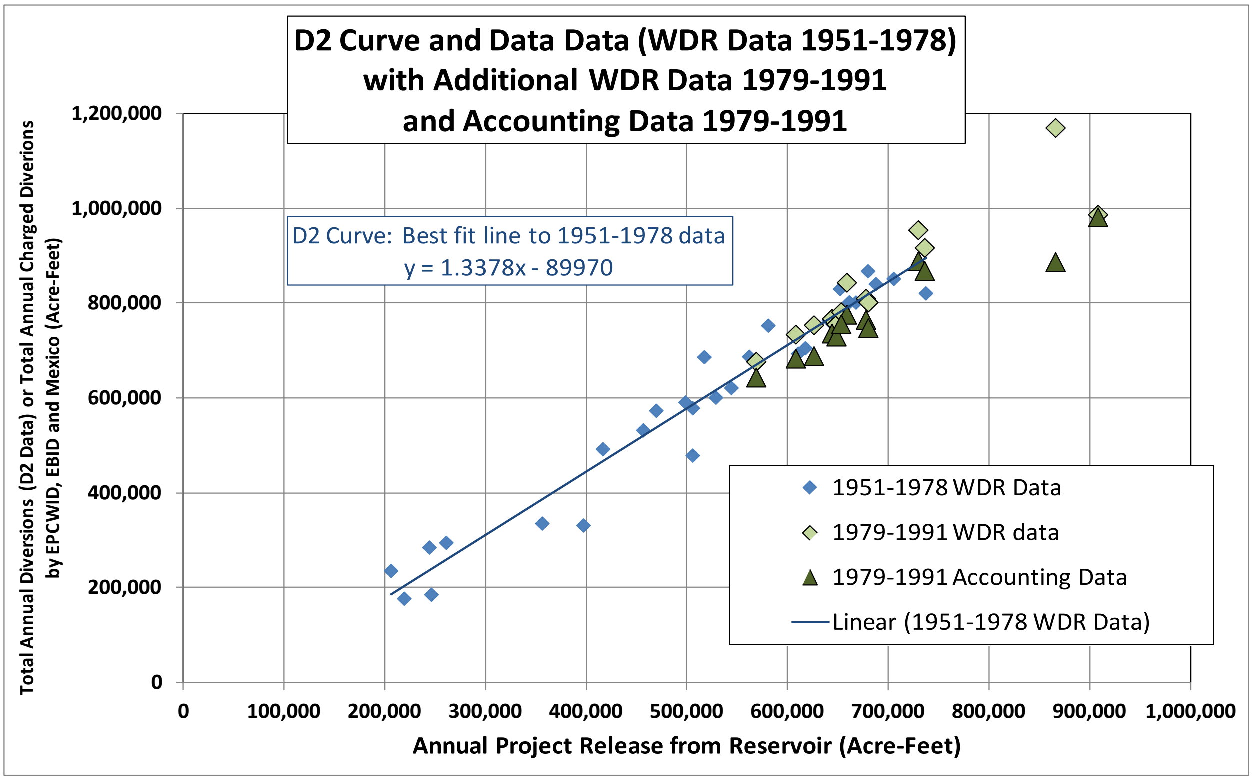
The 1985 Draft Operating Agreement included a description of the process by which the Districts order water and the process for calculating charges and credits, including a statement that "*All diversions made by the Districts during the nonirrigation season utilizing return flow waters shall not be charged against the Districts' respective allocations.*"[11] Only limited information is available regarding the early application of Post-1978 Accounting, and it is uncertain to what extent non-irrigation season diversions were included in the calculation of charged diversion during this time.

Accounting data in the form of charged diversions (or allocation charges) are available for each District starting in 1979 (at least in summary form). In Figure D.7 I have combined the total annual charged diversions for the Districts with the Mexican diversion, and plotted this data from 1979 through 1991 together with the D2 Curve, the D2 data set, and the WDR data from 1979 through 1991.

[10] 1985 Draft Operating Agreement, p 13.

[11] 2008 Operations Manual, p.3.

Figure D.7. D2 Curve and D2 Data (1951-1978), with Additional WDR Data (1979 – 1991), and Accounting Data (1979 – 1991)



Data in Figure D.7 indicate that charged diversions from Project Accounting are systematically lower than data from the WDR reports for the same years. This indicates that Project accounting data are systematically different than the WDR data. This suggests that the accounting process itself is responsible for part of the negative departure from the D2 Curve.

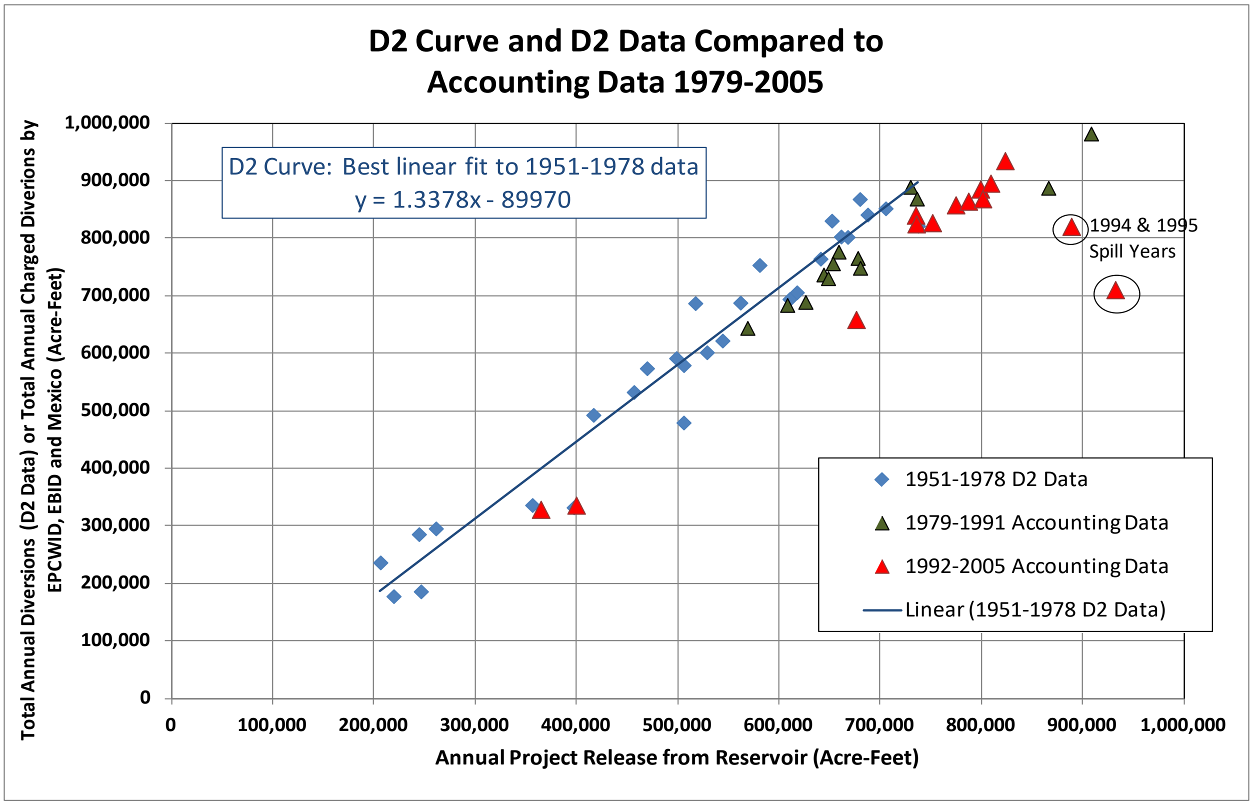
The practical effect of a negative departure from the D2 Curve is that more water will have to released from Caballo to deliver a given amount of charged diversions to the District and Mexico than the D2 Curve would predict.

In recent years, negative departures from the D2 Curve are interpreted by Reclamation as evidence that the performance of the Rio Grande Project has deteriorated since the D2 Period (1951 – 1978).[12] This view is reflected in D3 Allocation (discussed below), which reduces total allocation to account for this negative departure, and "charges" EBID for that entire amount, assuming the discrepancy is all associated with the actions of New Mexico and its citizens, and not taking into account the effect of changes in accounting.

[12] Continued Implementation of the 2008 Operating Agreement for the Rio Grande Project, New Mexico and Texas, Final Environmental Impact Statement, Bureau of Reclamation, September 30, 2016.

In Figure D.8, I have plotted Project accounting data from 1979 through 2005 together with the D2 Curve and associated D2 data. The accounting data consists of annual total Charged Diversions from EBID and EPCWID, combined with the gaged Mexican Diversion at Acequia Madre.

Figure D.8. D2 Curve and D2 data plotted together with 1979 – 2005 Charged Diversions as reported by Reclamation, calculated using Post -1979 Accounting



The 1979-2005 Charged Diversions in Figure D.8 are systematically lower than the D2 Curve. This means that in these years, the total amount of allocation that was delivered to Project headings and Mexico was less than what would be predicted by the D2 Curve, and therefore less than what was allocated under D1/D2 Allocation. This result suggests that Reclamation may have allocated more water than it could have actually delivered as charged diversions in most years since 1979. However, since the Project had a full supply every year between 1979 and 2002, and neither District ordered the full amount allocated to it, there were no resulting operational problems.

I conclude that D1/D2 Allocation, as applied until 2006, generated higher allocations than could be delivered as charged diversions. However, because in the full-supply years of 1979 through 2002 neither District ordered all of its allocation, this issue did not become apparent. There was enough water available to supply all orders, if not the full amount allocated. The problem did become acute, however, in 2003 when the amount of water available to the Project was far below full supply. This condition led Reclamation to allocate by an ad hoc method, without reference to the D2 Curve in 2003 and 2004.

2 ALLOCATION AND ACCOUNTING 2006 – 2019 (D3 ALLOCATION WITH CARRYOVER)

Considerable controversy arose during the 1990s and early 2000s over Project operations. Litigation between the Districts and Reclamation and New Mexico was occurring in a number of judicial venues. During some of this time there were confidential negotiations concerning Project operations, which included the Districts, Reclamation, and the States. It is my understanding that other negotiations took place during this time frame that only included the Districts and Reclamation.

In the spring of 2006, EBID proposed a new and different allocation method, the D3 Allocation method.[13] New Mexico expressed support for this proposal, with the proviso that "additional study is needed before adoption of a permanent change in Project operations."[14] D3 Allocation was implemented by Reclamation in that same year. At about the same time, EPCWID demanded the ability to "carry over" unused allocation from year to year for its individual use,[15] rather than the historic practice of incorporating that unused allocation into the pool of water available for allocation the next year. EPCWID argued that since it did not use all of the water allocated to it in every year, it should be able to "carry over" the excess, and not have to share it with EBID as part of the following year's allocation process, although this had been the practice for "nearly 100 years."[16]

Reclamation partially implemented carryover of unused allocation in 2006, starting the 2007 allocation for each District with what shall be called "Carryover" equal to one-half of the District's unexpended 2006 allocation.[17] EPCWID filed suit against EBID and Reclamation in US District Court for the Western District of Texas in 2007 as a result of this partial (rather than full) implementation of Carryover.

In 2007 Reclamation published and adopted the 2007 Operating Procedures for the Rio Grande Project.[18] These Operating Procedures included the D3 Allocation method as proposed by EBID, and provisions for Carryover of unused allocation as demanded by EPCWID. Also in 2007 confidential

[13] Letter 2006 0426, from James Salopek, EBID to Connie Rupp, Reclamation, RE Project allocation water.

[14] Letter 2006 0605, from John D'Antonio, NM State Engineer, to Connie Rupp, Reclamation, RE: Project operations.

[15] Letter 2006 0719, from James Salopek, EBID, to Connie Rupp, Reclamation, RE: Project allocation of water.

[16] Cortez, F., Affidavit*, El Paso County Water Improvement District No. 1 v. Elephant Butte Irrigation District, et al.,* Cause No. EP-07-CA-0027-PRM, In the U.S.D.C., W. Dist. of Texas, April 20, 2007.

[17] Letter 2007 0119, from Connie Rupp, Reclamation, to Jesus Reyes, EPCWID, RE: Operating plan and 2006 Project allocation.

[18] 2007 Operating Procedures for the Rio Grande Project, U.S. Bureau of Reclamation, Elephant Butte Irrigation District and El Paso County Water Improvement District No. 1, May 15, 2007.

settlement negotiations took place between the Districts and Reclamation (but not including the states of New Mexico or Texas), that in 2008 resulted in settlement of litigation between those parties.

The 2008 Settlement Agreement[19] associated with the two federal cases among Reclamation, EBID, and EPCWID was executed by the Districts and Reclamation. The 2008 Settlement Agreement included the 2008 Operating Agreement[20] adopting D3 Allocation and Carryover.

The 2008 OA included provision for the development of an Operations Manual[21] to "contain detailed information regarding the methods, equations, and procedures used by EBID, EPCWID and the United States to account for all water charges and operating procedures for the Rio Grande Project." An Operations Manual was adopted in 2008, and has been modified since (2010 and 2012) as new issues arose and additional data analysis warrented.

Under the D3 Allocation method, Mexico and EPCWID are generally allocated water according to the D1 and D2 Curves, as described in the previous section, but EBID's allocation is calculated based on the Project Diversion Ratio, a new term in Project allocation.

The Diversion Ratio is calculated as the ratio of the annual Project Charged Diversions (including Mexico) divided by the annual Project release from Caballo. This term is used to estimate the total amount of allocation that can be delivered to the Districts and Mexico (Project Supply) for a given Project release. In effect, the Diversion Ratio is a measure of current Project delivery efficiency or performance, although it is calculated using charged diversions rather than total actual diversions.

The effect of the Diversion Ratio in the D3 Allocation method is shown in Table D.2. The calculation shown is highly simplified, in that Carryover and ACE Credit are assumed to be zero, but accurately represents the effect of the Diversion Ratio. The example shown is for full-supply conditions. The two columns of data show the resulting D3 Allocation as calculated assuming two different diversion ratios: 1.1 and 1.0. Both calculations provide Mexico and EPCWID are allocated the same amounts: 60,000 AF and 377,000 respectively, as calculated using the D1 and D2 Curves.[22] EBID's allocation is calculated using the diversion ratio, and varies greatly between the two scenarios. EBID is allocated 403,000 AF if the diversion ratio equals 1.1, but only 327,000 AF if the diversion ratio is 1.0.

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[19] Agreement between the U.S./USBR, EBID, and EPCWID, executed August 15, 2008, settling cases: *EBID and The City of Cruces/Intervenor v. U.S./USBR and EPCWID,* Cause No. CIV 00-1309 JB/KBM in the District Court of New Mexico, and *EPCWID v. U.S./USBR,* Cause No. EP-07-CA-0027-PRM in the Western District of Texas – El Paso Div. ("2008 Settlement Agreement").

[20] 2008 Operating Agreement for the Rio Grande Project, Agreement between Elephant Butte Irrigation District, El Paso County Water Improvement District No, 1, and the United States through the Bureau of Reclamation, signed March 10, 2008.

[21] 2008 OA, Section 1.12.

[22] The D2 calculation for EPCWID is made in accordance with the 2008 OA, in which the D2 Curve has been extended to a release of 790,000 AF.

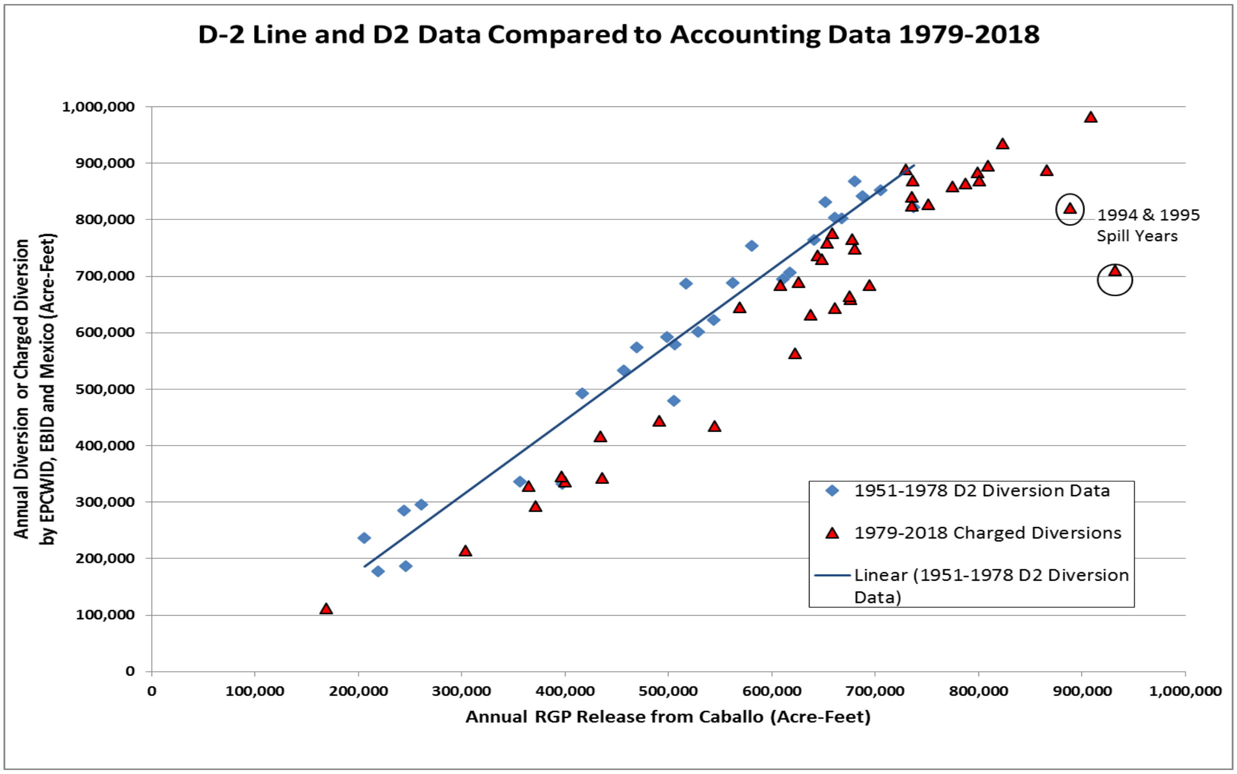
Table D.2. Illustration of the Effect of Variation in the Diversion Ratio (D3 Allocation, Full-Supply)

Illustration of the Effect of Variation in the Diversion Ratio under D3 Allocation. (Values rounded to nearest 1000 AF)		
Diversion Ratio (unitless)	1.1	1.0
Usable Water (AF)	764,000	764,000
Mexican Allocation (AF)	60,000	60,000
EPCWID's Allocation (AF)	377,000	377,000
EBID's Allocation (AF) [(Usable Water x Diversion Ratio) – Mexican Allocation – EPCWID Allocation]	403,000	327,000

Roughly speaking, under the D3 Allocation method, Mexico's D1 Allocation and EPCWID's D2 Allocation are subtracted from the Project Supply (calculated using the Diversion Ratio), and the remainder is allocated to EBID. D3 Allocation has the effect of reducing EBID's allocation by any amount by which the estimated deliverable or actual Charged Diversions falls short of the Net Supply calculated by the D1/D2 Allocation method.

The D3 Allocation is based on a comparison of Project Charged Diversions versus Caballo Release data compared with the D2 Curve. In Figure D.9, I have plotted Project accounting data from 1979 through 2018 together with the D2 Curve and associated D2 data. The accounting data consists of annual total Charged Diversions from EBID and EPCWID, combined with the gaged Mexican Diversion at Acequia Madre.

Figure D.9. D2 Curve and D2 data plotted together with 1979 – 2018 Charged Diversions as reported by Reclamation, calculated using Post -1979 Accounting

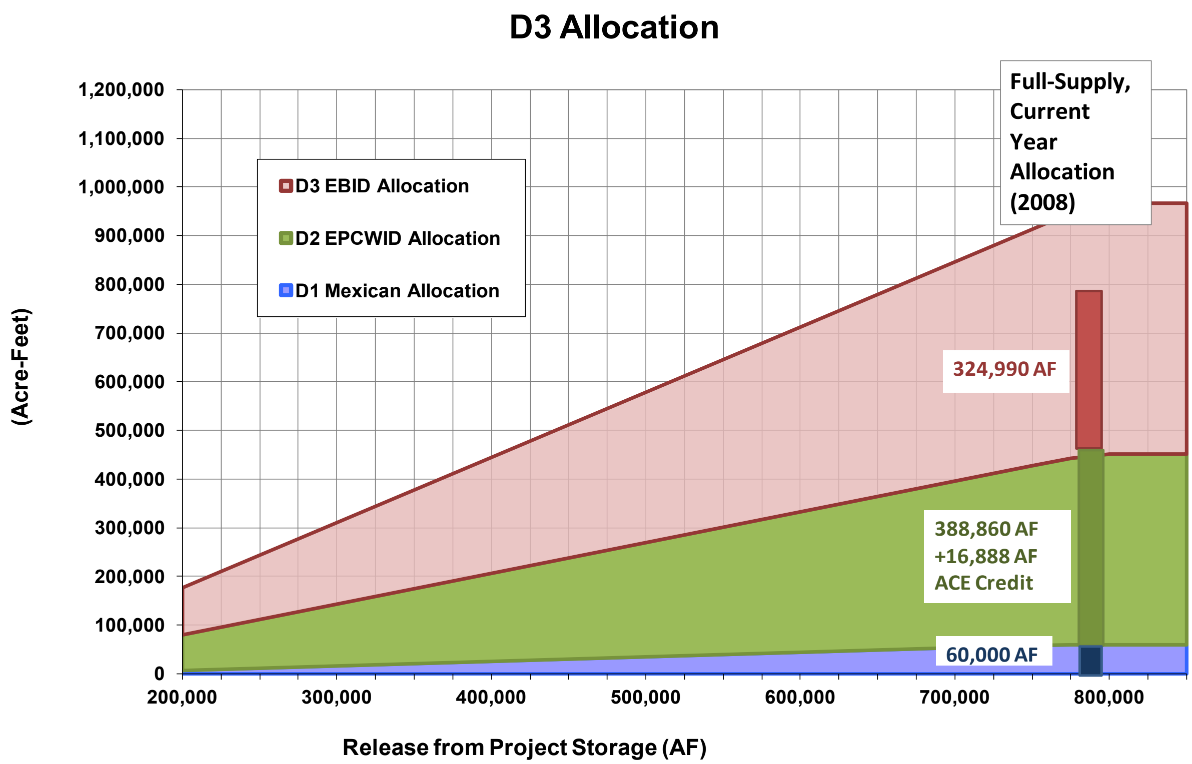


The D3 Allocation method, as applied, uses the Diversion Ratio to reduce the total amount allocated each year to account for deficiencies in Project performance. The total D3 Allocation should, in theory, closely approximate the amount of charged diversions the Project can deliver to canal headings under the hydrologic conditions existing in each year. Mexico's and EPCWID's allocations, however, are still determined using the old D1/D2 method, meaning they suffer no consequences related to changes, or apparent changes, to Project performance. EBID's allocation is reduced to make up the difference; that is, EBID's allocation is reduced by the difference of the total D3 Allocation and the total D1/D2 Allocation, or the negative departure from the D2 Curve.

The import of this negative impact on EBID by D3 Allocation is illustrated for a full supply year (2008) in Figure D.9, which superimposes a bar showing 2008 current-year allocations on top of a D1/D2 Allocation distribution graphic.[23] The effect of D3 Allocation is illustrated by comparing the full-supply allocation bar in Figure D.10 to that of Figure D.4.

[23] The D1/D2 allocation graphic includes the "extension of the D2 curve" included in the 2008 OA, which increases EPCWID's full-supply, current-year allocation from 377,000 AF to 388,000 AF, not including ACE Credit.

Figure D.10. D3 Allocation Illustration with Current-Year Allocation Data from 2008



The D2 Curve, a plot of total water delivered to canal heading versus total release from Caballo, is in effect a historical efficiency or performance relationship for Project delivery. The D3 Allocation method is intended to reduce EBID's allocation to account for all negative departures from the Project's historical performance.[24] As set forth in Section 6 of the Report, Reclamation stated that *"any river system losses in New Mexico that affect the deliveries in EPCWID and Mexico will be replaced from EBID allocated water."*

That is, the D3 Allocation procedure reduces EBID's allocation to account for all negative departures from the D2 Curve (unless multi-year drought conditions apply, in which case the standard for Project performance is eased). The assumption that all negative departures from the D2 Curve are caused by New Mexico is unsupported, and as will be shown in this report, is contradicted by fact.

In sum, D3 Allocation calculates Mexico's allocation using the D1 Curve, EPCWID's allocation using the D2 Curve, and then allocates EBID any water that is left over. New Mexico is only allocated water after EPCWID and Mexico have gotten their full shares.

[24] In theory, EBID's allocation would be increased above its D2 Allocation if Project performance is better than the D2 curve would predict. This occurred only once, in 2011.

2.1 D3 PLUS CARRYOVER ALLOCATION METHOD DESCRIPTION

Project allocation under the 2008 OA is accomplished by the Allocation Committee, which consists of technical representatives from Reclamation, EBID and EPCWID. The Allocation Committee meets before the irrigation season begins, and regularly throughout the irrigation season, to determine the current Diversion Ratio, and update the allocation of water between the Districts and Mexico as necessary.

2008 OA allocation is performed using a spreadsheet with embedded formulas that make allocation calculations. In general, the D3 Allocation method is performed as follows:

1) "Total Usable Water Available for Release" is calculated by subtracting Compact Credit and San Juan-Chama water from the total amount of water in storage in Elephant Butte and Caballo reservoirs. (When allocation is performed during the irrigation season, any water already released from Caballo is also added back in.) A buffer to account for "Reservoir Evaporation/Dead storage" may also be subtracted.
2) Mexico's allocation is calculated using the D1 Curve, based either on the "Total Usable Water Available for Release", or the estimated release from Caballo for the year.
3) Usable Water for Current Year's Allocation is calculated by subtracting the Carryover Obligation (the amount of reservoir water that would be needed to deliver the allocations carried over from the previous year) from the Total Usable Water.
4) EPCWID's current-year allocation is calculated using an adjusted D2 Curve, based on Usable Water for Current Year's Allocation. The D2 adjustments consist of:
    a. A multi-year drought D2 Curve correction factor, lowering the D2 Curve, that is applied during and immediately after extended low-supply conditions, and
    b. An extension to the D2 Curve in high-supply years, so that increasing allocations are calculated up to a newly defined full-supply release of 790,000 AF.
5) EPCWID's current-year allocation is increased by the amount of the American Canal Extension (ACE) credit.
6) The Diversion Ratio is determined, either estimated based on hydrologic conditions (early in the irrigation season), or calculated based on the ratio of charged diversions over Caballo releases to date.
7) The amount of Project Supply (or deliverable allocation) is calculated based on the Diversion Ratio and the estimated release of water for the year.
8) EBID's D3 Allocation is calculated as the Project Supply minus Mexico's D1 allocation and EPCWID's D2 allocation and EPCWID's ACE credit.
9) If EBID's D3 Allocation is greater than what EBID would have been allocated under the D2 Curve, and the supply of Usable Water is less than 600,000 AF, then 43% of that positive departure from the D2 Curve is subtracted from EBID's D3 Allocation and awarded to EPCWID.
10) The amounts resulting from steps 5, 8 (and 9 if applicable) above constitute EBID's and EPCWID's current-year allocations.
11) The total allocation for each District is the sum of each District's current-year allocation plus any Carryover from the prior year.
12) Carryover for the next year is the difference between each District's total allocation and its charged diversions, limited to a maximum of 232,915 AF for EPCWID and 305,918 AF for EBID.

These Carryover limits are based on 60% of each District's full supply allocation. If a District's unused allocation exceeds its Carryover limit, the excess is awarded to the other District.

Under the 2008 OA, a full-supply release is 790,000 AF, and in a full-supply year EPCWID's current-year allocation is 388,192 AF. EBID's allocation always depends on the Diversion Ratio, and so there is no one number that can describe EBID's full-supply, current-year allocation.

Table D.3 provides a simplified version of allocation under the 2008 OA in a full-supply year.

Table D.3. Simplified Allocation Example, D3 Allocation plus Carryover, Full-Supply Year, Amounts rounded to nearest 1000 AF

	Allocation Term	Quantity (AF)	Calculation
A	Total Usable Water Available for Release	1,000,000	
B	EBID Carryover from Previous Year	20,000	
C	EPCWID Carryover from Previous Year	190,000	
D	Total Usable Water Available for Current Year Allocation	790,000	A – B- C
E	Mexican Allocation	60,000	Use D1 Curve
F	EPCWID Current-Year Allocation	390,000	Use Extended D2 Curve
G	EPCWID ACE Credit	20,000	
H	Diversion Ratio	1.0	
I	Deliverable Allocation	790,000	D x H
J	EBID Current-Year Allocation	320,000	I – E – F – G
K	EBID Total Allocation	340,000	J + B
L	EPCWID Total Allocation	580,000	F + C
M	Mexican Allocation	60,000	E

2.2 Post-2008 Changes to Project Allocation Process

The Allocation Committee has made modifications to 2008 OA allocation process since 2008. Three significant changes have been made since 2008:

- A "Multiyear Extreme Drought D2 Correction Factor", introduced in 2012, allows EBID a larger allocation in some low-supply years. The Extreme Drought Factor effectively lowers the D2 Curve in years of successive years of low supply (that is, Caballo releases less than 400,000 AF). The introduction of the Extreme Drought Factor is a recognition that some of the D2 data from the multi-year drought of the 1950s fall below the D2 Curve. The effect of Extreme Drought Factor is to reduce the historical performance target in such years, which reduces EPCWID's allocation and increases EBID's allocation. This term affected Project Allocation in years 2012 through 2016, increasing EBID's allocation, and decreasing EPCWID's.

- An "Estimate End of Season Adjustment of Project Water Due to Evaporation" was added in 2012. The Evaporation Adjustment introduces a cushion into the allocation process by removing some water from the total amount to be allocated in certain years, taking into account that evaporation during the irrigation season may reduce the actual amount of "wet" (or physically available) water available below the amount that might otherwise be allocated. The documentation in the 2008 Operations Manual does not clearly specify when this term will be applied, and how this term is to be calculated. So far, this term has been applied in years 2013, 2014, 2015, 2016 and 2018, and the values applied have range from 5,000 AF to 15,000 AF. This term reduces the chance that the Allocation Committee will allocate more water than can be delivered. In 2011, the year before this Adjustment was introduced, Reclamation had problems delivering all the water it had allocated, and it is likely that this factor was introduced to prevent this situation from arising again. There is no other term in Project allocation or accounting that explicitly accounts for evaporation of Project Supply or of District Carryover accounts.

- Another significant change was introduced in 2011 associated with the calculation of Usable Water Available for Release. Usable Water is a Rio Grande Compact term and is defined as the amount of water in reservoir storage, minus the amount of Compact Credits and omitting imported San Juan-Chama water, as determined by the Rio Grande Compact Commission. In the first years of the 2008 OA allocations, Usable Water was calculated in accordance with the Compact and the amounts of Compact Credit determined by the Compact Commission each March. Starting in 2011, the Project Allocation Committee started to estimate Compact Credits by other methods, reducing the Compact Commission's values for additional evaporation during the irrigation season, thus freeing up more "Usable Water" for Project allocation and release but decreasing New Mexico's Compact Credit Water to its detriment.[25] New Mexico objected forcefully to this change, and it has had repercussions on Compact Accounting that continue to the present time. *See* Estevan Lopez Expert Report, 2019, for a full discussion of this issue.

2.3 Post-2008 Changes to Project Accounting

In addition to changes in allocation, following the adoption of the 2008 OA there have been a number of modifications to the Project accounting process. These changes have taken the form of additional charges against EPCWID's allocation:

- In 2012 a charge for "Upper Valley Pumps" was added to EPCWID's accounting summary. It is my understanding that this term is intended to account for the water pumped by EPCWID District-owned and operated wells in the southern Mesilla Valley. The amounts of water associated with this new charge have been small (less than 500 AF/Y) and in some years this term is omitted from the accounting summary altogether. (There is no term associated with farmer-owned and operated irrigation wells in the Texas part of the Mesilla Valley, which are estimated to pump over 10,000 AF/Y in low-supply years.)

- In 2016 a change was made to EPCWID's accounting summary, labeled "Proposed 2016 CWF Resolution and NWWTP Flow." This charge reappears in 2017, and in 2018 is replaced by a

[25] As a result of this calculation, in 2011 Reclamation released Compact Credit water from Elephant Butte reservoir, leading to New Mexico's lawsuit against Reclamation in August of 2011. *State of New Mexico v U.S. Bureau of Reclamation, et al.,* Case No. 1-11-cv-00691-JB-KK, In the United States District Court, District of New Mexico.

charge for "CWF Technical Memorandum 1/9/2019." It is my understanding that these charges are associated with the El Paso Water Utility's Canutillo Well Field. The Canutillo Well Field is located in the southern Mesilla Valley in Texas, along the Rio Grande. The Canutillo Well Field pumps 20,000 AF to 24,000 AF annually, depleting the flows of the Rio Grande stream system.[26] The associated annual "CWF" charges to EPCWID range from 4,500 AF to 8,000 AF. Based on my familiarity with prior discussions on how to account for Canutillo Well Field pumping effects on the Project, I conclude that the discrepancy between the amount pumped and the amount charged to EPCWID is caused by: 1) an assumption that pumping effects that occur outside of the irrigation season do not have to be charged, and 2) return flow credit awarded for waste water effluent from the North West WWTP; essentially a return flow credit.

2.4 Carryover

An important concern with the 2008 OA allocation process is related to the magnitude and the treatment of Carryover accounts. Allocation that is not used by a District in one year is now carried over into the District's allocation the following year. The limits on these Carryover accounts are high: 232,915 AF for EPCWID, and 305,918 AF for EBID.[27] Recall that prior to 2007, allocated water not used by either District was simply included in pool of water available for allocation the next year.

In practice, EBID has only carried over small amounts of water from one year to the next. In fact, EBID's allocation under the D3 Curve has been insufficient to supply EBID's irrigation water needs, and so EBID generally takes all of the water it is allocated. Typically any unused allocation EBID carries over results from late season allocation increases by Reclamation, or Carryover transfers, that EBID cannot make use of during the current irrigation season. EPCWID, on the other hand, has carried over large amounts of water in some years. For instance, in 2009 EPCWID reached its Carryover limit of 232,915, and transferred 82,044 AF of excess Carryover to EBID.[28]

Early in the allocation process Carryover accounts, plus additional water needed to deliver the amount Carryover,[29] are subtracted from the Usable Water in storage, and effectively sequestered from the allocation process. Current-year allocation is then calculated from the remainder of Usable Water. Some part of the Carryover accounts, however, may not actually be associated with water in storage. Carryover accounts are not reduced for evaporation. Since evaporation does in fact occur, inflows to

[26] Rio Grande stream system includes both the mainstem of the Rio Grande and associated Project conveyances, particularly drains, which are depleted by groundwater pumping.

[27] 2008 OA, p 3.

[28] While in 2010 a transfer of 10,271 AF was made from EPCWID to EBID, this transfer appears to be associated with an attempt to address depletions to Project Supply caused by the EPWU Canutillo Well Field, which is located in the southern Mesilla Basin above Courchesne. The transfer associated with Canutillo Well Field impacts was not repeated; however, starting in 2016 an accounting charge averaging 6,700 AF/Y associated with Canutillo impacts was applied to EPCWID. This is discussed further in the Report, Section 6.3.6.

[29] The amount of allocation in the Carryover accounts is divided by the Diversion Ratio to determine the reservoir release needed to deliver the Carryover allocation. If the Diversion Ratio is less than 1.0, that inflates the amount of water sequestered for Carryover, before any current-year allocation can be made.

the reservoir that otherwise would have been available for allocation are instead sequestered to make the Carryover accounts whole.

In addition, some of the Carryover allocation may be associated with Project credits, such as the ACE Credit, or the accounting credits, rather than any reduction in District orders. As a result, some part of a Carryover account may consist of "paper water," that is not associated with any water in reservoir storage (as opposed to wet, physically existing water). Despite this fact, the allocation process gives the Carryover accounts first priority in allocation, and therefore new inflows to the reservoir are first assigned to fulfill, and reserved for the delivery of, the Carryover accounts, before any of these inflows are available for current-year allocation.

Any Carryover in excess of wet water results in a reduction to the current year allocation of both Districts. The net effect is a negative impact on EBID's the total allocation, because EBID gets so little of the benefits of Carryover. See, for instance, the concrete example below.

2.4.1 2010/2011 Example of Carryover Impact

A clear example of the negative impact to EBID caused by the current Carryover method that occurred in late 2010 through early 2011. Table D.4 summarizes reservoir storage and Carryover conditions at the end of the 2010 irrigation season in October 2010 (releases from Caballo ended on October 7, 2010). As of October 15, 2010, there was a total of 386,735 AF combined storage in Elephant Butte and Caballo storage. When I subtract from that Compact Credit and San Juan-Chama water from that amount, I calculate a total of 224,739 AF of Usable Water in storage. The total unused allocation from 2010, which was carried over into the Districts' 2011 allocations, was 244,362 AF. That is, the amount of Usable Water in storage was less than the amount allocated to the Districts through their Carryover accounts. As a result, all of the inflows to the reservoir for the next several weeks, up to 19,723 AF, went straight into these Carryover accounts, and was not available for "current year" allocation to the Districts.[30] Since EPCWID's Carryover account was by far the largest, most of these inflows accrued to EPCWID.

Once the allocation process for 2011 began, the Project's Carryover Obligation was calculated. The Carryover Obligation is the amount of Caballo release needed to actually deliver the amount of water in the Carryover Accounts, taking into account the hydrologic conditions (gains/losses) obtaining in 2011. The Carryover Obligation is calculated by dividing the total amount in Carryover Accounts by the Diversion Ratio, which was 0.85 in 2011 (final value for the year). The resulting Carryover obligation was 287,485 AF, and this corresponds to the amount of water sequestered from reservoir storage before any Current-Year Allocation is made from the remaining Usable Water.

The net result is that 62,846 AF of the inflow to Elephant Butte occurring after the end of the 2010 irrigation season were required to fulfill Carryover obligations (mostly to EPCWID) under the 2008 OA. As a result there was 62,846 AF less water available for Current-Year Allocation. Both Districts received lower Current-Year Allocations, but EPCWID received the benefit of a large Carryover account from which no evaporative losses had been subtracted, nor any deduction for paper water had been made.

[30] Allocation is measured at canal headings. To compare an allocation amount with the amount of reservoir water release needed to deliver that allocation, it is necessary to divide the allocation amount by the Diversion Ratio. In the comparison I have made in this paragraph, there is an implicit assumption that the diversion ratio is 1.0.

As it turned out, the inflows to Elephant Butte during 2011 were very low, and EBID's Current-Year Allocation was only 67,000 AF. Presumably, if 62,846 AF of the reservoir inflows had not been sequestered to make up EPCWID's large Carryover Account and the resulting Carryover obligation, EBID's Current-Year allocation would have been considerably larger.

Table D.4. 2010 – 2011 Example of New Inflow to Reservoir Needed to Fulfill Existing Carryover Accounts and Obligation

2010 - 2011 Example of when Carryover Accounts Required Additional Inflows			
		Storage, Carryover and Credit Conditions as of October 15 2010	Storage, Carryover and Credit Conditions as of January 1, 2011
Total Water in Reservoir Storage	(AF)	386,735	497,789
CO Compact Credit	(AF)	800	2,700
NM Compact Credit	(AF)	100,500	164,700
San Juan Chama Water	(AF)	60,796	64,250
Usable Water In Storage	(AF)	224,639	266,139
		Project Accounting 2010	Project Accounting 2011
EBID 2010 Unused Allocation (Carryover from 2010 to 2011)	(AF)	20,014	
EBID 2010 Unused Allocation (Carryover from 2010 to 2011)	(AF)	224,348	
Total Carryover (Carryover from 2010 to 2011)	(AF)	244,362	
2011 Diversion Ratio	(unitless)	0.98	0.85
2011 Carryover Obligation (divide total Carryover by 2011 Diversion Ratio	(AF)		287,485
Inflows to Elephant Butte after October 15, 2010 required to fulfill Carryover Obligation			62,846

3 POST-1978 PROJECT ACCOUNTING CREDITS

Project Credits are an adjustment to either allocation or accounting that increases the amount of water a District can divert. Some accounting credits are associated with the approved diversion and waste of water that is then re-diverted at another location, becoming part of the accounting charge at the second location. Such is the case with the EBID credits described here, and EPCWID's Ascarate Credit. Other credits are associated with the diversion of water that is not considered "Project Supply," diversion and waste of water in excess of orders, and changes in Project infrastructure.

3.1 EBID CREDITS

El Paso Bypass or El Paso Carriage: During dry periods, the canal system may be more efficient than the bed of the Rio Grande at conveying water. Therefore, in some years water destined for delivery to Texas was diverted into the EBID canal system so it could be transported through the canals instead via the Rio Grande, and then wasted back (or returned) to the Rio Grande at the bottom of the Mesilla Basin where it was then delivered to EPCWID canal headings in the El Paso Valley. Project WDRs indicate that such bypass water has been diverted at Percha, Leasburg and Mesilla dams.

Water Delivered to EPCWID in Mesilla Basin: EBID supplies water to Texas lands in the lower Mesilla Basin from the Eastside and Westside Canals. EBID is charged with the total diversions at Mesilla Dam, and then credited with the water delivered to those Texas lands, plus bypass water returned to the river (at Wasteway 32), plus some additional water for carriage. The total credit given to EBID is larger than the charge to EPCWID for water delivered to Texas lands in the lower Mesilla. The water wasted to the Rio Grande at Wasteway 32 is available for diversion and use by EPCWID in the El Paso Valley.

3.2 EPCWID CREDITS

3.2.1 Credit for Diversions Greater than Orders

At times there is more water available at EPCWID's canal headings than was ordered ("excess water"). This occurs despite the fact that Caballo releases are adjusted so as to minimize any excess water at these locations.

EPCWID charges in the El Paso Valley are based on the District's actual diversions at its canal headings in the El Paso Valley. EPCWID is allowed to divert water in excess of its orders. If EPCWID diverts excess water, but then does not use all of that excess water, and returns it through certain wasteways, it will be given credit for the amount of that return. According to Bert Cortez and Phil King[31] this credit is awarded so to encourage EPCWID to use all the surface water that is available to it, in the interests of increasing Project efficiency. Allowing EPCWID to divert water in excess of its order, and crediting it for the unused part of that excess diversion, is believed to increase the total amount both used and charged.

Calculation of the water returned is made on a daily basis using flow measurements from various canals, laterals, drains, and wasteways. Credit for this return is only awarded for days on which the daily

[31] Filberto Cortez of Reclamation and Phil King, Consulting Engineer for EBID.

“adjusted flow” (a measure of the net diversion, adjusted downward for credits already given) is greater than the total order at Franklin and Riverside. The size of the credit is limited by the difference between the adjusted flow and the total order.

3.2.2 Ascarate Wasteway

The Ascarate Wasteway historically discharged water from the Franklin Canal to the Rio Grande. Ascarate was an integral part of Project operations until the completion of the American Canal Extension in 1988.

American Dam gives the Project the ability to divert water from the Rio Grande upstream of the Mexican Diversion. Since 1938, Project practice has been to divert all the water in the Rio Grande at American Dam, except for part that needed to supply the Mexican Diversion required by the Treaty.[32] A large part of the water diverted at American Dam was then wasted back to the Rio Grande delivery to the Riverside Dam. Some of this water was wasted from American Canal, before any EPCWID charge was made on it. The rest of this water was diverted into the Franklin Canal, and charged as part of the Franklin Diversion, and then wasted back to the Rio Grande through the Ascarate Wasteway. To avoid charging that Ascarate water twice, both at Franklin and again at Riverside, the amount of the Ascarate waste was credited to EPCWID. This credit was similar to EBID’s credits, in that it was a credit assigned for a planned waste of water that would then be re-diverted at Project canal heading downstream, and charged in the Project accounting for that location.

Riverside Dam failed in 1987 and was replaced by a temporary rock cofferdam that was in use until completion of the American Canal Extension in 1998.[33] Since that time, the Riverside Canal has diverted water from the American Canal Extension instead of from the Rio Grande. It would appear that accounting changed to reflect this in 1999. Prior to 1999, EPCWID received credit for the full amount wasted at Ascarate: typically 20,000 to 30,000 AF. In 1999 and 2000 no credit associated with Ascarate was given. Starting in 2001, some small credits associated with Ascarate were granted, but these credits were not equal to the total water wasted, indicating a change in Project Accounting has been made to reflect the change in operations.

3.2.3 Haskell R. Street Waste Water Treatment Plant Effluent

EPCWID also receives credit associated with effluent from the Haskell R Street Waste Water Treatment Plant (location shown in Figure D.11; hereinafter ”Haskell WWTP”). Haskell WWTP discharges effluent into the American Canal upstream from the Riverside heading, where that water is diverted together with the other water available at that location. The entire amount diverted at the Riverside canal heading is gaged and included in EPCWID’s Project accounting charges.[34] EPCWID is then awarded a credit in Project Accounting equal to the amount of the Haskell WWTP effluent discharge.

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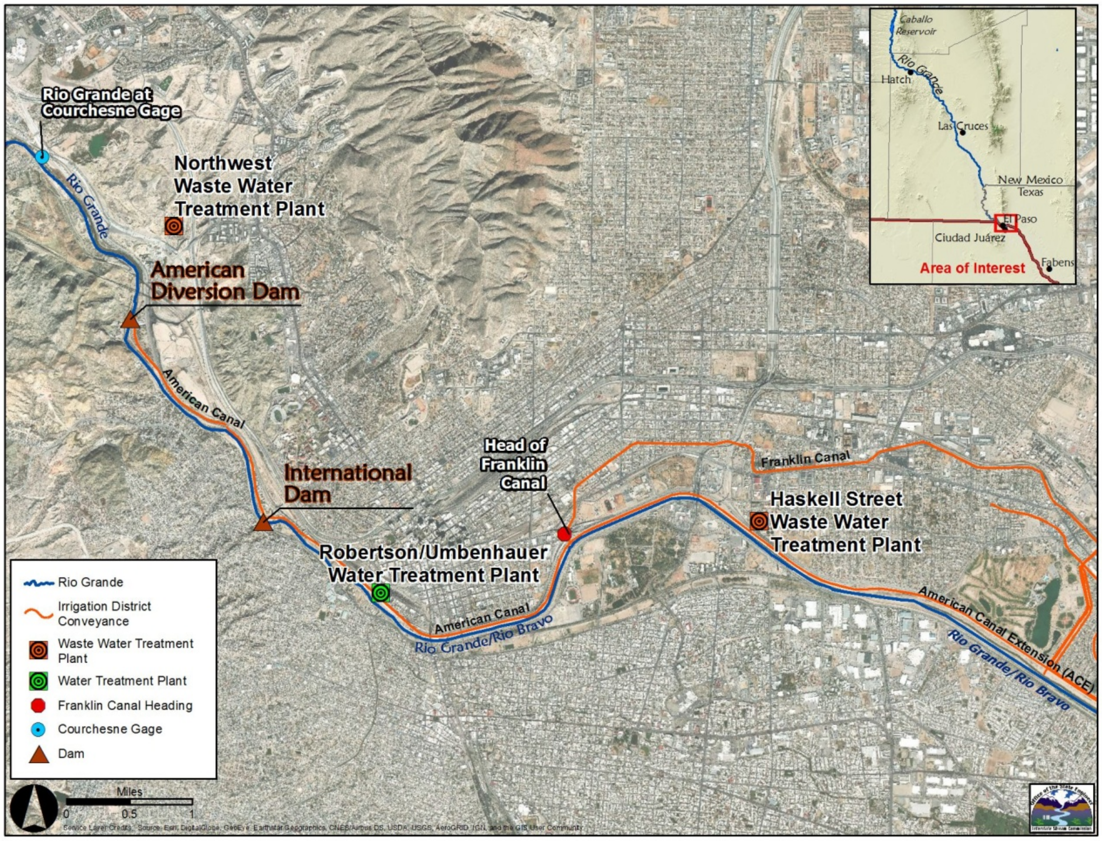
[32] RGPH 1943, Hydrometry Section, starting p. 29/312.

[33] 2001 Final Environmental Assessment for “Replacement of the Old American Canal” Located in El Paso, Texas. prepared for U.S. IBWC by ENCON International, Inc., December 6, 2001 (2001 FEIS).

[34] Part of the water diverted at the Riverside canal heading is gaged as it is diverted to EPWU’s Jonathan Rogers municipal water treatment plant, and the remainder is gaged below the EPWU diversion.

Figure D.11. Location Map of Project Structures in the El Paso Area and Haskell WWTP



The basis for this credit is described in a 1999 letter from Filberto Cortez (Manager of Reclamation's El Paso Office) to El Fifer (General Manager of EPCWID).[35] According to this letter, EPCWID requested that it be given accounting credit for Haskell WWTP effluent, because that water is "non-Project due to the fact that it does not reach the bed of the Rio Grande." The justification provided for this position is EPCWID's Transfer Contract,[36] which states that "Project Water Supply shall mean stored water legally available for release in the Elephant Butte and Caballo Reservoirs and including the legally appropriated waters reaching the bed of the Rio Grande between Caballo Dam and Riverside Diversion Dam."

Prior to 1999, effluent from the Haskell WWTP discharged directly into the Rio Grande below International Dam, and diversion of this water at Riverside was charged to EPCWID.[37] After the

[35] Letter 1999 0708, from Filiberto Cortez, USBR, to Edd Fifer, EPCWID, RE Summary of June 25, 1999 meeting on water accounting.

[36] Contract 1980 0314, No. 0-07-54-X090, for Transfer of the Operation and Maintenance of Project Works, between Bureau of Reclamation and El Paso County Water Improvement District No. 1.

[37] Op. cit. "water charges were based on actual flows at Riverside Canal heading, which included the Haskell Street effluent discharge."

completion of the American Canal Extension in 1998, Haskell WWTP effluent was intercepted by the ACE. I have illustrated the configuration of Project conveyances and the Haskell WWTP effluent discharge in a schematic diagram in Figure D.12.

In 1999, EPCWID argued that the interception of the Haskell WWTP effluent before it reached the bed of the Rio Grande rendered it "non-Project water," and therefore EPCWID should not be charged for diverting and using that water. Reclamation agreed to EPCWID's request, and EPCWID and Reclamation agreed on a modification to Project accounting which gave EPCWID credit for the amount Haskell WWTP effluent discharged into the ACE (no adjustment is made for losses between the point of discharge and the Riverside heading). The annual amount of the Haskell WWTP credit awarded to EPCWID has ranged from 1,700 AF to 12,700 AF.

It is my opinion that the effluent water discharged at Haskell WWTP originated as Project water diverted at EPWU's Robertson/Umbenhauer drinking water treatment plan, combined with groundwater pumped from wells in the Mesilla or Hueco basins which have impacted the water supply available to the Project. This effluent is basically Project return flow, and should be considered Project Supply. The fact that this effluent is now intercepted by the ACE does not change its character, and there is no reason why EPCWID should not be charged for diverting and making use of this water.

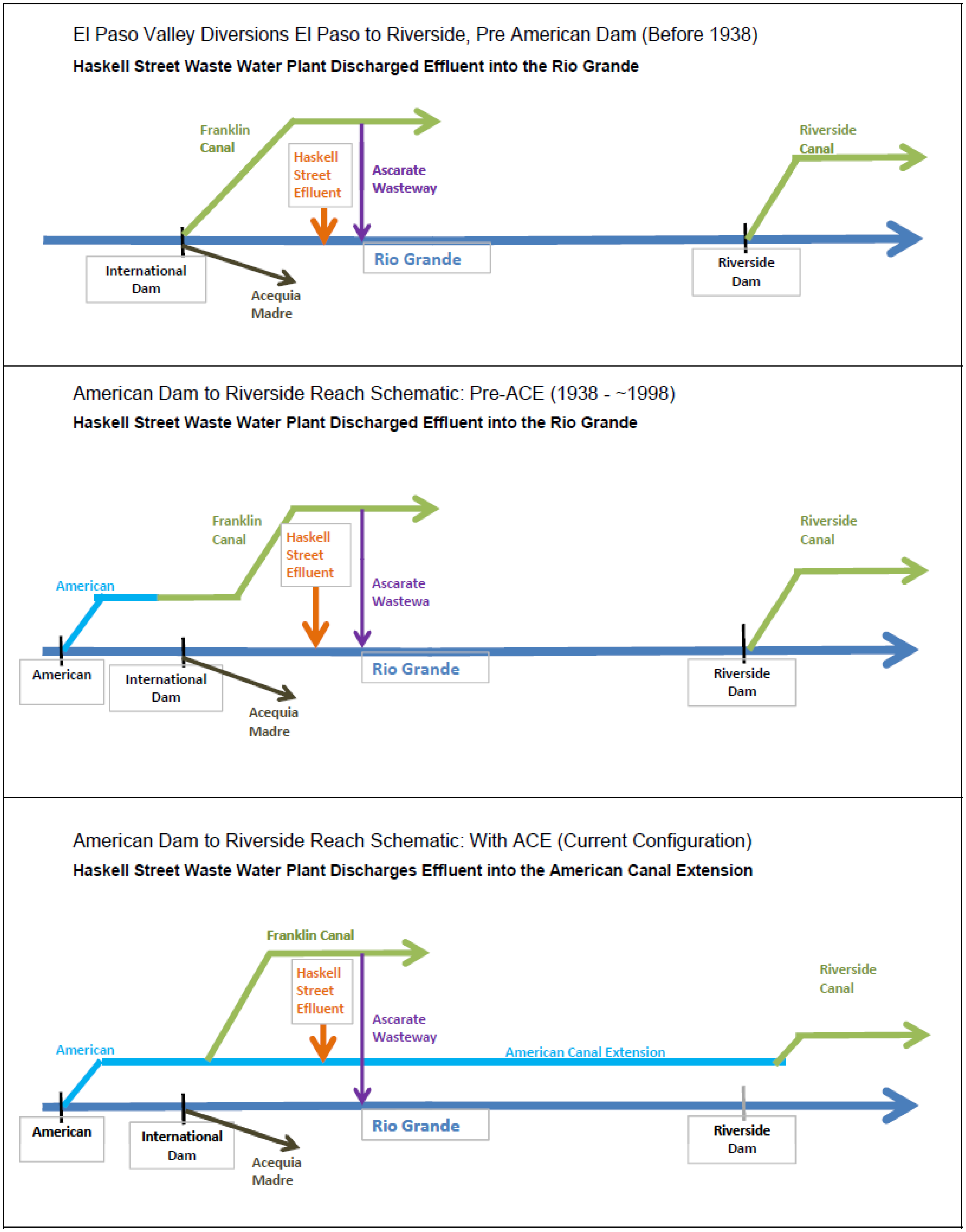
Furthermore, the bed of the Rio Grande is no longer used to convey water to Project headings in the El Paso Valley. The function of the Rio Grande has now been usurped by the ACE. It is therefore reasonable to consider any discharge into the ACE to be Project Water.

Prior to the adoption of D3 Allocation, EPCWID's Haskell WWTP credit had little or no effect on Project allocation. Once D3 Allocation was adopted, the Haskell WWTP credit had a detrimental effect on EBID's D3 allocation:

- Haskell WWTP effluent was part of the water diverted and tabulated during the D2 Period, and therefore is part of the D2 Curve. Since 1999, EPCWID's diversion of Haskell WWTP effluent is now longer included in its charged diversions, and therefore contributes to the negative departure (or gap) from the D2 Curve.
- The net effect of the Haskell WWTP credit is to reduce EPCWID's charged diversions and thereby to reduce the Diversion Ratio (which is based on total charged diversions). EBID's allocation is reduced by any reduction in the Diversion Ratio.

As a result, the Haskell WWTP effluent credit awarded to EPWID has the net effect of reducing the EBID allocation, to the detriment of New Mexico.

Figure D.12. Schematic Diagram of Rio Grande and Project Conveyances in the El Paso to Riverside area, showing the relative location of the discharge of Haskell WWTP effluent



3.2.4 American Canal Extension / Conservation Credit

In 1998 the American Canal Extension ("ACE") project was completed, which lined parts of the existing American Canal, and extended the American Canal to the Riverside Canal heading (as illustrated in Figure D.12). Since 2003, EPCWID's allocation has been increased by a "conservation credit" ("ACE Credit") associated with the ACE.

The ACE Credit is a result of the following conveyance history. Since the completion of the American Dam in 1938, EPCWID diverted into the American Canal all water not needed to supply the Mexican diversion. Prior to the ACE, EPCWID had to waste a large amount of water from American Canal and Franklin Canal back to the Rio Grande, for diversion at its Riverside several miles downstream. The extension of the American Canal has allowed EPCWID to keep this water out of the Rio Grande and deliver it to the Riverside heading through the ACE, presumably reducing conveyance losses.

EPCWID has estimated the amount of water conserved by delivering water to Riverside through the ACE instead of the Rio Grande main stem and this calculation is the basis for a credit awarded to EPCWID, which varies depending on the amount of water EPCWID diverts. The ACE Credit was first granted in 2003. It is my understanding that a dispute the Districts and Reclamation followed. The ACE Credit was not granted in 2005, but was reinstituted in 2006. This Credit is applied as an increase in EPCWID's allocation instead of a reduction in EPCWID's total charges. EPWU was involved in the financing of the ACE, and has gained an increase in the amount of water it can buy from EPCWID as a result.

The effect of the ACE Credit is to reduce EBID's allocation. This can occur in two ways; the first way is by applying it within the allocation spreadsheet; the second way it by adding it onto EPCWID's allocation at the end of the year during the Project accounting process.

- First method: As the 2008 OA is written, the ACE credit is applied within the allocation spreadsheet. The ACE Credit is added to EPCWID's allocation before EBID's allocation is calculated. The allocation spreadsheet calculates the amount of water available for current-year allocation, and then subtracts Mexico's ad EPCWID's allocations to calculate EBID's D3 allocation. As a result, the amount of the ACE credit is subtracted directly (1:1) from EBID's allocation.

  The effect of the ACE in the allocation spreadsheet is illustrated in Figure D.13, which is an image of a modified version of the 2009 allocation spreadsheet. In order to test the effect of the ACE credit on EBID's allocation, I modified the 2010 allocation spreadsheet by copying the 2009 allocation calculations into a second allocation column labeled: Modified No ACE Credit. When I copied the 2009 allocation calculations, I kept all formulas and data entered for 2009, except that I set the ACE Credit (Row 21) to zero. The Total Allocations calculated as a result of this change are shown in Rows 36 and 37, and the difference between the allocations with and without the ACE is shown, highlighted, next to those columns. The net effect of removing the ACE Credit of 17,998 AF is to increase EBID's allocation by 17,998 AF and decrease EPCWID's allocation by that same amount. Therefore, I conclude, that the ACE Credit, as awarded to EPCWID in the allocation spreadsheet, is taken directly out of EBID's allocation, one-for-one. In effect, the allocation of water has become a zero sum game: any increase to EPCWID's allocation comes at the expense of EBID.

Figure D.13. Image of Reclamation Allocation Spreadsheet from 2009, Modified to Test Effect of ACE Credit on Allocation

TestACE_AllocationSS.xlsx 2009 Allocation-ACE

1	**Rio Grande Project Diversion Allocations (EOM OCT 2009 Project Data)**	**Original Data**		**Modified: No ACE credit**	
2	Elephant Butte Reservoir Storage	454,530		454,530	
3	Caballo Reservoir Storage	26,100		26,100	
4	Total Rio Grande Project Storage	480,630		480,630	
5	Estimated Rio Grande Compact Credit Waters	-126,600		-126,600	
6	Estimated San Juan-Chama Water	-37,298		-37,298	
7	Water Released from Storage	693,289		693,289	
8	Total Usable Water Available for Release	1,010,021		1,010,021	
9	Carryover Obligation using Estimated Diversion Ratio	235,960		235,960	
10	Total Usable Water Available for Current Year Allocation	774,061		774,061	
11	EBID Allocation Balance (Previous Year)	-4,304		-4,304	
12	EPCWID Allocation Balance (Previous Year)	232,882		232,882	
13	EBID Allocation Balance (End-of-Year)	40,343		40,343	
14	EPCWID Allocation Balance (End-of-Year)	232,915		232,915	
15	Storage for EBID and EPCWID Allocation Balance (End-of-Year)	276,869		276,869	
16	Current Usable Water	733,152		733,152	
17	End-of-Year Release for Diversion Ratio	693,289		693,289	
18	D1 Delivery	470,416		470,416	
19	Mexico's Current Diversion Allocation	53,386		53,386	
20	Gross D2 Diversion Allocation	942,117		942,117	
21	EPCWID ACE Conservation Credit	17,998		0	
22	Net D2 Diversion Allocation for EBID and EPCWID	888,731		888,731	
23	D2 Diversion Allocation for EPCWID	384,161		384,161	
24	EPCWID Diversion Allocation (w/o Conservation Credit)	617,043		617,043	
25	EPCWID Diversion (w/o Conservation Credit or 67/155ths of Row 30)	384,128		384,128	
26	Diversion Ratio	0.986956		0.987	
27	Diversion Ratio Adjustment	-9,563		-9,563	
28	Sum of Release and Diversion Ratio Adjustment	723,589		723,589	
29	EBID D2 Diversion Allocation	504,570		504,570	
30	Difference between EBID Diversion Ratio Allocation and D2 Diversion Allocation	0		0	
31	EBID Diversion Ratio Allocation	268,077		286,075	
32	EBID Diversion Allocation	268,077		286,075	
33	Total EBID Diversion Allocation (includes 88/155th of Value in Row 30)	263,773		281,771	
34	Total EPCWID Allocation (includes Row 21 and 67/155th of Value in Row 30)	635,041		617,043	
35	District to District Allocation Transfer (OA 1.11 Excess Carryover Balance)	82,044		82,044	
36	Total EBID Diversion Allocation (After Transfer)	345,817		363,815	17,998
37	Total EPCWID Allocation (After Transfer)	552,997		534,999	-17,998
38	Total EBID, EPCWID, and Mexico Allocation	952,200		952,200	
39	EPCWID 2009 Allocation Charges (calculated)	320,082		302,084	
40	EBID 2009 Allocation Charges (calculated)	305,474		323,472	
41	EPCWID 2009 Allocation Charges (actual)	320,083		320,083	
42	EBID 2009 Allocation Charges (actual)	305,475		305,475	
43	Mexico 2009 Allocation Charges (actual)	58,688		58,688	
44	Difference in Mexico's Charges and Allocation	-5,302		-5,302	
45	EPCWID Share	-2,292		-2,292	
46	EBID Share	-3,010		-3,010	

- Second method: The ACE Credit has been applied differently in some recent years. Instead of being applied through the allocation spreadsheet, as provided for by the 2008 OA, the ACE Credit has been added onto EPCWID's allocation at the end of the year during the Project accounting process. This application has a negative impact on EBID, but not as great an impact as when it is applied within the Allocation Spreadsheet. When added onto EPCWID's allocation at the end of the year, outside of the Allocation Spreadsheet, the effect of the ACE is to increase EPCWID's Carryover for the next year. This increase in EPCWID's Carryover reduces the amount of Usable Water available for Current-Year Allocation, which will reduce the Current-Year Allocation of both Districts. The associated reduction in EBID's will be on the order of one-half of the ACE Credit, instead of the entire amount of the ACE Credit.

3.2.5 Compilation of EPCWID Credit Data

The tables below summarize the data presently available as to the credits awarded to EPCWID since 1997. Table D.5 is a summary of the total annual accounting credits awarded to EPCWID.

Table D.5. Summary of Project Accounting Credits assigned to EPCWID, extracted from Project Accounting Records

Table D.5. Credits to EPCWID Extracted from Project Accounting (Acre-feet)				
Year	Ascarate Credit	Credit to District for Diversions Greater than Orders	Haskell Effluent Credit	Sum
1997	27701	29956	0	57657
1998	9289	23219	0	32508
1999	0	13758	12732	26490
2000	0	16721	10700	27421
2001	1587	25197	11360	38144
2002	1179	1235	10844	13258
2003	0	1016	9595	10611
2004	0	1925	10759	12684
2005	0	0	9923	9923
2006	0	6412	10347	16759
2007	0	7173	11038	18211
2008	0	7070	11625	18695
2009	0	3307	11597	14904
2010	0	1951	10240	12191
2011	0	0	4337	4337
2012	0	0	5401	5401
2013	0	0	1703	1703
2014	0	0	2489	2489
2015	0	1438	4032	5470
2016	0	0	7712	7712
2017	0	111	7839	7950
2018	0	0	4838	4838

Table D.6 summarizes the ACE Credit quantities that EPCWID has been awarded. In the years 2008-2010 the accounting and allocation records are not clear as to exactly how this credit has been applied. In any case, the ACE Credit is applied to increase EPCWID's allocation. In some years this appears to have been done during the allocation process as part of the allocation spreadsheet. In other years, the ACE Credit is added onto EPCWID's allocation at the end of the year, and shows up only in EPCWID's accounting summary. In some years, the ACE Credit appears in both allocation and accounting, and while it may not have been "double counted," the records we have are not completely clear on this matter.

Table D.6. Summary of American Canal Extension Credits assigned to EPCWID, Increasing EPCWID's Annual Allocation, extracted from Project Allocation and Accounting Records

Table D.5. American Canal Extension (ACE) Credit (a.k.a. Conservation Credit)	
2003	12,127
2004	13,025
2005	0
2006	14,511
2007	13,386
2008	16,818
2009	17,998
2010	17,347
2011	0
2012	0
2013	0
2014	7,485
2015	11,651
2016	0
2017	13,650
2018	0

APPENDIX E

ANALYSIS OF THE D2 DATA SET

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Appendix E: Analysis of the D2 Data Set

The purpose of this Appendix is to describe the origin of the Rio Grande Project diversion and delivery data used to derive the D1 and D2 Curves described in Reclamation's Rio Grande Project Water Allocation Procedures ("WSAP") document[1] and that are now incorporated in the D3 Allocation procedure of the 2008 Operating Agreement ("2008 OA"), and to discuss the impact of certain data included in the D2 data set. Project allocation methods are described in more detail in Appendix D.

It is my understanding that the D2 Curve was derived from year-round monthly diversion data and is therefore inflated, compared to the irrigation-season, Post-1979 Accounting data to which the D2 Curve is compared under D3 Allocation. As a result, EBID's annual allocation is reduced to its detriment because of a fundamental accounting discrepancy.

1 D1/D2 Allocation

Both D1/D2 Allocation and D3 Allocation methods are based upon the D1 and D2 Curves. These Curves are linear regression relationships calculated from Project delivery data from 1951 through 1978.

D1 Curve: Defines the correlation between annual reservoir releases and "Total Deliveries." Total Deliveries consist of:

- Total farm deliveries within the U.S.,
- "Non-Farm Deliveries" to the City of El Paso, and
- Total delivery to Mexico at Acequia Madre.

Under D1/D2 Allocation, the D1 Curve is used to determine the allocation to Mexico (the Mexican Delivery). The Mexican Delivery is reduced from the full Treaty amount of 60,000 AF in proportion to any water supply shortage affecting U.S. lands, and this is quantified using the D1 Curve.

D2 Curve: Defines the correlation between annual reservoir releases and "Total Heading Diversions." Total Heading Diversions consist of:

- "Project Net Supply", and
- Total delivery to Mexico at Acequia Madre.

Under D1/D2 Allocation, the D2 Curve was used to determine the total amount of Project Supply to be allocated (for delivery to Project diversion headings) as a function of the amount of Usable Water available in reservoir storage. Once the total amount of Project Supply was calculated, Mexico's share (calculated using the D1 Curve) was deducted, and the remainder of the Project Supply was split: 88/155 (or ~57%) to EBID, and 67/155 (or ~43%) to EPCWID (the 57:43 split).

[1] Water Supply Allocation Procedures, undated, circa 1990, provided to New Mexico by F. Cortez of Reclamation in 2005.

Reclamation's WSAP and 1985 and 1989 Draft Operating Agreements describe the D1/D2 Allocation method, and how these Curves were to be used allocate Project Supply. The D2 Curve was clearly evolving over this period, as different versions of these operating documents have different versions of the D2 data set. My analysis focuses on the D2 data set contained in Reclamation's WSAP document, which appears to have been adopted for Project allocation in 1991.[2] This D2 data set and the resulting D2 Curve have been used for Project Allocation from 1991-2005 as part of D1/D2 Allocation, and from 2006 to present as part of D3 Allocation.

2 D2 Data Source and Analysis

The focus of this analysis is on the nature of the D2 dataset itself. The data used in this analysis include:

1) Reclamation[3] D1 and D2 dataset obtained from Rio Grande Project WSAP drafted by Reclamation circa 1990;
2) 1951-1978 Reclamation Monthly Water Distribution Reports (WDRs) extracted from Rio Grande Project Histories;[4]
3) Supplementary WDRs obtained from Reclamation El Paso Field Office by New Mexico;[5] and
4) Gaged flow data for Rio Grande below Caballo Dam location obtained from the International Boundary Water Commission ("IBWC") website.[6]

2.1 Reclamation D1 and D2 Data Sets

The data tabulated in the WSAP document for the D1 and D2 Curves are provided below in Tables E.1 and E.2. The data set spans the years from 1951 through 1978, and this period of time will be referred to as the D2 Period.

[2] Full-supply District allocation amounts from 1991 through 2002 are equal to the full-supply District allocations defined in the WSAP document.

[3] 1985 Draft Operating Agreement (cover letter dated 1985), 1989 Draft Operating Agreement (undated, latest data contained in it are dated 1989).

[4] Reclamation Form 7-322 in Reclamation's "Project Histories of the Rio Grande Project."

[5] Supplementary Monthly Water Distribution Reports.

[6] The gages are: DIVERSIONS FROM THE RIO GRANDE, ACEQUIA MADRE AT CD. JUAREZ, CHIH. 08-3625.00 and RIO GRANDE BELOW CABALLO DAM, NEW MEXICO 08-3655.00 as downloaded from http://www.ibwc.gov/Water_Data/histflo1.htm.

Table E.1. D1 Data Set from Reclamation WSAP

Table E.1. D1 Dataset Reclamation's Rio Grande Project WSAP Document (circa 1990)					
Calendar Year	Delivered to Farms	Acequia Madre	Non Farm Deliveries	Total Deliveries	Release from Storage
	Acre-feet	Acre-feet	Acre-feet	Acre-feet	Acre-feet
1951	287,618	33,059	7,018	327,695	469,450
1952	331,846	49,890	6,597	388,333	543,975
1953	310,440	37,760	5,955	354,155	528,628
1954	102,270	10,147	1,752	114,169	244,165
1955	80,463	8,185	2,071	90,719	219,157
1956	69,458	7,864	1,002	78,324	246,140
1957	170,117	23,290	2,155	195,562	397,103
1958	400,767	60,050	6,432	467,249	737,125
1959	406,989	60,110	6,772	473,871	687,414
1960	402,400	60,320	6,527	469,247	705,162
1961	325,981	48,610	4,949	379,540	561,697
1962	411,420	60,057	6,234	477,711	651,941
1963	313,006	39,693	3,828	356,527	517,172
1964	64,968	6,653	938	72,559	206,085
1965	234,600	36,658	4,034	275,292	505,598
1966	301,468	49,618	8,341	359,427	610,341
1967	225,269	29,829	4,021	259,119	456,517
1968	255,721	39,677	7,475	302,873	505,691
1969	364,068	59,884	10,423	434,375	667,669
1970	388,549	60,065	9,670	458,284	661,125
1971	269,090	34,847	5,722	309,659	498,375
1972	122,652	16,077	2,719	141,448	260,911
1973	338,769	60,000	10,850	409,619	617,461
1974	351,904	60,050	13,291	425,245	640,843
1975	345,686	60,052	13,545	419,283	580,617
1976	375,070	60,172	13,794	449,036	679,676
1977	193,221	24,824	5,234	223,279	416,496
1978	112,349	14,903	3,587	130,839	356,167

Table E.2. D2 Data Set from Reclamation WSAP

Table E.2. D2 Dataset Reclamation's Rio Grande Project WSAP Document (circa 1990)				
	Acequia Madre	Project Net Supply	Total Heading Diversions	Release from Storage
Year	Acre-feet	Acre-feet	Acre-feet	Acre-feet
1951	33,059	541,171	574,230	469,450
1952	49,890	572,430	622,320	543,975
1953	37,760	564,209	601,969	528,628
1954	10,147	275,615	285,762	244,165
1955	8,185	169,754	177,939	219,157
1956	7,864	178,408	186,272	246,140
1957	23,290	309,029	332,319	397,103
1958	60,050	761,712	821,762	737,125
1959	60,110	781,248	841,358	687,414
1960	60,320	791,861	852,181	705,162
1961	48,610	639,574	688,184	561,697
1962	60,057	770,701	830,758	651,941
1963	39,693	647,655	687,348	517,172
1964	6,653	229,936	236,589	206,085
1965	36,658	443,130	479,788	505,598
1966	49,618	644,994	694,612	610,341
1967	29,829	503,037	532,866	456,517
1968	39,677	539,878	579,555	505,691
1969	59,884	742,543	802,427	667,669
1970	60,065	743,097	803,162	661,125
1971	34,847	556,910	591,757	498,375
1972	16,077	279,618	295,695	260,911
1973	60,000	646,177	706,177	617,461
1974	60,050	704,544	764,594	640,843
1975	60,052	693,609	753,661	580,617
1976	60,172	808,169	868,341	679,676
1977	24,824	468,239	493,063	416,496
1978	14,903	321,478	336,381	356,167

The data in the columns "Acequia Madre" and "Release from Storage" are consistent with IBWC gage data from pertinent gages within 0.2%.

The "Project Net Supply", "Delivered to Farms", and "Non-Farm Deliveries" data is consistent with Reclamation's WDRs, as described in the following section.

2.2 WATER DISTRIBUTION REPORTS (WDRS)

Project water distribution data was summarized and reported annually by Reclamation during the D2 Period (1951-1978) using Form 7-322, which is titled "Monthly Water Distribution." One set of the historical forms upon which I rely was obtained from Reclamation's Project Histories of the Rio Grande Project. Additional historical forms (some duplicative) were obtained directly from the Reclamation El Paso Field Office by New Mexico OSE/ISC staff and contractors.

The WDR forms for the D2 Period summarize monthly and annual distribution data for the Project as a whole, and typically for each of four Project Service Units that comprise the Project: Rincon Valley Unit, Leasburg Unit, Mesilla Unit, and El Paso Valley Unit. Summary forms are also available for the Mesilla Valley which comprises the Leasburg Unit and Mesilla Unit. Distribution data from the Project-wide WDRs can be obtained by summing the applicable values from the Rincon, Leasburg, Mesilla and El Paso Valley Units, adjusting for water by-passed from one unit to another.

The WDR forms typically include the following types of data:

1) Diverted from Stream[7]
2) Net Supply
3) Total Waste
4) Total Losses
5) Non-Irrigation Deliveries
6) Total Deliveries to Farm
7) Additional fields related to El Paso Carriage, Leasburg by-pass, EBID Wells and other local distribution terms

After thorough review of the Project-wide WDR data, I conclude that these Reclamation forms are the source of the D1 and D2 data sets provided in the Reclamation WSAP, and the basis of the D1 and D1 Curves that are used in the 2008 OA and associated operating manuals. Comparison of the Project-wide WDR data to the D1 and D2 data sets is shown in the following two sections, and observations and conclusions follow thereafter.

[7] "Diverted from Stream" is a measure of the amount of water diverted into Project canals that is available to unit (or units). In the Project-wide WDRs, "Net Supply" is identical to "Diverted from Stream." In Unit or Valley WDRs, some "Net Supply" values differ "Diverted from Stream" values, having been adjusted downward to prevent double counting of El Paso Carriage (intended for delivery to Texas), or upward to include the waste of water from the Leasburg Unit into the Mesilla Unit.

2.3 Tabulation of WDR Data and Comparison with D1 Data Set

Table E.3 shows a comparison of values extracted from the Project-wide WDRs for the D1/D2 Period to the D1 data set from the WSAP. All values are identical, except for farm deliveries in 1957 (off by 133 AF) and Non-irrigation Deliveries in 1967 (off by 11,299 AF), which I have highlighted. At this time there is no information as to which of the differing values are correct.

Table E.3. Comparison of WSAP D1 Data Set with Delivery Data from Reclamation WDR sheets

Table E.3. Comparison of WSAP D1 Dataset with Data Extracted from Reclamation Water Distribution Reports (Discrepancies between data sets highlighted)

Calendar Year	WSAP D1 Data Set	Reclamation WDR for Project		WSAP D1 Data Set	Reclamation WDR for Project	
	Delivered to Farms	Delivered to Farms	Discrepancy	Non-Farm Deliveries	Non-Irrigation Deliveries	Discrepancy
	Acre-feet	Acre-feet	Acre-feet	Acre-feet	Acre-feet	Acre-feet
1951	287,618	287,618	0	7,018	7,018	0
1952	331,846	331,846	0	6,597	6,597	0
1953	310,440	310,440	0	5,955	5,955	0
1954	102,270	102,270	0	1,752	1,752	0
1955	80,463	80,463	0	2,071	2,071	0
1956	69,458	69,458	0	1,002	1,002	0
1957	170,117	169,984	-133	2,155	2,155	0
1958	400,767	400,767	0	6,432	6,432	0
1959	406,989	406,989	0	6,772	6,772	0
1960	402,400	402,400	0	6,527	6,527	0
1961	325,981	325,981	0	4,949	4,949	0
1962	411,420	411,420	0	6,234	6,234	0
1963	313,006	313,006	0	3,828	3,828	0
1964	64,968	64,968	0	938	938	0
1965	234,600	234,600	0	4,034	4,034	0
1966	301,468	301,468	0	8,341	8,341	0
1967	225,269	225,269	0	4,021	15,320	11,299
1968	255,721	255,721	0	7,475	7,475	0
1969	364,068	364,068	0	10,423	10,423	0
1970	388,549	388,549	0	9,670	9,670	0
1971	269,090	269,090	0	5,722	5,722	0
1972	122,652	122,652	0	2,719	2,719	0
1973	338,769	338,769	0	10,850	10,850	0
1974	351,904	351,904	0	13,291	13,291	0
1975	345,686	345,686	0	13,545	13,545	0
1976	375,070	375,070	0	13,794	13,794	0
1977	193,221	193,221	0	5,234	5,234	0
1978	112,349	112,349	0	3,587	3,587	0

2.4 Tabulation of WDR Data for Comparison with D2 Data Set

Table E.4 shows a comparison of data from the "Diverted from Stream" or "Net Supply" field of the Project-wide WDR to the WSAP D2 data set's "Project Net Supply." These two sets are identical except for the year 1961, when the values in the D2 data set is 115,084 AF lower than that reported in the WDR. Review of the 1961 Project History, and of the other WDR's for that year does not provide any insight into this discrepancy. One possible explanation is that El Paso Conveyance was not properly accounted for in the copies of the WDR forms available to me, but that adjustment was made in other copies, or by Reclamation staff when they compiled the D2 data set.

Table E.4. Comparison of WSAP D2 Data Set with Diversion Data from Reclamation WDR sheets

Table E4.
Comparison of D2 Data Set with Data Extracted from Reclamation Water Distribution Records (Discrepancies between data sets highlighted)

	Reclamation Project-Wide WDR from Project Histories	D2 Data Set from WSAP	
Year	Diverted from Stream/ Net Supply	Project Net Supply	Discrepancy
1951	541,171	541,171	0
1952	572,430	572,430	0
1953	564,209	564,209	0
1954	275,615	275,615	0
1955	169,754	169,754	0
1956	178,408	178,408	0
1957	309,029	309,029	0
1958	761,712	761,712	0
1959	781,248	781,248	0
1960	791,861	791,861	0
1961	754,658	639,574	-115,084
1962	770,701	770,701	0
1963	647,655	647,655	0
1964	229,936	229,936	0
1965	443,130	443,130	0
1966	644,994	644,994	0
1967	503,037	503,037	0
1968	539,878	539,878	0
1969	742,543	742,543	0
1970	743,097	743,097	0
1971	556,910	556,910	0
1972	279,618	279,618	0
1973	646,177	646,177	0
1974	704,544	704,544	0
1975	693,609	693,609	0
1976	808,169	808,169	0
1977	468,239	468,239	0
1978	321,478	321,478	0

2.5 COMPARISON OF WDR PROJECT-WIDE DATA WITH WDR UNIT DATA

This section presents tabulation of monthly and annual WDR Diversions (from the "Diverted from Stream" and "Net Supply" fields of Tables E3 and E4).[8] In Table E.5, monthly WDR Diversions from Rincon Valley, Leasburg Unit, Mesilla Unit and El Paso Valley WDRs are tabulated and compared with Project-wide monthly WDR Diversions. In Table E6, the monthly WDR Diversions for each of these Units and Valleys are summed into annual values, and then these unit/valley values are summed for comparison with the Project-wide reported annual WDR Diversions. These Project-wide reported WDR Diversions are again compared with the "Project Net Supply" values from Reclamation's WSAP document.

Tables E.5 and E.6 show (with a few discrepancies) that:

1) Monthly WDR data from the Project-wide can be derived as the sum of the monthly WDR data from the Rincon, Leasburg and El Paso Valley Units;
2) Annual WDR Diversions are the sum of monthly WDR Diversions from January through December; and
3) Annual WDR Diversions form the basis of the D2 Curve.

The annual total Net Supply or Diverted from Stream values are derived as the sum of monthly Net Supply or Diverted from Stream values from the ***entire calendar year***, January through December.

2.6 DISCUSSION OF EL PASO VALLEY DIVERSION ISSUES

In general, the WDR diversions for the Rincon Valley Unit, Leasburg Unit, Mesilla Unit and Mesilla Valley can be obtained from available data on the total gaged diversions in those parts of the Project, with adjustment for El Paso Valley Carriage and waste from the Leasburg Unit into the Mesilla Unit.
The diversion data from the El Paso Valley unit is more complex. In WDR's from the 1940's and 1950's, some copies of the El Paso Valley Unit WDR (*see* Figure C.16 in Appendix C) include notes on what terms are included in the diversion, as follows (from 1951):

(1) Franklin Canal
(2) Riverside Canal
(3) Drain to Canal
(4) Less Ascarate W.W.
(5) Less Riverside W.W. 1 & 2
(6) Less Playa Lateral Waste to Riverside Canal

The first two terms, Franklin and Riverside, are the main diversions in the El Paso Valley that we would expect to form the basis of the reported diversions. The third term, Drain to Canal, is discussed in more detail in Section 7 of the report as well as Appendix C, and represents a discrepancy from current Project accounting, and perhaps a change in what water is actually available for diversion in the El Paso Valley. The fourth term, "Less Ascarate W.W.," represents an adjustment for planned, approved Project Waste. The Ascarate adjustment is made to avoid double counting of water that is diverted at Franklin

[8] Selection of diversion data from the WDR forms was made so as to avoid double counting of El Paso Carriage and water wasted from the Leasburg Unit to the Mesilla Unit.

then wasted back to the Rio Grande for rediversion, and is applied to avoid double counting. The Ascarate adjustment is similar to the adjustments for El Paso Valley Carriage that is made for the WDRs in the Rincon, Leasburg and Mesilla Unit WDRs to avoid double counting of water that is diverted above Courchesne for the sole purpose of delivering that water to American Dam more efficiently so that it can be rediverted for the El Paso Valley. The Ascarate wasteway adjustment (or credit) was applied in Project accounting until 1999, at which time this waste/rediversion operation was discontinued due to the completion of the ACE (*see* Appendices C and D).

The other two terms, "Less Riverside W.W. 1 & 2" and "Less Play Lateral Waste to Riverside Canal" are less well understood or documented. There is no available documentation of how those terms were calculated, nor any records of the resulting quantities. It is therefore unclear as to what effect these terms have on the D2 Curve and on the current negative departures from D2. It is possible that the "Less Riverside W.W. 1 & 2" term represents an early version of the current Project accounting term: "Credit to District for Diversions Greater than Orders" (*see* Appendix D).

3 INCONSISTENCY BETWEEN THE D2 DATA SET AND POST-1978 ACCOUNTING TO THE DETRIMENT OF EBID

As shown above, the D2 Curve was derived from data from the twelve-month calendar year. However, Post-1978 Accounting[9] does not charge either District for water diverted at times when there are no releases made from Caballo. The 1985 Draft Operating Agreement, which appears to summarize Post-1978 Accounting, states on page 3: "*All diversions made by the Districts during the nonirrigation season utilizing return flow waters shall not be charged against the Districts' respective allocations.*" The 2008 Operations Manual states on page 3: "*All diversions made by the Districts during the non-irrigation season utilizing return flow waters shall not be charged against the District's respective allocations*."

This is an important discrepancy between the premises upon which the D2 Curve is based and Post-1978 Project accounting practices. I estimate the amount of this discrepancy by determining how much water was diverted during the "off-season," when no releases were being made from Caballo, during the D2 Period.

Table E.7 contains the monthly (WDR) diversion data from D2 Period for the Rincon, Leasburg, Mesilla and El Paso Valley Units. Also included in Table E.7 is the monthly gaged flow below Caballo Dam, and a column of indicator values which are set to "1" during months in which Caballo Releases are occurring, and set to zero if no releases are being made (or if no diversion of released water occurring, as in February 1967 and February of 1968, when releases began on the last days of the month).[10] Review of the data in Table E.7 indicates that in some years substantial amounts of diversion occurred in late-fall and winter months, when no releases were being made from Caballo. Most of the water diverted

[9] *See* Appendix D of this Report for a detailed discussion of Post-1978 Accounting.

[10] Review of the daily release data indicates that Caballo releases during this period ended several days before the end of the last month of release, except for 1973, 1975 and 1976, so that in most years my analysis will not be influenced by the residual diversion of the last releases of the season.

during these times was diverted by the El Paso Valley Unit, with smaller amounts diverted by the Leasburg and Mesilla Units.

Table E.8 contains annual totals of the monthly Sum of All Unit Diversion from Table E.7, as well as the dates of the first and last releases from Caballo for each year as determined from the daily gaged flow below Caballo Dam. Annual diversion totals are provided for the entire calendar year (January-December) and for the release period of each year, defined using the Caballo gage data, with adjustment when Caballo releases ended close to the end of a month.[11] The final column is the amount of the total annual diversion that occurred outside of the release season: the amount varies from approximately 40,000 AF/Y during periods of high supply, to 5,000 AF/Y during the drought of the 1950s.

What this means as far as the D2 Curve being relied upon to allocate water to EPCWID is that ***the D2 Curve is inflated*** by the inclusion of diversions that are no longer counted as Project Supply. In effect, the 5,000 AF to 40,000 AF of off-season diversions that were historically supplied by drain flow and effluent, are now included as part of the demand for Caballo release. This inconsistency between the D2 Curve, based upon the D2 data set, and current accounting artificially inflates the negative departure (or gap) between recent accounting data and the D2 Curve. Since EBID's allocation is reduced by the amount of this negative departure, EBID's allocation is reduced by the amount of this accounting discrepancy.

In recent years, EBID's allocations have been extremely low, partly due to drought but partly due to D3 Allocation under the 2008 OA. These low-supply conditions have contributed to the reduction in drain flows in the Rincon and Mesilla Valley. El Paso Valley drain flows have also been greatly depleted by extensive groundwater pumping by Texans in the Hueco Bolson; *see* Appendix C. As a result, in recent years the amount of water available for off-season diversion, and the amounts of off-season diversions actually made, are probably relatively small. Regardless of the amount of winter diversions, these diversions would not be charged under Post-1978 Accounting procedures documented in both the 1985 Draft Operating Agreement and the 2008 Operations Manual. If aquifer recovery increases drain flows and off-season diversions, these diversions would still not be charged, resulting in an artificial departure from the D2 Curve. As discussed more completely in Appendix D, it is New Mexico and New Mexico alone being penalized for these negative departures from the D2 Curve through the application of the 2008 OA D3 Allocation.

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[11] In 1973, 1975 and 1976 Caballo releases ended so late in September that a portion of the October diversion included reservoir release water. I performed an adjustment in those years to account for this. This adjustment consisted of calculating the amount of the October diversions that was in excess of the 1972 or 1974 October diversions (which I assume to be free from reservoir release water), and adding that amount to the "Total Diversion During Release Season" and omitting that amount from the "Non-Release Season Diversions."

Table E.5. Tabulation and Analysis of Monthly Diversion Data from Reclamation Water Distribution Reports (Form 7-322) 1951-1978
Data Selected from "Diverted from Stream" or "Net Supply" Columns of WDR (Data adjusted if necessary to omit El Paso Carriage and avoid double counting of water entering Mesilla Unit from Leasburg Canal)

Date	Mo	Year	WDR Rincon Valley	WDR Leasburg Unit	WDR Mesilla Unit	Sum of WDR Diversions above Courchesne: Rincon, Leasburg, Mesilla	WDR El Paso Valley	Sum of WDR Diversions for Project: Rincon, Leasburg, Mesilla, El Paso Valley	WDR Project-wide (NM-TX)	Discrepancy between Reported Project Diversion and Sum of Unit/Valley Diversions
			Diverted from Stream/Net Supply (ac-ft)	Diverted from Stream/Net Supply (ac-ft)	Net Supply (ac-ft)	(ac-ft)	Diverted from Stream (ac-ft)	(ac-ft)	Net Supply (ac-ft)	(ac-ft)
Jan-51	1	1951	0	0	0	0	341	341	341	0
Feb-51	2	1951	0	0	0	0	5,946	5,946	5,946	0
Mar-51	3	1951	5,790	12,780	22,800	41,370	24,693	66,063	66,063	0
Apr-51	4	1951	10,800	16,100	30,200	57,100	31,911	89,011	89,011	0
May-51	5	1951	2,040	5,290	9,420	16,750	13,059	29,809	29,809	0
Jun-51	6	1951	7,860	11,880	25,280	45,020	25,905	70,925	70,925	0
Jul-51	7	1951	11,900	18,930	36,850	67,680	35,948	103,628	103,628	0
Aug-51	8	1951	12,180	21,210	39,030	72,420	36,794	109,214	109,214	0
Sep-51	9	1951	4,540	10,790	13,761	29,091	17,198	46,289	46,289	0
Oct-51	10	1951	0	1,360	0	1,360	6,217	7,577	7,577	0
Nov-51	11	1951	0	1,150	0	1,150	5,621	6,771	6,771	0
Dec-51	12	1951	0	860	0	860	4,737	5,597	5,597	0
Jan-52	1	1952	0	530	0	530	664	1,194	1,194	0
Feb-52	2	1952	0	294	0	294	3,100	3,394	3,394	0
Mar-52	3	1952	1,730	3,168	7,790	12,688	8,230	20,918	20,918	0
Apr-52	4	1952	8,480	10,500	24,670	43,650	21,550	65,200	65,200	0
May-52	5	1952	7,120	6,690	19,860	33,670	21,280	54,950	54,950	0
Jun-52	6	1952	9,820	14,491	28,570	52,881	33,770	86,651	86,651	0
Jul-52	7	1952	15,730	20,733	41,270	77,733	40,560	118,293	118,293	0
Aug-52	8	1952	15,370	24,647	46,030	86,047	44,160	130,207	130,207	0
Sep-52	9	1952	6,550	15,450	20,750	42,750	30,173	72,923	72,923	0
Oct-52	10	1952	0	2,100	0	2,100	6,230	8,330	8,330	0
Nov-52	11	1952	0	1,140	0	1,140	4,970	6,110	6,110	0
Dec-52	12	1952	0	1,200	0	1,200	3,060	4,260	4,260	0
Jan-53	1	1953	0	797	0	797	615	1,412	1,412	0
Feb-53	2	1953	0	365	0	365	1,514	1,879	1,879	0
Mar-53	3	1953	8,580	13,391	28,640	50,611	33,054	83,665	83,665	0
Apr-53	4	1953	9,870	10,368	22,490	42,728	29,072	71,800	71,800	0
May-53	5	1953	4,380	7,640	21,230	33,250	14,681	47,931	47,931	0
Jun-53	6	1953	9,310	11,440	29,790	50,540	26,707	77,247	77,247	0
Jul-53	7	1953	11,940	19,088	33,260	64,288	29,811	94,099	94,099	0
Aug-53	8	1953	13,130	21,239	38,490	72,859	34,644	107,503	107,503	0
Sep-53	9	1953	6,470	14,180	21,290	41,940	22,166	64,106	64,106	0
Oct-53	10	1953	0	1,180	0	1,180	4,756	5,936	5,936	0
Nov-53	11	1953	0	415	0	415	3,910	4,325	4,325	0
Dec-53	12	1953	0	561	0	561	3,745	4,306	4,306	0
Jan-54	1	1954	0	484	0	484	258	742	742	0
Feb-54	2	1954	0	186	0	186	1,010	1,196	1,196	0
Mar-54	3	1954	3,090	3,170	5,800	12,060	5,123	17,183	17,183	0
Apr-54	4	1954	6,540	10,030	20,900	37,470	16,685	54,155	54,155	0
May-54	5	1954	2,440	4,420	18,490	25,350	7,471	32,821	32,821	0
Jun-54	6	1954	4,880	6,024	27,460	38,364	10,408	48,772	48,772	0
Jul-54	7	1954	6,240	7,768	31,560	45,568	12,682	58,250	58,250	0
Aug-54	8	1954	3,060	10,090	15,480	28,630	9,094	37,724	37,724	0
Sep-54	9	1954	992	5,700	5,010	11,702	2,641	14,343	14,343	0
Oct-54	10	1954	0	2,555	2,701	5,256	3,888	9,144	9,144	0
Nov-54	11	1954	0	54	0	54	221	275	275	0
Dec-54	12	1954	0	0	0	0	1,010	1,010	1,010	0
Jan-55	1	1955	0	0	0	0	0	0	0	0
Feb-55	2	1955	0	0	0	0	1,080	1,080	1,080	0
Mar-55	3	1955	1,920	2,940	5,696	10,556	4,941	15,497	15,497	0
Apr-55	4	1955	3,382	5,360	7,038	15,780	6,156	21,936	21,936	0
May-55	5	1955	341	910	1,687	2,938	2,790	5,728	5,728	0
Jun-55	6	1955	1,684	2,950	7,050	11,684	5,467	17,151	17,151	0
Jul-55	7	1955	2,216	6,410	8,368	16,994	11,092	28,086	28,086	0
Aug-55	8	1955	5,068	8,032	16,145	29,245	10,415	39,660	39,660	0
Sep-55	9	1955	5,314	8,520	12,118	25,952	10,094	36,046	36,046	0
Oct-55	10	1955	0	387	702	1,089	1,365	2,454	2,454	0
Nov-55	11	1955	0	0	0	0	996	996	996	0
Dec-55	12	1955	0	0	0	0	1,120	1,120	1,120	0
Jan-56	1	1956	0	0	0	0	106	106	106	0

Table E.5. Tabulation and Analysis of Monthly Diversion Data from Reclamation Water Distribution Reports (Form 7-322) 1951-1978
Data Selected from "Diverted from Stream" or "Net Supply" Columns of WDR (Data adjusted if necessary to omit El Paso Carriage and avoid double counting of water entering Mesilla Unit from Leasburg Canal)

Date	Mo	Year	WDR Rincon Valley	WDR Leasburg Unit	WDR Mesilla Unit	Sum of WDR Diversions above Courchesne: Rincon, Leasburg, Mesilla	WDR El Paso Valley	Sum of WDR Diversions for Project: Rincon, Leasburg, Mesilla, El Paso Valley	WDR Project-wide (NM-TX)	Discrepancy between Reported Project Diversion and Sum of Unit/Valley Diversions
			Diverted from Stream/Net Supply (ac-ft)	Diverted from Stream/Net Supply (ac-ft)	Net Supply (ac-ft)	(ac-ft)	Diverted from Stream (ac-ft)	(ac-ft)	Net Supply (ac-ft)	(ac-ft)
Feb-56	2	1956	0	0	0	0	1,340	1,340	1,360	20
Mar-56	3	1956	4370	5,770	9,005	19,145	10,541	29,686	29,686	0
Apr-56	4	1956	3836	5,870	12,113	21,819	10,049	31,868	31,890	22
May-56	5	1956	327	1,110	1,201	2,638	1,457	4,095	4,095	0
Jun-56	6	1956	3990	5,530	11,766	21,286	7,539	28,825	28,825	0
Jul-56	7	1956	3995	6,480	13,731	24,206	9,114	33,320	33,323	3
Aug-56	8	1956	4928	6,480	10,707	22,115	5,542	27,657	27,657	0
Sep-56	9	1956	2740	4,100	6,962	13,802	3,924	17,726	17,726	0
Oct-56	10	1956	0	0	0	0	1,080	1,080	1,060	-20
Nov-56	11	1956	0	0	0	0	1,340	1,340	1,340	0
Dec-56	12	1956	0	0	0	0	1,340	1,340	1,340	0
Jan-57	1	1957	0	0	0	0	682	682	682	0
Feb-57	2	1957	0	0	0	0	1,240	1,240	1,240	0
Mar-57	3	1957	734	2,240	4,010	6,984	2,613	9,597	9,597	0
Apr-57	4	1957	2,692	3,420	7,126	13,238	5,140	18,378	18,378	0
May-57	5	1957	0	270	206	476	1,398	1,874	1,874	0
Jun-57	6	1957	3,725	6,030	13,346	23,101	11,413	34,514	34,514	0
Jul-57	7	1957	5,974	10,174	23,792	39,940	24,598	64,538	64,538	0
Aug-57	8	1957	13,030	20,500	34,196	67,726	30,502	98,228	98,228	0
Sep-57	9	1957	9,507	15,216	19,425	44,148	20,285	64,433	64,433	0
Oct-57	10	1957	0	4,650	2,880	7,530	3,944	11,474	11,474	0
Nov-57	11	1957	0	1,040	381	1,421	1,310	2,731	2,731	0
Dec-57	12	1957	0	0	0	0	1,340	1,340	1,340	0
Jan-58	1	1958	0	0	0	0	22	22	22	0
Feb-58	2	1958	0	0	0	0	1,770	1,770	1,770	0
Mar-58	3	1958	11,750	18,968	29,019	59,737	29,259	88,996	88,996	0
Apr-58	4	1958	13,523	19,978	26,994	60,495	25,862	86,357	86,357	0
May-58	5	1958	13,010	16,890	26,067	55,967	24,435	80,402	80,402	0
Jun-58	6	1958	17,627	24,469	40,346	82,442	36,643	119,085	119,085	0
Jul-58	7	1958	19,783	32,059	49,164	101,006	51,862	152,868	152,868	0
Aug-58	8	1958	15,769	26,216	43,322	85,307	42,651	127,958	127,958	0
Sep-58	9	1958	8,072	13,304	19,569	40,945	32,094	73,039	73,039	0
Oct-58	10	1958	0	6,460	2,626	9,086	7,863	16,949	16,949	0
Nov-58	11	1958	0	3,010	0	3,010	6,376	9,386	9,386	0
Dec-58	12	1958	0	1,600	0	1,600	3,280	4,880	4,880	0
Jan-59	1	1959	0	1,470	0	1,470	270	1,740	1,740	0
Feb-59	2	1959	0	12	0	12	3,747	3,759	3,759	0
Mar-59	3	1959	14,164	22,341	36,238	72,743	49,446	122,189	122,189	0
Apr-59	4	1959	11,331	20,506	25,004	56,841	25,135	81,976	81,976	0
May-59	5	1959	13,518	16,631	24,866	55,015	30,180	85,195	85,195	0
Jun-59	6	1959	16,051	23,065	39,793	78,909	44,505	123,414	123,414	0
Jul-59	7	1959	18,607	27,867	49,419	95,893	45,659	141,552	141,552	0
Aug-59	8	1959	14,016	23,968	37,723	75,707	44,087	119,794	119,794	0
Sep-59	9	1959	8,859	18,350	24,807	52,016	27,038	79,054	79,054	0
Oct-59	10	1959	0	3,640	99	3,739	6,553	10,292	10,292	0
Nov-59	11	1959	0	2,430	10	2,440	3,777	6,217	6,217	0
Dec-59	12	1959	0	2,170	0	2,170	3,896	6,066	6,066	0
Jan-60	1	1960	0	1,990	0	1,990	560	2,550	2,550	0
Feb-60	2	1960	0	36	0	36	5,339	5,375	5,375	0
Mar-60	3	1960	14,736	21,911	37,155	73,802	53,911	127,713	127,713	0
Apr-60	4	1960	12,399	15,538	25,876	53,813	27,334	81,147	81,147	0
May-60	5	1960	14,110	13,738	26,465	54,313	26,546	80,859	80,859	0
Jun-60	6	1960	13,698	22,022	39,950	75,670	39,016	114,686	114,686	0
Jul-60	7	1960	17,301	25,309	44,033	86,643	42,982	129,625	129,625	0
Aug-60	8	1960	18,839	26,556	48,146	93,541	48,168	141,709	141,709	0
Sep-60	9	1960	8,129	19,882	26,200	54,211	28,267	82,478	82,478	0
Oct-60	10	1960	0	4,320	0	4,320	7,693	12,013	12,013	0
Nov-60	11	1960	0	2,340	0	2,340	4,100	6,440	6,440	0
Dec-60	12	1960	0	2,130	0	2,130	5,136	7,266	7,266	0
Jan-61	1	1961	0	1,890	0	1,890	0	1,890	1,890	0
Feb-61	2	1961	0	1,267	0	1,267	10,303	11,570	11,570	0

Table E.5. Tabulation and Analysis of Monthly Diversion Data from Reclamation Water Distribution Reports (Form 7-322) 1951-1978
Data Selected from "Diverted from Stream" or "Net Supply" Columns of WDR (Data adjusted if necessary to omit El Paso Carriage and avoid double counting of water entering Mesilla Unit from Leasburg Canal)

Date	Mo	Year	WDR Rincon Valley	WDR Leasburg Unit	WDR Mesilla Unit	Sum of WDR Diversions above Courchesne: Rincon, Leasburg, Mesilla	WDR El Paso Valley	Sum of WDR Diversions for Project: Rincon, Leasburg, Mesilla, El Paso Valley	WDR Project-wide (NM-TX)	Discrepancy between Reported Project Diversion and Sum of Unit/Valley Diversions
			Diverted from Stream/Net Supply (ac-ft)	Diverted from Stream/Net Supply (ac-ft)	Net Supply (ac-ft)	(ac-ft)	Diverted from Stream (ac-ft)	(ac-ft)	Net Supply (ac-ft)	(ac-ft)
Mar-61	3	1961	9,492	18,591	30,663	58,746	44,501	103,247	103,247	0
Apr-61	4	1961	9,749	13,560	22,745	46,054	37,233	83,287	83,287	0
May-61	5	1961	10,932	11,722	20,924	43,578	24,296	67,874	67,874	0
Jun-61	6	1961	12,401	14,140	34,032	60,573	42,597	103,170	103,170	0
Jul-61	7	1961	13,011	23,731	44,068	80,810	51,194	132,004	132,004	0
Aug-61	8	1961	12,294	21,128	42,808	76,230	49,883	126,113	126,113	0
Sep-61	9	1961	4,308	12,604	16,156	33,068	40,409	73,477	73,477	0
Oct-61	10	1961	0	3,060	133	3,193	18,756	21,949	21,949	0
Nov-61	11	1961	0	2,260	0	2,260	15,260	17,520	17,520	0
Dec-61	12	1961	0	1,220	0	1,220	11,337	12,557	12,557	0
Jan-62	1	1962	0	1,050	0	1,050	113	1,163	1,163	0
Feb-62	2	1962	0	392	0	392	4,485	4,877	4,877	0
Mar-62	3	1962	12,052	19,264	37,211	68,527	51,412	119,939	119,939	0
Apr-62	4	1962	13,398	17,342	25,208	55,948	23,405	79,353	79,353	0
May-62	5	1962	13,420	12,934	23,946	50,300	20,592	70,892	70,892	0
Jun-62	6	1962	14,513	22,805	44,397	81,715	38,102	119,817	119,817	0
Jul-62	7	1962	14,505	23,796	47,105	85,406	46,797	132,203	132,203	0
Aug-62	8	1962	16,613	27,470	47,360	91,443	50,010	141,453	141,453	0
Sep-62	9	1962	7,019	13,202	19,069	39,290	28,706	67,996	67,996	0
Oct-62	10	1962	0	4,390	1,051	5,441	11,400	16,841	16,841	0
Nov-62	11	1962	0	2,720	0	2,720	5,710	8,430	8,430	0
Dec-62	12	1962	0	2,600	0	2,600	5,137	7,737	7,737	0
Jan-63	1	1963	0	480	0	480	993	1,473	1,473	0
Feb-63	2	1963	0	0	0	0	4,781	4,781	4,781	0
Mar-63	3	1963	15,336	23,840	39,921	79,097	50,046	129,143	129,143	0
Apr-63	4	1963	7,675	18,576	26,325	52,576	21,938	74,514	74,514	0
May-63	5	1963	9,916	18,176	27,181	55,273	11,297	66,570	66,570	0
Jun-63	6	1963	11,041	19,454	41,172	71,667	28,783	100,450	100,450	0
Jul-63	7	1963	14,945	22,857	43,000	80,802	36,491	117,293	117,293	0
Aug-63	8	1963	11,827	18,477	34,849	65,153	28,545	93,698	93,698	0
Sep-63	9	1963	4,246	10,002	10,585	24,833	16,917	41,750	41,750	0
Oct-63	10	1963	0	2,110	0	2,110	7,012	9,122	9,122	0
Nov-63	11	1963	0	1,260	0	1,260	4,225	5,485	5,485	0
Dec-63	12	1963	0	1,330	0	1,330	2,046	3,376	3,376	0
Jan-64	1	1964	0	471	0	471	341	812	812	0
Feb-64	2	1964	0	0	0	0	4,300	4,300	4,300	0
Mar-64	3	1964	4,154	4,958	7,456	16,568	8,882	25,450	25,450	0
Apr-64	4	1964	4,542	7,060	8,840	20,442	8,131	28,573	28,573	0
May-64	5	1964	0	180	0	180	2,513	2,693	2,693	0
Jun-64	6	1964	4,512	11,260	8,680	24,452	7,198	31,650	31,650	0
Jul-64	7	1964	3,810	21,298	11,830	36,938	9,456	46,394	46,394	0
Aug-64	8	1964	6,392	21,624	12,724	40,740	10,373	51,113	51,113	0
Sep-64	9	1964	2,744	11,324	8,481	22,549	10,524	33,073	33,073	0
Oct-64	10	1964	0	19	0	19	1,963	1,982	1,982	0
Nov-64	11	1964	0	0	0	0	2,074	2,074	2,074	0
Dec-64	12	1964	0	0	0	0	1,822	1,822	1,822	0
Jan-65	1	1965	0	0	0	0	0	0	0	0
Feb-65	2	1965	0	0	0	0	1,725	1,725	1,725	0
Mar-65	3	1965	2,448	3,111	3,980	9,539	5,027	14,566	14,566	0
Apr-65	4	1965	5,608	5,406	10,018	21,032	11,138	32,170	32,170	0
May-65	5	1965	0	210	0	210	2,101	2,311	2,311	0
Jun-65	6	1965	12,266	12,869	26,246	51,381	30,490	81,871	81,871	0
Jul-65	7	1965	15,834	21,437	41,230	78,501	43,575	122,076	122,076	0
Aug-65	8	1965	17,675	21,106	40,907	79,688	37,188	116,876	116,876	0
Sep-65	9	1965	5,983	13,125	20,266	39,374	22,540	61,914	61,914	0
Oct-65	10	1965	0	1,850	0	1,850	2,903	4,753	4,753	0
Nov-65	11	1965	0	736	0	736	2,510	3,246	3,246	0
Dec-65	12	1965	0	34	0	34	1,588	1,622	1,622	0
Jan-66	1	1966	0	0	0	0	165	165	165	0
Feb-66	2	1966	0	0	0	0	2,003	2,003	2,003	0
Mar-66	3	1966	12,066	15,078	28,039	55,183	38,934	94,117	94,117	0

Table E.5. Tabulation and Analysis of Monthly Diversion Data from Reclamation Water Distribution Reports (Form 7-322) 1951-1978
Data Selected from "Diverted from Stream" or "Net Supply" Columns of WDR (Data adjusted if necessary to omit El Paso Carriage and avoid double counting of water entering Mesilla Unit from Leasburg Canal)

Date	Mo	Year	WDR Rincon Valley	WDR Leasburg Unit	WDR Mesilla Unit	Sum of WDR Diversions above Courchesne: Rincon, Leasburg, Mesilla	WDR El Paso Valley	Sum of WDR Diversions for Project: Rincon, Leasburg, Mesilla, El Paso Valley	WDR Project-wide (NM-TX)	Discrepancy between Reported Project Diversion and Sum of Unit/Valley Diversions
			Diverted from Stream/Net Supply (ac-ft)	Diverted from Stream/Net Supply (ac-ft)	Net Supply (ac-ft)	(ac-ft)	Diverted from Stream (ac-ft)	(ac-ft)	Net Supply (ac-ft)	(ac-ft)
Apr-66	4	1966	12424	14,096	27,395	53,915	26,896	80,811	80,811	0
May-66	5	1966	8,809	9,370	16,837	35,016	18,050	53,066	55,066	2,000
Jun-66	6	1966	12,470	15,769	26,177	54,416	31,730	86,146	103,287	17,141
Jul-66	7	1966	15,397	24,098	34,895	74,390	43,164	117,554	117,554	0
Aug-66	8	1966	12,881	19,456	37,562	69,899	33,640	103,539	103,539	0
Sep-66	9	1966	10,967	17,158	19,125	47,250	18,968	66,218	66,218	0
Oct-66	10	1966	0	3,420	198	3,618	7,527	11,145	11,145	0
Nov-66	11	1966	0	821	0	821	6,006	6,827	6,827	0
Dec-66	12	1966	0	0	0	0	4,262	4,262	4,262	0
Jan-67	1	1967	0	9	33	42	5,497	5,539	5,539	0
Feb-67	2	1967	0	0	0	0	3,831	3,831	3,831	0
Mar-67	3	1967	12,315	18,508	35,994	66,817	37,852	104,669	104,669	0
Apr-67	4	1967	7,767	6,109	14,819	28,695	15,030	43,725	43,725	0
May-67	5	1967	8,293	6,080	13,857	28,230	14,630	42,860	42,860	0
Jun-67	6	1967	5,542	7,090	14,219	26,851	20,509	47,360	47,360	0
Jul-67	7	1967	8,755	13,859	24,457	47,071	32,026	79,097	79,097	0
Aug-67	8	1967	10,790	13,879	27,786	52,455	31,293	83,748	83,748	0
Sep-67	9	1967	7,520	16,169	21,395	45,084	32,583	77,667	77,667	0
Oct-67	10	1967	0	2,520	0	2,520	3,975	6,495	6,495	0
Nov-67	11	1967	0	1,310	0	1,310	3,119	4,429	4,429	0
Dec-67	12	1967	0	0	0	0	3,617	3,617	3,617	0
Jan-68	1	1968	0	90	0	90	3,757	3,847	3,847	0
Feb-68	2	1968	0	140	0	140	3,125	3,265	3,265	0
Mar-68	3	1968	10,609	11,318	28,788	50,715	35,603	86,318	86,318	0
Apr-68	4	1968	8,253	8,750	17,709	34,712	15,532	50,244	50,244	0
May-68	5	1968	8,032	5,328	15,099	28,459	13,190	41,649	41,649	0
Jun-68	6	1968	11,990	14,699	27,568	54,257	29,465	83,722	83,722	0
Jul-68	7	1968	11,415	17,189	34,087	62,691	25,941	88,632	88,632	0
Aug-68	8	1968	14,501	18,527	39,066	72,094	28,565	100,659	100,659	0
Sep-68	9	1968	8,789	14,220	20,846	43,855	19,758	63,613	63,613	0
Oct-68	10	1968	0	2,980	0	2,980	5,834	8,814	8,814	0
Nov-68	11	1968	0	1,210	0	1,210	4,615	5,825	5,825	0
Dec-68	12	1968	0	0	0	0	3,290	3,290	3,290	0
Jan-69	1	1969	0	0	0	0	4,763	4,763	4,763	0
Feb-69	2	1969	0	0	0	0	3,460	3,460	3,460	0
Mar-69	3	1969	12,725	19,970	34,905	67,600	37,460	105,060	105,060	0
Apr-69	4	1969	11,081	10,964	21,337	43,382	19,850	63,232	63,232	0
May-69	5	1969	10,624	8,230	20,949	39,803	19,320	59,123	59,123	0
Jun-69	6	1969	17,323	17,617	39,504	74,444	39,732	114,176	114,176	0
Jul-69	7	1969	13,637	27,824	53,823	95,284	42,758	138,042	138,042	0
Aug-69	8	1969	15,243	30,797	58,531	104,571	51,886	156,457	156,457	0
Sep-69	9	1969	8,099	11,580	23,238	42,917	25,201	68,118	68,118	0
Oct-69	10	1969	0	3,950	0	3,950	11,100	15,050	15,050	0
Nov-69	11	1969	0	1,400	0	1,400	6,459	7,859	7,859	0
Dec-69	12	1969	0	0	0	0	7,203	7,203	7,203	0
Jan-70	1	1970	0	0	0	0	5,100	5,100	5,100	0
Feb-70	2	1970	446	1,543	1,321	3,310	4,899	8,209	8,209	0
Mar-70	3	1970	13,402	18,801	35,523	67,726	46,301	114,027	114,027	0
Apr-70	4	1970	11,890	13,640	25,736	51,266	20,724	71,990	71,990	0
May-70	5	1970	10,754	13,325	26,664	50,743	25,990	76,733	76,733	0
Jun-70	6	1970	11,842	19,006	34,450	65,298	29,238	94,536	94,536	0
Jul-70	7	1970	17,135	27,779	48,267	93,181	44,071	137,252	137,252	0
Aug-70	8	1970	17,514	25,682	48,103	91,299	40,221	131,520	131,520	0
Sep-70	9	1970	8,027	17,860	25,120	51,007	26,977	77,984	77,984	0
Oct-70	10	1970	0	4,560	143	4,703	8,845	13,548	13,548	0
Nov-70	11	1970	0	1,320	0	1,320	6,180	7,500	7,500	0
Dec-70	12	1970	0	0	0	0	4,698	4,698	4,698	0
Jan-71	1	1971	0	0	0	0	5,294	5,294	5,294	0
Feb-71	2	1971	0	0	0	0	4,045	4,045	4,045	0
Mar-71	3	1971	10,459	17,736	37,195	65,390	48,471	113,861	113,861	0
Apr-71	4	1971	9,198	8,173	18,736	36,107	17,787	53,894	53,894	0

Table E.5. Tabulation and Analysis of Monthly Diversion Data from Reclamation Water Distribution Reports (Form 7-322) 1951-1978
Data Selected from "Diverted from Stream" or "Net Supply" Columns of WDR (Data adjusted if necessary to omit El Paso Carriage and avoid double counting of water entering Mesilla Unit from Leasburg Canal)

Date	Mo	Year	WDR Rincon Valley	WDR Leasburg Unit	WDR Mesilla Unit	Sum of WDR Diversions above Courchesne: Rincon, Leasburg, Mesilla	WDR El Paso Valley	Sum of WDR Diversions for Project: Rincon, Leasburg, Mesilla, El Paso Valley	WDR Project-wide (NM-TX)	Discrepancy between Reported Project Diversion and Sum of Unit/Valley Diversions
			Diverted from Stream/Net Supply (ac-ft)	Diverted from Stream/Net Supply (ac-ft)	Net Supply (ac-ft)	(ac-ft)	Diverted from Stream (ac-ft)	(ac-ft)	Net Supply (ac-ft)	(ac-ft)
May-71	5	1971	6,236	7,875	19,569	33,680	21,439	55,119	55,119	0
Jun-71	6	1971	8,711	11,619	26,722	47,052	27,960	75,012	75,012	0
Jul-71	7	1971	11,689	16,775	34,980	63,444	34,581	98,025	98,025	0
Aug-71	8	1971	12,699	17,746	34,827	65,272	28,440	93,712	93,712	0
Sep-71	9	1971	3,658	10,399	13,100	27,157	13,640	40,797	40,797	0
Oct-71	10	1971	3	1,120	0	1,123	6,452	7,575	7,572	-3
Nov-71	11	1971	0	0	0	0	5,543	5,543	5,543	0
Dec-71	12	1971	0	0	0	0	4,036	4,036	4,036	0
Jan-72	1	1972	0	0	0	0	3,415	3,415	3,415	0
Feb-72	2	1972	0	0	0	0	4,338	4,338	4,338	0
Mar-72	3	1972	7,881	10,056	26,665	44,602	28,738	73,340	73,340	0
Apr-72	4	1972	4,027	4,110	11,551	19,688	8,230	27,918	27,918	0
May-72	5	1972	1,828	1,320	4,935	8,083	6,829	14,912	14,912	0
Jun-72	6	1972	2,430	2,291	5,647	10,368	5,972	16,340	16,340	0
Jul-72	7	1972	6,055	8,377	21,164	35,596	19,174	54,770	54,770	0
Aug-72	8	1972	4,740	9,018	17,987	31,745	20,976	52,721	52,721	0
Sep-72	9	1972	2,620	3,787	4,486	10,893	10,820	21,713	21,713	0
Oct-72	10	1972	0	40	0	40	4,359	4,399	4,399	0
Nov-72	11	1972	0	0	0	0	3,007	3,007	3,007	0
Dec-72	12	1972	0	0	0	0	2,745	2,745	2,745	0
Jan-73	1	1973	0	0	0	0	2,106	2,106	2,106	0
Feb-73	2	1973	0	0	0	0	2,420	2,420	2,420	0
Mar-73	3	1973	4,871	8,142	20,887	33,900	24,483	58,383	58,383	0
Apr-73	4	1973	8,219	11,525	23,833	43,577	22,618	66,195	66,195	0
May-73	5	1973	6,753	9,378	21,693	37,824	23,211	61,035	61,035	0
Jun-73	6	1973	10,976	16,107	34,402	61,485	33,385	94,870	94,870	0
Jul-73	7	1973	12,455	17,120	41,405	70,980	36,296	107,276	107,276	0
Aug-73	8	1973	15,923	23,307	49,618	88,848	46,391	135,239	135,239	0
Sep-73	9	1973	11,210	17,569	33,715	62,494	31,441	93,935	93,935	0
Oct-73	10	1973	0	4,515	225	4,740	10,668	15,408	15,408	0
Nov-73	11	1973	0	0	0	0	5,170	5,170	5,170	0
Dec-73	12	1973	0	0	0	0	4,140	4,140	4,140	0
Jan-74	1	1974	0	0	0	0	4,149	4,149	4,149	0
Feb-74	2	1974	0	0	0	0	3,984	3,984	3,984	0
Mar-74	3	1974	12,234	17,935	37,452	67,621	46,407	114,028	114,028	0
Apr-74	4	1974	8,433	15,638	26,827	50,898	22,674	73,572	73,572	0
May-74	5	1974	10,248	15,143	28,260	53,651	27,691	81,342	81,342	0
Jun-74	6	1974	13,132	21,987	40,378	75,497	45,160	120,657	120,657	0
Jul-74	7	1974	6,117	13,829	36,494	56,440	44,714	101,154	101,154	0
Aug-74	8	1974	11,099	17,854	37,898	66,851	43,158	110,009	110,009	0
Sep-74	9	1974	8,269	15,579	23,249	47,097	25,522	72,619	72,619	0
Oct-74	10	1974	0	714	674	1,388	5,274	6,662	6,662	0
Nov-74	11	1974	0	0	0	0	7,648	7,648	7,648	0
Dec-74	12	1974	0	0	0	0	8,720	8,720	8,720	0
Jan-75	1	1975	565	0	722	1,287	8,664	9,951	10,001	50
Feb-75	2	1975	198	1,010	1,880	3,088	8,053	11,141	11,141	0
Mar-75	3	1975	7,411	9,887	24,356	41,654	30,506	72,160	72,160	0
Apr-75	4	1975	7,320	12,259	24,298	43,877	28,771	72,648	72,648	0
May-75	5	1975	12,100	13,468	26,863	52,431	32,030	84,461	84,461	0
Jun-75	6	1975	12,951	16,740	34,153	63,844	37,153	100,997	100,997	0
Jul-75	7	1975	11,253	21,139	42,531	74,923	33,930	108,853	108,853	0
Aug-75	8	1975	15,430	21,628	44,793	81,851	39,217	121,068	121,068	0
Sep-75	9	1975	6,565	14,068	30,614	51,247	26,947	78,194	78,194	0
Oct-75	10	1975	20	2,404	1,735	4,159	14,140	18,299	18,299	0
Nov-75	11	1975	0	0	0	0	7,530	7,530	7,530	0
Dec-75	12	1975	0	0	0	0	8,257	8,257	8,257	0
Jan-76	1	1976	2,664	1,384	8,680	12,728	12,774	25,502	25,502	0
Feb-76	2	1976	6,358	3,219	15,095	24,672	15,700	40,372	40,372	0
Mar-76	3	1976	9,412	15,618	34,714	59,744	37,476	97,220	97,220	0
Apr-76	4	1976	11,167	17,087	33,114	61,368	36,108	97,476	97,476	0
May-76	5	1976	14,827	16,829	38,434	70,090	45,108	115,198	115,198	0

Table E.5. Tabulation and Analysis of Monthly Diversion Data from Reclamation Water Distribution Reports (Form 7-322) 1951-1978
Data Selected from "Diverted from Stream" or "Net Supply" Columns of WDR (Data adjusted if necessary to omit El Paso Carriage and avoid double counting of water entering Mesilla Unit from Leasburg Canal)

Date	Mo	Year	WDR Rincon Valley	WDR Leasburg Unit	WDR Mesilla Unit	Sum of WDR Diversions above Courchesne: Rincon, Leasburg, Mesilla	WDR El Paso Valley	Sum of WDR Diversions for Project: Rincon, Leasburg, Mesilla, El Paso Valley	WDR Project-wide (NM-TX)	Discrepancy between Reported Project Diversion and Sum of Unit/Valley Diversions
			Diverted from Stream/Net Supply (ac-ft)	Diverted from Stream/Net Supply (ac-ft)	Net Supply (ac-ft)	(ac-ft)	Diverted from Stream (ac-ft)	(ac-ft)	Net Supply (ac-ft)	(ac-ft)
Jun-76	6	1976	11,978	18,691	36,906	67,575	35,136	102,711	102,711	0
Jul-76	7	1976	10,657	20,313	39,457	70,427	30,322	100,749	100,749	0
Aug-76	8	1976	14,808	22,890	47,804	85,502	44,289	129,791	129,791	0
Sep-76	9	1976	8,527	16,266	26,105	50,898	23,142	74,040	74,040	0
Oct-76	10	1976	0	2,920	99	3,019	14,462	17,481	17,481	0
Nov-76	11	1976	0	0	0	0	7,570	7,570	7,570	0
Dec-76	12	1976	0	0	0	0	59	59	59	0
Jan-77	1	1977	0	0	0	0	6,073	6,073	6,073	0
Feb-77	2	1977	0	0	0	0	4,481	4,481	4,481	0
Mar-77	3	1977	5,508	7,550	19,532	32,590	29,858	62,448	62,448	0
Apr-77	4	1977	5,092	12,329	21,553	38,974	9,870	48,844	48,844	0
May-77	5	1977	6,729	12,037	20,549	39,315	18,197	57,512	57,512	0
Jun-77	6	1977	8,367	13,689	24,420	46,476	28,197	74,673	74,673	0
Jul-77	7	1977	7,465	13,418	27,507	48,390	27,052	75,442	75,442	0
Aug-77	8	1977	10,706	16,172	31,822	58,700	32,399	91,099	91,099	0
Sep-77	9	1977	3,842	8,381	11,393	23,616	15,078	38,694	38,694	0
Oct-77	10	1977	0	115	0	115	3,538	3,653	3,653	0
Nov-77	11	1977	0	0	0	0	2,750	2,750	2,750	0
Dec-77	12	1977	0	0	0	0	2,570	2,570	2,570	0
Jan-78	1	1978	0	0	0	0	4,139	4,139	4,139	0
Feb-78	2	1978	0	0	0	0	3,747	3,747	3,747	0
Mar-78	3	1978	1,841	3,282	6,400	11,523	16,136	27,659	27,659	0
Apr-78	4	1978	4,080	6,410	11,991	22,481	9,262	31,743	31,743	0
May-78	5	1978	107	1,760	544	2,411	3,370	5,781	5,781	0
Jun-78	6	1978	5,860	8,053	18,857	32,770	29,610	62,380	62,380	0
Jul-78	7	1978	7,398	8,840	25,699	41,937	23,440	65,377	65,377	0
Aug-78	8	1978	7,567	12,791	28,595	48,953	29,366	78,319	78,319	0
Sep-78	9	1978	4,481	9,742	13,939	28,162	7,851	36,013	36,013	0
Oct-78	10	1978	0	79	0	79	1,961	2,040	2,040	0
Nov-78	11	1978	0	0	0	0	2,880	2,880	2,880	0
Dec-78	12	1978	0	0	0	0	1,400	1,400	1,400	0

Table E.6 Annual Diversion Data from Reclamation Water Distribution Reports
Summed Monthly Diversions by Unit/Valley Compared with Reported RGP Annual Diversions
Data Selected from "Diverted from Stream" or "Net Supply" Columns of WDR (Data adjusted if necessary to eliminate El Paso Carriage and avoid double counting of water entering Mesilla Unit from Leasburg Canal)

Year	WDR Rincon Valley	WDR Leasburg Unit	WDR Mesilla Unit	WDR Paso Valley	WDR Rincon, Leasburg, Mesilla, El Paso Valley (NM+TX)	WDR Project-Wide (NM+TX)	Water Allocation Procedures for the RGP, "Curve D2" Project Net Supply
	Sum Monthlies (ac-ft)	Sum Monthlies (ac-ft)	Sum Monthlies (ac-ft)	Sum Monthlies (ac-ft)	Sum of Monthly Sums (af-ft)	Reported Annual Net Supply (ac-ft)	Reported Annual (ac-ft)
1951	55,110	100,350	177,341	208,370	541,171	541,171	541,171
1952	64,800	100,943	188,940	217,747	572,430	572,430	572,430
1953	63,680	100,664	195,190	204,675	564,209	564,209	564,209
1954	27,242	50,481	127,401	70,491	275,615	275,615	275,615
1955	19,925	35,509	58,804	55,516	169,754	169,754	169,754
1956	24,186	35,340	65,485	53,372	178,383	178,408	178,408
1957	35,662	63,540	105,362	104,465	309,029	309,029	309,029
1958	99,534	162,954	237,107	262,117	761,712	761,712	761,712
1959	96,546	162,450	237,959	284,293	781,248	781,248	781,248
1960	99,212	155,772	247,825	289,052	791,861	791,861	791,861
1961	72,187	125,173	211,529	345,769	754,658	754,658	639,574
1962	91,520	147,965	245,347	285,869	770,701	770,701	770,701
1963	74,986	136,562	223,033	213,074	647,655	647,655	647,655
1964	26,154	78,194	58,011	67,577	229,936	229,936	229,936
1965	59,814	79,884	142,647	160,785	443,130	443,130	443,130
1966	85,014	119,266	190,228	231,345	625,853	644,994	644,994
1967	60,982	85,533	152,560	203,962	503,037	503,037	503,037
1968	73,589	94,451	183,163	188,675	539,878	539,878	539,878
1969	88,732	132,332	252,287	269,192	742,543	742,543	742,543
1970	91,010	143,516	245,327	263,244	743,097	743,097	743,097
1971	62,653	91,443	185,129	217,688	556,913	556,910	556,910
1972	29,581	38,999	92,435	118,603	279,618	279,618	279,618
1973	70,407	107,663	225,778	242,329	646,177	646,177	646,177
1974	69,532	118,679	231,232	285,101	704,544	704,544	704,544
1975	73,813	112,603	231,945	275,198	693,559	693,609	693,609
1976	90,398	135,217	280,408	302,146	808,169	808,169	808,169
1977	47,709	83,691	156,776	180,063	468,239	468,239	468,239
1978	31,334	50,957	106,025	133,162	321,478	321,478	321,478

Table E.7 Monthly Data Compiled from Reclamation Water Distribution Records (Monthly Water Data) 1951 - 1978									
Data compiled by Beiling Liu/ISC/03/26/12 and Peggy Barroll 11/6/2012									
Date	Mo	Year	Gaged flow below Caballo	Release Period	Rincon Unit Diversions	Leasburg Unit Diversions	Mesilla Unit Diversions	El Paso Valley Unit Diversions	Sum of All Unit Diversions
			AF	1 = Yes	AF	AF	AF	AF	AF
Jan-51	1	1951	80	0	0	0	0	341	341
Feb-51	2	1951	104	0	0	0	0	5,946	5,946
Mar-51	3	1951	69754	1	5,790	12,780	22,800	24,693	66,063
Apr-51	4	1951	67857	1	10,800	16,100	30,200	31,911	89,011
May-51	5	1951	23459	1	2,040	5,290	9,420	13,059	29,809
Jun-51	6	1951	75648	1	7,860	11,880	25,280	25,905	70,925
Jul-51	7	1951	102684	1	11,900	18,930	36,850	35,948	103,628
Aug-51	8	1951	103418	1	12,180	21,210	39,030	36,794	109,214
Sep-51	9	1951	26233	1	4,540	10,790	13,761	17,198	46,289
Oct-51	10	1951	52	0	0	1,360	0	6,217	7,577
Nov-51	11	1951	39	0	0	1,150	0	5,621	6,771
Dec-51	12	1951	38	0	0	860	0	4,737	5,597
Jan-52	1	1952	40	0	0	530	0	664	1,194
Feb-52	2	1952	59	0	0	294	0	3,100	3,394
Mar-52	3	1952	34026	1	1,730	3,168	7,790	8,230	20,918
Apr-52	4	1952	62656	1	8,480	10,500	24,670	21,550	65,200
May-52	5	1952	58850	1	7,120	6,690	19,860	21,280	54,950
Jun-52	6	1952	100740	1	9,820	14,491	28,570	33,770	86,651
Jul-52	7	1952	115878	1	15,730	20,733	41,270	40,560	118,293
Aug-52	8	1952	123630	1	15,370	24,647	46,030	44,160	130,207
Sep-52	9	1952	47772	1	6,550	15,450	20,750	30,173	72,923
Oct-52	10	1952	56	0	0	2,100	0	6,230	8,330
Nov-52	11	1952	38	0	0	1,140	0	4,970	6,110
Dec-52	12	1952	42	0	0	1,200	0	3,060	4,260
Jan-53	1	1953	57	0	0	797	0	615	1,412
Feb-53	2	1953	71	0	0	365	0	1,514	1,879
Mar-53	3	1953	99264	1	8,580	13,391	28,640	33,054	83,665
Apr-53	4	1953	58019	1	9,870	10,368	22,490	29,072	71,800
May-53	5	1953	47379	1	4,380	7,640	21,230	14,681	47,931
Jun-53	6	1953	78367	1	9,310	11,440	29,790	26,707	77,247
Jul-53	7	1953	93876	1	11,940	19,088	33,260	29,811	94,099
Aug-53	8	1953	105560	1	13,130	21,239	38,490	34,644	107,503
Sep-53	9	1953	45918	1	6,470	14,180	21,290	22,166	64,106
Oct-53	10	1953	52	0	0	1,180	0	4,756	5,936
Nov-53	11	1953	26	0	0	415	0	3,910	4,325
Dec-53	12	1953	32	0	0	561	0	3,745	4,306
Jan-54	1	1954	32	0	0	484	0	258	742
Feb-54	2	1954	26	0	0	186	0	1,010	1,196
Mar-54	3	1954	31891	1	3,090	3,170	5,800	5,123	17,183
Apr-54	4	1954	58439	1	6,540	10,030	20,900	16,685	54,155
May-54	5	1954	30177	1	2,440	4,420	18,490	7,471	32,821
Jun-54	6	1954	46867	1	4,880	6,024	27,460	10,408	48,772
Jul-54	7	1954	48419	1	6,240	7,768	31,560	12,682	58,250
Aug-54	8	1954	20527	1	3,060	10,090	15,480	9,094	37,724

Table E.7 Monthly Data Compiled from Reclamation Water Distribution Records (Monthly Water Data) 1951 - 1978									
Data compiled by Beiling Liu/ISC/03/26/12 and Peggy Barroll 11/6/2012									
Date	Mo	Year	Gaged flow below Caballo	Release Period	Rincon Unit Diversions	Leasburg Unit Diversions	Mesilla Unit Diversions	El Paso Valley Unit Diversions	Sum of All Unit Diversions
			AF	1 = Yes	AF	AF	AF	AF	AF
Sep-54	9	1954	7730	1	992	5,700	5,010	2,641	14,343
Oct-54	10	1954	15	0	0	2,555	2,701	3,888	9,144
Nov-54	11	1954	9	0	0	54	0	221	275
Dec-54	12	1954	23	0	0	0	0	1,010	1,010
Jan-55	1	1955	20	0	0	0	0	0	0
Feb-55	2	1955	13	0	0	0	0	1,080	1,080
Mar-55	3	1955	29631	1	1,920	2,940	5,696	4,941	15,497
Apr-55	4	1955	29266	1	3,382	5,360	7,038	6,156	21,936
May-55	5	1955	5261	1	341	910	1,687	2,790	5,728
Jun-55	6	1955	37018	1	1,684	2,950	7,050	5,467	17,151
Jul-55	7	1955	28171	1	2,216	6,410	8,368	11,092	28,086
Aug-55	8	1955	49004	1	5,068	8,032	16,145	10,415	39,660
Sep-55	9	1955	40738	1	5,314	8,520	12,118	10,094	36,046
Oct-55	10	1955	21	0	0	387	702	1,365	2,454
Nov-55	11	1955	7	0	0	0	0	996	996
Dec-55	12	1955	6	0	0	0	0	1,120	1,120
Jan-56	1	1956	42	0	0	0	0	106	106
Feb-56	2	1956	32	0	0	0	0	1,340	1,340
Mar-56	3	1956	52789	1	4370	5,770	9,005	10,541	29,686
Apr-56	4	1956	44757	1	3836	5,870	12,113	10,049	31,868
May-56	5	1956	1900	1	327	1,110	1,201	1,457	4,095
Jun-56	6	1956	46943	1	3990	5,530	11,766	7,539	28,825
Jul-56	7	1956	45792	1	3995	6,480	13,731	9,114	33,320
Aug-56	8	1956	35635	1	4928	6,480	10,707	5,542	27,657
Sep-56	9	1956	18183	1	2740	4,100	6,962	3,924	17,726
Oct-56	10	1956	31	0	0	0	0	1,080	1,080
Nov-56	11	1956	16	0	0	0	0	1,340	1,340
Dec-56	12	1956	19	0	0	0	0	1,340	1,340
Jan-57	1	1957	19	0	0	0	0	682	682
Feb-57	2	1957	19	0	0	0	0	1,240	1,240
Mar-57	3	1957	24869	1	734	2,240	4,010	2,613	9,597
Apr-57	4	1957	31285	1	2,692	3,420	7,126	5,140	18,378
May-57	5	1957	75	1	0	270	206	1,398	1,874
Jun-57	6	1957	70655	1	3,725	6,030	13,346	11,413	34,514
Jul-57	7	1957	91317	1	5,974	10,174	23,792	24,598	64,538
Aug-57	8	1957	113589	1	13,030	20,500	34,196	30,502	98,228
Sep-57	9	1957	63079	1	9,507	15,216	19,425	20,285	64,433
Oct-57	10	1957	123	0	0	4,650	2,880	3,944	11,474
Nov-57	11	1957	40	0	0	1,040	381	1,310	2,731
Dec-57	12	1957	37	0	0	0	0	1,340	1,340
Jan-58	1	1958	39	0	0	0	0	22	22
Feb-58	2	1958	59	0	0	0	0	1,770	1,770
Mar-58	3	1958	96605	1	11,750	18,968	29,019	29,259	88,996
Apr-58	4	1958	88112	1	13,523	19,978	26,994	25,862	86,357

Table E.7 Monthly Data Compiled from Reclamation Water Distribution Records (Monthly Water Data) 1951 - 1978

Data compiled by Beiling Liu/ISC/03/26/12 and Peggy Barroll 11/6/2012

Date	Mo	Year	Gaged flow below Caballo	Release Period	Rincon Unit Diversions	Leasburg Unit Diversions	Mesilla Unit Diversions	El Paso Valley Unit Diversions	Sum of All Unit Diversions
			AF	1 = Yes	AF	AF	AF	AF	AF
May-58	5	1958	93441	1	13,010	16,890	26,067	24,435	80,402
Jun-58	6	1958	128787	1	17,627	24,469	40,346	36,643	119,085
Jul-58	7	1958	153362	1	19,783	32,059	49,164	51,862	152,868
Aug-58	8	1958	119246	1	15,769	26,216	43,322	42,651	127,958
Sep-58	9	1958	57029	1	8,072	13,304	19,569	32,094	73,039
Oct-58	10	1958	126	0	0	6,460	2,626	7,863	16,949
Nov-58	11	1958	138	0	0	3,010	0	6,376	9,386
Dec-58	12	1958	183	0	0	1,600	0	3,280	4,880
Jan-59	1	1959	202	0	0	1,470	0	270	1,740
Feb-59	2	1959	324	0	0	12	0	3,747	3,759
Mar-59	3	1959	126169	1	14,164	22,341	36,238	49,446	122,189
Apr-59	4	1959	72313	1	11,331	20,506	25,004	25,135	81,976
May-59	5	1959	83464	1	13,518	16,631	24,866	30,180	85,195
Jun-59	6	1959	129164	1	16,051	23,065	39,793	44,505	123,414
Jul-59	7	1959	132972	1	18,607	27,867	49,419	45,659	141,552
Aug-59	8	1959	87148	1	14,016	23,968	37,723	44,087	119,794
Sep-59	9	1959	55491	1	8,859	18,350	24,807	27,038	79,054
Oct-59	10	1959	77	0	0	3,640	99	6,553	10,292
Nov-59	11	1959	71	0	0	2,430	10	3,777	6,217
Dec-59	12	1959	70	0	0	2,170	0	3,896	6,066
Jan-60	1	1960	76	0	0	1,990	0	560	2,550
Feb-60	2	1960	69	0	0	36	0	5,339	5,375
Mar-60	3	1960	135190	1	14,736	21,911	37,155	53,911	127,713
Apr-60	4	1960	72629	1	12,399	15,538	25,876	27,334	81,147
May-60	5	1960	83643	1	14,110	13,738	26,465	26,546	80,859
Jun-60	6	1960	115656	1	13,698	22,022	39,950	39,016	114,686
Jul-60	7	1960	115557	1	17,301	25,309	44,033	42,982	129,625
Aug-60	8	1960	128132	1	18,839	26,556	48,146	48,168	141,709
Sep-60	9	1960	53922	1	8,129	19,882	26,200	28,267	82,478
Oct-60	10	1960	108	0	0	4,320	0	7,693	12,013
Nov-60	11	1960	92	0	0	2,340	0	4,100	6,440
Dec-60	12	1960	87	0	0	2,130	0	5,136	7,266
Jan-61	1	1961	74	0	0	1,890	0	0	1,890
Feb-61	2	1961	68	0	0	1,267	0	10,303	11,570
Mar-61	3	1961	104060	1	9,492	18,591	30,663	44,501	103,247
Apr-61	4	1961	63814	1	9,749	13,560	22,745	37,233	83,287
May-61	5	1961	66218	1	10,932	11,722	20,924	24,296	67,874
Jun-61	6	1961	92985	1	12,401	14,140	34,032	42,597	103,170
Jul-61	7	1961	118929	1	13,011	23,731	44,068	51,194	132,004
Aug-61	8	1961	95096	1	12,294	21,128	42,808	49,883	126,113
Sep-61	9	1961	20218	1	4,308	12,604	16,156	40,409	73,477
Oct-61	10	1961	81	0	0	3,060	133	18,756	21,949
Nov-61	11	1961	76	0	0	2,260	0	15,260	17,520
Dec-61	12	1961	68	0	0	1,220	0	11,337	12,557

Table E.7 Monthly Data Compiled from Reclamation Water Distribution Records (Monthly Water Data) 1951 - 1978

Data compiled by Beiling Liu/ISC/03/26/12 and Peggy Barroll 11/6/2012

Date	Mo	Year	Gaged flow below Caballo	Release Period	Rincon Unit Diversions	Leasburg Unit Diversions	Mesilla Unit Diversions	El Paso Valley Unit Diversions	Sum of All Unit Diversions
			AF	1 = Yes	AF	AF	AF	AF	AF
Jan-62	1	1962	69	0	0	1,050	0	113	1,163
Feb-62	2	1962	66	0	0	392	0	4,485	4,877
Mar-62	3	1962	120419	1	12,052	19,264	37,211	51,412	119,939
Apr-62	4	1962	69741	1	13,398	17,342	25,208	23,405	79,353
May-62	5	1962	70649	1	13,420	12,934	23,946	20,592	70,892
Jun-62	6	1962	119742	1	14,513	22,805	44,397	38,102	119,817
Jul-62	7	1962	108139	1	14,505	23,796	47,105	46,797	132,203
Aug-62	8	1962	132190	1	16,613	27,470	47,360	50,010	141,453
Sep-62	9	1962	30638	1	7,019	13,202	19,069	28,706	67,996
Oct-62	10	1962	103	0	0	4,390	1,051	11,400	16,841
Nov-62	11	1962	92	0	0	2,720	0	5,710	8,430
Dec-62	12	1962	91	0	0	2,600	0	5,137	7,737
Jan-63	1	1963	92	0	0	480	0	993	1,473
Feb-63	2	1963	84	0	0	0	0	4,781	4,781
Mar-63	3	1963	132720	1	15,336	23,840	39,921	50,046	129,143
Apr-63	4	1963	45570	1	7,675	18,576	26,325	21,938	74,514
May-63	5	1963	47018	1	9,916	18,176	27,181	11,297	66,570
Jun-63	6	1963	97174	1	11,041	19,454	41,172	28,783	100,450
Jul-63	7	1963	108825	1	14,945	22,857	43,000	36,491	117,293
Aug-63	8	1963	72089	1	11,827	18,477	34,849	28,545	93,698
Sep-63	9	1963	13310	1	4,246	10,002	10,585	16,917	41,750
Oct-63	10	1963	104	0	0	2,110	0	7,012	9,122
Nov-63	11	1963	96	0	0	1,260	0	4,225	5,485
Dec-63	12	1963	86	0	0	1,330	0	2,046	3,376
Jan-64	1	1964	89	0	0	471	0	341	812
Feb-64	2	1964	82	0	0	0	0	4,300	4,300
Mar-64	3	1964	35019	1	4,154	4,958	7,456	8,882	25,450
Apr-64	4	1964	25470	1	4,542	7,060	8,840	8,131	28,573
May-64	5	1964	123	1	0	180	0	2,513	2,693
Jun-64	6	1964	36268	1	4,512	11,260	8,680	7,198	31,650
Jul-64	7	1964	41282	1	3,810	21,298	11,830	9,456	46,394
Aug-64	8	1964	46697	1	6,392	21,624	12,724	10,373	51,113
Sep-64	9	1964	20861	1	2,744	11,324	8,481	10,524	33,073
Oct-64	10	1964	69	0	0	19	0	1,963	1,982
Nov-64	11	1964	58	0	0	0	0	2,074	2,074
Dec-64	12	1964	64	0	0	0	0	1,822	1,822
Jan-65	1	1965	62	0	0	0	0	0	0
Feb-65	2	1965	60	0	0	0	0	1,725	1,725
Mar-65	3	1965	31330	1	2,448	3,111	3,980	5,027	14,566
Apr-65	4	1965	43345	1	5,608	5,406	10,018	11,138	32,170
May-65	5	1965	85	1	0	210	0	2,101	2,311
Jun-65	6	1965	120444	1	12,266	12,869	26,246	30,490	81,871
Jul-65	7	1965	142314	1	15,834	21,437	41,230	43,575	122,076
Aug-65	8	1965	127259	1	17,675	21,106	40,907	37,188	116,876

Table E.7 Monthly Data Compiled from Reclamation Water Distribution Records (Monthly Water Data) 1951 - 1978									
Data compiled by Beiling Liu/ISC/03/26/12 and Peggy Barroll 11/6/2012									
Date	Mo	Year	Gaged flow below Caballo	Release Period	Rincon Unit Diversions	Leasburg Unit Diversions	Mesilla Unit Diversions	El Paso Valley Unit Diversions	Sum of All Unit Diversions
			AF	1 = Yes	AF	AF	AF	AF	AF
Sep-65	9	1965	40570	1	5,983	13,125	20,266	22,540	61,914
Oct-65	10	1965	58	0	0	1,850	0	2,903	4,753
Nov-65	11	1965	40	0	0	736	0	2,510	3,246
Dec-65	12	1965	43	0	0	34	0	1,588	1,622
Jan-66	1	1966	53	0	0	0	0	165	165
Feb-66	2	1966	52	0	0	0	0	2,003	2,003
Mar-66	3	1966	120446	1	12,066	15,078	28,039	38,934	94,117
Apr-66	4	1966	78716	1	12,424	14,096	27,395	26,896	80,811
May-66	5	1966	70544	1	8,809	9,370	16,837	18,050	53,066
Jun-66	6	1966	96998	1	12,470	15,769	26,177	31,730	86,146
Jul-66	7	1966	118687	1	15,397	24,098	34,895	43,164	117,554
Aug-66	8	1966	89998	1	12,881	19,456	37,562	33,640	103,539
Sep-66	9	1966	34579	1	10,967	17,158	19,125	18,968	66,218
Oct-66	10	1966	77	0	0	3,420	198	7,527	11,145
Nov-66	11	1966	105	0	0	821	0	6,006	6,827
Dec-66	12	1966	74	0	0	0	0	4,262	4,262
Jan-67	1	1967	82	0	0	9	33	5,497	5,539
Feb-67	2	1967	2767	0	0	0	0	3,831	3,831
Mar-67	3	1967	116093	1	12,315	18,508	35,994	37,852	104,669
Apr-67	4	1967	41585	1	7,767	6,109	14,819	15,030	43,725
May-67	5	1967	46911	1	8,293	6,080	13,857	14,630	42,860
Jun-67	6	1967	50333	1	5,542	7,090	14,219	20,509	47,360
Jul-67	7	1967	77256	1	8,755	13,859	24,457	32,026	79,097
Aug-67	8	1967	73482	1	10,790	13,879	27,786	31,293	83,748
Sep-67	9	1967	47801	1	7,520	16,169	21,395	32,583	77,667
Oct-67	10	1967	72	0	0	2,520	0	3,975	6,495
Nov-67	11	1967	69	0	0	1,310	0	3,119	4,429
Dec-67	12	1967	74	0	0	0	0	3,617	3,617
Jan-68	1	1968	74	0	0	90	0	3,757	3,847
Feb-68	2	1968	5449	0	0	140	0	3,125	3,265
Mar-68	3	1968	95365	1	10,609	11,318	28,788	35,603	86,318
Apr-68	4	1968	47018	1	8,253	8,750	17,709	15,532	50,244
May-68	5	1968	49265	1	8,032	5,328	15,099	13,190	41,649
Jun-68	6	1968	97269	1	11,990	14,699	27,568	29,465	83,722
Jul-68	7	1968	84186	1	11,415	17,189	34,087	25,941	88,632
Aug-68	8	1968	83062	1	14,501	18,527	39,066	28,565	100,659
Sep-68	9	1968	43627	1	8,789	14,220	20,846	19,758	63,613
Oct-68	10	1968	188	0	0	2,980	0	5,834	8,814
Nov-68	11	1968	77	0	0	1,210	0	4,615	5,825
Dec-68	12	1968	92	0	0	0	0	3,290	3,290
Jan-69	1	1969	83	0	0	0	0	4,763	4,763
Feb-69	2	1969	3027	0	0	0	0	3,460	3,460
Mar-69	3	1969	113568	1	12,725	19,970	34,905	37,460	105,060
Apr-69	4	1969	63921	1	11,081	10,964	21,337	19,850	63,232

Table E.7 Monthly Data Compiled from Reclamation Water Distribution Records (Monthly Water Data) 1951 - 1978									
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Date	Mo	Year	Gaged flow below Caballo	Release Period	Rincon Unit Diversions	Leasburg Unit Diversions	Mesilla Unit Diversions	El Paso Valley Unit Diversions	Sum of All Unit Diversions
			AF	1 = Yes	AF	AF	AF	AF	AF
May-69	5	1969	62491	1	10,624	8,230	20,949	19,320	59,123
Jun-69	6	1969	116945	1	17,323	17,617	39,504	39,732	114,176
Jul-69	7	1969	129759	1	13,637	27,824	53,823	42,758	138,042
Aug-69	8	1969	141779	1	15,243	30,797	58,531	51,886	156,457
Sep-69	9	1969	35839	1	8,099	11,580	23,238	25,201	68,118
Oct-69	10	1969	100	0	0	3,950	0	11,100	15,050
Nov-69	11	1969	71	0	0	1,400	0	6,459	7,859
Dec-69	12	1969	75	0	0	0	0	7,203	7,203
Jan-70	1	1970	86	0	0	0	0	5,100	5,100
Feb-70	2	1970	10083	1	446	1,543	1,321	4,899	8,209
Mar-70	3	1970	111477	1	13,402	18,801	35,523	46,301	114,027
Apr-70	4	1970	70967	1	11,890	13,640	25,736	20,724	71,990
May-70	5	1970	79144	1	10,754	13,325	26,664	25,990	76,733
Jun-70	6	1970	99412	1	11,842	19,006	34,450	29,238	94,536
Jul-70	7	1970	125375	1	17,135	27,779	48,267	44,071	137,252
Aug-70	8	1970	115636	1	17,514	25,682	48,103	40,221	131,520
Sep-70	9	1970	48781	1	8,027	17,860	25,120	26,977	77,984
Oct-70	10	1970	117	0	0	4,560	143	8,845	13,548
Nov-70	11	1970	79	0	0	1,320	0	6,180	7,500
Dec-70	12	1970	63	0	0	0	0	4,698	4,698
Jan-71	1	1971	63	0	0	0	0	5,294	5,294
Feb-71	2	1971	4760	0	0	0	0	4,045	4,045
Mar-71	3	1971	106790	1	10,459	17,736	37,195	48,471	113,861
Apr-71	4	1971	53038	1	9,198	8,173	18,736	17,787	53,894
May-71	5	1971	60044	1	6,236	7,875	19,569	21,439	55,119
Jun-71	6	1971	81818	1	8,711	11,619	26,722	27,960	75,012
Jul-71	7	1971	93084	1	11,689	16,775	34,980	34,581	98,025
Aug-71	8	1971	78684	1	12,699	17,746	34,827	28,440	93,712
Sep-71	9	1971	19957	1	3,658	10,399	13,100	13,640	40,797
Oct-71	10	1971	91	0	3	1,120	0	6,452	7,575
Nov-71	11	1971	60	0	0	0	0	5,543	5,543
Dec-71	12	1971	61	0	0	0	0	4,036	4,036
Jan-72	1	1972	55	0	0	0	0	3,415	3,415
Feb-72	2	1972	12	0	0	0	0	4,338	4,338
Mar-72	3	1972	86055	1	7,881	10,056	26,665	28,738	73,340
Apr-72	4	1972	27935	1	4,027	4,110	11,551	8,230	27,918
May-72	5	1972	12976	1	1,828	1,320	4,935	6,829	14,912
Jun-72	6	1972	25289	1	2,430	2,291	5,647	5,972	16,340
Jul-72	7	1972	59566	1	6,055	8,377	21,164	19,174	54,770
Aug-72	8	1972	41851	1	4,740	9,018	17,987	20,976	52,721
Sep-72	9	1972	6757	1	2,620	3,787	4,486	10,820	21,713
Oct-72	10	1972	151	0	0	40	0	4,359	4,399
Nov-72	11	1972	131	0	0	0	0	3,007	3,007
Dec-72	12	1972	132	0	0	0	0	2,745	2,745

Table E.7 Monthly Data Compiled from Reclamation Water Distribution Records (Monthly Water Data) 1951 - 1978

Data compiled by Beiling Liu/ISC/03/26/12 and Peggy Barroll 11/6/2012

Date	Mo	Year	Gaged flow below Caballo	Release Period	Rincon Unit Diversions	Leasburg Unit Diversions	Mesilla Unit Diversions	El Paso Valley Unit Diversions	Sum of All Unit Diversions
			AF	1 = Yes	AF	AF	AF	AF	AF
Jan-73	1	1973	123	0	0	0	0	2,106	2,106
Feb-73	2	1973	128	0	0	0	0	2,420	2,420
Mar-73	3	1973	73929	1	4,871	8,142	20,887	24,483	58,383
Apr-73	4	1973	72972	1	8,219	11,525	23,833	22,618	66,195
May-73	5	1973	70362	1	6,753	9,378	21,693	23,211	61,035
Jun-73	6	1973	103398	1	10,976	16,107	34,402	33,385	94,870
Jul-73	7	1973	92414	1	12,455	17,120	41,405	36,296	107,276
Aug-73	8	1973	129263	1	15,923	23,307	49,618	46,391	135,239
Sep-73	9	1973	74400	1	11,210	17,569	33,715	31,441	93,935
Oct-73	10	1973	197	0	0	4,515	225	10,668	15,408
Nov-73	11	1973	80	0	0	0	0	5,170	5,170
Dec-73	12	1973	83	0	0	0	0	4,140	4,140
Jan-74	1	1974	63	0	0	0	0	4,149	4,149
Feb-74	2	1974	61	0	0	0	0	3,984	3,984
Mar-74	3	1974	122440	1	12,234	17,935	37,452	46,407	114,028
Apr-74	4	1974	74337	1	8,433	15,638	26,827	22,674	73,572
May-74	5	1974	82697	1	10,248	15,143	28,260	27,691	81,342
Jun-74	6	1974	121329	1	13,132	21,987	40,378	45,160	120,657
Jul-74	7	1974	92616	1	6,117	13,829	36,494	44,714	101,154
Aug-74	8	1974	97113	1	11,099	17,854	37,898	43,158	110,009
Sep-74	9	1974	49950	1	8,269	15,579	23,249	25,522	72,619
Oct-74	10	1974	151	0	0	714	674	5,274	6,662
Nov-74	11	1974	94	0	0	0	0	7,648	7,648
Dec-74	12	1974	64	0	0	0	0	8,720	8,720
Jan-75	1	1975	6112	1	565	0	722	8,664	9,951
Feb-75	2	1975	1195	1	198	1,010	1,880	8,053	11,141
Mar-75	3	1975	72770	1	7,411	9,887	24,356	30,506	72,160
Apr-75	4	1975	70856	1	7,320	12,259	24,298	28,771	72,648
May-75	5	1975	82020	1	12,100	13,468	26,863	32,030	84,461
Jun-75	6	1975	99709	1	12,951	16,740	34,153	37,153	100,997
Jul-75	7	1975	93104	1	11,253	21,139	42,531	33,930	108,853
Aug-75	8	1975	107068	1	15,430	21,628	44,793	39,217	121,068
Sep-75	9	1975	47270	1	6,565	14,068	30,614	26,947	78,194
Oct-75	10	1975	204	0	20	2,404	1,735	14,140	18,299
Nov-75	11	1975	179	0	0	0	0	7,530	7,530
Dec-75	12	1975	184	0	0	0	0	8,257	8,257
Jan-76	1	1976	21032	1	2,664	1,384	8,680	12,774	25,502
Feb-76	2	1976	24904	1	6,358	3,219	15,095	15,700	40,372
Mar-76	3	1976	88036	1	9,412	15,618	34,714	37,476	97,220
Apr-76	4	1976	94090	1	11,167	17,087	33,114	36,108	97,476
May-76	5	1976	108833	1	14,827	16,829	38,434	45,108	115,198
Jun-76	6	1976	97686	1	11,978	18,691	36,906	35,136	102,711
Jul-76	7	1976	80840	1	10,657	20,313	39,457	30,322	100,749
Aug-76	8	1976	116172	1	14,808	22,890	47,804	44,289	129,791

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Data compiled by Beiling Liu/ISC/03/26/12 and Peggy Barroll 11/6/2012

Date	Mo	Year	Gaged flow below Caballo	Release Period	Rincon Unit Diversions	Leasburg Unit Diversions	Mesilla Unit Diversions	El Paso Valley Unit Diversions	Sum of All Unit Diversions
			AF	1 = Yes	AF	AF	AF	AF	AF
Sep-76	9	1976	47422	1	8,527	16,266	26,105	23,142	74,040
Oct-76	10	1976	184	0	0	2,920	99	14,462	17,481
Nov-76	11	1976	189	0	0	0	0	7,570	7,570
Dec-76	12	1976	203	0	0	0	0	59	59
Jan-77	1	1977	178	0	0	0	0	6,073	6,073
Feb-77	2	1977	169	0	0	0	0	4,481	4,481
Mar-77	3	1977	68824	1	5,508	7,550	19,532	29,858	62,448
Apr-77	4	1977	51644	1	5,092	12,329	21,553	9,870	48,844
May-77	5	1977	47524	1	6,729	12,037	20,549	18,197	57,512
Jun-77	6	1977	75717	1	8,367	13,689	24,420	28,197	74,673
Jul-77	7	1977	65671	1	7,465	13,418	27,507	27,052	75,442
Aug-77	8	1977	85882	1	10,706	16,172	31,822	32,399	91,099
Sep-77	9	1977	21660	1	3,842	8,381	11,393	15,078	38,694
Oct-77	10	1977	108	0	0	115	0	3,538	3,653
Nov-77	11	1977	55	0	0	0	0	2,750	2,750
Dec-77	12	1977	46	0	0	0	0	2,570	2,570
Jan-78	1	1978	51	0	0	0	0	4,139	4,139
Feb-78	2	1978	57	0	0	0	0	3,747	3,747
Mar-78	3	1978	36106	1	1,841	3,282	6,400	16,136	27,659
Apr-78	4	1978	35409	1	4,080	6,410	11,991	9,262	31,743
May-78	5	1978	8764	1	107	1,760	544	3,370	5,781
Jun-78	6	1978	76433	1	5,860	8,053	18,857	29,610	62,380
Jul-78	7	1978	80936	1	7,398	8,840	25,699	23,440	65,377
Aug-78	8	1978	87408	1	7,567	12,791	28,595	29,366	78,319
Sep-78	9	1978	30820	1	4,481	9,742	13,939	7,851	36,013
Oct-78	10	1978	74	0	0	79	0	1,961	2,040
Nov-78	11	1978	67	0	0	0	0	2,880	2,880
Dec-78	12	1978	68	0	0	0	0	1,400	1,400

Data from Reclamation Monthly Water Distribution sheets in Reclamation's archive file: "Project Histories of the Rio Grande Project 1912-1988" on CD, and from Notebook of Water Distribution Reports obtained from Reclamation El Paso Office by NM Staff and Contractors.

Table E.8 Annual Totals of Monthly WDR Diversion Data, Comparing Total Annual Diversion with Diversion Occuring during Release Season

Compiled from WDR Monthly Data

Year	Date of First Release	Date of Last Release	Total Annual Diversion	Total Diverson During Release Season	Non-Release Season Diversions	
	IBWC Gage Records		AF	AF	AF	
1951	6-Mar	12-Sep	541,171	514,939	26,232	
1952	20-Mar	12-Sep	572,430	549,142	23,288	
1953	10-Mar	12-Sep	564,209	546,351	17,858	
1954	20-Mar	5-Sep	275,615	263,248	12,367	
1955	20-Mar	14-Sep	169,754	164,104	5,650	
1956	18-Mar	10-Sep	178,383	173,177	5,206	
1957	20-Mar	22-Sep	309,029	291,562	17,467	
1958	1-Mar	25-Sep	761,712	728,705	33,007	
1959	2-Mar	17-Sep	781,248	753,174	28,074	
1960	2-Mar	16-Sep	791,861	758,217	33,644	
1961	10-Mar	10-Sep	754,658	689,172	65,486	
1962	5-Mar	14-Sep	770,701	731,653	39,048	
1963	5-Mar	10-Sep	647,655	623,418	24,237	
1964	15-Mar	10-Sep	229,936	218,946	10,990	
1965	20-Mar	17-Sep	443,130	431,784	11,346	
1966	5-Mar	18-Sep	625,853	601,451	24,402	
1967	27-Feb	18-Sep	503,037	479,126	23,911	
1968	27-Feb	20-Sep	539,878	514,837	25,041	
1969	27-Feb	22-Sep	742,543	704,208	38,335	
1970	23-Feb	19-Sep	743,097	712,251	30,846	
1971	26-Feb	8-Sep	556,913	530,420	26,493	
1972	1-Mar	13-Sep	279,618	261,714	17,904	
1973	9-Mar	30-Sep	646,177	627,942	18,235	*
1974	2-Mar	16-Sep	704,544	673,381	31,163	
1975	24-Jan	30-Sep	693,559	673,373	20,186	*
1976	16-Jan	28-Sep	808,169	796,141	12,028	*
1977	3-Mar	11-Sep	468,239	448,712	19,527	
1978	10-Mar	14-Sep	321,478	307,272	14,206	

* In 1973, 1975 and 1976, Caballo releases ended late enough in September so that a portion of October diversion included reservoir water. I corrected for this by including the amount of the October diversions in those years in excess of the 1972 October diversion as part of the "Total Diversion During Release Season" and omitting that amount from the "Non-Release Season Diversions."

APPENDIX F

TIMELINES

IMPORTANT RIO GRANDE COMPACT AND RIO GRANDE PROJECT DATES

1890

- 1890s — Contention among Colorado, New Mexico, Texas and Mexico users over supply of Rio Grande water
- 1905 — Congress authorized the USBR to construct the Rio Grande Project
- JUNE 1906 — Contract among USBR, Elephant Butte Water Users Association, and El Paso Valley Water Users Association
- 1906 — 1906 Convention between the U.S. and Mexico
- 1907 — New Mexico Water Code enacted
- 1912 — Construction of some Project infrastructure began
- 1915 — USBR made 1st deliveries of Project water: equal water to each Project acre
- 1918 — Necessity for drainage on the Project became apparent

1920

- 1920s — EBID and EPCWID organized
- 1925 — Tornillo Canal completed; system of open drains completed
- 1929 — Rio Grande Compact (temporary) entered
- 1929 — New Mexico Groundwater Code enacted
- 1937 — Rio Grande Joint Investigation concluded; contracts executed between US/EBID and US/EPCWID

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IMPORTANT RIO GRANDE COMPACT AND RIO GRANDE PROJECT DATES

1938 — Rio Grande Compact entered; EBID/EPCWID Interdistrict Contract executed; IBWC Rectification river realignment completed; American Dam, Caballo Dam and reservoir constructed

DECEMBER 1939 — Rules and Regulations for the Administration of the Rio Grande Compact adopted by RGCC

1940

1940 — First year under the Rio Grande Compact

1941 — First Project municipal and industrial contract: USBR/EPWU/EPCWID

1943 — IBWC Canalization Project completed

1948 — RGCC Resolution amending Compact Article IV

LATE 1940s — Project farmers began to drill irrigation wells

1950

1950s — Pumping within the Project escalated to deal with drought

1951 — USBR limited allotment of Project water to individual US farms each year; farmers supplemented through pumping

1979 — Districts repaid USBR; USBR changed Project allocation, accounting and operations

1979-1980 — Transfer contracts signed between USBR, EBID, and EPCWID

SEPT 1980 — New Mexico State Engineer declared Lower Rio Grande Groundwater Basin

EARLY 1980s — USBR developed and implemented D1/D2 Curves based upon 1951-1978 historical water distribution data

IMPORTANT RIO GRANDE COMPACT AND RIO GRANDE PROJECT DATES

1983 — *City of El Paso v. Reynolds*, 563 F.Supp. 379 (D.N.M.1983) -federal court holds New Mexico Compact delivery obligation is to Elephant Butte Reservoir

1985 — USBR released 1985 Draft Operating Agreement with D1/D2 Allocation method

2000

EARLY 2000s — Litigation initiated between the Districts and USBR in a number of judicial forums relating to Project operations

2003-2004 — USBR employed an ad hoc allocation method without reference to the D-2 Curve

2004 — New Mexico State Engineer AWRM regulations promulgated, including Metering Order; litigation ensued

2006 — USBR unilaterally allocated in accordance with D3 Curve and carried over 1/2 of Districts' unused allocation at end of year; RGCC issued Directive regarding Credit Water

2007 — USBR unilaterally implemented new Project operating procedures incorporating D3 Allocation and Carryover

MAR 2008 — Districts and USBR entered Settlement Agreement as to 2 litigations; includes the 2008 OA

2009 — Metering Order by New Mexico OSE in effect

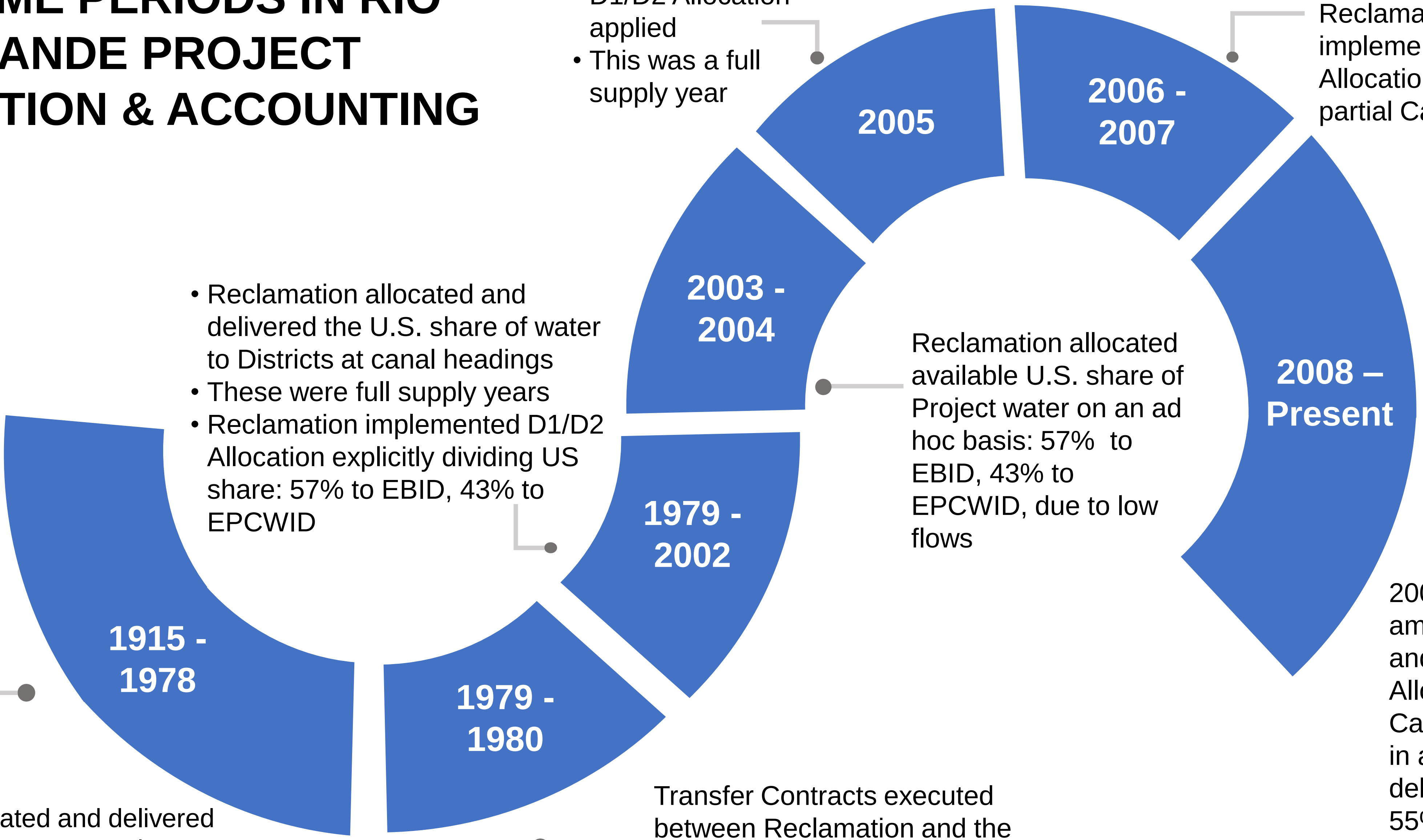
2010

2011 — USBR made an unauthorized New Mexico Credit Water release to Texas; New Mexico filed litigation in Federal district court against USBR

2013 — Texas filed Complaint against New Mexico and Colorado in United States Supreme Court (Original Action No. 141)

2018 — US Supreme Court decision that the Rio Grande Compact is inextricably intertwined with the Rio Grande Project and Downstream Contracts

KEY TIME PERIODS IN RIO GRANDE PROJECT ALLOCATION & ACCOUNTING



Reclamation allocated and delivered the U.S. share of water to Project farms: each Project acre is entitled to equal delivery equating roughly to 57% to EBID, 43% to EPCWID

Transfer Contracts executed between Reclamation and the Districts resulting in transfer of Project conveyances and responsibilities to Districts

- Reclamation allocated and delivered the U.S. share of water to Districts at canal headings
- These were full supply years
- Reclamation implemented D1/D2 Allocation explicitly dividing US share: 57% to EBID, 43% to EPCWID

Reclamation allocated available U.S. share of Project water on an ad hoc basis: 57% to EBID, 43% to EPCWID, due to low flows

- D1/D2 Allocation applied
- This was a full supply year

Reclamation implemented D3 Allocation with a partial Carryover

2008 OA executed among Reclamation and Districts: D3 Allocation with Carryover, resulting in an average of 45% delivered to EBID, 55% delivered to EPCWID

US_MSJ_00000845

APPENDIX G

Copies / Enlargements of all Figures and Tables in Report and Appendices

Figure 1.1. General location of the Rio Grande Project

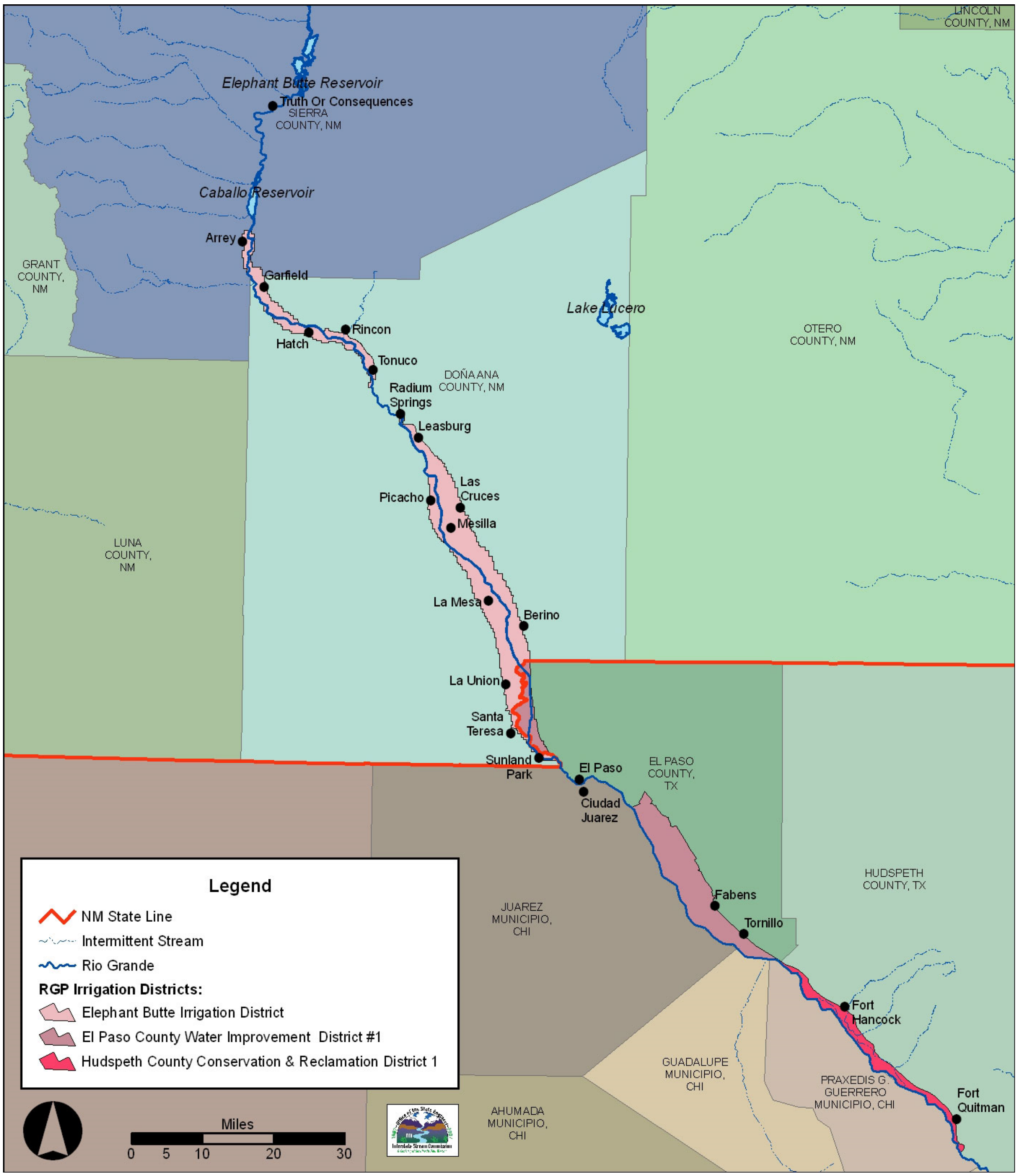


Figure 1.2. River Valleys and Sedimentary Basins within the Project Area

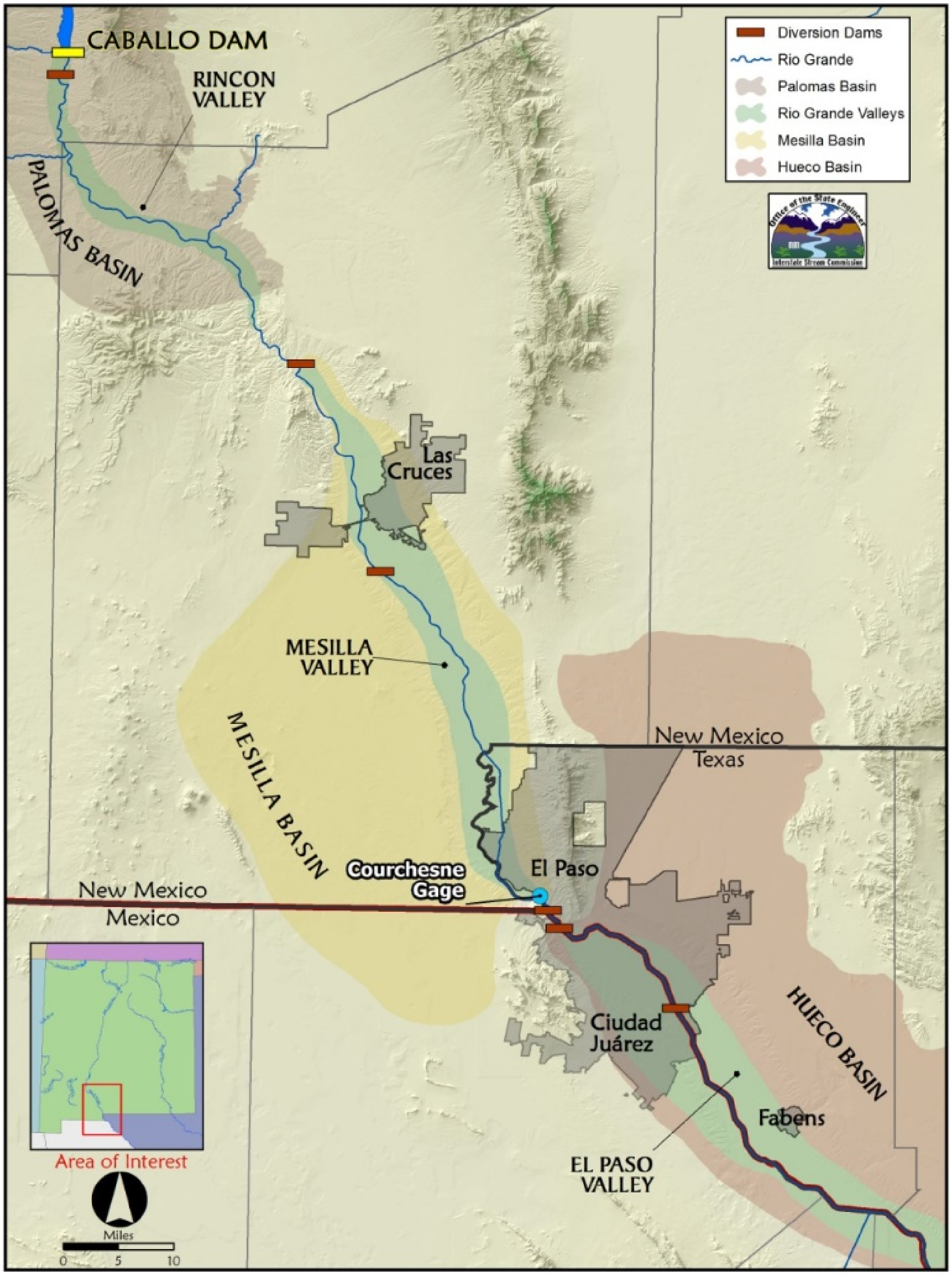


Figure 1.3. Sample East-West Cross Section of LRG alluvial aquifer system in the north-central Mesilla Basin from Hawley and Kennedy, 2004

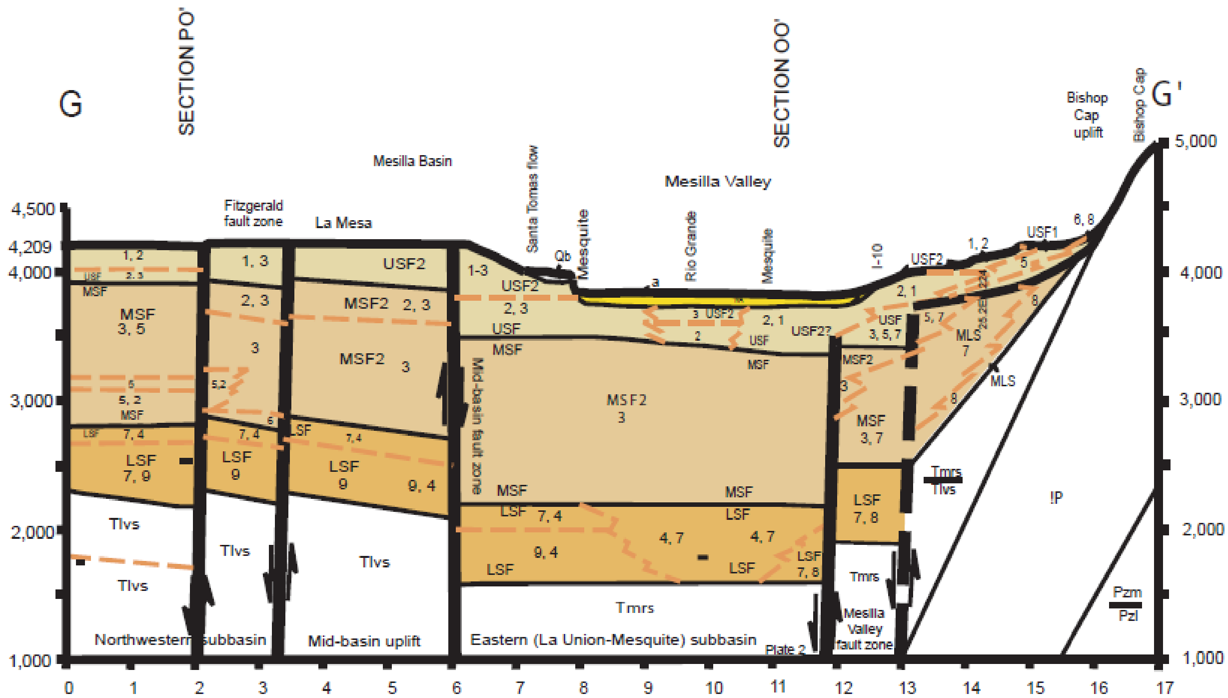


Figure 1.4. Main Diversion Structures for the Project

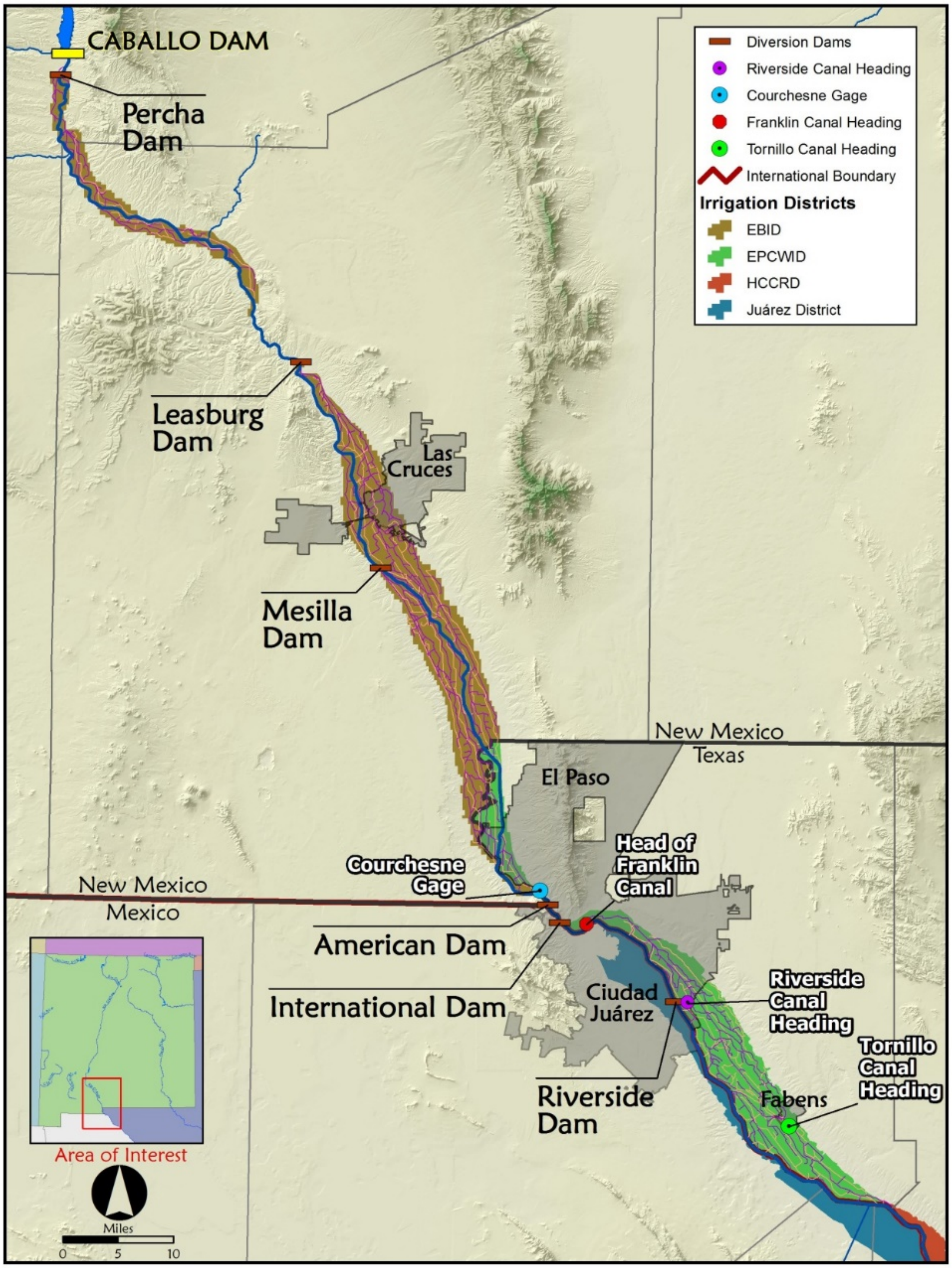


Figure 1.5. Detail Map of the El Paso Area showing Courchesne Gage, Diversion Dams, and El Paso Waterwater Treatment Plants

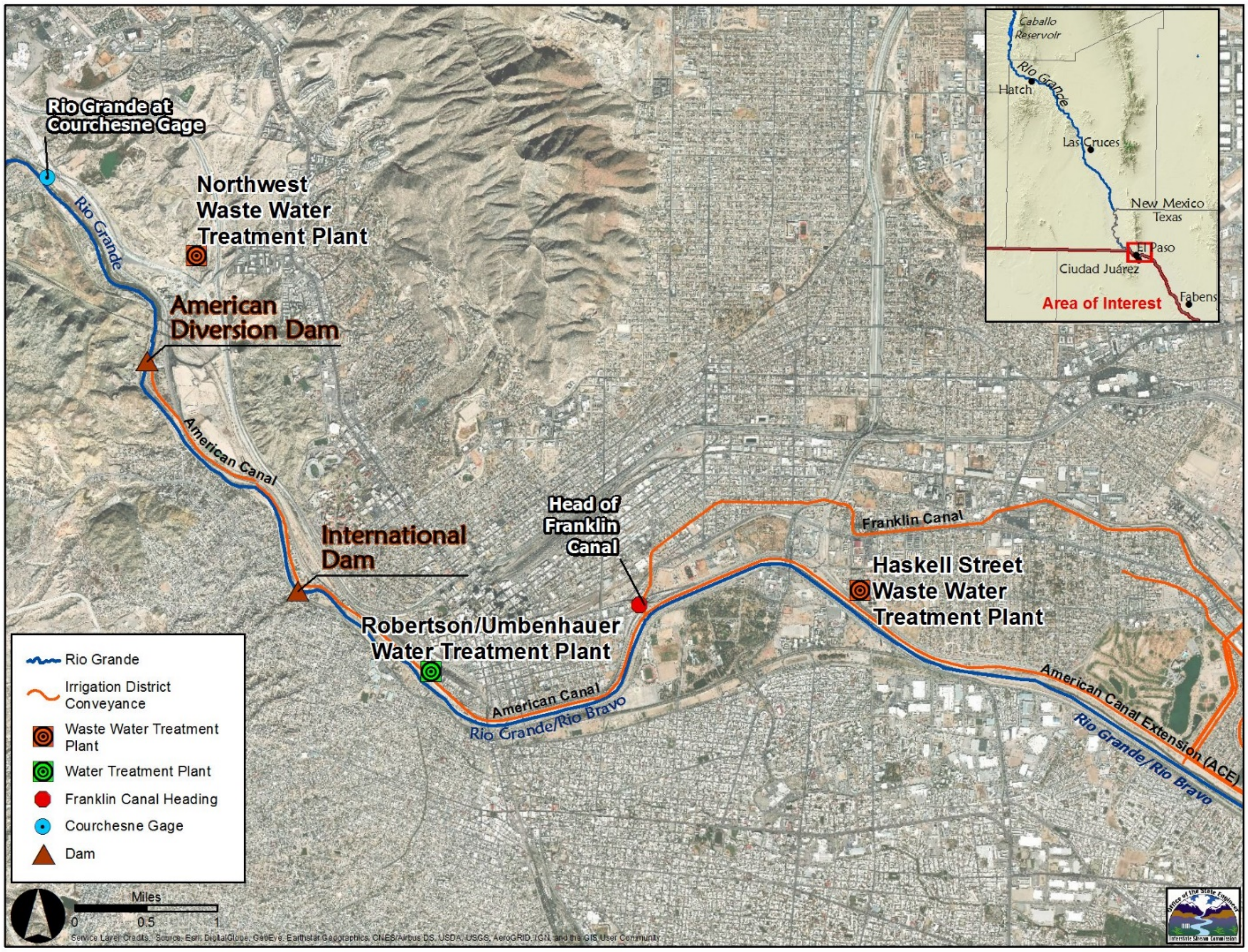


Figure 2.1. Project Order Sheet extracted from 1985 Draft Operating Agreement

PROJECT WATER ORDER

Order for period from ____________ to ____________ Date: ____________

Upper Valley Water Order EBID and EPCWID No. 1

Arrey Canal ________ cfs

Leasburg Canal ________ cfs

California Lateral ________ cfs

Del Rio Lateral ________ cfs

East Side Canal ________ cfs

Three Saints East Lateral ________ cfs

West Side Canal ________ cfs

La Union West

New Mexico ________ cfs

Texas ________ cfs

Total ________ cfs

La Union East

New Mexico ________ cfs

Texas ________ cfs

Total ________ cfs

Total Upper Valley ________ cfs

Lower El Paso Valley EPCWID No. 1 Water Order

Franklin Canal ________ cfs

City of El Paso ________ cfs

Riverside Canal ________ cfs

Total Lower Valley ________ cfs

Total Project Water Order

Upper Valley ________ cfs

Lower Valley ________ cfs

Mexico ________ cfs

Total Water Ordered ________ cfs

Less Drain Water to River ________ cfs

Plus River Loss ________ cfs

Release from Caballo ________ cfs

Flow Meter Setting ________ cfs

Time ________ Date ________

Ordered by ____________

Caballo Readings

Date ________ Time ________

Hydrographer ________ (Initials)

Discharge ________ cfs

Gage Height ____________

Flow Meter CFS ____________

East Gate ____________

West Gate ____________

Elevation ____________

Exhibit 4

Figure 2.2. Project Order Sheet extracted from 2012 Project Operations Manual

Figure 1 - Internet-Based Order Forms

RIO GRANDE PROJECT ORDER

Ord:1124	Effective Date: 7/8/2008		Prior:1123	Effective Date: 7/7/2008	
BOR	Date/Time Received: 07/08/08 15:36	Received By: IO	BOR	Date/Time Received: 07/07/08 15:09	Received By: IO
EPCWID #1	Date/Time Entered: 07/08/08 08:39	Approved By: RR	EPCWID #1	Date/Time Entered: 07/07/08 09:49	Approved By: RR
EBID	Date/Time Entered: 07/08/08 08:49	Approved By: MJN	EBID	Date/Time Entered: 07/07/08 09:51	Approved By: MJN

Upper Valley From: 7/8/2008 To: 7/9/2008

Location	Current	Prior	Change
Arrey Canal	140	140	0
(-) Bypass	0	0	0
River Pumps	0	0	0
Leasburg Canal	170	230	-60
(-) Bypass	0	0	0
California Ext.	0	0	0
Del Rio Lateral	0	0	0
Eastside Canal	110	140	-30
Westside Canal	380	400	-20
(-) Bypass WW32	-30	-70	40
Total Upper Valley	770	840	-70

State Line From: 7/8/2008 To: 7/9/2008

Location	Current	Prior	Change
La Union West TX	20	30	-10
La Union West NM	20	30	-10

Gate Settings	Current	Prior	Change
East Gate Recommended	3.98	4.41	-0.43
West Gate Recommended	3.98	4.41	-0.43

EBID Comments

-

SUMMARY

	Current	Prior	Change
RIVER BOOST	50	0	50

River Reaches/Stations	Current	Prior	Change
Caballo Release	1683	1873	-190
Flow below Percha Dam	1543	1733	-190
Gain/Loss (+/-) above Leasburg	50	0	50
Flow at Leasburg Cable	1423	1503	-80
Gain/Loss (+/-) Leasburg/Mesilla	0	0	0
Flow below Mesilla Dam	933	963	-30
Gain/Loss (+/-) Mesilla-American	0	0	0
Flow at American Dam	963	1033	-70

District Totals	Current	Prior	Change
Total for EBID	690	780	-90
Total for EPCWID #1	866	916	-50
Total for Both Districts	1556	1696	-140

Project Totals	Current	Prior	Change
Total Gains/Loss	50	0	50
Total EBID, EPCWID, Mexico	1733	1873	-140
Release	1683	1873	-190

State Line From: 7/10/2008 To: 7/12/2008

Location	Current	Prior	Change
La Union East TX	60	30	30
La Union East NM	30	20	10
3 Saints East TX	0	0	0
3 Saints East NM	0	0	0
Total State Line	130	110	20

Lower Valley From: 7/11/2008 To: 7/13/2008

Location	Current	Prior	Change
UR-WTP	56	56	0
Franklin Canal	160	130	30
JR-WTP	85	85	0
Riverside Canal	485	585	-100
Total Lower Valley	786	856	-70

Comments - EPCWID

-

Mexico From: 7/11/2008 To: 7/13/2008

Location	Current	Prior	Change
Mexico	177	177	0
Total Mexico	177	177	0

Comments - Mexico

-

Reclamation Order # 1124

Caballo Elevation	Current	Prior	Change
USBR Elevation (ft)	4148.58	4148.44	0.14
Recommended River Boost (cfs)	0.00	0.00	0
Accretions (cfs)	50.00	0.00	50

Gate Settings	Current	Prior	Change
East Gate (ft)	3.98	4.41	-0.43
West Gate (ft)	3.98	4.41	-0.43

Recommended Flow Setting	Current	Prior	Change
CFS	1683	1873	-190

Scheduled Time of Change	10:00

USBR River Measurement	Date	Time	Flow
Measured Flow (cfs)	7/8/2008	13:15	1756

USBOR Confirmation of Mexico Order	Yes

Comments

BOR recom. gate settings @ 3.86 ea.=1683 Dist. recom. gate settings @ 3.98 ea.=1735

Date/Time Received: 07/08/08 15:36 Received By: IO

FIGURE 3.1 AND C.4. Schematic of El Paso Valley Conveyance Reconfiguration above Riverside in 1938

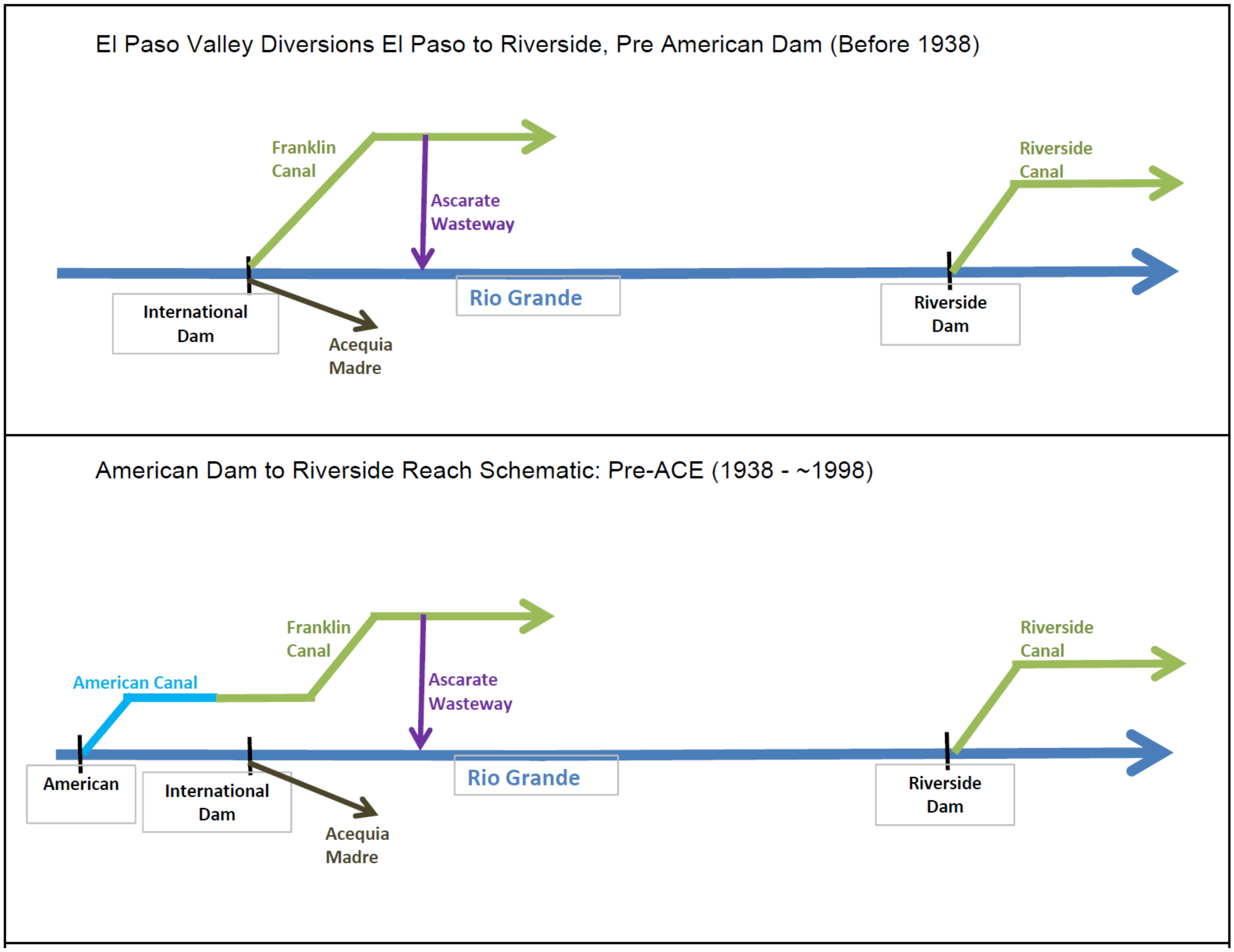


Figure 3.2 AND C.5. Major Changes in the Position of the Rio Grande, 1903 to Present

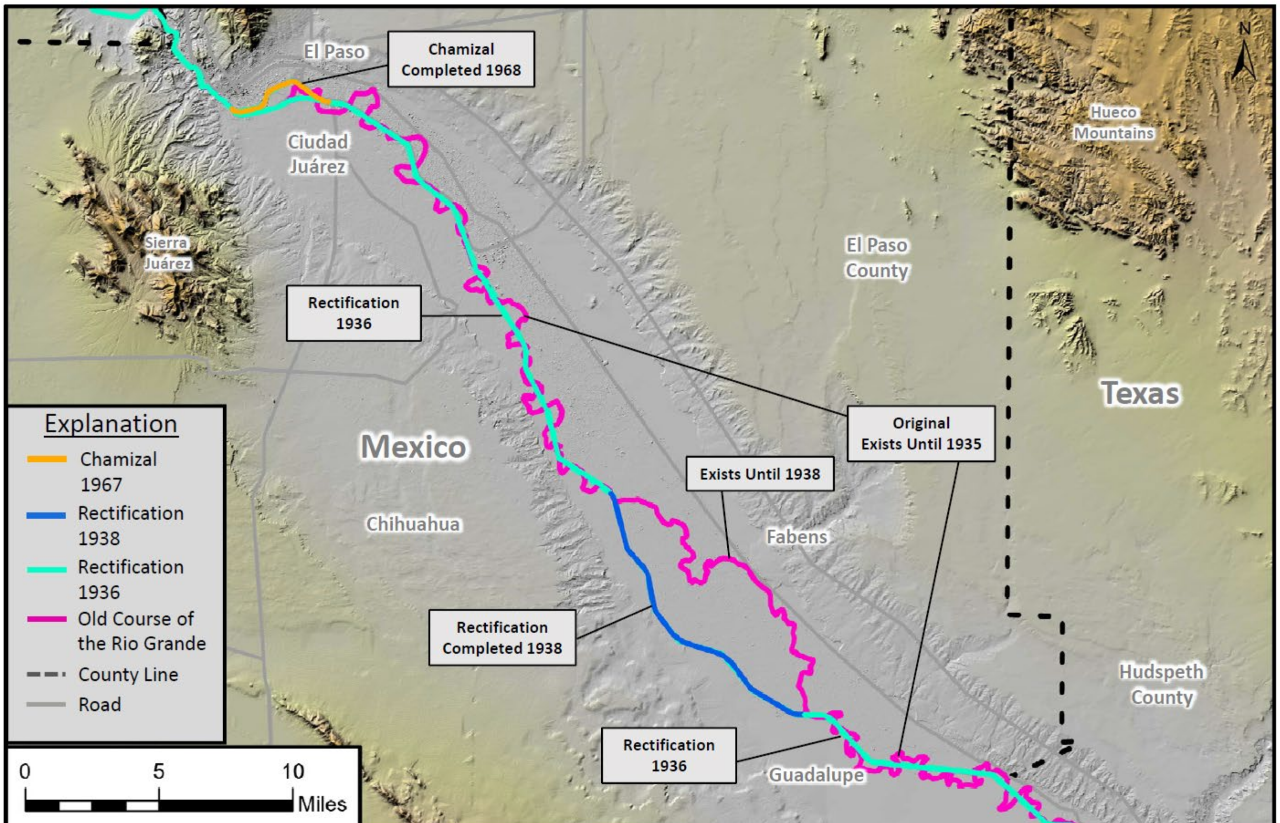


Figure 4.5a – Major changes in the position of the Rio Grande, 1903 to present.

McDonald Morrissey Associates, LLC Ground Water Hydrologists

Figure 3.3. Hydrologic Cycle of the Rio Grande Project Irrigation System, Illustrating the Source of Water in Project Drains

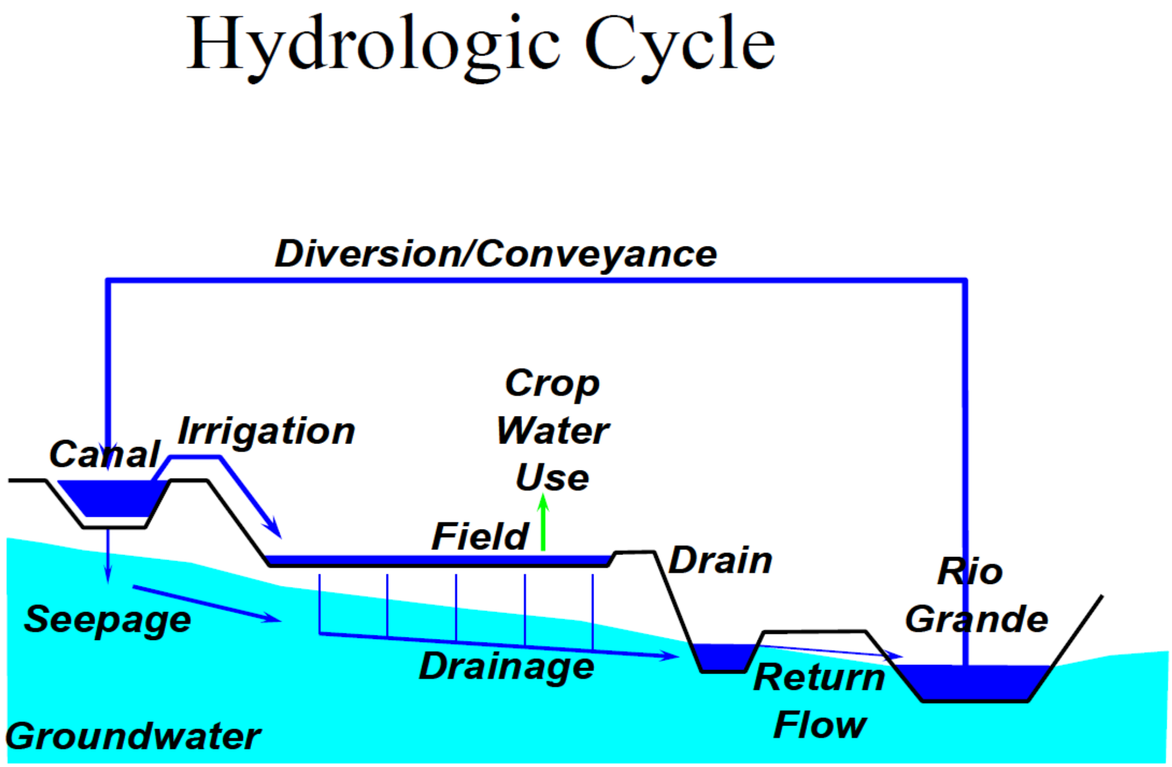


Table 4.1. EBID Irrigation Well Pumping Estimates from Gunaji (1961) Tables II and V

Table 4.1. EBID Irrigation Well Pumping Estimates from Gunaji 1961 Tables II and V		
Year	Surface Water Allotment (AF/A)	Estimated Quantify of Ground Water Pumped (AF)
1950	(No Limiting Allotment)	No significant pumping
1951	1.75	176,864
1952	2.50	101,388
1953	1.90	164,948
1954	0.50	286,122
1955	0.417	294,939
1956	0.392	282,732
1957	1.17	213,752
1958	4.00	No significant pumping
1959	3.50	No significant pumping
1960	3.25	No significant pumping

Figure 4.1. Hydrologic Cycle of the Rio Grande Project Irrigation System, Illustrating the effect of groundwater pumping

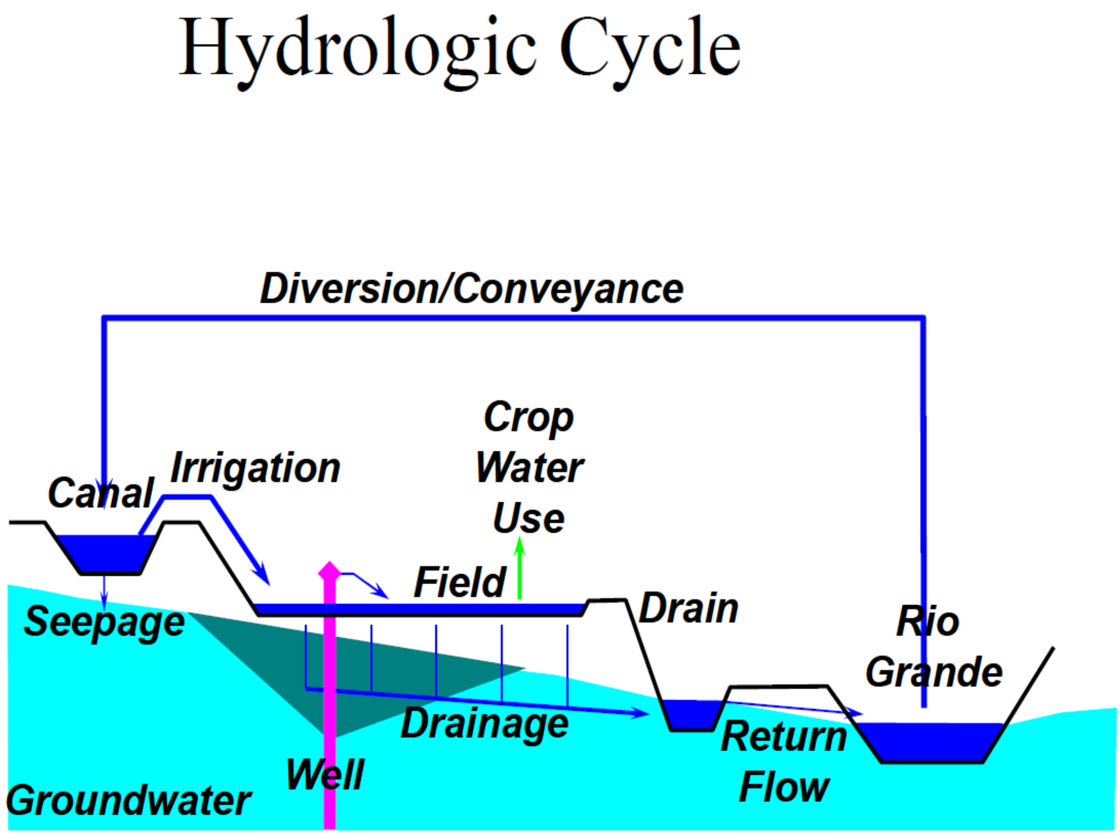


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Table 4.2. Surface Water Delivery and Irrigation Well Pumping Data in New Mexico, Calculation of Total Farm Delivery per Acre

Calculation of the Total Farm Delivery to Irrigated Lands in New Mexico, 2008 - 2018								
	Surface Water Charged to EBID Canal Headings	EBID Reported Farm Delivery	Metered Irrigation Well Pumping	Total Farm Delivery of Water (GW + SW)	Irrigated Acreage	Average Farm Delivery per irrigated acre	Assessed Acreage	Average Farm Delivery per assessed acreage
Year	Reclamation Project Accounting Records	EBID Board Meeting Minutes	NM OSE Water Master Records	Calculated	Intera 2019	Calculated	EBID Total Assesssed Acreage	Calculated
	Acre-Feet	Acre-Feet	Acre-Feet	Acre-Feet	Acres	Acre-Feet /Acre	Acres	Acre-Feet /Acre
2008	329,294	187,899	**133,000**	320,899	81,061	4.0	90,640	3.5
2009	305,475	187,694	133,000	320,694	75,607	4.2	90,640	3.5
2010	282,082	155,416	137,600	293,016	79,669	3.7	90,640	3.2
2011	59,771	24,149	279,400	303,549	76,002	4.0	90,640	3.3
2012	133,060	54,002	265,000	319,002	72,524	4.4	90,640	3.5
2013	54,002	**21,818**	286,000	307,818	77,199	4.0	90,640	3.4
2014	99,007	**39,999**	252,000	291,999	76,771	3.8	90,640	3.2
2015	143,404	**57,935**	219,000	276,935	73,616	3.8	90,640	3.1
2016	175,199	**87,600**	216,000	303,600	74,884	4.1	90,640	3.3
2017	258,954	139,589	157,000	296,589	74,218	4.0	90,640	3.3
2018	130,000	67,366	244,000	311,366	73,849	4.2	90,640	3.4

Estimated Values:
2008 Irrigation Well Pumping assumed equal to metered 2009 Irrigation Well Pumping,
EBID Farm Deliveries in 2013 - 2015 calculated assuming 40% delivery efficiency, 2016 EBID Farm delivery calculated assuming delivery efficiency of 50%.

Figure 5.1: Total Annual Gaged Drain Flow in the Rincon and Mesilla Valleys, Drain flows combined by reach into which drain flows discharge

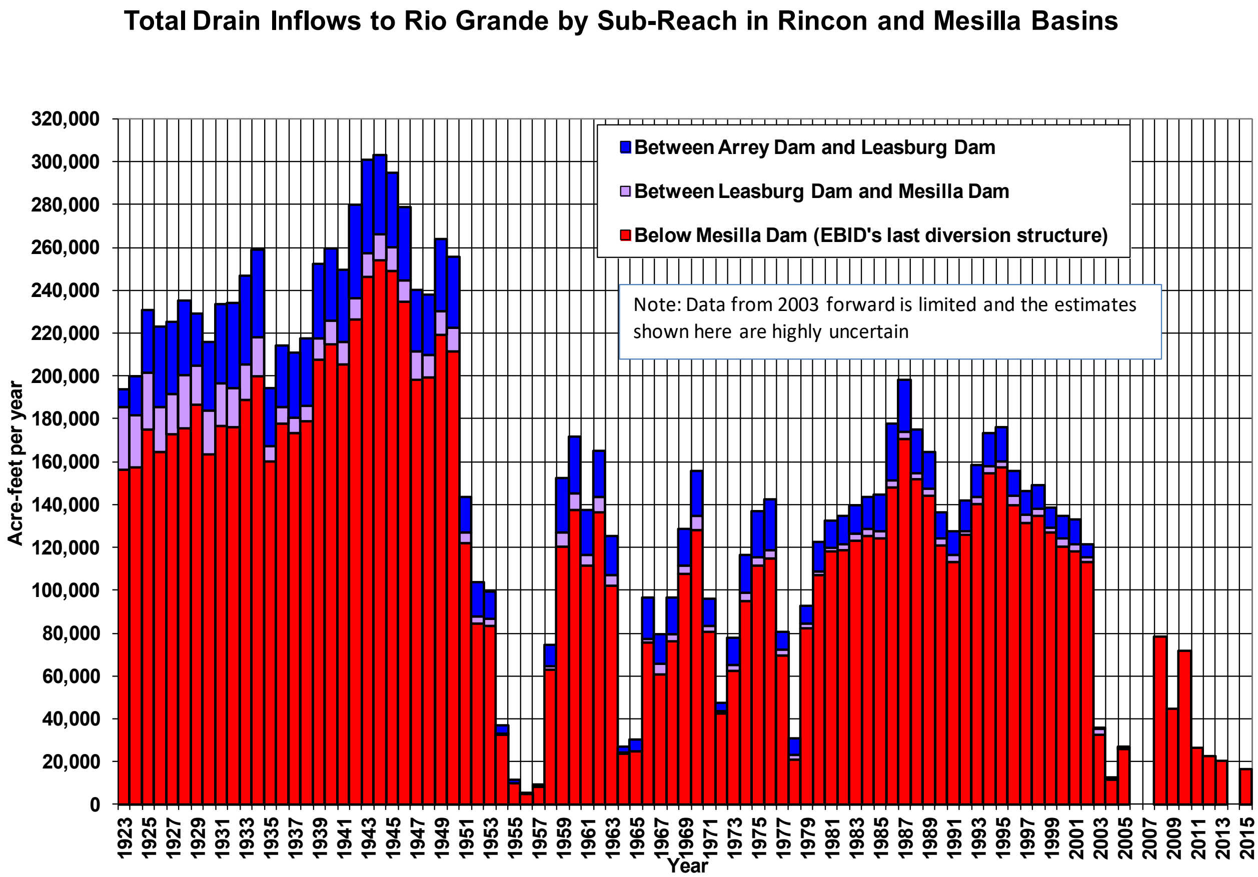


Figure 5.2. Total Annual Gaged Drain Flow for El Paso Valley Drains Above Fabens

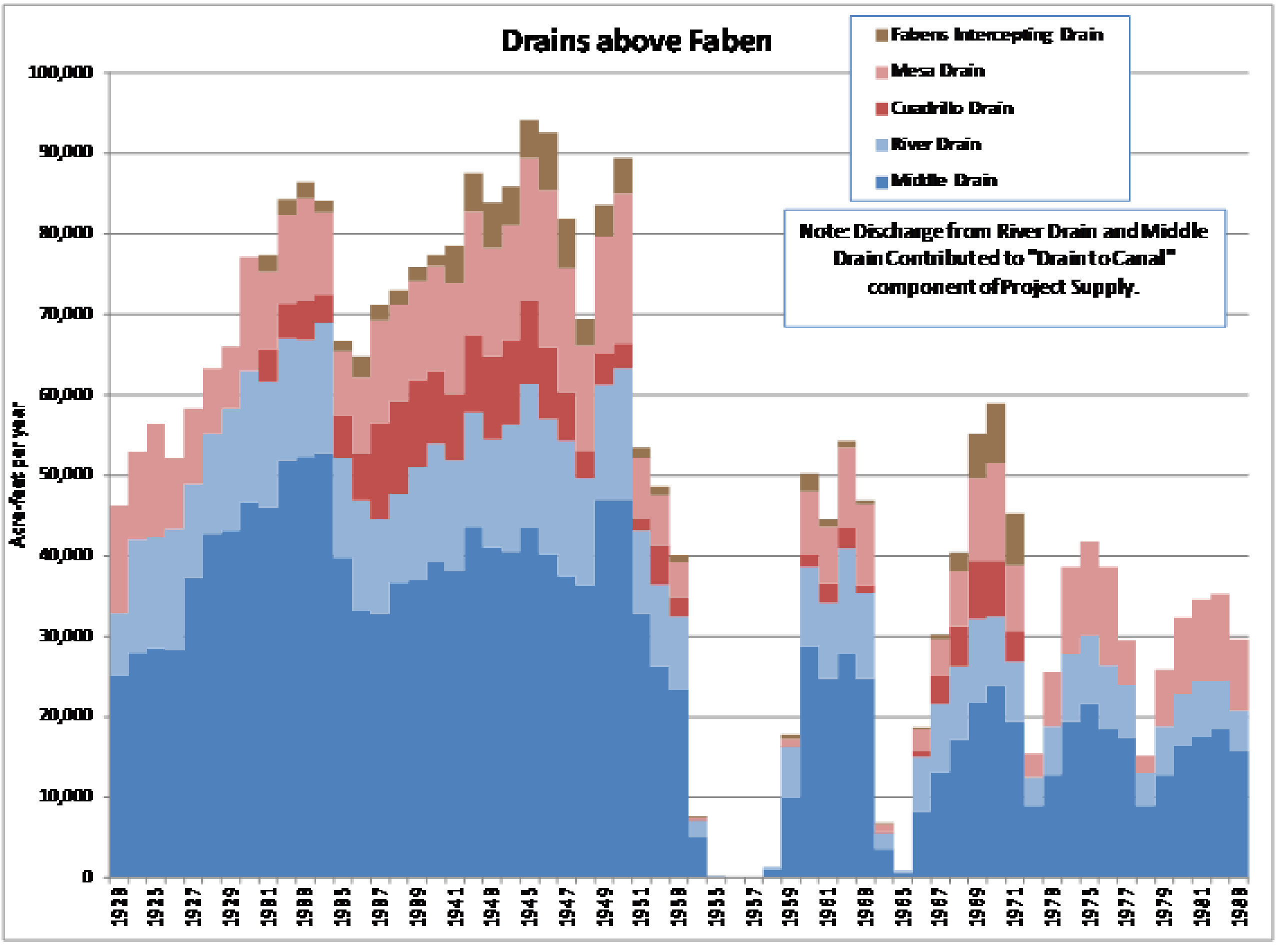


Figure 5.3 AND C.6. Schematic showing Rio Grande and Project conveyances and drains before and after Rectification realignment of river

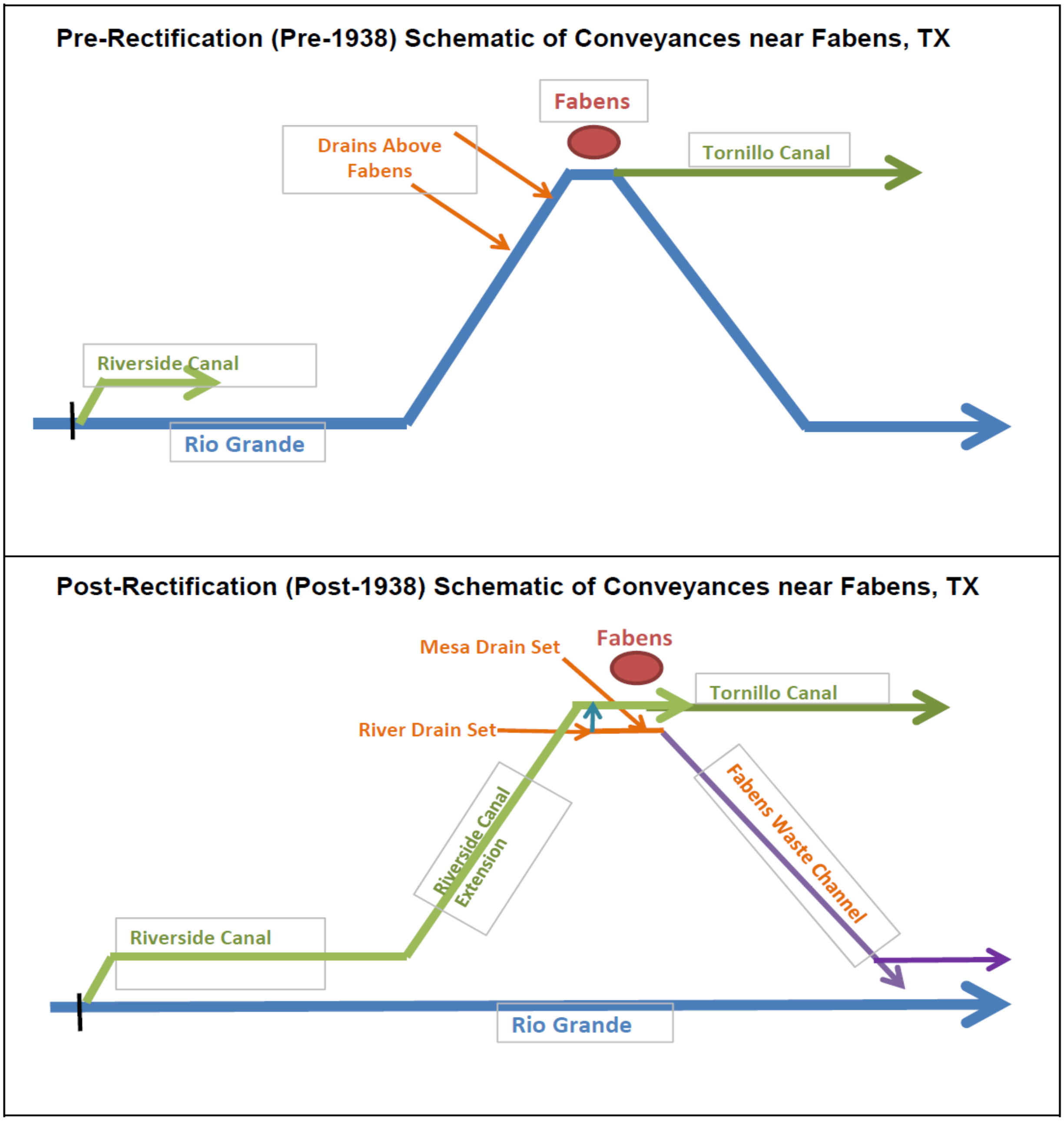


Figure 6.1 AND D.1. Reclamation's D1 Curve from F. Cortez

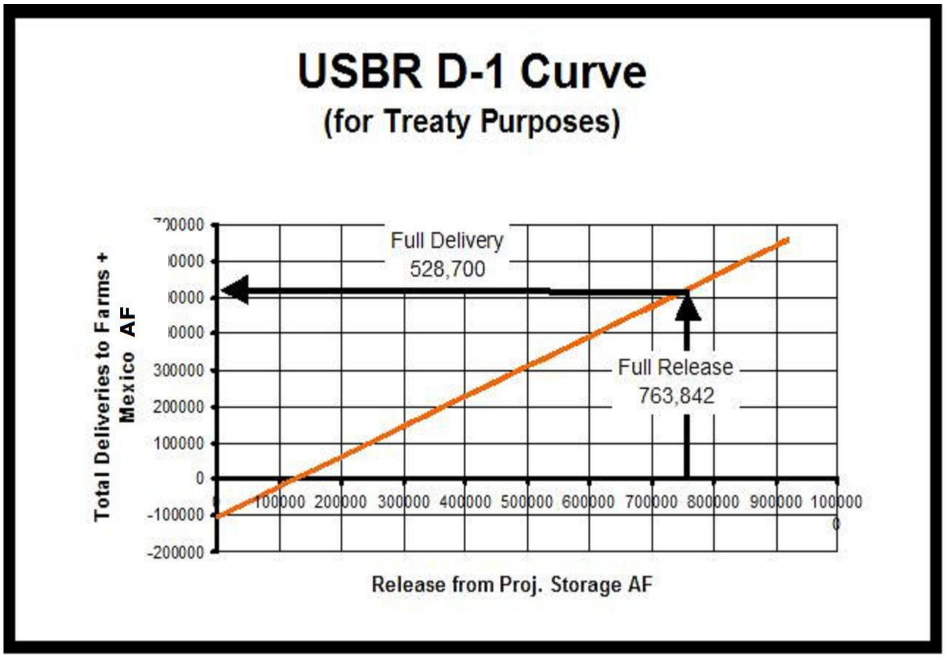


Figure 6.2 AND D.2. Reclamation's D2 Curve from F. Cortez

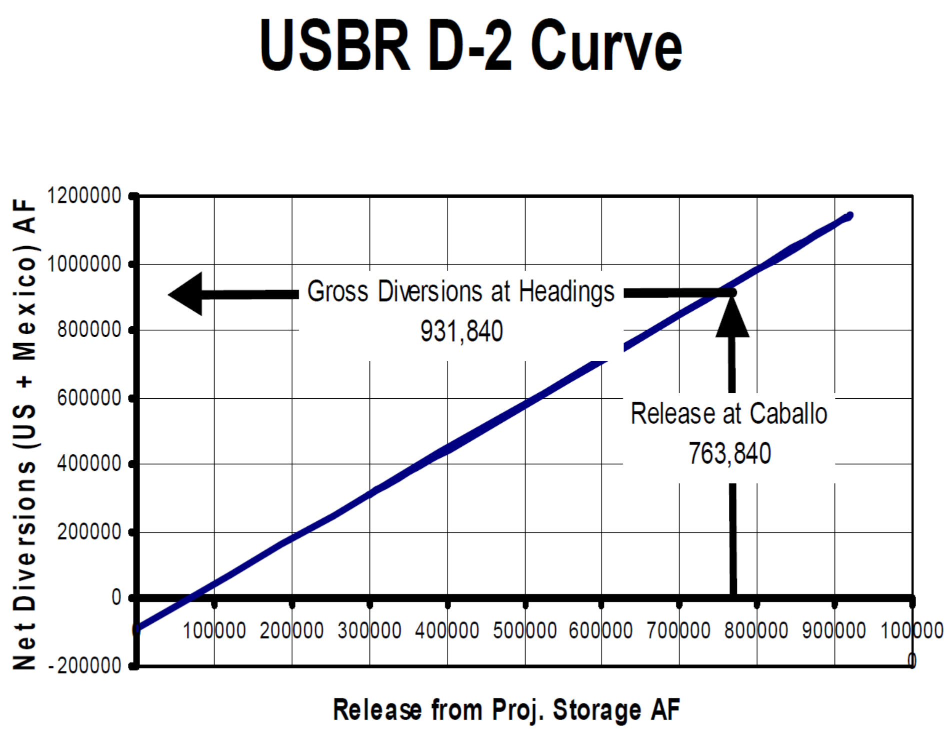


Figure 6.3. D2 Curve (or D2 Relationship) plotted with Original D2 Data from 1951-1978

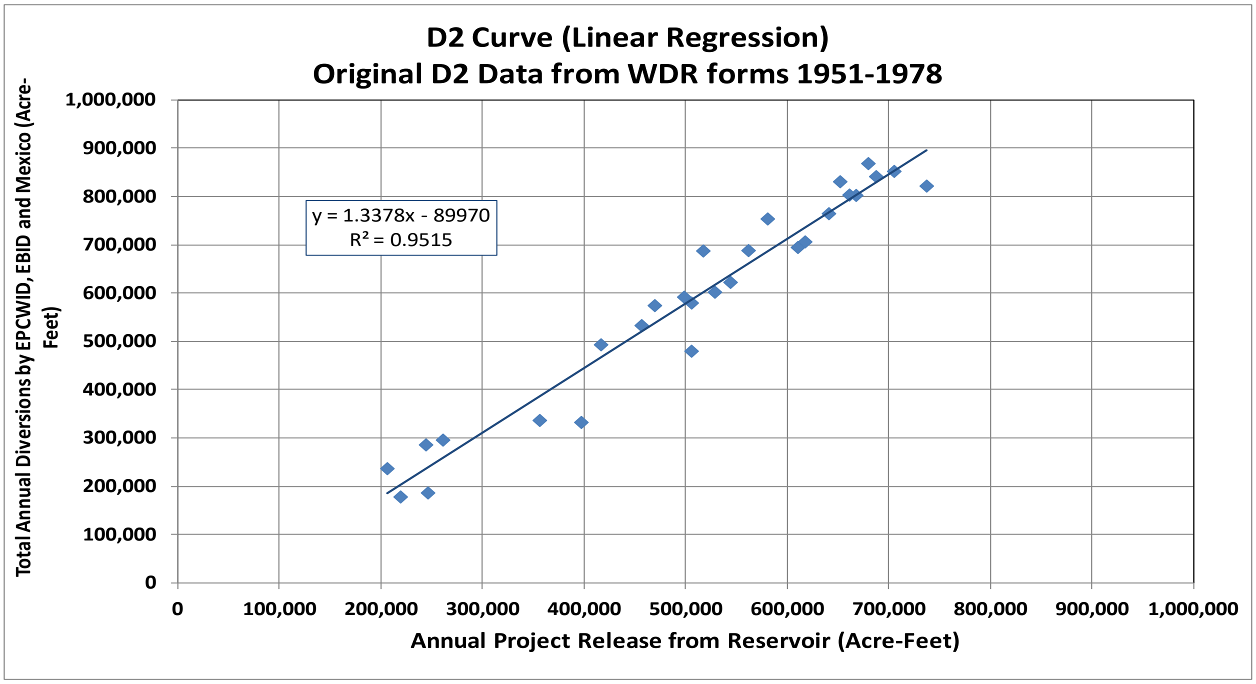


Figure 6.4 AND D.4. Illustration of Project Supply based on WSAP D2 Analysis, and D1/D2 Allocation among Districts and Mexico

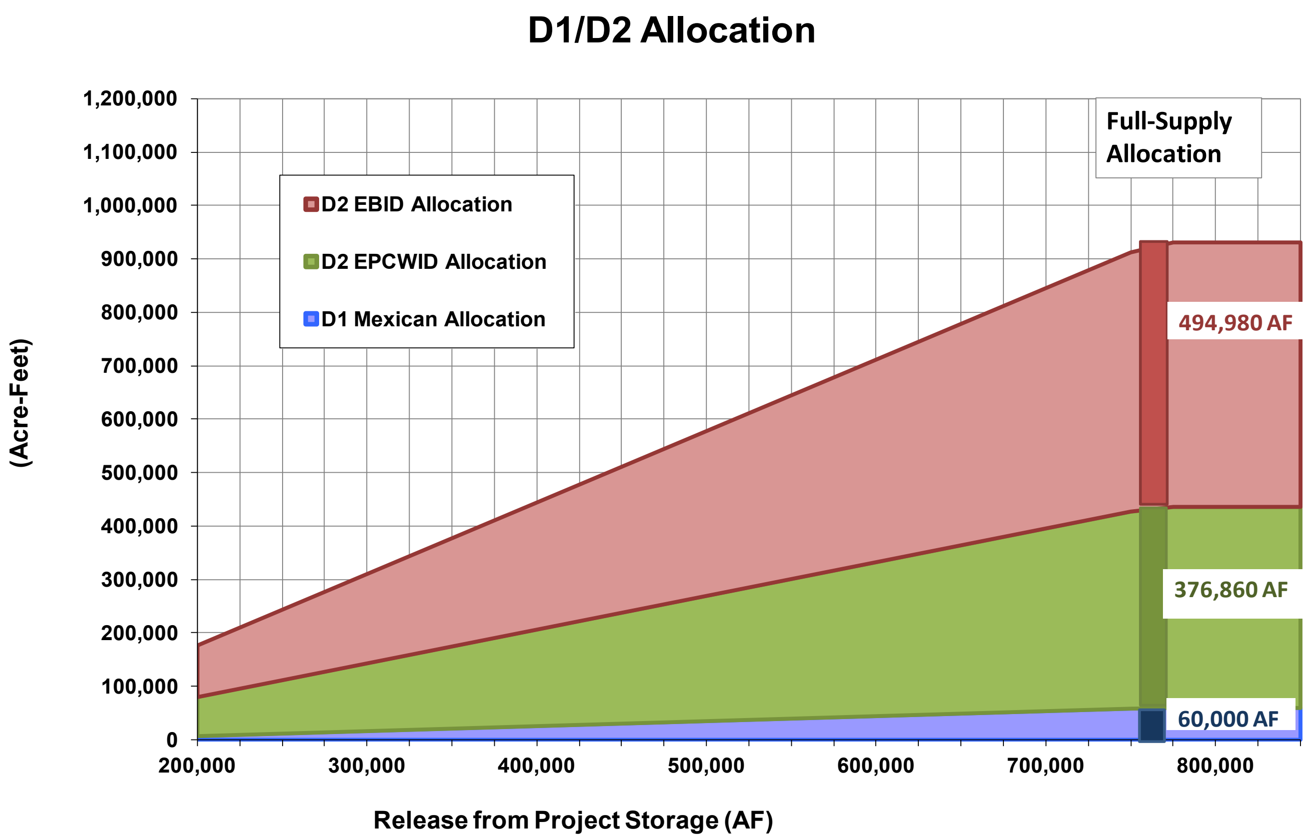
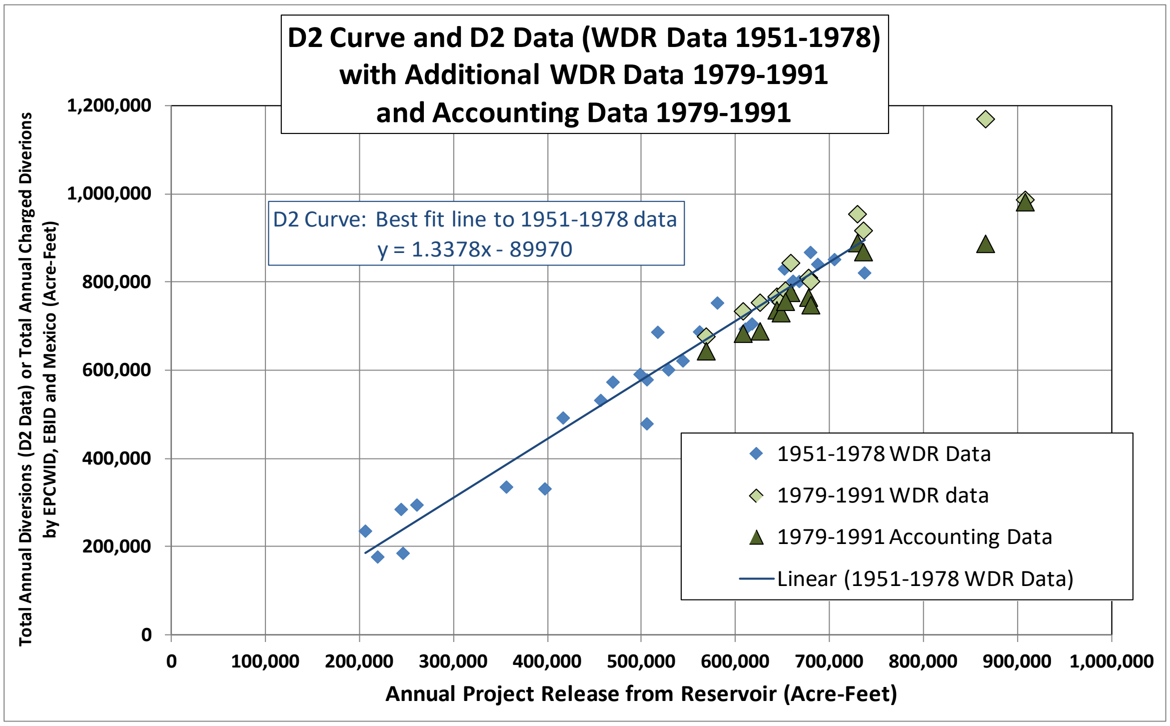


Figure 6.5. Upper Graph: D2 Curve and D2 Data from WDR forms, Additional WDR Data 1979 – 1991, and Accounting Data 1979 – 1991. Lower Graph: Zoomed to Facilitate Comparison of WRD Data 1979 – 1991 and Accounting Data 1979 – 1991



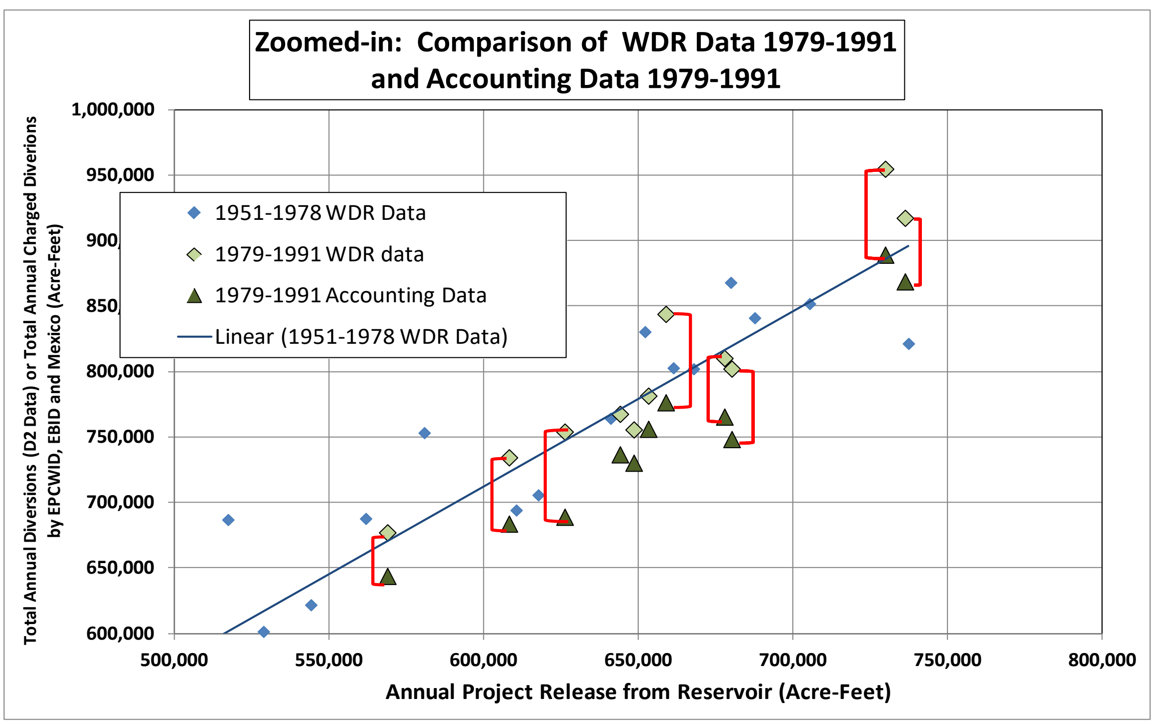


Figure 6.6. D2 Curve and D2 data plotted together with 1979 – 2018 Charged Diversions as reported by Reclamation, calculated using Post -1978 Accounting

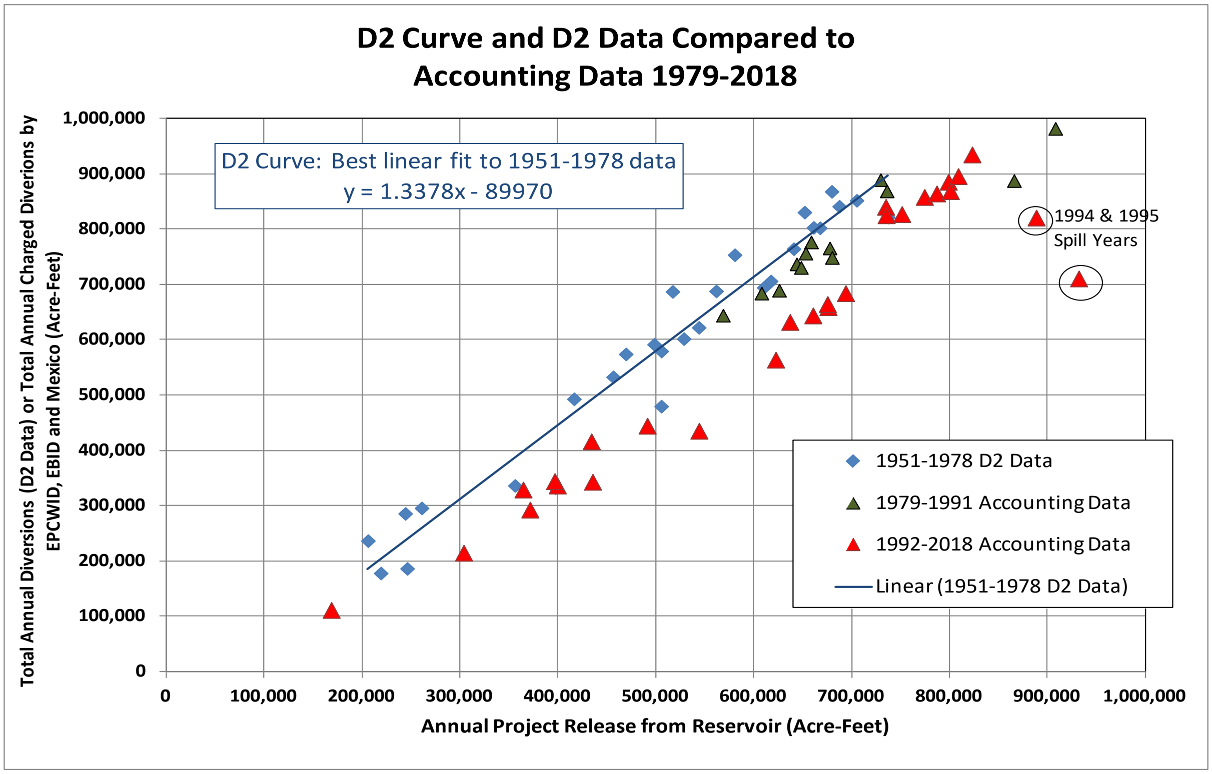


Figure 6.7 AND D.10. Illustration of D3 Allocation with Current-Year Allocation Data from 2008

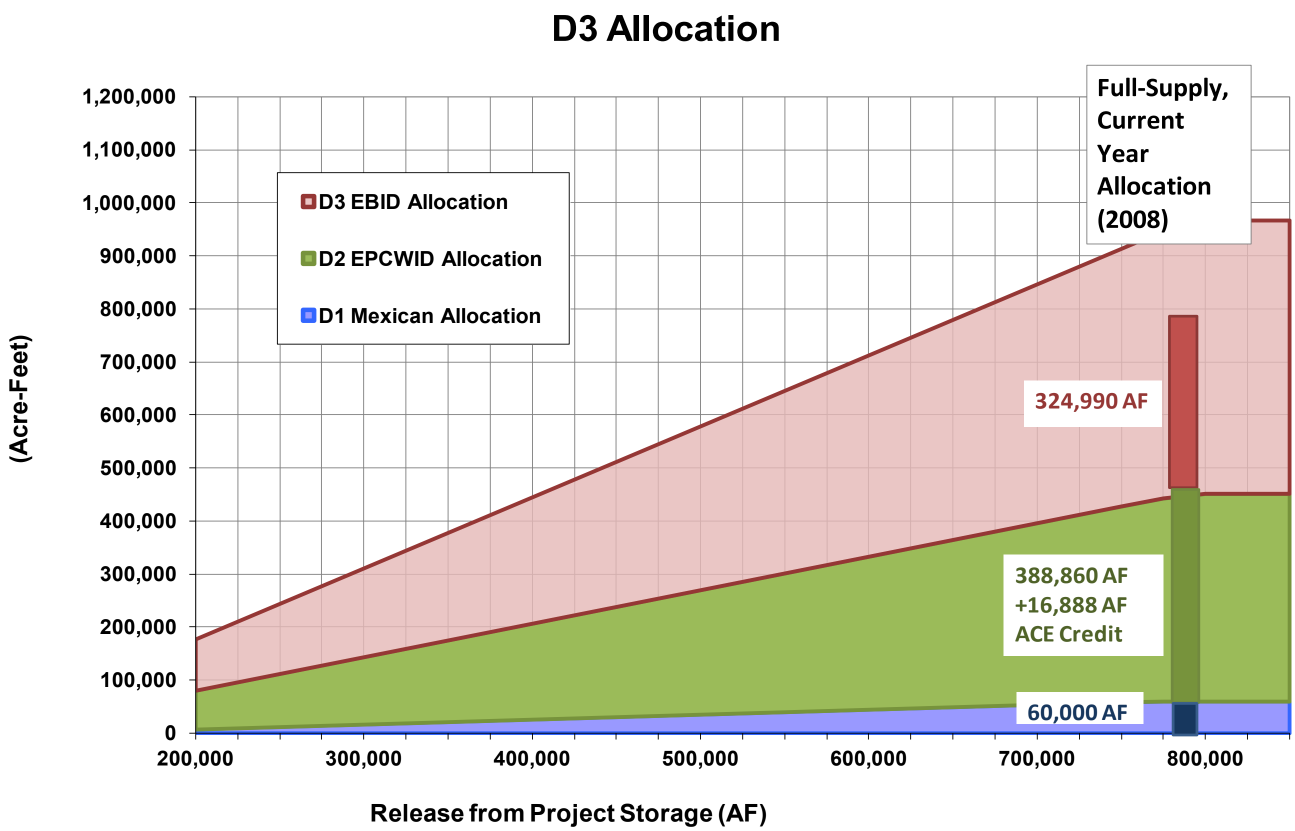


Figure 6.8 AND D.13. Image of Reclamation Allocation Spreadsheet from 2009, Modified to Test Effect of ACE Credit on Allocation

TestACE_AllocationSS.xlsx 2009 Allocation-ACE

1	**Rio Grande Project Diversion Allocations (EOM OCT 2009 Project Data)**	**Original Data**		**Modified: No ACE credit**	
2	Elephant Butte Reservoir Storage	454,530		454,530	
3	Caballo Reservoir Storage	26,100		26,100	
4	Total Rio Grande Project Storage	480,630		480,630	
5	Estimated Rio Grande Compact Credit Waters	-126,600		-126,600	
6	Estimated San Juan-Chama Water	-37,298		-37,298	
7	Water Released from Storage	693,289		693,289	
8	Total Usable Water Available for Release	1,010,021		1,010,021	
9	Carryover Obligation using Estimated Diversion Ratio	235,960		235,960	
10	Total Usable Water Available for Current Year Allocation	774,061		774,061	
11	EBID Allocation Balance (Previous Year)	-4,304		-4,304	
12	EPCWID Allocation Balance (Previous Year)	232,882		232,882	
13	EBID Allocation Balance (End-of-Year)	40,343		40,343	
14	EPCWID Allocation Balance (End-of-Year)	232,915		232,915	
15	Storage for EBID and EPCWID Allocation Balance (End-of-Year)	276,869		276,869	
16	Current Usable Water	733,152		733,152	
17	End-of-Year Release for Diversion Ratio	693,289		693,289	
18	D1 Delivery	470,416		470,416	
19	Mexico's Current Diversion Allocation	53,386		53,386	
20	Gross D2 Diversion Allocation	942,117		942,117	
21	EPCWID ACE Conservation Credit	17,998		0	
22	Net D2 Diversion Allocation for EBID and EPCWID	888,731		888,731	
23	D2 Diversion Allocation for EPCWID	384,161		384,161	
24	EPCWID Diversion Allocation (w/o Conservation Credit)	617,043		617,043	
25	EPCWID Diversion (w/o Conservation Credit or 67/155ths of Row 30)	384,128		384,128	
26	Diversion Ratio	0.986956		0.987	
27	Diversion Ratio Adjustment	-9,563		-9,563	
28	Sum of Release and Diversion Ratio Adjustment	723,589		723,589	
29	EBID D2 Diversion Allocation	504,570		504,570	
30	Difference between EBID Diversion Ratio Allocation and D2 Diversion Allocation	0		0	
31	EBID Diversion Ratio Allocation	268,077		286,075	
32	EBID Diversion Allocation	268,077		286,075	
33	Total EBID Diversion Allocation (includes 88/155th of Value in Row 30)	263,773		281,771	
34	Total EPCWID Allocation (includes Row 21 and 67/155th of Value in Row 30)	635,041		617,043	
35	District to District Allocation Transfer (OA 1.11 Excess Carryover Balance)	82,044		82,044	
36	Total EBID Diversion Allocation (After Transfer)	345,817		363,815	17,998
37	Total EPCWID Allocation (After Transfer)	552,997		534,999	-17,998
38	Total EBID, EPCWID, and Mexico Allocation	952,200		952,200	
39	EPCWID 2009 Allocation Charges (calculated)	320,082		302,084	
40	EBID 2009 Allocation Charges (calculated)	305,474		323,472	
41	EPCWID 2009 Allocation Charges (actual)	320,083		320,083	
42	EBID 2009 Allocation Charges (actual)	305,475		305,475	
43	Mexico 2009 Allocation Charges (actual)	58,688		58,688	
44	Difference in Mexico's Charges and Allocation	-5,302		-5,302	
45	EPCWID Share	-2,292		-2,292	
46	EBID Share	-3,010		-3,010	

Figure 7.1. D2 Curve and D2 Data (from WDR forms) Compared with Accounting Data (Charged Diversions) from 1979 – 2018

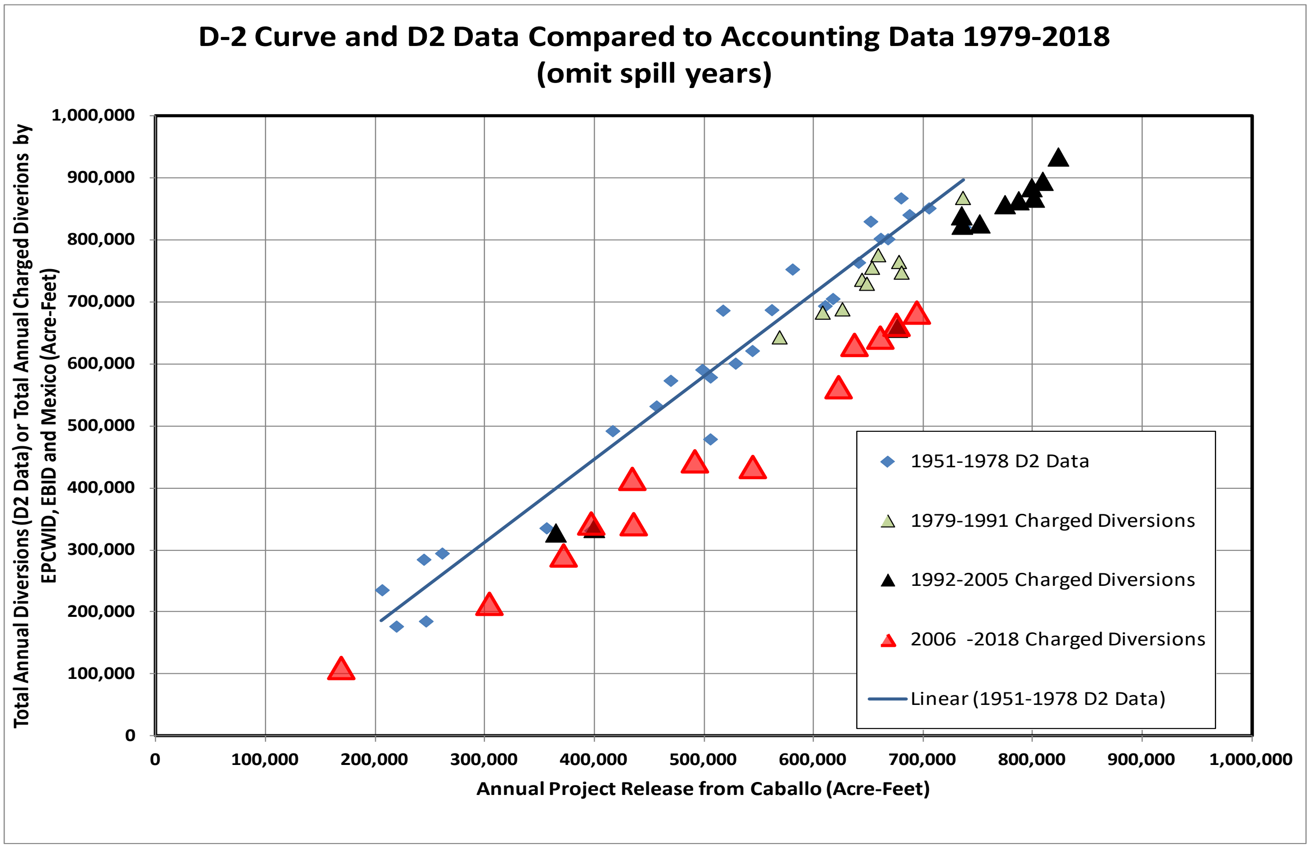


Figure 7.2. D2 Curve and D2 Data, Highlighting the 1969 data point

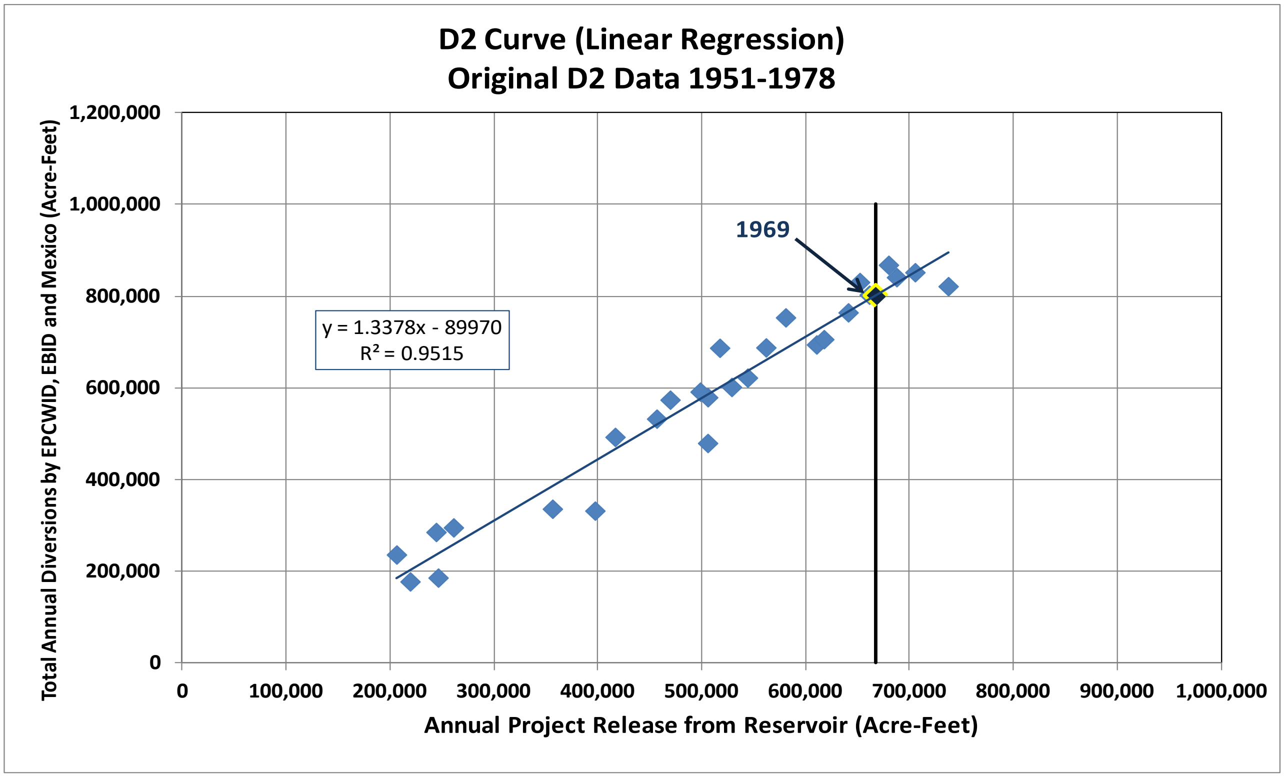


Table 7.1. Analysis of 1968 Diversions as reported in Reclamation WRD forms

Analysis of 1969 WDR Diversions			
	WDR Values*	WDR Values by Component	Estimated Charged Diversion using Post-1978 Accounting
EBID Diversion	421,000	404,000	404,000
EPCWID Diversion	321,000	263,708	263,708
Mexico	60,000	60,000	60,000
Off-Season Diversions		38,000	
EPV Drain to Canal		2,292	
Estimated Post-1978 Credits EBID **		17,000	
Estimated Post-1978 Credits EP#1**		17,000	
Total	802,000	802,000	727,708

* WDR Values adjusted so that Mesilla Dam Diversions are split between the Districts Pro-Rata

** Total Estimated Post-1978 Credits calculated as the difference between total diversions and Charged Diversion in a year of similar water supply to 1969. This total was split 50:50 between EBID and EPCWID

Figure 7.3. 1969 Project Diversion Analysis

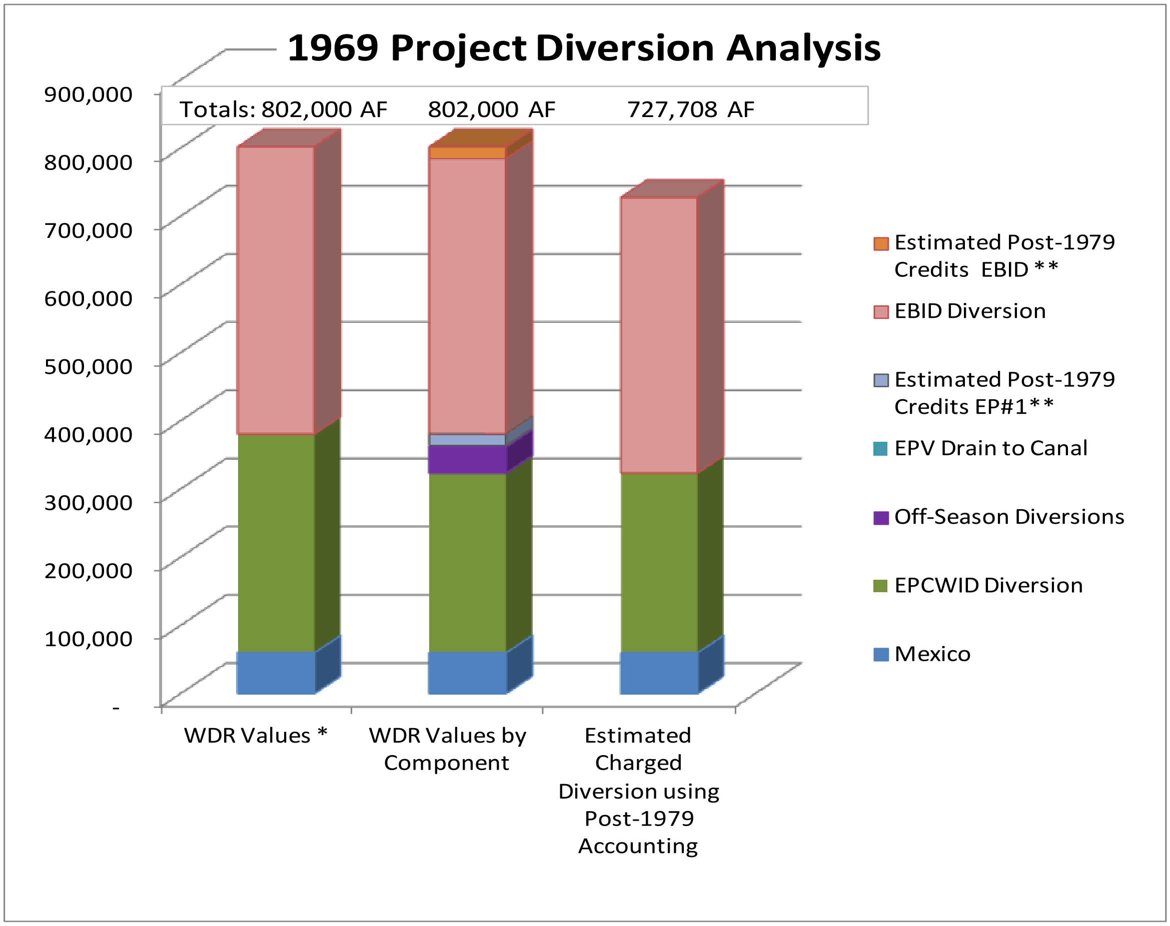


Figure 7.4. D2 Curve and D2 Data, Accounting Data from 2006-2018, Illustrating effect of Post-1978 Accounting on 1969 Diversion Data

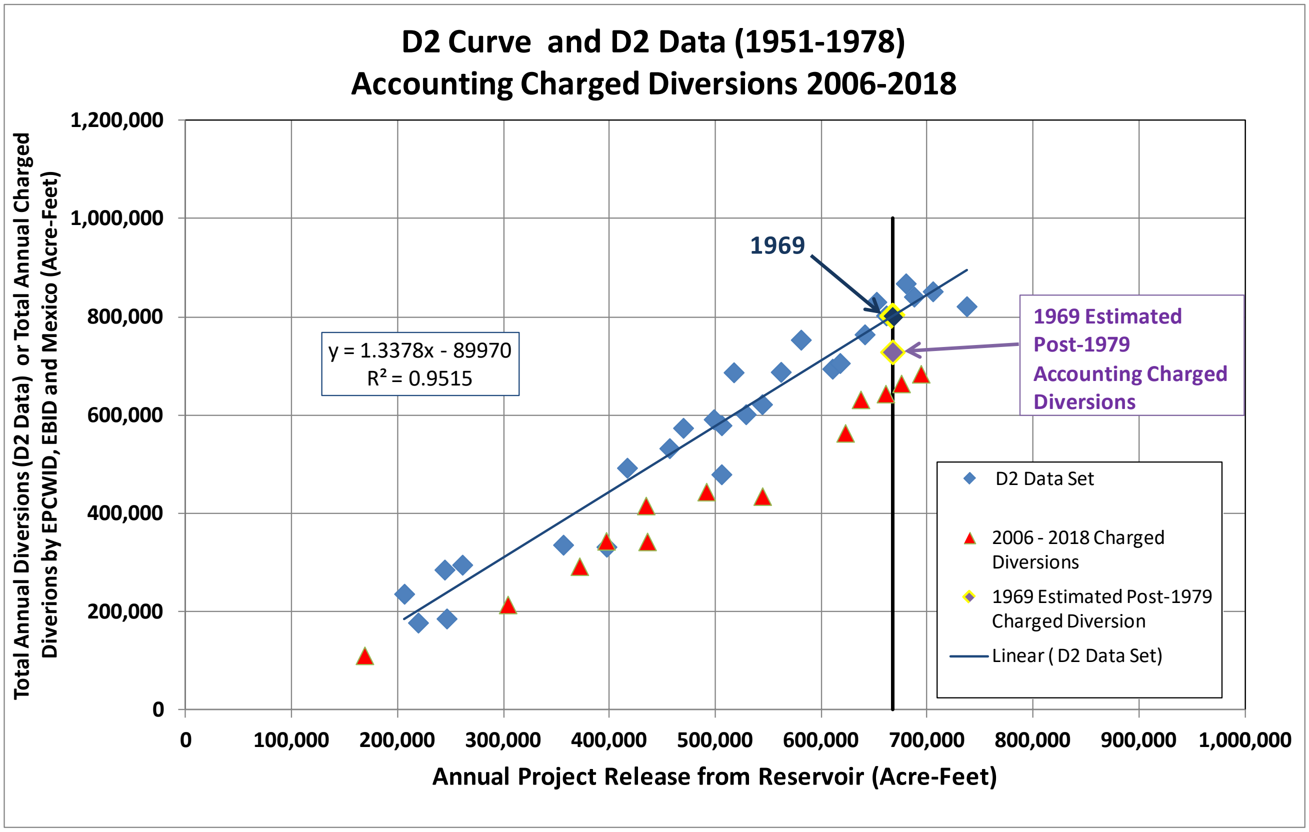


Figure 8.1. Project Accounting Data 2006 – 2018 (Charged deliveries to EBID and EPCWID plus the delivery to Mexico) Plotted together with the D2 Curve

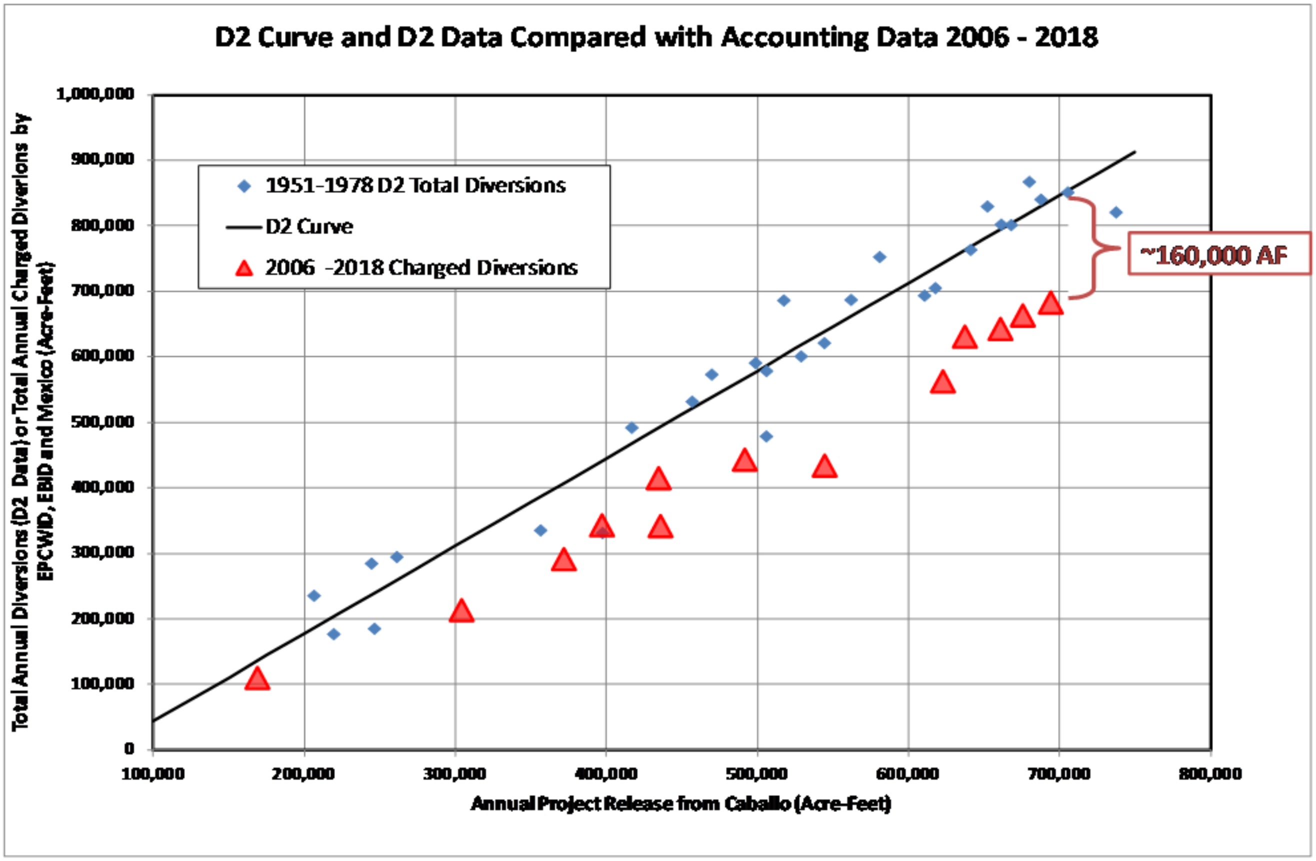
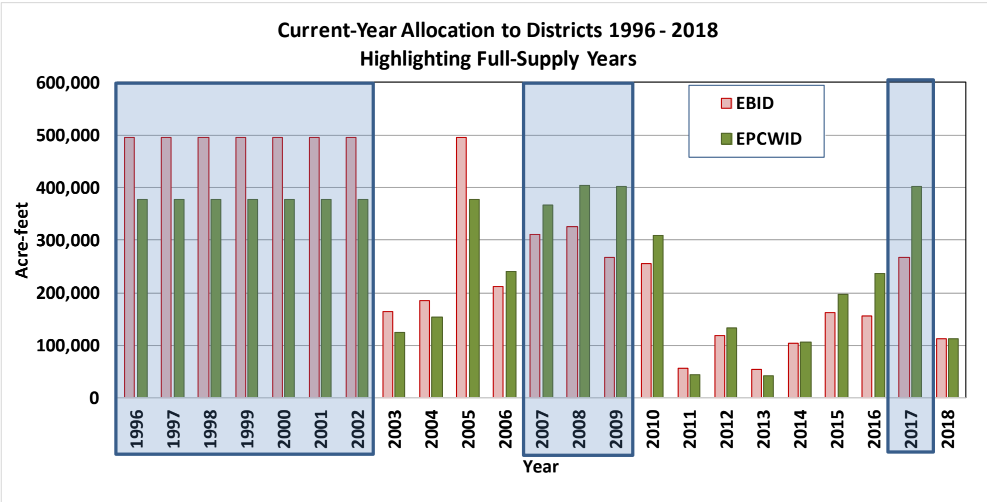
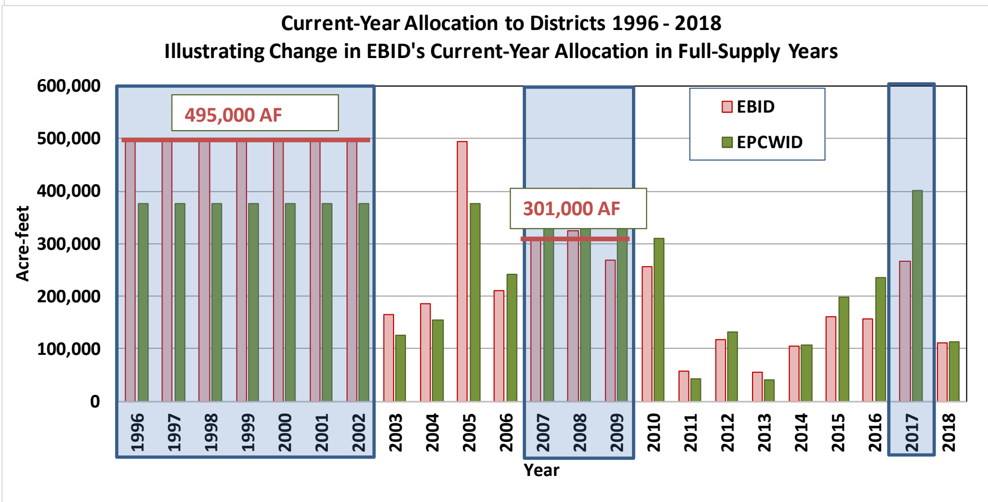


Table 8.1. Reported Usable Water, EPCWID Current-Year Allocation and Mexican Allocation for Years Designated "Full-Supply" Under D3 Allocation

Year	Total Usable Water Available for Release (Allocation Spreadsheet, Row 8)	EPCWID's current-year allocation	Mexican Allocation
2007	Unknown	367,291 AF	58,769 AF
2008	1,118,436 AF	405,073 AF	60,000 AF
2009	1,010,021 AF	402,159 AF	53,386 AF
2017	876,901 AF	401,842 AF	60,000 AF

Figure 8.2. Current-Year Allocation Data for EBID and EPCWID, 1990 – 2018





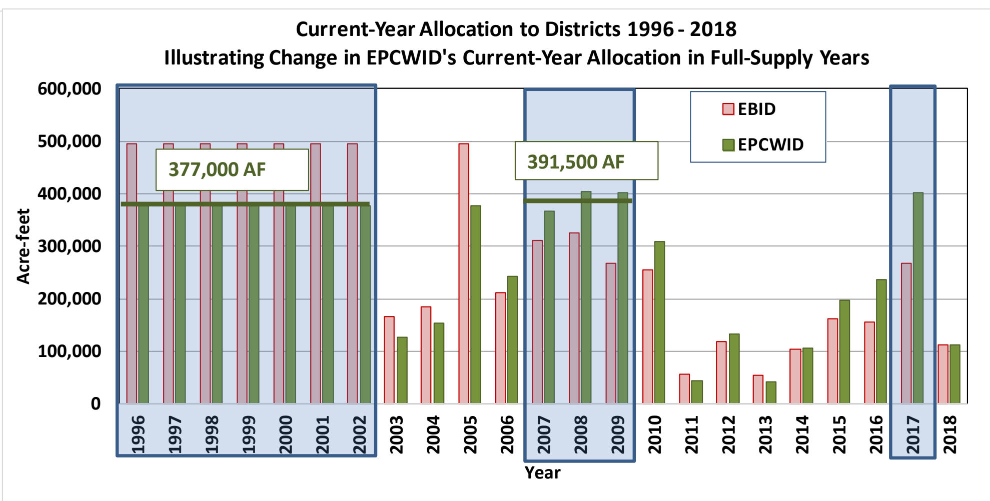
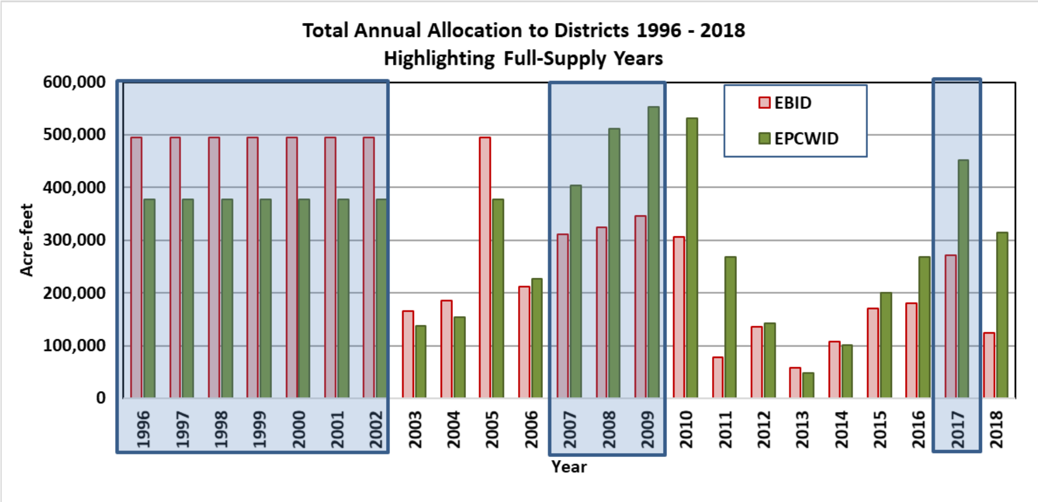
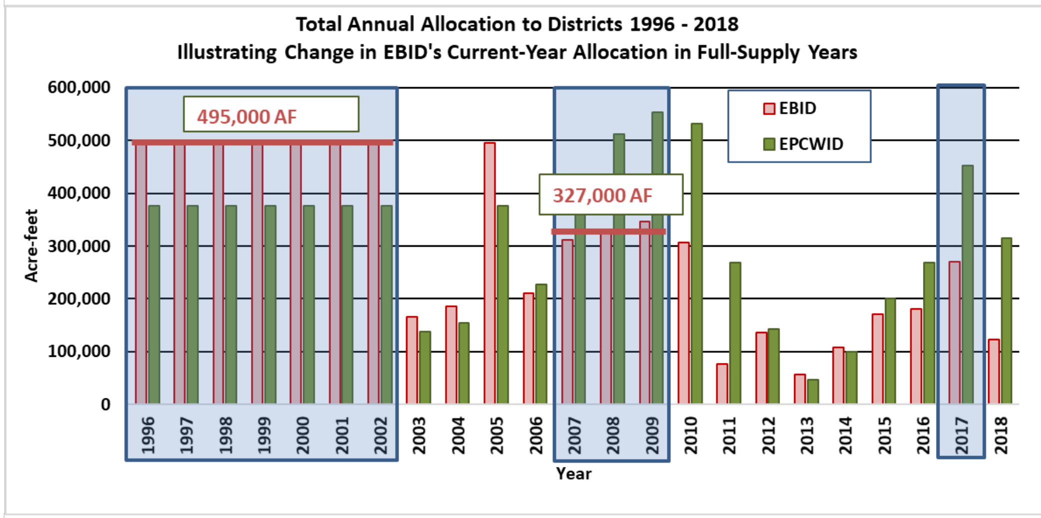


Figure 8.3. Total Allocation Data (including Carryover) for EBID and EPCWID 1990 – 2018





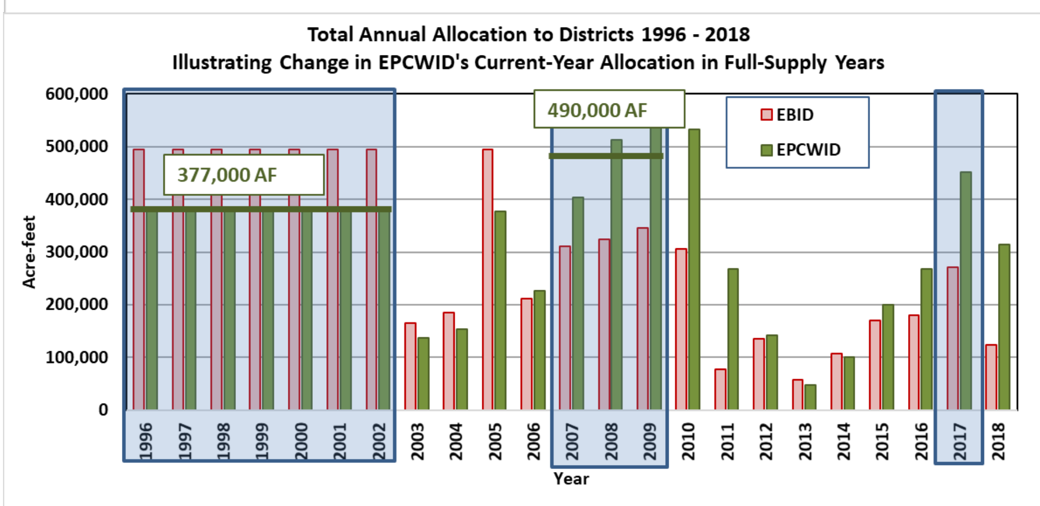
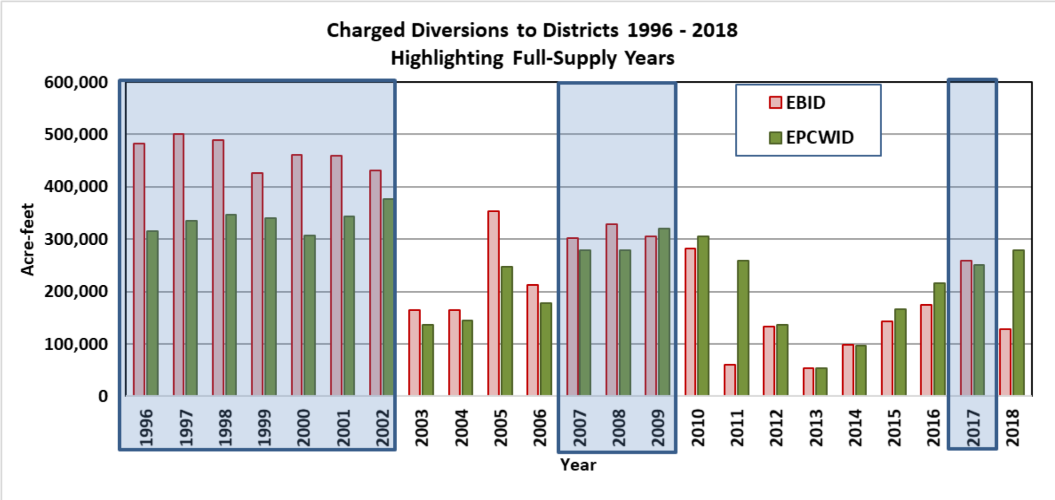
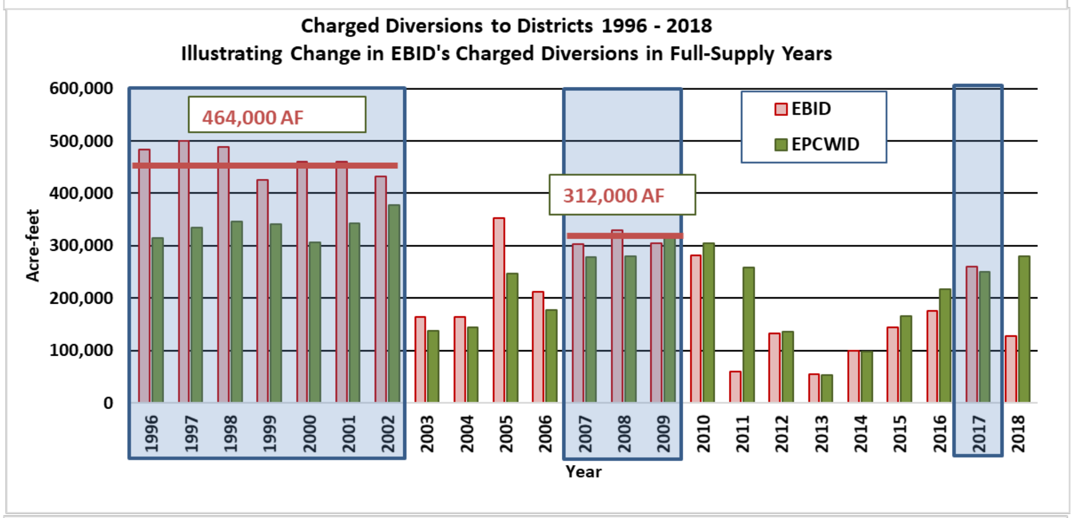


Figure 8.4. Delivery Data (Total Charged Diversions) for EBID and EPCWID 1990 – 2018





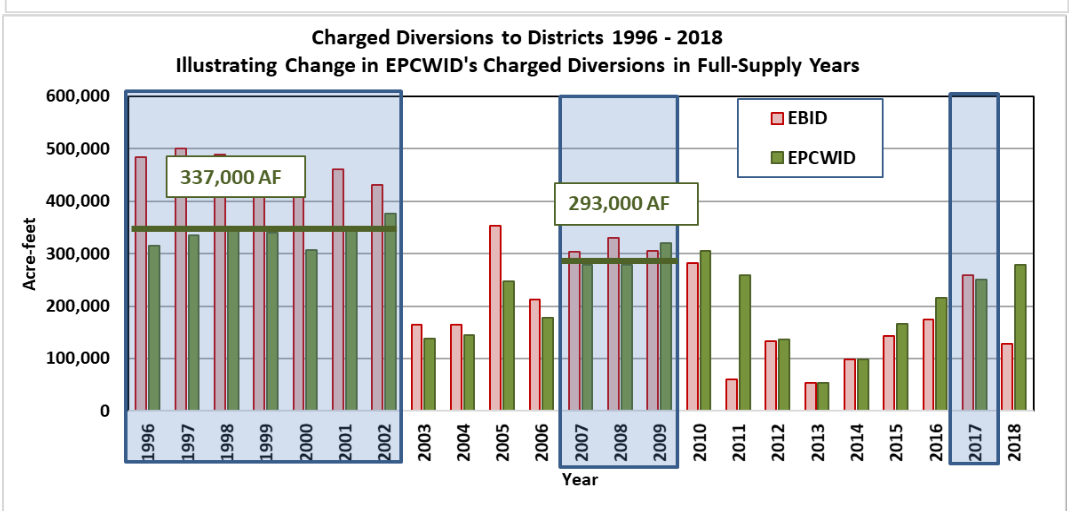
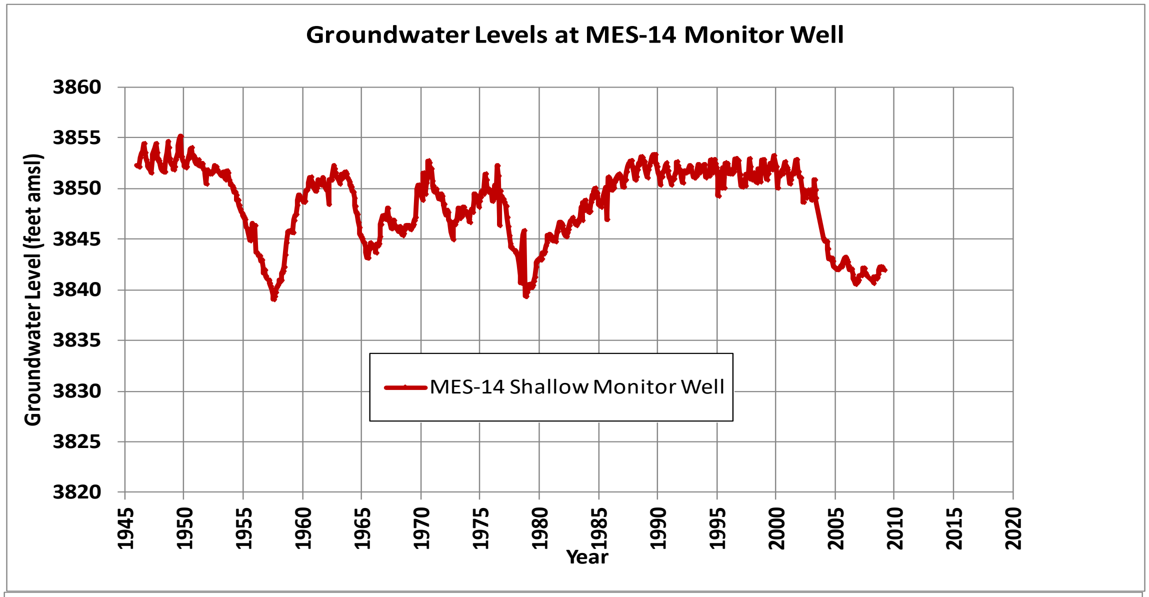


Figure 9.1. Groundwater Levels at EBID Shallow Monitor Well, 1945-2009. Upper Plot: Historical Groundwater Levels; Lower Plot: Groundwater Levels plotted with Project Release % of a Full-Supply Release (763,842 AF)



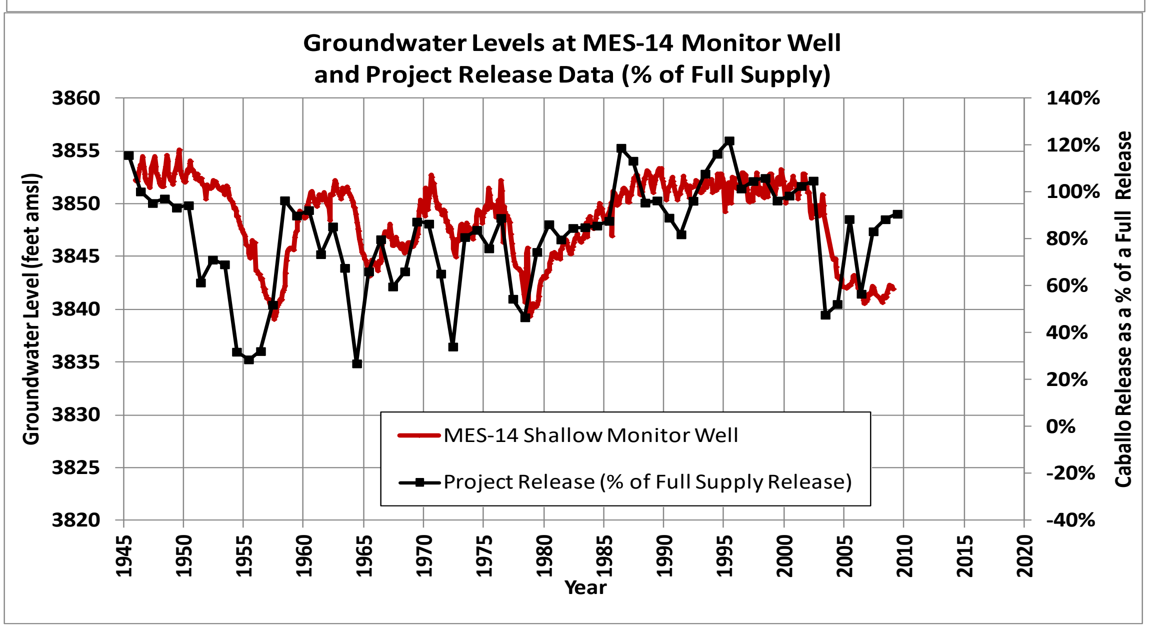
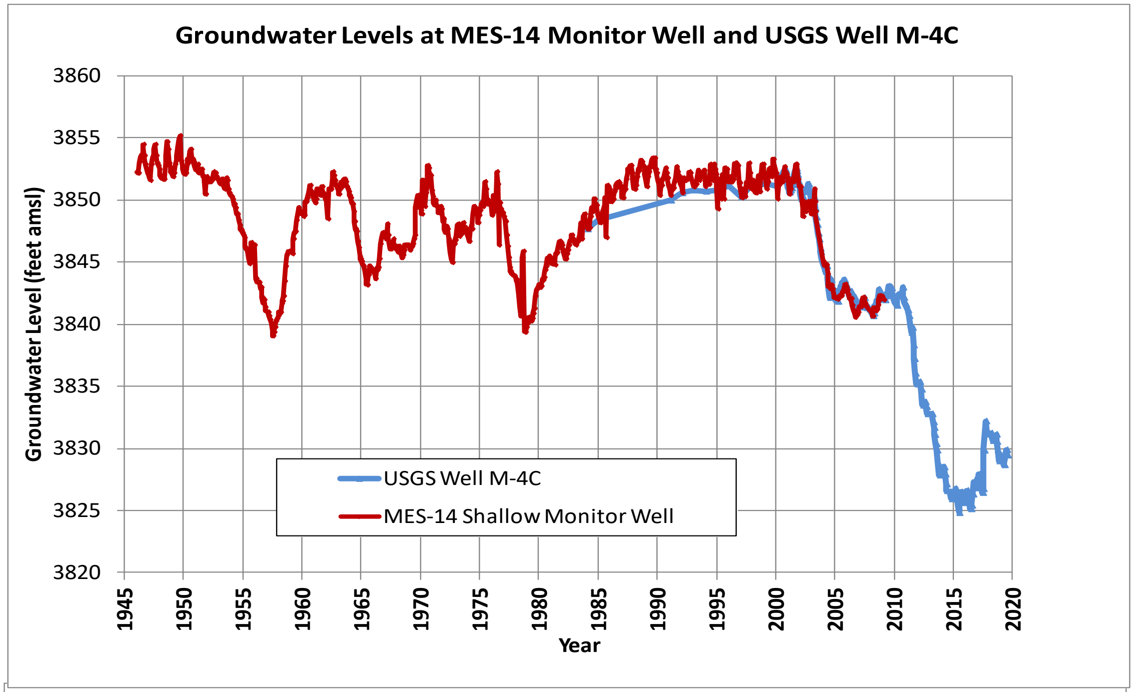


Figure 9.2. Location Map for Shallow Monitor Wells/Piezometers MES-14 and M-4C (wells referenced in Figures 9.1 and 9.3)

Figure 9.3. Groundwater Levels at EBID Shallow Monitor Wells. Upper Plot: Historical Groundwater Levels; Lower Plot: Groundwater Levels plotted with Project Release % of a Full-Supply Release (763,800 AF)



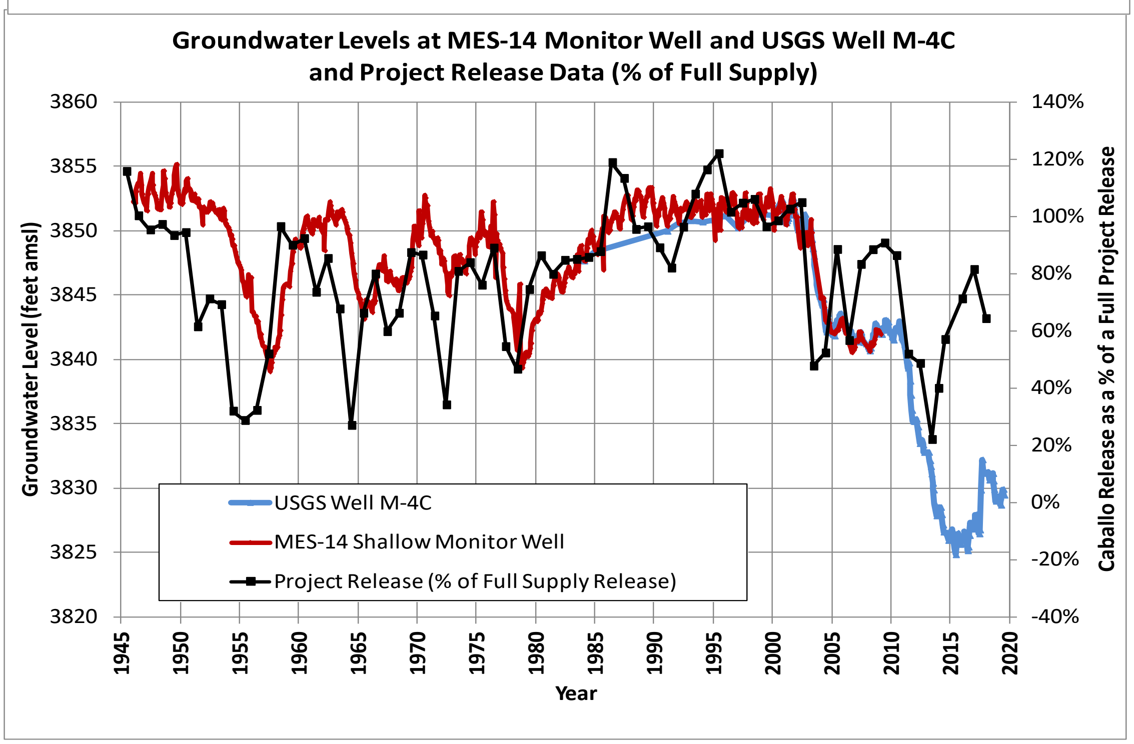


Figure A.1: Project Allotments Set by Reclamation 1951-1978

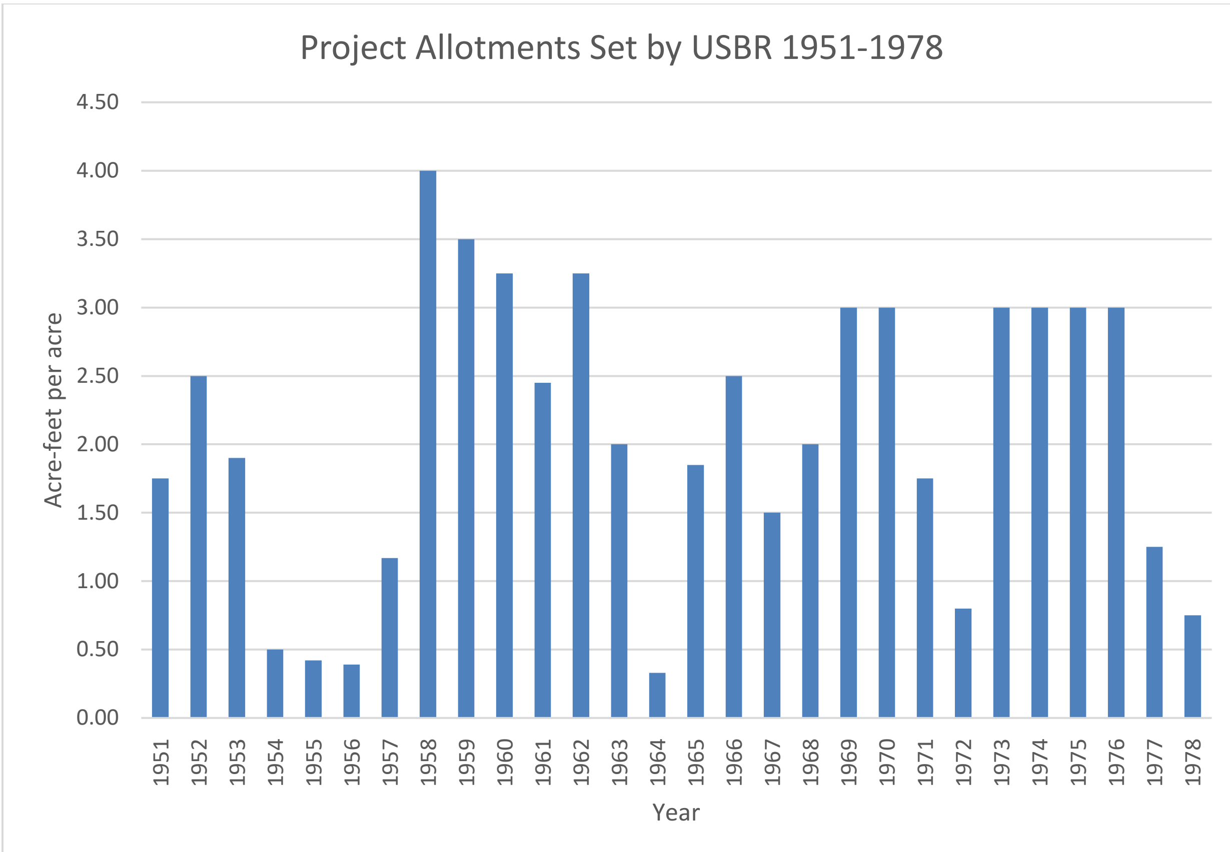


Table A.1: Project Allotments Set by Reclamation 1951-1978

Historical USBR Allotments to RGP Lands (NLA = No Limiting Allotment Set)		
	Initial Allotment to Project Lands	Final Allotment to Project Lands/EBID Lands
1940	NLA	NLA
1941	2.00	NLA
1942	NLA	NLA
1943	NLA	NLA
1944	NLA	NLA
1945	NLA	NLA
1946	NLA	NLA
1947	NLA	NLA
1948	2.00	3.00
1949	NLA	NLA
1950	NLA	NLA
1951	1.00	1.75
1952	0.21	2.50
1953	1.00	1.90
1954	0.42	0.50
1955	0.21	0.42
1956	0.33	0.39
1957	0.10	1.17
1958	1.75	4.00
1959	3.00	3.50
1960	2.25	3.25
1961	1.25	2.45
1962	1.75	3.25
1963	1.85	2.00
1964	0.25	0.33
1965	0.17	1.85
1966	1.75	2.50
1967	1.25	1.50
1968	1.00	2.00
1969	1.33	3.00
1970	2.00	3.00
1971	1.50	1.75
1972	0.60	0.80
1973	1.00	3.00
1974	3.00	3.00
1975	1.00	3.00
1976	2.50	3.00
1977	1.00	1.25
1978	0.25	0.75

Figure A.2: Water Distribution Report (WDR) for the Mesilla Unit, 1958

Form 7-322 (May 1937)

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

MONTHLY WATER DISTRIBUTION

Project Rio Grande, New Mexico-Texas Mesilla Unit (East Side and West Side Canal System) Area Irrigated 48,911 Year 1958

QUANTITIES IN ACRE-FEET

MONTH	Diverted from Stream[1]	INFLOW FROM— Reservoirs[2]	INFLOW FROM— Leasburg Canal	Delivered to Reservoirs[2]	Net Supply[3]	Total Waste to River	Total Losses	Delivered to Laterals[4]	Lateral Waste	Lateral Losses	Charged TO FARMS[5] Total	Charged TO FARMS[5] Per Acre
January,	0		0		0	0	0				0	-
February,	0		0		0	0	0				0	-
March,	29,019		0		29,019	2,980	15,449				10,[illegible]90	0.22
April,	26,994		167		27,161	1,450	4,578				21,[illegible]33	0.43
May,	26,067		60		26,127	1,310	11,774				13,[illegible]43	0.27
June,	40,346		214		40,560	1,820	15,913				22,[illegible]27	0.47
July,	49,164		216		49,380	2,010	17,682				29,[illegible]88	0.60
August,	43,322		296		43,618	3,320	13,822				26,476	0.54
September,	19,569		381		19,950	4,090	4,443				11,417	0.24
October,	2,626		1,750		4,376	2,790	1,442				1[illegible]4	-
November,	0		1,550		1,550	311	1,192				[illegible]7	-
December,	0		444		444	61	365				[illegible]18	-
Total,	237,107		5,078		242,185	20,142	86,660				135,3[illegible]3	2.77
Acre ft. per acre,	4.85		0.10		4.95	0.41	1.77				2.[illegible]7	-
Per cent Net Supply,	97.9		2.1		100	8.3	35.8				55.[illegible]	-

[1] Diversion amount exclusive of waste at head gates for sand sluicing, etc.
[2] Reservoirs connected with distributing system only.
[3] Diversions plus inflow from reservoirs and other sources less delivery to reservoirs.
[4] Measured at
[5] Measured at

Table A.2: District Diversions 1931 – 1978 (Page 1)

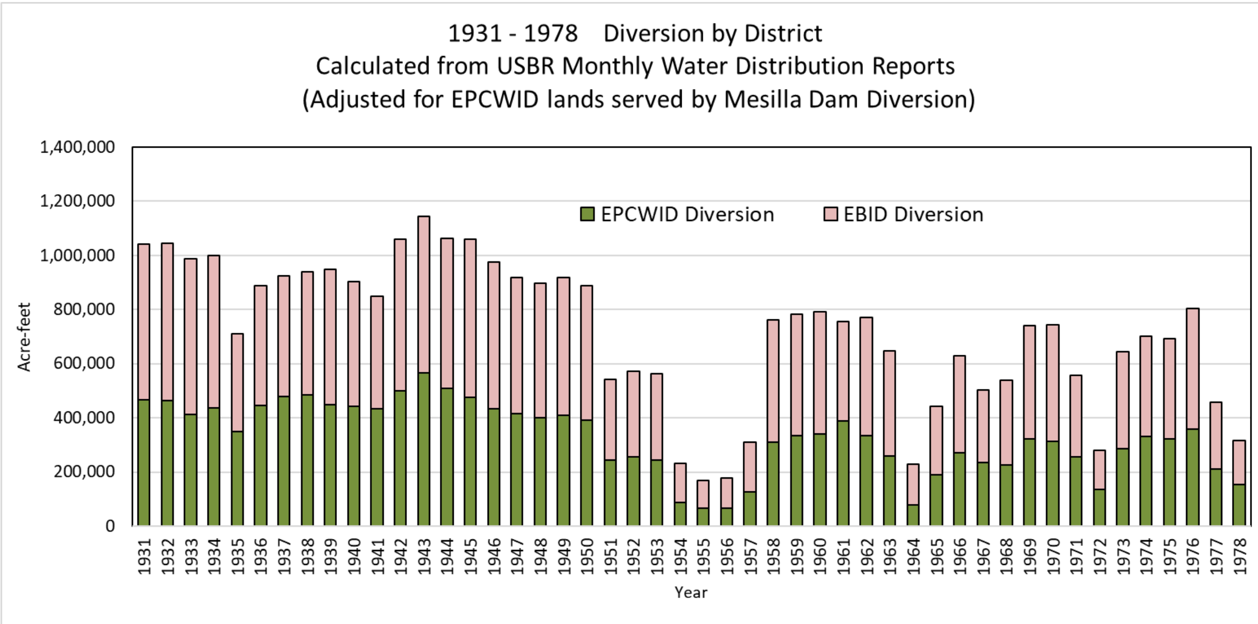
Year	EBID Diversion		EPCWID Diversion	
	AF	% of US Diversion	AF	% of US Diversion
1931	576,170	55.3%	465,745	44.7%
1932	579,603	55.5%	464,387	44.5%
1933	574,740	58.2%	413,280	41.8%
1934	563,596	56.4%	435,549	43.6%
1935	361,249	50.7%	351,076	49.3%
1936	443,168	49.9%	445,786	50.1%
1937	445,084	48.2%	478,116	51.8%
1938	455,382	48.5%	483,282	51.5%
1939	499,116	52.6%	449,602	47.4%
1940	458,687	50.9%	442,991	49.1%
1941	416,074	49.0%	433,885	51.0%
1942	560,187	52.8%	500,363	47.2%
1943	577,619	50.5%	565,512	49.5%
1944	552,802	52.0%	509,641	48.0%
1945	583,718	55.1%	475,622	44.9%
1946	542,043	55.5%	433,967	44.5%
1947	501,052	54.6%	416,298	45.4%
1948	497,826	55.5%	399,604	44.5%
1949	509,707	55.5%	408,263	44.5%
1950	497,407	56.1%	390,001	43.9%
1951	297,156	54.9%	244,015	45.1%
1952	317,204	55.4%	255,226	44.6%
1953	320,359	56.8%	243,850	43.2%
1954	144,840	62.4%	87,451	37.6%
1955	102,423	60.3%	67,395	39.7%
1956	111,812	62.7%	66,596	37.3%
1957	183,276	59.3%	125,941	40.7%
1958	452,182	59.4%	309,530	40.6%
1959	448,460	57.4%	332,788	42.6%
1960	452,520	57.1%	339,341	42.9%
1961	365,828	48.5%	388,830	51.5%
1962	435,501	56.5%	335,200	43.5%
1963	389,295	60.1%	258,360	39.9%

1964	150,923	65.6%	79,087	34.4%
1965	253,713	57.2%	189,703	42.8%
1966	359,166	57.1%	269,681	42.9%
1967	268,909	53.4%	234,693	46.6%
1968	313,758	58.1%	226,120	41.9%
1969	422,170	56.8%	320,686	43.2%
1970	430,298	57.9%	312,858	42.1%
1971	302,296	54.3%	254,586	45.7%
1972	142,290	51.0%	136,926	49.0%
1973	358,265	55.5%	287,327	44.5%
1974	372,939	53.0%	331,156	47.0%
1975	371,360	53.6%	321,615	46.4%
1976	449,660	55.7%	357,981	44.3%
1977	259,775	55.3%	209,634	44.7%
1978	168,694	52.4%	153,081	47.6%
Average 1931-1978	392,506	54.5%	327,138	45.5%

Average 1951-1978	308,753	56.2%	240,702	43.8%

Table A.2: District Diversions 1931 – 1978 (Page 2)

Figure A.3: District Diversions 1931 - 1978



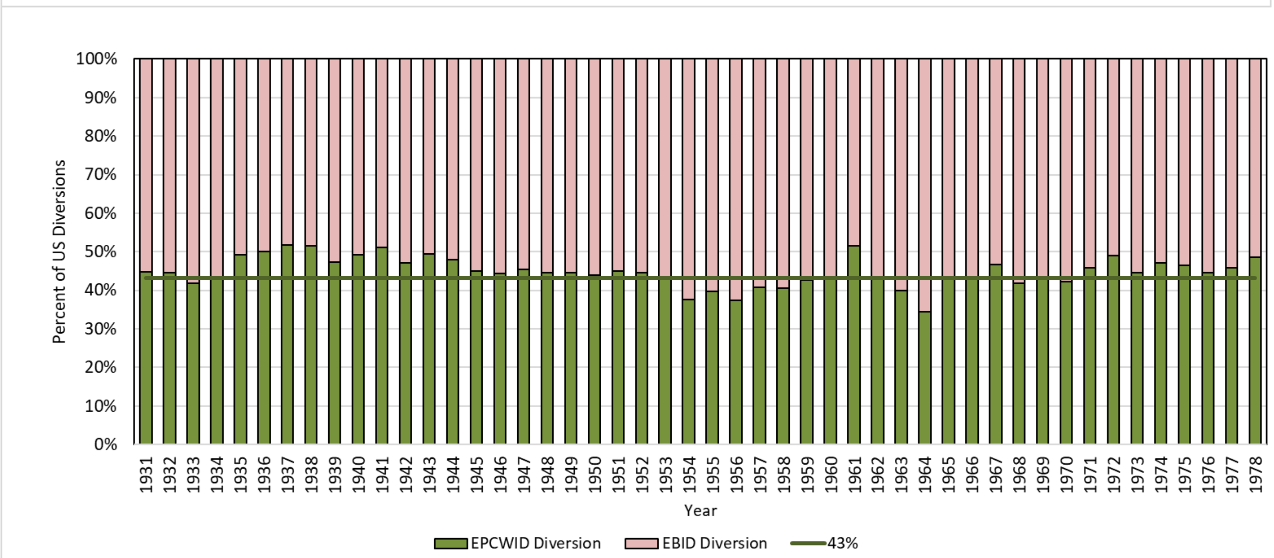


Table A.3: Farm Delivery Data from Project WDR forms, adjusted for EPCWID lands in Mesilla Unit (Page 1)

Year	EBID Farm Delivery		EPCWID Farm Delivery	
	AF	% of US Diversion	AF	% of US Diversion
1931	176,158	54.3%	148,463	45.7%
1932	191,784	56.1%	149,778	43.9%
1933	181,564	51.9%	168,470	48.1%
1934	215,780	55.2%	175,076	44.8%
1935	161,722	55.3%	130,904	44.7%
1936	221,690	58.0%	160,631	42.0%
1937	241,916	57.7%	177,069	42.3%
1938	220,463	59.7%	149,067	40.3%
1939	257,014	58.7%	180,855	41.3%
1940	250,792	57.5%	185,481	42.5%
1941	212,421	59.7%	143,343	40.3%
1942	230,294	60.0%	153,263	40.0%
1943	280,757	58.1%	202,399	41.9%
1944	275,601	58.4%	196,212	41.6%
1945	310,434	58.0%	224,816	42.0%
1946	282,868	56.7%	216,092	43.3%
1947	264,126	56.6%	202,774	43.4%
1948	260,632	57.7%	191,118	42.3%
1949	270,740	56.5%	208,850	43.5%
1950	275,318	56.4%	212,705	43.6%
1951	144,378	50.2%	143,240	49.8%
1952	159,437	48.0%	172,409	52.0%
1953	153,729	49.5%	156,711	50.5%
1954	53,492	52.3%	48,778	47.7%
1955	40,578	50.4%	39,885	49.6%
1956	35,794	51.5%	33,664	48.5%
1957	83,937	49.4%	86,047	50.6%
1958	219,768	54.8%	180,999	45.2%
1959	208,296	51.2%	198,693	48.8%
1960	217,585	54.1%	184,815	45.9%
1961	167,441	51.4%	158,540	48.6%
1962	225,253	54.8%	186,167	45.2%
1963	167,068	53.4%	145,938	46.6%

1964	31,493	48.5%	33,475	51.5%
1965	126,893	54.1%	107,707	45.9%
1966	171,516	56.9%	129,952	43.1%
1967	119,803	53.2%	105,466	46.8%
1968	145,137	56.8%	110,584	43.2%
1969	202,407	55.6%	161,661	44.4%
1970	222,715	57.3%	165,834	42.7%
1971	146,098	54.3%	122,992	45.7%
1972	62,288	50.8%	60,364	49.2%
1973	199,720	59.0%	139,049	41.0%
1974	204,430	58.1%	147,474	41.9%
1975	201,428	58.3%	144,258	41.7%
1976	221,216	59.0%	153,854	41.0%
1977	107,746	55.8%	85,475	44.2%
1978	57,328	51.0%	55,021	49.0%
Average 1938-1978	182,645	55.8%	144,537	44.2%
Average 1951-1978	146,321	54.2%	123,538	45.8%

Table A.3: Farm Delivery Data from Project WDR forms, adjusted for EPCWID lands in Mesilla Unit (Page 2)

Table A.4: Total Allocation to Districts and Mexico: D1/D2 Allocation (1979-2005)

Table A.4. Total Allocation of Project Water to Districts and Mexico 1979-2005 (D1/D2 Allocation)					
	57% Allocation to EBID	43% Allocation to EPCWID	ACE Credit to EPCWID	Total Allocation to EPCWID	Mexico
	Acre-feet	Acre-feet			Acre-feet
1979	414,448	315,548		315,548	60,000
1980	414,448	315,548		315,548	60,000
1981	393,300	296,700		296,700	60,000
1982	414,448	315,548		315,548	60,000
1983	414,448	315,548		315,548	60,000
1984	478,037	363,963		363,963	60,000
1985	478,037	363,963		363,963	60,000
1986	478,037	363,963		363,963	60,000
1987	478,037	363,963		363,963	60,000
1988	478,037	363,963		363,963	60,000
1989	471,735	359,165		359,165	60,000
1990	471,735	359,165		359,165	60,000
1991	494,979	376,862		376,862	60,000
1992	494,979	376,862		376,862	60,000
1993	494,979	376,862		376,862	60,000
1994	494,979	376,862		376,862	60,000
1995	494,979	376,862		376,862	60,000
1996	494,979	376,862		376,862	60,000
1997	494,979	376,862		376,862	60,000
1998	494,979	376,862		376,862	60,000
1999	494,979	376,862		376,862	60,000
2000	494,979	376,862		376,862	60,000
2001	494,979	376,862		376,862	60,000
2002	494,979	376,862		376,862	60,000
2003	165,144	125,735	12,127	137,862	26,616
2004	185,507	141,240	13,025	154,265	27,197
2005	494,979	376,862		376,862	60,000

Figure A.5: Total Allocation to Districts and Mexico: D1/D2 Allocation (1979-2005)

Table A.5: Total Charged Diversions for Each District and Mexico (1979-2005)

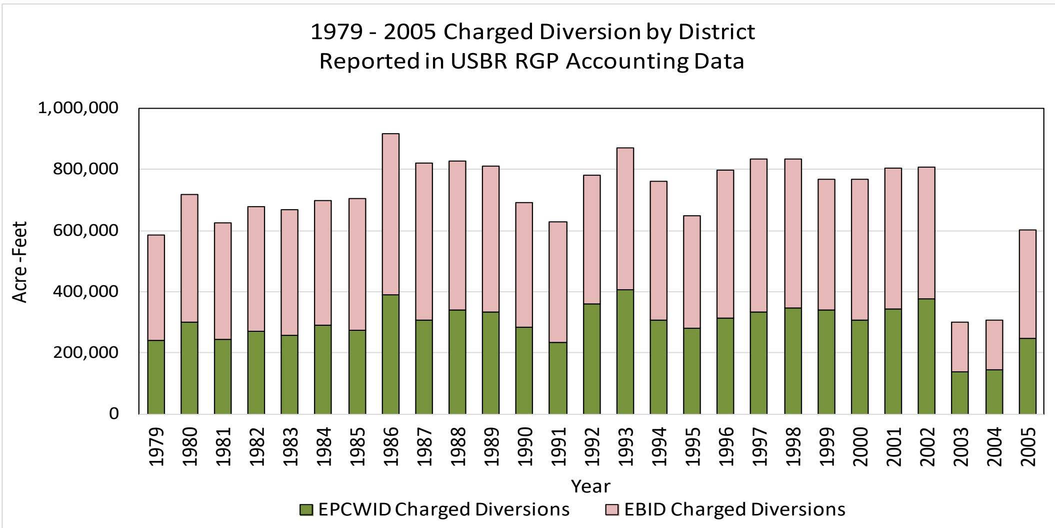
Project Release, Charged Diversion of Project Water by Districts, and Mexican Delivery 1979 - 2005				
	Release from Caballo	EBID Charged Diveersions	EPCWID Charged Diveersions	Mexican Delivery
	Acre-feet	Acre-feet	Acre-feet	Acre-feet
1979	568,689	343,811	240,471	60,055
1980	658,680	414,452	302,339	60,033
1981	608,002	381,211	242,754	60,262
1982	643,877	406,059	271,797	59,257
1983	648,335	414,069	256,034	60,621
1984	653,046	408,028	289,976	58,588
1985	677,648	430,098	275,540	60,276
1986	1,396,122	526,325	389,740	66,163
1987	1,376,204	513,174	308,850	65,866
1988	837,001	487,021	340,574	61,935
1989	736,005	477,083	333,183	58,854
1990	679,995	407,662	282,749	58,353
1991	626,007	395,933	234,303	59,242
1992	734,866	421,533	360,712	58,080
1993	823,085	465,666	405,681	63,763
1994	888,564	454,492	306,247	60,167
1995	1,095,934	367,520	279,723	63,618
1996	774,392	483,214	315,001	60,063
1997	798,814	500,483	334,751	50,442
1998	808,861	488,516	346,782	60,626
1999	735,415	426,132	340,727	58,306
2000	751,294	460,278	306,375	60,611
2001	786,889	460,182	343,365	61,037
2002	800,935	431,521	376,926	60,324
2003	364,528	164,740	137,250	26,948
2004	399,519	164,572	144,005	27,613
2005	676,031	353,261	247,607	58,091

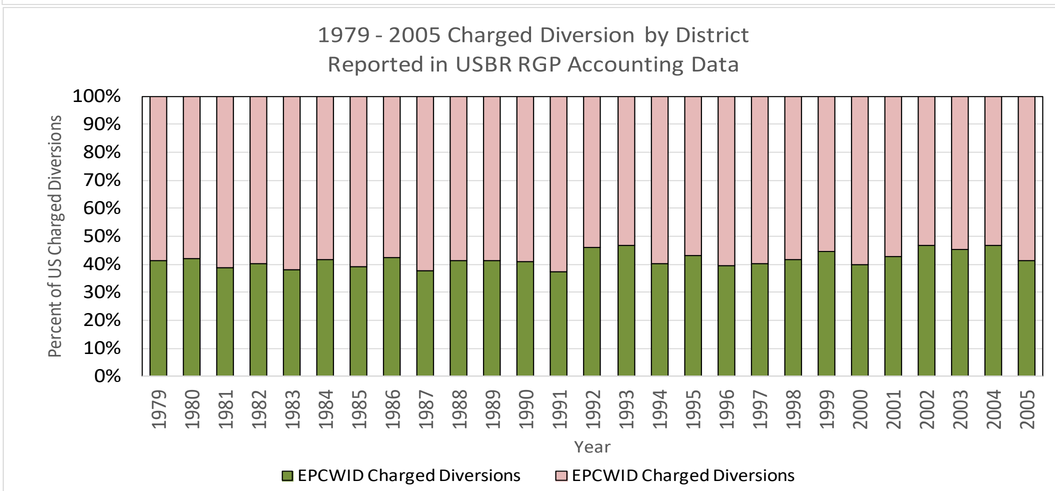
Average 1979 - 2002	440,186	311,858	
Average 1979 - 2005	416,557	296,795	

Table A.6: Charged Diversions of Project Water to Districts (1979-2005)

Charged Diversions of Project Water, Diverted at Canal Headings, from Project Accounting Records				
	EBID Charged Diversions		EPCWID Charged Diversions	
	Acre-feet	% of US Charged Diversions	Acre-feet	% of US Charged Diversions
1979	343,811	59%	240,471	41%
1980	414,452	58%	302,339	42%
1981	381,211	61%	242,754	39%
1982	406,059	60%	271,797	40%
1983	414,069	62%	256,034	38%
1984	408,028	58%	289,976	42%
1985	430,098	61%	275,540	39%
1986	526,325	57%	389,740	43%
1987	513,174	62%	308,850	38%
1988	487,021	59%	340,574	41%
1989	477,083	59%	333,183	41%
1990	407,662	59%	282,749	41%
1991	395,933	63%	234,303	37%
1992	421,533	54%	360,712	46%
1993	465,666	53%	405,681	47%
1994	454,492	60%	306,247	40%
1995	367,520	57%	279,723	43%
1996	483,214	61%	315,001	39%
1997	500,483	60%	334,751	40%
1998	488,516	58%	346,782	42%
1999	426,132	56%	340,727	44%
2000	460,278	60%	306,375	40%
2001	460,182	57%	343,365	43%
2002	431,521	53%	376,926	47%
2003	164,740	55%	137,250	45%
2004	164,572	53%	144,005	47%
2005	353,261	59%	247,607	41%
Average	416,557	58%	296,795	42%

Figure A.6: Charged Diversions of Project Water to Districts (1979-2005)





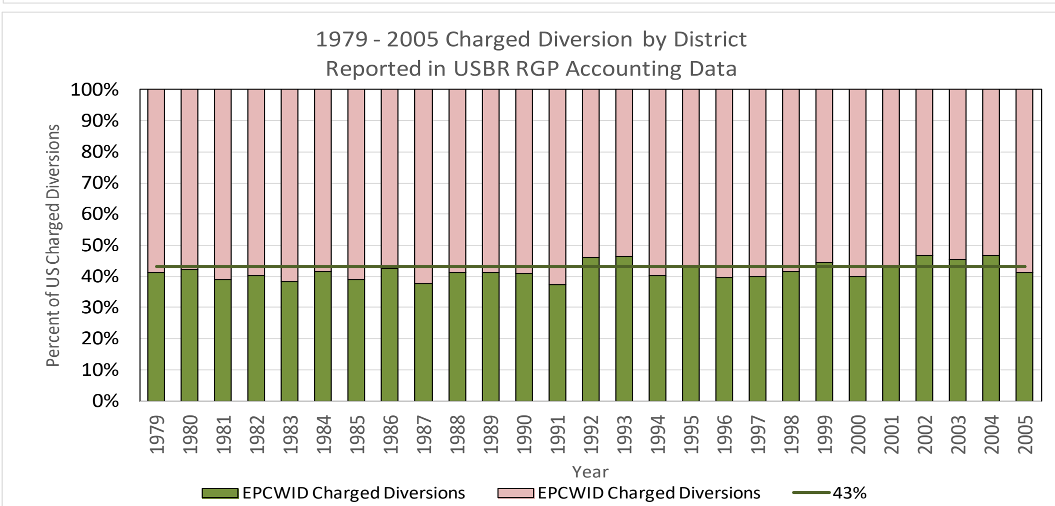


Figure A.4: Farm Delivery Data from Project WDR forms, adjusted for EPCWID lands in Mesilla Unit

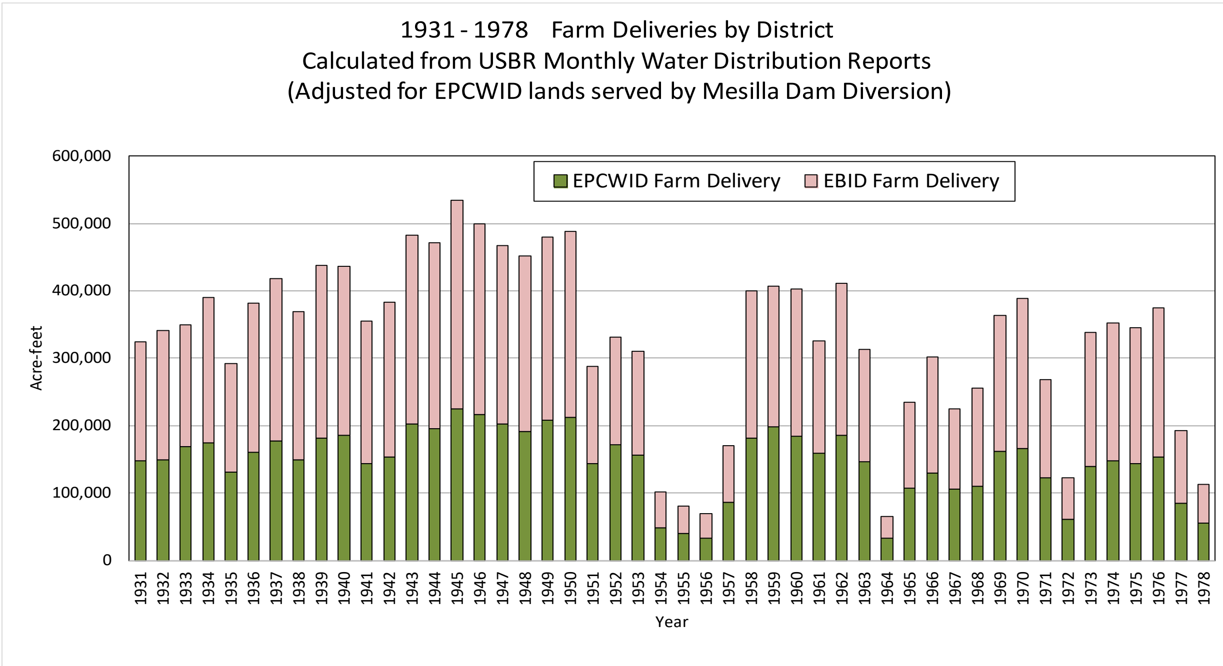
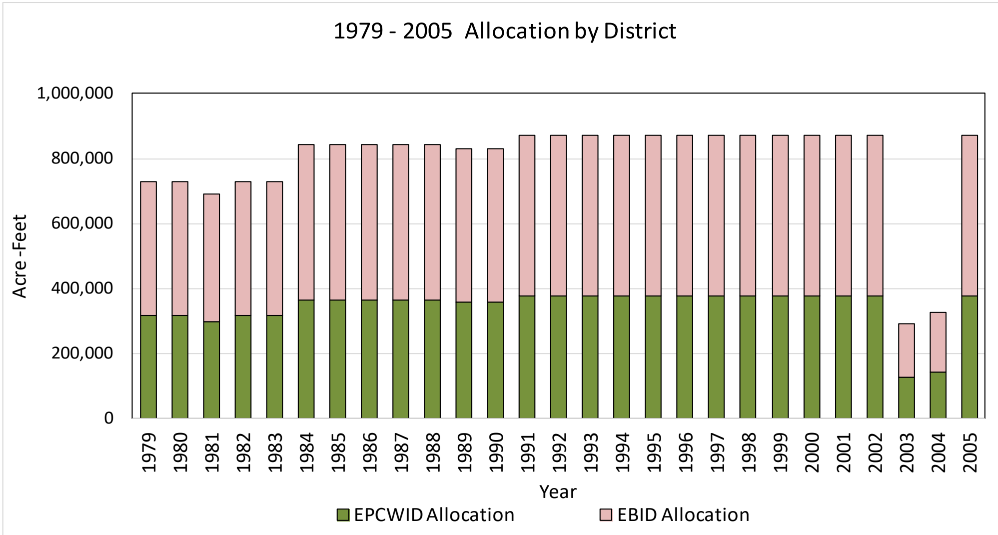
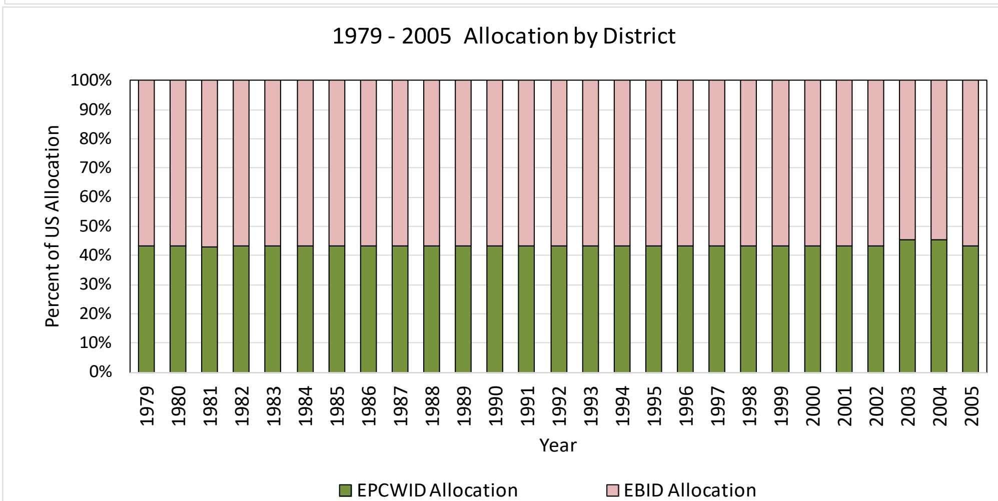


Figure A.5: Total Allocation to Districts and Mexico: D1/D2 Allocation (1979-2005)





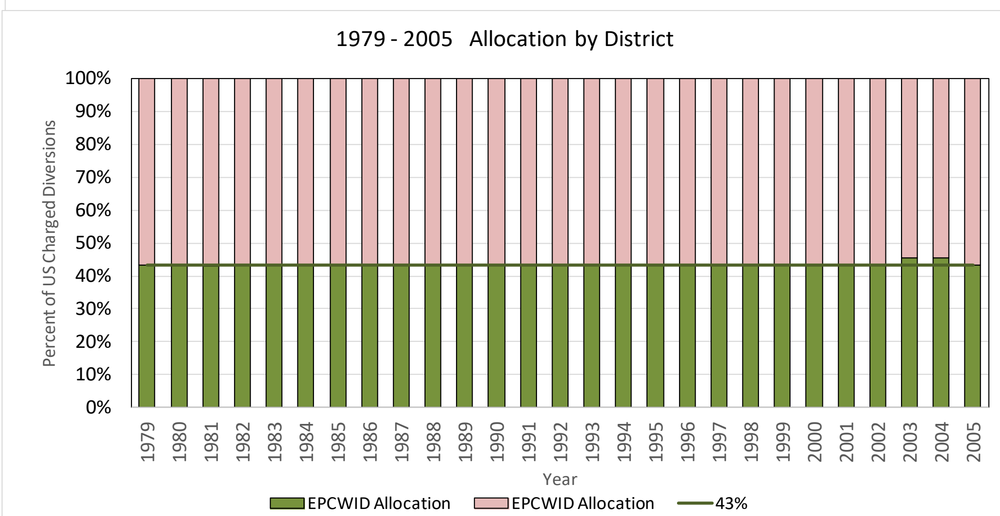


Table A.7: Final EBID Allotment (1979 - 2005)

Table A.7 Final EBID Allotment (1979 – 2005)	
Year	Allotment (AF/A)
1979	3.00
1980	3.00
1981	3.00
1982	3.00
1983	3.00
1984	3.00
1985	3.00
1986	3.00
1987	3.00
1988	3.00
1989	3.00
1990	3.00
1991	3.00
1992	3.00
1993	3.00
1994	3.00
1995	3.00
1996	3.00
1997	3.00
1998	3.00
1999	3.00
2000	3.00
2001	3.00
2002	3.00
2003	0.67
2004	0.67
2005	3.00

Table A.8: Reported Deliveries to Districts' Farm Headgates and EPWU (1979-2005)

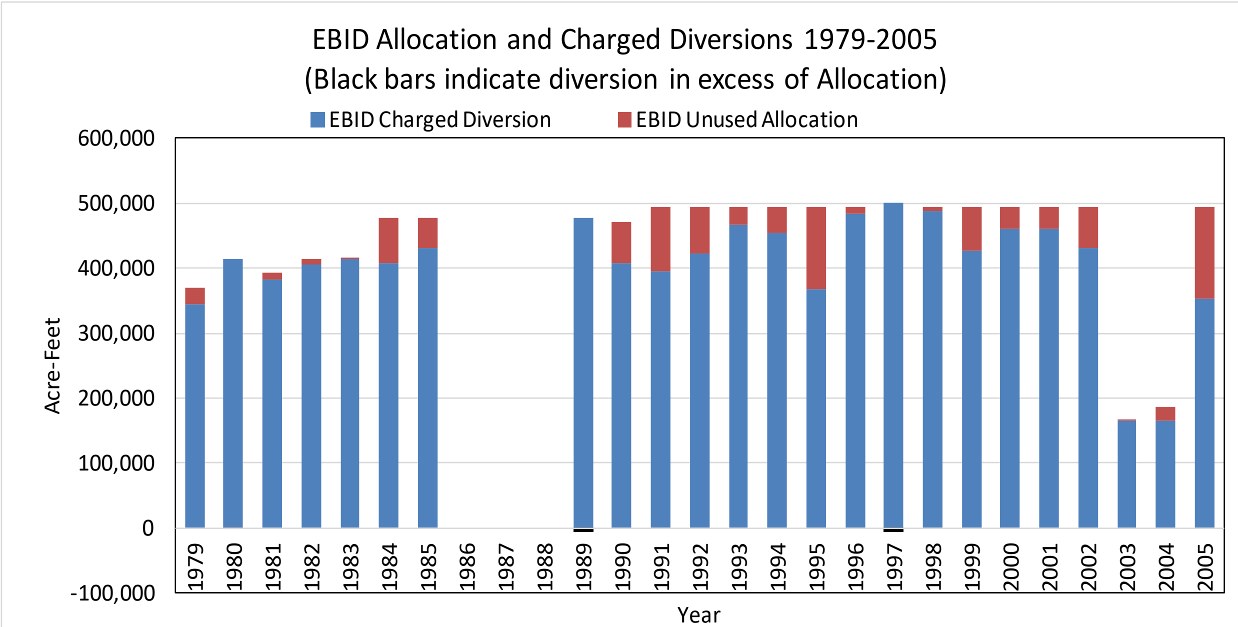
Reported Deliveries to Farm Headgates, and to EPWU for Municipal Purposes 1979 - 2005			
Year	EBID	EPCWID	
	Farm Delivery	Farm Delivery	Delivery to EPWU
Year	Acre-feet	Acre-feet	Acre-feet
1979	169,378	126,825	13,518
1980	223,709	139,704	19,937
1981	208,862	138,574	20,018
1982	226,723	167,336	17,388
1983	227,976	136,781	20,993
1984	222,445	129,391	17,988
1985	255,215	134,335	19,651
1986	263,583	133,007	21,846
1987	263,906	133,471	17,682
1988	250,674	132,791	21,541
1989	244,326	134,528	22,918
1990	NA	123,626	26,714
1991	227,403	161,801	24,390
1992	NA	108,630	31,475
1993	241,891	140,713	45,663
1994	274,025	171,690	55,721
1995	254,849	169,591	56,603
1996	247,373	210,064	46,248
1997	260,531	140,505	53,820
1998	263,725	151,315	52,470
1999	221,255	233,024	54,611
2000	245,283	155,935	41,916
2001	243,890	187,351	47,677
2002	234,619	245,015	57,843
2003	55,719	NA	24,862
2004	55,644	NA	29,357
2005	180,359	NA	50,723

Figure A.7: Reported Deliveries to Districts' Farm Headgates and EPWU (1979-2005)

Table A.9: Comparison of District Allocation and Charged Diversions, 1979-2005

Comparison of Allocation and Charged Diversions 1979 - 2005 (Omitting 1986, 1987 and 1988, due to high-flow conditions)						
	EBID Allocation	EBID Charged Diversion	EBID Unused Allocation	EPCWID Allocation	EPCWID Charged Diversion	EPCWID Unused Allocation
	Acre-feet	Acre-feet	Acre-feet	Acre-feet	Acre-feet	Acre-feet
1979	369,939	343,811	26,128	281,660	240,471	41,189
1980	414,448	414,452	(4)	315,548	302,339	13,209
1981	393,300	381,211	12,089	296,700	242,754	53,946
1982	414,448	406,059	8,389	315,548	271,797	43,751
1983	414,448	414,069	379	315,548	256,034	59,514
1984	478,037	408,028	70,009	363,963	289,976	73,987
1985	478,037	430,098	47,939	363,963	275,540	88,423
1986	478,037	526,325		363,963	389,740	
1987	478,037	513,174		363,963	308,850	
1988	478,037	487,021		363,963	340,574	
1989	471,735	477,083	(5,348)	359,165	333,183	25,982
1990	471,735	407,662	64,073	359,165	282,749	76,416
1991	494,979	395,933	99,046	376,862	234,303	142,559
1992	494,979	421,533	73,446	376,862	360,712	16,150
1993	494,979	465,666	29,313	376,862	405,681	(28,819)
1994	494,979	454,492	40,487	376,862	306,247	70,615
1995	494,979	367,520	127,459	376,862	279,723	97,139
1996	494,979	483,214	11,765	376,862	315,001	61,861
1997	494,979	500,483	(5,504)	376,862	334,751	42,111
1998	494,979	488,516	6,463	376,862	346,782	30,080
1999	494,979	426,132	68,847	376,862	340,727	36,135
2000	494,979	460,278	34,701	376,862	306,375	70,487
2001	494,979	460,182	34,797	376,862	343,365	33,497
2002	494,979	431,521	63,458	376,862	376,926	(64)
2003	165,144	164,740	404	125,735	137,250	(11,515)
2004	185,507	164,572	20,935	154,265	144,005	10,260
2005	494,979	353,261	141,718	376,862	247,607	129,255

Figure A.8: Comparison of District Allocation and Charged Diversions, 1979-2005



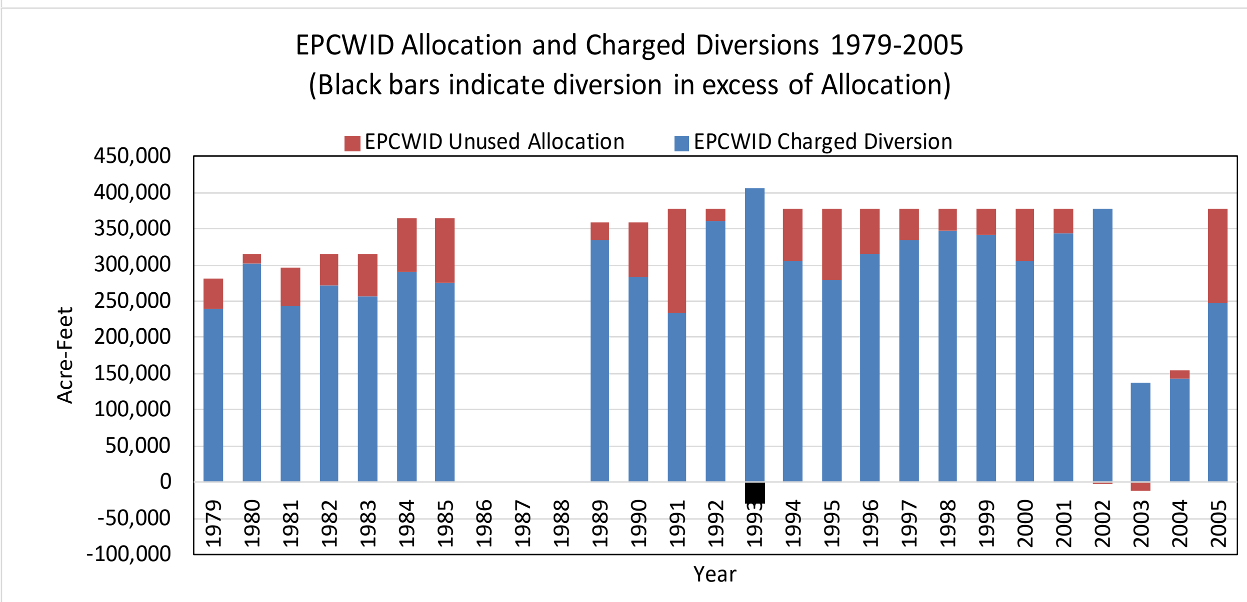
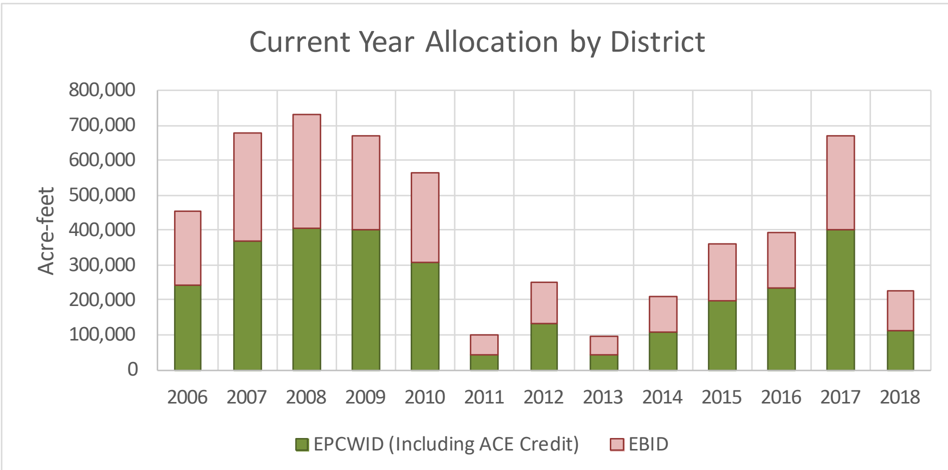
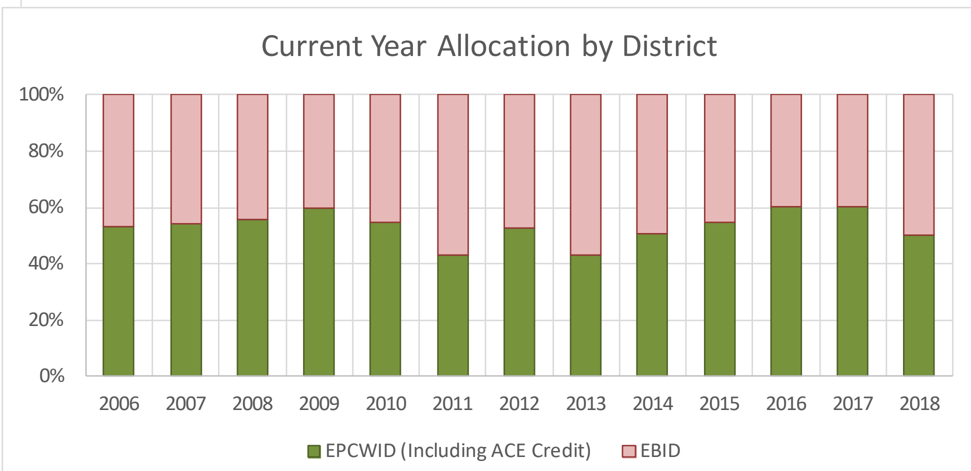


Table A.10: Current-Year Allocation to Districts (2006-2018)

Current-Year Project Allocation to Districts 2006 -2018 (D3 Allocation)							
	EBID	EBID % of US Share	EPCWID	EPCWID ACE Credit	EPCWID (Including ACE Credit)	EPCWID % of US Share
Year	AF		AF	AF	AF	
2006	211,385	47%	227,146	14,511	241,657	53%
2007	310,894	46%	353,905	13,386	367,291	54%
2008	324,990	45%	388,192	16,881	405,073	55%
2009	268,077	40%	384,161	17,998	402,159	60%
2010	255,257	45%	291,905	17,610	309,515	55%
2011	57,090	57%	43,466	-	43,466	43%
2012	118,300	47%	132,935	-	132,935	53%
2013	54,438	57%	41,446	-	41,446	43%
2014	104,651	50%	99,105	7,485	106,590	50%
2015	161,940	45%	185,978	11,651	197,629	55%
2016	156,310	40%	235,908	-	235,908	60%
2017	267,523	40%	388,192	13,650	401,842	60%
2018	112,076	50%	112,418	-	112,418	50%
Average	184,889	44%			230,610	56%

Figure A.9: Current-Year Allocation to Districts (2006-2018)





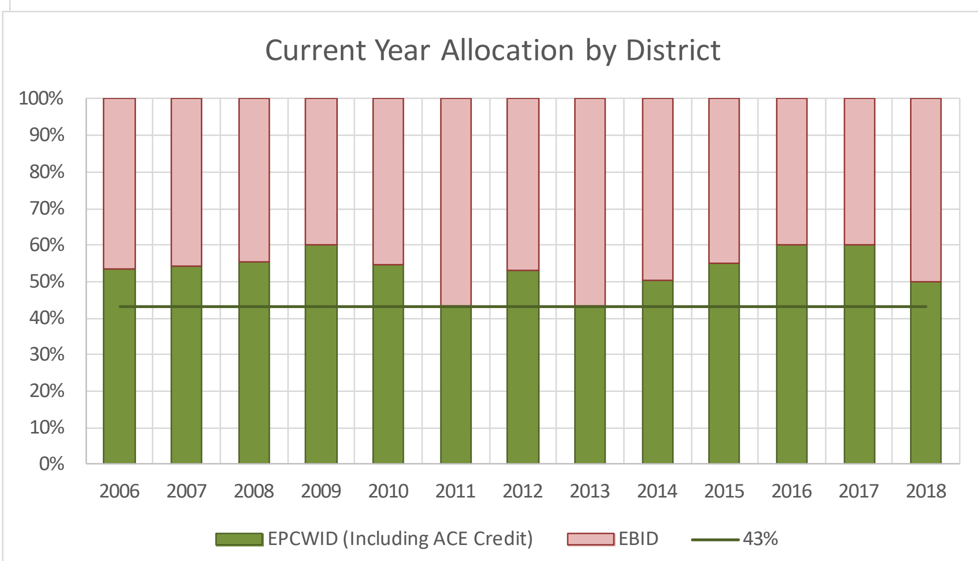
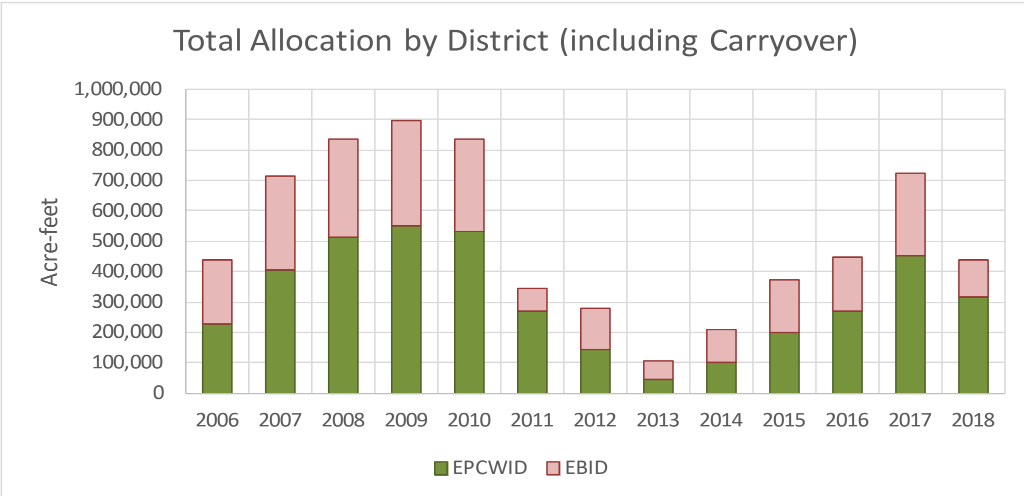
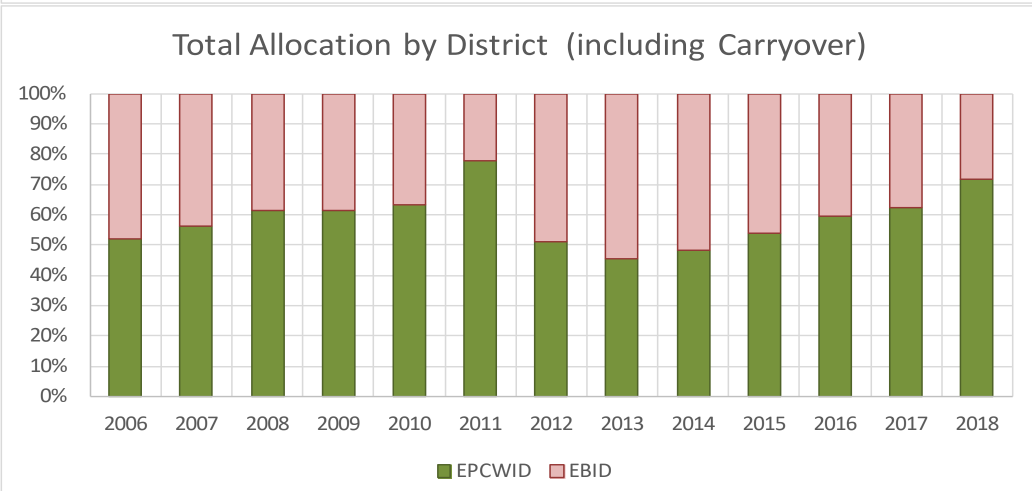


Table A.11: Total Project Allocation to Districts and Mexico (2006-2018)

Total Project Allocation to Districts and Mexico 2006 - 2018 (D3 Allocation)					
	EBID	EBID % of US Share	EPCWID	EPCWID % of US Share	Mexico
Year	AF		AF		AF
2006	211,385	47%	241,657	53%	33,895
2007	311,517	44%	403,491	56%	58,769
2008	324,990	39%	512,055	61%	60,000
2009	345,817	38%	552,997	62%	53,386
2010	305,870	36%	532,158	64%	50,235
2011	77,104	22%	267,813	78%	25,649
2012	135,633	49%	141,977	51%	23,196
2013	57,011	55%	47,043	45%	3,665
2014	107,659	52%	100,103	48%	18,216
2015	170,593	46%	200,314	54%	35,355
2016	180,912	40%	268,381	60%	46,497
2017	270,749	37%	452,021	63%	60,000
2018	123,315	28%	314,520	72%	37,670
Average	190,878	38%	308,126	62%	

Figure A.10: Total Project Allocation to Districts and Mexico (2006-2018)





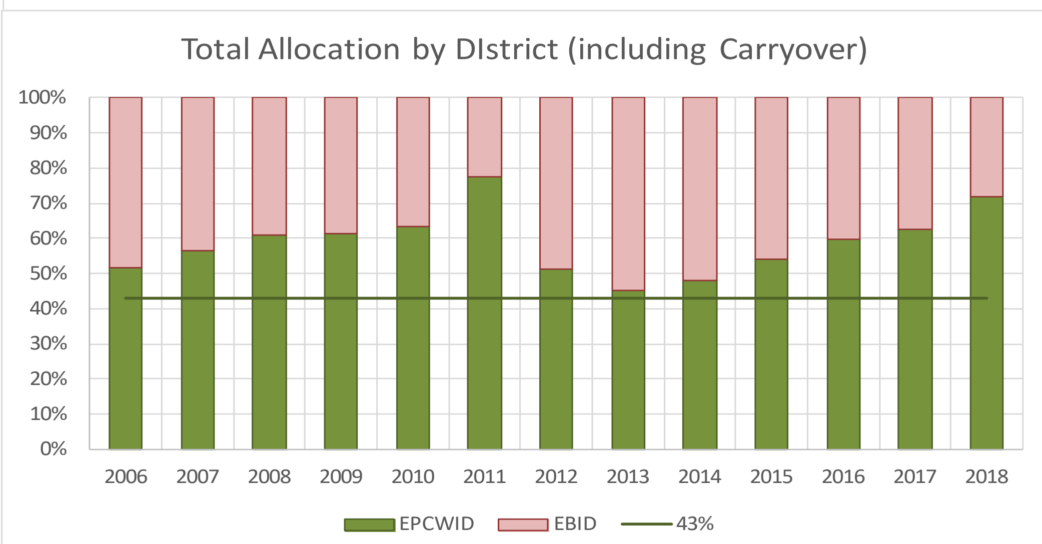
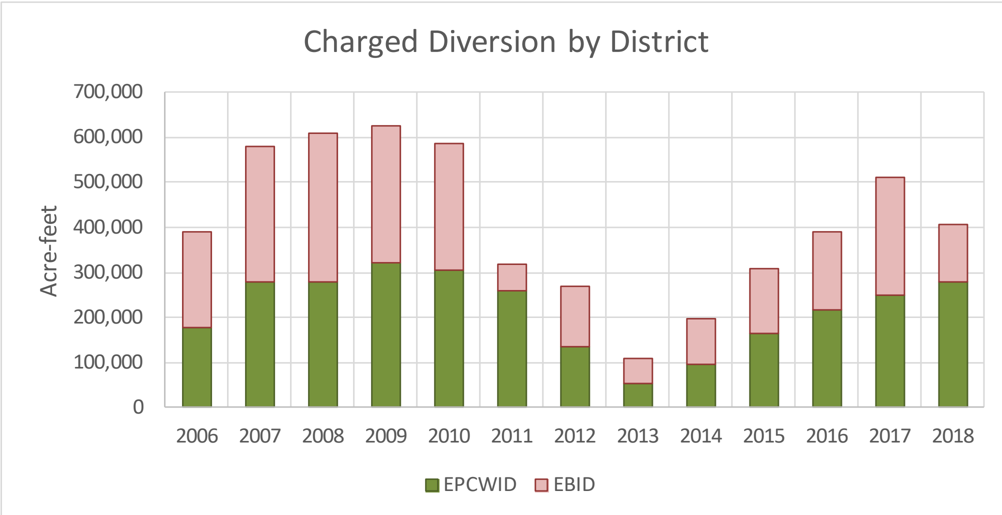
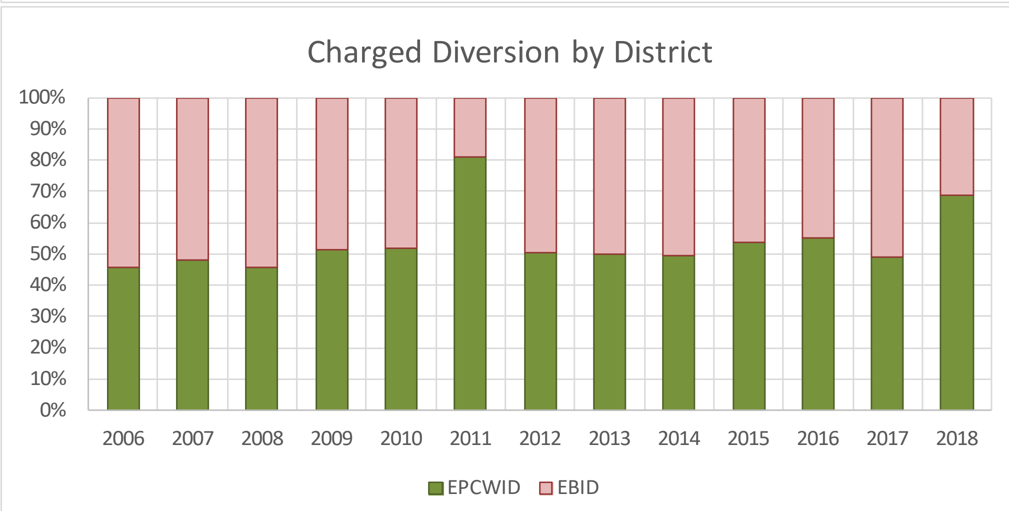


Table A.12: Charged Districts' Diversions and Delivery to Mexico (2006-2018)

Table A.12. Charged Districts Diversions and Delivery to Mexico 2006 - 2018 (D3 Allocation)						
	Release from Caballo	EBID	EBID % of US Share	EPCWID	EPCWID % of US Share	Mexico
Year	AF	AF		AF		AF
2006	434,228	211,841	54%	177,183	46%	27,112
2007	636,993	302,665	52%	278,252	48%	51,245
2008	674,724	329,294	54%	279,173	46%	56,048
2009	693,289	305,475	49%	320,083	51%	58,688
2010	659,679	282,082	48%	304,937	52%	56,883
2011	396,444	59,771	19%	258,772	81%	25,650
2012	371,271	133,060	49%	136,380	51%	23,187
2013	168,201	54,002	50%	53,530	50%	3,709
2014	306,900	99,007	50%	97,418	50%	18,261
2015	435,483	143,404	46%	165,872	54%	33,772
2016	544,181	175,199	45%	216,309	55%	43,787
2017	622,467	259,510	51%	249,919	49%	54,506
2018	491,305	127,487	31%	279,211	69%	37,735
Average		178,936	45%	214,691	55%	

Figure A.11: Charged Districts' Diversions and Deliveries to Mexico (2006-2018)





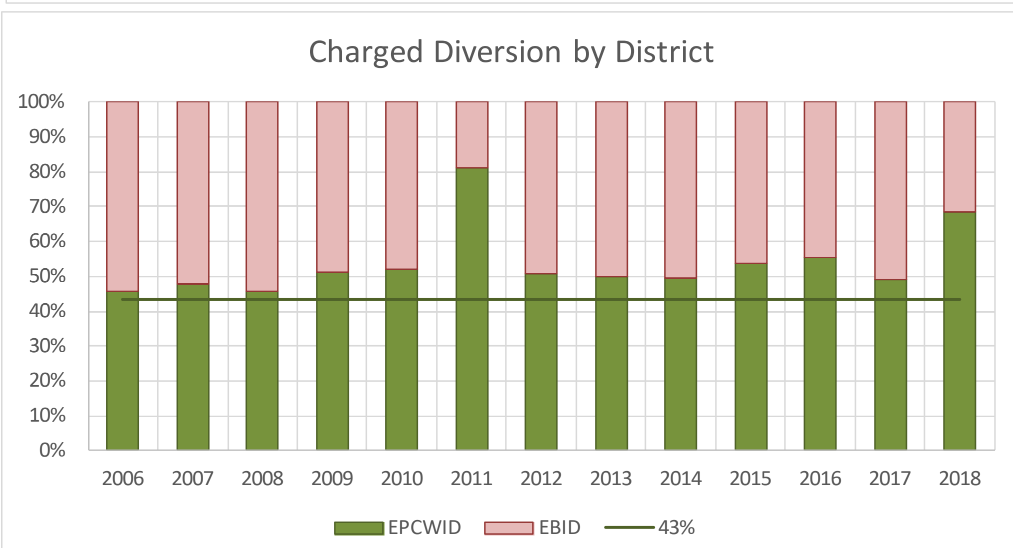


Table A.13: EBID Allocation and Charged Delivery Summary (2006-2018)

	EBID Allocation and Charged Delivery Summary 2006 - 2018							
	Current-Year Allocation	Carryover from Previous Year	Transfer from EPCWID	Total Allocation	Total Charged Diversions	Unused Allocation	Mexican Adjust-ment	Potential Carryover to Next Year
Year	AF	AF	AF	AF	AF	AF	AF	AF
2006	211,385	0	0	211,385	211,841	-456	0	-456
2007	310,894	623	0	311,517	302,665	8,852	0	8,852
2008	324,990	0	0	324,990	329,294	-4,304	0	-4,304
2009	268,077	-4,304	82,044	345,817	305,475	40,342	0	40,342
2010	255,257	40,342	10,271	305,870	282,082	23,788	-3,774	20,014
2011	57,090	20,014	0	77,104	59,771	17,333	-1	17,332
2012	118,300	17,333	0	135,633	133,060	2,573	0	2,573
2013	54,438	2,573	0	57,011	54,002	3,009	0	3,009
2014	104,651	3,009	0	107,659	99,007	8,652	0	8,652
2015	161,940	8,653	0	170,593	143,404	27,189	-2,586	24,603
2016	156,310	24,602	0	180,912	175,199	5,713	-2,487	3,226
2017	267,523	3,226	0	270,749	259,510	11,239	0	11,239
2018	112,076	11,239	0	123,315	127,487	-4,172	-1,865	-6,037

Table A.14: Allocation and Charged Delivery Summary (2006-2018)

	EPCWID Allocation and Charged Delivery Summary 2006 - 2018							
	Current-Year Allocation + ACE Credit	Carryover from Previous Year	Transfer to EBID	Total Allocation	Total Charged Diversions	Unused Allocation	Mexican Adjust-ment	Potential Carryover to Next Year
Year	AF	AF	AF	AF	AF	AF	AF	AF
2006	241,657	0		241,657	177,183	64,474	0	64,474
2007	367,291	36,200		403,491	278,252	125,239	0	125,239
2008	405,073	106,982		512,055	279,173	232,882	0	232,882
2009	402,159	232,882	-82,044	552,997	320,083	232,914	0	232,914
2010	309,515	232,914	-10,271	532,158	304,937	227,221	-2,874	224,347
2011	43,466	224,347		267,813	258,772	9,041	-1	9,040
2012	132,935	9,042		141,977	136,380	5,597	0	5,597
2013	41,446	5,597		47,043	53,530	-6,487	0	-6,487
2014	106,590	-6,487		100,103	97,418	2,685	0	2,685
2015	197,629	2,685		200,314	165,872	34,442	-1,969	32,473
2016	235,908	32,473		268,381	216,309	52,072	-1,893	50,179
2017	401,842	50,179		452,021	249,919	202,102	0	202,102
2018	112,418	202,102		314,520	279,211	35,309	-1,420	33,889

Table A.15: EBID Final Allotment (2006-2018)

Table A.15. Final EBID Allotment (2006 - 2018)	
Year	Allotment (AF/A)
2006	1.17
2007	2.00
2008	3.00
2009	2.50
2010	2.00
2011	0.33
2012	0.83
2013	0.29
2014	0.63
2015	0.92
2016	1.08
2017	2.00
2018	0.83
2019	0.50

Figure A.12: EBID Final Allotment (1979-2018)

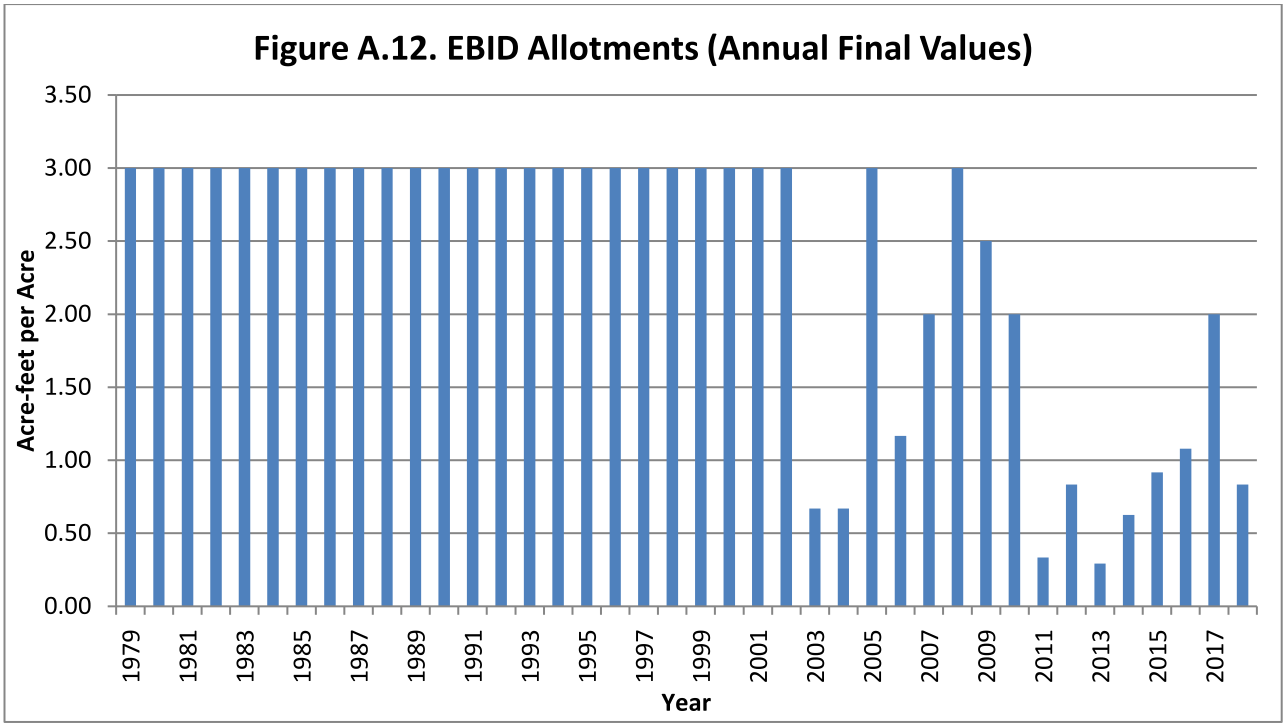


Figure B.1. Sample Calculation of Necessary Caballo Release from 1943 Project History

Desired at El Paso (El Paso Valley order and Mexican Canal)	1,111	second	feet
Estimated waste return to river from Mesilla Division	-60	"	"
Drainage flow to river from Mesilla Division	-425	"	"
Subtotal	626	"	"
Add estimate of transmission losses between Mesilla Dam and El Paso (This will vary during year from 20 CFS minimum to 85 CFS maximum)	+85	"	"
Necessary flow below Mesilla Dam	711	"	"
Add East Side and West Side Order	+800	"	"
Subtract drain flow Leasburg Division	-19	"	"
Add estimate of losses Leasburg to Mesilla (This will vary from 20 CFS minimum to 60 CFS maximum)	+ 40	"	"
Subtotal	1,532	"	"
Necessary flow below Leasburg Dam			
Add Leasburg Canal Order	+565	"	"
Subtract drainage flow to river from Rincon Valley	-80	"	"
Subtract estimated waste from Rincon Valley	35	"	"
Add estimate of river losses Caballo Dam to Leasburg Dam (This will vary from 40 to 70 CFS)	40	"	"
Add order for Arrey Canal	250		
Total necessary release from Caballo Dam	2,272	Second	Feet

Figure B.2. Project Water Order Form from 1985 Draft Operating Agreement

PROJECT WATER ORDER

Order for period from ____________ to ___________ Date: ____________

Upper Valley Water Order EBID and EPCWID No. 1		Lower El Paso Valley EPCWID No. 1 Water Order	
Arrey Canal	________ cfs	Franklin Canal	________ cfs
Leasburg Canal	________ cfs	City of El Paso	________ cfs
California Lateral	________ cfs	Riverside Canal	________ cfs
Del Rio Lateral	________ cfs	Total Lower Valley	________ cfs
East Side Canal	________ cfs	**Total Project Water Order**	
Three Saints East Lateral	________ cfs	Upper Valley	________ cfs
West Side Canal	________ cfs	Lower Valley	________ cfs
La Union West		Mexico	________ cfs
New Mexico	________ cfs	Total Water Ordered	________ cfs
Texas	________ cfs	Less Drain Water to River	________ cfs
Total	________ cfs	Plus River Loss	________ cfs
La Union East		Release from Caballo	________ cfs
New Mexico	________ cfs	Flow Meter Setting	________ cfs
Texas	________ cfs	Time ________ Date ________	
Total	________ cfs	Ordered by ____________	
Total Upper Valley	________ cfs		
		Caballo Readings	
		Date ________ Time ________	
		Hydrographer ________ (Initials)	
		Discharge	________ cfs
		Gage Height ____________	
		Flow Meter CFS ____________	
		East Gate ____________	
		West Gate ____________	
		Elevation ____________	

Exhibit 4

Figure B.3. Excel Version of Rio Grande Project Internet Order Sheet

	Rio Grande Project Order Sheet Calculations, from Figure 1 of The 2012 Operations Manual from the 2008 OA				
	Orders and Gains/Losses to Rio Grande			Estimated Flow in Rio Grande	
		Orders	Gains/Losses	Location	
		cfs	cfs	cfs	
				1683	Caballo Release
	Arrey Canal	140			
				1543	Below Percha Dam
	above Leasburg		50		
Upper	Leasburg Canal	170			
Valley				1423	Below Leasburg Dam
	Leasburg/Mesilla		0		
	Eastside Canal	110			
	Westside Canal	380			
				933	Below Mesilla Dam
	(-) Bypass WW32	-30			
	Mesilla/American		0		
				963	At American Dam
	Franklin	160			
Lower	Riverside	485			
Valley	EPWU	141			
	Mexico	177			
	Total Lower Valley Orders plus Mexico	963			

Figure B.4. Functional Excel Version of Project Internet Order Form

Valley	Rio Grande Project Order Sheet Calculations, Modified from Figure 1of the 2012 Operations Manual from the 2008 OA (Functional Version)				
	Orders and Gains/Losses to Rio Grande			Estimated Flow in Rio Grande	
		Orders	Gains/Losses		
		cfs	cfs	cfs	Location
	Caballo Release			1623	Caballo Release
Upper Valley	**Arrey Canal**	**140**			
Upper Valley				1483	Below Percha Dam
Upper Valley	above Leasburg		50		
Upper Valley	**Leasburg Canal**	**170**			
Upper Valley				1363	Below Leasburg Dam
Upper Valley	Leasburg/Mesilla		30		
Upper Valley	**Eastside Canal**	**110**			
Upper Valley	**Westside Canal**	**380**			
				903	Below Mesilla Dam
	(-) Bypass WW32	-30			
	Mesilla/American		30		
				963	At American Dam
Lower Valley	**Franklin**	**160**			
Lower Valley	**Riverside**	**485**			
Lower Valley	**EPWU**	**141**			
	Mexico	**177**			
	Total Lower Valley Orders plus Mexico	**963**			

Figure C.1: Excerpt from Joint Investigation illustrating the configuration of Project conveyances near Fabens, Texas

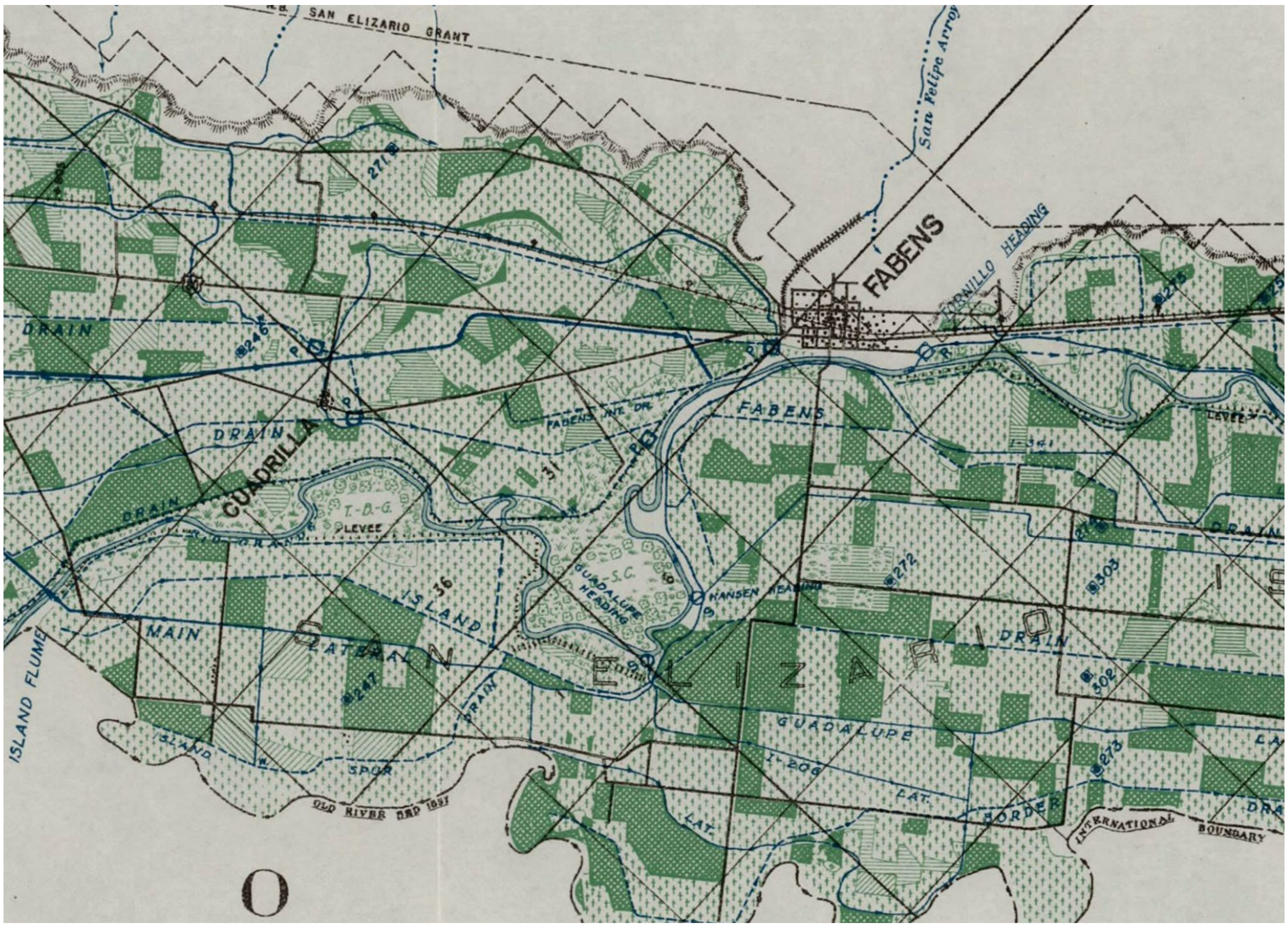
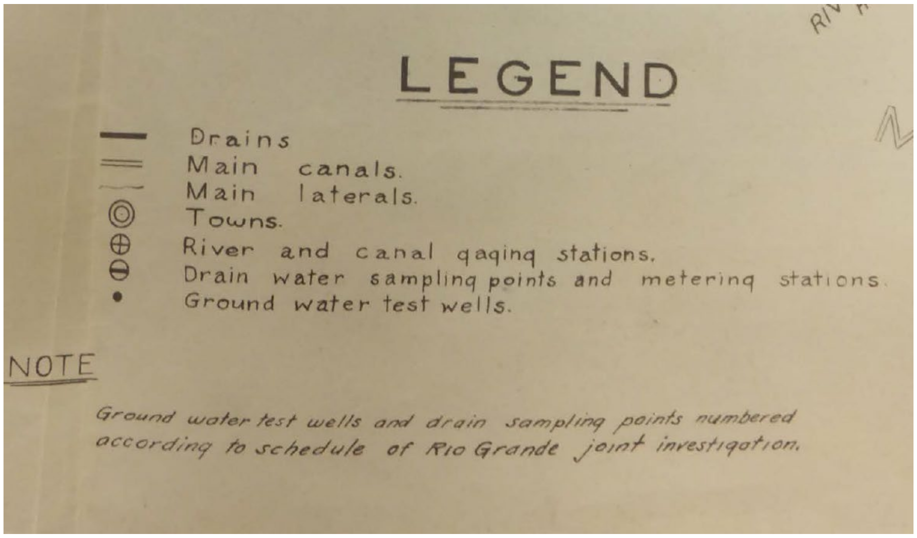
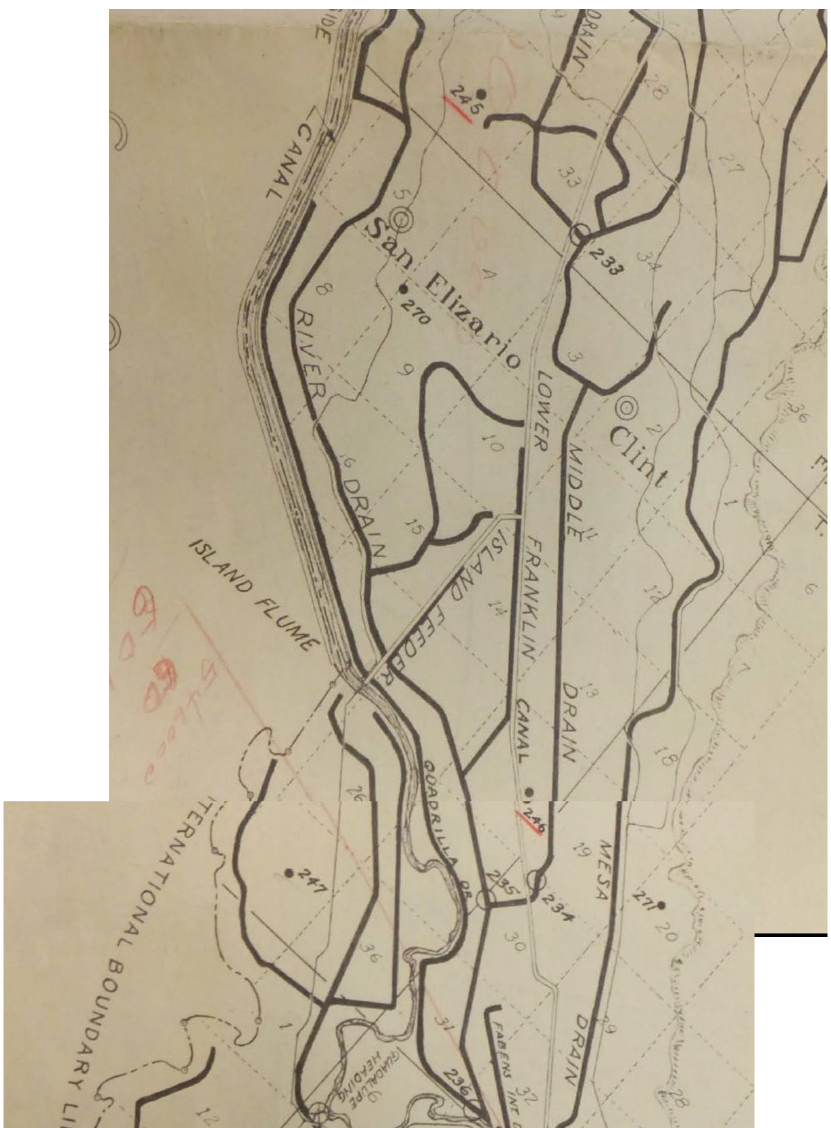


Figure C.2: Excerpts from a Reclamation map contemporaneous with the Joint Investigation illustrating the Project conveyance system near Fabens, TX





US_MSJ_00000918

Figure C.3: Gaged Discharge of El Paso Valley Drains Above Fabens

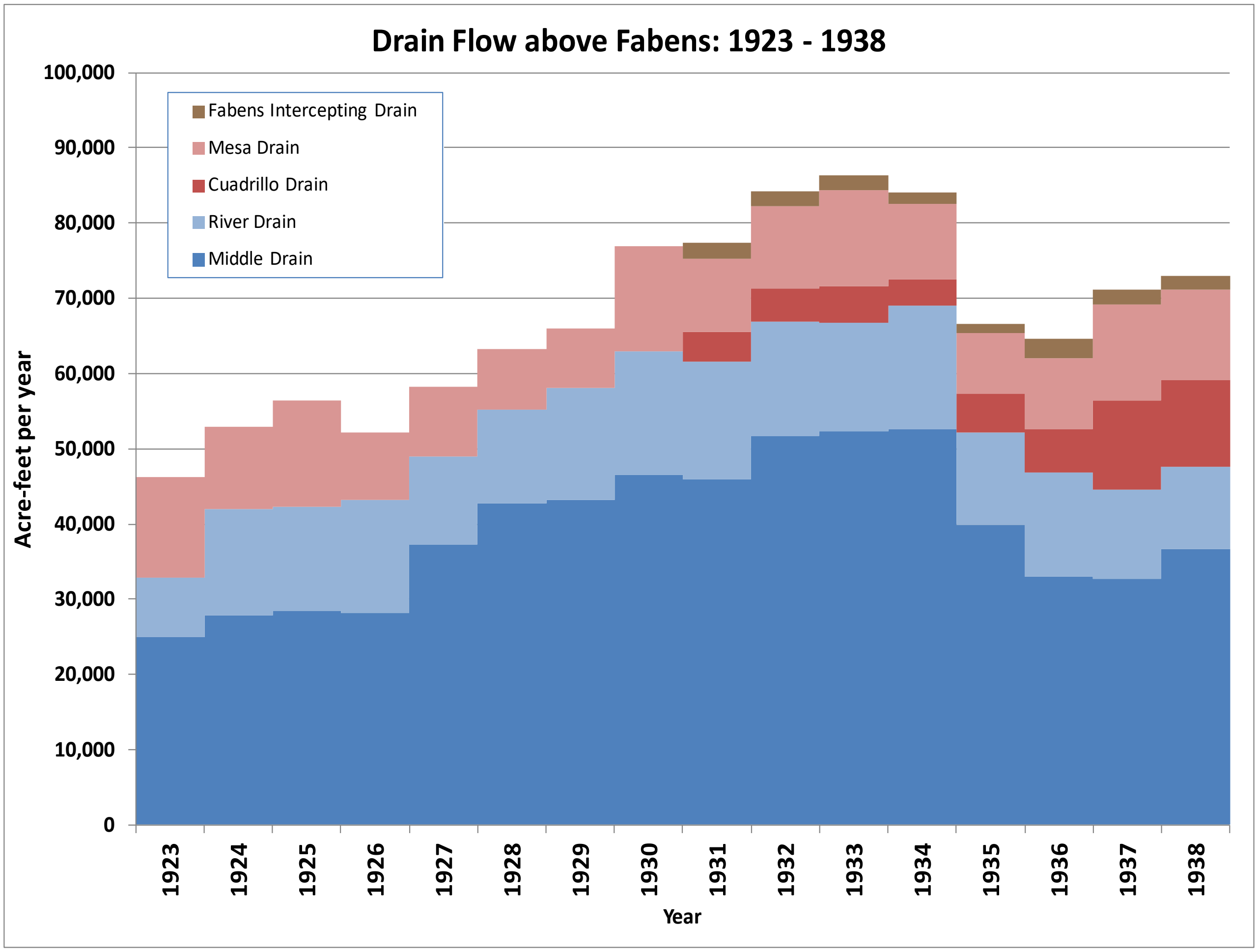


Figure C.7: Reclamation Project Map, Fabens Area, Post-Rectification

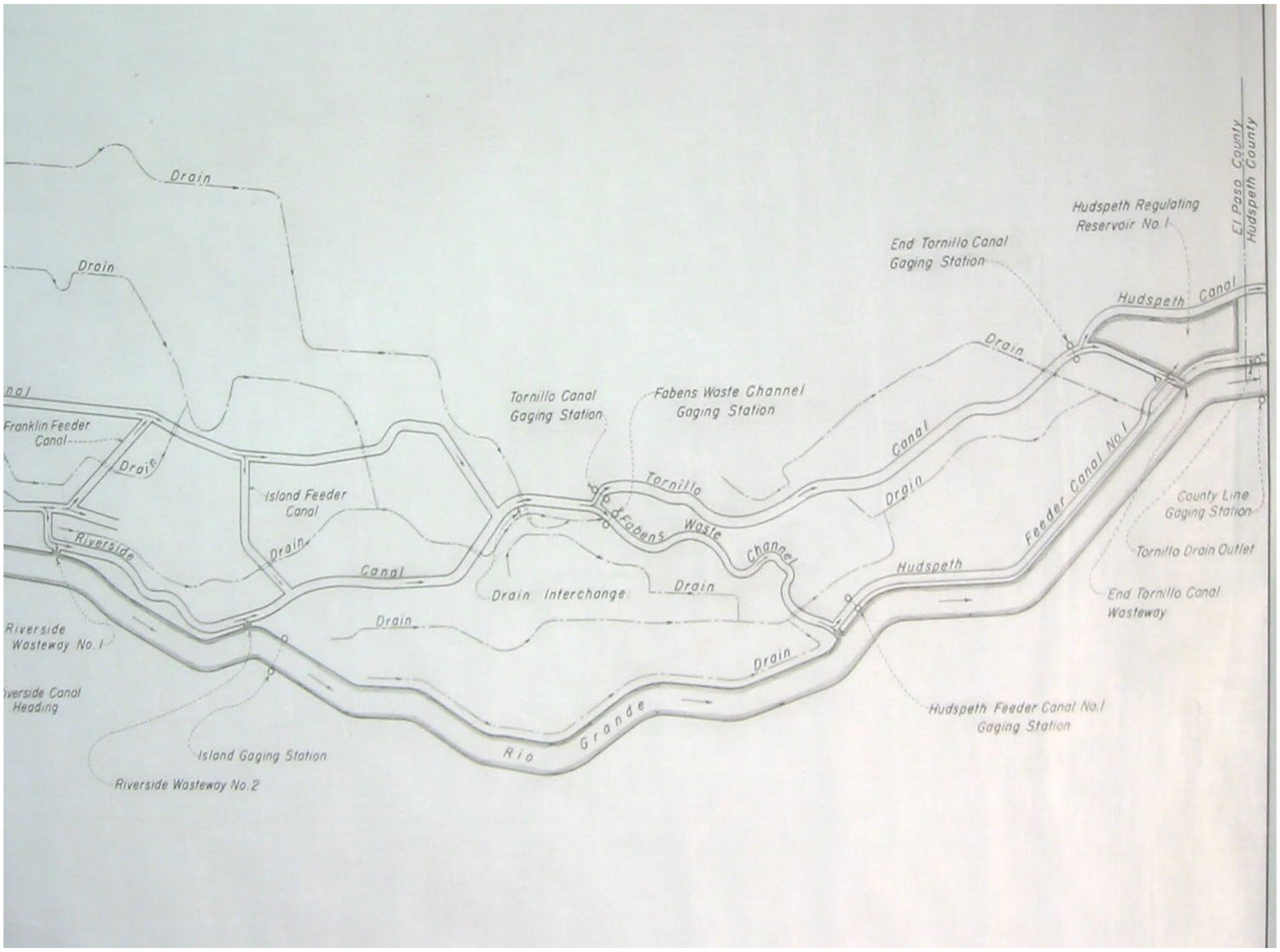


Figure C.8: Schematic of the Project conveyance system in part of the El Paso Valley

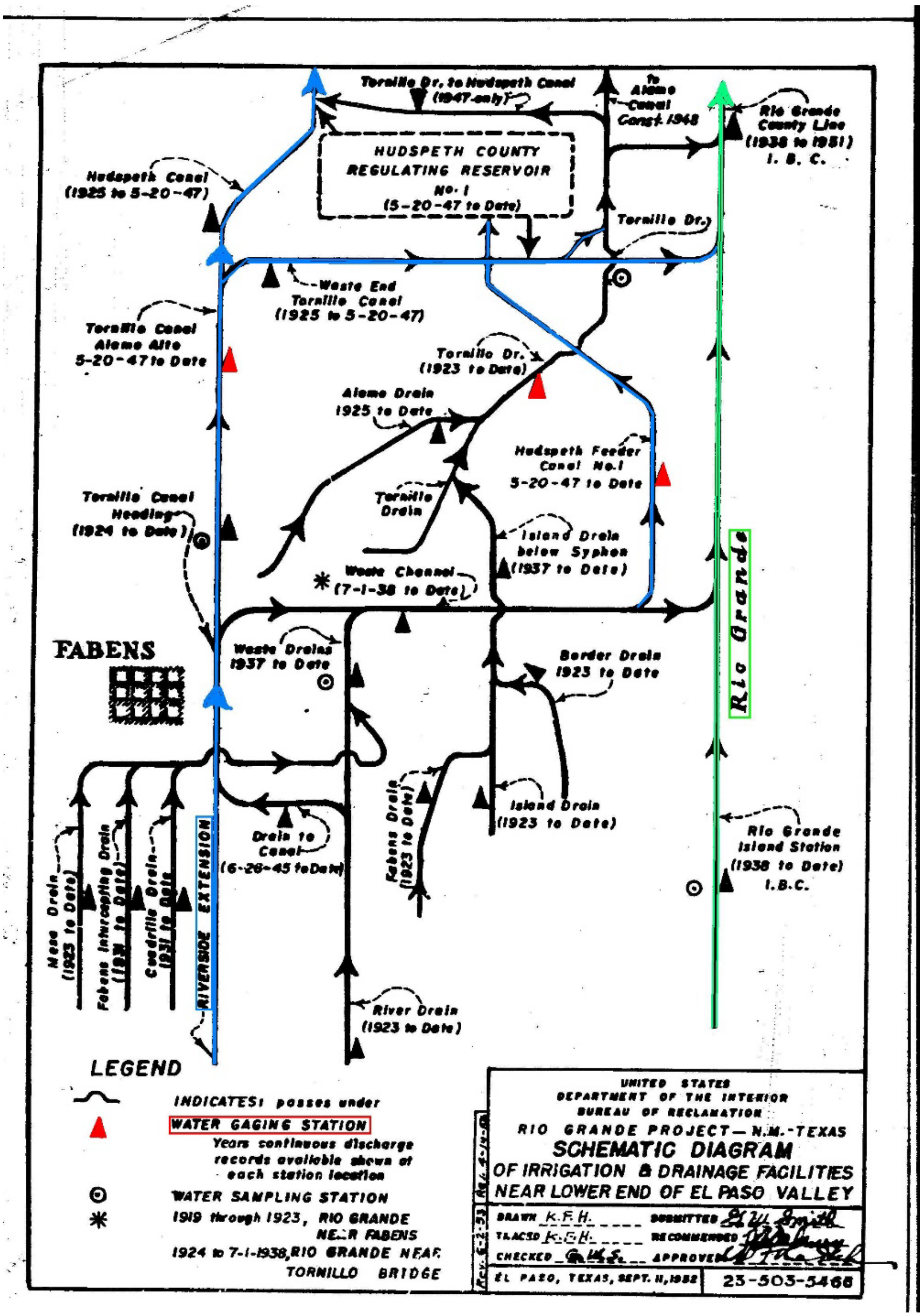


Figure C.9: Diagram by Dr Peggy Barroll of Project conveyances near Fabens, based on 2014 field visit add consultation with Rolf Schmidt-Peterson and Charles Spalding III

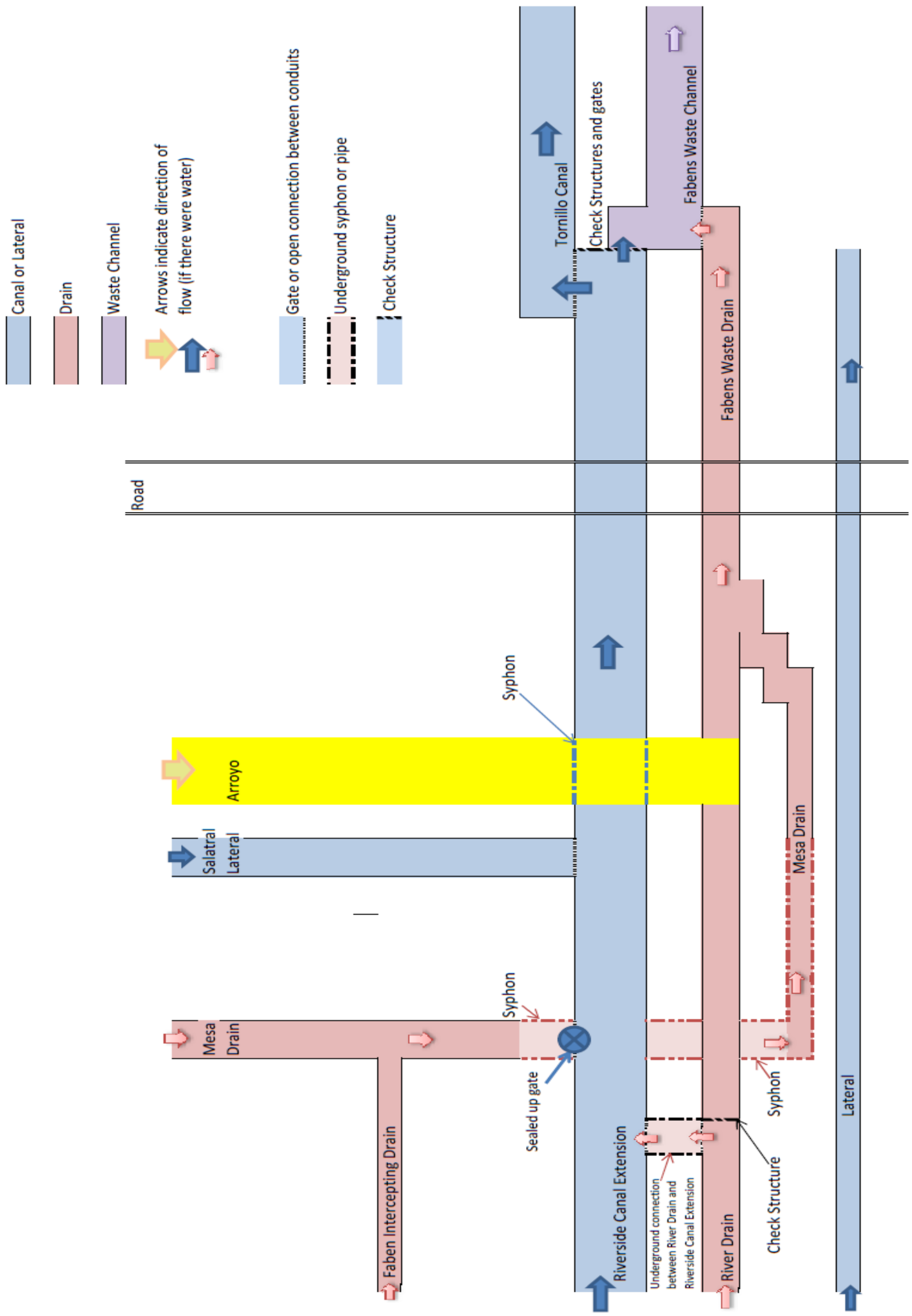


Figure C.10: From Lloyd and Marston

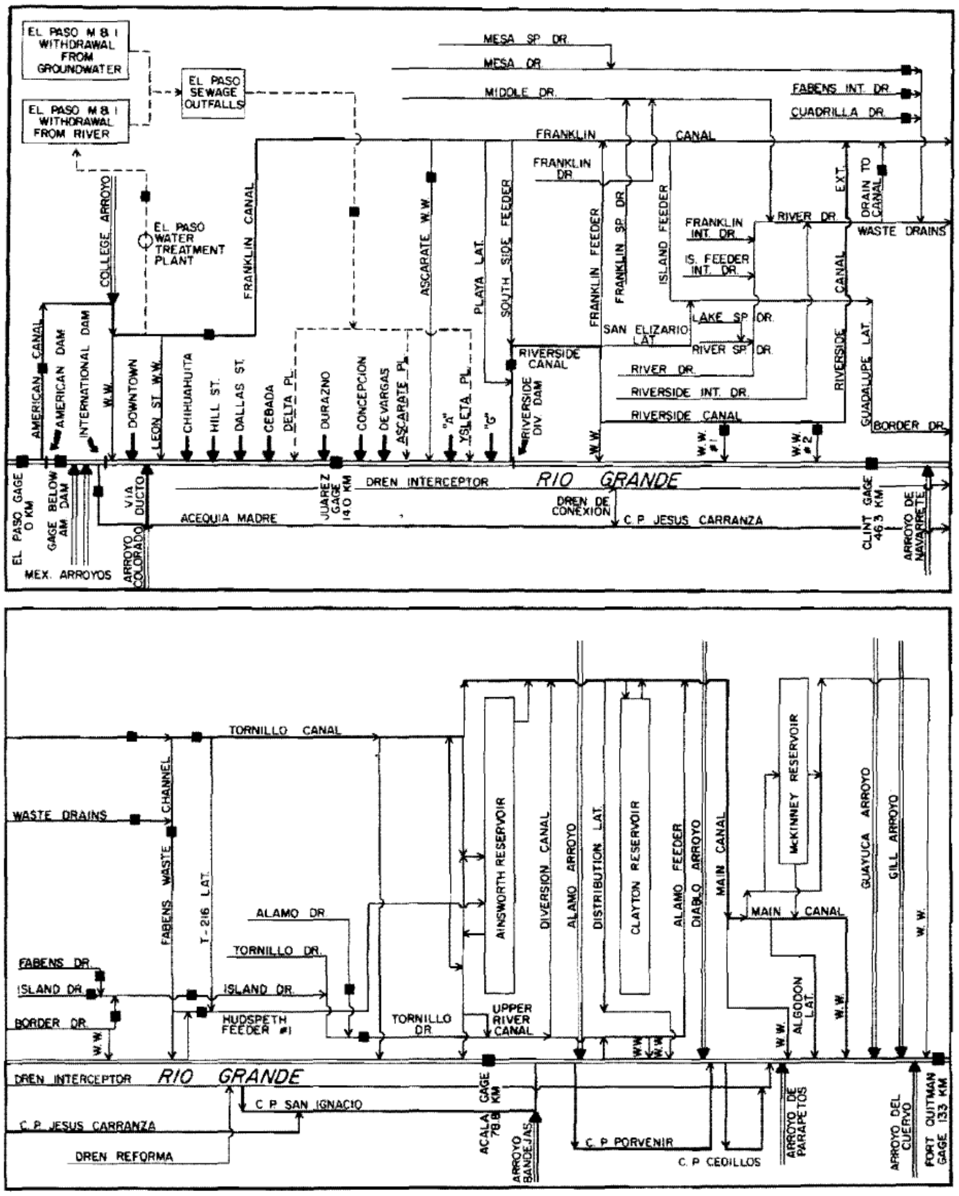


Figure 3. Schematic diagrams of present-day inflows and outflows to the Rio Grande and routing of river water through the El Paso–Juarez Valley. The bottom diagram is a continuation of the upper diagram. Solid boxes represent gages; solid triangles represent arroyo inflows to river; bold arrows represent urban runoff inflows to river; dashed arrows represent El Paso sewage inflows to river; other arrows represent irrigation transfers.

Figure C.11: Excerpt of Reclamation Project strip map of the El Paso Valley

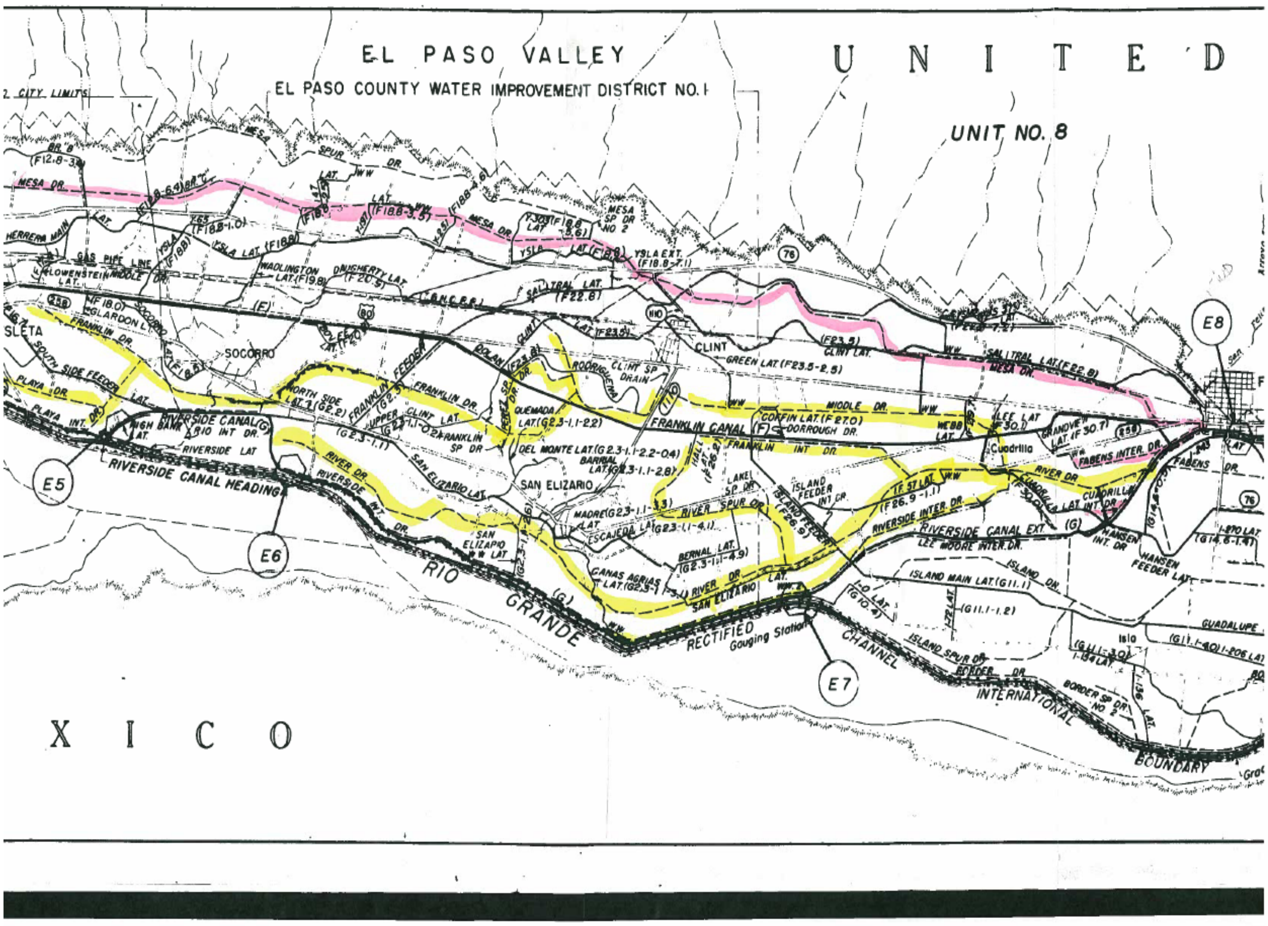


Figure C.12. Schematic of Project: American Dam to Riverside, before and after completion of the American Canal Extension (ACE)

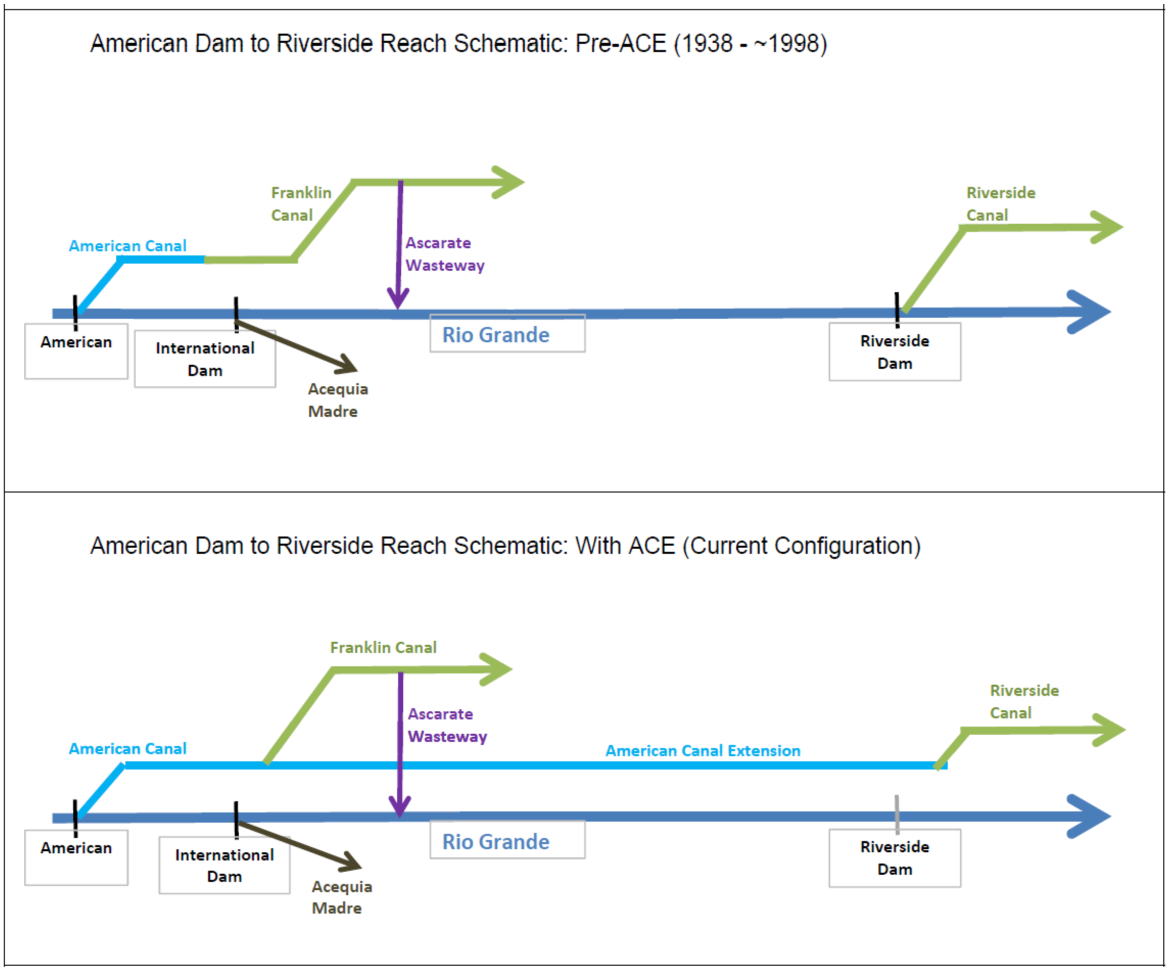


Figure C.13: Reclamation Illustration of Project from Courchesne Gage to Riverside Dam, showing planned location of ACE

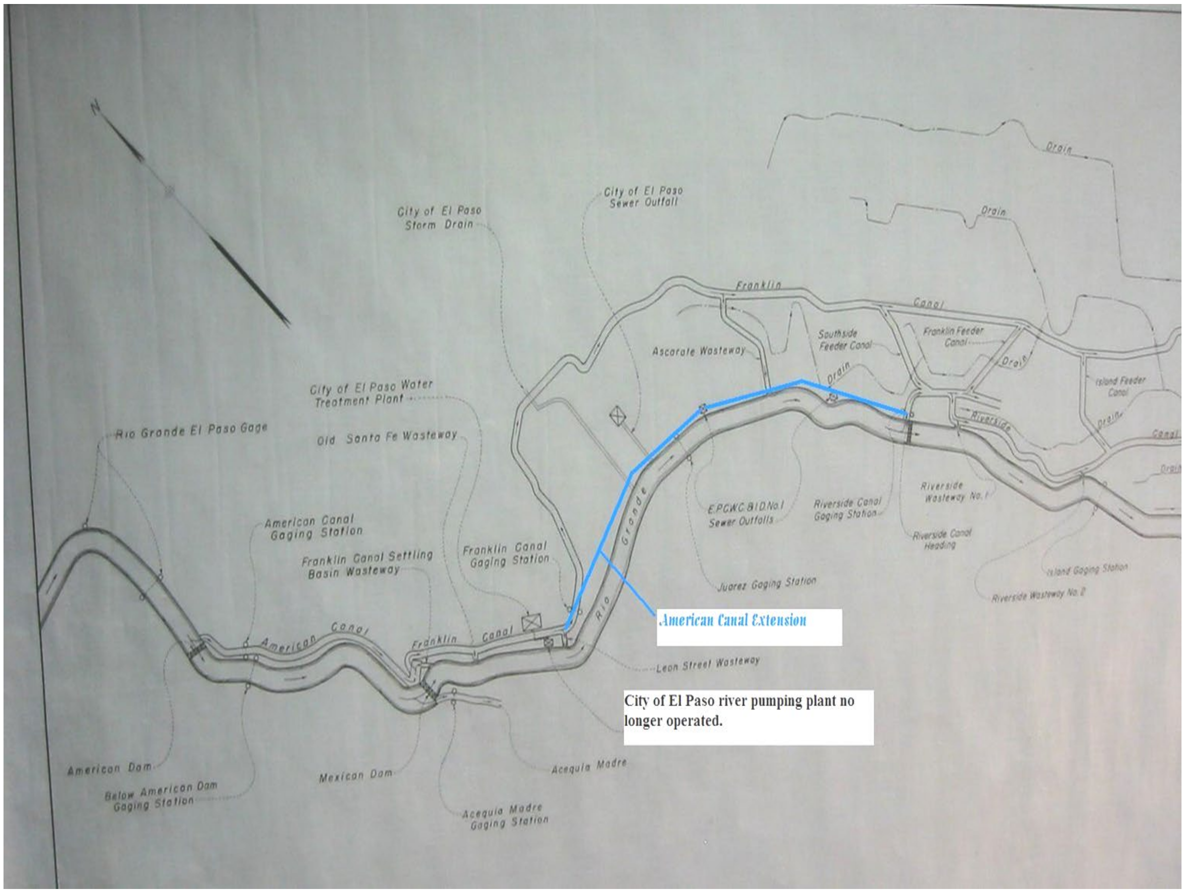


Figure C.14: Gaged Discharge of El Paso Valley Drains Above Fabens, 1939-1983

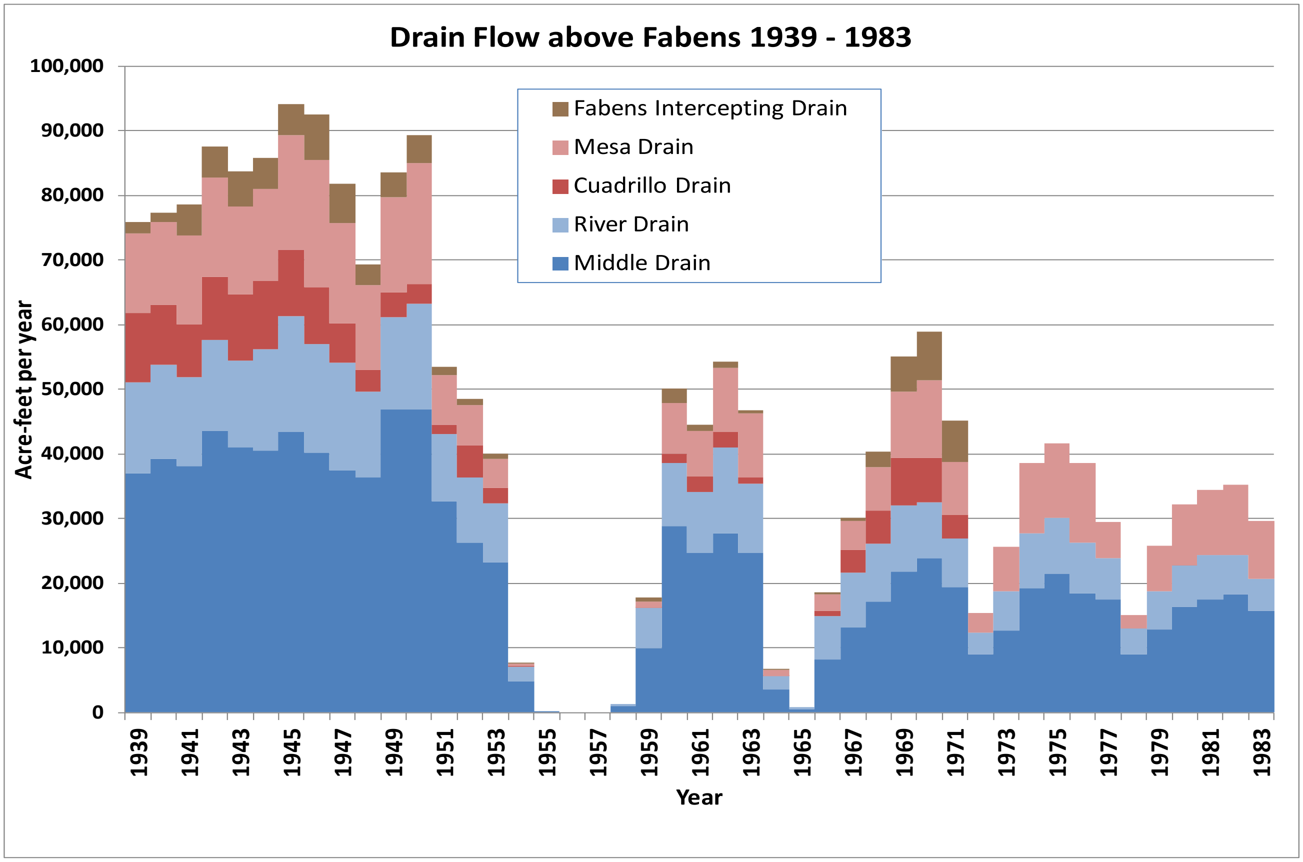


Figure C.15a: Excerpt from Reclamation Drainage Data Report, 1948

DRAINS	LENGTH IN MILES JAN 1ST. 1947	LENGTH IN MILES JAN 1ST. 1948	JANUARY MAXIMUM C.F.S.	JANUARY MINIMUM C.F.S.	JANUARY MEAN C.F.S.	JANUARY TOTAL ACRE FT.	JANUARY C.F.S. PER MILE
LENGTH OF DRAINS ARE ABOVE GAGING STATIONS							
GARFIELD	12.1	12.1	5.2	3.7	4.7	290	0.4
HATCH	11.4	11.4	7.9	3.9	5.5	340	0.5
ANGOSTURA	4.0	4.0	0.5	0.4	0.4	20	0.1
RINCON	14.4	14.4	7.0	1.8	3.8	230	0.3
TOTAL FOR VALLEY	41.9	41.9			14.3	880	0.3
SELDEN	4.6	4.6	2.0	1.3	1.7	100	0.4
LEASBURG	12.1	12.1	2.4	2.3	2.4	150	0.2
PICACHO	7.3	7.3	7.5	6.3	6.7	410	0.9
MESILLA	17.5	17.5	5.3	3.3	4.3	260	0.2
DEL RIO (INCLUDES LEASBURG AND MESILLA)	75.2	75.2	72.2	64.0	67.7	4160	0.9
CHAMBERINO	5.1	5.1	1.6	1.8	1.7	100	0.3
LA MESA	27.3	27.3	14.2	11.4	12.8	790	0.5
EAST	22.7	22.7	10.0	7.2	8.4	520	0.4
ANTHONY	7.9	7.9	1.2	1.0	1.1	70	0.1
NEMEXAS	19.7	19.7	11.5	10.5	11.0	680	0.6
WEST	39.1	39.1	30.9	28.6	29.7	1830	0.8
MONTOYA (INCLUDES NEMEXAS AND WEST)	67.6	67.6	50.6	43.9	46.4	2850	0.7
TOTAL FOR VALLEY	217.7	217.7			146.4	9000*	0.7
SANTO TOMAS & MONTOYA INTERCEPTING DRAINS NOT INCL							
PLAYA	22.3	22.3	20.2	20.2	20.2	1240	0.9
FRANKLIN	33.7	33.7	25.9	23.2	24.6	1510	0.7
MIDDLE (INCLUDES PLAYA AND FRANKLIN)	52.9	52.9	34.1	28.5	31.3	1920	0.6
RIVER	18.9	18.9	11.3	10.2	10.8	660	0.6
CUADRILLA	13.5	13.5	1.9	1.7	1.8	110	0.1
MESA	28.4	28.4	10.8	10.5	10.6	650	0.4
FABENS INTERCEPTING	4.2	4.2	1.6	1.5	1.6	100	0.4
TOTAL ABOVE FABENS	117.9	117.9	70.0	57.0	63.7	3920	0.5
BORDER °	14.5	14.5	13.5	13.4	13.4	820	0.9
ISLAND	16.3	16.3	7.9	7.6	7.8	480	0.5
FABENS	9.1	9.1	3.7	3.6	3.6	220	0.4
ISLAND SYPHON	43.8	43.8	31.5	28.4	30.0	1840	0.7
ALAMO	21.2	21.2	6.6	5.1	5.8	360	0.[illegible]
TORNILLO (INCLUDES ALAMO, ISLAND, BORDER & FABENS)	81.6	81.6	40.7	37.4	40.3	2480	0.5
TOTAL FOR VALLEY	199.5	199.5			104.1	6400	0.5
TOTAL PROJECT	459.1	459.1			264.8	16280	0.6

* Of which 33,440 A.F. was diverted from River Drain to Riverside Ext.-Tornillo Canal.
° Beginning in 1948 Border Drain carries waste from end of Guadalupe Lateral.

Figure C.15b: Excerpt from NMA&MA Reports to EBID

DRAIN WATER DIVERTED AT FABENS

SOURCE: Letters from Resch to Gregg 11/17/52

Year	Discharge - A. F.	Remarks
1945	6,660	Started July 26
1946	38,760	
1947	28,250	
1948	33,440	
1949	16,580	
1950	20,900	
1951	29,600	
1952	23,690	
1953	19,350	
1954	4,586	
1955	0	
1956		
1957		
1958		
1959		
1960		
1961		
1962		
1963		
1964		
1965		

Figure C.15c: Reclamation Daily Discharge Record for Drain to Canal at Fabens

7-212
(January 1937)

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

DAILY GAGE HEIGHT OR DISCHARGE—YEAR SHEET

Note: River Drain at point of diversion to Tornillo Canal includes flow of River Drain and Middle Drain.

DAILY ~~gage height, in feet,~~ discharge, in second-feet, of Drain to Canal at ~~River~~ Fabens (River Drain Water diverted to Tornillo Canal) for 1948 , Observer)

Note - Flow held in Tornillo Canal in Jan. and part of February at the request of the I.B.&W.C. to facilitate construction of Hudspeth Reservoir. Not for irrigation use.

DAY	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
1	51	42	39	78	84	85	109	60	42	82	0	0
2	51	41	42	75	90	46	84	101	108	69		0
3	51	41	41	74	98	13	54	31	108	70		0
4	51	40	40	75	94	20	20	0	114	82		0
5	51	42	40	78	25	41	0	79	110	79		17
6	51	42	40	89	0	30	58	111	93	61		57
7	51	42	40	86	0	35	115	111	108	79		53
8	49	42	40	86	33	8	112	111	62	76	0	67
9	49	26	41	81	83	0	106	115	0	68	21	30
10	49	0	38	87	92	0	118	123	0	75	41	0
11	47		37	85	87	0	110	123	0	80	0	
12	45		38	76	78	0	121	112	0	86		
13	47		37	77	87	0	105	71	0	74		
14	47		38	85	80	53	118	7	0	77		
15	47		40	82	92	87	93	0	0	43		
16	47		33	86	66	80	113	0	41	0		
17	47		36	82	60	83	123	0	28			
18	46		38	85	59	80	51	0	81			
19	45		38	79	70	87	0	0	69			
20	45		40	82	73	80		43	51			
21	45		40	80	79	60		100	65			
22	45		43	86	82	80		110	94			
23	44	0	50	89	84	93		111	96			
24	44	29	51	95	69	96		97	99			
25	44	38	49	95	49	92		113	92			
26	44	38	56	90	32	83		114	93			
27	44	38	51	83	50	10		118	88			
28	44	35	54	85	46	0		118	88			
29	44	38	65	87	51	76		115	79			
30	43	—	62	88	77	99	0	108	86		0	
31	43	—	78	—	90	—	60	121	—	0	—	0
S.F.D.	1451	574	1375	2506	2060	1517	1670	2423	1895	1101	62	224
A.F.	2880	1140	2730	4970	4090	3010	3310	4810	3760	2180	120	440

Total A.F. 33440

U.S. GOVERNMENT PRINTING OFFICE 6—7984

Table C.1: Tabulation of the Annual Diversions from the River Drain into Riverside Extension

Tabulation of the Annual Diversions from the River Drain into Riverside Extension from Annual Reclamation Discharge Records				
Year	Drain to Canal Diversions		Year	Drain to Canal Diversions
	(acre-feet)			(acre-feet)
1945	6,660 (partial year)		1965	44
1946	38,760		1966	6,842
1947	28,250		1967	16,106
1948	33,440		1968	14,099
1949	16,580		1969	2,292
1950	20,900		1970	150
1951	29,600		1971	12,318
1952	23,690		1972	10,382
1953	19,350		1973	6,171
1954	4,586		1974	5,761
1955	0		1975	0
1956	0		1976	0
1957	0		1977	9,229
1958	0		1978	7,453
1959	5,727		1979	3,415
1960	9,781		1980	438
1961	18,874		1981	696
1962	12,212		1982	155
1963	17,470		1983	0
1964	2,758			

Figure C.16: Sample Reclamation Monthly Project Water Distribution for the El Paso Valley

Form 7-322 (May 1937)

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

MONTHLY WATER DISTRIBUTION

Project Rio Grande, New Mexico-Texas   Area Irrigated 166) 55,730)   55,896   Year 1951

El Paso Valley Unit (Ysleta Branch)

QUANTITIES IN ACRE-FEET

MONTH	Diverted from Stream[1]	Inflow from— Reservoirs[2]	Inflow from— Other Sources	Delivered to Reservoirs[2]	Net Supply[3]	Total ~~Main Canal~~ Waste	Total ~~Main Canal~~ Losses	Delivered to Laterals[4]	Lateral Waste	Lateral Losses	Delivered to Farms[5] Total	Delivered to Farms[5] Per Acre
January,	341)					(190)					0	0
February,	5,946)					(231)	2,628				3,238	0.06
March,	24,693					672	14,271				9,750	0.18
April,	31,911					937	7,574				23,400	0.42
May,	13,059					1,236	430				11,393	0.20
June,	25,905					983	11,030				13,892	0.25
July,	35,948					1,451	13,448				21,049	0.38
August,	36,794					2,260	8,630				25,904	0.46
September,	17,198					2,704	3,936				10,558	0.19
October,	6,217					1,277	1,922				3,018	0.05
November,	5,621					1,445	2,281				1,895	0.03
December,	4,737					1,737	1,390				1,610	0.03
Total,	208,370					15,123	67,540				125,707	2.25
Acre ft. per acre,	3.73					0.27	1.21				2.25	
Per cent Net Supply,	100					7	33				60	

[1] Diversion amount exclusive of waste at head gates for sand sluicing, etc.
[2] Reservoirs connected with distributing system only.
[3] Diversions plus inflow from reservoirs and other sources less delivery to reservoirs.
[4] Measured at
[5] Measured at

GOVERNMENT PRINTING OFFICE 6—7283

NOTE: Tabulation does not include water delivered to City of El Paso Water Treatment Plant.

(OVER)

(A) Diversions

(1) Franklin Canal
(2) Riverside Canal
(3) Drain to Canal
(4) Less Ascarate W.W.
(5) Less Riverside W.W. 1 & 2
(6) Less Playa Lateral Waste to Riverside Canal

(B) Waste

(1) Total from Island
(2) Tornillo No. 1
(3) Tornillo No. 2
(4) T - 131
(5) T - 216
(6) T-520
(7) Residual Waste at Fabens

Figure D.3. D2 Curve plotted with Original D2 Data from 1951-1978

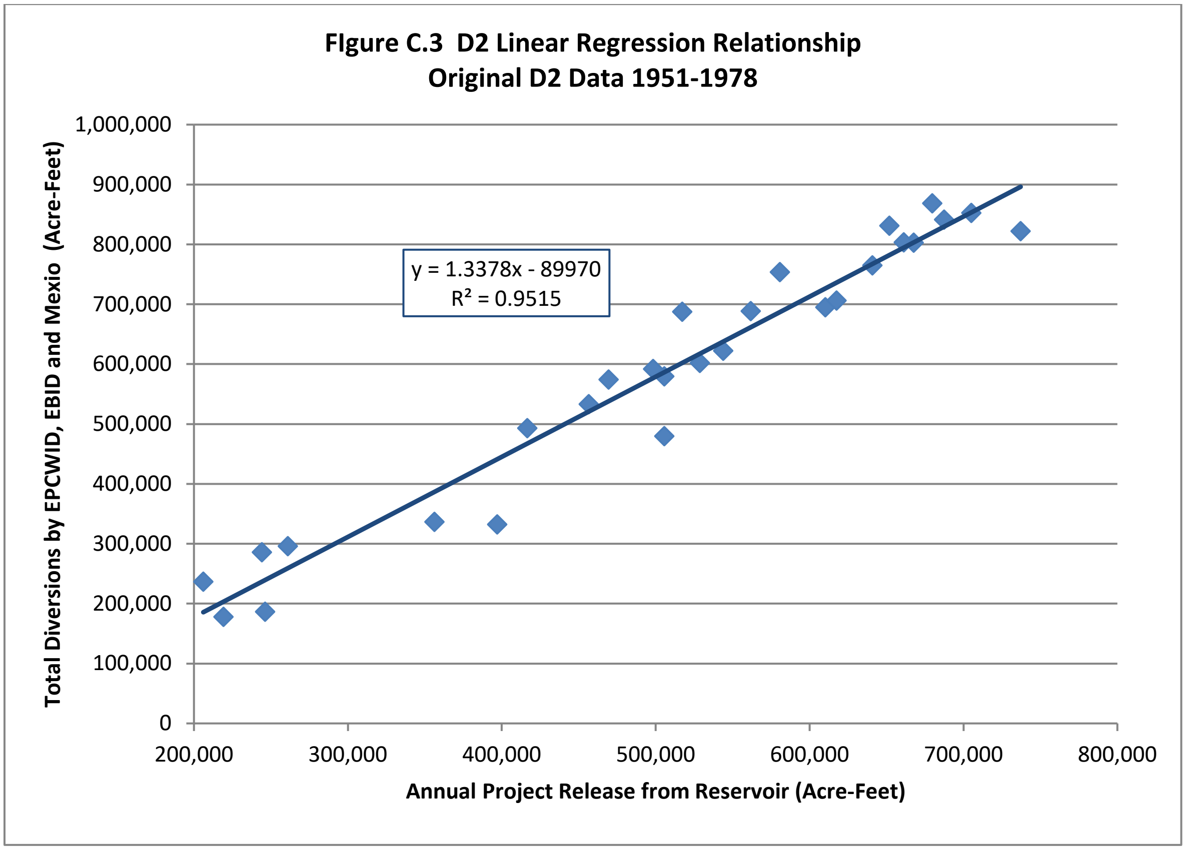


Table D.1. D1/D2 Rio Grande Project Allocations for Full Water Supply from WSAP

Allocations for a Full Water Supply[1] (acre-feet)						
Release Requirement[2]	Net Diversions at Headings[3]	Mexico Allocation	EBID Allocation	EBID Percentage[4]	EPCWID Allocation	EPCWID Percentage[4]
763,842	931,841	60,000	494,979	56.77%	376,860	43.23%

1. Full water supply is 468,700 acre-feet to farm head gates of US lands (3.024 AF/A for 155,000 authorized acres) and 60,000 acre-feet to Mexico at the International Dam
2. Release from Caballo Reservoir necessary to meet full water supply at diversion headings
3. Net Diversion at Headings determined from Curve D2 (includes US and Mexico)
4. Percentage is based upon the net amount remaining to U.S., after deducting Mexico's allocation

Figure D.6. D2 Curve and D2 Data (WDR), with additional 1979 – 1991 data from Project WDR sheets

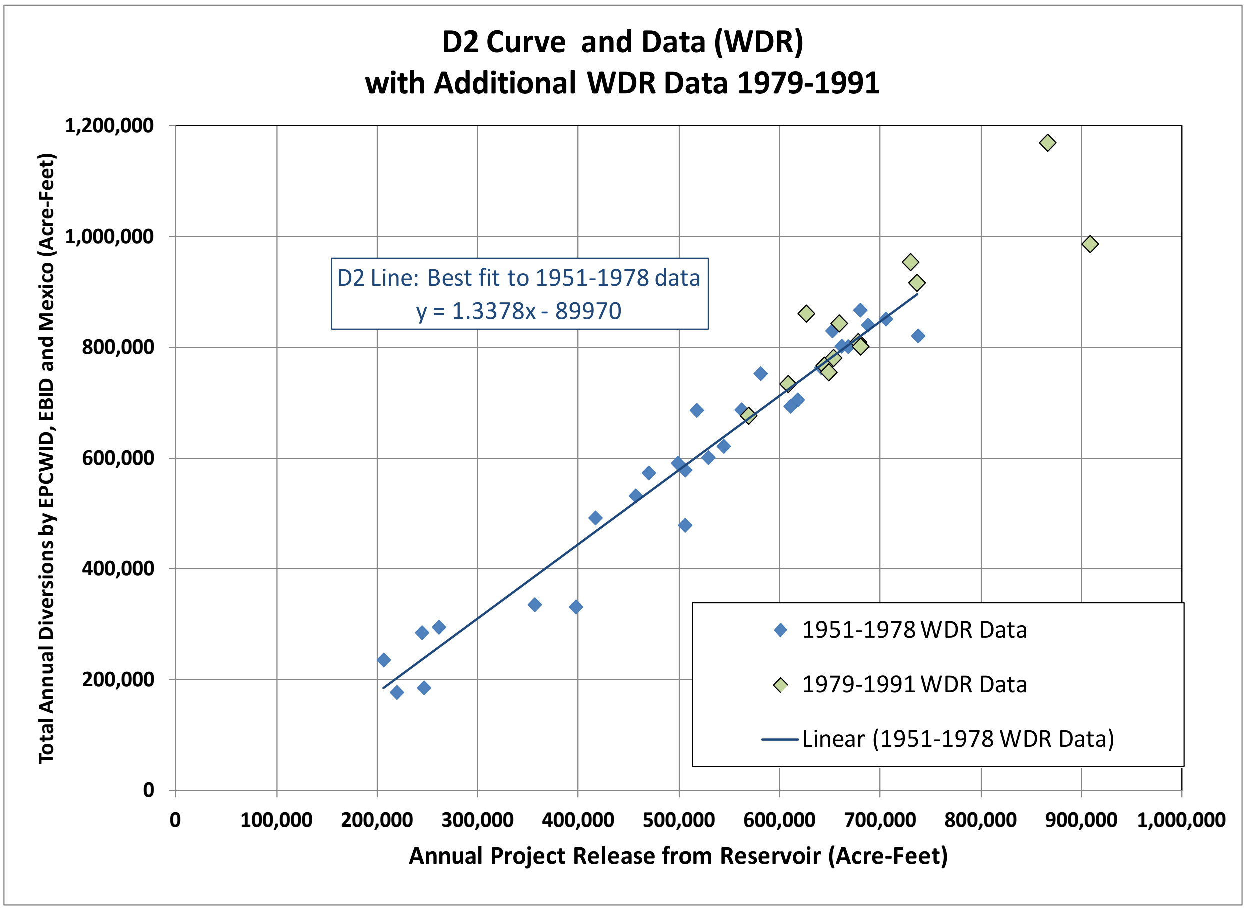


Figure D.7. D2 Curve and D2 Data (1951-1978), with Additional WDR Data (1979 – 1991), and Accounting Data (1979 – 1991)

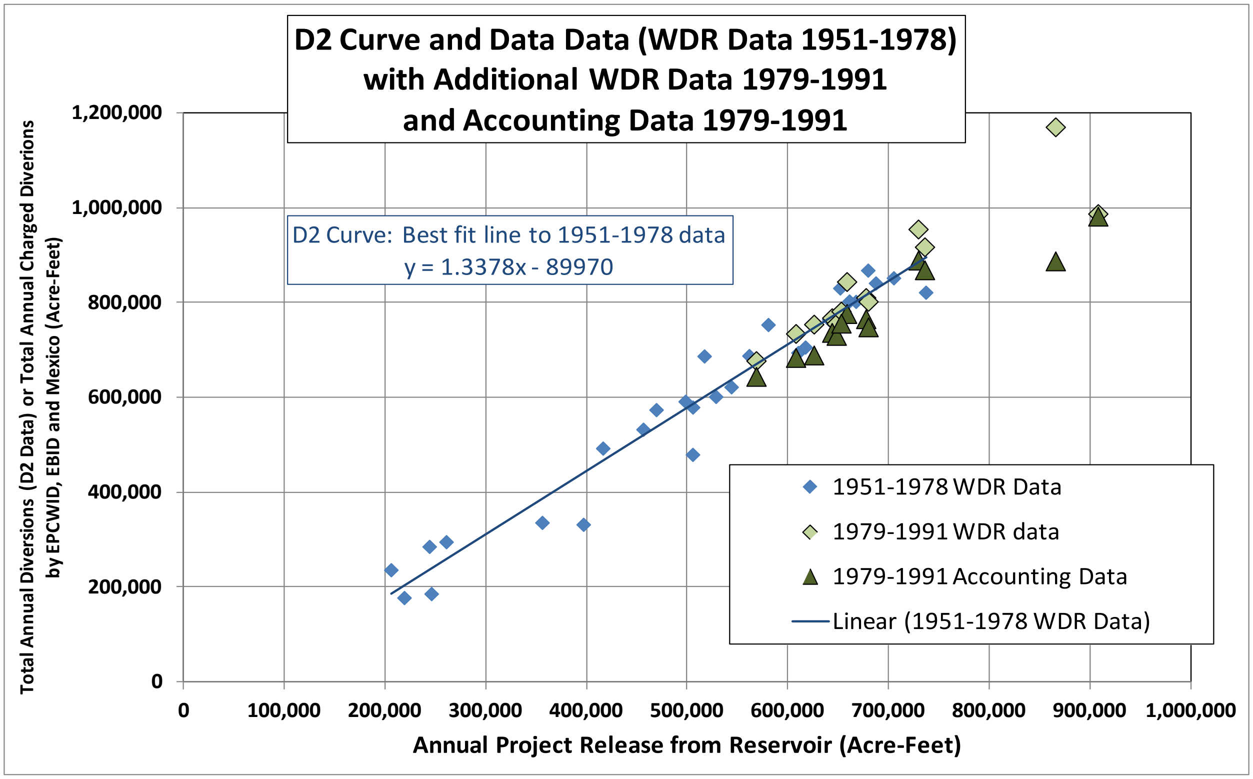


Figure D.8. D2 Curve and D2 data plotted together with 1979 – 2005 Charged Diversions as reported by Reclamation, calculated using Post -1979 Accounting

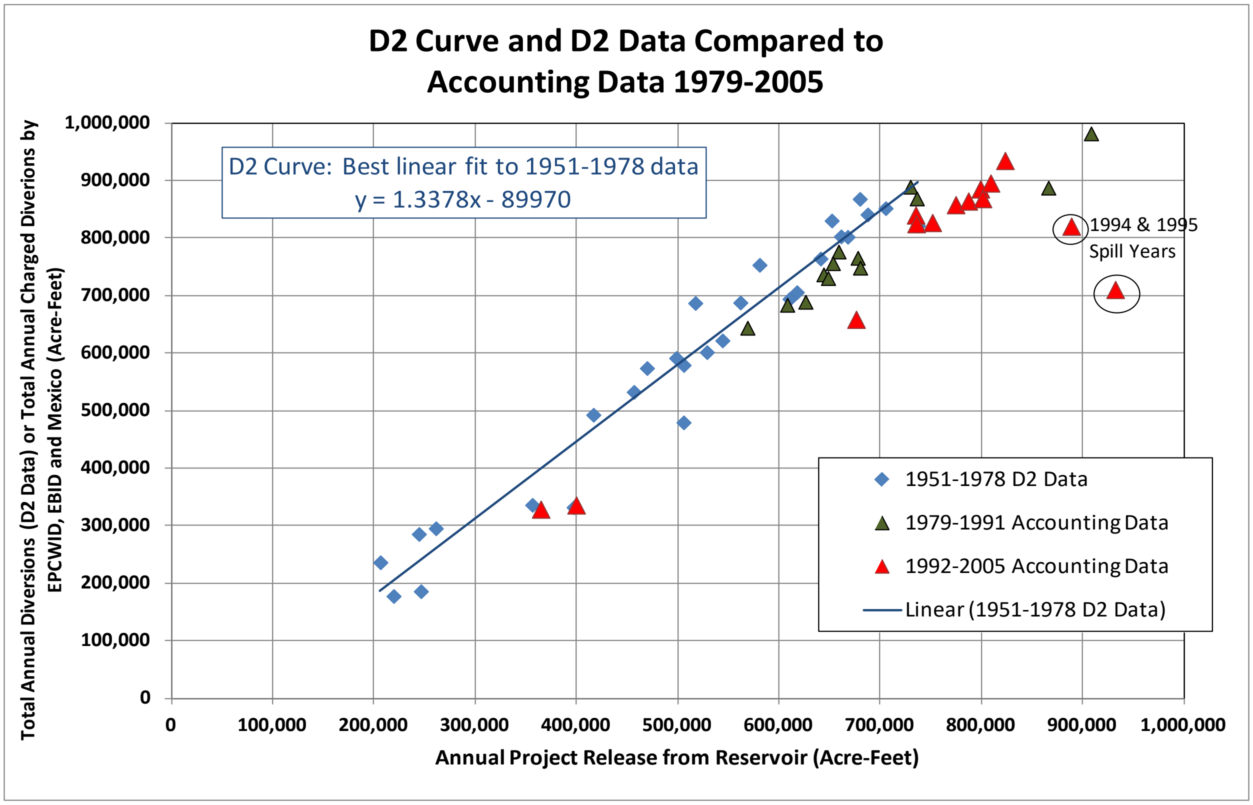


Table D.2. Illustration of the Effect of Variation in the Diversion Ratio
(D3 Allocation, Full-Supply)

Illustration of the Effect of Variation in the Diversion Ratio under D3 Allocation. (Values rounded to nearest 1000 AF)		
Diversion Ratio (unitless)	1.1	1.0
Usable Water (AF)	764,000	764,000
Mexican Allocation (AF)	60,000	60,000
EPCWID's Allocation (AF)	377,000	377,000
EBID's Allocation (AF) [(Usable Water x Diversion Ratio) – Mexican Allocation – EPCWID Allocation]	403,000	327,000

Figure D.9. D2 Curve and D2 data plotted together with 1979 – 2018 Charged Diversions as reported by Reclamation, calculated using Post -1979 Accounting

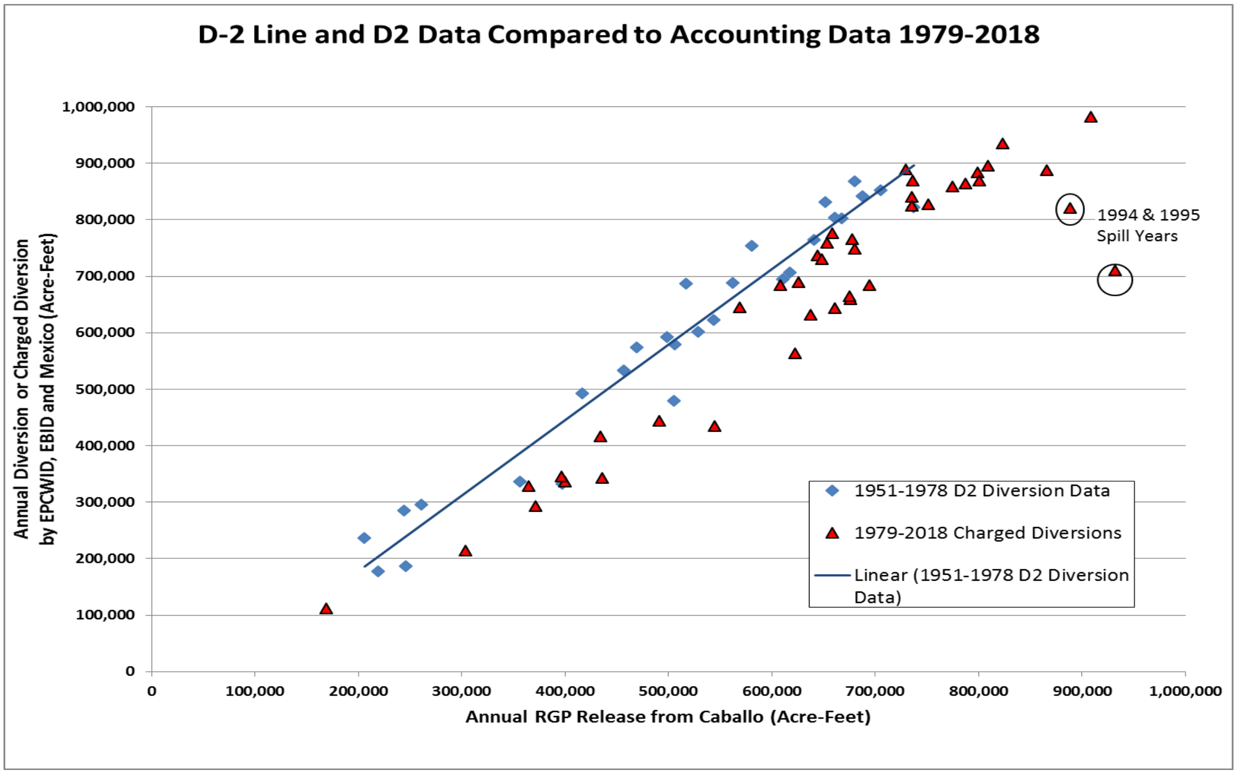


Table D.3. Simplified Allocation Example, D3 Allocation plus Carryover, Full-Supply Year, Amounts rounded to nearest 1000 AF

	Allocation Term	Quantity (AF)	Calculation
A	Total Usable Water Available for Release	1,000,000	
B	EBID Carryover from Previous Year	20,000	
C	EPCWID Carryover from Previous Year	190,000	
D	Total Usable Water Available for Current Year Allocation	790,000	A – B- C
E	Mexican Allocation	60,000	Use D1 Curve
F	EPCWID Current-Year Allocation	390,000	Use Extended D2 Curve
G	EPCWID ACE Credit	20,000	
H	Diversion Ratio	1.0	
I	Deliverable Allocation	790,000	D x H
J	EBID Current-Year Allocation	320,000	I – E – F – G
K	EBID Total Allocation	340,000	J + B
L	EPCWID Total Allocation	590,000	F + C
M	Mexican Allocation	60,000	E

Table D.4. 2010 – 2011 Example of New Inflow to Reservoir Needed to Fulfill Existing Carryover Accounts and Obligation

2010 - 2011 Example of when Carryover Accounts Required Additional Inflows			
		Storage, Carryover and Credit Conditions as of October 15 2010	Storage, Carryover and Credit Conditions as of January 1, 2011
Total Water in Reservoir Storage	(AF)	386,735	497,789
CO Compact Credit	(AF)	800	2,700
NM Compact Credit	(AF)	100,500	164,700
San Juan Chama Water	(AF)	60,796	64,250
Usable Water In Storage	(AF)	224,639	266,139
		Project Accounting 2010	Project Accounting 2011
EBID 2010 Unused Allocation (Carryover from 2010 to 2011)	(AF)	20,014	
EBID 2010 Unused Allocation (Carryover from 2010 to 2011)	(AF)	224,348	
Total Carryover (Carryover from 2010 to 2011)	(AF)	244,362	
2011 Diversion Ratio	(unitless)	0.98	0.85
2011 Carryover Obligation (divide total Carryover by 2011 Diversion Ratio	(AF)		287,485
Inflows to Elephant Butte after October 15, 2010 required to fulfill Carryover Obligation			62,846

Figure D.11. Location Map of Project Structures in the El Paso Area and Haskell WWTP

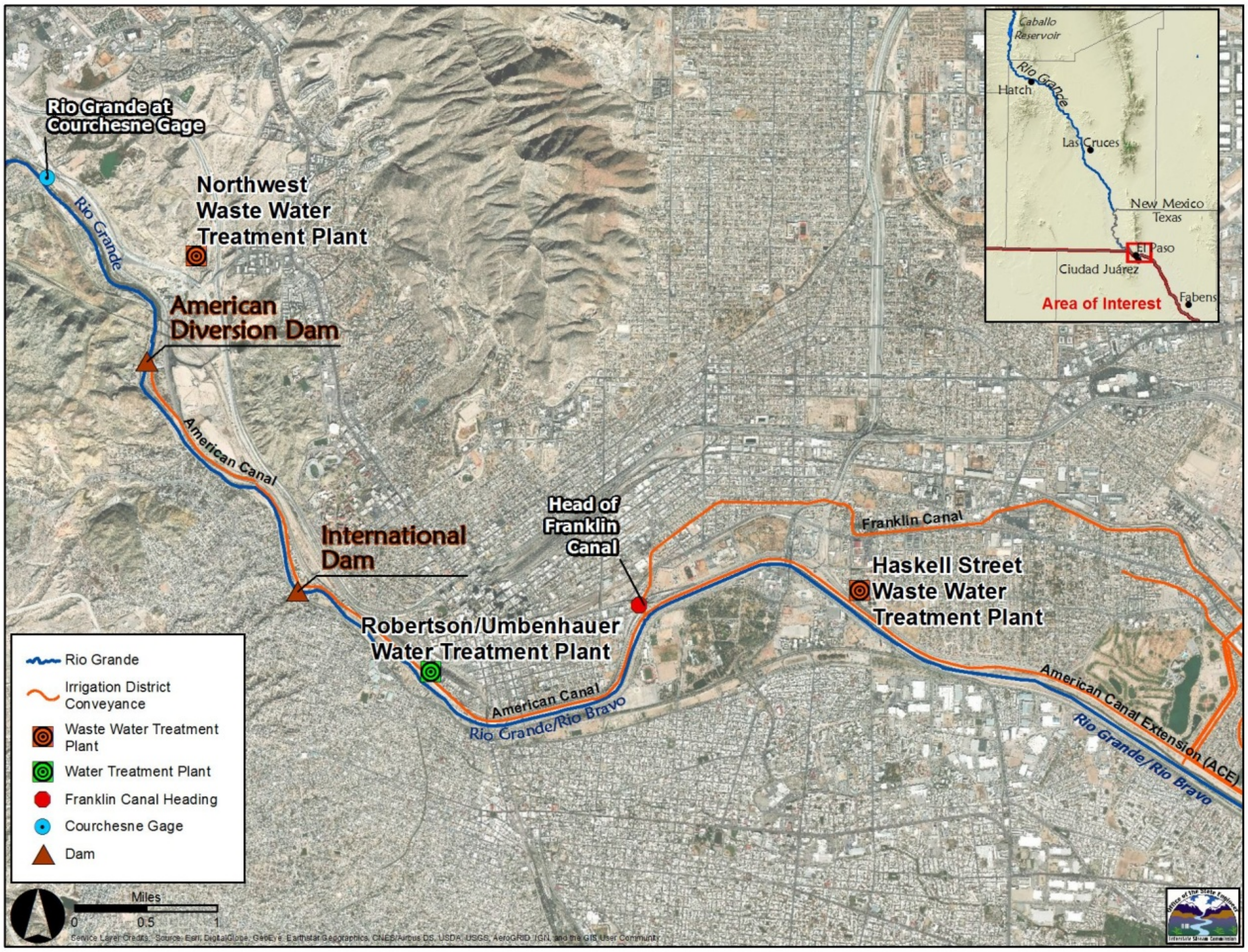


Figure D.12. Schematic Diagram of Rio Grande and Project Conveyances in the El Paso to Riverside area, showing the relative location of the discharge of Haskell WWTP effluent.

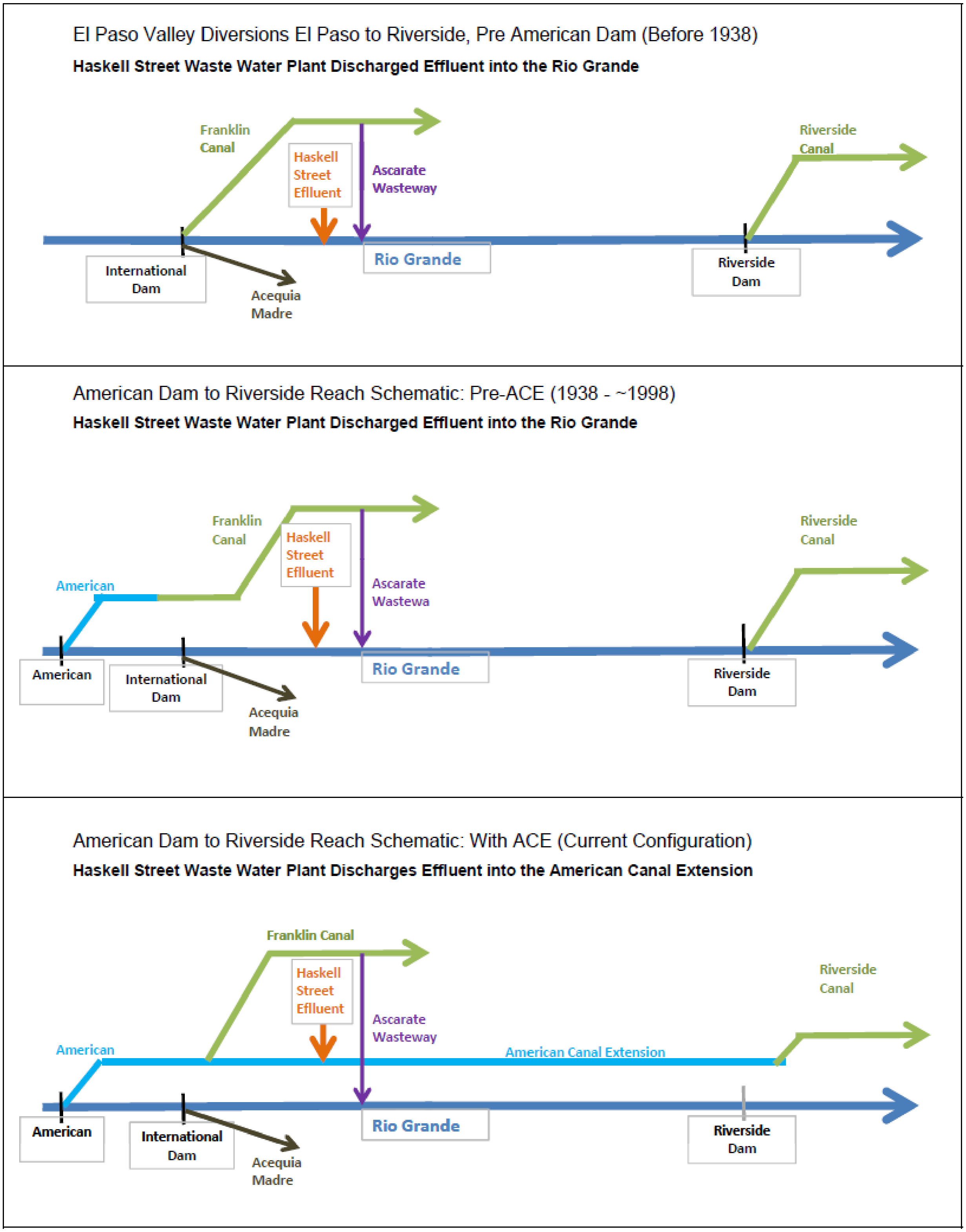


Table D.5. Summary of Project Accounting Credits assigned to EPCWID, extracted from Project Accounting Records

Table D.5. Credits to EPCWID Extracted from Project Accounting (Acre-feet)				
Year	Ascarate Credit	Credit to District for Diversions Greater than Orders	Haskell Effluent Credit	Sum
1997	27701	29956	0	57657
1998	9289	23219	0	32508
1999	0	13758	12732	26490
2000	0	16721	10700	27421
2001	1587	25197	11360	38144
2002	1179	1235	10844	13258
2003	0	1016	9595	10611
2004	0	1925	10759	12684
2005	0	0	9923	9923
2006	0	6412	10347	16759
2007	0	7173	11038	18211
2008	0	7070	11625	18695
2009	0	3307	11597	14904
2010	0	1951	10240	12191
2011	0	0	4337	4337
2012	0	0	5401	5401
2013	0	0	1703	1703
2014	0	0	2489	2489
2015	0	1438	4032	5470
2016	0	0	7712	7712
2017	0	111	7839	7950
2018	0	0	4838	4838

Table D.6. Summary of American Canal Extension Credits assigned to EPCWID, Increasing EPCWID's Annual Allocation, extracted from Project Allocation and Accounting Records

Table D.5. American Canal Extension (ACE) Credit (a.k.a. Conservation Credit)	
2003	12,127
2004	13,025
2005	0
2006	14,511
2007	13,386
2008	16,818
2009	17,998
2010	17,347
2011	0
2012	0
2013	0
2014	7,485
2015	11,651
2016	0
2017	13,650
2018	0

Table E.1. D1 Data Set from Reclamation WSAP (undated, circa 1990)

Table E.1. D1 Dataset Reclamation's Rio Grande Project WSAP Document (circa 1990)					
Calendar Year	Delivered to Farms	Acequia Madre	Non Farm Deliveries	Total Deliveries	Release from Storage
	Acre-feet	Acre-feet	Acre-feet	Acre-feet	Acre-feet
1951	287,618	33,059	7,018	327,695	469,450
1952	331,846	49,890	6,597	388,333	543,975
1953	310,440	37,760	5,955	354,155	528,628
1954	102,270	10,147	1,752	114,169	244,165
1955	80,463	8,185	2,071	90,719	219,157
1956	69,458	7,864	1,002	78,324	246,140
1957	170,117	23,290	2,155	195,562	397,103
1958	400,767	60,050	6,432	467,249	737,125
1959	406,989	60,110	6,772	473,871	687,414
1960	402,400	60,320	6,527	469,247	705,162
1961	325,981	48,610	4,949	379,540	561,697
1962	411,420	60,057	6,234	477,711	651,941
1963	313,006	39,693	3,828	356,527	517,172
1964	64,968	6,653	938	72,559	206,085
1965	234,600	36,658	4,034	275,292	505,598
1966	301,468	49,618	8,341	359,427	610,341
1967	225,269	29,829	4,021	259,119	456,517
1968	255,721	39,677	7,475	302,873	505,691
1969	364,068	59,884	10,423	434,375	667,669
1970	388,549	60,065	9,670	458,284	661,125
1971	269,090	34,847	5,722	309,659	498,375
1972	122,652	16,077	2,719	141,448	260,911
1973	338,769	60,000	10,850	409,619	617,461
1974	351,904	60,050	13,291	425,245	640,843
1975	345,686	60,052	13,545	419,283	580,617
1976	375,070	60,172	13,794	449,036	679,676
1977	193,221	24,824	5,234	223,279	416,496
1978	112,349	14,903	3,587	130,839	356,167

Table E.2. D2 Data Set from Reclamation WSAP (undated, circa 1990)

Table E.2. D2 Dataset Reclamation's Rio Grande Project WSAP Document (circa 1990)				
	Acequia Madre	Project Net Supply	Total Heading Diversions	Release from Storage
Year	Acre-feet	Acre-feet	Acre-feet	Acre-feet
1951	33,059	541,171	574,230	469,450
1952	49,890	572,430	622,320	543,975
1953	37,760	564,209	601,969	528,628
1954	10,147	275,615	285,762	244,165
1955	8,185	169,754	177,939	219,157
1956	7,864	178,408	186,272	246,140
1957	23,290	309,029	332,319	397,103
1958	60,050	761,712	821,762	737,125
1959	60,110	781,248	841,358	687,414
1960	60,320	791,861	852,181	705,162
1961	48,610	639,574	688,184	561,697
1962	60,057	770,701	830,758	651,941
1963	39,693	647,655	687,348	517,172
1964	6,653	229,936	236,589	206,085
1965	36,658	443,130	479,788	505,598
1966	49,618	644,994	694,612	610,341
1967	29,829	503,037	532,866	456,517
1968	39,677	539,878	579,555	505,691
1969	59,884	742,543	802,427	667,669
1970	60,065	743,097	803,162	661,125
1971	34,847	556,910	591,757	498,375
1972	16,077	279,618	295,695	260,911
1973	60,000	646,177	706,177	617,461
1974	60,050	704,544	764,594	640,843
1975	60,052	693,609	753,661	580,617
1976	60,172	808,169	868,341	679,676
1977	24,824	468,239	493,063	416,496
1978	14,903	321,478	336,381	356,167

Table E.3. Comparison of WSAP D1 Data Set with Delivery Data from Reclamation WDR sheets

Table E.3. Comparison of WSAP D1 Dataset with Data Extracted from Reclamation Water Distribution Reports (Discrepancies between data sets highlighted)						
	WSAP D1 Data Set	Reclamation WDR for Project		WSAP D1 Data Set	Reclamation WDR for Project	
Calendar Year	Delivered to Farms	Delivered to Farms	Discrepancy	Non-Farm Deliveries	Non-Irrigation Deliveries	Discrepancy
	Acre-feet	Acre-feet	Acre-feet	Acre-feet	Acre-feet	Acre-feet
1951	287,618	287,618	0	7,018	7,018	0
1952	331,846	331,846	0	6,597	6,597	0
1953	310,440	310,440	0	5,955	5,955	0
1954	102,270	102,270	0	1,752	1,752	0
1955	80,463	80,463	0	2,071	2,071	0
1956	69,458	69,458	0	1,002	1,002	0
1957	170,117	169,984	-133	2,155	2,155	0
1958	400,767	400,767	0	6,432	6,432	0
1959	406,989	406,989	0	6,772	6,772	0
1960	402,400	402,400	0	6,527	6,527	0
1961	325,981	325,981	0	4,949	4,949	0
1962	411,420	411,420	0	6,234	6,234	0
1963	313,006	313,006	0	3,828	3,828	0
1964	64,968	64,968	0	938	938	0
1965	234,600	234,600	0	4,034	4,034	0
1966	301,468	301,468	0	8,341	8,341	0
1967	225,269	225,269	0	4,021	15,320	11,299
1968	255,721	255,721	0	7,475	7,475	0
1969	364,068	364,068	0	10,423	10,423	0
1970	388,549	388,549	0	9,670	9,670	0
1971	269,090	269,090	0	5,722	5,722	0
1972	122,652	122,652	0	2,719	2,719	0
1973	338,769	338,769	0	10,850	10,850	0
1974	351,904	351,904	0	13,291	13,291	0
1975	345,686	345,686	0	13,545	13,545	0
1976	375,070	375,070	0	13,794	13,794	0
1977	193,221	193,221	0	5,234	5,234	0
1978	112,349	112,349	0	3,587	3,587	0

Table E.4. Comparison of WSAP D2 Data Set with Diversion Data from Reclamation WDR sheets

Table E4. Comparison of D2 Data Set with Data Extracted from Reclamation Water Distribution Records (Discrepancies between data sets highlighted)			
	Reclamation Project-Wide WDR from Project Histories	D2 Data Set from WSAP	
Year	Diverted from Stream/ Net Supply	Project Net Supply	Discrepancy
1951	541,171	541,171	0
1952	572,430	572,430	0
1953	564,209	564,209	0
1954	275,615	275,615	0
1955	169,754	169,754	0
1956	178,408	178,408	0
1957	309,029	309,029	0
1958	761,712	761,712	0
1959	781,248	781,248	0
1960	791,861	791,861	0
1961	754,658	639,574	-115,084
1962	770,701	770,701	0
1963	647,655	647,655	0
1964	229,936	229,936	0
1965	443,130	443,130	0
1966	644,994	644,994	0
1967	503,037	503,037	0
1968	539,878	539,878	0
1969	742,543	742,543	0
1970	743,097	743,097	0
1971	556,910	556,910	0
1972	279,618	279,618	0
1973	646,177	646,177	0
1974	704,544	704,544	0
1975	693,609	693,609	0
1976	808,169	808,169	0
1977	468,239	468,239	0
1978	321,478	321,478	0

No. 141, Original Action

In the

Supreme Court of the United States

Texas v. New Mexico and Colorado

Rebuttal Expert Report of

Margaret Barroll, Ph.D.

June 15, 2020

Prepared for:

State of New Mexico

Margaret Barroll, Ph.D.

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OVERVIEW

I have reviewed the Summary Rebuttal Opinions of experts Drs. Ferguson, King, and Blair proffered by the United States in December of 2019. None of these experts refutes my quantitative conclusions as to the extent to which implementation of the D3 Method in the 2008 Operating Agreement has reduced EBID's full-supply allocation and delivery of Project Supply (by approximately 1/3, or more than 150,000 AF in full-supply or near-full-supply years).[1] The only apparent disagreement with my numbers was by Dr. Ian Ferguson in his Summary Rebuttal Opinions (page 8) with reference to my Opinion 8, stated that he calculated different percentages of allocation distribution for recent years. Dr. Ferguson did not provide his calculated values in his written opinions, or at deposition, but my analysis of the data he provided in discovery suggests the differences between our percentage averages numbers are minor and result merely from differences in calculation period and averaging method.[2]

Rather than refuting my conclusions and opinions, the United States' experts instead attempt to justify and explain the reasons behind this large change in allocation. Their explanations assign to New Mexico all responsibility for the negative departure in Project performance relative to the levels obtaining during the D2 period (1951 – 1978). The U.S. experts completely ignore the other factors I identified that contribute to this negative departure. None of the U.S. experts address the fact that changes in Project Accounting since the D2 period, the current exemption of all El Paso Valley municipal wastewater from being accounted as Project Supply, and the effects of Texas groundwater pumping have also contributed to the changes in Project performance as measured by the Diversion Ratio.

The Diversion Ratio is a new feature of Project Allocation, introduced in 2006 as part of the D3 Allocation Method. It is a measure of Project Performance, or delivery efficiency. The Diversion Ratio is calculated as the total amount of Project Supply delivered and charged each year divided by that year's Release from Caballo. As explained in Barroll (2019) at pages D14 and D15, the Diversion Ratio is used to calculate EBID's Allocation, and EBID's Allocation is extremely sensitive to small changes in Diversion Ratio. The lower the Diversion Ratio, the less water EBID receives. The Diversion Ratio is ostensibly a

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[1] References to my conclusions are to those set forth in my initial Expert Report of Margaret Barroll, Ph.D., October 31, 2019, hereinafter "Barroll (2019)."

[2] My review of Dr. Ferguson's spreadsheet calculations suggests that the difference in percentage distribution values is caused, in part, by differences in what years were included in the calculations. In Dr Ferguson's spreadsheet Compare_Allocations_EBIDvEPCWID.xlsx, which he provided during Discovery, in the Compare Alloc tab, his table "Percent of Total Diversion Allocation (With ACE, Excluding Carryover)" tabulates the same type of data as my Table A10. I calculate EPCWID's % of US Allocation to be 56% whereas Dr. Ferguson calculates 53%. There are the following differences in our calculations: 1) Dr. Ferguson tabulates and averages data from 2008 through 2018, whereas I tabulate data from 2006 through 2018, 2) Dr. Ferguson takes an average of the allocation percentages, whereas I calculate the percentage of the average allocations, which takes into account the larger influence of higher supply years. Similarly, Dr. Ferguson's Table "Percent of Total Diversion Allocation (With Carryover and ACE)" generally tabulates the same type of data as my Table A11, although Dr. Ferguson does not include Carryover Transfers in his table. I calculate EPCWID percentage of Total US Allocation to be 62% (2008 – 2018) or 61% (2006 – 2018) whereas Dr. Ferguson calculates 61% (2008 – 2018).

measure of Project Performance, but it is also impacted by Project Accounting: if water diverted and used is not charged in Project Accounting, then the Diversion Ratio will be lower as a result, and EBID will be allocated less water. My report demonstrates the impact of the accounting issues that I raise on the Diversion Ratio and the reduction in EBID's Allocation that is attributable to these factors.

In summary: the analyses, conclusions, and opinions in Barroll (2019) stand uncontested.

R1 THE UNITED STATES ASSERTS THE 2008 OPERATING AGREEMENT IS INTENDED TO OFFSET THE EFFECTS OF NEW MEXICO GROUNDWATER PUMPING ON THE BASIS THAT NEW MEXICO GROUNDWATER PUMPING IS IN EXCESS OF THE LEVELS OBTAINING DURING THE D2 PERIOD (1951 – 1978).

Dr. Ferguson (Opinion under heading B, page 4) states that the D2 Curve (which was used to determine Project Supply from approximately 1980 through approximately 2005, and is currently used to determine EPCWID's allocation) *"incorporates effects of groundwater pumping on Project water supplies during the period 1951 – 1978."* Dr. Ferguson, Dr. King and Dr. Blair indicate that the D3 method is intended to offset impacts of "excessive" New Mexico groundwater pumping that was occurring prior to the initiation of D3 allocation, to protect EPCWID from those impacts, and/or account for Project water captured by New Mexico groundwater pumping.

Dr. King (3rd Opinion, page 7) states that *"the largest factor in deviations from D2 is increased groundwater withdrawals in New Mexico relative to the 1951-1978 D2 period, consisting of EBID constituent pumping and non-Project pumping,"* and Dr. Blair (Opinion #6, page 6) states *"the largest component of which [reduction in Project diversions] is groundwater pumping in New Mexico which is capturing Project Water supply."*

Dr. Barroll Reply: First, it is important to note that the US rebuttal experts concede that the D2 Curve "grandfathered-in" the groundwater pumping occurring from 1951-78.

As to the substance of the US's rebuttal arguments, while the D3 Method does reduce EBID's allocation to account for the effects of any New Mexico groundwater pumping in excess of that occurring during the D2 period, it also reduces EBID's allocation as a result of changes in Project water accounting since the D2 period unrelated to New Mexico groundwater pumping.

Neither Dr. Blair nor Dr. King provide evidence supporting their contention that increases in New Mexico pumping relative to the D2 period cause the largest part of the recent deviation from the D2 Curve. Furthermore, even if this contention is true, it does not justify reducing EBID's allocation for all deviations from the D2 Curve, including those not resulting from New Mexico groundwater pumping. As I demonstrated in Barroll (2019) Section 7 and Appendix D changes in Project accounting since the D2 period have created significant inconsistencies between current accounting data and the data used to calculate the D2 Curve. These accounting discrepancies cause a significant part of the observed departure from the D2 Curve.

Historical irrigation groundwater pumping data and estimates by New Mexico experts (Expert Report of Gregory K. Sullivan and Heidi M. Welsh, Spronk Water Engineers, Inc., October 31, 2019, hereinafter

“Spronk (2019)”)[3] are shown in Figures 1 and 2. I have calculated the pumping averages over various time intervals, and included these results on Figure 1. The data in these figures indicate:

1) Irrigation well pumping in recent years of low Project Supply are comparable to those occurring in low-supply years during the D2 period.
2) Irrigation pumping amounts have historically been highly variable, depending on Project Supply levels (which depend on runoff from the northern New Mexico and Colorado mountains), and therefore it is difficult to make a useful comparison between the irrigation pumping levels during the D2 period to those levels during recent years. As illustrated in Figure 1, calculated averages vary substantially depending on which time intervals the averages are calculated over.
3) Since 2006, New Mexico irrigation well pumping has not dropped below 100,000 AF/yr even in full supply years such at 2007, 2008, 2009 and 2017[4]. This high level of pumping in full-supply years reflects New Mexico’s increased need to pump groundwater because of the low surface water allocations given EBID under D3 Allocation.
4) Irrigation well pumping in New Mexico during the full-supply years 1979 through 2002 (shown in Figures 1 and 2), averaged approximately 65,000 AF/yr according to Spronk (2019) and approximately 85,000 AF/yr according to estimates by Texas experts (Expert Report of Staffan W. Schorr and Collin P. Kikuchi, Montgomery and Associates, May 31, 2019, hereinafter “Montgomery & Associates (2019)”). Neither set of estimates suggests an upward trend in irrigation well pumping in New Mexico during the 1979 through 2002 period.

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[3] Prior to 2009, in the absence of irrigation well meter data, Spronk estimates irrigation well pumping based on the difference between the farm demand (based on Consumptive Irrigation Requirement and estimated farm efficiency) and the reported delivery of surface water.

[4] I define full-supply” years as those in which over 764,000 AF of Usable Water are available to the Project. Dr. Ferguson differs, suggesting a higher standard (Ferguson rebuttal opinion, page 8). The application of either standard in my analysis produces similar results, and does not change the conclusions of my work. “Low-supply years” are less well defined, and depending on context may suggest that less than 600,000 AF or less than 400,000 AF of Usable water are available to the Project. Note that Dr. Ferguson, on page 8 of his rebuttal opinion, indicates that under the 2008 OA, the definition of full-supply conditions changed from a threshold of 763,800 acre-feet of Usable Water (my definition) to a threshold equal to 790,000 AF **plus** the total amount of District Carryover (which has often exceeded 200,000 AF) **plus** any water needed to deliver that Carryover. As a result, Dr. Ferguson does not consider 2009 a full-supply year even through Reclamation’s Allocation Spreadsheet for that year indicates that the “Total Usable Water Available for Release” was 1,020,021 AF.

Figure 1. Annual Irrigation Well Pumping in New Mexico LRG Spronk (2019)

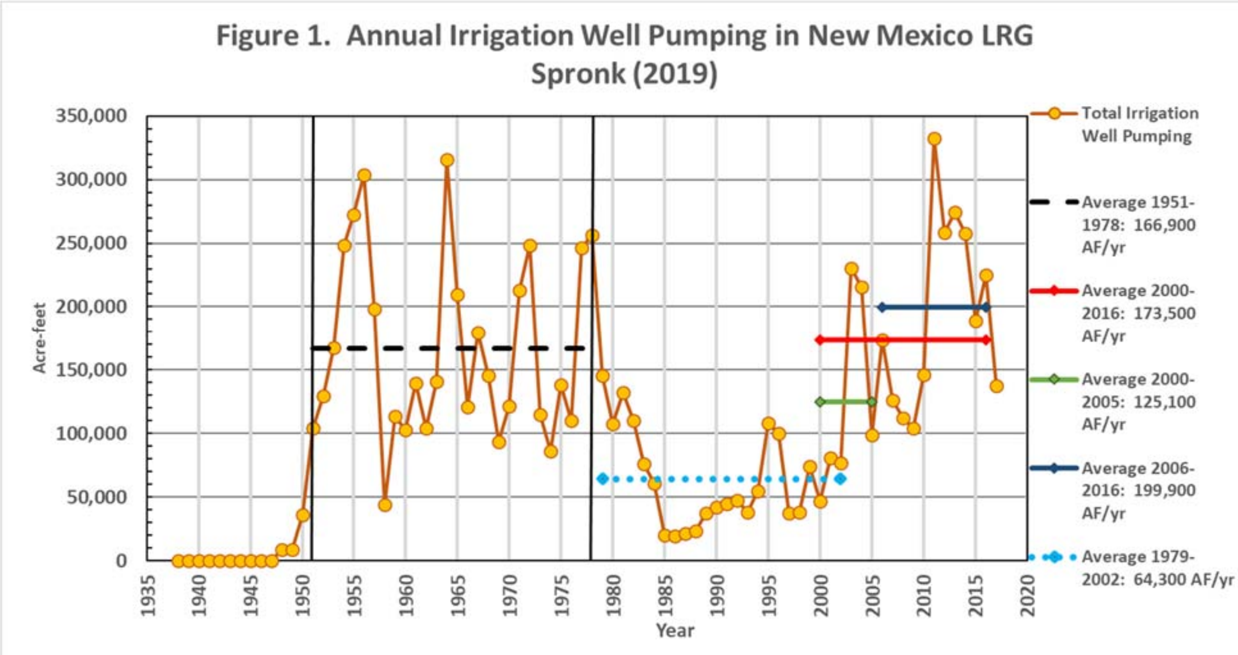
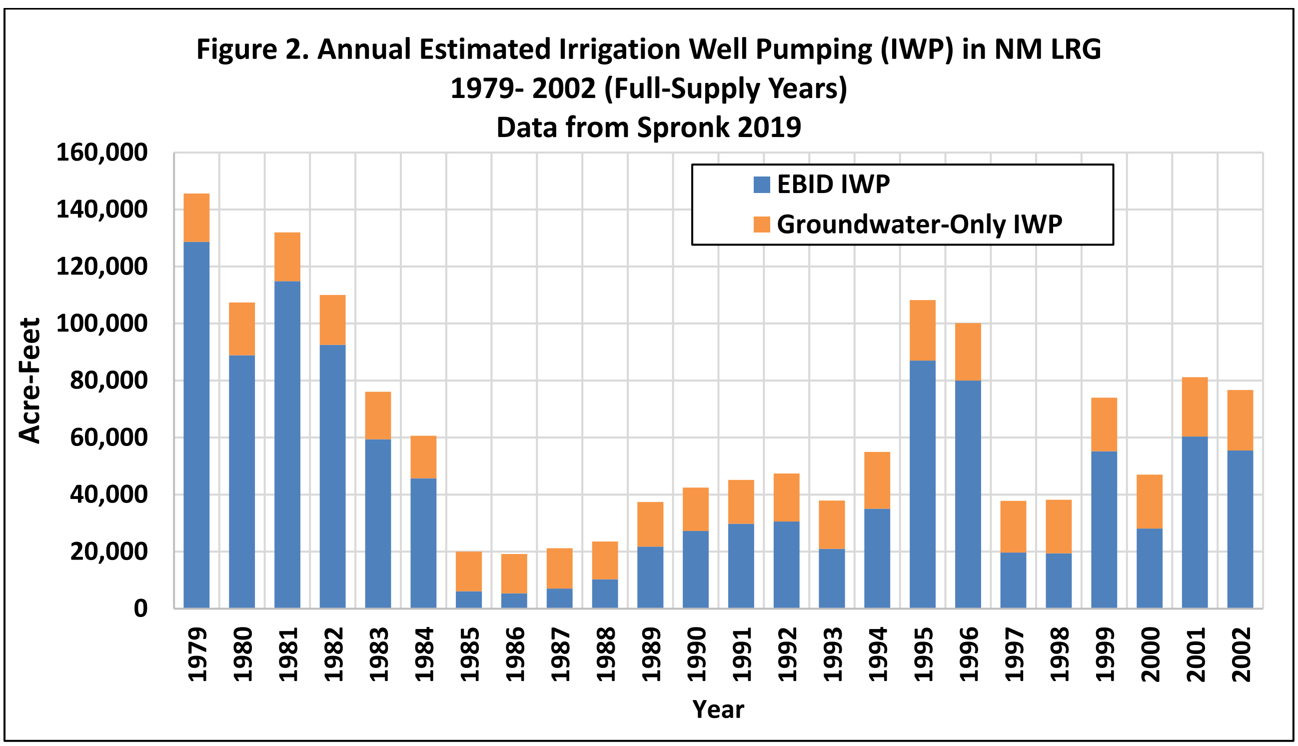


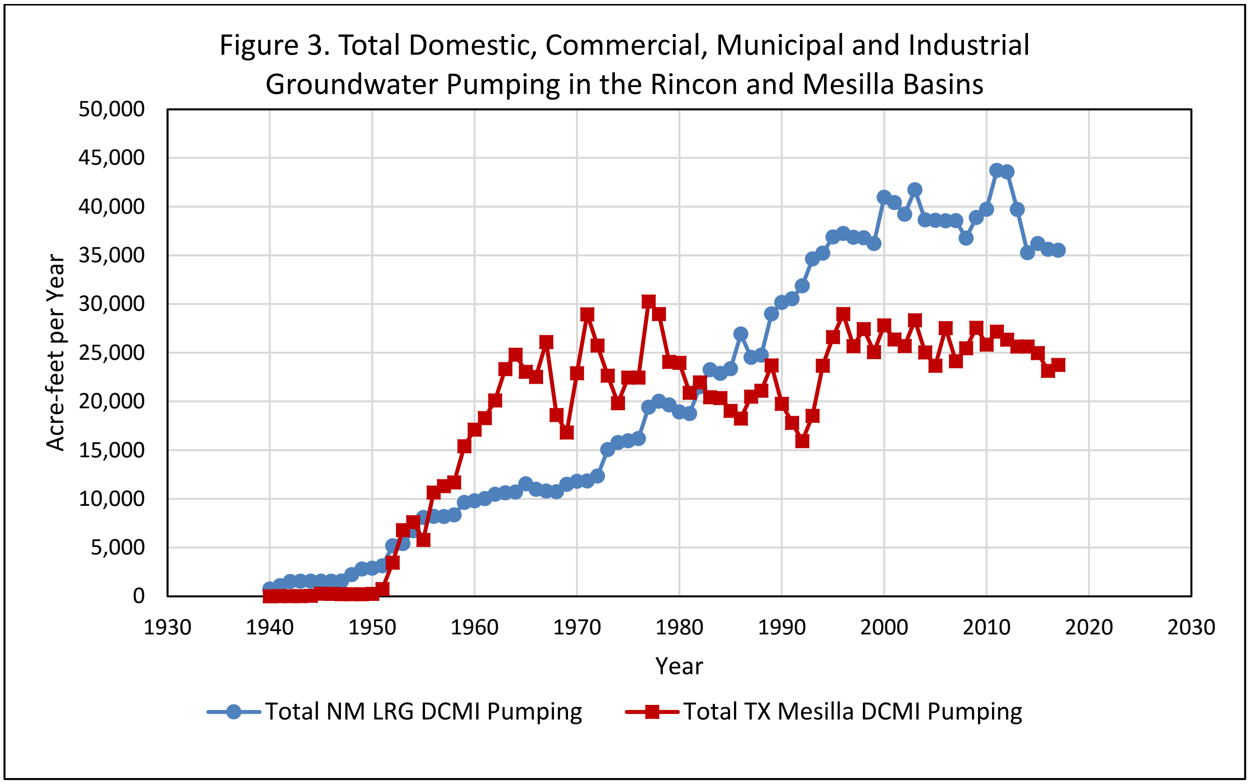
Figure 2. Annual Estimated Irrigation Well Pumping (IWP) in NM LRG 1979-2002 (Full-Supply Years)



Groundwater diversions for domestic use, drinking water, and commercial (DCMI) use in the Rincon and Mesilla basins in New Mexico increased with time from 1940 through the year 2000, Over the past 20 years there is no trend of increased DCMI pumping in New Mexico, as shown in Figure 3.

Note that DCMI pumping does not have a 1:1 impact on stream flows. The larger municipal users, such as the City of Las Cruces, generate treated effluent that is returned to the Rio Grande, and the diversion and use of this water is treated as Project Supply. The municipal effluent acts to offset part of Las Cruces' pumping impacts on the stream and on the Project. In addition, Las Cruces makes use of water pumped from the Jornada del Muerto basin, which has very little hydrologic connection with the Rio Grande stream system. Effluent returns into the Rio Grande from Las Cruces's Jornada pumping is largely imported water that provides additional mitigation for Las Cruces pumping within the Mesilla basin.

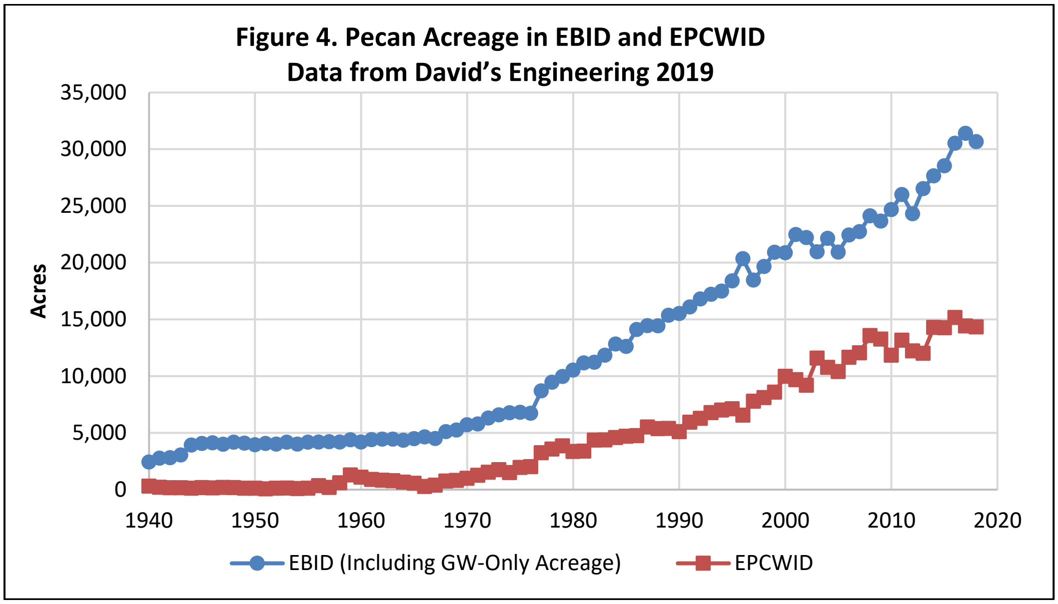
Figure 3. Total Domestic, Commercial, Municipal and Industrial Groundwater Pumping in the Rincon and Mesilla Basins



The irrigation water demand on a per-acre basis has increased over past decades in both New Mexico and Texas as more water-intensive crops have replaced cotton. The transition to more profitable and more water-intensive crops, such as pecans, has occurred in both the New Mexico and Texas parts of the Rio Grande Project as shown in Figures 4 (acreage) and Figure 5 (percentages). In recent years, pecan orchards comprise approximately 40% of the irrigated acreage in both EBID and EPCWID. Both EBID farmers and farmers in large parts of EPCWID have access to groundwater that allows them to successfully maintain these orchards in years when the Project has a short supply.

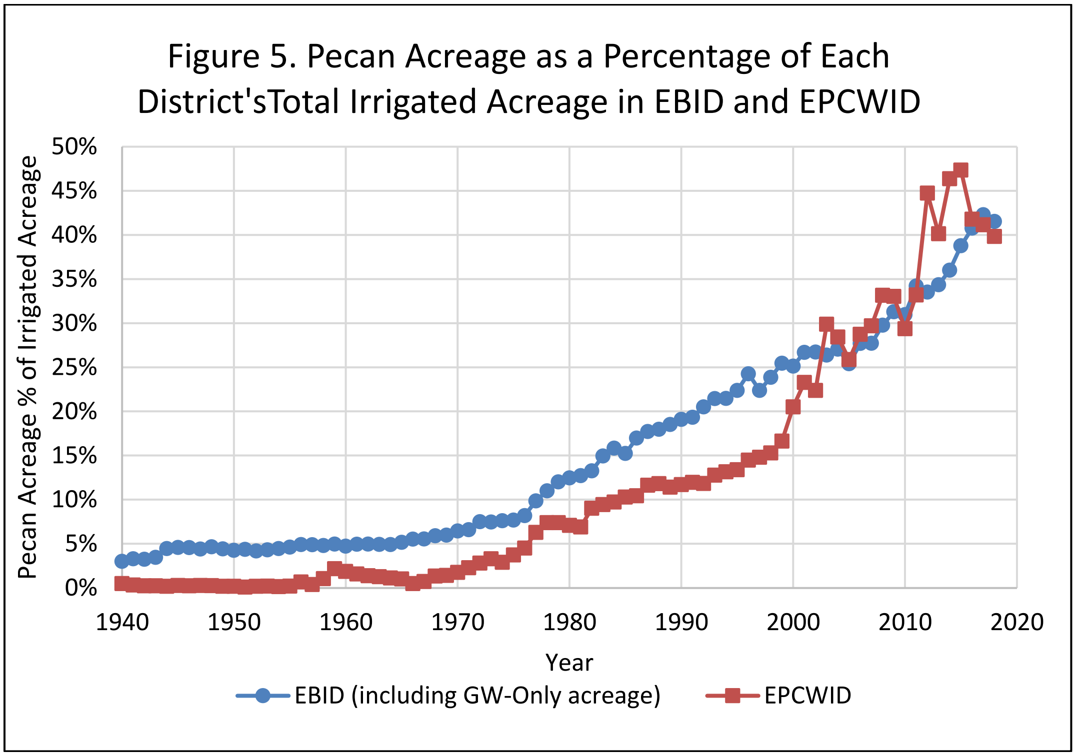
Data compiled in Spronk's Rio Grande Project Canal and Farm Budget spreadsheet[5] indicate an increase in the consumption of irrigation water per irrigated acre in New Mexico through time, from an average of 2.6 acre-feet per acre (AF/A) during the 1951 – 1978 period to an average of 2.9 AF/A in more recent years. (Similarly, within EPCWID, the per acre consumption rose from 2.4 AF/a to 2.6 AF/A).

Figure 4. Pecan Acreage in EBID and EPCWID



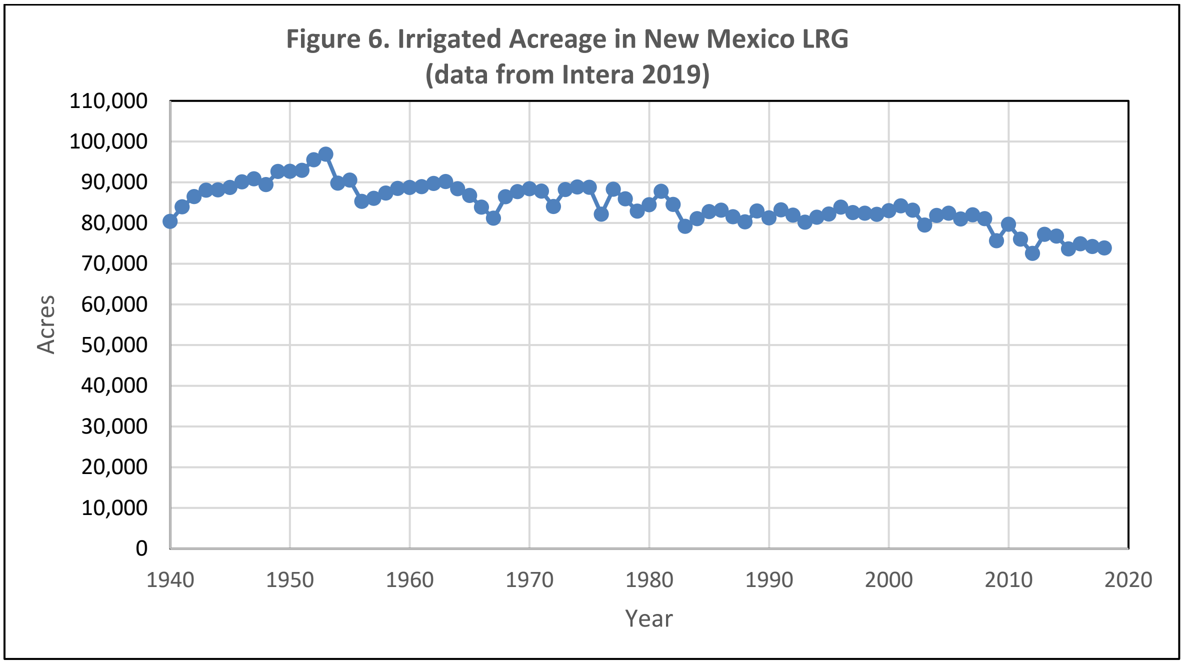
[5] Spronk Spreadsheet named 2019-10-25 Rio Grande Project Canal and Farm Budget.xlsx, analysis of data from the tab named TablsAnn for EBID Total.

Figure 5. Pecan Acreage as a Percentage of Each District's Total Irrigated Acreage in EBID and EPCWID



While per acre irrigation consumption in New Mexico appears to have increased, the total irrigated acreage in the New Mexico part of the LRG has declined, from a reported high exceeding 90,000 acres during the 1950's, to approximately 75,000 acres in recent years, as shown in Figure 6. Total irrigation demand is the product of the per-acre demand and the irrigated acreage. As will be shown in the figures below, data from New Mexico experts indicates that the decrease in irrigated acreage has compensated for the increase in per acre consumptions, and that total consumption of irrigation water in New Mexico has not increased.

Figure 6. Irrigated Acreage in New Mexico LRG



The availability of meter data from irrigation wells in the New Mexico portion of the Project starting in 2009 allows us to explore the actual relationship between irrigation pumping and surface water supply using hard data. All groundwater use in the Rio Grande Project in New Mexico is measured by calibrated flow meters.[6] Table 1 (a revised version of Table 4.2 from Barroll (2019)) shows annual values of key Project Supply parameters related to EBID, and the annual metered irrigation well pumping, for the period 2008 through 2018. The metered irrigation well pumping is strongly dependent on surface water supply: when EBID's supply of Project water is low, metered irrigation well pumping is high, and vice-versa.

When EBID's farm deliveries (of Project surface water) are added to irrigation well pumping, the result represents the total farm delivery of groundwater and surface water. The total farm delivery of groundwater and surface water can be divided by the irrigated acreage to calculate the average farm delivery per acre. Table 1 shows that the average farm delivery per irrigated acre in recent years is 4.0 AF/A, which is the same amount of water that EPCWID allots to its farmers in full-supply years (Blair 2001[7]). If that same total farm delivery of groundwater and surface water is instead divided by the

[6] Except for some exempt small stock and single-family domestic wells

[7] Blair, 2001, Sources and Quantity of Rio Grande Project Water Available for Conversion to Uses Other than Irrigation under the Proposed Third Party Implementing Contract among EPCWID, the City of El Paso, and the United States. Exhibit D of Contract No. 01-Wc-40-6760, page 57 of 74, line 10, "In this report, the determination of a "full supply" year … assumes a District Project Water delivery requirement of 4.0 acre-feet per acre per year to all lands held by taxable owners of "First Class" Water Rights Lands…"

EBID's authorized acreage, 90,640 acres, I calculate an average farm delivery per assessed acre of 3.4 AF/A. This value is somewhat higher than the full-supply farm delivery value calculated by Reclamation for the period 1946 through 1950, 3.024 AF/A, suggesting a net increase in total irrigation water demand since the late 1940's. In 1961 Gunaji reported that "The normal use of water per acre ranges from 3.25 to 3.5 acre-feet per acre delivered to first class water right land [in EBID]"[8] When calculating irrigation demand for the 1950's, Gunaji uses a per-acre farm demand of 3.5 AF/A, consistent with the farm delivery per assessed acre value I calculate in Table 1.

Table 1. Surface Water Allocation and Delivery, and Irrigation Well Pumping Data in New Mexico Calculation of Total Farm Delivery per Acre

Table 1. (Modified Version of Table 4.2 Barroll 2019. Modifications: adding Data from 2019, EBID Allocation Data and Column Averages, plus minor revision to EBID Reported Farm Deliveries based on data from Spronk, 2019)
Surface Water Allocation and Delivery, and Irrigation Well Pumping Data in New Mexico
Calculation of Total Farm Delivery per Acre

Calculation of Total Farm Delivery to Irrigated Lands in New Mexico

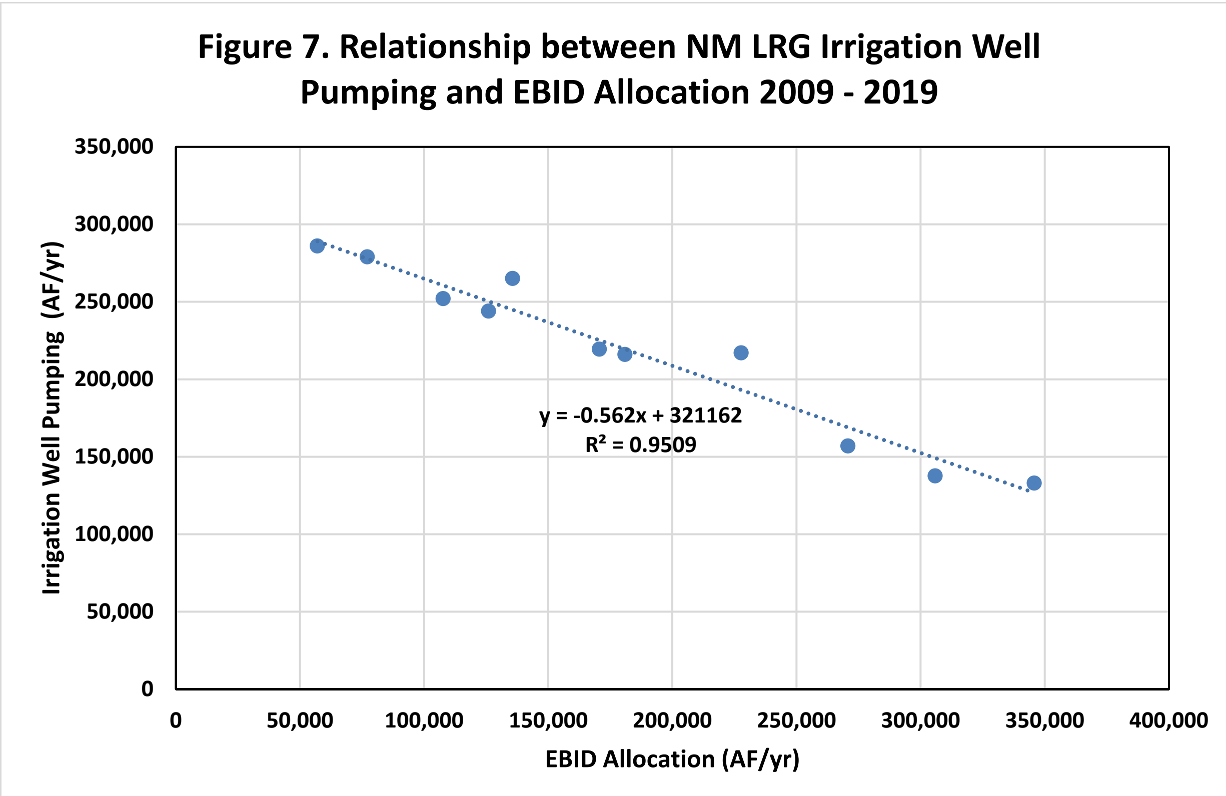
Year	Project Allocation to EBID	Surface Water Delivered/ Charged to EBID Canal Headings	EBID Reported Farm Delivery	Metered Irrigation Well Pumping	Total Farm Delivery of Water (GW + SW)	Irrigated Acreage	Average Farm Delivery per irrigated acre	Assessed acreage	Average Farm Delivery per assessed acre~~age~~
	Project Accounting Records	Project Accounting Records	EDID Board Meeting Minutes	NM OSE Water Master Records		Intera 2019			
	Acre-Feet	Acre-Feet	Acre-Feet	Acre-Feet	Acre-Feet	Acres	AF/A	Acres	AF/A
2008	324,990	329,294	187,899	133,000	320,899	81,061	4.0	90,640	3.5
2009	345,817	305,475	187,694	133,000	320,694	75,607	4.2	90,640	3.5
2010	305,870	282,082	155,417	137,600	293,017	79,669	3.7	90,640	3.2
2011	77,104	59,771	24,149	279,000	303,149	76,002	4.0	90,640	3.3
2012	135,633	133,060	57,014	265,000	322,014	72,524	4.4	90,640	3.6
2013	57,011	54,002	19,711	286,000	305,711	77,199	4.0	90,640	3.4
2014	107,659	99,007	48,135	252,000	300,135	76,771	3.9	90,640	3.3
2015	170,593	143,404	70,416	219,400	289,816	73,616	3.9	90,640	3.2
2016	180,912	175,199	83,103	216,000	299,103	74,884	4.0	90,640	3.3
2017	270,749	258,954	139,589	157,000	296,589	74,218	4.0	90,640	3.3
2018	125,958	127,487	67,366	244,000	311,366	73,849	4.2	90,640	3.4
2019	277,737	191,462	90,134	217,000	307,134	74,000	4.2	90,640	3.4
Averages					**305,802**		**4.0**		**3.4**

Estimated Values: 2008 Irrigation well pumping set equal to metered 2009 irrigation well pumping. 2019 Irrigated Acreage set to reflect levels in recent years.

[8] Gunaji, Narendra, *Ground Water Conditions in Elephant Butte Irrigation District*, Engineering Experiment Station, NM State University, November 1961.

In Figure 7, I plot metered annual irrigation well pumping from 2009 through 2019 as a function of EBID's allocation of Project Water. As expected, irrigation well pumping is higher when the allocation is low, and vice versa. The data are tightly correlated, with a regression coefficient (R^2) of 0.95, showing that **variation in irrigation well pumping is almost completely driven by variation in surface water supply** and the resulting shortage of water necessary to maintain crops.

Figure 7. Relationship between NM LRG Irrigation Well Pumping and EBID Allocation 2009-2019



In Figure 8 I plot the total reported farm delivery of Project water in EBID with total metered irrigation well pumping in the New Mexico LRG for the years in which this meter data is available: 2009 – 2018. This plot represents actual farm demand in the New Mexico Project area[9] over this period and shows a stable level of demand over this period. Figure 9 is the equivalent plot for the historical record since 1940, using values for irrigation well pumping calculated by Spronk[10] (2019). This plot also shows a relatively stable farm demand for water in the New Mexico Project area over a much longer period of time.

[9] Including irrigation well pumping on EBID lands, and also pumping for a few thousand irrigated acres in New Mexico that are not part of EBID, and that use exclusively groundwater for irrigation.
[10] Prior to 2009, in the absence of irrigation well meter data, Spronk (2019) estimates irrigation well pumping based on the difference between the farm demand (based on Consumptive Irrigation Requirement and estimated farm efficiency) and the reported delivery of surface water.

Figure 8. Total Reported Farm Delivery of Surface Water and Irrigation Well Pumping in NM LRG (2009-2018)

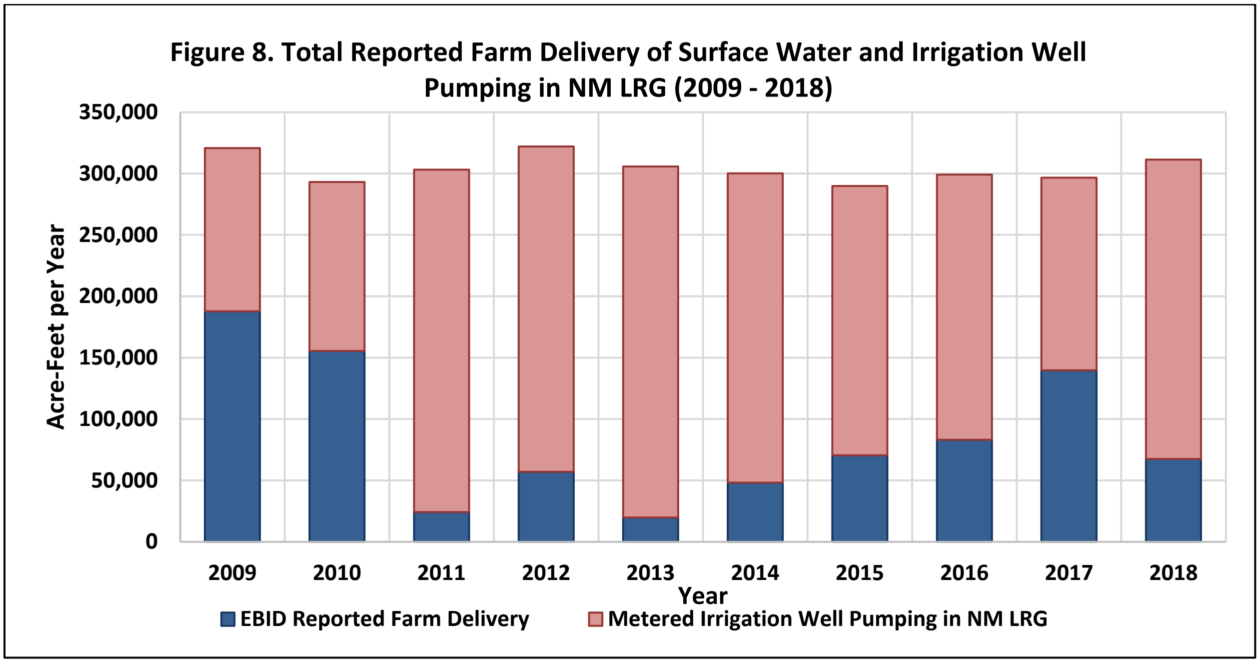
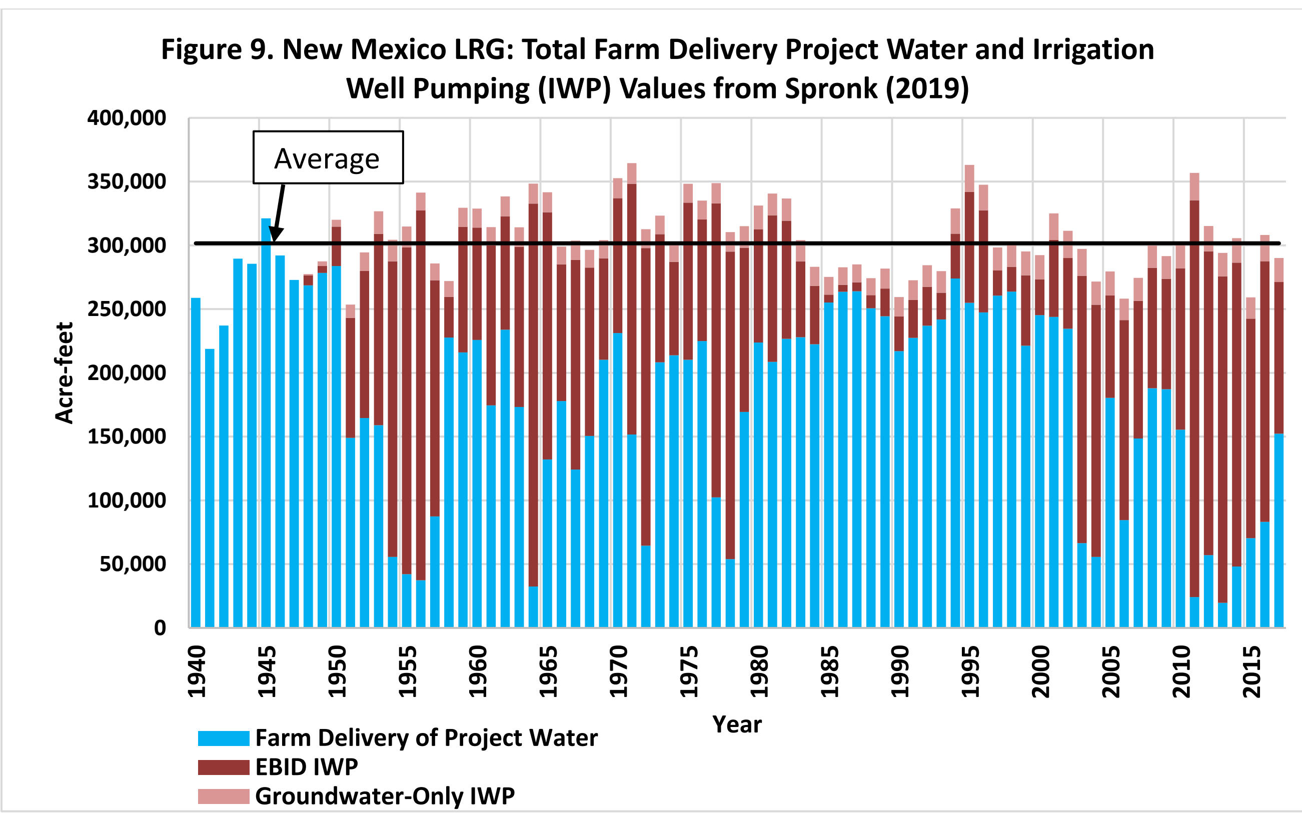


Figure 9. New Mexico LRG: Total Farm Delivery Project Water and Irrigation Well Pumping (IWP) Values from Spronk (2019)



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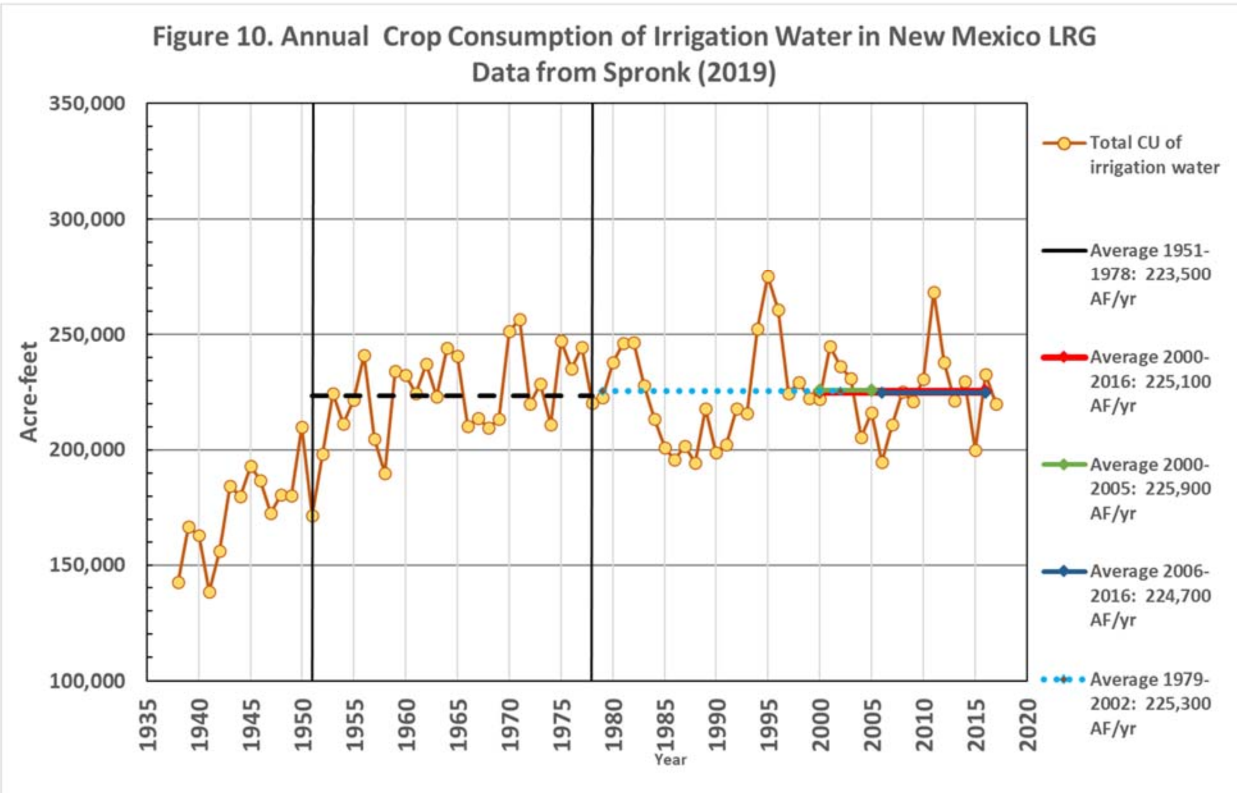
In Figure 10 I plot the total crop consumption of irrigation water calculated by the New Mexico experts, and summarized in Spronk (2019). This plot shows a relatively stable level of irrigation consumptive use in New Mexico over many years, and also shows how the "average" does not vary perceptibly based upon the range of years selected to average. Unlike irrigation well pumping, the level of agricultural depletions has remained relatively stable, and the average value obtained for different sub-periods does not differ by more than 2,000 acre-feet.

Figure 10. Annual Crop Consumption of Irrigation Water in New Mexico LRG Spronk (2019)



My conclusion, based on these data, is that total New Mexico irrigation demand is currently stable. New Mexico's best estimates (summarized in the Canal and Farm Budget spreadsheets produced by Spronk (2019) indicates that this demand has not increased over the demand occurring during the D2 period. While irrigation pumping does now occur during Project full-supply years, the estimated pumping amount did not systematically increase between 1979 (the end of the D2 period) and 2002 (the last full-supply years of a 24 year stretch of consecutive full-supply years). Variation in New Mexico irrigation pumping is driven by variation in EBID's Project water supply, and therefore recent levels of pumping in New Mexico are higher than they otherwise would have been because the 2008 Operating Agreement has reduced EBID's share of Project Supply. New Mexico's best estimates of the total consumption of irrigation water in New Mexico also indicates that the consumption of irrigation water in New Mexico has not increased compared with the D2 period.

These data do not support the contentions of Drs. Ferguson, King or Blair that the large reallocation of Project Supply effected by D3 Allocation is a necessary or appropriate response to increased levels of depletion or groundwater pumping in New Mexico. Deposition testimony by Drs. King and Ferguson show that the 2008 Operating Agreement itself was a compromise reached to in order to achieve settlement of a legal dispute; the 2008 Operating Agreement was a product of consensus, and was not founded in technical analysis.

R2. The United States Experts Claim that the D3 Method Allocation Adjustments are not Strictly Negative for EBID.

Dr. Ferguson states that the D3 Method *"increases EBID's annual diversion allocation compared with the "D1/D2 Method" in years when actual current-year Project delivery performance exceeds historical delivery performance as represented by the D2 Curve."* (Ferguson, page 4 paragraph 1 and page 10 first full paragraph)

Dr. Barroll Reply: Project delivery performance, as described by Dr. Ferguson, is a measure of the amount of water that can be delivered to District canal headings for a given release of water from Caballo Reservoir. In **theory** the D3 Method can increase EBID's diversion allocation compared with the "D1/D2 Method" when current-year Project delivery performance exceeds historical delivery performance as represented by the D2 Curve. Under the 2008 OA, if Project performance defined by the Diversion Ratio exceeds D2 Curve levels, EBID is awarded part of the surplus, while when Project performance falls short of D2 Curve levels, EBID must bear the entire shortfall.

In **practice** this has not actually benefitted EBID and is not likely to ever do so. Since 2006, Project performance defined by the Diversion Ratio has only exceeded D2 Curve levels one (1) time, in the year 2011. In that year, EBID's allocation was calculated by adding 12,325 AF (57% of the 21,708 AF Supply "surplus") to EBID's "D2 Current-Year Diversion Allocation." However under the 2008 OA, EBID's "D2 Current Year Diversion Allocation" is calculated using the "Usable Water Available for Current Year Allocation," which can be much smaller than the total amount of Usable Water in storage[11] because the Carryover Obligation,[12] has been subtracted. In the end of 2010, EPCWID's carryover account was 224,347 acre-feet, and this large amount of Carryover had a significant impact on allocation as

[11] Which was the historic starting point for calculation.

[12] Carryover Obligation is another creature of the 2008 Operating Agreement as fully explained in Barroll (2019) at Appendix D, page D21-D22. Each year, a District can now carry unused Allocation over into the next. Allocation is determined and measured at canal headings. In order to determine how much reservoir release will be required to deliver that amount of Carryover to canal headings in the following year, the total amount of Carryover is divided by the new Diversion Ratio to obtain the Carryover Obligation. Since the Diversion Ratios occurring since 2008 have mostly been less than 1.0, this means that the Carryover Obligation is greater than the amount of Allocation carried over. Under the order of operations in the Allocation spreadsheet, this Carryover Obligation is subtracted off from the Usable Water before determining Current-Year Allocations.

described in Barroll (2019), Appendix D, Section 2.4, and in this report, Section R6. In essence, approximately 60,000 of off-season inflows to Elephant Butte had to be dedicated to making up for the paper part of EPCWID's Carryover Account and Carryover Obligation, reducing the amount of reservoir water available for "Current-Year Allocation" by that same amount.

If the historic 57:43 allocation had been applied to the entire amount of Project water available in 2011 ("Total Usable Water Available for Release" in the allocation spreadsheet) EBID would have been allocated far more water than they were allocated under the D3 Method, even including the additional 12,325 AF. I estimate that if the total Usable Water available in 2011 (426,821 AF) had been allocated according to the historic 57:43 split between EBID and EPCWID, EBID would have been allocated approximately 195,000 AF[13], as compared with the 77,000 AF that EBID was actually allocated under the D3 method in that year. I also estimate that if the D3 Method had been applied to the total Usable Water, with no reduction for Carryover, EBID would have been allocated 148,000 AF, still much more than the amount EBID was allocated (77,000 AF) using the D3 Method with Carryover.

The predictable effect of this reduced allocation on EBID was an increased need for groundwater pumping. In 2011 metered groundwater pumping in New Mexico was 303,000 AF. If EBID's allocation had been 195,000 AF, using Figure 7 I estimate that irrigation pumping in New Mexico would have been 209,000 AF, approximately 2/3 (two-thirds) of the actual amount.

Furthermore, the extra water EBID received in 2011 as a result of Project performance exceeding D2 levels was only 57% of the amount of extra supply associated with this performance level.[14] This is in contrast to what happens when Project performance **falls short** of D2 levels. When Project performance is below D2 levels, EBID's allocation under the D3 method is reduced by the **entire** supply deficit. For example, in the full-supply year of 2008, D3 allocation reduced EBID's allocation by 170,000 AF, the full amount of the negative departure from the D2 Curve; in full-supply year 2017, D3 allocation reduced EBID's allocation by 227,000 AF.

The largest allocation changes associated with the D3 method occur in these full-supply and near full-supply years. In such years it would be necessary for the Diversion Ratio to exceed 1.2 in order for EBID to obtain the touted benefits of a D3-method allocation higher than the D2 allocation. This is extremely unlikely to ever happen. One of the factors that makes this prospect so unlikely is the change in accounting that has occurred since the D2 period (1951 – 1978) by which significant components of water diverted by EPCWID which formed part of the D2 data set are no longer counted as part of its

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[13] I calculate Project Supply for 2011 as total Usable Water (427,000 AF), adjusted by the Diversion Ratio (0.87). Then I subtract Mexico's share (calculated as 26,000 AF using the D2 curve) and split the remainder 57:43. Using this calculation, I find that New Mexico's 57% share would be 0.57 × [427,000 AF × 0.87 – 26,000 AF] = 195,000 AF.

[14] When Project performance exceeds D2 levels, EBID's Diversion Ratio allocation is greater than its D2 allocation. Under these circumstances, EBID is awarded its D2 Allocation plus either 57% of the difference between the D2 allocation and the Diversion Ratio allocation if Current Usable Water is below 600,000 AF, or 100% of the difference between the D2 allocation and the Diversion Ratio Allocation if Current Usable Water exceeds 600,000 AF. This is in opposition to what happens when the Project Performance is below D2 levels, in which case EBID is always awarded its Diversion Ratio allocation, and thus is always docked for 100% of the difference between the D2 allocation and the Diversion Ratio allocation.

charged diversion, and therefore are not part of the Diversion Ratio calculation. These components include City of El Paso effluent in the El Paso Valley, off-season diversions[15] and El Paso Valley drain flow.

For a concrete example, I include my analysis of 1969 Project diversions,[16] which are a part of the D2 data set. This analysis is also set forth in Barroll (2019), pages 57 through 60. In Table 2 I show the results of my analysis of 1969 diversion. The column labeled “WDR Values” shows the diversions obtained from those Reclamation records from 1969, and Mexican Diversion and Caballo release data. The total of these diversions, 802,000 AF, is part of the D2 data set. When this value is divided by the Caballo release of 667,700 AF a contemporaneous “Diversion Ratio” of 1.2 is calculated.

The next column in Table 2 breaks down those WDR diversions into some of their component parts: (a) the amount of the WDR diversion occurring outside of the Project release season, (b) the amount consisting of El Paso Valley drain flows, and (c) the estimated amount of accounted diversion that would be reduced by other accounting credits, if current accounting methods had been used in 1969[17].

The next column (Estimated Charged Diversions using Post-1979 Accounting) takes the 1969 WDR data and subtracts off the diversion components that would not have been included under current accounting protocols ((a) off-season diversions, (b) El Paso Valley drain flows, and (c) the net effect of credits). The resulting “1969 Charged Diversion”, estimated using current accounting methods is only 727,708 AF, a reduction of 74,292 AF from the Total WDR Diversion. The Diversion Ratio that is calculated using the “1969 Charged Diversion” is [727,708/667,669] which equals 1.09. **Therefore even the diversion data from 1969, a year from the D2 period which actually falls directly on the D2 Curve, falls well below the D2 Curve when employing current accounting methods**. This effect of changes in accounting makes it extremely unlikely that the Diversion Ratio calculated for any future year using current accounting procedures will ever exceed the “D2 delivery performance predicted by the D2 Curve” and thus the benefit to EBID claimed by Dr. Ferguson is a chimera.

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[15] Off-season diversions are diversions occurring at times when there are no releases being made from Caballo Reservoir, typically because it is outside of irrigation season. Historically, up to about 40,000 AF of off-season diversions were made during the D2 period (1951 – 1978), largely by EPCWID, (Barroll, 2019 Appendix E, Table E.7). These diversions were included in the D2 data set that is now used to determine EPCWID’s allocation. Such off-season diversions are no longer charged or accounted as Project water.

[16] I chose 1969 for analysis for two reasons: 1) the 1969 release and diversion data point lies on the D2 curve, 2) there is a recent year (2008) with almost exactly the same Reservoir release that can be readily compared with 1969. Analysis of other years during the D2 period provided similar results.

[17] The effect of other accounting credits is estimated by analysis of data from 2008, a year of approximately the same release from Caballo, in which current accounting methods have been applied.

Table 2. Analysis of 1969 WDR Diversions

Table 2. (Modified Table 7.1 from Barroll (2019) Components reordered, Calculated Diversion Ratio added). Analysis of 1969 WDR Diversions				
	WDR Values *	WDR Values broken down by Component	Estimated Charged Diversion using Post-1979 Accounting	Difference in Total Accounted Diversions: WDRs vs. Post-1979 Accounting
EBID Diversion	421,000	404,000	404,000	17,000
EPCWID Diversion	321,000	263,708	263,708	57,292
(a) Off-Season Diversions		38,000		
(b) EPV Drain to Canal		2,292		
(c) Estimated Post-1979 Credits EBID **		17,000		
(c) Estimated Post-1979 Credits EP#1**		17,000		
Mexico	60,000	60,000	60,000	
Total Accounted Diversions	802,000	802,000	727,708	74,292
Caballo Release	667,700	667,700	667,700	
Diversion Ratio	1.20		1.09	
* WDR Values adjusted so that Mesilla Dam Diversions are split between the Districts Pro-Rata				
** Total Estimated Post-1979 Credits calculated as the difference between total diversions and charged diversion in 2008, a year of similar water supply to 1969. This total was split 50:50 between EBID and EPCWID				

Next, Table 3 shows the effect such a difference in Diversion Ratio would have on EBID's allocation under the D3 method. A Diversion Ratio of 1.2 would result in a D3 allocation to EBID of 480,000 AF, while the Diversion Ratio of 1.09 (calculated using "1969 Charged Diversion") would result in a D3 allocation of only 396,000 AF. In this example, this difference in accounting method to calculate the Diversion Ratio results in 84,000 AF less water to EBID than calculating a Diversion Ratio from the same type of Water Distribution Report data and accounting methods that were used to develop the D2 curve.

Table 3. Illustration of the Effect of Variation in the Diversion Ratio

Table 3. Illustration of the Effect of Variation in the Diversion Ratio Example			
Compare D3 Allocation with Diversion Ratio Calculated Using WDR Diversions, to D3 Allocation with Diversion Ratio Calculated Using Post-1978 Accounting			
(Values rounded to nearest 1000 AF)			
	D3 Allocation		**Difference**
Diversion Ratio (unitless)	1.20	1.09	0.11
Usable Water (AF)*	764,000	764,000	
Mexican Allocation (AF)	60,000	60,000	
EPCWID's Allocation (AF)	377,000	377,000	0
EBID's Allocation (AF)**	480,000	396,000	-84,000
* 1969 was a full-supply year (final allotment = 3.0 AF/A) and so I assume the amount of Usable Water available to the Project that year is at least 764,000 AF.			
** Calculation: EBID's Allocation = (Usable Water x Diversion Ratio) – Mexican Allocation – EPCWID Allocation]			

R3. TEXAS AND THE UNITED STATES CLAIM EPCWID'S SHARE OF WATER UNDER THE D3 METHOD APPROXIMATES ITS SHARE UNDER D2 ALLOCATION.

Dr. Blair contends (in his 10th Opinion, on page 8, last sentence) that the D3 Method is "*a reasoned attempt to return EPCWID's share of the Project Water supply to the amounts based upon the 1951-1978 conditions represented by the D2 Curve.*"
Dr. Ferguson states in his opinion in the middle of page 6 "*The annual allocation to EPCWID may be greater under the 'D3 Method' than under the 'D1/D2 Method' only in years when the Usable Water available for current-year allocation is between 763,842 acre-feet and 790,000 acre-feet. In all other years, the annual allocation to EPCWID under the 'D3 Method' is the same or less than under the 'D1/D2 Method.' During multi-year droughts, the annual allocation to EPCWID is less under the 'D3 Method' due to the Drought Correction Factor in the OA.*"
Also Dr. King in his 3rd opinion, page 7, states "*Under the D3 Allocation, deliveries to EPCWID and Mexico are consistent with historical conditions*."

Dr. Barroll Reply: The 2008 OA allocation procedures do not "return EPCWID's share of Project Water supply to the amounts based on the 1951 – 1978 conditions represented by the D2 Curve," nor do these three US experts provide any data supporting their conclusory contentions. Rather, the 2008 OA results in EPCWID getting a much larger share and larger amount of water under similar conditions than at any time during the D2 period.

While EPCWID's D3 allocation amount is based on the D2 Curve, changes in Project Accounting since the D2 period allows EPCWID to divert and use more Project Water than EPCWID received during the D2 period. The D2 Curve includes off-season diversions, and the diversion of El Paso Valley drain flow and effluent (items a, b, and c in Table 2). See Barroll (2019), section 7. EPCWID's D2 allocation is based on its past diversion and use of that water. Current Project accounting does not charge EPCWID for diversion or use of these sources of water (i.e. off-season diversions, and El Paso Valley drain flows and effluent), and so EPCWID is now entitled to divert its D2 share **plus also use** any off-season flows, El Paso Valley drain flows, and municipal effluent **free of charge.**

The addition of the Multi-Year-Drought Correction Factor to the Operations Manual in 2012 was a welcome admission by the Districts and Reclamation that the original 2008 OA was too extreme in its reallocation of Project water away from EBID during severe drought conditions. Even with that change, however, EBID's Total Allocation in these drought years is less than 57% of the water allocated to the Districts. Furthermore, this one change does not alter the much larger reallocation of Project water away from EBID during full-supply years.

Furthermore, in full-supply years, EPCWID's Current-Year Allocation (excluding Carryover) has been as high as 405,000 AF (Barroll (2019) Table A.10). This is a significant increase from EPCWID's full-supply allocation prior to 2006 of 376, 862 AF. This comparison does not even take include the effect of Carryover, which has increased EPCWID's Total Allocation to over 500,000 AF in some years.

As a result of this, and the large reductions in EBID's allocations, **EPCWID now gets a far larger share of Project water than ever before.**

R4. The United States Arbitrarily Minimizes the Effects of Texas Groundwater Pumping in the Mesilla Basin, and Equates the Reallocation of the Operating Agreement with New Mexico Pumping Effects Based on Unproven Assumptions.

Drs. Ferguson and King contend that groundwater pumping in the Rincon Basin by New Mexico and in the Mesilla Basin by both New Mexico and Texas impact the surface water supply, and can impact the operations of the Rio Grande Project. Dr. Ferguson suggests that Texas pumping in the Mesilla Basin is relatively small compared to the amount pumped by New Mexico. Furthermore, Dr. Ferguson suggests that the effects of Texas Mesilla Basin pumping on the Project do not need to be considered in Project allocation because Texas pumping in the Mesilla Basin has not increased substantially (<10%) since the D2 period (1951 – 1978) (see Ferguson pages 3 and 11).

<u>Dr. Barroll Reply:</u> I agree that groundwater pumping in the Mesilla Basin by both New Mexico and Texas impacts the surface water supply and can impact the operations of the Rio Grande Project by depleting the flows of surface water features. I also agree with Dr. Ferguson that the total amount of Texas groundwater pumping in the Mesilla basin is less than the total amount of New Mexico groundwater pumping in the Rincon and Mesilla Basins. However, because little meter data is available from Texas, the exact relationship between the pumping amounts can only be estimated. Texas irrigation well pumping in the Mesilla Basin can be estimated based on irrigation demand calculations for the Texas Mesilla lands. There is no recent data on commercial or industrial pumping in the Texas Mesilla.

Groundwater pumping can impact the flows in streams or other surface water features (such as drains and canals) by lowering the groundwater table in the vicinity of that surface water feature. The effect is either to intercept groundwater that would otherwise have discharged into that stream, or to increase the amount of seepage from that stream into groundwater. These negative impacts can be offset by the effects of return flow associated with the groundwater pumping such as effluent from a municipal use or deep percolation associated with use of wells for irrigation. The net impact of all these factors is the stream depletion associated with the groundwater pumping.

In theory, if the top of the groundwater surface (the water table) is sufficiently deep below the base of the stream, the rate of seepage from that stream achieves a maximum amount and will no longer increase as a result of additional pumping. When additional groundwater pumping has no additional effect on stream flows, that is referred to as hydrologic disconnection; that is to say, the stream is disconnected from the water table or aquifer. This has happened in the El Paso Valley, and occurs intermittently within the Mesilla Basin. Where stream disconnection occurs, the impacts of groundwater pumping can be displaced onto other streams or other, connected parts of the same stream. In addition, the impacts of groundwater pumping on disconnected parts of stream system can be delayed, depleting stream flows long after pumping has ceased.

In this situation, if adjustment to the Project Allocation is justified by reference to increases in pumping or increases in stream depletion caused by pumping, these adjustments should be based on technical analysis of the actual amounts of increase in pumping or stream depletion. At present, EBID's allocation is adjusted downward by the entire negative departure from the D2 Curve, resulting in decreases in EBID's allocation as great as 227,000 AF (in 2017[18]). The magnitude of this reduction is not supported by any comparable estimates of increases in New Mexico groundwater pumping or increases in depletion within New Mexico**.** For more details on comparison of estimated pumping and depletions between the D2 period and recent years, see section R1 above. None of the U.S. experts has provided any technical evidence quantifying the increase in groundwater pumping or depletions in New Mexico that support this massive downward adjustment of EBID's allocation. Nor can Dr. Ferguson's assertion that Texas Mesilla pumping has increased less than 10% be the basis for completely discounting any impacts of Texas Mesilla pumping. There is no scientific or technical basis to use a 10% increase in pumping, or a 15% increase, or a 5% increase as the standard for evaluation of impacts.

[18] This value is obtained by subtracting EBID's allocation in 2017, a full supply year, from the allocation EBID was given in full-supply years prior to 2006. EBID's allocation in 2017 was 267,523 AF, while before 2006 EBID's full-supply allocation was 494,979 AF. The difference between these two values is 227,456 AF.

R5. WITHOUT FULL EXPLANATION OR TECHNICAL ANALYSIS, THE U.S. MINIMIZES THE EFFECTS OF GROUNDWATER PUMPING IN THE HUECO BOLSON

Dr. Ferguson indicates that groundwater pumping in the Hueco Bolson has no impact on Project operations. In Dr. Ferguson's first opinion (under heading A, on page 3) he cites modeling results by New Mexico experts and "*the construction of the American Canal Extension ("ACE"), which eliminates the effects of groundwater/surface-water interactions on Project deliveries in the El Paso Valley.*" Dr. King (page 10) also appears skeptical that pumping in the Hueco can impact Project operations.

Dr. Barroll Reply: Current pumping in the Hueco Bolson aquifer probably has little ***additional*** impact on current Project Supply. However, the United States ignores why this is so. Groundwater pumping by Texas and Mexico in the Hueco Bolson has caused over 100 feet of drawdown in a large area[19] and largely disconnected the Hueco Bolson aquifer from the surface water system in the upper El Paso Valley. While current pumping can no longer increase stream depletions in a disconnected stream, that does not change the fact that earlier groundwater pumping increased stream losses until these losses reach their maximum rate and actually disconnected the Rio Grande from its aquifer so that it no longer acts as an integrated stream system.

Historical pumping in the Hueco Bolson reduced Project Supply in the El Paso Valley through:

a. depleting drain flows that had been part of Project Supply, and
b. increasing seepage losses from the canals, laterals and the Rio Grande.

Thus, pumping by Texas in the Hueco Bolson depleted the part of Project Supply that had historically originated in the Hueco Bolson, that had been historically relied upon for Project delivery. Depletions to EPCWID surface flows upstream of Project delivery points force Reclamation to release more water in order to meet orders for Project water. These increased releases reduce the reservoir supply available for subsequent allocation to the Districts, including EBID. Texas pumping reduced Project efficiency and performance in the El Paso Valley below the levels obtaining at the time of the signing of the Rio Grande Compact and conditions obtaining during the D1/D2 period (1951-1978). ***In short, Texas disconnected its aquifer through over-pumping and thereby substantially altered the sources of Project Supply, increasing its need for releases from the Reservoir, and now requires New Mexico to pay for Texas's own behavior.***

Sources of Project Supply arising in the Hueco include El Paso Valley drain flows generated above Fabens. The 1938 Rio Grande Joint Investigation noted that 57% of the water diverted at Fabens (Tornillo Canal) consisted of drain flow, while on 35% of the water diverted upstream at Franklin consisted of drain flow. The difference between those two percentages represent drain flows generated within the El Paso Valley itself, between Franklin and Fabens, that were diverted into Tornillo Canal. Diversion and use of this El Paso Valley drain flow by the Project continued after the Compact was signed, as reported in Reclamation drainage and diversion records as "Drain to Canal" diversions (Barroll (2019), Appendix C). During the D1/D2 period (1951 – 1978), up to 30,000 AF/yr of water was diverted

[19] See the dramatic interactive representation contained in Expert Report of Charles P. Spalding and Daniel J. Morrissey, McDonald Morrissey Associates, LLC, October 31, 2019, hereinafter MMA (2019), at Appendix Q.

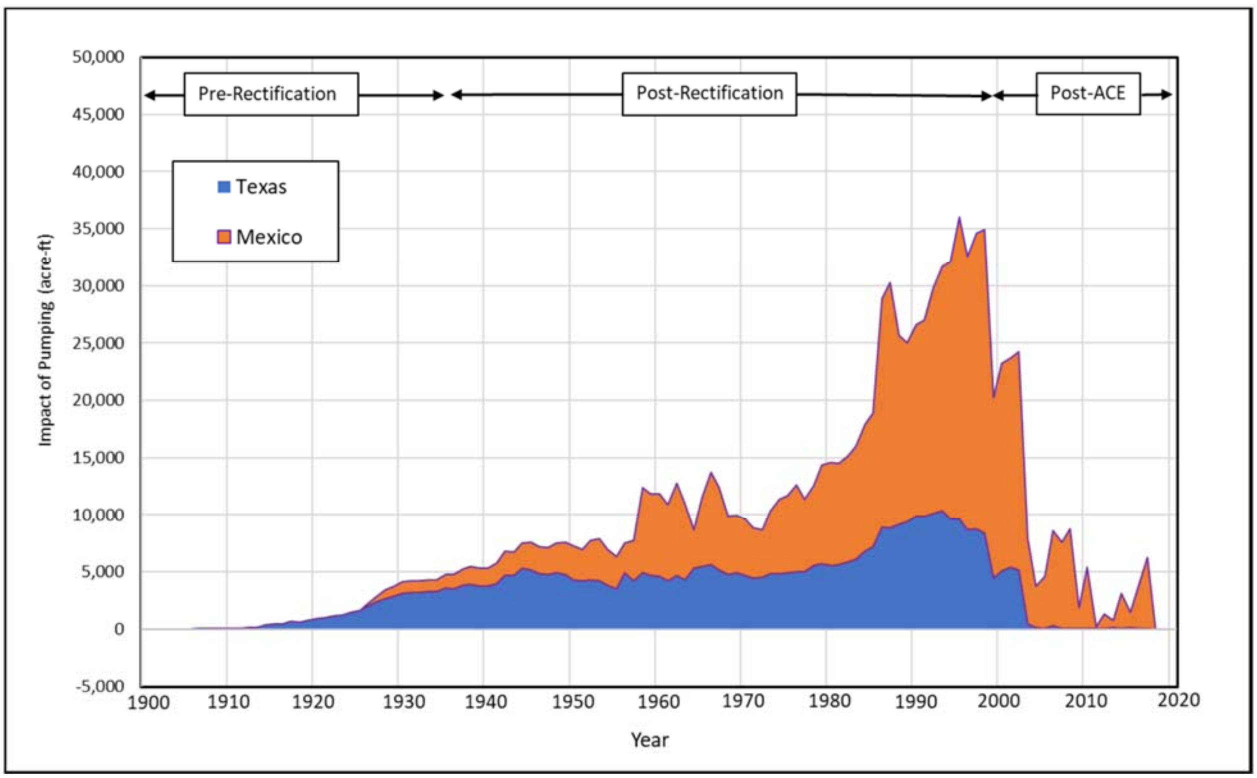
from the River Drain into the Riverside Canal Extension for delivery to the Tornillo Canal Heading in EPWCID.

A description of EPCWID's historical use of El Paso Valley drain flows can be found in Kirby (1994). Kirby was an engineer with the Project starting in 1949, and he served as Project Superintendent from 1966 until his retirement in 1980. As a consultant to EBID in 1994, Kirby wrote:

> *It is my remembrance that this admission [of the Tornillo Division into the Project] was only agreed to by EBID provided that the Tornillo Division would divert and use, as part of their water supply, the drain waters that accumulated into a collection channel at Fabens. There was a pumping station at this location later changed to a gravity diversion that moved water into the Tornillo Canal.* (Emphasis in the original)

The effects of Hueco pumping on the surface water system in the El Paso Valley is simulated by New Mexico's Hueco Model (MMA (2019), Figure 9.2 and 9.3), which shows increasing seepage losses in the reach of the Rio Grande between American Dam and Riverside from about 10,000 AF/yr in 1938 (when the Rio Grande was rectified) to about 40,000 AF/yr in the years before the American Canal Extension bypassed this reach of the river in 1998. Further analysis by MMA (2019) (MMA Figure 9.5, reproduced here as Figure 11) indicate that between 1940 and 1998 impacts to the Rio Grande caused by Texas and Mexico pumping increased by almost 30,000 AF/yr, and between 1980 and 1998 impacts to the Rio Grande caused by Texas and Mexico pumping increased by almost 20,000 AF/yr. That is, the El Paso Valley pumping was drawing down the groundwater table further and further such that surface water from the river – Project Supply – was seeping into the riverbed at a greater and greater rate.

Figure 11. (MMA (2019) Figure 9.5) Graph showing impact of pumping by Texas and Mexico for the Rio Grande from American Dam to the Riverside Diversion for the non-reoperated runs, 1903 to 2017



This effect of this Hueco pumping increasing the seepage from the Rio Grande in the El Paso Valley is described in Blair (2000),[20] who cites a USGS study indicating the "withdrawals from the Hueco for El Paso and Juarez … may have caused seepage to increase from 15,000 ac-ft/year in 1968 to 39,000 ac-ft/year in 1992." That is: Hueco pumping increased seepage loss from the Rio Grande by 24,000 AF per year from 1968 to 1991, thereby increasing the amount of water lost to the Project. Dr. Blair also cites a 1975 joint USGS/Texas Water Development Board study by Meyer suggesting that as a result of groundwater pumping "*the Rio Grande between American and Riverside dams changed from a gaining reach to a losing reach between 1936 and 1948.*" Modeling by New Mexico experts MMA (2019) does not support the conclusion that the Rio Grande actually gained water (i.e. the flow in that stretch of the river was augmented by inflow from groundwater) in the reach above Riverside Dam during the 20th century, but it does support the conclusion that losses from that reach increased due to groundwater pumping in the Hueco Bolson by Texas and Mexico.

The effect of Hueco groundwater pumping was to reduce the Project delivery efficiency in the El Paso Valley, and thereby reducing the total Project Supply. Since 1938, there have been changes in the El Paso Valley that act to partially mitigate these negative effects. The discharge of El Paso municipal effluent into EPCWID's conveyances largely offsets the effect of El Paso municipal pumping on EPCWID itself. However, this effluent is not considered Project water,[21] and use of the effluent by EPCWID is not charged against its allocation. Another mitigating change was the construction of the American Canal Extension (ACE) which allows EPCWID to bypass the bed of the Rio Grande when delivering water to the Riverside heading, avoiding the Rio Grande seepage losses caused by groundwater pumping in Texas and Mexico. However, EPCWID is then awarded a credit (the ACE Credit) for this bypass operation, and so gets a credit for resolving a problem that Texas helped create. In effect, municipal effluent and the ACE help to mitigate the effects of Hueco pumping on EPCWID, but the failure to treat this effluent as Project water, and the imposition of ACE Credit, act to the detriment of EBID.

The problems caused by the ACE Credit will be discussed in more detail in Section R8.

R6. THE UNITED STATES IGNORES THE REAL EFFECT OF CARRYOVER UNDER THE 2008 OA

Dr. Ferguson argues that Project Allocations, and thus Carryover Allocations, do not represent water in Project Storage, and therefore there is no need to reduce Carryover to reflect evaporation losses (Ferguson (2019), second half of page 14).

[20] Blair, A. W. 2000, page 8 of 18. *Salvage of Water in El Paso County Water Improvement District No. 1 Canal System.* Prepared for District No. 1, Draft Report, January 26, 2000. Al Blair is the long-time consulting engineer to both EPCWID and Hudspeth County Conservation and Reclamation District No. 1 ("HCCRD), and is another non-retained expert proffered by the United States.
[21] See Barroll (2019), at page 49-50 and D-25, D-26, and Section R7 of this report for a complete discussion of this anomaly.

<u>Dr. Barroll Reply:</u> Dr. Ferguson misses the points I fully explained in Barroll (2019) at pages D-21 through D-23. While Project allocation is not strictly equivalent to water in Project storage, Project allocations are ***supplied*** by Project storage. Part of the problem in the Project operations in 2011 was that unused allocation under the 2008 OA is now allowed to be "carried over" without reference to the water in Project Storage, and without reference to the physical processes such as evaporation that impact storage. As a result, in the 2010-2011 time frame, the amount of Carryover allocation (that is, allocation calculations on paper) exceeded the amount of Usable Water in storage (that is, actual wet water), and over 60,000 AF of the inflows during that very dry winter went directly into "liquifying" the paper water in the Carryover accounts, 90% of which belonged to EPWCID. As a result, there was 60,000 AF less water available for that current-year allocation, and EBID's allocation suffered proportionally. The data supporting this conclusion is shown in Table 4, reproduced from Appendix D of Barroll 2019.

Table 4. 2010-2011 Example of New Inflow to Reservoir Needed to Fulfill Existing Carryover Accounts and Obligation. Reproduced from Barroll, 2019, Table D.4.

Table D.4. 2010 – 2011 Example of New Inflow to Reservoir Needed to Fulfill Existing Carryover Accounts and Obligation

2010 - 2011 Example of when Carryover Accounts Required Additional Inflows			
		Storage, Carryover and Credit Conditions as of October 15 2010	Storage, Carryover and Credit Conditions as of January 1, 2011
Total Water in Reservoir Storage	(AF)	386,735	497,789
CO Compact Credit	(AF)	800	2,700
NM Compact Credit	(AF)	100,500	164,700
San Juan Chama Water	(AF)	60,796	64,250
Usable Water In Storage	(AF)	224,639	266,139
EBID 2010 Unused Allocation (Carryover from 2010 to 2011)	(AF)	20,014	
EBID 2010 Unused Allocation (Carryover from 2010 to 2011)	(AF)	224,348	
Total Carryover (Carryover from 2010 to 2011)	(AF)	244,362	
Diversion Ratio	(unitless)	0.98	0.85
2011 Carryover Obligation (divide total Carryover by 2011 Diversion Ratio	(AF)		287,485
Inflows after October 15 required to fulfill Carryover Obligation			62,846

Furthermore, EPCWID's allocation in full-supply or near full-supply years exceeds EPCWID's Project demand by approximately 100,000 AF/yr. That is, in full supply years, EPCWID's current-year allocation including ACE credit has been approximately 400,000 AF. In these years, and other years in which EPCWID's total allocation has exceeded 400,000 AF, (2007 through 2010) the amount of Project EPWID has ordered, and had charged against its allocation has averaged 295,000 AF, approximately 100,000 AF less than it's full-supply allocation.[22]

It is true that eventually EPCWID may make use of the allocation carried over on paper in subsequent low-supply years. However, historically the Project was operated on an annual basis, as was the case when the Compact was negotiated and signed, and the water in Project storage associated with any unordered allocation or allotment "returned to the pool" and was available for allocation proportionally to both Districts the following year. This changed in 2006, when EPCWID convinced Reclamation to institute Carryover allocation. Now any unused allocation is carried over for EPCWID into the following year, and that amount of water plus the additional water needed to deliver it,[23] is subtracted from the total Usable Water early in the allocation process, when calculating the amount of "Total Usable Water Available for Current Year Allocation". The amount of water available for current-year allocation consists of the Usable reservoir water that remains **after** this Carryover Obligation has been subtracted.

The Carryover Obligation is calculated as the total Carryover divided by the Diversion Ratio. This introduces its own effect. Typically, Carryover is accumulated in high-supply years, when the Diversion Ratio tends to relatively high (0.9 - 1.0). Carryover is then used in lower supply years, when the Diversion Ratio is typically much lower (0.6 – 0.8). Dividing the total Carryover by a smaller Diversion Ratio leads to an even higher Carryover Obligation. Thus, a large amount of Carryover requires an even larger amount of Carryover Obligation, which is subtracted out before any calculation of Current-Year Allocation begins. Another way of looking at this is that delivery of an allocation amount in a good-supply year requires release of reservoir water that is approximately equal to that allocation amount. When the same amount of allocation is Carried over to a low-supply year, a significantly greater amount of reservoir release is going to be required to deliver it. That extra release is taken out of the water available to the other District.

No adjustment is made to Carryover accounts for evaporation, which further aggravates this problem.[1] A rough estimate of the amount of evaporation associated with EPCWID's Carryover in 2010 can be obtained by looking at the Rio Grande Compact Commission (RGCC) determination of Compact Credit evaporation during that year (in Compact Accounting, evaporation is applied pro-rata to Compact Credits, San Juan Chama water, and Usable water pools). According to the 2010 Report of the RGCC,[24] New Mexico had 180,500 AF of Compact Credit in Elephant Butte that year, and the RGCC determined that 20,800 AF evaporation were associated with that Credit. EPCWID started 2010 with a Carryover balance of 232,914 AF, and ended 2010 with 224,347 AF, effectively maintaining a Carryover balance of 224,347 AF throughout the entire year. Presumably, the evaporation associated with that amount of water would have exceeded the 20,800 AF associated with 180,500 AF of Compact Credit water.

Because no adjustment is made to reduce the Carryover obligation for the effects of evaporation, or the effects of "paper water" allocation, of the amount of water available for current year allocation is

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[22] The data used to make this calculation can be found in Barroll (2019) Appendix A, Table A.14.
[23] The "water needed to deliver" the Carryover depends on the Project Performance in the following year, and is calculated by dividing the amount carried over by the Diversion Ratio.
[24] RGCC 2010 Annual Report, Records of Releases and Deliveries, page 5.

further reduced. This reduction negatively impacts EBID more than EPCWID because EBID is not able to take advantage of Carryover to the extent that EPCWID can and does.[25]

R7. Texas Employs Technicalities to Avoid Being Charged for their Diversion and Use of the Municipal Effluent Component of Project Supply

Dr. Ferguson (last full paragraph of Page 9) and Dr. Blair (Opinion # 11, page 9) state that EPCWID is not charged for its diversion and use of treated municipal effluent, including effluent that has its origin in the diversion and use of Project Supply, because that effluent does not meet the definition of Project Water in Section 1.6 of the 2008 OA; that is, because that water does not *"reach the bed of the Rio Grande."*

Dr. Barroll Reply: Nothing in the opinions by Drs. Ferguson or Blair changes my opinion that the Project should charge EPCWID for the diversion and use of all municipal effluent by EPCWID and its members. The restrictive interpretation of Project Water -- and thus Compact water – applied by Texas to El Paso Valley effluent has resulted in a significant and one-sided change to Project accounting. The fact that the Project **currently does not** charge EPCWID for the diversion and use of that effluent constitutes an important change in Project accounting and is a direct cause of part of the current negative departure of Project performance from the D2 Curve.

At the present time, EPCWID is **not charged** for the diversion and use of an average of 24,000 AF/yr of treated effluent discharged from the City of El Paso wastewater treatment plants ("WWTPs") in the El Paso Valley during the Caballo release season.[26]

The El Paso Water Utility ("EPWU") obtains Project water for municipal use through EPCWID pursuant to several contracts between El Paso or EPWU, Reclamation, and EPCWID.[27] EPWU diverts its part of

[25] EBID makes less use of Carryover because EBID's allocation under the D3 Allocation Method is insufficient to meet its irrigation demand, even in years when the Project has a full supply. See Barroll 2019, page 71.

[26] The total annual discharge of El Paso Valley effluent into EPCWID conveyances is even greater, but current Project Accounting does not charge for the diversion and use of **any water** unless releases from Caballo are in progress or have recently ceased. Off-season diversions, however, were included in the D2 Curve, which is the standard against which current Project Performance is measured. The elimination of off-season diversion accounting itself constitutes part of the current discrepancy from D2 as demonstrated in Barroll 2019 Section 7 and Appendix E.

[27] All City of El Paso surface water treatment plants (WTPs), which divert water from the Project (and prepare it for human and other municipal use) and WWTPs (which treat municipal water after its use and discharge that effluent into the Project) are operated by El Paso Water Utility.

EPCWID's allocation during the Caballo release season at two water treatment plants: Robertson/Umbenhauer[28] and Jonathan Rogers.[29] These diversions are charged to EPCWID in Project Accounting. EPWU also pumps groundwater in the Hueco Bolson, but Project water constitutes the larger part of its supply in the El Paso Valley part its system, and therefore most of EPWU's El Paso Valley effluent originates as Project Supply. This effluent should most certainly be characterized as return flow from a Project beneficiary, and the diversion and use of this water should be charged to the Project beneficiaries as any other Project return flows would be.

Starting in 1923, and for many years, all of the City of El Paso's municipal effluent was discharged from the Haskell R. Street WWTP into the Rio Grande above Riverside. EPCWID's diversion of Haskell R. Street WWTP effluent water at the Riverside heading was consistently counted as part of Project Supply until 1999, when the newly built ACE intercepted Haskell R. Street WWTP effluent before it reached the "bed of the Rio Grande."

Additional WWTPs in the El Paso Valley (Socorro, superseded by Bustamante) came online starting in the late 1960's, and these plants discharged water into EPCWID's Riverside Canal. This use of the effluent from these WWTPs was apparently not ever charged against EPCWID's allocation.

EPWU operates another WWTP in the southernmost Mesilla Valley which treats and discharges effluent that largely originated as groundwater pumped by the Canutillo well field in Texas part of the Mesilla Valley. The diversion and use of this effluent **is** charged as Project Supply, and this effluent is used in Project Accounting as an offset against the stream depletion effects of Canutillo pumping. The treatment in Project Accounting of effluent from this WWTP is not at issue.

The amounts of treated effluent discharged from the El Paso Valley WWTPs into EPCWID conveyances, both during the Project release season, and for the entire calendar year, are tabulated in Table 5.

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[28] Robertson/Umbenhauer Water Treatment Plant (aka the Canal Street Water Treatment Plant) was initially opened in 1943 and expanded in 1967. "The plant treats Rio Grande water to drinking water standards during the irrigation season (March-September) for distribution to customers. The plant can also blend and treat water pumped from wells during the non-irrigation season." https://www.epwater.org/cms/one.aspx?portalId=6843488&pageId=7421580.)

[29] Jonathan Rogers Water Treatment Plant became operational in 1993 and expanded in 2002. "This plant, along with the Robertson/Umbenhauer Water Treatment Plant operates during the seven-month irrigation season when Rio Grande Project water is available." https://www.epwater.org/cms/one.aspx?portalId=6843488&pageId=7421563.)

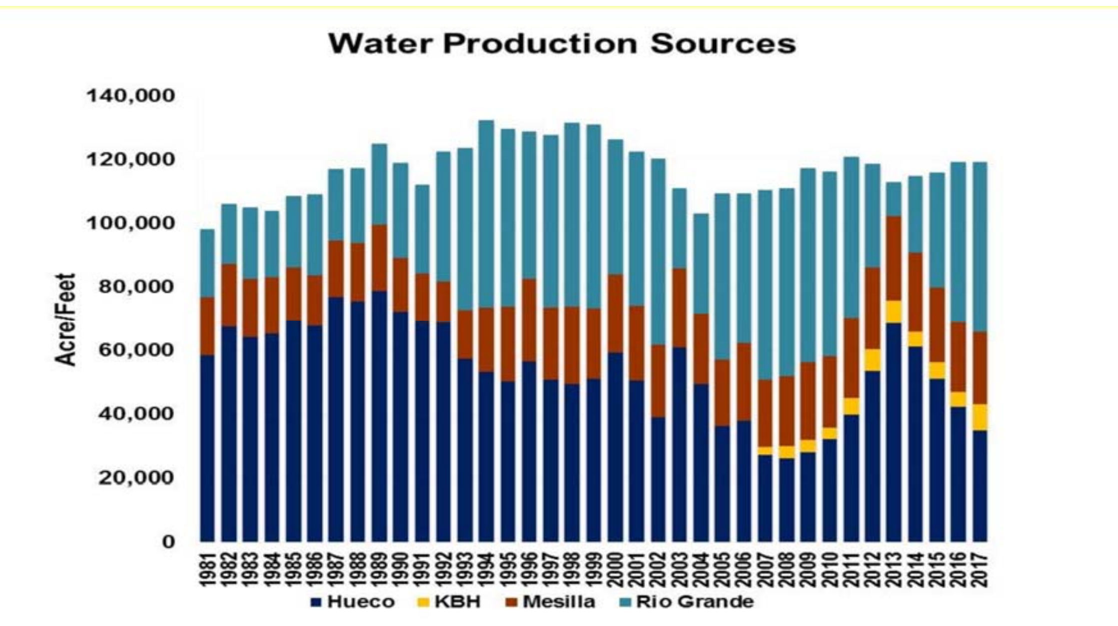
Table 5. Tabulation of EPWU Discharge of Treated Effluent into EPCWID Conveyances, 1999-2017

Table 5. El Paso Water Utilities (EPWU) Effluent Discharge in El Paso Valley

	Haskell Credit for Discharge to ACE during Release Season	Total Annual Haskell Discharge to ACE	Bustamante to Riverside during Release Season	Total Annual Bustamante Discharge to Riverside	Total EPWU Effluent in El Paso Valley During Release Season	Total EPWU Effluent in El Paso Valley During Calendar Year
1999	12,732	17,150	21,775	22,984	34,507	40,134
2000	10,700	15,323	19,583	19,583	30,283	34,906
2001	11,360	17,776	16,070	17,832	27,430	35,608
2002	10,844	16,055	5,876	7,659	16,720	23,714
2003	9,595	15,959	15,556	26,403	25,151	42,362
2004	10,758	17,611	16,558	23,884	27,316	41,495
2005	9,924	17,319	18,583	21,256	28,507	38,575
2006	10,347	16,989	19,541	25,229	29,888	42,218
2007	11,038	16,008	18,735	24,626	29,773	40,634
2008	11,624	16,683	19,325	24,786	30,949	41,469
2009	11,521	16,614	15,471	19,109	26,992	35,723
2010	10,239	16,744	15,390	19,118	25,629	35,862
2011	4,338	15,152	17,045	25,692	21,382	40,844
2012	5,401	17,179	16,165	28,598	21,566	45,777
2013	1,703	15,637	5,259	26,314	6,962	41,951
2014	3,586	14,382	10,856	28,903	14,442	43,285
2015	5,461	15,987	12,027	23,016	17,488	39,003
2016	7,712	16,125	17,102	21,839	24,814	37,964
2017	7,204	14,159	14,651	24,980	21,855	39,139
Average	**8,741**	**16,255**	**15,556**	**22,727**	**24,298**	**38,982**

Figure 12 is a graphical summary of EPWU Water Production Sources that I downloaded from EPWU's website. The City of El Paso gets water from three main sources[30] as labeled in Figure 12[31]:
1) Mesilla: groundwater pumping from the Canutillo well field in the Mesilla Basin,
2) Hueco: groundwater pumping from the City's well field in the Hueco Bolson,
3) Rio Grande Project diversions in the Rio Grande Valley:
    a. Project Supply diverted from the American Canal at the Robertson/Umbenhauer WTP, and
    b. Project Supply diverted from Riverside Canal at the Jonathan Rogers WTP.

Figure 12. City of El Paso's Water Production Sources
https://www.epwater.org/our_water/water_resources Accessed by Peggy Barroll 3/5/2019



The water diverted in the Mesilla Basin at the Canutillo well field is generally delivered to business and residential customers in western El Paso, in the Mesilla Basin. Return flow from this use is treated at the Northwest WWTP and discharged into the Rio Grande above American Dam. Under past and current accounting methods, EPCWID is charged for the diversion and use of this water during the Caballo release season.

[30] EPWU claims that 40% of its water comes from the Rio Grande, 38% from Hueco wells, 17% from the Mesilla, and 5% from desalination. (https://www.epwater.org/our_water/water_resources.) EPWU admits: "Heavy aquifer pumping up to the late 1980s resulted in significantly reduced water levels in most of the Hueco Bolson and some of the Mesilla… El Paso Water has taken steps to reduce pumping in recent decades through major conservation efforts, increasing use of river water and using treated wastewater …." (https://www.epwater.org/cms/one.aspx?portalId=6843488&pageId=7416446; emphasis mine.) See Section R5 regarding the result of Texas's "heavy aquifer pumping up to the late 1980s".
[31] A minor source of EPWU supply is the saline groundwater pumped to supply the Kay Bailey Hutchinson desalination plant ("KBH" in Figure 12).

However, this reasonable and fair accounting treatment is not applied to municipal effluent in the El Paso Valley. EPWU combines its Project Supply with the groundwater it pumps in the Hueco Bolson, and the return flow from these sources, in the form of treated effluent, is returned to the American Canal Extension and the Riverside Canal. This water is diverted by EPCWID, and according to Dr. Ferguson[32] is used by EPCWID farmers, **but EPCWID is not charged for the diversion and use of this water.** Other evidence indicates that EPCWID considers this effluent to be an important component of its water supply. Blair (2001) (which comprises part of the 2001 Third Party Implementing Contract between EPCWID, the US and EPWU) contains a table (reproduced here as Table 6) which tabulates all the sources of water that EPCWID delivers to its farmers. The sources include 376,860 AF of "Project Water" **plus** "Usable Haskell Effluent – Non-Project Water" and "Usable Bustamante Effluent – Non-Project Water"[33].

Note that the 2001 Third Party Implementing Contract contains a substantial amount of language regarding the water quality requirement and standards for "Usable" EPWU effluent. This is part of Contract language that gives EPWU credit that allows it additional Project Supply in exchange for the discharge of "Usable Effluent" into the EPCWID system. EPCWID uses this effluent as "District Water" (but not Project Water). Or it may be that EPCWID is selling this water outside of the Project altogether under Contracts with Hudspeth[34].

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[32] Deposition of Dr. Ian Ferguson 2/2020, page 250, line 7: "A. Yes. My understanding is that effluent discharged into EP1's [EPCWID's] conveyance system is delivered to irrigators to meet irrigation demands."

[33] EPCWID's "Project Water" amount of 376,860 AF was calculated using the D1 and D2 curves, and **included** municipal effluent, off-season diversions, and El Paso Valley drain flows. Now EPCWID requires these sources of water **in addition to** an even larger Project Water amount. (EPCWID full-supply allocation under D3 Allocation is 388,000 AF plus ~20,000 ACE allocation credit.)

[34] 2001 Agreement for the Sale of Sewage Effluent for Irrigation entered into between Hudspeth County Conservation and Reclamation District No. 1 ("HCCRD") and the El Paso County Water Improvement District No. 1 ("EPCWID") *and* 2010 Agreement for the Sale of Sewage Effluent for Irrigation entered into between HCCRD and EPCWID.

Table 6. Reproduced from Blair, 2001, "Table 1. Sources and Quantities of District Water Including a Conservation Credit". Page 59 of 74 of the 2001 Third-Party Implementing Contract

Table 1 - Sources and Quantities of District Water Including a Conservation Credit

Item	DISTRICT WATER SUPPLY and DELIVERY REQUIREMENTS (Maximum Effluent Diversions and Conservation Credit)	acres	Delivery ac-ft/ac	Diversion ac-ft	Delivery ac-ft
1	EPCWID's Diversion Allocation of Project Water	69,010		376,860	275,551
2	Conservation Credit from American Canal Extension Project			29,928	21,883
3	Usable Bustamante Effluent - Non-Project Water			13,333	9,749
4	Usable Haskell Effluent - Non-Project Water			15,000	10,968
5	Total District Water (Project and Non-Project Water)			435,121	318,150
6	Estimated Difference (Diversion to Delivery)			-116,971	
7	City 1941 and 1962 Contract Deliveries (max. of 3.5 ac-ft/ac)	7,241	-3.50		-25,344
8	LVWD 1988 Contract Delivery (4.0 ac-ft/ac)	2,922	-4.00		-11,688
9	Irrigated Land Delivery (4.0 ac-ft/ac)	57,847	-4.00		-231,388
10	2001 Contract 1,000 acres City Owned Land >2000 acres	1,000	-4.00		-4,000
11	2001 Contract Deliveries under section 7A2				0
12	2001 Contract Other District Water 7A1				-24,116
13	2001 Contract Total				**-28,116**
14	Non-Project Water (sum of items 3 and 4)				20,716
15	Reserve Balance of District Project Water				**899**
16	Reserve Balance of District Water				21,615
17	District Delivery Efficiency	73.1%			

NOTES:

The numbers in this table are based on the following assumptions:

1) execution of the 2001 Contract,
2) the present allocation and accounting methodology of Reclamation, and
3) acreage in Column A for rows 7, 8, and 10 was obtained from EPCWID Authorization for Water Service Report date 1/22/2001

The composition of EPWU's water supply in the El Paso Valley, which is the origin of Haskell and Bustamante WWTPs effluent, is shown In Table 7. This table provides EPWU diversion data for Project water in the El Paso Valley, and EPWU groundwater pumping in the Hueco Bolson. The amount of groundwater pumping occurring during months in which Project releases were occurring has been calculated, and is tabulated here.

The relative proportions of groundwater and surface water in the EPWU Hueco/El Paso Valley supply varies depending on EPCWID's allocation of Project Supply. In relatively high supply years, Project water constitutes up to 84% of EPWU's supply for the City of El Paso municipal use during the Project release season (Figure 13 and Figure 14). In years of low Project supply, Project water still constitutes 40% to 60% of EPWU's supply during the Caballo release season.

Table 7. Composition of EPWU Municipal Supply in the El Paso Valley

Table 7. Percentage of EPWU Supply Consisting of Project Water Release Season in the El Paso Valley

Year	Total EPWU Hueco Groundwater Pumping	EPWU Hueco Groundwater Pumping during Release Season	Total EPWU Diversion of Project Water	Total EPWU Diversion during Release Season	% EPWU Project Water during Release Season (El Paso Valley)
2000	60,157	49,814	41,914	91,728	46%
2001	52,340	36,471	47,677	84,148	57%
2002	40,406	25,966	57,843	83,809	69%
2003	66,483	39,049	24,862	63,911	39%
2004	49,976	26,347	29,357	55,704	53%
2005	37,427	19,013	50,723	69,736	73%
2006	39,196	20,244	42,948	63,192	68%
2007	28,628	11,369	58,789	70,158	84%
2008	32,810	13,293	57,889	71,182	81%
2009	34,114	14,370	59,943	74,313	81%
2010	37,729	13,522	54,839	68,361	80%
2011	45,174	18,688	48,384	67,072	72%
2012	59,933	27,139	22,125	49,264	45%
2013	80,083	12,590	7,901	20,491	39%
2014	64,010	15,423	23,494	38,917	60%
2015	56,074	15,526	35,514	51,040	70%
2016	47,795	17,682	47,965	65,647	73%
2017	35,531	6,741	51,517	58,258	88%
Average		21,292	42,427	63,718	67%

Figure 13. Project Release Season Municipal Diversions by EPWU in the Hueco Bolson/El Paso Valley

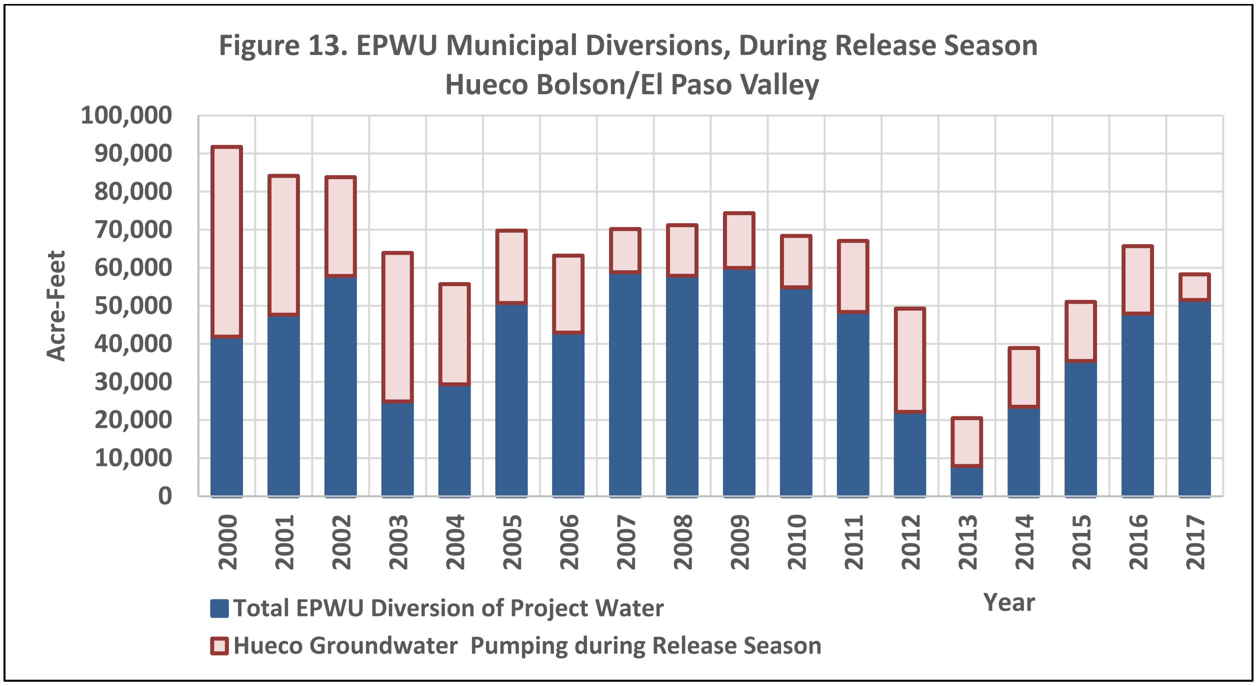
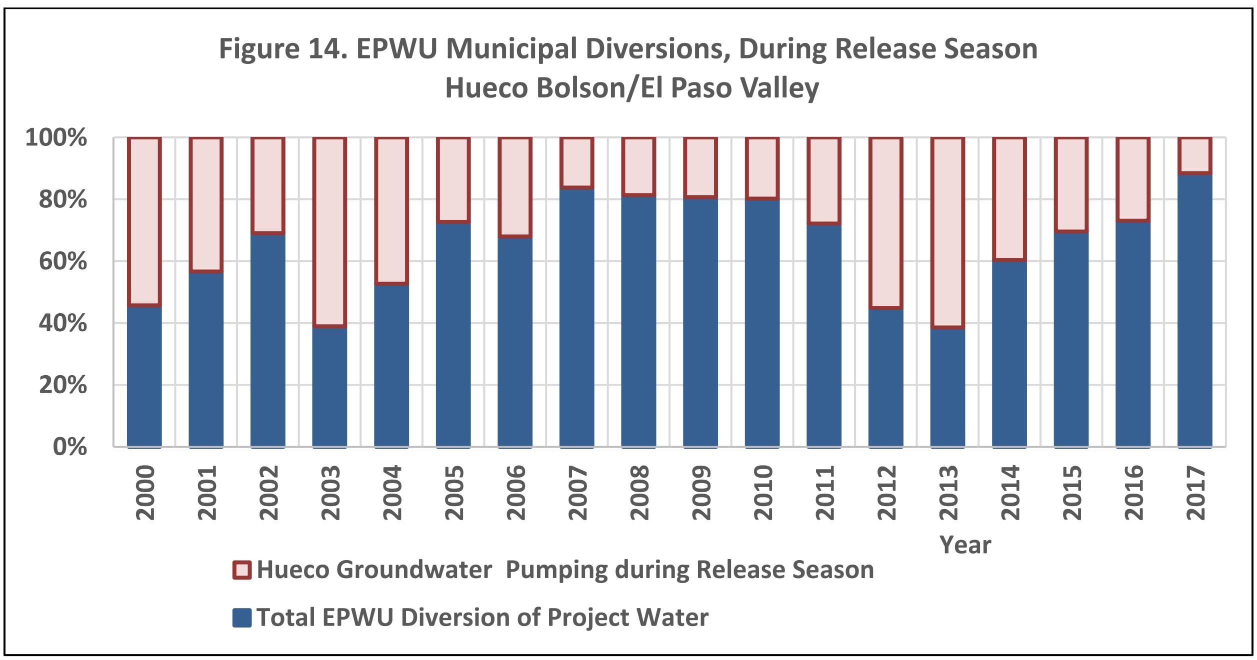


Figure 14. Project Release Season Municipal Diversions by EPWU in the Hueco Bolson/El Paso Valley



Haskell R. Street Wastewater Treatment Plant Treated Effluent

The City of El Paso's first wastewater treatment plant was the Haskell R. Street WWTP,[35] which for many decades was the City's only wastewater treatment plant. Treated effluent from this plant discharged into the Rio Grande until 1999, and the diversion of this water at Riverside Dam was counted as Project Supply both in early Project WDRs, and as part of post-1978 accounting. (*See* Barroll (2019), page 30, pages 49-50 and D-25 through D-27.)

In 1998 the American Canal Extension ("ACE") was completed, a lined conveyance **located immediately adjacent to the Rio Grande river.** In the vicinity of the Haskell plant the ACE is less than 200 feet away from the Rio Grande. The ACE conveys Project water diverted from the Rio Grande at American Dam directly to the Riverside Canal heading. The Riverside Canal now diverts water directly from the ACE, which now substitutes for the nearby Rio Grande riverbed. See Figures 15, 16 and 17.

Since early 1999 the effluent discharged from the Haskell R. Street plant has been intercepted by the ACE before it reaches the bed of the Rio Grande, and the ACE conveys the effluent to the Riverside Canal heading where it is diverted, passes the Riverside gage, and is then used for irrigation within EPCWID. Project accounting, however, **no longer charges EPCWID for this diversion and use even though this water is gaged at EPCWID's Riverside charge point**.

[35] Haskell R. Street WWTP became operational in 1923. "This plant is designed to treat wastewater and discharge it to either the Rio Grande or the American Canal. The preferred discharge point is to the American Canal in order to provide irrigation water to farmers in the Lower Valley. In exchange for this irrigation water, El Paso Water obtains valuable water credits for surface water that is treated to drinking water standards, reducing our dependence on groundwater." (https://www.epwater.org/cms/One.aspx?portalId=6843488&pageId=7422911; emphasis mine.)

Figure 15. Haskell R. Street Wastewater Treatment Plant Area Map

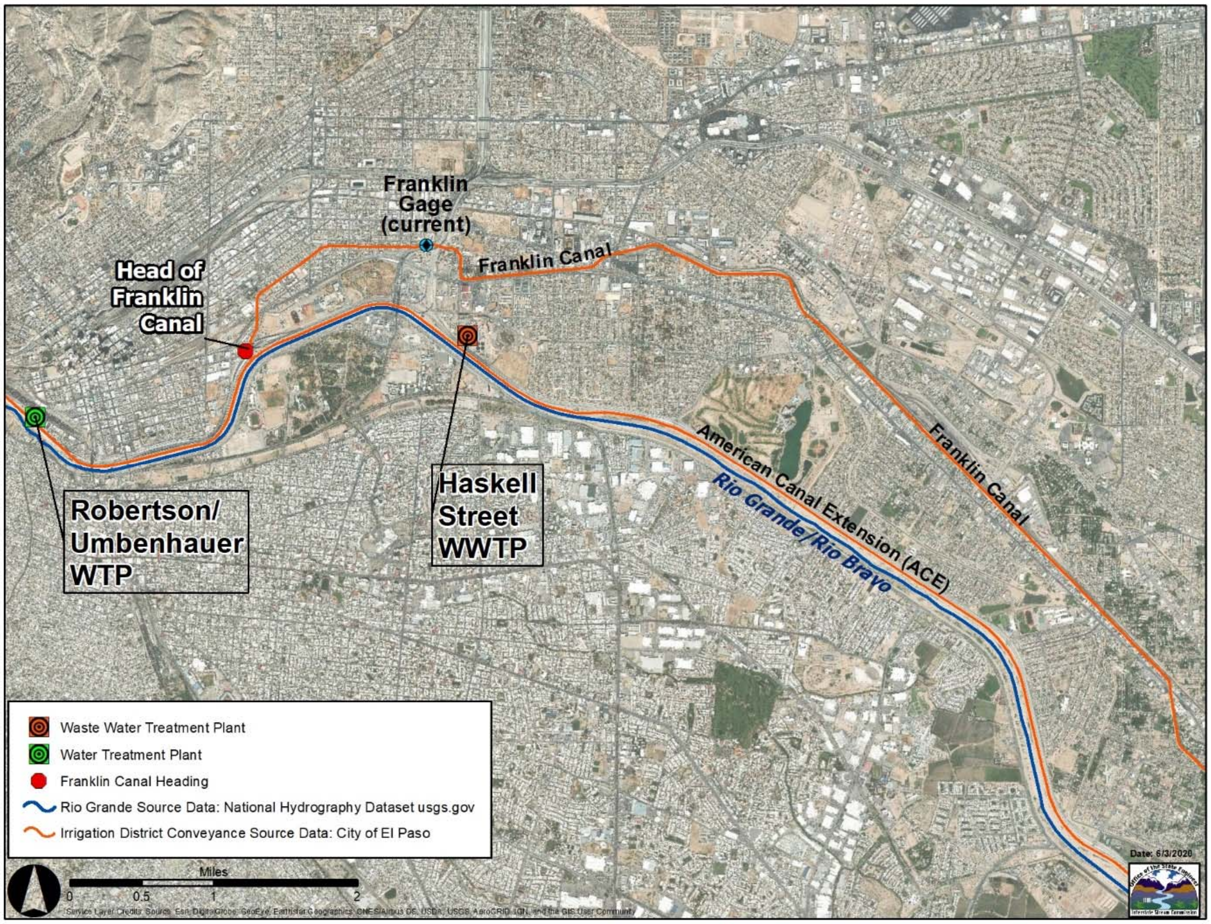


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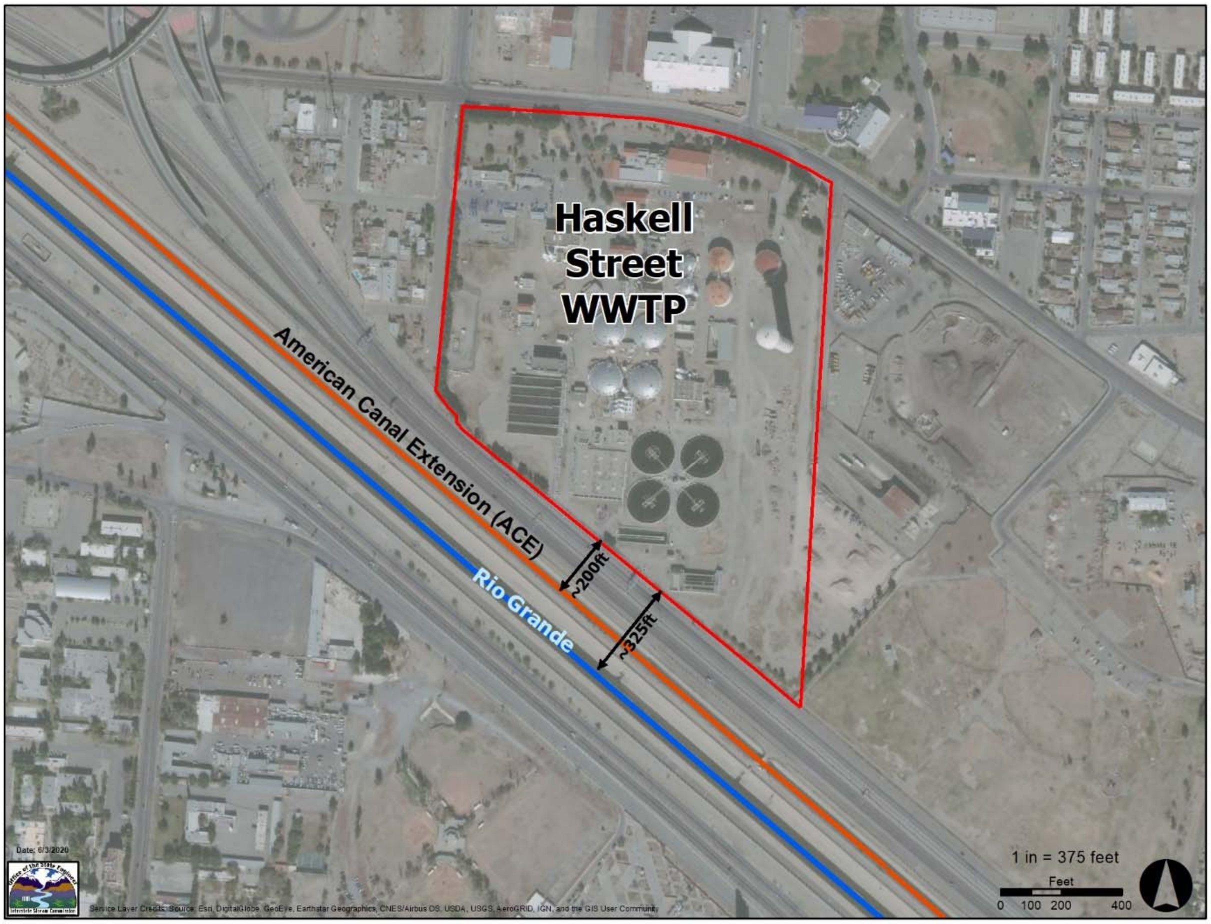
Figure 16. Haskell R. Street Wastewater Treatment Plant Detail map



The decision to no longer charge EPCWID for diversion and use of this water was made in a 1999 meeting between EPCWID staff and Reclamation staff that was summarized by Reclamation's F. Cortez,[36] and in which the parties making the decision did not mention the potential impact of this accounting change on the Project as a whole. Instead of continuing to charge the diversion of this effluent as it passed the Riverside gage, as had previously been the practice, EPCWID and Reclamation agreed that the diversion and use of this effluent would continue, but now the amount discharged from Haskell into the ACE ten (10) miles upstream of the Riverside Canal heading, is now **subtracted** from the Riverside Canal heading diversion in the form of an accounting credit. As a result, not only does EPCWID divert and use Haskell R. Street effluent free of charge, but that effluent gets to "ride on top" of the rest of the Project water conveyed in the ACE, arriving at the Riverside heading intact, not reduced for evaporation or other losses, thus maximizing the amount of the Haskell Credit. This accounting anomaly has the ultimate result of reducing the Diversion Ratio, in essence causing EBID to pay for EPCWID's "free" Project supply water. EPCWID's Haskell R. Street Credit has been awarded since 1999 and has averaged 8,700 AF/year.

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[36] Cortez Letter Summary of June 25, 1999 Meeting to Discuss Water Accounting Procedures at Riverside Canal and Haskell Street Waste Water Treatment Plant Discharge.

Since the entire amount of Haskell effluent discharged into the ACE is credited to EPCWID when diverted at Riverside, it is implicitly assumed that no water is lost from the ACE between the Haskell Plant discharge point, and the Riverside heading. This implicit assumption is inconsistent with the results of seepage study performed and documented by Blair (Blair, 2000), which measured "a seepage loss of 3.23 +/- 1.5 cfs for the 5.25 mile reach of the ACE upstream of the Riverside Canal Heading metering bridge.[37]" Over the course of a 150 day irrigation season, this loss rate would result in about 1,000 AF of total loss.

EPCWID and Reclamation take the position that the discharge of effluent derived from Project supply into the American Canal Extension is fundamentally different than discharge of that same water into the Rio Grande. This is despite the fact that **the ACE simply substitutes for the Rio Grande** in the delivery of Project water to EPCWID. That is, EPCWID is now charged for diversions from the ACE instead of from the Rio Grande, and the ACE was designed and constructed to take the place of the Rio Grande specifically for that purpose.

Bustamante Wastewater Treatment Plant Treated Effluent

The Bustamante WWTP is located downstream of Haskell, and discharges EPWU municipal effluent into the Riverside Canal system during the irrigation season, and into a drain leading to the Rio Grande during a few winter months. See photo, Figure 17. According to Dr. Ferguson, effluent discharged into Riverside Canal is used to supply farm demand within EPCWID just as the rest of the Project water is but is not charged against EPCWID's allocation[38]. There is no explicit Project accounting credit for Bustamante effluent, because since it enters Riverside below the gage, it is not included in the gaged diversions. Dr. Ferguson testified that because the Bustamante effluent enters the Riverside Canal system below the Riverside gage, "it would not be charged as Project water"[39]. The amount of water discharged from Bustamante into the Riverside Canal during the Project Release season has averaged approximately 15,500 AF/yr since 1999.

Essentially, approximately 24,000 AF/yr of Project return flow mysteriously loses its character as Project supply[40] through the agreement of Reclamation and EPCWID; although it is diverted and used during the Project release season it is not charged against EPCWID's allocation. **This contributes to the fact that EPCWID's charged diversions are generally much less than its full-supply allocation, allowing EPCWID to carry over large amounts of unused allocation under the 2008 OA. Under the current D3 Allocation method this results in corresponding decreases in EBID's allocation having nothing to do with actions by New Mexico actors.**

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[37] Blair, A.W., 2000. Salvage of Water in El Paso County Water Improvement District No. 1 Canal System. Prepared for EPWCID No.1 Draft Report January 26, 2000.

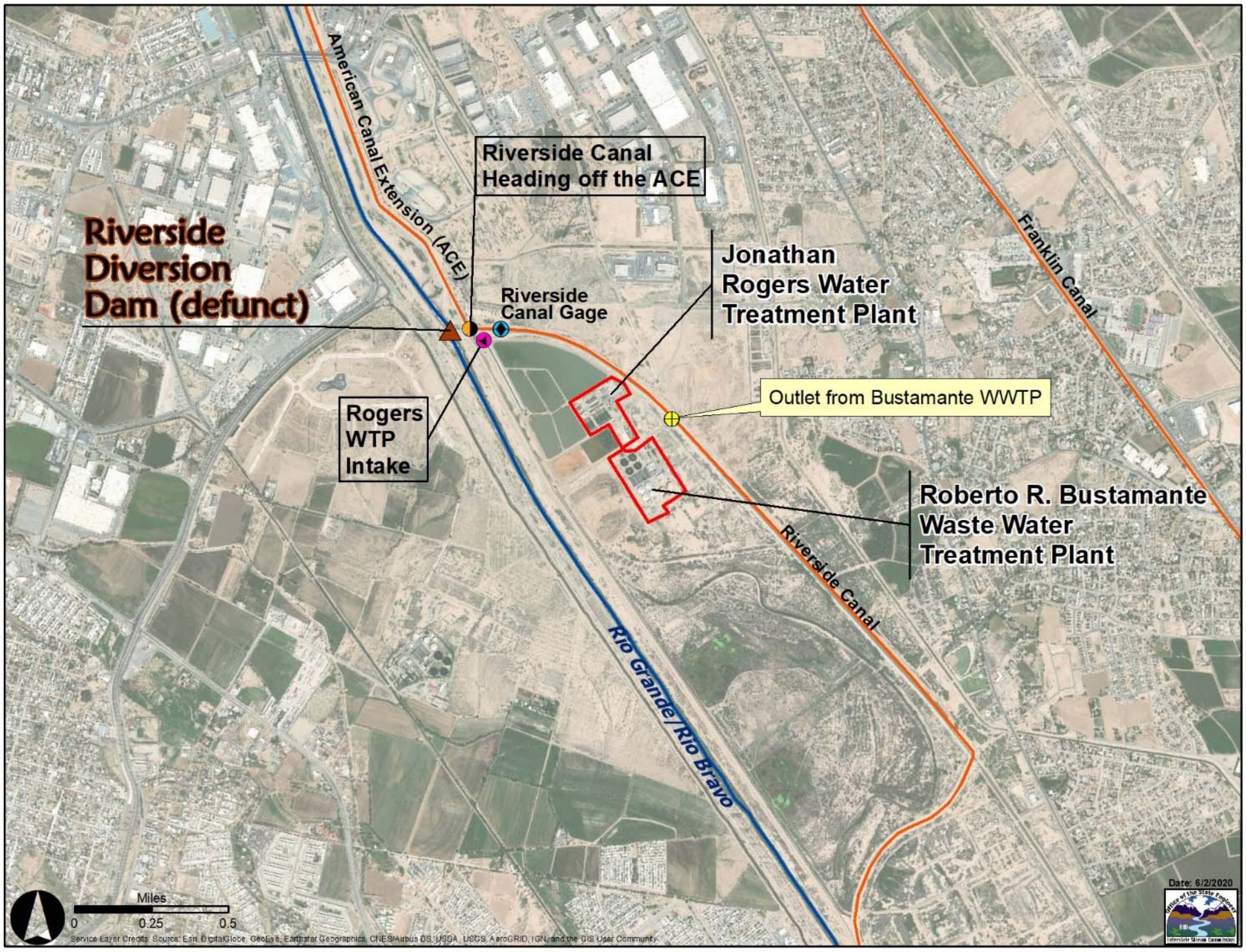
[38] Deposition of Dr. Ian Ferguson, 2/19/2020, page 151, line 21.

[39] Deposition of Dr. Ian Ferguson, 2/19/2020, page 151 line 25, page 152 line 1.

[40] Further, while EPCWID asserts that it has earned the benefit of Carryover due to the laudatory water conservation measures it employs, for at least this approximately 24,000 AF/yr the "conservation" is actually a result of accounting sleight-of-hand.

See Barroll (2019), Appendix C, for more detailed discussion of the structure of the El Paso Valley conveyance system and changes thereto.

Figure 17. Bustamante Wastewater Treatment Plant Location near the Riverside Canal and Heading



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R8. ACE CREDIT

Dr. Blair defends the ACE Credit (18th Opinion, pages 13 and 14) stating:

> *EPCWID does not receive any greater benefit for the American Canal Extension under the 2008 Operating Agreement than prior to the Agreement; and in some years, EPCWID receives no use of the credit and in other years the credit accrues to the benefit of EBID. The ACE canal credit is less than the reduction in seepage losses in the Rio Grande resulting from the construction of concrete lined ACE canal. These seepage losses existed since 1938 until the ACE canal was completed in 1996. The ACE canal credit does not reduce the annual diversion allocation to EBID. It does allow an appropriate credit to EPCWID for water conservation associated with EPCWID's payment of the local cost-share for constructing the ACE canal, and for the cost to operate and maintain the ACE canal.*

Dr. Ferguson also defends the ACE Credit (his 13th Opinion, page 13) in similar language:

> *The ACE Conservation Credit is less than the estimated reduction in seepage losses. As a result, the ACE Conservation Credit does not reduce the annual diversion allocation to EBID; rather, it allows EPCWID to benefit from water conservation achieved by the district's investment in constructing the ACE. Also, Dr. Barroll does not acknowledge that the ACE Conservation Credit has not been applied in several recent years by agreement between EBID and EPCWID; these years include the extremely dry years of 2011, 2013, and 2016. Finally, Dr. Barroll does not acknowledge that, in the event that EPCWID's carryover reaches the limit specified in Section 1.11 of the OA, carryover in excess of that specified limit, including carryover resulting from the ACE Conservation Credit, is transferred to EBID's carryover balance.*

Dr. Barroll Reply: The American Canal Extension (ACE), completed in 1998, connects the end of the original American Canal, below the Franklin Canal heading, to the Riverside Canal heading (see Figures 15 and 17). The ACE allows EPCWID to divert all of the water needed by Franklin, Riverside, and EPWU at American Dam, and completely bypass the bed of the Rio Grande below American Dam when delivering water to the Riverside heading. See Barroll (2019) Section 6.4 and Appendix D, for more detailed description of the ACE and ACE related Project Accounting issues.

Use of the ACE to by-pass the bed of the Rio Grande for delivery to Riverside avoids the seepage losses occurring in the 15-mile reach of the Rio Grande above Riverside. The seepage losses in this reach, however, are a result of groundwater pumping in Texas and Mexico – see Section R5 for an explanation of the impacts of Texas groundwater pumping. Rio Grande Project accounting then awards EPCWID a credit (the "ACE Credit") for this bypass operation. The application of the ACE Credit reduces EBID's share of Project Supply as discussed below. In other words, Texas gets credit for resolving a problem it created, and EBID and New Mexico lose water as a result. See Barroll (2019) Section 6.4 and Appendix D for more detailed description of the ACE and ACE related Project Accounting issues.

It can be demonstrated through testing of the Allocation Spreadsheet (which is the heart of the 2008 OA) that the amount of the ACE credit awarded to EPCWID within that Spreadsheet is subtracted, 1:1 from EBID's allocation. This effect is illustrated in Figure 6.8 of Barroll (2019) which demonstrates that the effect of awarding EPCWID a 17,998 AF ACE Conservation Credit is to reduce EBID's allocation by that same amount: 17,998 AF. Therefore, the effect of the ACE credit, when applied through the Allocation Spreadsheet as described in the 2008 OA is to decrease EBID's allocation by the amount of EPCWID's ACE credit.

In recent years the ACE credit has sometimes been omitted, or been applied inconsistently. In some years the ACE credit has been applied by increasing the allocation at the end of the year during the accounting process, instead of through the Allocation Spreadsheet. When the ACE Credit is added on to EPCWID's allocation at the end of the irrigation season, the net effect is to increase EPCWID's Carryover to the subsequent year. Since the ACE Credit is not associated with any water in reservoir storage, this increase in Carryover is an increase in the amount of paper water in Carryover. In some years, this will mean that increased amounts of winter inflows to storage will be automatically converted into Carryover, in order to supply that Carryover account.

Allocation the subsequent year begins with calculation of the Carryover obligation (the total amount carried over from the previous years plus the amount of extra release needed to deliver that Carryover allocation to canal headings), and subtracting that off from Usable water before calculating Current-Year Allocations. In this way, the increase in Carryover caused by the ACE Credit reduces the amount of water available for Current-Year Allocation the following year, negatively impacting EBID's Allocation.

The issues that I raise related to the ACE Credit are independent of whether the ACE Credit has been awarded in every year. Similarly, the issues with the ACE Credit are independent of whether Carryover transfer has the potential to result in benefit to EBID (as suggested by Dr. Ferguson). As for Carryover transfer, New Mexico cannot depend on this benefit to EBID occurring in the future. Carryover Transfer to EBID only occurs if EPCWID has accumulated unused allocation in excess of its Carryover Limit, which is 232,915 AF, and such transfers would be greatly reduced or even eliminated if EPCWID increases its diversions in full-supply years.

R9. EPCWID CARRYOVER AND ITS CLAIMED "LINK TO CONSERVATION"

Drs. Ferguson and Blair argue that it is good management and conservation measures that have allowed EPCWID to carry over such large amounts of water since the inauguration of the D3 Allocation Method. Dr. Ferguson states (Ferguson's 9th opinion, pages 9 and 10):

> *Dr. Barroll incorrectly characterizes carryover accrued by EPCWID as "unused" and "unneeded." EPCWID implements water conservation measures to allow the district to accrue carryover when possible (e.g., in years when the district's diversion allocation is average or above average).*

Dr. Ferguson adds (in his 13th opinion on page 13)

> *EPCWID actively manages its allocation to accrue carryover when possible and to utilize carryover during drought periods, as part of the District's approach to improving water supply reliability during severe drought conditions. Dr. Barroll's opinion does not acknowledge that the OA provides EBID the opportunity to accrue and utilize carryover in the same manner as EPCWID. However, EBID chooses not to actively manage its*

allocation to take advantage of carryover; instead, irrigators within EBID increase their groundwater use to meet crop water demands during drought periods.

Dr. Blair states (in his Opinion #13 on pages 10 and 11):

> *EPCWID manages its use of allocated Project Water to meet the needs of its water users which includes the conservation of water for future use. EPCWID actively conserves water in years with full allocations for use in drought years, and uses all of its allocated water in the time and manner it deems most beneficial to the District and its water users. The corollary to Dr. Barroll's conclusion is that EPCWID and EBID must drain the reservoir every year so that no water is ever carried-over into the next year. There has been "carryover" of Rio Grande Project water since the first-year water was stored in Elephant Butte Reservoir in 1916. Storage and carry-over of water from year-to-year is an appropriate and prudent operation of a water supply reservoir.*

Dr. Barroll Reply: Since the implementation of D3 allocation in 2006, EPCWID's allocation in full-supply or near full-supply years exceeds EPCWID's charged diversion by approximately 100,000 AF/yr. Part of the discrepancy between EPCWID's allocation and its charged diversion is that part of the water EPCWID actually diverts and makes use of is not charged against its allocation. As discussed in section R7 above, under current Project accounting rules EPCWID can divert and use approximately 25,000 AF/yr of El Paso municipal effluent free of charge. This accounting maneuver does not constitute an "active conservation measure."

EBID's inability to take advantage of Carryover to the same extent as EPCWID is a result of the large reduction in EBID's full-supply allocation caused by D3 allocation, not a result of management decisions. EBID's allocation has been reduced below the level needed to supply the crops grown on its current irrigated acreage. EBID farmers currently irrigate approximately 70,000 acres, and within New Mexico there are also approximately 4,500 irrigated acres that are not part of EBID. Thus, the total irrigated acreage in the New Mexico part of the LRG is already much less than the 90,640 acres authorized by the Rio Grande Project.

Under the historical operations of the Project, prior to 2006, any unused allocation would return "to the pool" and be available for current-year allocation to both Districts. As described in Filberto (Bert) Cortez's 2007 affidavit, submitted on behalf of the **United States when it was arguing against** implementation of Carryover storage,[41] statement 19: "The practice for nearly 100 years of Project Operation was that any unreleased storage or unused diversion allocation from either district went back into the Project supply to be allocated anew the next year." During the years that led up to the adoption of the D3 method in 2006, both Districts often had unused allocation at the end of the irrigation season, and any reservoir storage that might be associated with this unused allocation, regardless of which district had the unused allocation, was returned to the pool for allocation (on a 57/43 basis) the following year, as shown in Table 8.

[41] Filberto (Bert) Cortez's 2007 Declaration in Cause No. EP07CA0017 (PRM), EPCWID v EBID, and the US DOI.

Table 8. Unused Allocation in the Years Leading up to Implementation of Carryover Comparison of Allocation and Charged Diversions 1999-2005

Table 8. Unused Allocation in the Years Leading up to Implementation of Carryover Comparison of Allocation and Charged Diversions 1999 - 2005						
	EBID Allocation	EBID Charged Diversion	EBID Unused Allocation	EPCWID Allocation	EPCWID Charged Diversion	EPCWID Unused Allocation
	Acre-feet	Acre-feet	Acre-feet	Acre-feet	Acre-feet	Acre-feet
1999	494,979	426,132	68,847	376,862	340,727	36,135
2000	494,979	460,278	34,701	376,862	306,375	70,487
2001	494,979	460,182	34,797	376,862	343,365	33,497
2002	494,979	431,521	63,458	376,862	376,926	(64)
2003	165,144	164,740	404	125,735	137,250	(11,515)
2004	185,507	164,572	20,935	154,265	144,005	10,260
2005	494,979	353,261	141,718	376,862	247,607	129,255
1999-2005 Average	403,649		52,123	309,187		38,294
District % of unused Allocation			58%			42%

Furthermore, Table 8 demonstrates that prior to the adoption of D3 allocation in 2006, EBID did not use all of its allocation in full supply years, leaving significant amounts of water behind in the reservoir to be reallocated the following year: in fact, in some years EBID contributed more to the “pool” than did EPCWID. This changed immediately in 2006 when EBID’s full-supply allocation was reduced dramatically, below the amount needed to supply its crops.

Finally, Dr. Blair’s “corollary” is a strawman argument. I do **not** contend that the Project cannot store water in Elephant Butte or Caballo reservoirs from year to year. Rather I contend that Project Carryover accounting under the 2008 OA is a significant change from historical Project operations, and that can and does harm New Mexico water users by reducing the current-year allocation to EBID in some years.[42]

[42] See Lopez (2019) Section 7 for his discussion on how Carryover impacts New Mexico’s Compact rights and obligations.

R10. THE UNITED STATES DOES NOT REFUTE MY EVIDENCE THAT UNTIL 2006, PROJECT ALLOTMENT AND ALLOCATION ENTITLED EBID AND EBID FARMERS TO 57% OF THE US SHARE PROJECT SUPPLY, AND THAT HISTORICAL PROJECT DELIVERY DATA INDICATES THAT THE ACTUAL DELIVERY OF PROJECT WATER TO THE DISTRICT WAS APPROXIMATELY 57% TO EBID AND 43% TO EPCWID.

Dr. Ferguson (5th Opinion on page 7 of Ferguson 2019) writes: "*Dr. Barroll's statement that 'from 1938 – 1978, Reclamation operated the Project so that EBID's farmers were entitled to 57% of the US share of Project Supply' is also incorrect*." Dr. Ferguson then contradicts himself by writing: "*From 1951-1978 Reclamation allotted water equally to all acres.*" Allotting water equally to all acres is exactly the same as giving every acre an equal entitlement to water, and since 57% of those acres were in EBID, EBID farmers were indeed entitled to 57% of the water. In his 6th opinion (page 7) Dr. Ferguson does not refute my assertion that "starting in 1979 Reclamation explicitly allocated Project Supply to the Districts in the ratio of 57% to EBID and 43% to EPCWID." Dr. King (in his 2nd opinion at the top of page 7 of King 2019) concedes that from 1979 to 2007 Reclamation allocated the US share of Project supply 57/43; he only differs with the details of my explanation. Dr. Blair does not refute the fact that EBID was allocated 57% from 1979 – 2006, but also quibbles about the description of the allocation method during that time in his 4th opinion (page 5 of Blair 2019).

On his page 7 Dr. Ferguson points out that prior to 2006 the percentages of Project water actually diverted by the Districts and delivered to District farmers varied from year to year, and writes that "*Reclamation did not guarantee equal **delivery** to all lands*" (emphasis mine.) This is correct, but it does not change the fact that Reclamation's equal-allotment-to-lands meant that EBID lands were **entitled** to order 57% of the US share of Project Supply. Dr. Ferguson himself explains the variability in actual delivery, writing: "*Actual deliveries to farms depended on the amount of water called for by farmers*", and "*The amounts of water diverted by the Districts and delivered to their farmers depended on the amounts of water called for by the districts and farmers respectively*." Again, this variation in actual delivery does not change the amount the District and their farmers were entitled to order. And while there was variability in actual delivery, on average the percentages of actual EBID diversions and farm deliveries were consistent with 57%. From 1951 through 1978, on average EBID's diversions were 56% and EBID' farm deliveries were 54% of total District diversions and farmer deliveries. From 1978 through 2005, on average EBID's diversions were 58% of total District diversions.

Dr. Blair (2019, page 4) states that "There is no requirement or documentation under the Rio Grande Compact or otherwise which directs that 'each Project acre was entitled to the same delivery of water.'" He does not, however, refute my conclusion that in practice the Allotment and Allocation procedures of the Project until 2006 entitled each acre to order the same amount of water.

In 2007, then Project Manager FIlberto (Bert) Cortez wrote in a formal Declaration:

The allocation has historically been equally divided to all Project lands on an acre foot per acre basis. Before 1980, Reclamation operated the Rio Grande Project in its entirety, combining storage and return flows so that each acre of farm land received and equal amount of water regardless of the source of the water or what district the land was located"

And

EBID is allocated 88/155 of the available Project water supply and EPCWID is allocated 67/155 of the available water supply.

R11. THE UNITED STATES IGNORES THE ACTUAL OPERATION OF THE 2008 OA AS WELL AS STATEMENTS BY ITS AUTHORS

Dr. Blair (Opinion 12, page 10) states that "*The 2008 Operating Agreement does not assume that all of the 'negative departures from historical performance are caused by New Mexico*.'" Dr. Ferguson agrees with Dr. Blair, as stated in Dr. Ferguson's 2nd opinion (Ferguson page 4) and 10th opinion (Ferguson page 10).

Dr. Barroll Reply:

I base my assertion that that "the 'D3 Method' is based on the assumption that any negative departure from historical Project performance is caused by New Mexico in part upon my understanding of Reclamation's allocation spreadsheet, and also from various written and verbal statements from the authors of the 2008 OA. For instance, the Reclamations EIS states: *"Moreover, it [the 2008 OA] ensures that deviations in performance relative to historical conditions would be accounted for by adjusting the annual allocation to EBID*." (FEIS page 7). Also, in a report by Dr. Ferguson himself[43] he states on page 9: "*The diversion ratio adjustment provision of the OA therefore mitigates potential negative effects of changes in Project performance, which result predominately from the actions of individual landowners within EBID, by ensuring that Project allocations and deliveries to EPCWID remain consistent with historical Project performance*." Since the 2008 OA assigns all "deviations in performance" to EBID, and ensures "*that Project allocations and deliveries to EPCWID remain consistent with historical Project performance"* it certainly appears that the OA is predicated on an assumption that all deviations are caused by EBID. **Regardless of whether the 2008 OA is actually predicated on such an assumption, because it reduces EBID's allocation by all deviations from historical Project performance regardless of their cause, it emphatically has that effect as a practical matter.**

Based on the calculation embedded into the 2008 OA Allocation Spreadsheet, it is clear that the effect of D3 Allocation is to reduce EBID's allocation in an amount equal to the entire negative departure from the D2 Curve (except under multi-year drought conditions, a modification that was added in 2012.) Meanwhile, EPCWID's allocation has not been reduced to account for the impacts of any pumping in

[43] Dr. Ferguson's own report (Memorandum No. 86-68210–2015-05 Simulation of Rio Grande Project Operations in the Rincon and Mesilla Basins: Summary of Model Configuration and Results, Appendix C of the Continued Implementation of the 2008 Operating Agreement for the Rio Grande Project Environmental Impact Statement, 2016) on page 9.

Texas, or changes in Project accounting that except some EPCWID diversions from being counted as Project deliveries.

Drs. Ferguson, Blair and King all emphasize that the 2008 OA was a "negotiated settlement." However, it is unclear that EBID has obtained the bargain it attempted to obtain. In Dr. King's rebuttal he indicates that the deviation from the D2 curve in Project performance is caused by increased groundwater withdrawals ***"relative to the 1951 – 1978 D2 period"*** (King page 7), and that the 2008 OA is intended *"to offset groundwater depletions in New Mexico relative to the 1951 – 1978 D2 period."* (King page 8) These statements reflect an understanding that the 2008 OA was intended to grandfather-in New Mexico groundwater pumping levels from the D2 period, and that adjustments made to EBID's allocation were intended to offset **additional** amounts of pumping above and beyond the D2 period. Similarly, EBID presentations from the 2008 time-period reflect that same understanding. A 2008 presentation to the New Mexico State Legislature states "D2 level of groundwater pumping grandfathered into Project allocation."[44] This is the bargain that EBID apparently thought it was making in negotiating the 2008 OA; however, this is not what EBID got.

Instead, the 2008 OA takes large amounts of allocation away from EBID, far larger than any available estimates of increased pumping in New Mexico since the D2 period. Instead of reducing EBID's allocation solely to account for increased groundwater pumping in New Mexico since the D2 period, the 2008 OA also reduces EBID's allocation to compensate for changes in Project accounting that have benefitted EPCWID by allowing EPCWID to divert and use, without charge, sources of water that had previously been considered Project water.

R12. QUANTIFICATION OF D3 REALLOCATION

In this section I perform a first-order analysis to quantify the amount of Project Supply reallocated under the Operating Agreement through analysis of the reported Allocation data from 2006 through 2019. I use Current-Year Allocation data to avoid any potential "double counting" of allocations carried over for multiple years.

Table 9 contains Current-Year Allocation data for the Districts from 2006 through 2019, and calculates of the amount by which EPWID's Current-Year Allocation exceeds 43% of the Current Allocation to both Districts. The total reallocation calculated by this method is 693,408 AF, which is the amount EPCWID's allocation has been increased at the expense of EBID.

[44] Esslinger, G., 2008. Elephant Butte Irrigation District Update for the Water and Natural Resources Committee. Presentation to the New Mexico State Legislature, August 4, 2008.

Table 9. EPWID Current-Year Allocation in Excess of 43% of Current-Year Allocation to Districts

Table 9. EPCWID Current-Year Allocation in Excess of 43% of Current-Year Allocation to Districts						
	Current-Year Allocation from Reclamation Allocation Records					
	EBID	EPCWID (Including ACE Credit)	Total Current-Year Allocation to Districts	43% of District Allocation	EPCWID Allocation in Excess of 43%	Cumulative Sum of EPCWID Exceedance
Year	AF	AF	AF	AF	AF	AF
2006	211,385	241,657	453,042	195,831	45,826	45,826
2007	310,894	367,291	678,185	293,151	74,140	119,966
2008	324,990	405,073	730,063	315,576	89,497	209,463
2009	268,077	402,159	670,236	289,715	112,444	321,907
2010	255,257	309,515	564,772	244,127	65,388	387,295
2011	57,090	43,466	100,556	43,466	0	387,295
2012	118,300	132,935	251,235	108,598	24,337	411,632
2013	54,438	41,446	95,884	41,447	-1	411,631
2014	104,651	106,590	211,241	91,311	15,279	426,910
2015	161,940	197,629	359,569	155,427	42,202	469,113
2016	156,310	235,908	392,218	169,539	66,369	535,481
2017	267,523	401,842	669,365	289,338	112,504	647,985
2018	114,419	116,437	230,856	99,789	16,648	664,633
2019	203,933	205,952	409,885	177,176	28,776	693,408
Total					**693,408**	

I have performed similar analysis on the District Accounting data from the period 2006 through 2019, and show the results in Table 10. Table 10 shows that EPCWID's Charged Diversions exceed 43% of Total District Charged Diversions by a total of 531,389 AF over this 14-year period.

Table 10. EPCWID Charged Diversion in Excess of 43% of Total Charged Diversions to Districts

Table 10. EPCWID Charged Diversion in Excess of 43% of Total Charged Diversions to Districts						
	Charged Diversions from District Accounting Records					
	EBID	EPCWID	Total Charged Diversions to Districts	43% of Total Charged Diversions	EPCWID Diversion in Excess of 43%	Cumulative Sum of EPWID Exceedance
Year	AF	AF	AF	AF	AF	AF
2006	211,841	177,183	389,024	168,159	9,024	9,024
2007	302,665	278,252	580,917	251,106	27,146	36,170
2008	329,294	279,173	608,467	263,015	16,158	52,328
2009	305,475	320,083	625,558	270,402	49,681	102,009
2010	282,082	304,937	587,019	253,744	51,193	153,202
2011	59,771	258,772	318,543	137,693	121,079	274,282
2012	133,060	136,380	269,440	116,468	19,912	294,194
2013	54,002	53,530	107,532	46,482	7,048	301,242
2014	99,007	97,418	196,425	84,906	12,512	313,754
2015	143,404	165,872	309,276	133,687	32,185	345,939
2016	175,199	216,309	391,508	169,232	47,077	393,015
2017	259,510	249,919	509,429	220,205	29,714	422,730
2018	127,487	280,674	408,161	176,431	104,243	526,973
2019	194,510	155,872	350,382	151,455	4,417	531,389
Total					**531,389**	

However, under current Project Accounting, EPCWID diverts and uses an average of 24,000 AF of EPWU effluent, essentially Project return flow, without charge. If the amount of EPWU effluent that is provided to EPCWID during the Caballo Release season is included with EPCWID's Charged Diversions, as shown in Table 11, the total amount that EPCWID diverts in excess of 43% is 708,000 AF.

Table 11. EPCWID Diversion (including Effluent) in Excess of 43% of Total District Diversions

Table 11. EPCWID Diversion (including Effluent) in Excess of 43% of Total District Diversions

	Charged Diversions from District Accounting Records		Release Season				
	EBID	EPCWID	EPCWID Uncharged Effluent	Total District Diversions	43% of Total Diversions	EPCWID Diversion in Excess of 43%	Cumulative Sum of EPCWID Exceedance
Year	AF	AF	AF	AF	AF	AF	AF
2006	211,841	177,183	29,888	418,912	181,078	25,993	25,993
2007	302,665	278,252	29,773	610,690	263,976	44,050	70,043
2008	329,294	279,173	30,949	639,416	276,393	33,729	103,772
2009	305,475	320,083	26,992	652,550	282,070	65,005	168,777
2010	282,082	304,937	25,629	612,648	264,822	65,744	234,521
2011	59,771	258,772	21,382	339,925	146,935	133,219	367,740
2012	133,060	136,380	21,566	291,006	125,790	32,157	399,896
2013	54,002	53,530	6,962	114,494	49,491	11,001	410,897
2014	99,007	97,418	14,442	210,867	91,149	20,711	431,608
2015	143,404	165,872	17,488	326,764	141,246	42,113	473,722
2016	175,199	216,309	24,814	416,322	179,958	61,164	534,886
2017	259,510	249,919	21,855	531,284	229,652	42,122	577,008
2018	127,487	280,674	***20,000***	428,161	185,076	115,598	692,606
2019	194,510	155,872	***20,000***	370,382	160,101	15,771	708,377
Total						**708,377**	

Estimated Values of Release Season El Paso Valley Effluent Discharge 2018 and 2019

Thus, analysis of the actual Allocation and Diversion data indicate that over the past 14 years, EPCWID has obtained approximately 700,000 AF of Project water in excess of its rightful 43%. Note that prior to 2006, Project Allocation methods either explicitly allocation 43% of the US share of Project Supply (from 1979 – 2005) or allotted water equally to all Project acres, so that EPCWID farmers, with 43% of the Project acreage, was entitled to order 43% of the US share.

This analysis presented above is a first-order analysis, in that it does not attempt to calculated the change to the hydrologic system that would occur under a different distribution of Project Supply. In all likelihood, if the upper part of the Project (EBID) were allocated and received more surface water, the delivery performance of the Project would increase, as a result of improved aquifer conditions, to the benefit of the Project.

The physical mechanism that would improve Project delivery performance is as follows: improved allocation and supply to EBID would lead to:

- An increase in recharge to the Rincon and Mesilla valley aquifer from canal seepage, and
- Reduced groundwater pumping within EBID.

These benefits would result in higher-than-otherwise groundwater levels within the Rincon and Mesilla valleys within New Mexico. This change in groundwater levels would lead to:

- Reduced seepage losses from the Rio Grande, and
- Increased drain flows above Courchesne.

As a result of these hydrologic improvements, it would not be necessary to release as much Project water to meet District orders and the Mexican delivery schedule, and the Project Diversion Ratio would be proportionally increased. These processes can only be simulated with an integrated groundwater and surface water operations model. The ILGM has already performed preliminary runs of this nature (Sponk 2019), but that model is currently undergoing revision in response to rebuttal criticism, and the revised model results will be completed after this report is concluded.

The increase in Project Diversion Ratio would lead to a further increase in the amount of Project Supply available for allocation and delivery. Under D3 Allocation rules, that increase would go to EBID; under 57:43 Allocation, the extra water would accrue to both Districts. In either case, EBID would reap some of the benefit, which would result in further improvement to the hydrologic system within EBID, and further improvements to Project delivery performance.

This process is the flip side of the “vicious cycle” I describe in Barroll (2019) Section 9.7, and also the flip side of the “double whammy” and “positive feedback effect” that Dr. King describes in his 2019 rebuttal on page 11 and 12. **In summary, any improvement to EBID’s Allocation will help start a “virtuous” cycle, in which greater surface water supplies to EBID improve the Project delivery performance, leading to a greater total Project Supply.**

This result is consistent with the general operating principles of large irrigation systems: water is applied upstream provides return flows for downstream parts of the system. Diversion of these return flows (recycling), allows the same water to diverted 2 or 3 times as it passes downstream. In our case, the extra water to EBID also improves aquifer conditions in the upper part of the Project by reducing stream flow losses and improving drain flows, contributing to an increase in the total amount of deliverable Project Supply.

R13 ADDITIONAL REFERENCES:

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Appendix A to Rebuttal Report of Margaret Barroll, Ph.D.

NO. 141, ORIGINAL ACTION IN THE SUPREME COURT OF THE UNITED STATES

TEXAS v. NEW MEXICO AND COLORADO

June 15, 2020

Prepared for: State of New Mexico

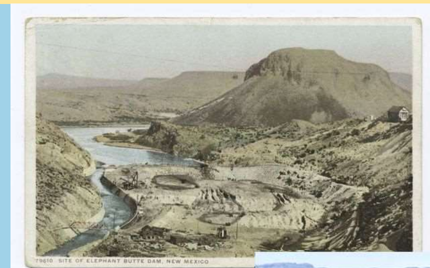
1

Elephant Butte 2012

2

1. Introduction to Rio Grande Project

- Basics:
  - Origin and Scope
  - Districts
  - Geography
  - Infrastructure
- Sources of Water:
  - Reservoir Release
  - Return Flows
  - Inflows below Caballo
- Project Water Users
  - Farmers (irrigation)
  - City of El Paso (drinking water/other municipal use)



New York Public Library

Las Cruces Sun

Rio Grande Project

- The Project was designed to deliver water in New Mexico and Texas, and to Mexico.
  - Authorized by Congress in 1905
  - Construction began 1912
  - Began deliveries of water in 1915 (while still under construction)
- New Mexico farmers district: Elephant Butte Irrigation District (EBID)
- Texas farmers district: El Paso County Water Improvement District #1 (EPCWID or EP1)
  - Texas has added the City of El Paso under Miscellaneous Purposes Act Contracts

Rio Grande Project

- The Project was already in place at the time of the 1938 Rio Grande Compact.
- A 1938 Contract between the Districts sets forth a division of Project water supply between the Districts in accordance with the proportions of Project acreage: 88,000 of 155,000 Project acres (57%) to EBID, and 67,000 of 155,000 Project acres (43%) to EPCWID.
- The 1938 Compact limits Project Supply to “Usable Water in Storage” not including Compact Credits

Sources of Project Supply

- **Project Storage**: Water released from Caballo and diverted at Project canal headings
- **Return Flows**: Water that had been diverted by a Project user and then returned to the Project (drain flows, Project waste, effluent)
- **Drain Flows**: Water discharged from drains that can be diverted within Project
- **Municipal Effluent**: Treated municipal wastewater that can be diverted within the Project
- Any other usable inflows below Caballo Dam (storm flows)

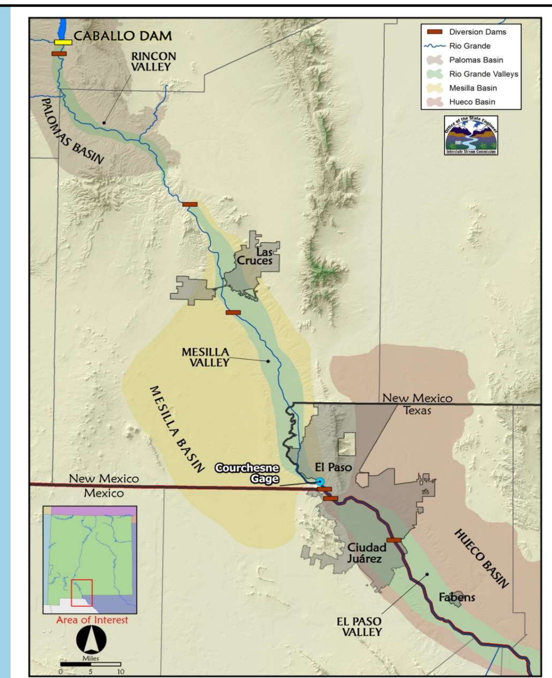
Geography

Project lands are within river valleys, with thin alluvial aquifers

- Rincon Valley
- Mesilla Valley
- El Paso Valley

These valleys are within larger Sedimentary Basins

- Palomas Basin
- Mesilla Basin
- Hueco Bolson



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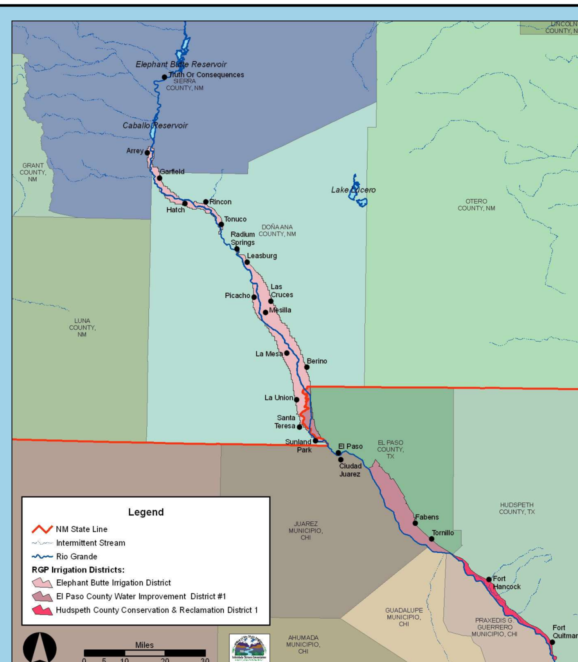
RGP Map

Districts limited to Authorized Acreages:

EBID: 88,000 acres
(+ 3% Cushion: 90,640 acres)
~57% of Project Authorized Acreage

EPCWID : 67,000 acres
(+ 3% Cushion: 69,010 acres)
~43% of Project Authorized Acreage



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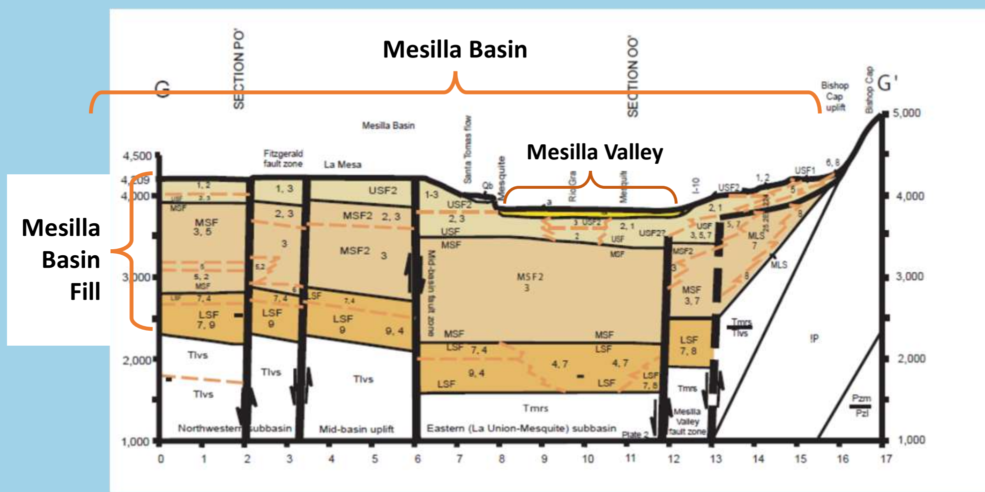
Cross Section: West to East

River valleys, with thin riverine alluvial sediments, incised into larger deep basins



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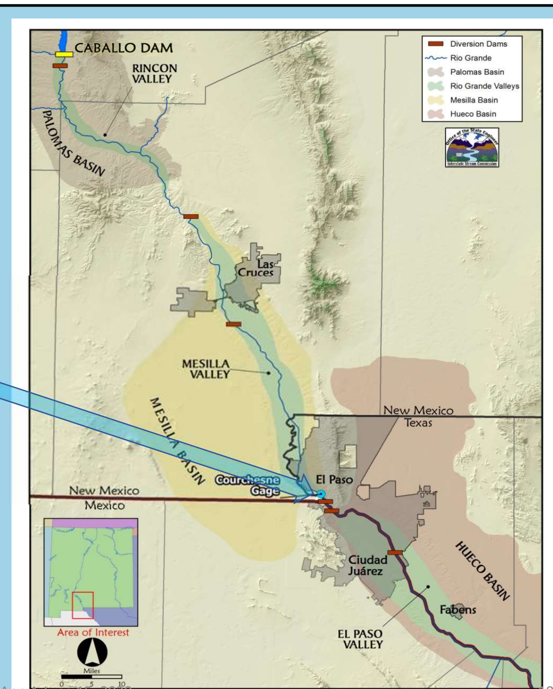
Geography

Natural dividing point at El Paso: Courchesne Gaging Station

Separates:
Mesilla Basin from Hueco Bolson
and
Mesilla Valley from El Paso Valley



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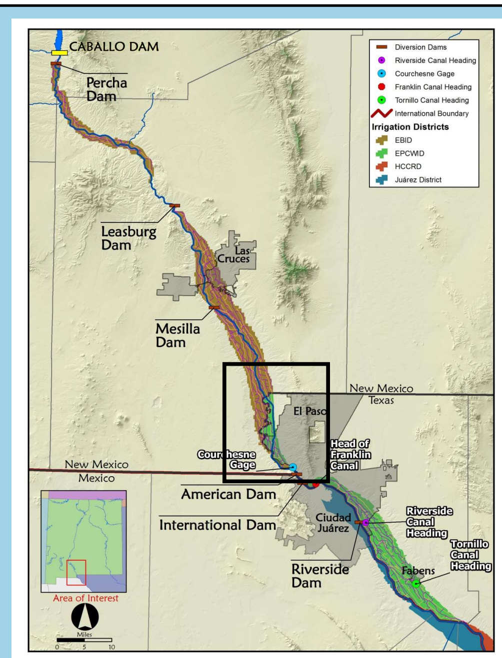
Part of EPCWID is located above Courchesne, in the Mesilla Valley.



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These Broad Areas Will be Explained in Detail

- Operations
  - Reservoir release calculated to meet orders, including gains and losses between reservoir and delivery points.
  - Districts order water to be delivered to their canal headings
  - Operational history: change in 1979, change in 2006
- Groundwater Pumping
  - 1950's drought: irrigation wells drilled throughout Project by farmers in response to insufficient Project Supply
- Project Allocation and Accounting
  - Before 1979 Reclamation allotted Project water directly to farmers
  - 1979 to present Reclamation allocates Project water to Districts
    - Districts allot water to farmers
  - Formal Project Accounting was created (post-1978 Accounting)

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2. Entitlement and Delivery of Project Water Between Districts From Early Project until 2006

- Early Project through 1978
  - Each authorized acre equally entitled to order Project Water
  - Authorized Acreage split between Districts 57:43
  - Implicit split in Project water entitlement: 57:43
  - Actual District deliveries varied but were generally consistent with 57:43
- 1979 – 2005: Reclamation allocated water to Districts:
  - No formal operating agreement in place
  - Total Allocation based on D1/D2 Curve, developed using WDR delivery data from 1951 – 1978
  - Allocation split explicitly 57% to EBID, 43% to EPCWID
  - Actual District deliveries varied but were generally consistent with 57:43

Project Allocation and Accounting

Allocation determines how much water each District is entitled to order each year (prior to 1979 this took the form of allotment to farmers defining their order entitlement).

Accounting is a "post-fact" determination of how much of its Allocation each District actually received each year.

3. Change of Project Allocation in 2006

- Concerns about reduced Project delivery performance and the effects of NM groundwater pumping resulted in new Allocation Procedure:
  - EBID proposed D3 Allocation in 2006
  - EPCWID demanded Carryover of unused Allocation
  - Partially implemented starting in 2006
- Negotiation between Districts and US led to a settlement: the 2008 Operating Agreement (2008 OA)
- 2008 OA includes D3 Allocation plus Carryover
  - EPCWID is guaranteed Allocation consistent with D2 levels
  - All negative departures from the D2 Curve are taken out of EBID's Allocation
  - Any unused District Allocation (up to set limits) can be carried over into following year

4. Allocation and Delivery Amount Changes under D3 Allocation plus Carryover

- EBID's Allocation and diversion in full-supply years dropped by approximately one-third - more than 150,000 AF
- EPWCID's Allocation in full-supply years increased by approximately 20,000 AF, plus any allocation "carried over"
- On average, the split of Current-Year Allocation between the Districts changed from:
  - Pre-2006: 57% to EBID; 43% to EPCWID
  - 2006 – 2019: 43% to EBID; 57% to EPCWID
- On average, the split of Charged Diversions between the Districts changed from:
  - 1979 – 2006: 58% to EBID; 42% to EPCWID
  - 2006 – 2019: 47% to EBID; 53% to EPCWID

5. Cause of EBID's Allocation Reduction

EBID's Allocation is reduced for any negative departure from historical Project performance as defined by the D2 Curve.

- The US and TX argue that the negative departure from D2 is caused predominantly or entirely by excess groundwater pumping (or depletions) in New Mexico.
- New Mexico argues that part of the negative departure from D2 may indeed be caused by NM actions, but not ALL of that departure is caused by NM.
- Instead, NM argues that a significant part of the problems with Project Performance are caused by non-New Mexico factors.

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6. Accounting Factors that Effect Project Performance

- The D2 Curve was developed from diversion data from 1951 – 1978.
- This diversion data is calculated very differently than current Charged Diversions. Charged Diversions omit diversions that were included in the D2 Curve.
- Under D3 Allocation, EBID's Allocation is reduced when total Charged Diversions fall short of the D2 Curve.

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7. Accounting Factors

a) Off-Season Diversions

b) El Paso Valley Effluent

c) c) El Paso Valley Drain Flow

8. How do these Accounting Factors Affect the Distribution of Project Supply?

- Off-Season diversions: The D2 Curve is artificially inflated by the inclusion of flows that are no longer counted. Under D3 Allocation, EBID's allocation is reduced for any negative departure from the D2 Curve, therefore EBID's allocation is being artificially reduced.
- EPWU effluent: EPCWID diverts and uses the effluent it gets from EPWU in the El Paso Valley. Because this water use is not charged to EPCWID, the sum of the Charged Diversions is lower than it should be, increasing the discrepancy between Charged Diversion and the D2 Curve.
- El Paso Valley drain flow: Again, the D2 Curve is artificially inflated by the inclusion of flows that no longer exist or are no longer counted as Charged Diversions.

9. Effects of Pumping in the Hueco Bolson / El Paso Valley

- As in New Mexico, Texas groundwater pumping can
  - Reduce discharge of groundwater into drains, reducing Project Supply
  - Increase seepage from streams and canals, reducing Project efficiency

10. American Canal Extension Credit

- American Canal Extension (ACE) built to bypass a losing reach of the Rio Grande between American Dam and Riverside Canal heading.
- Losses in the reach of the Rio Grande were caused/exacerbated by groundwater pumping in the Hueco Bolson, largely by Texas.
- ACE mitigates these losses, but then EPCWID gets a credit for having done so (up to ~20,000 AF).
- ACE Credit applied under 2008 OA reduces EBID's Allocation.
- ACE Credit gives EPCWID (and thus Texas) a credit for mitigating a problem caused by Texas.

11. Effects of Carryover on EBID and New Mexico

- EBID's Allocation is now so low it can make little use of Carryover.
- EPCWID's Allocation in full-supply years is much higher than its demand, and so it can carry over large amounts of unused Allocation.
- Under the 2008 OA, Carryover plus water needed to deliver it is subtracted from Usable Water before performing Current-Year Allocation.
- Carryover accounts are never reduced for evaporation and may include paper water.
- EPCWID's large Carryover accounts have acted to reduce Current Year Supply and the amount of water allocated to EBID.

12. Net Effect of 2008 OA on EBID and New Mexico

- D3 Reduces Allocation to EBID
  - Reduces aquifer recharge from canal seepage
  - Increases need for groundwater pumping to meet demand
- Groundwater levels in Rincon and Mesilla valleys decline further
  - Drain flows decrease
  - River losses increase
- Further reduction in Project performance
- Further reduction in EBID's Allocation

Net Result: Vicious Cycle
(Double Whammy/Positive Feedback Loop as stated by Dr. Phil King)

13. US Claim: D3 Reallocation is Necessary to Offset NM Pumping Impacts on EPCWID and Protect EPCWID's Project Supply

- US provides no technical analysis to quantify the effect of NM pumping on Project Supply or EPCWID deliveries
- New Mexico pumping has not greatly increased since D2 Period
- A significant part of the apparent discrepancy from D2 is caused by factors other than New Mexico pumping

14. Neither TX nor US Refute Barroll Analysis Showing:

- Before 2006 EBID and EBID farmers were entitled to order 57% of US Project Supply.
- Before 2006 the actual distribution of Project Supply between the Districts was approximately 57% to EBID and 43% to EPCWID.
- Starting in 2006 there was a large reduction in the share of Project Supply allocated to EBID and the share of water EBID received.
- The large reallocation that began in 2006 is due to the new D3 Allocation method plus Carryover,
  - D3 Allocation reduces EBID's Allocation for all negative departures in Project performance from historical levels defined by the D2 Curve.
- A significant part of the negative departure from D2 is caused by changes in Project Accounting and other factors not related to New Mexico.

15. Neither TX nor US Refute Barroll Analysis Showing:

- EBID's Allocation is now so low that it is impossible for EBID to take advantage of Carryover.
- EPCWID has been able to create large Carryover accounts from its unused allocation in full-supply years. Part of the reason EPCWID can accumulate large amounts of unused Allocation is because it can now use El Paso municipal effluent in the El Paso Valley - free of charge.
- Carryover is never reduced for evaporation. Carryover may include paper water. EPCWID's large Carryover account can reduce the amount of water available for Current-Year Allocation, and thus the amount of water allocated to EBID.

SUPPORT FOR BARROLL'S OPINIONS AND HOW THEY WERE DERIVED

The numbered topic headings below correspond to the Barroll opinions expressed above

Project Infrastructure

- Reservoirs
- Diversion Dams
- Canals
- Drains
- Wasteways

Project Infrastructure: Reservoirs Used for Project Storage

Elephant Butte Dam
- Completed: 1916
- Maximum Storage: ~ 2,000,000 AF

Cortez 2003

Project Infrastructure: Reservoirs Used for Project Storage

- Caballo
  - Dam Completed: 1938
  - Maximum Storage: ~ 330,000 AF

Cortez 2003

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Project Infrastructure: Diversion Dams

Small Dams on the Rio Grande that can divert water into Project conveyances

Percha Dam (Cortez 2003)

Leasburg Dam (Cortez 2003)

American Dam (Cortez 2003)

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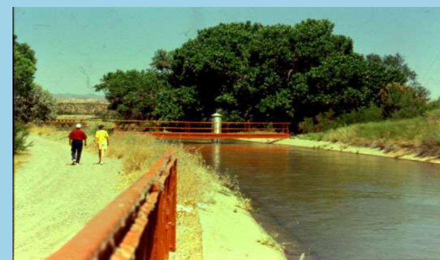
Rio Grande Project Conveyances

- Canals: > 100 miles
- Laterals: > 400 miles

Arrey Canal (Cortez 2003)



American Canal (Cortez 2003)

Riverside Canal (Cortez 2003)

Project Diversion Dams and Main Canals in New Mexico

Rincon Valley, New Mexico

- Arrey Canal diverts from Rio Grande at Percha Dam

Project Diversion Dams and Main Canals in New Mexico

Mesilla Valley, New Mexico and Texas

- Leasburg Canal diverts from Rio Grande at Leasburg Dam
- Eastside and Westside Canals divert from Rio Grande at Mesilla Dam (serving lands in both NM and TX)

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Project Diversion Dams and Main Canals in El Paso Valley Texas / Mexico

El Paso Valley, Texas

- American Canal diverts from Rio Grande at American Dam
- Franklin Canal diverts from American Canal
- Riverside Canal diverts from American Canal Ext.
- Tornillo Canal supplied by Riverside Canal Ext.

Mexico

- Acequia Madre diverts from Rio Grande at International Dam

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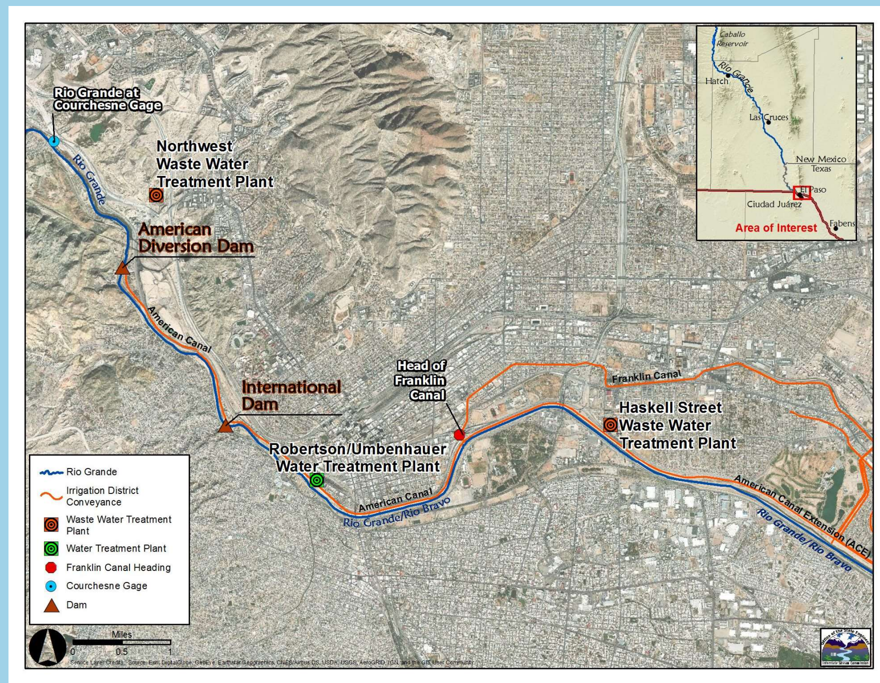
Details in El Paso Area



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Project Infrastructure: Wasteways

Conveyances used to return unused water to the Rio Grande

- Waste: excess water needed to
  - Push deliveries throughout system
  - Keep level of water in canal high enough to allow gravity flow into farm ditches
- Bypass water historically transported through canals rather than in riverbed for reasons of efficiency
  - El Paso Carriage in New Mexico, Ascarate Wasteway in Texas.

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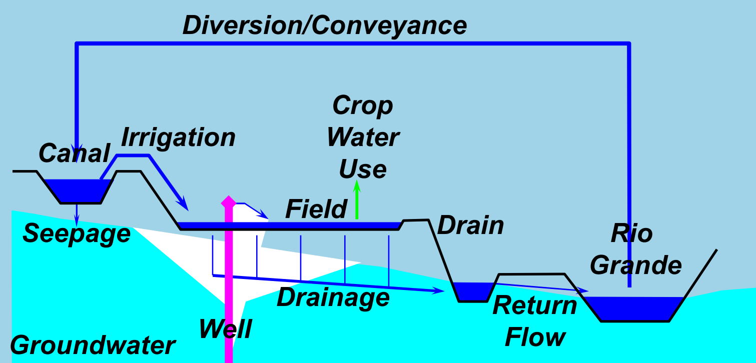
Rio Grande Project Water Distribution Cycle (from King, 2003)



King 2003

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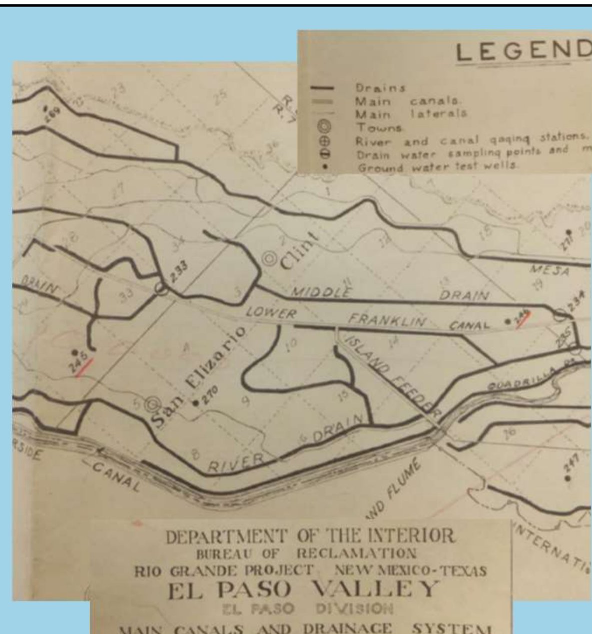
Project Infrastructure: Drains

- Drains take in groundwater from water-logged lands, and return that water to Rio Grande
- Drains were installed from about 1918 – 1925 throughout entire Project
- Drain flow returning to Rio Grande above a Project canal heading is diverted and used within the Project (a form of Project return flow)



Map from the Papers of Raymond Hill

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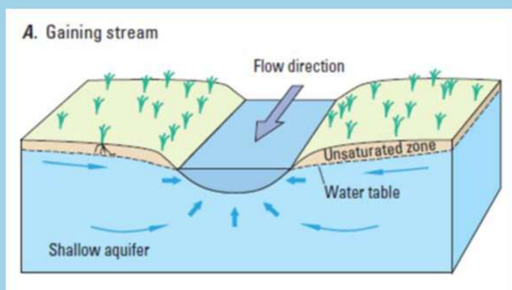
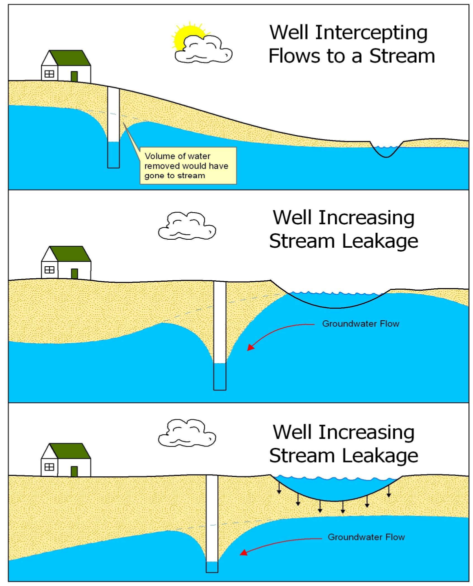
Drains

Active drains are "gaining streams"
Like streams, their flows can be depleted by groundwater pumping



MMA 2019



Importance of Drains

- Drains represent direct groundwater-surface water interaction
- Drain flows are a direct measurement of groundwater discharge
- Drain flows are directly dependent on groundwater levels

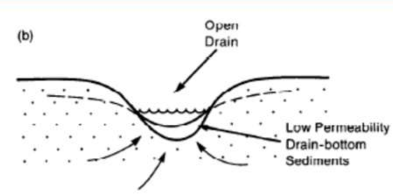
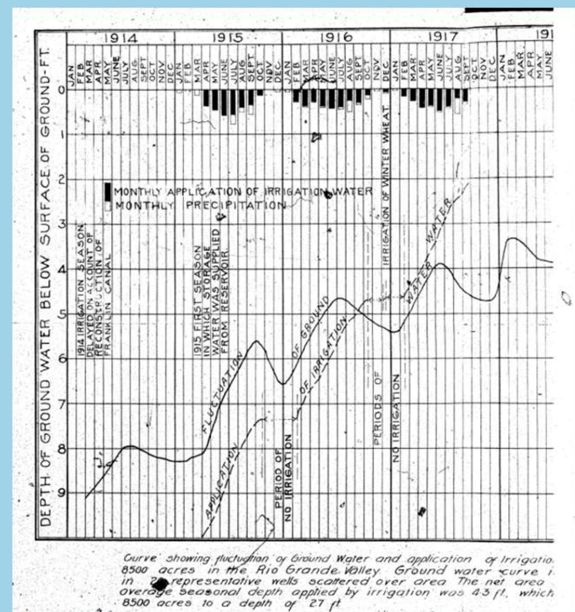


Figure 40.—Factors affecting head loss immediately around a drain: (a) buried drain pipe in backfilled ditch and (b) open drain.

McDonald and Harbaugh, 1988, USGS Techniques of Water Resource Investigations, Chapter A1, A Modular Three-Dimensional Finite-Difference Groundwater Model (MODFLOW).

Importance of Drains to Project

- In the early years of the Project, excess application of irrigation water throughout the Project caused water levels to rise, waterlogging lands
- Eventually over 450 miles of drains were installed, salvaging and protecting these lands



Rio Grande Project History 1918

Importance of Drains to LRG Studies

- Accurate groundwater discharge/recharge measurements are vital to developing a well-supported groundwater measurement.
- Drain flows are a great measure of groundwater discharge (although minor amounts of waste or storm flow are included in measurements)
- Groundwater discharge to Rio Grande main stem, or seepage from the Rio Grande, is much more difficult to measure accurately due to the large amount of surface water that is flowing through “on top of” any surface water - groundwater interaction.

For Decades Reclamation Kept Meticulous Records of Drain Flows

Major drains were gaged


UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
DAILY discharge, in second-feet, at EAST DRAIN, for 1938
USBR

Reclamation reported drain flow data in Project Histories

Rio Grande Project History 1944

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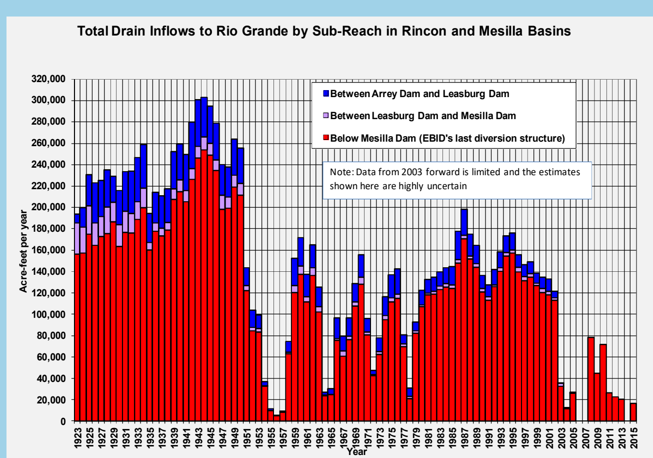
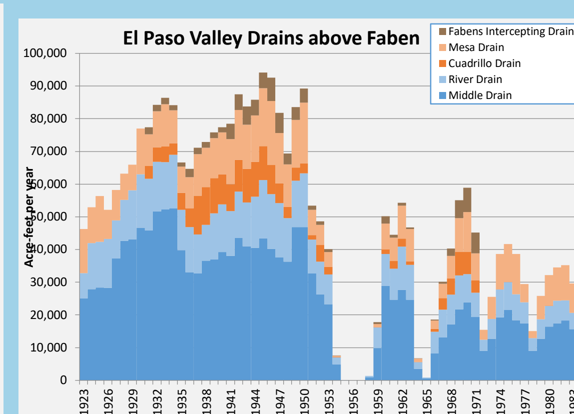
Historical Drain Flow Data





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Changes to Project Infrastructure in Rincon and Mesilla Valleys: Minimal

Addition of Caballo Reservoir

Caballo Dam completed 1938

Purposes: flood control and Project storage

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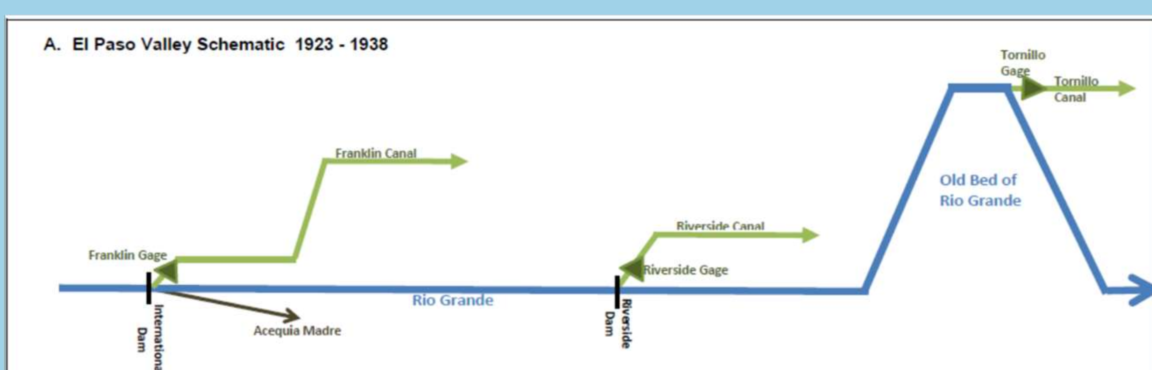
Changes to Project Infrastructure in EPV: Significant

- Pre-1938 EPCWID diversions
  - Franklin Canal from Rio Grande at International Dam (charge point ◀)
  - Riverside Canal from Rio Grande at Riverside Dam (charge point ◀)
  - Tornillo Canal from Rio Grande at Fabens (charge point ◀)



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Rio Grande Rectification and American Canal Project 1938

- 1939 - 1998 EPCWID Irrigation Diversions
  - American Canal from Rio Grande at American Dam
  - Franklin Canal from American Canal (charge point ◀)
  - Riverside Canal from Rio Grande at Riverside Dam (charge point ◀)

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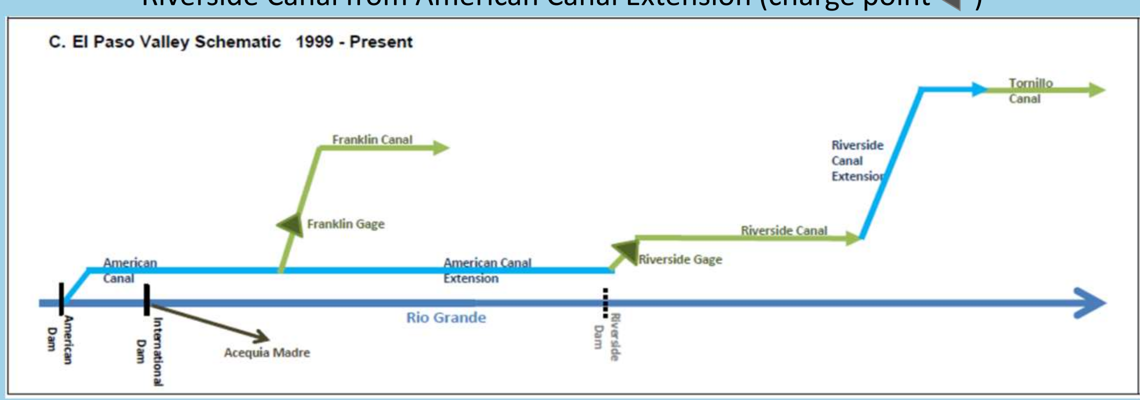
1999: American Canal Extension

- 1999 – Present: EPCWID irrigation diversions
  - American Canal from Rio Grande at American Dam
  - Franklin Canal from American Canal (charge point◀)
  - Riverside Canal from American Canal Extension (charge point ◀)



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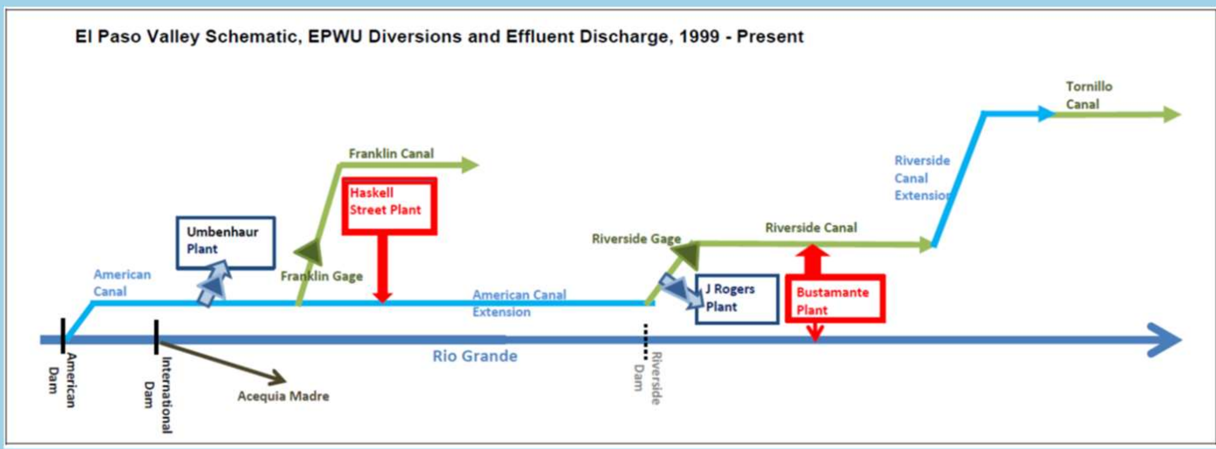
Same Schematic as Prior Slide Including El Paso Water Utility (EPWU) Diversions and Returns within EPCWID



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Non-Irrigation Project Water Use / M&I

- City of El Paso/ El Paso Water Utility (EPWU)
  - Municipal diversions of Project water started in ~1944
    - Project water supplemented existing municipal El Paso groundwater pumping
  - Groundwater sources
    - Canutillo well field in Mesilla Basin ~24,000 AF/yr
    - Hueco Bolson well field ~40,000 – 80,000 AF/yr
  - Project water diversions to Water Treatment Plants (WTP)
    - Up to 60,000 AF/yr
    - Umbenhauer/Canal WTP diverts from American Canal
    - Jonathan Rogers WTP diverts from Riverside Canal

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EPWU Sources of Supply

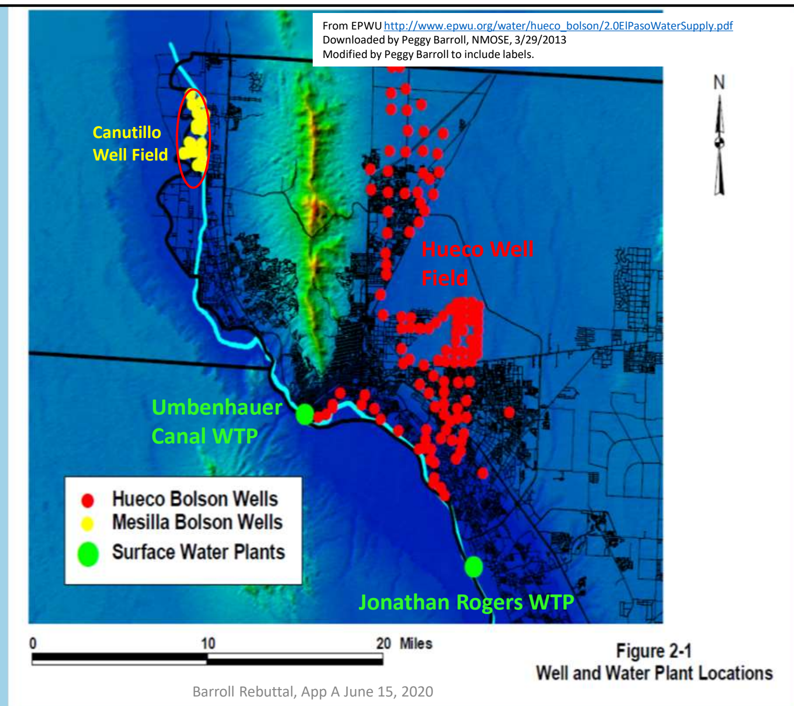

Figure 2-1
Well and Water Plant Locations

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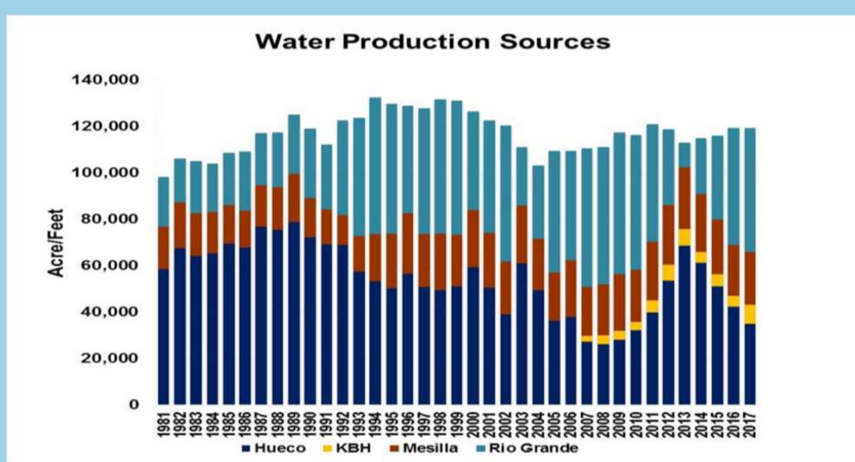
EPWU Historical Sources of Supply



Downloaded from EPWU Website

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EPWU Wastewater System

Treated SW/GW Effluent Discharge from Wastewater Treatment Plants (WWTP):

-Northwest WWTP
-Haskell WWTP
-Bustamante WWTP

From EPWU http://www.epwu.org/water/hueco_bolson/2.0ElPasoWaterSupply.pdf
Downloaded by Peggy Barroll, NMOSE, 3/29/2013
Modified by Peggy Barroll to label Canutillo well Field and to include Wastewater Treatment Plants (WWTP).

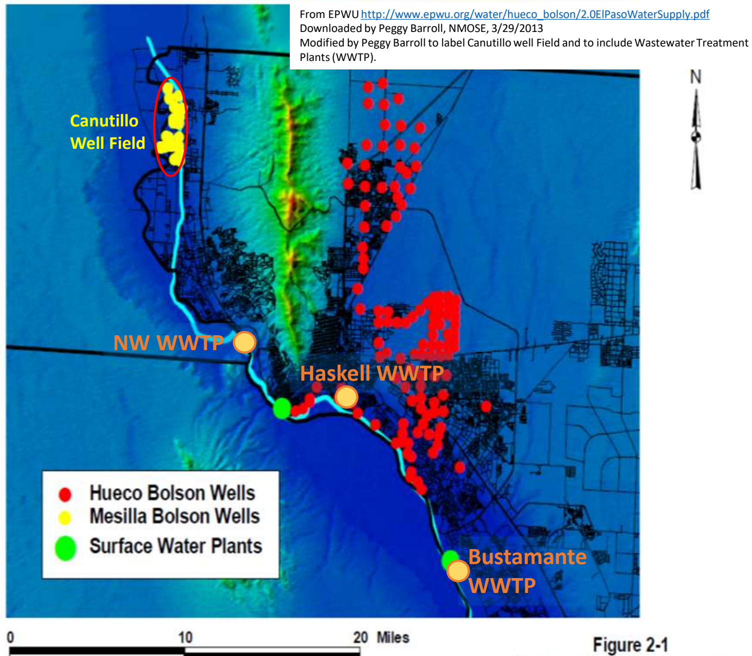


Figure 2-1
Well and Water Plant Locations

General Project Operations

- Reclamation allots or allocates water to Project beneficiaries and Mexico
- Mexico's Allocation is delivered according to a schedule provided by the US State Department
- EBID and EPCWID order water from Reclamation on an ongoing basis during the irrigation season
- Reclamation releases water from reservoir storage as necessary to meet orders
- Districts divert water at canal headings
- Ditch riders deliver water to farmers

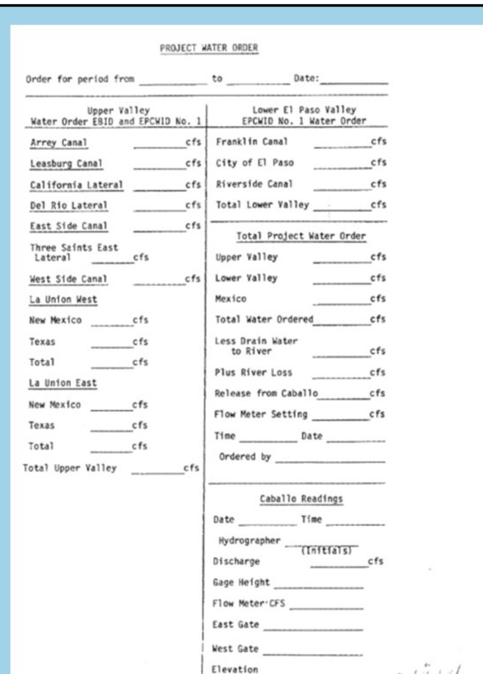
Project Operations

District/Project Level

- Districts order water from Reclamation to be delivered to main canal headings
- A District may continue to order water until it has used up its Allocation
- Releases from reservoir Storage are made in response to orders
- Amount released is the amount needed to deliver District orders to the canal heading, considering Supply already in the system

Project Orders

- Districts order water in terms of cubic feet per second (cfs) at their canal headings
- Reclamation will adjust the gate at Caballo Dam as necessary for the release rate in order to get the orders to the canal headings
  - If there are losses along the way, Reclamation increases the Caballo release accordingly
  - If there are gains along the way, Reclamation decreases the Caballo release accordingly



PROJECT WATER ORDER

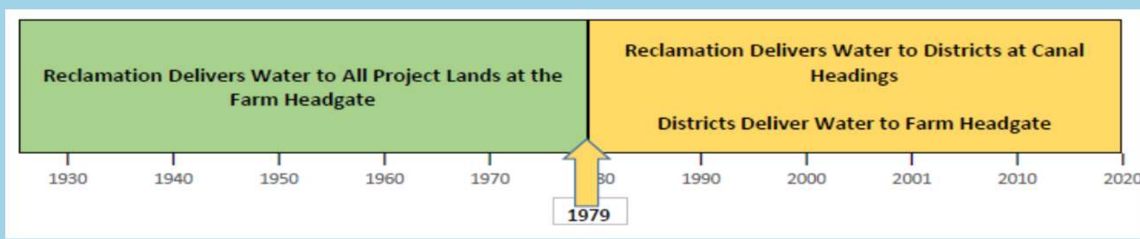
Order for period from __________ to __________ Date: __________

Upper Valley Water Order EBID and EPCWID No. 1	Lower El Paso Valley EPCWID No. 1 Water Order
Arrey Canal ______ cfs	Franklin Canal ______ cfs
Leasburg Canal ______ cfs	City of El Paso ______ cfs
California Lateral ______ cfs	Riverside Canal ______ cfs
Del Rio Lateral ______ cfs	Total Lower Valley ______ cfs
East Side Canal ______ cfs	Total Project Water Order
Three Saints East Lateral ______ cfs	Upper Valley ______ cfs
West Side Canal ______ cfs	Lower Valley ______ cfs
La Union West	Mexico ______ cfs
New Mexico ______ cfs	Total Water Ordered ______ cfs
Texas ______ cfs	Less Drain Water to River ______ cfs
Total ______ cfs	Plus River Loss ______ cfs
La Union East	Release from Caballo ______ cfs
New Mexico ______ cfs	Flow Meter Setting ______ cfs
Texas ______ cfs	Time ______ Date ______
Total ______ cfs	Ordered by ______
Total Upper Valley ______ cfs	Caballo Readings
	Date ______ Time ______
	Hydrographer ______ (Initials)
	Discharge ______ cfs
	Gage Height ______
	Flow Meter CFS ______
	East Gate ______
	West Gate ______
	Elevation ______

Overview of Operational History

Two major regimes:

- Pre-1979: Reclamation delivered water to farmers, operating Project as one entity
- 1979 forward: After the Districts payed off Project construction loans, Transfer Contracts were executed. Now Reclamation delivers water to Districts, and the Districts deliver water to farmers



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Irrigation Wells in the Rio Grande Project

- Farmers throughout the Project drilled irrigation wells during 1950's drought
- Irrigation wells drilled during 1950's drought:
  - EBID: ~1,200 wells
  - EPCWID: ~750 wells
- Reclamation encouraged farmers to use well water if possible
- Reclamation helped farmers use Project conveyances to distribute well water
- Probably (almost) all irrigated acres within Project received well water during 1950's drought

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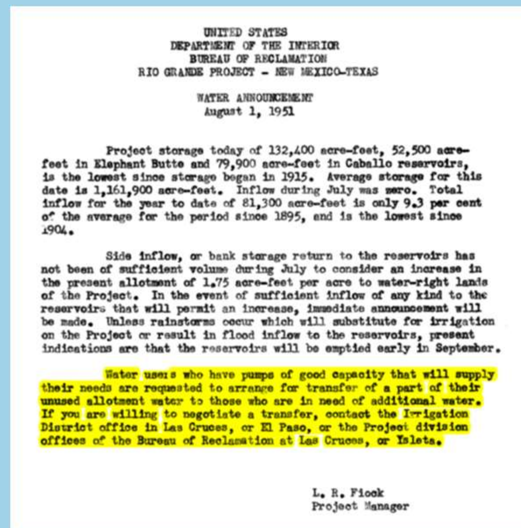
Quotes from Project Announcements

1951: “Water users who have pumps of good capacity that will meet their needs are requested to arrange for transfer of a part of their unused allotment water to those who are in need of additional water.”



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DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
RIO GRANDE PROJECT - NEW MEXICO-TEXAS

WATER ANNOUNCEMENT
August 1, 1951

Project storage today of 132,400 acre-feet, 52,500 acre-feet in Elephant Butte and 79,900 acre-feet in Caballo reservoirs, is the lowest since storage began in 1915. Average storage for this date is 1,161,900 acre-feet. Inflow during July was zero. Total inflow for the year to date of 81,300 acre-feet is only 9.3 per cent of the average for the period since 1895, and is the lowest since 1904.

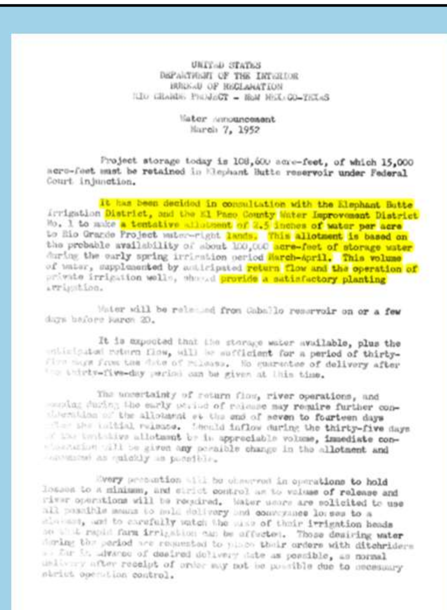
Side inflow, or bank storage return to the reservoirs has not been of sufficient volume during July to consider an increase in the present allotment of 1.75 acre-feet per acre to water-right lands of the Project. In the event of sufficient inflow of any kind to the reservoirs that will permit an increase, immediate announcement will be made. Unless rainstorms occur which will substitute for irrigation on the Project or result in flood inflow to the reservoirs, present indications are that the reservoirs will be emptied early in September.

Water users who have pumps of good capacity that will supply their needs are requested to arrange for transfer of a part of their unused allotment water to those who are in need of additional water. If you are willing to negotiate a transfer, contact the Irrigation District office in Las Cruces, or El Paso, or the Project division offices of the Bureau of Reclamation at Las Cruces, or Isleta.

L. R. Fiock
Project Manager

Quotes from Project Announcements

1952: “It has been decided … to make a tentative allotment of 2.5 inches of water per acre… This volume of water, supplemented by anticipated return flow **and the operation of private irrigation wells**, should provide a satisfactory planting irrigation.”



UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
RIO GRANDE PROJECT - NEW MEXICO-TEXAS

Water Announcement
March 7, 1952

Project storage today is 108,600 acre-feet, of which 15,000 acre-feet must be retained in Elephant Butte reservoir under Federal Court injunction.

It has been decided in consultation with the Elephant Butte Irrigation District, and the El Paso County Water Improvement District No. 1 to make a tentative allotment of 2.5 inches of water per acre to Rio Grande Project water-right lands. This allotment is based on the probable availability of about 100,000 acre-feet of storage water during the early spring irrigation period March-April. This volume of water, supplemented by anticipated return flow and the operation of private irrigation wells, should provide a satisfactory planting irrigation.

Water will be released from Caballo reservoir on or a few days before March 20.

It is expected that the storage water available, plus the anticipated return flow, will be sufficient for a period of thirty-five days from the date of release. No guarantee of delivery after the thirty-five-day period can be given at this time.

The uncertainty of return flow, river operations, and [illegible] during the early period of release may require further consideration of the allotment at the end of seven to fourteen days after the initial release. Should inflow during the thirty-five days of the tentative allotment be in appreciable volume, immediate consideration will be given any possible change in the allotment and announced as quickly as possible.

Every precaution will be observed in operations to hold losses to a minimum, and strict control as to volume of release and river operations will be required. Water users are solicited to use all possible means to hold delivery and conveyance losses to a minimum, and to carefully watch the size of their irrigation heads so that rapid farm irrigation can be effected. Those desiring water during the period are requested to place their orders with ditchriders as far in advance of desired delivery date as possible, as normal delivery after receipt of order may not be possible due to necessary strict operation control.

Quotes from Project Operations and Maintenance Reports

Ysleta Branch (El Paso Valley) 1954 : "The year 1954 was one of the most favorable on record… reservoir storage … allowed only a 5 inch allotment to start the season… increased to a total of ½ acre foot by the end of the release period. This supply, together with several small storm flows…, drain return flow, **and water from 418 irrigation wells, installed since 1950, was enough irrigation water for almost normal requirements**."

Emphasis added

OPERATION AND MAINTENANCE OF IRRIGATION SYSTEM - 1954
YSLETA BRANCH

General Conditions

The year 1954 was one of the most favorable on record for growing cotton, and as a result the yields were record breaking. Gross farm incomes were only slightly less than the previous year. This was in spite of a reduction in cotton acreage, a very small water allotment, slightly lower cotton prices, poor alfalfa yields, and low alfalfa prices. The season started with reservoir storage at about 17 per cent of normal, which allowed only a 5 inch allotment to start the season. As very little additional inflow became available the allotment was increased to a total of 1/2 acre foot by the end of the release period. This supply, together with several small storm flows originating below Caballo Reservoir, during July and August, drain return flow, and water from some 418 irrigation wells, installed since 1950, was enough irrigation water for almost normal requirements.

The Ysleta branch of the Rio Grande Project is located along the Rio Grande River in the extreme Western tip of Texas, in El Paso County. It extends from the American Dam, which is 2 1/2 miles above the heart of the City of El Paso, to 41 miles below the city, in a Southeastern direction, to the El Paso-Hudspeth County line. The Branch is comprised of 63,739 acres of irrigable and highly productive land, it lies immediately North and East of the Rio Grande channel which marks the international boundary between the United States and Mexico.

The Branch headquarters are located at Ysleta, Texas, 12 1/2 miles East of downtown El Paso. It is comprised of an office building, machine shop, carpenter shop, storage buildings, sheds, caretakers house, and sufficient yard storage space for normal operation and maintenance activities.

The headquarters staff is comprised of an Irrigation Superintendent, two Maintenance Supervisors, two Watermasters, one Supervisory Engineering Aide, two Engineering Aides, two General Clerks, a Clerk-Stenographer, and a Storekeeper.

The elevation of the area is between 3,500 ft. and 3,650 ft. above sea level. The climate may be classified as mild, with a mean annual temperature of 61.6 degrees F., with winter temperatures varying from -6 degrees to a maximum of 86 degrees. Summer temperatures range from a minimum of 46 degrees to a maximum of 108 degrees. Average rainfall is 8.86 inches, of which more than half occurs in July, August, and September. The average frost-free period is 242 days; however, the minimum has been 176 days. Adequate storage capacity in Elephant Butte and Caballo reservoirs is a very favorable factor in providing irrigation water for the project.

Quotes from Project Operations and Maintenance Reports

Las Cruces Branch (Rincon/Mesilla Valley) 1954: "Storage water carryover was so limited that even the first irrigation had to be made with a combination of water pumped from wells and water from the storage supply…

So with the limited storage water**, water pumped from farm wells, and conveyed in part through the project canals and laterals**, and the summer showers, a combination that made possible the production of one of the best yielding crops ever produced by this Branch."

Emphasis added

OPERATION AND MAINTENANCE OF IRRIGATION SYSTEM - 1954
Las Cruces Branch

The water users and Bureau personnel again faced a severe year from the point of available water supply, in fact the storage water carryover was so limited that even the first irrigation had to be made with a combination of water pumped from farm wells and water from the storage supply.

This drought condition was greatly alloviated from mid summer on by some providential showers, that not only benefited the crops direct but also caused floods in the Rio Grande which were diverted and used to good advantage. So, with the limited storage water, water pumped from farm wells, and conveyed in part through the project canals and laterals and the summer showers, a combination that made possible the production of one of the best yeilding crops ever produced by this Branch.

The Las Cruces Branch consists of two long, narrow valleys bordered on each side by desert mesa land and in some places by low-lying hills. The Rio Grande flows through these valleys, dividing the farm lands and making it necessary to pass the irrigation water over the river through flumes and under the river through siphons.

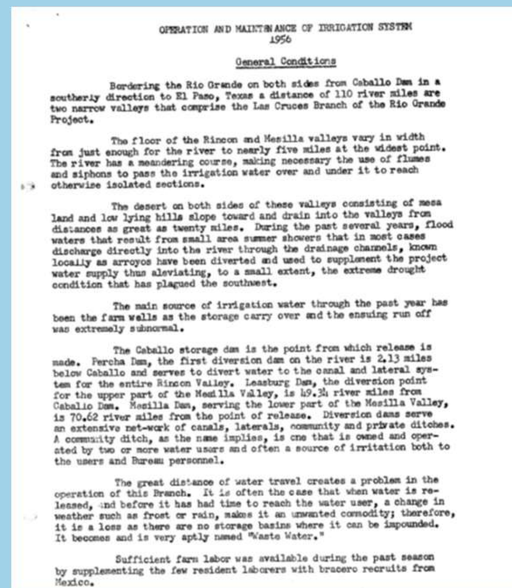
The Caballo storage dam is the point from which release is made. Percha Dam, the first diversion dam on the river, is 2.13 miles below Caballo and serves to divert water to the canal and lateral system for the entire Rincon Valley. Leasburg Dam, the diversion point for the upper part of the Mesilla Valley, is 49.34 river miles from Caballo Dam. Mesilla Dam, serving the lower part of the Mesilla Valley, is 70.62 river miles from the point of release. Diversion dams serve an extensive network of canals, laterals, community and private ditches. A community ditch, as the name implies, is one that is owned and operated by two or more water users and often a source of irritation both to the users and Bureau personnel.

The great distance of water travel creates a problem in the operation of this Branch. It is often the case that when water is released, and before it has had time to reach the water user, a change in weather such as frost or rain, makes it an unwanted commodity; therefore it is a loss as there are no storage basins where it can be impounded. It becomes and is very aptly named "waste water".

Transportation is sufficient in these two valleys; they are traversed by railroad, truck, and bus lines; also, there is an airport near Las Cruces with a daily schedule connecting with transcontinental travel to the north and south. The State and County highway systems have been improved during the past year and are now ample to care for all traffic and movement of crops from farm to market.

Quotes from Project Operations and Maintenance Reports

Las Cruces Branch 1956 : “The main source of irrigation water through the past year has been the farm wells as the storage carry over and the ensuing run off was extremely subnormal”



OPERATION AND MAINTENANCE OF IRRIGATION SYSTEM
1956

General Conditions

Bordering the Rio Grande on both sides from Caballo Dam in a southerly direction to El Paso, Texas a distance of 110 river miles are two narrow valleys that comprise the Las Cruces Branch of the Rio Grande Project.

The floor of the Rincon and Mesilla valleys vary in width from just enough for the river to nearly five miles at the widest point. The river has a meandering course, making necessary the use of flumes and siphons to pass the irrigation water over and under it to reach otherwise isolated sections.

The desert on both sides of these valleys consisting of mesa land and low lying hills slope toward and drain into the valleys from distances as great as twenty miles. During the past several years, flood waters that result from small area summer showers that in most cases discharge directly into the river through the drainage channels, known locally as arroyos have been diverted and used to supplement the project water supply thus aleviating, to a small extent, the extreme drought condition that has plagued the southwest.

The main source of irrigation water through the past year has been the farm wells as the storage carry over and the ensuing run off was extremely subnormal.

The Caballo storage dam is the point from which release is made. Percha Dam, the first diversion dam on the river is 2.13 miles below Caballo and serves to divert water to the canal and lateral system for the entire Rincon Valley. Leasburg Dam, the diversion point for the upper part of the Mesilla Valley, is 49.34 river miles from Caballo Dam. Mesilla Dam, serving the lower part of the Mesilla Valley, is 70.62 river miles from the point of release. Diversion dams serve an extensive net-work of canals, laterals, community and private ditches. A community ditch, as the name implies, is one that is owned and operated by two or more water users and often a source of irritation both to the users and Bureau personnel.

The great distance of water travel creates a problem in the operation of this Branch. It is often the case that when water is released, and before it has had time to reach the water user, a change in weather such as frost or rain, makes it an unwanted commodity; therefore, it is a loss as there are no storage basins where it can be impounded. It becomes and is very aptly named "Waste Water."

Sufficient farm labor was available during the past season by supplementing the few resident laborers with bracero recruits from Mexico.

Contemporaneous Estimates of Irrigation Well Pumping during 1950’s drought

- EBID:
  - Estimated maximum: 294,000 AF/yr
  - Gunaji 1961 (NM State University/EBID)

- El Paso Valley:
  - Estimated maximum: 125,000 AF/yr
  - Leggat 1962 (Texas Water Commission/USGS)

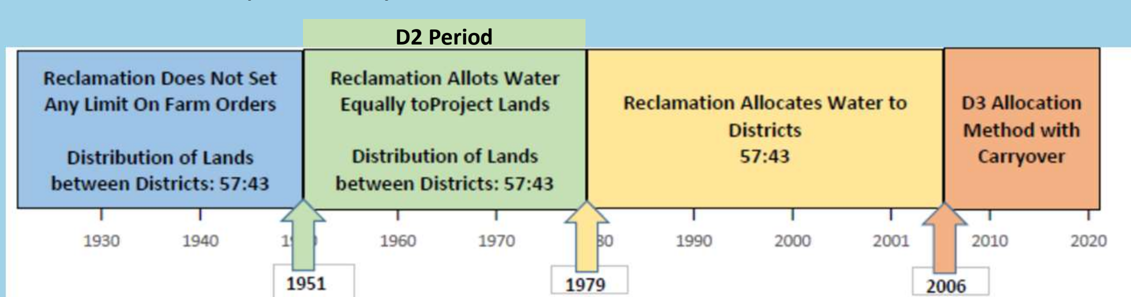
Project Allocation and Accounting

Allocation determines how much water each District is entitled to order each year (prior to 1979 this took the form of allotment to farmers defining their order entitlement).

Accounting is a "post-fact" determination of how much of its Allocation each District actually received each year.

Project Allocation

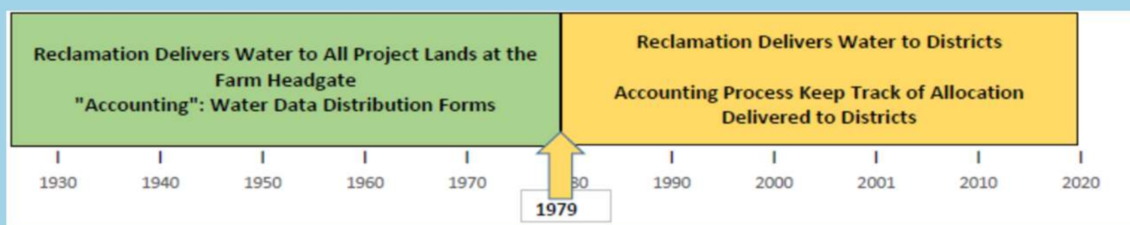
- Pre-1979: Reclamation allots equal water to all Project Acres
- 1979 – 2005: Reclamation allocates water to Districts 57:43
- 2006 – 2018: Reclamation allocates water to Districts using D3 Method plus Carryover



Project Accounting:
How the Project Keeps Track of Who Got What

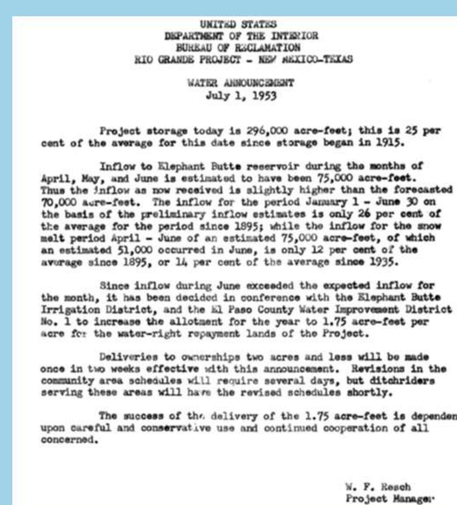
- Pre-1979: Reclamation kept track of diversions by "Units" or "Valleys" (not Districts) in Water Distribution Records (WDR)

- From 1979 on: Each District calculates its Charged Diversions using complex calculations determined by Accounting rules.



Early Allocation and Accounting: Before 1979

- Reclamation operated Project as one entity, and delivered water to farm headgates
- Allocation:
  - Starting in approximately 1951 Reclamation set limiting allotments for farm deliveries (in terms of acre-feet per acre)
  - Every authorized acre entitled to delivery of same amount water.
  - In the early 1950's Reclamation determined a full-supply allotment to be 3.024 AF/A based on data from 1946 – 1950.
- "Accounting":
  - Reclamation keep track of deliveries to "Units" or "Valleys"
  - Issued Water Distribution Reports (WDRs)



UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
RIO GRANDE PROJECT - NEW MEXICO-TEXAS

WATER ANNOUNCEMENT
July 1, 1953

Project storage today is 296,000 acre-feet; this is 25 per cent of the average for this date since storage began in 1915.

Inflow to Elephant Butte reservoir during the months of April, May, and June is estimated to have been 75,000 acre-feet. Thus the inflow as now received is slightly higher than the forecasted 70,000 acre-feet. The inflow for the period January 1 - June 30 on the basis of the preliminary inflow estimates is only 26 per cent of the average for the period since 1895; while the inflow for the snow melt period April - June of an estimated 75,000 acre-feet, of which an estimated 51,000 occurred in June, is only 12 per cent of the average since 1895, or 14 per cent of the average since 1935.

Since inflow during June exceeded the expected inflow for the month, it has been decided in conference with the Elephant Butte Irrigation District, and the El Paso County Water Improvement District No. 1 to increase the allotment for the year to 1.75 acre-feet per acre for the water-right repayment lands of the Project.

Deliveries to ownerships two acres and less will be made once in two weeks effective with this announcement. Revisions in the community area schedules will require several days, but ditchriders serving these areas will have the revised schedules shortly.

The success of the delivery of the 1.75 acre-feet is dependent upon careful and conservative use and continued cooperation of all concerned.

W. F. Resch
Project Manager

Early Project "Accounting" Data
Reclamation Water Distribution Records (WDRs)

- Reclamation Records
- Until 1979 this was the only "Accounting" data.
- Reports delivery of Project Supply at the level of "Units" or "Valleys" (not Districts)
- Net Supply (or River Headgate diversion RGH): Diversion at canal headings adjusted for by-pass
- Additional terms in El Paso Valley

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

MONTHLY WATER DISTRIBUTION

Project Rio Grande, New Mexico-Texas Mesilla Unit (East Side and West Side Canal System) Area Irrigated 48,911 Year 1958

QUANTITIES IN ACRE-FEET

Month	Diverted from Stream[1]	Inflow from— Reservoirs[2]	Inflow from— Leasburg Canal	Delivered to Reservoirs[2]	Net Supply[3]	Total Waste to River	Total Losses	Delivered to Laterals	Lateral Waste	Lateral Losses	Charged to farms Total	Charged to farms Per Acre
January,	0		0		0	0	0				0	-
February,	0		0		0	0	0				0	-
March,	29,019		0		29,019	2,980	15,449				10,190	0.22
April,	26,994		167		27,161	1,450	4,578				21,[illegible]33	0.43
May,	26,067		60		26,127	1,310	11,774				13,[illegible]43	0.27
June,	40,346		214		40,560	1,820	15,913				22,[illegible]27	0.47
July,	49,164		216		49,380	2,010	17,682				29,[illegible]88	0.60
August,	43,322		296		43,618	3,320	13,822				26,176	0.54
September,	19,569		381		19,950	4,090	4,443				11,417	0.24
October,	2,626		1,750		4,376	2,790	1,442				1[illegible]4	-
November,	0		1,550		1,550	311	1,192				[illegible]7	-
December,	0		444		444	61	365				[illegible]8	-
Total,	237,107		5,078		242,185	20,142	86,660				135,3[illegible]3	2.77
Acre ft. per acre,	4.85		0.10		4.95	0.41	1.77				2.[illegible]7	-
Per cent Net Supply,	97.9		2.1		100	8.3	35.8				55.[illegible]	-

[1] Diversion amount exclusive of waste at head gates for sand sluicing, etc.
[2] Reservoirs connected with distributing system only.
[3] Diversions plus inflow from reservoirs and other sources less delivery to reservoirs.
Measured at
Measured at

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Later Allocation and Accounting: 1979 - Present

- Reclamation delivers water to District canal heads, Districts deliver water to farmers
- Allocation:
  - Reclamation allocates to Districts (in terms of acre-feet) for diversion into canal headings
  - Until 2006, D2 Allocation Method split between Districts explicitly 57:43.
  - 2006 to present: D3 Allocation Method (**not** 57:43)
- Accounting:
  - Complex Post-1978 Accounting developed to track deliveries to Districts
  - Assorted credits evolved through time
  - Districts perform this Accounting

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Post-1978 Project Accounting

Each District performs its own monthly accounting

- Charged Diversions (Allocation charges) are based on amount ordered/diverted by each District at its charge points (canal headings)
- Complex accounting determines charges to each District for water delivered in southern Mesilla Valley
- Adjustments are made for credits
- When only one District is in operation, that District is charged for the amount released from Storage, not the amount it diverted
- Notes:
  - Districts do not always order their entire Allocation
  - Not all water diverted is charged

ELEPHANT BUTTE IRRIGATION DISTRICT
WATER ALLOTMENT CHARGES
September-10
SUBJECT TO REVISION

	GROSS DIVERSIO (AC-FT)	TO DATE	DIVERTED TO TEXAS (AC-FT)	TO DATE	NET DIVERSIONS (AC-FT)	TO DATE
ARREY CANAL	5,012	56,156			5,012	56,156
PERCHA LATERAL	26	557			26	557
LEASBURG CANAL	3,768	76,915			3,768	76,915
CALIFORNIA EXTENTION	0	400			0	400
EASTSIDE CANAL	3,898	52,330	-288	-2,047	3,610	50,283
DEL RIO LATERAL	182	2,686			182	2,686
WESTSIDE CANAL	15,433	148,352	-8,650	-54,012	6,783	94,340
PUMPED FROM RIVER**	12	66			12	66
GROSS TOTAL	28,332	337,461	-8,938	-56,059	19,394	281,403

	NET DIVERSION	TO DATE
TOTAL CHARGES (AC-FT)	19,394	281,403
CREDIT AT ARREY (-)	0	0
CREDIT AT LEASBURG (-)	0	-228
ADJUSTMENT FOR CHARGE AT HEADING (+)	80	942
NET ALLOTMENT CHARGE	19,474	282,116
DISTRICT ALLOTMENT		278,724
2010 Carryover Transfer		0
DISTRICT BALANCE		-3,392

** GREENWOOD AND DURAN RIVER PUMPS (EBID DATA)

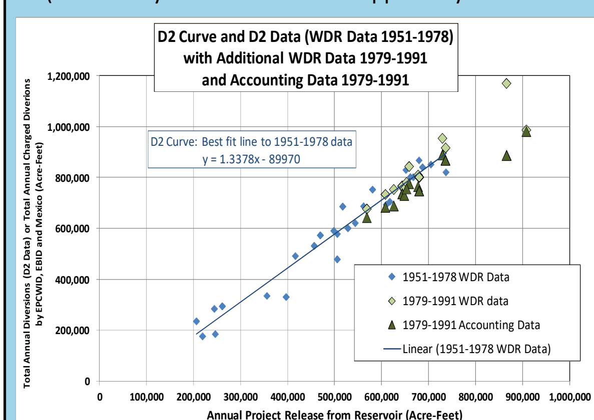
EPCWID Diversion Allocation Charges for September 2010

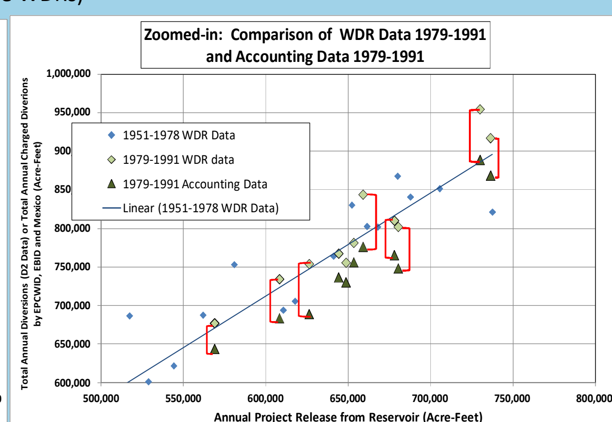
Diversion Location	Metered Volu ac-ft	Adjustment fc ac-ft	Diversion A ac-ft	Beginning-of-f ac-ft	End-of-Month ac-ft	Tota
L U E Canal - TX	3,342	95%	3,175	18,814	21,989	
L U W Canal - TX	1,114	95%	1,058	6,431	7,489	
Three Saints Lateral	243	100%	243	1,336	1,579	
Total Mesilla Valley (Texas)			4,476	26,581	31,057	
Umbenhauer/Robertson Water Treatment Plant	3,529	100%	3,529	17,649	21,179	
Franklin Canal	6,738	100%	6,738	43,933	50,670	
United States - Ysleta del Sur Agreement	0	100%	0	91	91	
United States Section - IBWC (Construction Water)	6	100%	6	0	6	
Jonathan W. Rogers Water Treatment Plant	5,100	100%	5,100	28,560	33,661	
Riverside Canal	17,830	100%	17,830	152,872	170,702	
Haskell R. Street WWTP Effluent	-1,683	100%	-1,683	-8,558	-10,240	
Credit for Diversions greater than Orders (El Paso Valley)	-365	100%	-365	-1,586	-1,951	
Totals			35,631	259,544	295,175	
Total Allotment Diversions Charges			35,631	259,544	295,175	
Diversion Allocation				505,901	516,614	
Estimated Release of Diversion Allocation for Conservation Credit				305,000	303,175	
Est. Annual Conservation Credit Diversion Allocation						17,566
Accrued Conservation Credit Diversion Allocation					17,102	
Total Diversion Allocation				520,890	533,716	
District Allotment Balance				261,346	238,541	
Estimate of Balance of 2008 Allocation at End-of-Year					230,541	

WDR Delivery Data is not Consistent with Post-1978 Accounting

There is a period of overlap, from 1979 – 1991 in which we have both kinds of data: Reclamation WDRs and post-1978 District Accounting.

(In the early 1990's the Districts apparently took over the WDRs)



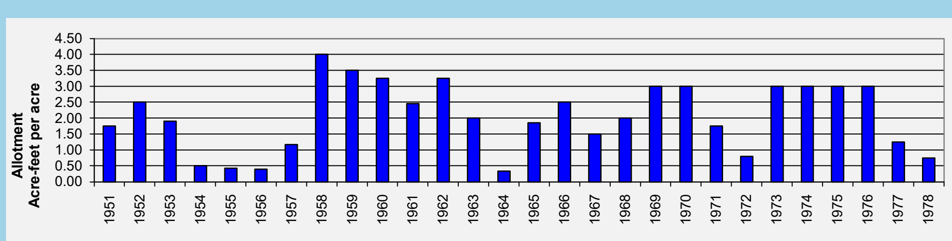


2. Entitlement and Delivery of Project Water between Districts From Early Project until 2006

- Early Project through 1978
  - Each authorized acre equally entitled to order Project Water
  - Authorized Acreage split between Districts 57:43.
  - Implicit split in Project water entitlement: 57:43
  - Actual District deliveries varied but were generally consistent with 57:43.
- 1979 – 2005: Reclamation allocated water to Districts:
  - No formal operating agreement in place
  - Total Allocation based on D1/D2 Curve, developed using WDR delivery data from 1951 – 1978
  - Allocation split explicitly 57% to EBID, 43% to EPCWID
  - Actual District deliveries varied but were generally consistent with 57:43

Pre-1979 Entitlement

- Reclamation allotted water to farms
- Every authorized Project acre entitled to equal water
  - No allotment limits set prior to 1951
  - 1951-1978 allotment (limit) set in terms of depth of water (acre-feet/acre or AF/A)
  - Authorized acreage breakdown
    - EBID: 88,000 Acres (+3% buffer, 90,640 acres) ~57%
    - EPCWID is 67,000 (+ 3% buffer, 69,010 acres) ~43%
  - <u>Thus the entitlement to water at the District level was 57:43</u>



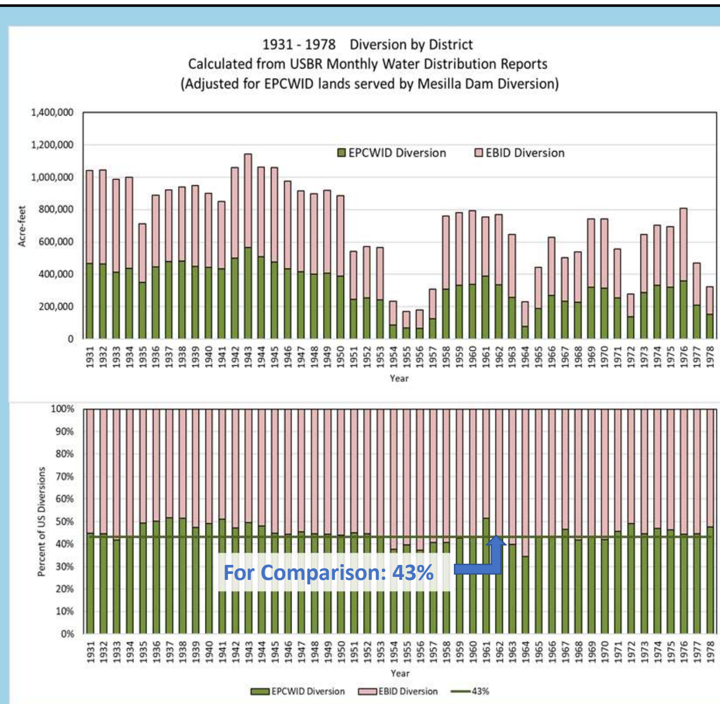
Allotment varied from year to year, but every authorized acre was entitled to the same amount.

Pre-1979 Diversions
(at Canal Headings)

Average 1931 – 1978
EBID: 55%
EPCWID: 45%

Average 1951 – 1978
EBID: 56%
EPCWID: 44%

The amounts the Districts received from 1931 – 1978 was generally **consistent** with a 57:43 split.
Note: the amount a District received depends on the amount its farmers ordered.



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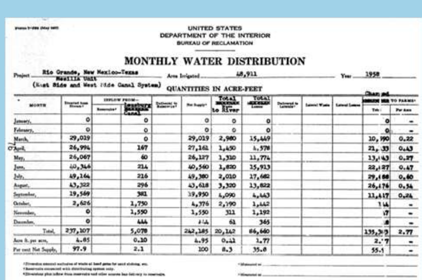
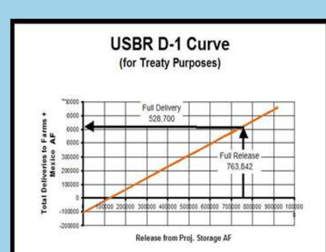
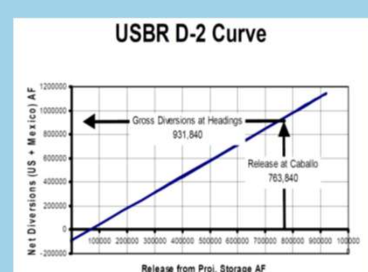
Post-1978 Project Allocation

- Reclamation starting allocating water to Districts in 1979
- Reclamation developed linear regressions between delivery data from WDRs for the period 1951 – 1978. These regressions are the D1 and D2 Curves.
- D1/ D2 Allocation method documented ~1990 in Water Supply Allocation Procedures document.







Barroll Rebuttal, App A June 15, 2020 78

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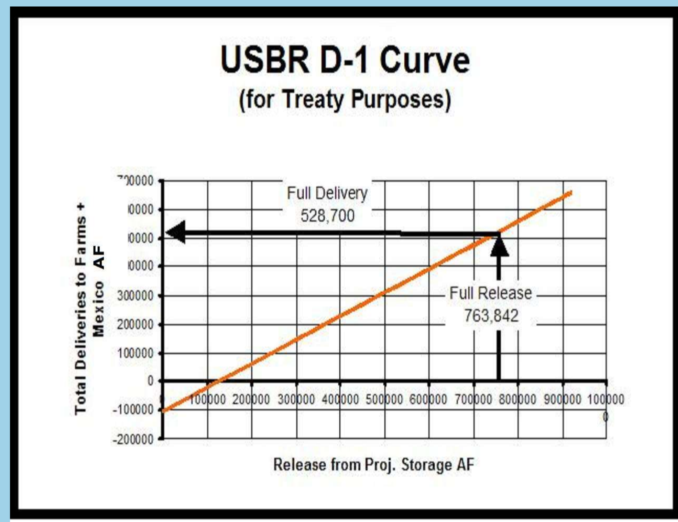
D1 Curve

- Linear Regression of data from 1951 - 1978
- X-Axis: Release from Caballo
- Y-Axis: Delivery to Farm Headgates plus Mexican diversion
- Used to determine Mexico's share based on available water in reservoir Storage



From Cortez, 2003

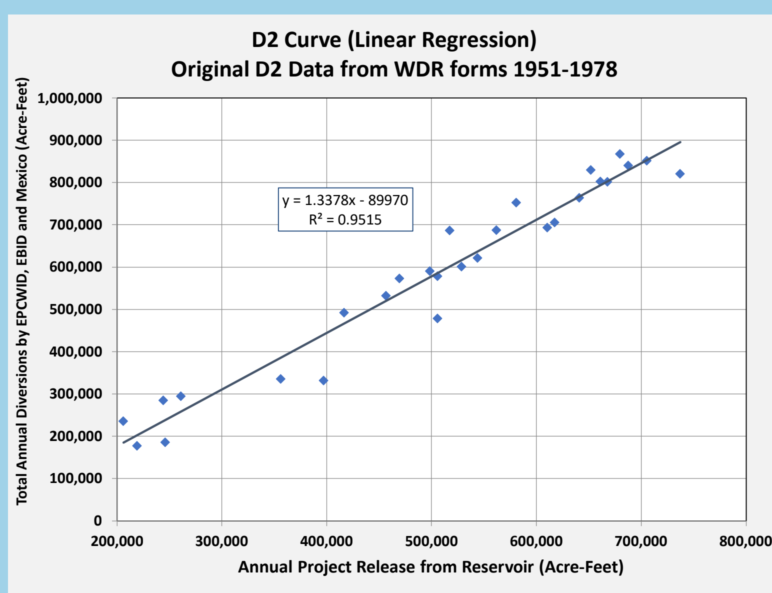
D2 Curve

A measure of Project performance or Project delivery efficiency

Linear Regression of Data from 1951 – 1978

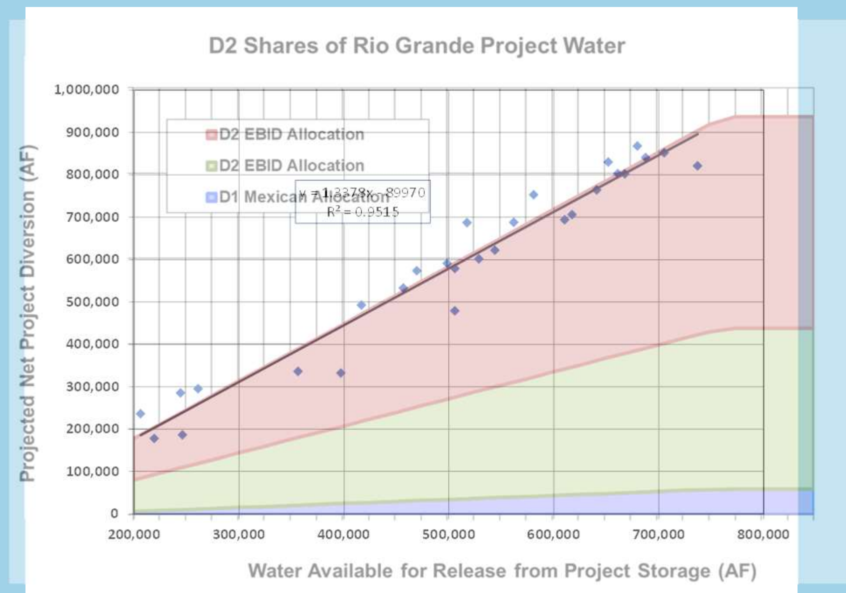
X-Axis: Annual Release from Caballo

Y-Axis: Annual Net Diversions by District and Mexico



Using the D2 Curve

Shares of Project Water to EBID, EPCWID and Mexico superimposed on D2 Curve



81

Using the D2 Curve

For a given Supply of Usable Water in Storage

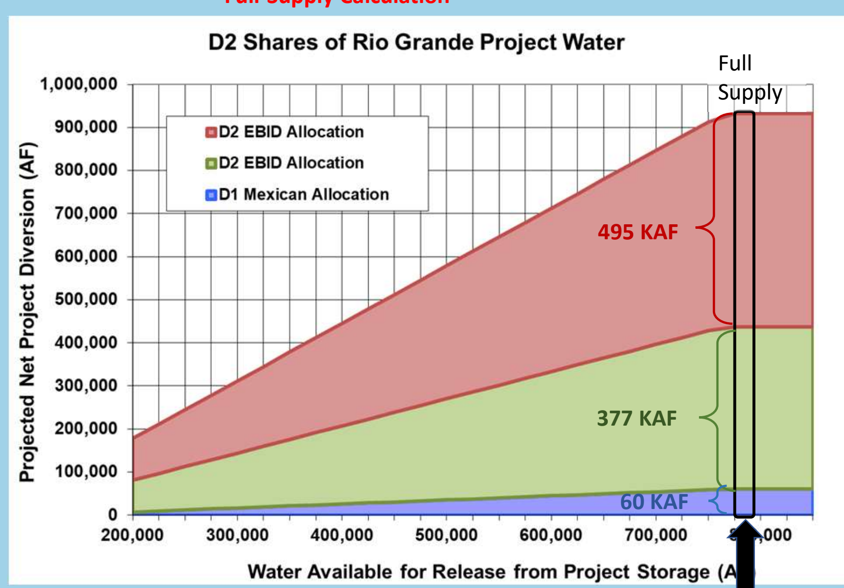
D2 Curve determines total Allocation amount (for diversion)

Mexico is assigned its share (using D1 Curve)

EBID and EPCWID split the rest 57:43.

Explicit 57:43 entitlement of Districts to order water

Full-Supply Calculation



82

Using the D2 Curve

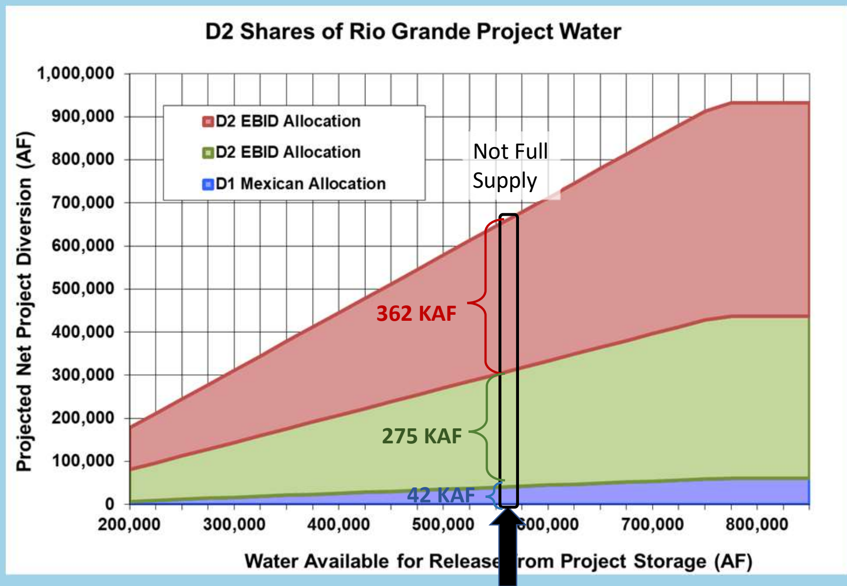
For a given Supply of Usable Water in Storage

D2 Curve determines total Allocation amount (for diversion)

Mexico is assigned its share (using D1 Curve)

EBID and EPCWID split the rest 57:43.

Explicit 57:43 entitlement of Districts to order water



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Using the D2 Curve

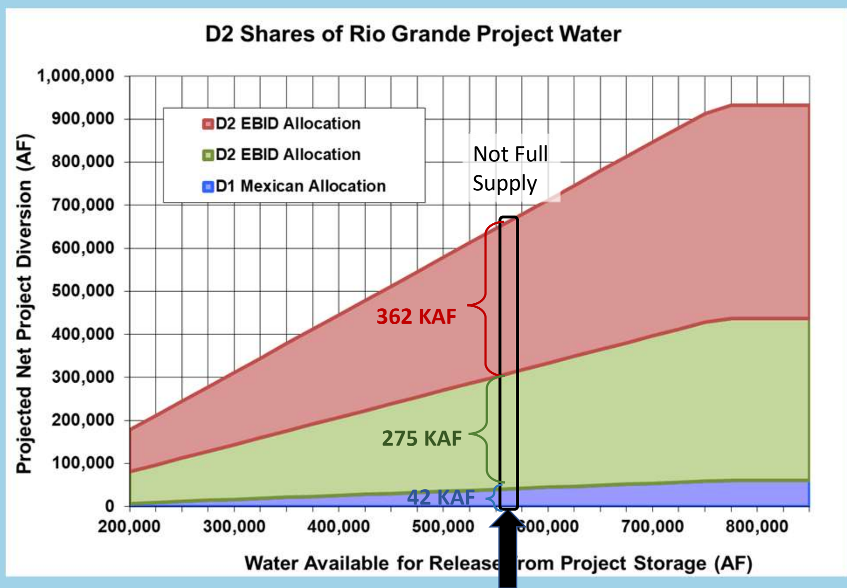
For a given Supply of Usable Water in Storage

D2 Curve determines total Allocation amount (for diversion)

Mexico is assigned its share (using D1 Curve)

EBID and EPCWID split the rest 57:43.

This works as long as the total amount of water you deliver for a given release falls close to the D2 Curve



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US_MSJ_00001045

3. Change of Project Allocation Method in 2006

- Concerns about reduced Project delivery performance and the effects on NM groundwater pumping resulted in new Allocation procedure:
  - EBID proposed D3 Allocation in 2006
  - EPCWID demanded Carryover of unused Allocation
  - Partially implemented starting in 2006
- Negotiation between Districts and US led to a settlement: the 2008 Operating Agreement (2008 OA)
- 2008 OA includes D3 Allocation plus Carryover
  - EPCWID guaranteed Allocation consistent with D2 levels
  - All negative departures from the D2 Curve are taken out of EBID's Allocation.
  - Any unused District Allocation (up to set limits) can be carried over into following year

Recap: Using the D2 Curve

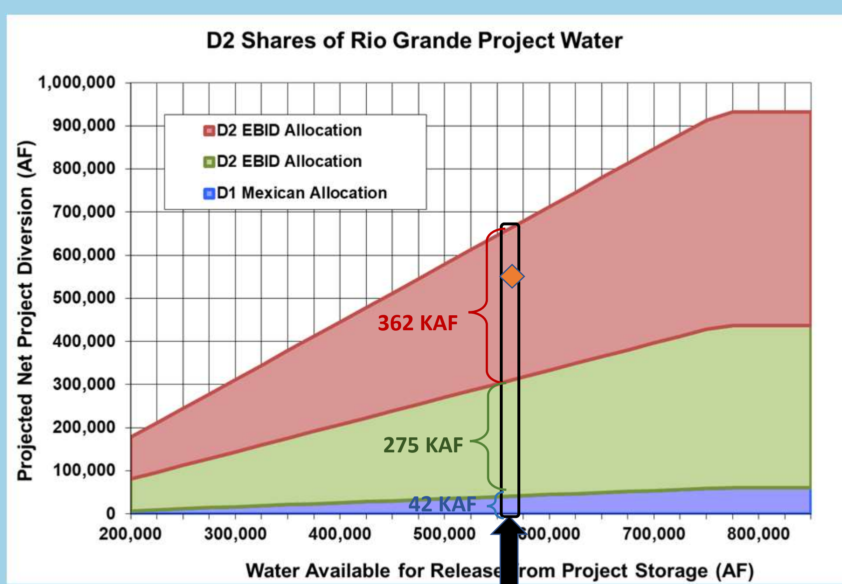
For a given Supply of Usable Water in Storage

D2 Curve determines total Allocation amount (for diversion)

Mexico is assigned its share (using D1 Curve)

EBID and EPCWID split the rest 57:43.

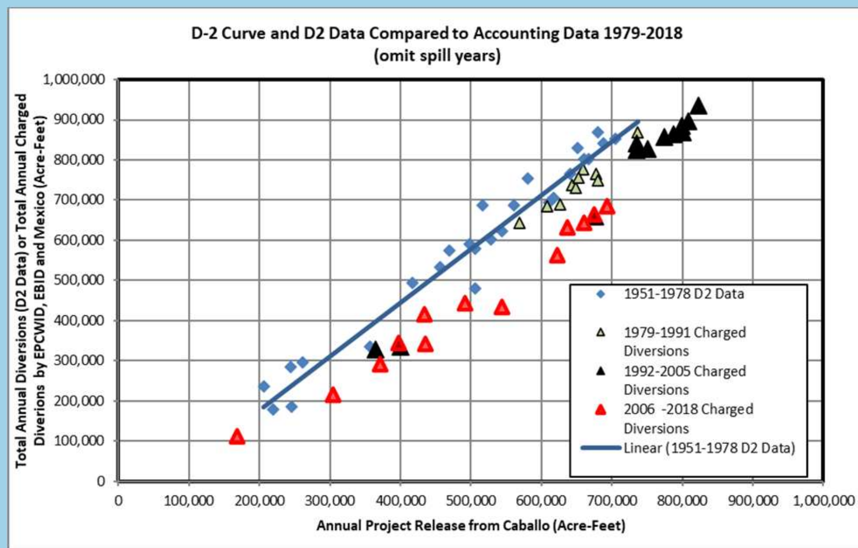
This works as long as the total amount of water you deliver for a given release falls close to the D2 Curve



Problem

Recent Total Charged Diversions calculated using Post-1978 Accounting Data all fall well below D2 line

This means that If Reclamation used the D2 Curve to determine total Allocations, it would be allocating more water than it can deliver (as Charged Diversions)



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District and Reclamation Solution to this Problem: D3 Allocation Method

• Proposed by EBID in 2006, Implemented in 2006

EBID

Elephant Butte Irrigation District
Of New Mexico

P.O. Drawer 1509
Las Cruces, NM 88004-1509
(Office located at 530 South Melendres)

Telephone
(505) 526-6671
Fax (505) 523-9666
Dispatch Fax (505) 526-8397
Warehouse Fax (505) 526-1530
Engineering Fax (505) 541-5716

Staff Members
Gary L. Esslinger, Treasurer/Manager
Henry Magallanez, Engineer
Ted Homer, Maintenance Chief
Ricardo Bejarano, Water Master
Gail Norvell, Controller
James Narvaez, Hydrology Director

Board of Direct
James Salopek, Presid
Robert Faubion, Vice-Presid
Robert Sloan, Secret
Jerry Fran
Bill G
Willie Koe
Joe Nei
Thomas C. Simp
Ramon Alva

April 26, 2006

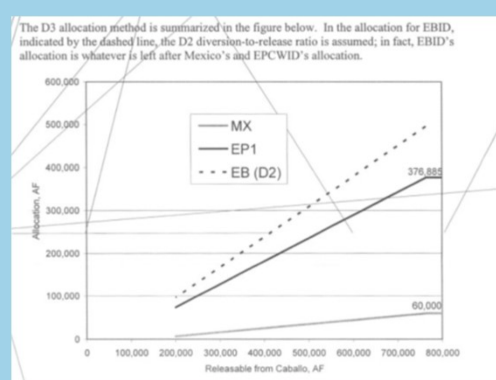
Connie Rupp, Area Manager
U.S. Department of the Interior
Bureau of Reclamation
555 Broadway Blvd. NE, Suite 100
Albuquerque, NM 87102-2352

Re: Allocation of Rio Grande Project Water.

Dear Ms. Rupp:

Our attorneys and consultants have been corresponding with the El Paso Water Improvement District No. 1 and your attorneys regarding the proposed "D-3 Curve". The Elephant Butte Irrigation District (hereinafter "EBID") hereby requests that the Bureau of Reclamation immediately implement a new allocation procedure that would assure equitable allocation of Project Water to El Paso County Water Improvement District No. 1 and the Republic of Mexico. We believe that the proposed D-3 Curve does this. EBID is concerned that the Bureau's current allocation method fails to ensure equity among Project Water users.

OFFICE OF THE
MAY 2006
STATE ENGINEER



The D3 allocation method is summarized in the figure below. In the allocation for EBID, indicated by the dashed line, the D2 diversion-to-release ratio is assumed; in fact, EBID's allocation is whatever is left after Mexico's and EPCWID's allocation.

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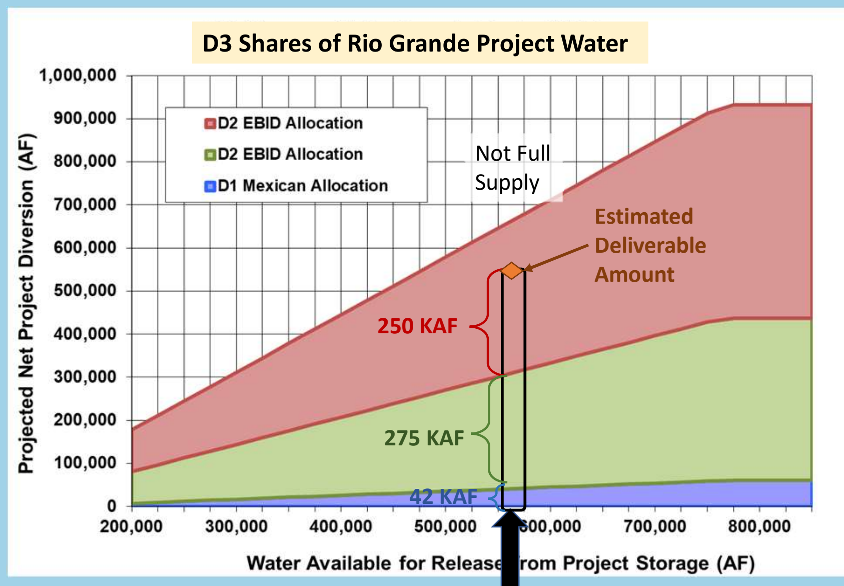
D3 Allocation Method



For a given Supply of Usable Water in Storage:

- Mexico's Allocation still uses D1 Curve
- EPCWID's share is determined using D2 method
- Diversion Ratio is used to estimate how much water can really be delivered to canal headings as Charged Diversions
- Subtract Mexican and EPCWID Allocation
- EBID gets remainder

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D3 Allocation using Diversion Ratio

- Diversion Ratio is calculated based on current Project performance
  - Used to estimate how much water can be delivered to Canal Headings as Charged Diversions
  - Determines EBID's Allocation
- Mexico still gets D1 Curve Allocation
- EPCWID Allocation approximately equal to what they did under D2
- EBID gets the remainder
- The entire discrepancy from D2 is subtracted from EBID's Allocation.

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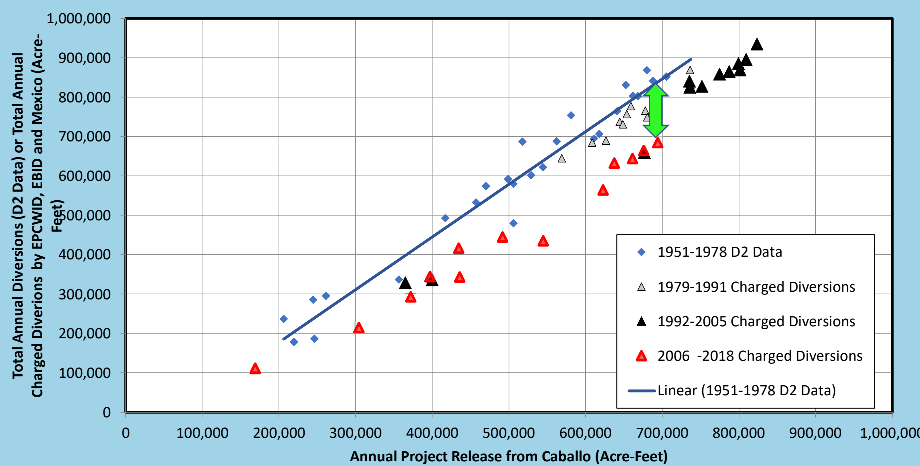
Under D3 EBID's Allocation is Reduced for the Entire Negative Departure from the D2 Curve

Recent Departures from D2 Curve are large



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Carryover

- Demanded by EPCWID
- Ability for each District to keep unused Allocation from one year and carry it over into the next year
- Partially implemented in 2007
  - Litigation ensued

IN THE UNITED STATES DISTRICT COURT
FOR THE WESTERN DISTRICT OF TEXAS
EL PASO DIVISION

2007 JAN 22 AM 11:37

EL PASO COUNTY WATER IMPROVEMENT DISTRICT NO. 1, Plaintiff,

v.

ELEPHANT BUTTE IRRIGATION DISTRICT and the UNITED STATES OF AMERICA, DEPARTMENT OF THE INTERIOR, BUREAU OF RECLAMATION Defendants.

CAUSE NO. JUDGE PHILIP MARTINE

EP07CA002

COMPLAINT FOR DECLARATORY AND INJUNCTIVE RELIEF

TO SAID HONORABLE COURT:

NOW COMES Plaintiff, El Paso County Water Improvement District No. 1 (hereinafter, "EPCWID"), and files this Complaint for Declaratory and Injunctive Relief (the "Complaint") and would respectfully show the court as follows:

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2008 Operating Agreement

- Arose from confidential Settlement Negotiations between Districts and US in 2007-2008
- Settled various on-going litigation
- Implemented D3 Allocation method using Diversion Ratio
- Implemented Carryover
  - Limits set on District Carryover: 60% of full supply Allocation
    - EPCWID: 232,915 AF
    - EBID: 305,918 AF
  - Any unused Allocation in excess of limit is transferred to other District

4. Allocation and Delivery Amount Changes under D3 Allocation plus Carryover

- EBID's Allocation and diversion in full-supply years dropped by approximately one-third, more than 150,000 AF/yr
- EPWCID's Allocation in full-supply years increased by approximately 22,000 AF/yr, plus any Allocation carried over
- On average, the split of Current-Year Allocation between the Districts changed from:
  - Pre-2006: 57% to EBID; 43% to EPCWID
  - 2006 – 2018: 44% to EBID; 56% to EPCWID
- On average, the split of Charged Diversions between the Districts changed from:
  - 1979 – 2006: 58% to EBID; 42% to EPCWID
  - 2006 – 2018: 47% to EBID; 53% to EPCWID

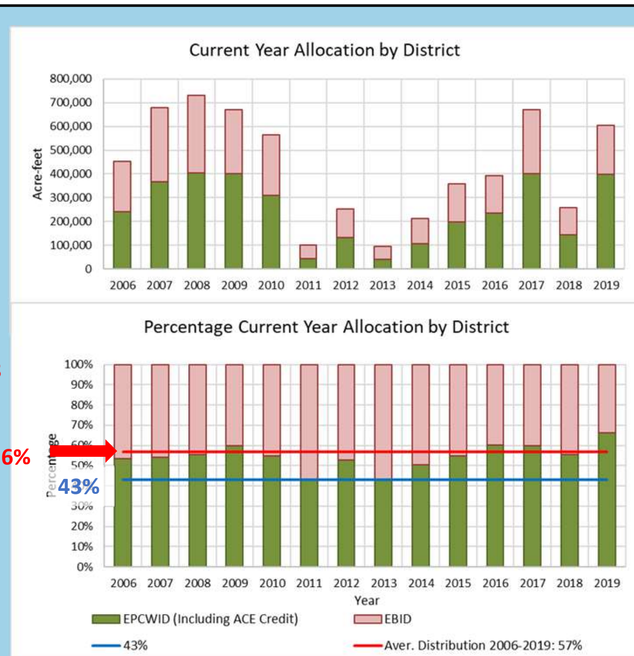
2006 – 2019 Entitlement:

Defined using new Allocation method

Allocation
(*Current Year, Omitting Carryover)

Average
EBID: 44%
EPCWID: 56%

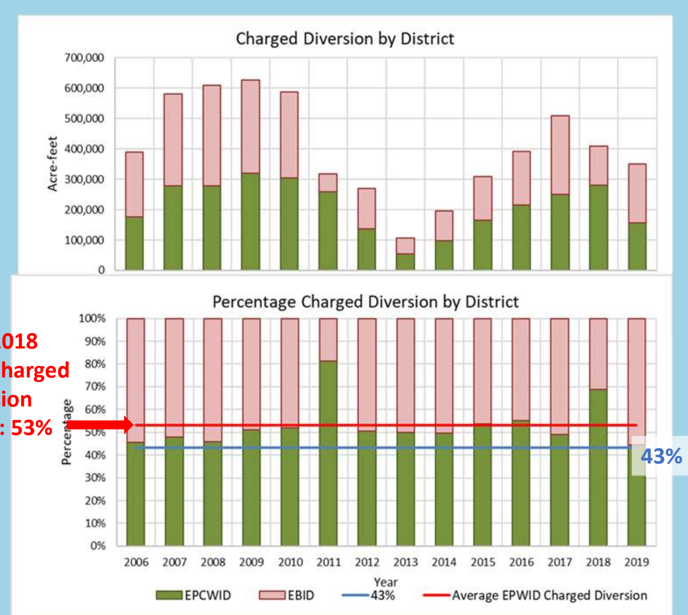
2006-2018 EPCWID Allocation Average: 56%



2006 – 2019 Delivery in terms of Charged Diversions

Averages:
EBID: 47%
EPCWID: 53%

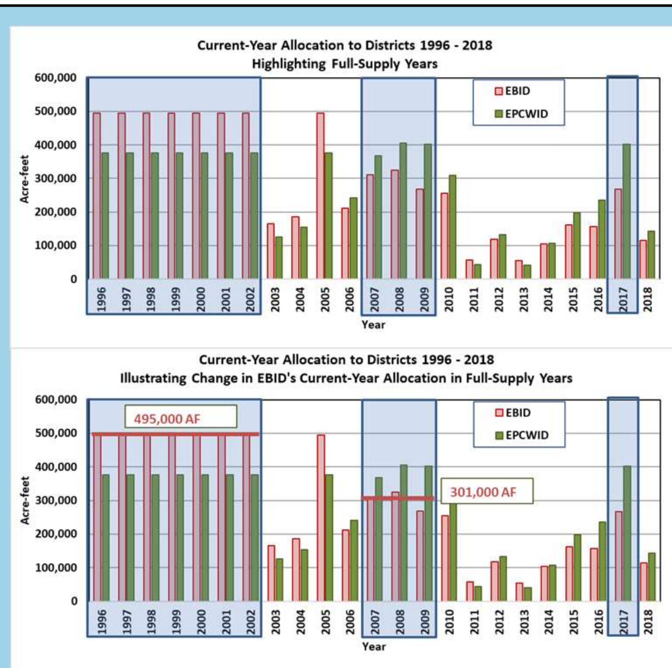
2006-2018 EPCWID Charged Diversion Average: 53%



Largest Redistributions Occur in Full-Supply Years

EBID's full-supply year Allocation* dropped from 495,000 AF to 301,000 AF
(Reduction: 194,000 AF)

*Current-Year Allocation



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EPCWID's Full-Supply Allocation

- Before 2006, Under D1/D2 Allocation, EPCWID's Allocation in full-supply years was **376,862 AF**
- Since 2006, under D3 Allocation, EPCWID's Allocation in full-supply years has been as high as **405,000 AF** (2008).
- Increase includes
  - Use of 790,000 as a Full-Supply Release values (instead of 763,800 AF previously)
  - American Canal Extension Credit (up to 20,000 AF)

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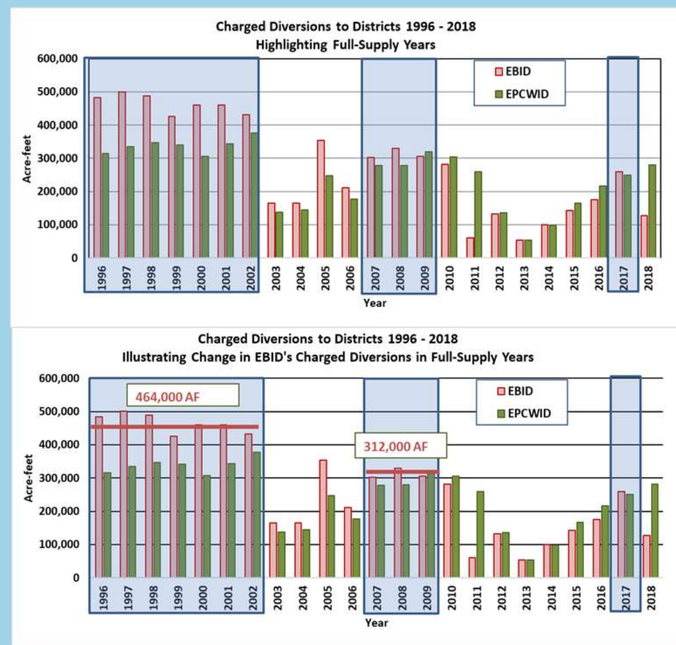
Largest Redistribution: Full-Supply Years

EBID's average diversion in full-supply years drops from 464,000 AF to 312,000 AF
(Reduction: 152,000 AF)



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EPCWID's Charged Diversion in Full-Supply Years

- 1996 – 2002 Average EPCWID Charged Diversion: **337,000** AF
- 2007 – 2009 Average EPCWID Charged Diversion: **293,000** AF
- Reduction in Charged Diversion in full-supply years may reflect reduction in demand, or desire to save water in EPCWID's Carryover Account

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How Much Water Does this Difference in Delivery Constitute?

If the actual Charged Diversions had been distributed 57:43, EBID would have diverted a total of 531,000 AF more water over these 14 years.

Table A.12.Rev1. Distribution of Charged Diversions between Districts
(Including revised 2018 and 2019 data, adding Totals, 57:43 Distribution, and Difference Calculations)

Year	Release from Caballo AF	EBID AF	EBID % of US Share	EPCWID AF	EPCWID % of US Share	Total US Diversions
2006	432,770	211,841	54%	177,183	46%	389,024
2007	636,993	302,665	52%	278,252	48%	580,917
2008	674,724	329,294	54%	279,173	46%	608,467
2009	693,289	305,475	49%	320,083	51%	625,558
2010	659,679	282,082	48%	304,937	52%	587,019
2011	396,444	59,771	19%	258,772	81%	318,543
2012	371,271	133,060	49%	136,380	51%	269,440
2013	168,201	54,002	50%	53,530	50%	107,532
2014	306,900	99,007	50%	97,418	50%	196,425
2015	435,483	143,404	46%	165,872	54%	309,276
2016	544,181	175,199	45%	216,309	55%	391,508
2017	622,467	259,510	51%	249,919	49%	509,429
2018	491,305	127,487	31%	280,674	69%	408,161
2019	453,564	194,510	56%	155,872	44%	350,382
Total Diversions		**2,677,307**	**47%**	**2,974,374**	**53%**	**5,651,681**
57:43 Distribution		**3,208,696**	**57%**	**2,442,985**	**43%**	**5,651,681**
Difference		**-531,389**		**531,389**		

But EPCWID Charged Diversions do not include their use of El Paso Effluent

- EPCWID diverts and uses a significant amount of treated effluent discharged by the El Paso Water Utility (EPWU) into Project canals.
- This effluent is largely Project return flow, and ordinarily would be considered Project Water, and EPCWID would be charged for its use.
- Owing to the technicality that this effluent doesn't "reach the bed of the Rio Grande", its diversion and use is not charged to EPCWID.
- If this water is included in the calculation as part of EPCWID's diversion of Project Supply, then the "difference" between what EBID got and 57% of Supply is 700,000 AF.

Data and Calculation of Project Supply Diversion Distribution, Including EPWU Effluent

Table A.12.Rev2. Distribution of Water between Districts

(Including revised 2018 and 2019 data, adding Totals, 57:43 Distribution, and Difference Calculations)

Year	Release from Caballo	EBID Charged Diversions	EBID % of US Share	EPCWID Charged Diversions	EPWCID Uncharged Effluent Use *	Total EPCWID Supply during Release Season	EPCWID % of US Share	Total US Diversions
Year	AF	AF		AF	AF			
2006	432,770	211,841	51%	177,183	29,888	207,071	49%	418,912
2007	636,993	302,665	50%	278,252	29,773	308,025	50%	610,690
2008	674,724	329,294	51%	279,173	30,949	310,122	49%	639,416
2009	693,289	305,475	47%	320,083	26,992	347,075	53%	652,550
2010	659,679	282,082	46%	304,937	25,629	330,566	54%	612,648
2011	396,444	59,771	18%	258,772	21,382	280,154	82%	339,925
2012	371,271	133,060	46%	136,380	21,566	157,946	54%	291,006
2013	168,201	54,002	47%	53,530	6,962	60,492	53%	114,494
2014	306,900	99,007	47%	97,418	14,442	111,860	53%	210,867
2015	435,483	143,404	44%	165,872	17,488	183,360	56%	326,764
2016	544,181	175,199	42%	216,309	24,814	241,123	58%	416,322
2017	622,467	259,510	49%	249,919	21,855	271,774	51%	531,284
2018	491,305	127,487	30%	280,674	20,000	300,674	70%	428,161
2019	453,564	194,510	53%	155,872	20,000	175,872	47%	370,382
Total Diversions		**2,677,307**	**45%**			**3,286,114**	**55%**	**5,963,421**
57:43 Distribution		**3,385,684**	**57%**			**2,577,737**	**43%**	**5,963,421**
Difference		**-708,377**				**708,377**		

* Discharge of Haskell Street Plant Effluent into ACE and Discharge of Bustamante Effluent into Riverside Canal, Release Season only, 2018 and 2019 values estimated in absence of reported data.

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5. Cause of EBID Allocation Reduction

Under D3 Allocation Method, EBID's Allocation is reduced for any negative departure from historical Project performance as defined by the D2 Curve.

- The US and TX argue that the negative departure from D2 is caused predominantly or entirely by excess groundwater pumping in New Mexico.
- New Mexico argues that part of the negative departure from D2 may indeed be caused by NM actions, but not ALL of that departure is caused by NM.
- Instead, NM argues that a significant part of the problems with Project Performance are caused by other factors.

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Mechanism by Which EBID's Allocation has been Reduced: D3 Allocation Method

- Adopted by Project in 2006
- Incorporated in to 2008 Project Operating Agreement (2008 OA)
- Intended to reduce EBID's Allocation in order to
  - **Offset effect of New Mexico pumping (King 2019, Ferguson 2019)**
  - **Protect EPCWID's Project Allocations from the impacts of New Mexico groundwater pumping (King 2019)**
  - **Account for Project Water "captured" by New Mexico groundwater pumping (Blair 2019)**

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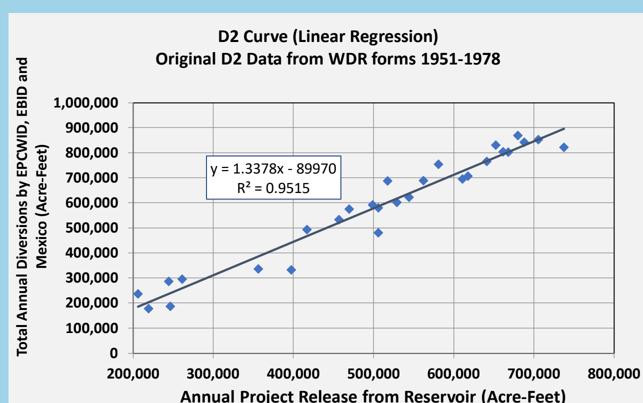
D3 Allocation Method

- Based on historical data from 1951 – 1978
  - Releases from Caballo
  - Net diversions
  - D2 "curve" (a linear regression of this data)
- EPCWID's Allocation is based on this historical data
- Mexico's Allocation is based on Treaty
- EBID gets remaining Allocation



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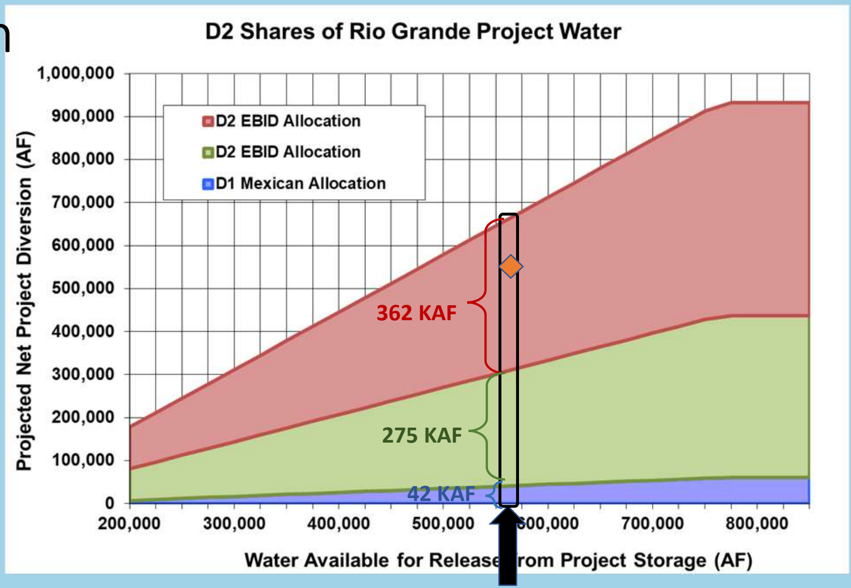
D2 Allocation



Allocates full amount determined by D2 Curve

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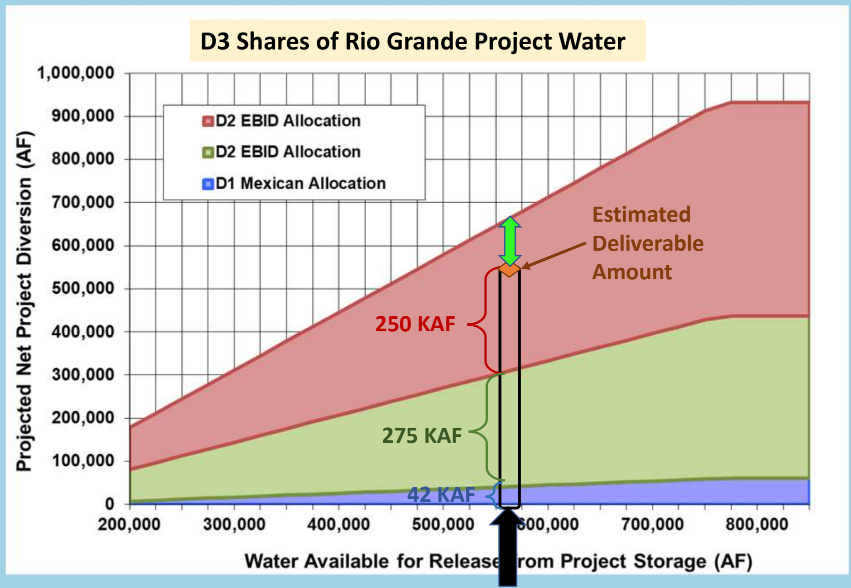
D3 Allocation Method



Entire negative departure (vertical distance) between D2 Curve and current Total Charged Diversion is taken out of EBID's Allocation

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EBID Gets "Remainder of Allocation"

- EBID's Allocation is reduced for the **entire negative** departure of current Charged Diversions from the D2 Curve
- Ferguson (page 4): "D3 Method" is not "based on the assumption that any negative departure from historical Project Performance is caused by New Mexico."
- Nevertheless, D3 Allocation <u>does in fact assign all negative departure from historical Project performance (D2 Curve) to New Mexico</u>, with a few exceptions (multi-year drought).

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Causes for Negative Departure from D2

1) Increased groundwater pumping/depletions within Project
2) Changes in Project Accounting
    A. Off-season diversions in D2 Curve: Average 23,000 AF
    B. Diversion of EPV drain flow in D2 Curve: Average 8,200 AF
    C. Diversion/use of EPV effluent <u>not</u> counted: Average 24,000 AF

New Mexico is responsible for **part of** the increased groundwater pumping/depletions

New Mexico is **not** responsible for changes in Project Accounting

Yet EBID's Allocation is reduced for the total negative departure from D2

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6. Accounting Factors that Impact Project Performance

- The D2 Curve was developed from diversion data from 1951 – 1978.
- This diversion data is calculated very differently than current Charged Diversions. Charged Diversions omit diversions that were included in the D2 Curve.
- Under D3 Allocation, EBID's Allocation is reduced when total Charged Diversions fall short of the D2 Curve.

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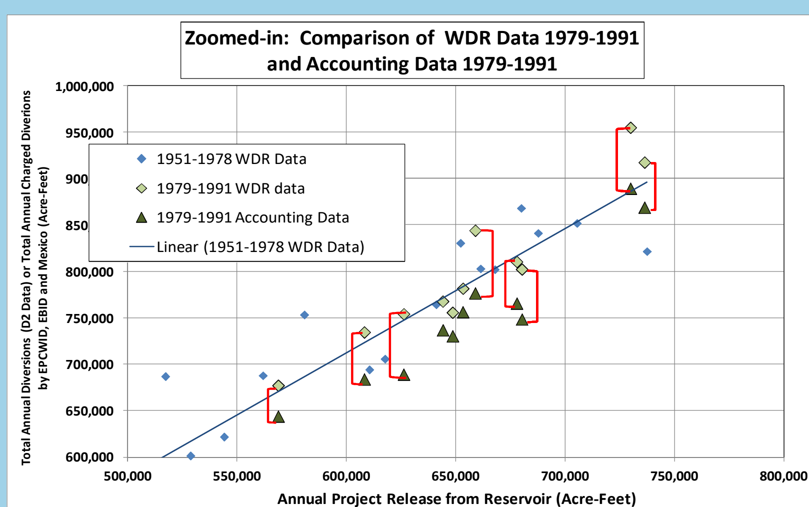
Problems with D3 Allocation Method

- Net Diversions from D2 period (1951 – 1978) are calculated differently than today's Charged Diversions (apples to oranges problem)
- Some of the current apparent discrepancy from the D2 Curve is caused by those differences in calculation (differences in Project Accounting)



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How Has Project Accounting Changed Since the D2 Period (1951 – 1978)?

1. Off-Season Diversions
   - D2 data includes diversions of return flows during the winter, during months when no releases were made from Caballo
   - Post-1978 Accounting only counts diversion made during the Caballo Release period
2. EPWU Effluent
   - During D2 period, effluent from EPWU Haskell R. Street Plant reached the Rio Grande, and when it was diverted at Riverside it was counted as diversion of Project Supply
   - Currently effluent from both the Haskell and Bustamante plants discharge into EPCWID conveyances where it is used by EPCWID farmers. The diversion and use of this water is **not** charged to EPCWID.

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How Has Project Accounting Changed Since D2 Period (1951 – 1978)? (continued)

3. Diversion of El Paso Valley Drain Flows
   - D2 data explicitly includes diversions of water from the River Drain into the Riverside Canal Extension near Fabens, Texas.
   - Post-1978 Accounting does not include any consideration of drain flows in the El Paso Valley
4. Other Project Accounting Credits

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7. Accounting Factor (a) Off-Season Diversions

- The D2 data set is based on Reclamation records that include diversions made throughout the calendar year.
- Current Project Accounting (since ~1979) does not count any diversions made during times when Caballo is not releasing water.
- EPCWID's guaranteed Allocations are based on 12-months of diversion, but they are only charged for diversions made during 4 to 8 months of the year.
- The D2 data includes an average of 22,400 AF/yr of off-season diversions. In full-supply years, off-season diversions were 30,000 - 40,000 AF.

Accounting Issue: Off-Season Diversions

Current Accounting (Post-1978 Accounting) does not include any diversions made outside of the Caballo release season

2008 Operating Agreement Operations Manual, Page 3:

Non-Allocated Water: water in the Rio Grande, during non-irrigation season and after the closing of the Caballo Dam release gates and prior to opening of the Caballo Dam release gates for the subsequent primary irrigation season, which originates from drain flows and other sources which may be diverted by the irrigation districts for application to irrigable land area within their boundaries. All diversions made by the Districts during the non-irrigation season utilizing return flow waters shall not be charged against the District's respective allocations.

Accounting Issue: Off-Season Diversions

The WDR's from the 1951 – 1978, upon which the D2 Curve is based, include diversions from the entire calendar year.

- An average of 23,000 AF/yr of off-season diversions occurred during that time, mostly in the El Paso Valley.

Form 7-322 (July 1960)

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

MONTHLY WATER DISTRIBUTION

Project Rio Grande, New Mexico-Texas El Paso Valley Area Irrigated 48,034 Acres Year 1968

QUANTITIES IN ACRE-FEET

MONTH	Diverted from Stream 1	Inflow from Reservoirs and other sources	Delivered to Reservoirs 2	Net Supply 3	Total Canal Waste	Total Canal Losses	Delivered to Laterals a	Lateral Waste	Lateral Losses	Non-Irrigation Deliveries 4	Charged Deliveries to Farms b Total	Charged Deliveries to Farms b Per Acre
January,	3,757			3,757	1,387	1,157					1,213	0.03
February,	3,125			3,125	215	943					1,967	0.04
March,	35,603			35,603	542	15,896					19,165	0.40
April,	15,532			15,532	424	6,362					8,746	0.18
May,	13,190			13,190	330	5,972					6,888	0.14
June,	29,465			29,465	1,688	13,012					14,765	0.31
July,	25,941			25,941	7,502	7,360					11,079	0.23
August,	28,565			28,565	6,191	6,871					15,503	0.32
September,	19,758			19,758	1,079	8,754					9,925	0.21
October,	5,834			5,834	736	2,596					2,502	0.05
November,	4,615			4,615	1,814	1,747					1,054	0.02
December,	3,290			3,290	2,249	936					105	-
Total,	188,675			188,675	24,157	71,606					92,912	1.93
Acre ft. per acre,	3.93			3.93	0.51	1.49					1.93	-
Per cent Net Supply,	100			100	12.8	38.0					49.2	-

1 Diversion amount exclusive of waste at head gates for sand sluicing, etc.
2 Reservoirs connected with distributing system only.
3 Diversions plus inflow from reservoirs and other sources less delivery to reservoirs.

a Measured at
b Measured at

Off-Season Diversions Example: 1968

- Caballo Reservoir Releases
  - Began: February 27 (first deliveries from these releases occurred in March)
  - Ended: September 20 (last deliveries from these releases occurred in late September
- Under current Accounting rules, diversions made in January, February, October, November and December **would not be counted.**

Off-Season Diversions: 1968		
	Diversion in New Mexico	Diversion in Texas
Month	Acre-feet	Acre-feet
January	0	3,757
February	0	3,125
October	0	5,834
November	0	4,615
December	0	3,290
Total	0	25,041

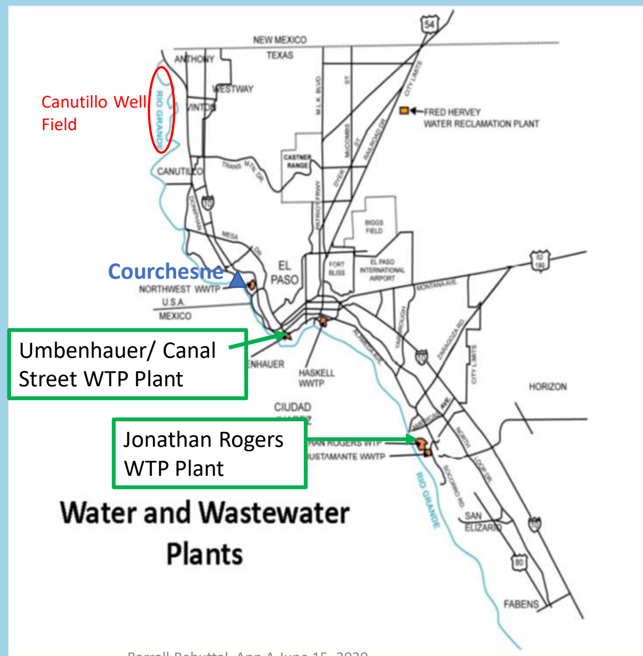
Impacts of Off-Season Accounting Issue

- The D2 Curve, and EPCWID's Allocation, are inflated by significant amounts of off-season diversions (averaging 22,400 AF) that are not considered part of Project Water.
- Off-season diversions largely consisted of drain flows, effluent, and base-flow gains to the bed of the Rio Grande.
- Currently, the amount of water available in the off-season is probably not large, but if the hydrologic system recovers, and off-season flows become significant again, **the use of these flows would still not be counted.**
- Since diversion of off-season diversions will not be charged, that will permanently depress the Diversion Ratio (which is calculated based on Charged Diversions).
- A low Diversion Ratio mean low Allocation to EBID

7. Accounting Factor (b) El Paso Valley Effluent

- The City of El Paso Water Utility (EPWU) supply in the El Paso Valley includes Project water and a smaller amount of Hueco groundwater.
- Municipal effluent from EPWU in the El Paso Valley consists of Project return flow and return flow from groundwater pumping.
- This effluent is discharged into a conveyance parallel to and close to Rio Grande that effectively takes the place of the Rio Grande.
- EPCWID diverts and uses this effluent but is no longer charged for it.
- Approximately 24,000 AF of this effluent is discharged during the Caballo release season, which EPCWID thus uses free of charge.

El Paso Water Utility (EPWU) System



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El Paso Water Utility (EPWU) Wastewater Plants

From EPWU http://www.epwu.org/water/hueco_bolson/2.0ElPasoWaterSupply.pdf
Downloaded by Peggy Barroll, NMOSE, 3/29/2013
Modified by Peggy Barroll to label Canutillo well Field and to include Wastewater Treatment Plants (WWTP)

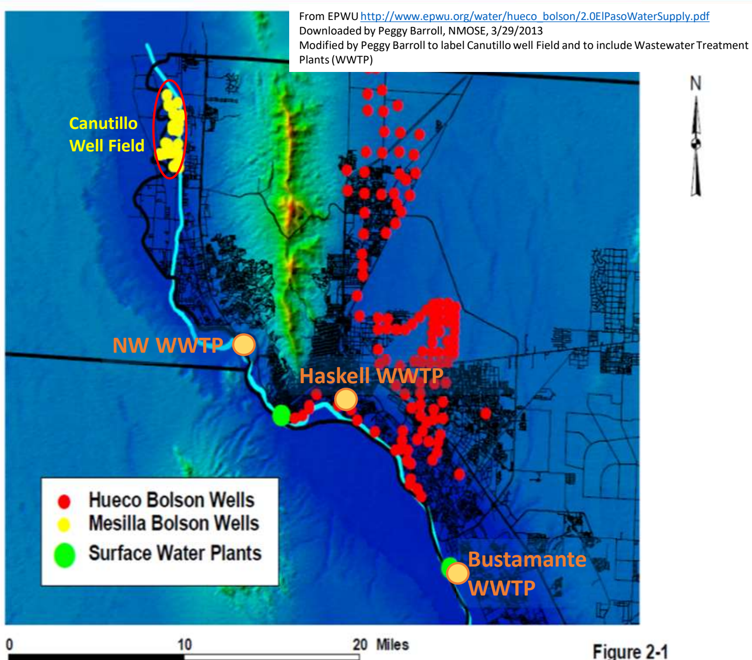

Figure 2-1
Well and Water Plant Locations

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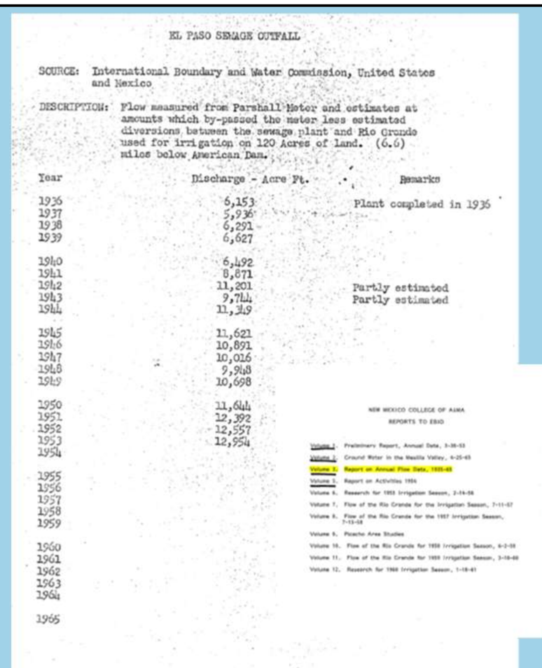
EPWU Effluent at the Time of the Compact

El Paso's effluent was discharged into Rio Grande at Haskell R. Street WWTP. Diversion of this effluent downstream at Riverside was counted as Project Supply.



EL PASO SEWAGE OUTFALL

SOURCE: International Boundary and Water Commission, United States and Mexico

DESCRIPTION: Flow measured from Parshall Meter and estimates at amounts which by-passed the meter less estimated diversions between the sewage plant and Rio Grande used for irrigation on 120 Acres of land. (6.6) miles below American Dam.

Year	Discharge - Acre Ft.	Remarks
1936	6,153	Plant completed in 1936
1937	5,936	
1938	6,291	
1939	6,627	
1940	6,492	
1941	8,871	
1942	11,201	Partly estimated
1943	9,744	Partly estimated
1944	11,349	
1945	11,621	
1946	10,891	
1947	10,016	
1948	9,948	
1949	10,698	
1950	11,644	
1951	12,392	
1952	12,557	
1953	12,954	
1954		
1955		
1956		
1957		
1958		
1959		
1960		
1961		
1962		
1963		
1964		
1965		

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REPORTS TO EBID

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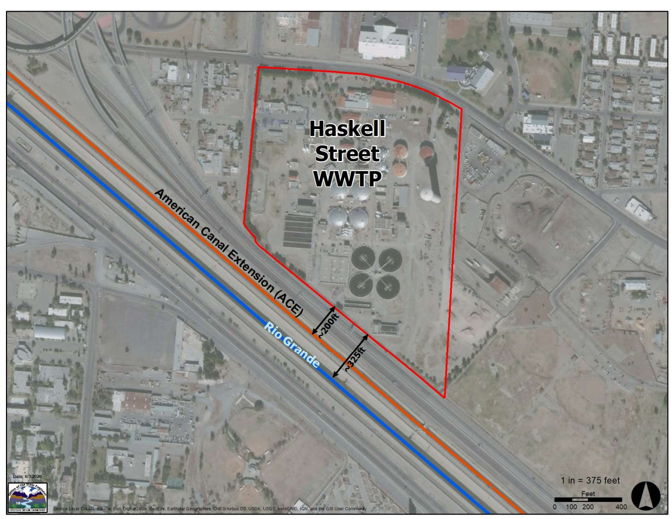
Volume 7. Flow of the Rio Grande for the Irrigation Season
Volume 8. Flow of the Rio Grande for the 1957 Irrigation Season
Volume 9. Picacho Area Studies
Volume 10. Flow of the Rio Grande for 1958 Irrigation Season
Volume 11. Flow of the Rio Grande for 1959 Irrigation Season
Volume 12. Research for 1960 Irrigation Season

Change in Disposition of Haskell R. Street Effluent

- Until 1999, Haskell effluent discharged into the Rio Grande, and diversion of that effluent at Riverside was counted as Project Supply.
- The ACE, completed in 1998, allows EPCWID to by-pass the bed of the Rio Grande when making deliveries to Riverside.
- Starting in 1999, Haskell effluent is discharged into ACE, less than 200 feet from the bed of the Rio Grande.



Change in Accounting of Haskell R. Street Effluent

- Haskell effluent is currently diverted into the Riverside Canal heading from the ACE and is used by EPCWID, but the diversion of this water is not included in EPCWID's Allocation Charges.
  - This effluent passes the Riverside gage with the rest of the Project water diverted at Riverside. Current EPCWID accounting **subtracts off the amount of Haskell effluent EPCWID as a Credit** during the release season
- Average annual discharge Haskell to ACE: 16,255 AF
- Average Haskell discharge during release season: 10,470 AF
- EPCWID now uses this water free of charge.

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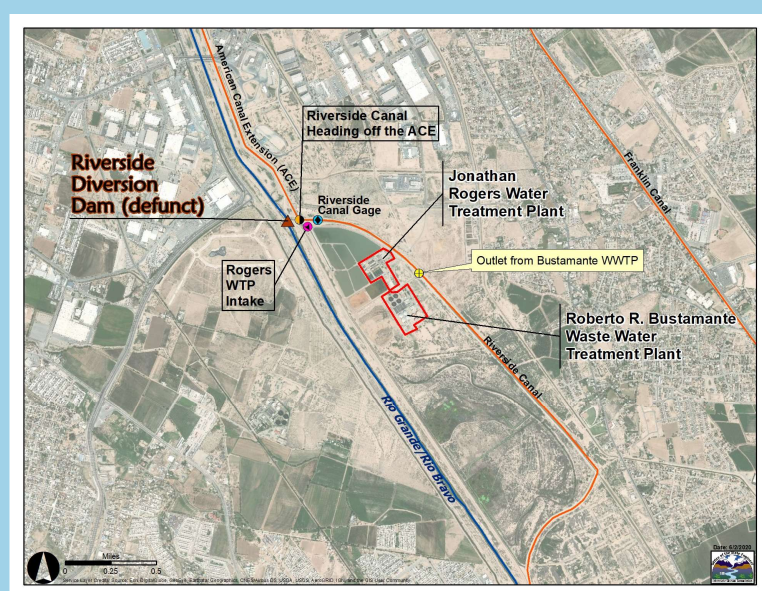
Bustamante Wastewater Treatment Plant

- Came on-line: 1960
- Effluent is discharged into Riverside Canal, 0.5 miles below the Riverside Gage
- EPCWID use of this effluent is not charged in Project Accounting



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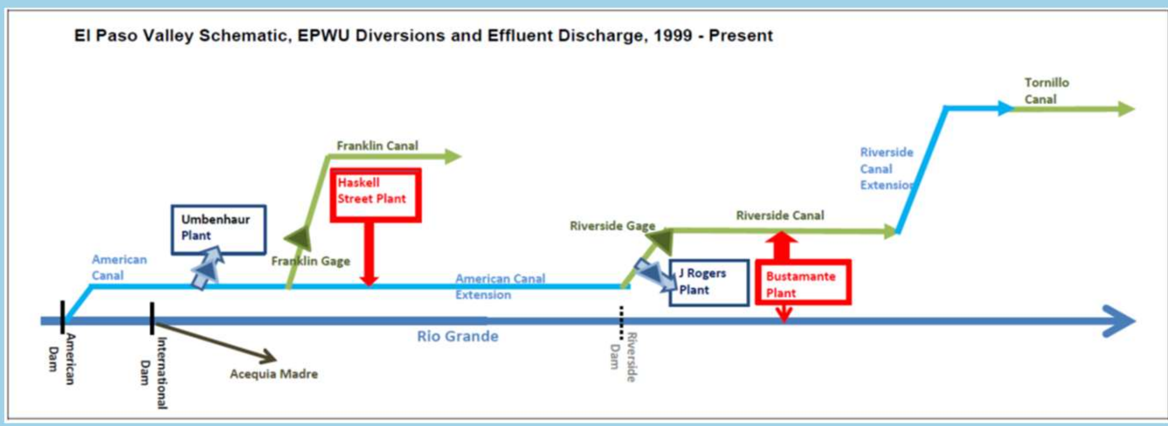
Schematic of El Paso Valley Conveyance System, Including EPWU



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Bustamante Effluent Amounts and Disposition

- During Irrigation Season Bustamante discharges effluent into Riverside Canal.
- Discharge into Riverside is used by EPCWID, but there is no Project Accounting charge.
- Average annual discharge to Riverside: 22,727 AF.
- Average discharge to Riverside during Release Season: 15,556 AF.

In some winter months, Bustamante effluent is sent to a drain and is not used by Project.

EPCWID has had contracts with Hudspeth Irrigation District to sell municipal effluent to Hudspeth.

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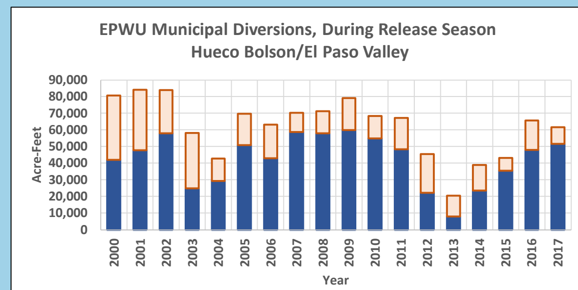
EPWU Sources of Supply in the El Paso Valley

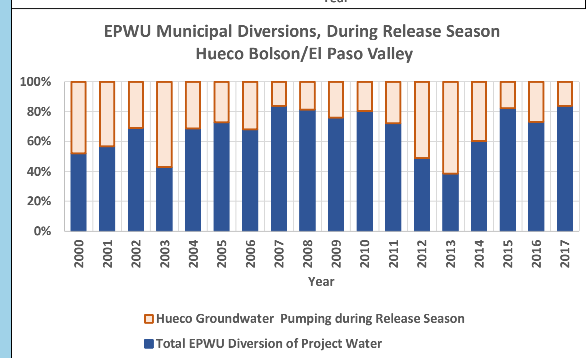
Below Courchesne, EPWU diverts Project water and pumps groundwater from the Hueco well-field)

Up to 80% of the water diverted during the Caballo release season** is Project water

Therefore most of EPWU effluent in the El Paso Valley is Project return flow

**Note that Project Accounting Charges now only include diversions made during Caballo release Season. In order to understand the composition of the uncharged Caballo release season effluent, I compare effluent discharge and EPWU Hueco pumping during that same period





Total EPWU Municipal Effluent Discharged into Project Works in El Paso Valley During Caballo Release Season

	Haskell Credit for Discharge to ACE during Release Season	Bustamante to Riverside during Release Season	Total EPWU Effluent in El Paso Valley During Release Season
1999	12,732	21,775	34,507
2000	10,700	19,583	30,283
2001	11,360	16,070	27,430
2002	10,844	5,876	16,720
2003	9,595	15,556	25,151
2004	10,758	16,558	27,316
2005	9,924	18,583	28,507
2006	10,347	19,541	29,888
2007	11,038	18,735	29,773
2008	11,624	19,325	30,949
2009	11,521	15,471	26,992
2010	10,239	15,390	25,629
2011	4,338	17,045	21,382
2012	5,401	16,165	21,566
2013	1,703	5,259	6,962
2014	3,586	10,856	14,442
2015	5,461	12,027	17,488
2016	7,712	17,102	24,814
2017	7,204	14,651	21,855
Averages:	**8,741**	**15,556**	**24,298**

Impact of Effluent Accounting in El Paso Valley

- EPCWID uses Project return flow free of charge
- EPCWID's Charged Diversions are smaller as a result
- EPCWID ends up with more unused Allocation which it can then "carry over"
- Total Project Charged Diversions are smaller, which reduces Diversion Ratio
- Smaller Diversion Ratio means that EBID's D3 Allocation is smaller

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7. Accounting Factor (c) El Paso Valley Drain Flow

- El Paso Valley drain flows comprised part of Project Supply at the time of the Compact and later.
- During the D2 period (1951 – 1978) Reclamation records indicate that an average of 8,200 AF/yr of El Paso Valley drain water was diverted into EPCWID's conveyances and this water was counted as Project Supply.
- Current Project Accounting does not include a term for El Paso Valley drain flows, and the flows of the pertinent drains have been depleted by groundwater pumping in Texas and Mexico.

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El Paso Valley Drain Flow

Historically, El Paso Valley drain flow was used within the Project as Documented by Rio Grande Joint Investigation

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TABLE 90.—*Estimated percentages of reservoir water, arroyo inflow, and drainage in net diversions and disposal of reservoir releases, Elephant Butte-Fort Quitman section, 1930–36*

Division or item	Mean disposal of reservoir water 1930-36 (percentage distribution)	Mean percentage content, 1930-36, in net diversions, of—			
		Unused reservoir releases [1]	Arroyo inflow	Drain flow and seepage	Total
Rincon	8.5	97.5	2.2	[2] 0.3	100.0
Mesilla	46.4	89.8	2.8	7.4	100.0
El Paso	18.4	58.4			
Upper El Paso (Franklin canal)		61.5	3.4	35.1	100.0
Lower El Paso (Tornillo canal)		38.2	4.1	57.7	100.0
Rio Grande Project	73.3	79.8	3.0	17.2	100.0
Hudspeth	2.2	33.9	6.1	60.0	100.0
Juarez (Mexico)	11.4	49.5	5.4	45.1	100.0
Upper Juarez		58.3	3.1	38.6	100.0
Lower Juarez		24.4	11.8	63.8	100.0
Riverbed losses	9.2				
Passing Fort Quitman	3.9	17.2	14.8	68.0	100.0
Total	100.0				

[1] Distinguished from returned drainage originally from the reservoir.
[2] Invisible accretion to river.

Estimates based on detail study of all available data, 1930–36, on river flow, reservoir releases, diversions, wastes, drain flow, and arroyo inflow.

A number of drains discharged into the Rio Grande in the El Paso Valley above the last Project diversions at Tornillo

Diversion of this water at the Tornillo Canal heading for use in the lower part of EPCWID was a normal part of Project Operations

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El Paso Valley Drains Above Fabens

Kirby (retired Project Superintendent) wrote in 1994:

It is my remembrance that this admission [of the Tornillo Division into the Project] was <u>only agreed to by EBID</u> provided that the Tornillo Division would divert and use, as part of their water supply, the drain waters that accumulated into a collection channel at Fabens. There was a pumping station at this location later changed to a gravity diversion that moved water into the Tornillo Canal. (Emphasis in the original.)

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El Paso Valley Drain Flow Component of Project Supply

In 1938 the course of the Rio Grande was rectified in the El Paso Valley near Fabens and the Tornillo Canal Heading

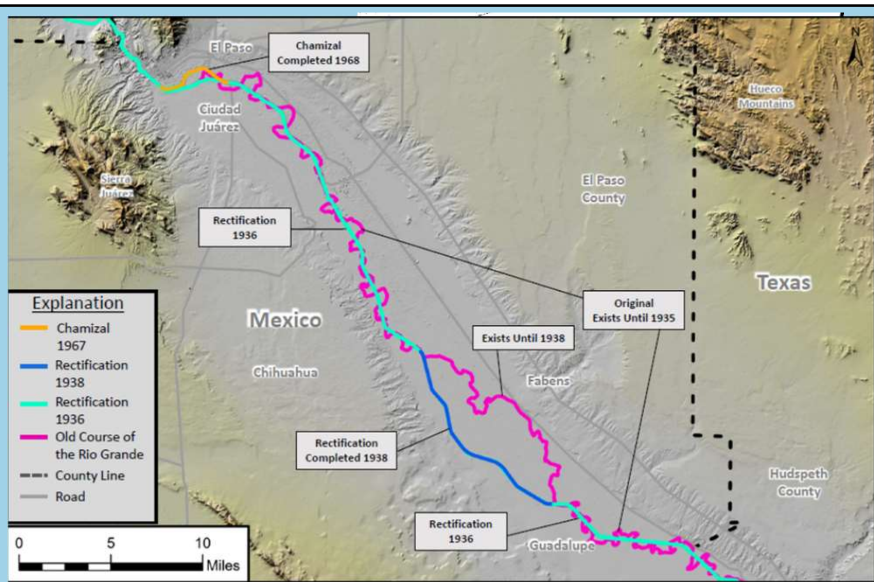

Figure 4.5a – Major changes in the position of the Rio Grande, 1903 to present.

McDonald Morrissey

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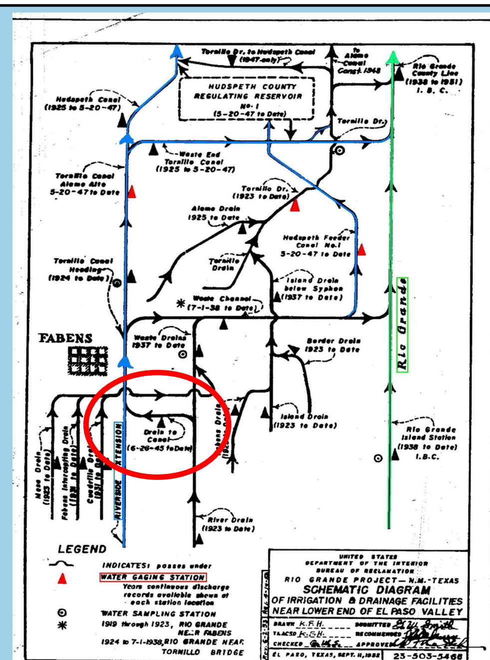
El Paso Valley Drain Flow Component of Project Supply

After Rectification, drains were rerouted.

The River Drain was engineered to discharge into the Riverside Canal Extension for delivery to the Tornillo Canal.



Schematic of the Project conveyance system in part of the El Paso Valley, from Cortez, 2005, slide 32:

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Numerous sources document the diversion of drain water into the EPCWID works at Fabens for Project Supply through ~1980

* Of which 33,440 A.F. was diverted from River Drain to Riverside Ext. - Tornillo Canal.
° Beginning in 1948 Border Drain carries waste from end of Guadalupe Lateral.

DRAINS: GARFIELD, HATCH, ANGOSTURA, RINCON, TOTAL FOR VALLEY; SELDEN, LEASBURG, PICACHO, MC'ILLA, DEL RIO, CHAMBERINO, LA MESA, EAST, ANTHONY, NEMEXAS, WEST, MONTOYA, TOTAL FOR VALLEY (SANTO TOMAS & MONTOYA INTERCEPTING DRAINS NOT INCL.); PLAYA, FRANKLIN, MIDDLE, RIVER, CUADRILLA, MESA, FABENS INTER., TOTAL ABOVE, BORDER °, ISLAND, FABENS, ISLAND SYPH., ALAMO, TORNILLO, TOTAL FOR V…, TOTAL PR…

JANUARY

7-212 (January 1937)

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

DAILY GAGE HEIGHT OR DISCHARGE—YEAR SHEET

DAILY ~~gage height, in feet,~~ discharge, in second-feet, of *Drain to Canal* River Creek at near *Fabens (River Drain Water* for 19*47* *diverted to Tornillo Canal)*, Observer)

Note: River Drain at point of diversion to Tornillo Canal includes flow of River Drain and Middle Drain.

DAY	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
1	48	10	25	33	73	71	98	113	59	0	64	0
2	48	10	42	20	75	64	89	115	100	0	60	
3	42	9	37	0	70	60	79	110	99	0	59	
4	47	8	43	29	70	51	75	102	115	0	59	
5	47	5	41	57	38	63	74	77	115	0	57	
6	50	8	48	4	68	78	81	66	118	0	62	
7	50	8	42	19	70	65	101	103	112	31	29	
8	51	8	39	0	64	70	105	113	112	83	0	
9	50	8	39	0	67	62	113	110	109	63	1	

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El Paso Valley Drain Flow

DRAIN RETURN FLOW - EL PASO VALLEY

SOURCE: Letters from Besch to Gregg 11/17/53 1945 - 1951 Letter from Gregg 12/18/52

DESCRIPTION: Parts of this drainage return is diverted back into the system, part is delivered to Hudspeth, and part reaches the Rio Grande.

Year	Discharge - A. F.
1935	109,500
1936	112,900
1937	125,100
1938	130,210
1939	129,680
1940	127,550
1941	127,310
1942	148,746
1943	139,590
1944	148,653
1945	154,650
1946	150,600
1947	136,180
1948	128,770
1949	144,970
1950	150,588
1951	77,480
1952	73,220
1953	62,840
1954	12,233
1955	334
1956	
1957	
1958	
1959	

EL PASO - DIVERSIONS

SOURCE: Letters from Besch to Gregg

DESCRIPTION: Includes drain water diverted at Fabens

Year	Discharge - A. F.
1935	308,210
1936	393,400
1937	424,300
1938	428,020
1939	386,620
1940	384,940
1941	382,500
1942	434,400
1943	501,910
1944	446,460
1945	407,630
1946	372,810
1947	459,050
1948	342,520
1949	349,290
1950	335,429
1951	208,370
1952	217,747
1953	204,675
1954	70,493
1955	55,516
1956	
1957	
1958	
1959	
1960	
1961	
1962	

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Volume 3. Report on Annual Flow Data, 1935-65
Volume 5. Report on Activities 1954
Volume 6. Research for 1955 Irrigation Season, 2-14-56
Volume 7. Flow of the Rio Grande for the Irrigation Season, 7-11-57
Volume 8. Flow of the Rio Grande for the 1957 Irrigation Season, 7-15-58
Volume 9. Picacho Area Studies
Volume 10. Flow of the Rio Grande for 1958 Irrigation Season, 6-2-59
Volume 11. Flow of the Rio Grande for 1959 Irrigation Season, 3-18-60
Volume 12. Research for 1960 Irrigation Season, 1-18-61

DRAIN WATER DIVERTED AT FABENS

SOURCE: Letters from Besch to Gregg 11/17/52

Year	Discharge - A. F.	Remarks
1945	6,660	Started July 26
1946	38,760	
1947	28,250	
1948	33,440	
1949	16,580	
1950	20,900	
1951	29,600	
1952	23,690	
1953	19,350	
1954	4,586	
1955	0	
1956		
1957		
1958		
1959		
1960		
1961		
1962		
1963		
1964		

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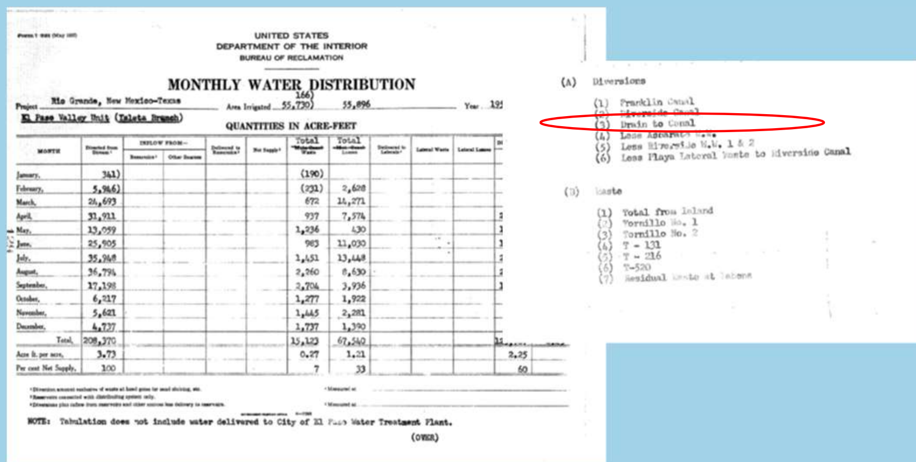
El Paso Valley Drain Flow is included as a component of supply in Project WDRs.



UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

MONTHLY WATER DISTRIBUTION

Project Rio Grande, New Mexico-Texas — Area Irrigated 166) 55,730) 55,896 — Year 19[illegible]
El Paso Valley Unit (Taleta Branch)

QUANTITIES IN ACRE-FEET

Month	Diverted from Stream	Inflow from Reservoirs	Inflow from Other Sources	Delivered to Reservoirs	Net Supply	Total Waste	Total Losses	Delivered to Laterals	Lateral Waste	Lateral Losses	[illegible]
January	341)					(190)					
February	5,946)					(231)	2,628				
March	24,693					672	14,271				
April	31,911					937	7,574				2
May	13,059					1,236	430				1
June	25,905					983	11,030				1
July	35,948					1,451	13,448				2
August	36,794					2,260	8,630				2
September	17,198					2,704	3,936				1
October	6,217					1,277	1,922				
November	5,621					1,445	2,281				
December	4,737					1,737	1,390				
Total	208,370					15,123	67,540				11[illegible]
Acre ft. per acre	3.73					0.27	1.21				2.25
Per cent Net Supply	100					7	33				60

NOTE: Tabulation does not include water delivered to City of El Paso Water Treatment Plant.

(OVER)

(A) Diversions

(1) Franklin Canal
(2) Riverside Canal
(3) Drain to Canal
(4) Less Ascarate W.W.
(5) Less Riverside W.W. 1 & 2
(6) Less Playa Lateral Waste to Riverside Canal

(B) Waste

(1) Total from Island
(2) Tornillo No. 1
(3) Tornillo No. 2
(4) T - 131
(5) T - 216
(6) T-520
(7) Residual Waste at Tabena

Amounts of El Paso Valley Drain flow diverted into Riverside Canal Extension for delivery to Tornillo Canal Heading

Average during D2 period: 8,500 AF/yr

Tabulation of the Annual Diversions from the River Drain into Riverside Extension from Annual Reclamation Discharge Records

Year	Drain to Canal Diversions (acre-feet)	Year	Drain to Canal Diversions (acre-feet)
1945	6,660 (partial year)	1965	44
1946	38,760	1966	6,842
1947	28,250	1967	16,106
1948	33,440	1968	14,099
1949	16,580	1969	2,292
1950	20,900	1970	150
1951	29,600	1971	12,318
1952	23,690	1972	10,382
1953	19,350	1973	6,171
1954	4,586	1974	5,761
1955	0	1975	0
1956	0	1976	0
1957	0	1977	9,229
1958	0	1978	7,453
1959	5,727	1979	3,415
1960	9,781	1980	438
1961	18,874	1981	696
1962	12,212	1982	155
1963	17,470	1983	0
1964	2,758		

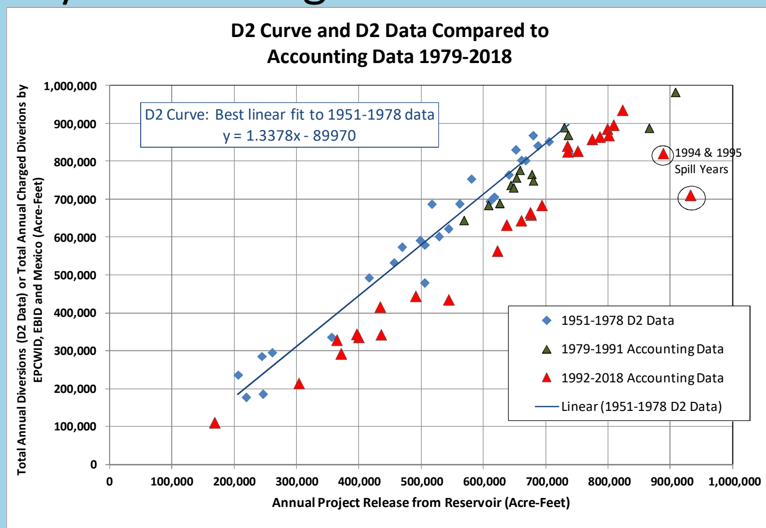
Current Status of El Paso Valley Drain Flows at Fabens

- These drain flows have likely been reduced because the amount of irrigation acreage above Fabens has decreased
- Remaining drain flows would likely have been depleted by the effects of Texas groundwater pumping
- There is no term in Project Accounting for diversion of drain flow in the El Paso Valley
- Part of the negative departure from D2 is likely related to:
  - The absence of these drain flows or
  - Failure to divert these drain flows, or
  - Failure to charge EPCWID for any diversion of these drain flows

8. How do these Accounting Factors Impact the Distribution of Project Supply?

- Off-season diversions: The D2 Curve is artificially inflated by the inclusion of flows that are no longer counted. Under D3 Allocation, EBID's Allocation is reduced for any negative departure from the D2 Curve, therefore EBID's Allocation is being artificially reduced.
- EPWU effluent: EPCWID diverts and uses the effluent it gets from EPWU in the El Paso Valley. Because this water use is not charged to EPCWID, the sum of the Charged Diversions is lower than it should be, increasing the discrepancy between Charged Diversion and the D2 Curve.
- El Paso Valley Drain Flow. Again, the D2 Curve is artificially inflated by the inclusion of drain flow diversion that either no longer exist or are no longer counted as Charged Diversions.

How Much of the Departure from D2 Could be Caused by Accounting Issues?



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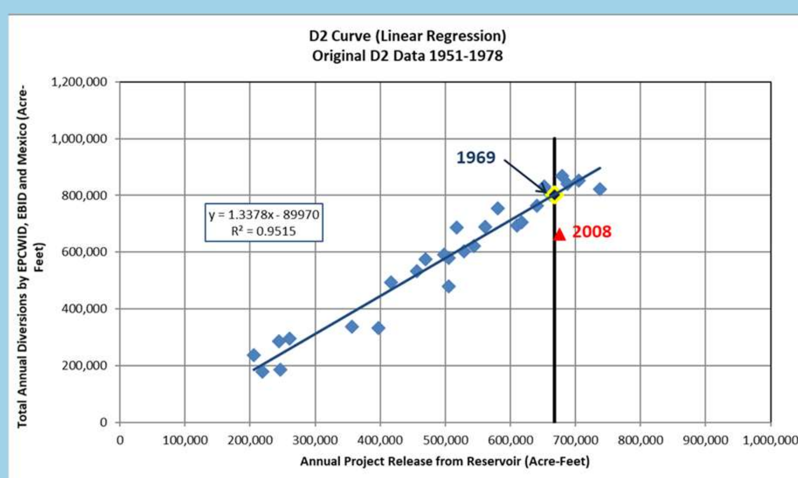
Examine the Application of Current Accounting Rules to Historical D2 Data: 1969

- 1969 was chosen because:
- 1969 falls "on the D2 Curve"
- There is more recent year (2008) which has approx. the same Caballo Release for ready comparison



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1969 WDR Data: How much would be charged today under post-1978 Accounting rules?

Charged Diversions would be 74,292 AF less than the reported 1969 diversions

Diversion Ratio calculation: 1969 recorded diversions: 1.20

Applying Current Account Rules: 1.09

Table 2. (Modified Table 7.1 from Barroll (2019) Components reordered, Calculated Diversion Ratio added). Analysis of 1969 WDR Diversions

	WDR Values *	WDR Values broken down by Component	Estimated Charged Diversion using Post-1979 Accounting	Difference in Total Accounted Diversions: WDRs vs. Post-1979 Accounting
EBID Diversion	421,000	404,000	404,000	17,000
EPCWID Diversion	321,000	263,708	263,708	57,292
(a) Off-Season Diversions		38,000		
(b) EPV Drain to Canal		2,292		
(c) Estimated Post-1979 Credits EBID **		17,000		
(c) Estimated Post-1979 Credits EP#1**		17,000		
Mexico	60,000	60,000	60,000	
Total Accounted Diversions	802,000	802,000	727,708	74,292
Caballo Release	667,700	667,700	667,700	
Diversion Ratio	1.20		1.09	

* WDR Values adjusted so that Mesilla Dam Diversions are split between the Districts Pro-Rata

** Total Estimated Post-1979 Credits calculated as the difference between total diversions and charged diversion in 2008, a year of similar water supply to 1969. This total was split 50:50 between EBID and EPCWID

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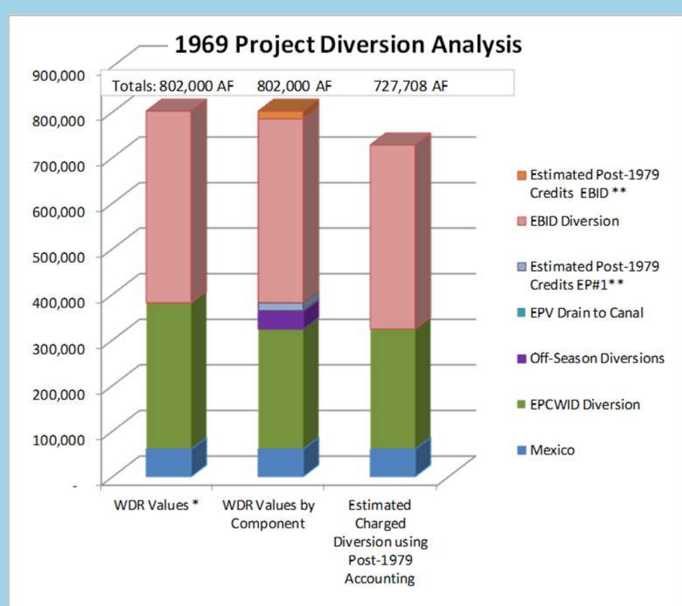
Chart of the breakdown of 1969 reported Diversions



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Effect of that Difference in the Diversion Ratio

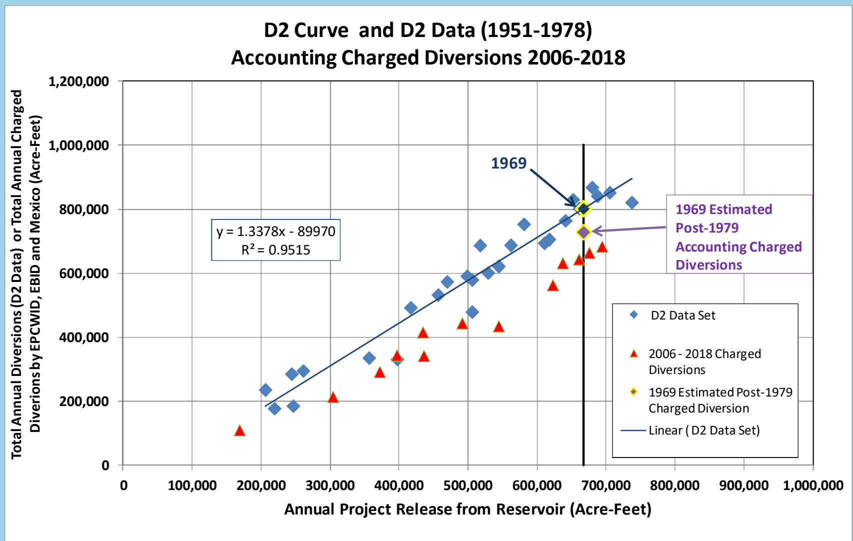
Applying that reduction in the Diversion Ratio in D3 Allocation results in a reduction to EBID's Allocation of 84,000 AF

Table D.2 Modified. Illustration of the Effect of Variation in the Diversion Ratio
Example: Project Performance during 1969
Compare D3 Allocation with Diversion Ratio Calculated Using WDR Diversions, to D3 Allocation with Diversion Ratio Calculated Using Post-1978 Accouting
(Values rounded to nearest 1000 AF)

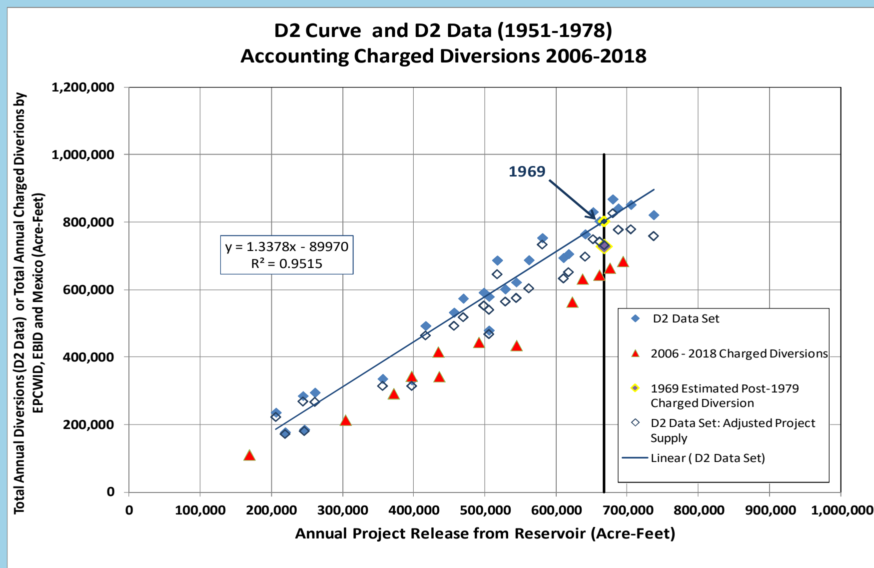
	D3 Allocation		**Difference**
Diversion Ratio (unitless)	1.20	1.09	0.11
Usable Water (AF)*	764,000	764,000	
Mexican Allocation (AF)	60,000	60,000	
EPCWID's Allocation (AF)	377,000	377,000	0
EBID's Allocation (AF)	480,000	396,000	-84,000
[(Usable Water x Diversion Ratio) – Mexican Allocation – EPCWID Allocation]			

* 1969 was a full-supply year (final allotment = 3.0 AF/A) and so I assume the amount of Usable Water available to the Project that year is at least 764,000 AF.

1969 Data Indicates that a Significant Portion of Current Departure from D2 is Related to Accounting



Similar Analysis for Other D2 years



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9. Effects of Pumping in the Hueco Bolson/ El Paso Valley

- As in New Mexico, groundwater pumping can
  - Reduce discharge of groundwater into drains, reducing Project Supply
  - Increase seepage from streams and canals, reducing Project Efficiency.

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Hueco Bolson Groundwater Pumping

- Texas started large groundwater withdrawals earlier than New Mexico
- Juarez has also pumped large amounts of groundwater in the Hueco Bolson

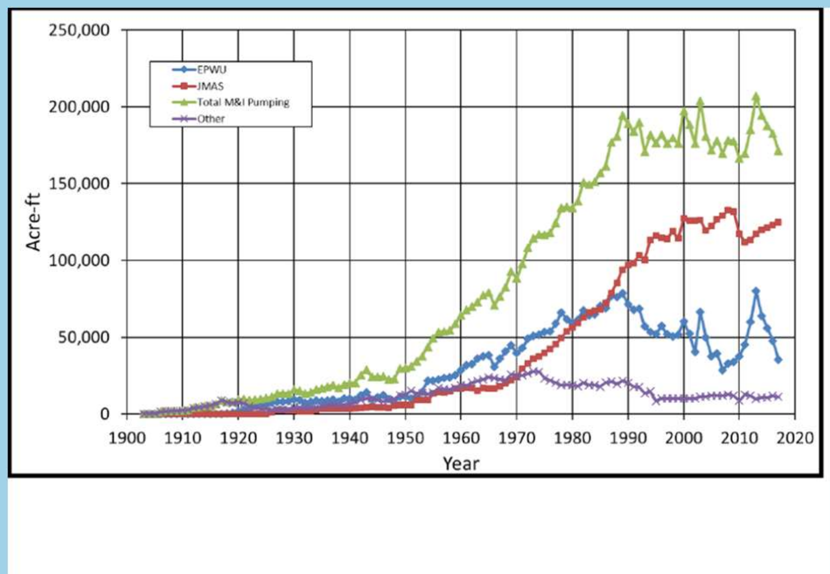

Figure 5.4 – Graph showing annual municipal and industrial pumping, 1903 to 2017.

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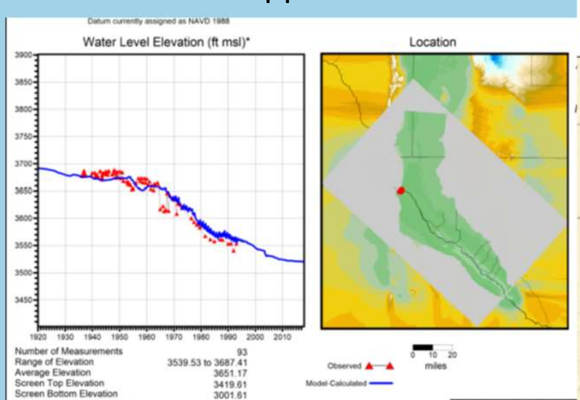
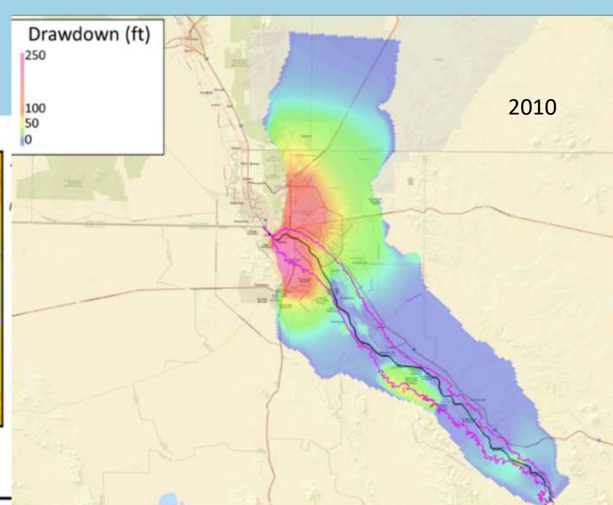
Drawdowns in El Paso Area Exceed 150 feet

- MMA 2019 Appendices O and Q



Hydrograph and location for well 4913702



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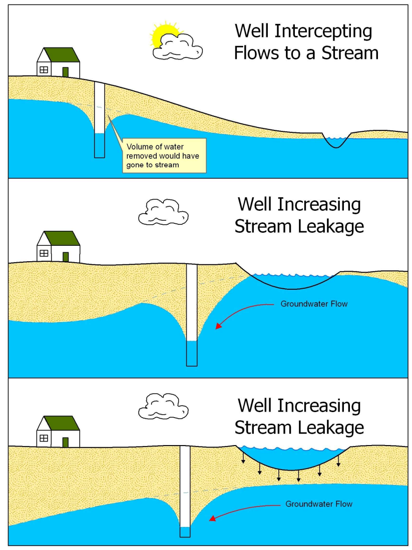
As in New Mexico, drawdowns in Texas impact stream flow and drain flow



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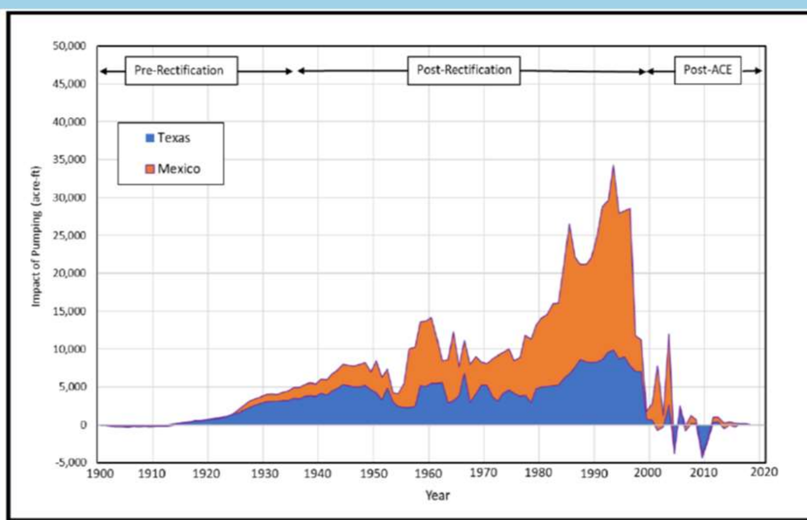
Rio Grande Main Stem Above Riverside Dam:

Seepage losses from the bed of the Rio Grande increased due to groundwater pumping in Texas and Mexico



Note: Impact includes changes in Rio Grande evaporation, which are negligible.

Figure 9.3 – Graph showing impact of pumping by Texas and Mexico for the Rio Grande from American Dam to the Riverside Diversion for the reoperated runs, 1903 to 2017.

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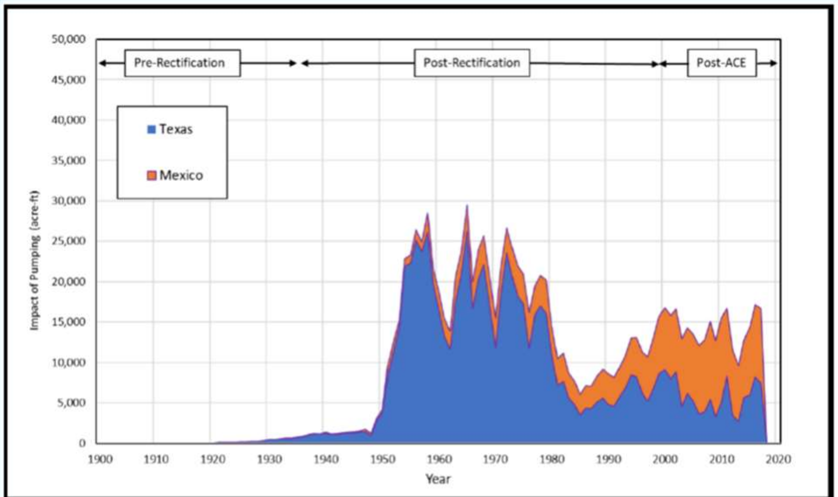
Drain Flows in the El Paso Valley Above Fabens

Drain flows were historically diverted by EPCWID near Fabens

These drain flows have been depleted by Texas groundwater pumping



Note: For run details see Table 9.1.

Figure 9.13 – Graph showing impact of pumping on EPCWID drain flows to Fabens, Texas for the reoperated runs, 1903 to 2017.

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EPCWID's Canals and Laterals

Some parts of these are hydrologically connected to groundwater and can be depleted by groundwater pumping

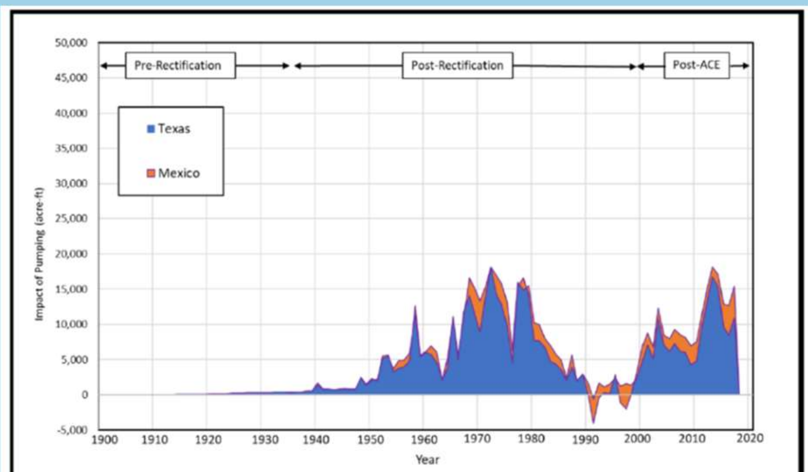

Figure 9.8 – Graph showing impact of pumping by Texas and Mexico on EPCWID canals and laterals for the reoperated runs, 1903 to 2017.

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10. American Canal Extension Credit

- American Canal Extension (ACE) was built to bypass the losing reach of the Rio Grande between American Dam and Riverside Canal heading.
- Losses in this reach of the Rio Grande were caused/exacerbated by groundwater pumping in the Hueco Bolson, largely by Texas.
- ACE mitigates these losses, but then EPCWID gets a credit for having done so (up to ~20,000 AF).
- ACE Credit applied under 2008 OA reduces EBID's Allocation.
- ACE Credit gives EPCWID (and thus Texas) a credit for mitigating a problem caused by Texas.

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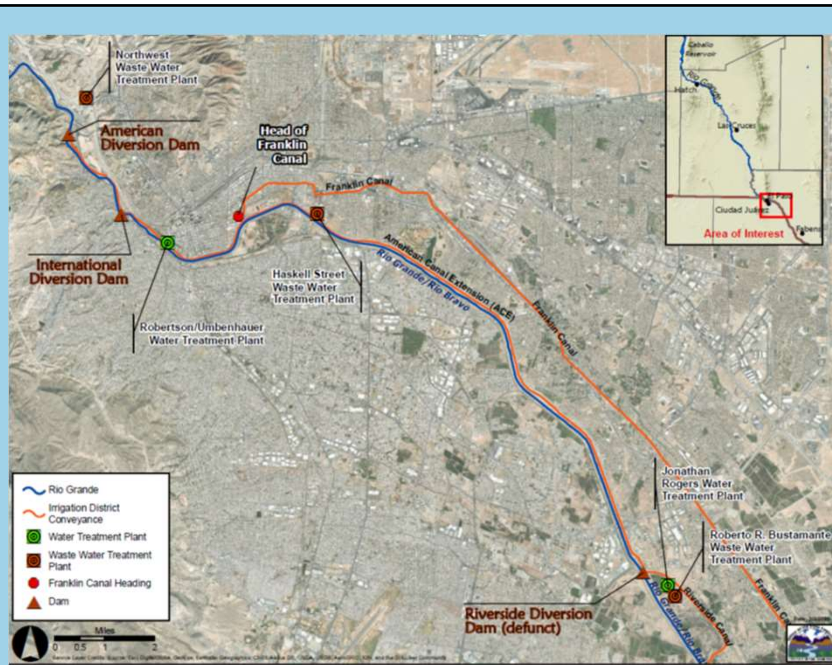
Map showing American Canal Extension



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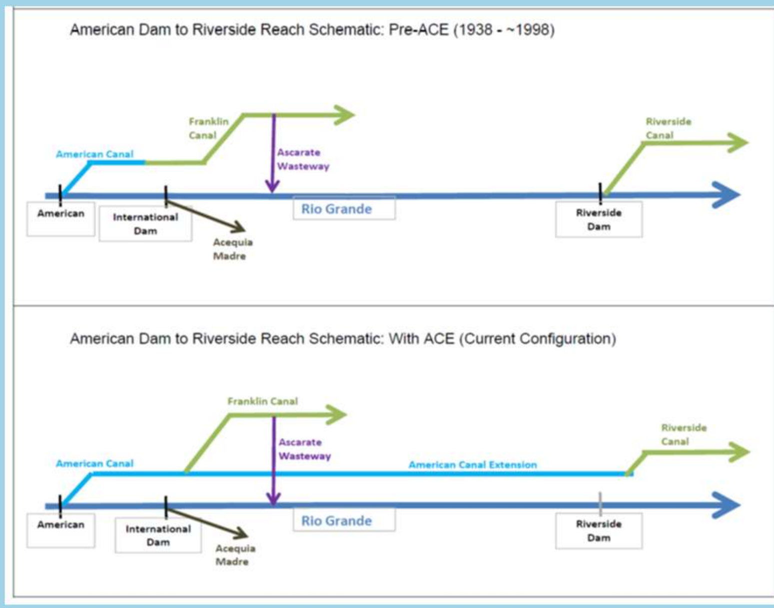
ACE Schematic

Illustrates how ACE allows EPCWID to by-pass Rio Grande main stem to deliver water to Riverside Canal



The ACE is concrete-lined

Cortez 2003

ACE Credit

- Use of the ACE to deliver water to Riverside almost certainly avoids seepage losses from Rio Grande main stem.
- EPCWID argues that the reduction of these losses means that smaller releases from Caballo are required to meet orders at Riverside.
- EPCWID argued (successfully) that it should get a Project "allocation credit"
- EPCWID uses the ACE Credit to increase the water it sells to the City of El Paso (EPWU).
- ACE Credit reduces EBID's Allocation

Application of ACE Credit

- As 2008 OA was written, ACE Credit is applied during Allocation Process in the Allocation Spreadsheet

20	Gross D2 Diversion Allocation	942,117
21	EPCWID ACE Conservation Credit	17,998
22	Net D2 Diversion Allocation for EBID and EPCWID	888,731

- If so applied, ACE Credit increases EPCWID's Allocation and reduced EBID's Allocation by the same amount

		2008 Allocation	2008 Allocation calculated with ACE Credit set to 0	Difference (Effect of ACE)
36	Total EBID Diversion Allocation (After Transfer)	345,817	363,815	-17,998
37	Total EPCWID Allocation (After Transfer)	552,997	534,999	+17,998

1	Rio Grande Project Diversion Allocations (EOM OCT 2009 Project Data)	USBOR orig	No ACE credit	
2	Elephant Butte Reservoir Storage	454,530	454,530	
3	Caballo Reservoir Storage	26,100	26,100	
4	Total Rio Grande Project Storage	480,630	480,630	
5	Estimated Rio Grande Compact Credit Waters	-126,600	-126,600	
6	Estimated San Juan-Chama Water	-37,298	-37,298	
7	Water Released from Storage	693,289	693,289	
8	Total Usable Water Available for Release	1,010,021	1,010,021	
9	Carryover Obligation using Estimated Diversion Ratio	235,960	235,960	
10	Total Usable Water Available for Current Year Allocation	774,061	774,061	
11	EBID Allocation Balance (Previous Year)	-4,304	-4,304	
12	EPCWID Allocation Balance (Previous Year)	232,882	232,882	
13	EBID Allocation Balance (End-of-Year)	40,343	40,343	
14	EPCWID Allocation Balance (End-of-Year)	232,915	232,915	
15	Storage for EBID and EPCWID Allocation Balance (End-of-Year)	276,869	276,869	
16	Current Usable Water	733,152	733,152	
17	End-of-Year Release for Diversion Ratio	693,289	693,289	
18	D1 Delivery	470,416	470,416	
19	Mexico's Current Diversion Allocation	53,386	53,386	
20	Gross D2 Diversion Allocation	942,117	942,117	
21	EPCWID ACE Conservation Credit	17,998		
22	Net D2 Diversion Allocation for EBID and EPCWID	888,731	888,731	
23	D2 Diversion Allocation for EPCWID	384,161	384,161	
24	EPCWID Diversion Allocation (w/o Conservation Credit)	617,043	617,043	
25	EPCWID Diversion (w/o Conservation Credit or 67/155ths of Row 30)	384,128	384,128	
26	Diversion Ratio	0.986956	0.987	
27	Diversion Ratio Adjustment	-9,563	-9,563	
28	Sum of Release and Diversion Ratio Adjustment	723,589	723,589	
29	EBID D2 Diversion Allocation	504,570	504,570	
30	Difference between EBID Diversion Ratio Allocation and D2 Diversion Allocation	0	0	
31	EBID Diversion Ratio Allocation	268,077	286,075	
32	EBID Diversion Allocation	268,077	286,075	
33	Total EBID Diversion Allocation (includes 88/155th of Value in Row 30)	263,773	281,771	
34	Total EPCWID Allocation (includes Row 21 and 67/155th of Value in Row 30)	635,041	617,043	
35	District to District Allocation Transfer (OA 1.11 Excess Carryover Balance)	82,044	82,044	
36	Total EBID Diversion Allocation (After Transfer)	345,817	363,815	-17,998
37	Total EPCWID Allocation (After Transfer)	552,997	534,999	17,998
38	Total EBID, EPCWID, and Mexico Allocation	952,200	952,200	
39	EPCWID 2009 Allocation Charges (calculated)	320,082	302,084	
	...llocation Charges (calculated)	305,474	323,472	
	...09 Allocation Charges (actual)	320,083	320,083	
	...llocation Charges (actual)	305,475	305,475	
	... Allocation Charges (actual)	58,688	58,688	
	... Mexico's Charges and Allocation	-5,302	-5,302	
	...are	-2,292	-2,292	
		-3,010	-3,010	

ACE Credit Has Been Applied Inconsistently

- In some years it is applied in Allocation spreadsheet
- In some years it is added on to EPCWID's Allocation in the Accounting records at the end of the year

DRAFT - EPCWID Diversion Allocation Charges for September 2015

Total Allotment Diversions Charges					**106,065**	**165,872**
Diversion Allocation					188,117	188,117
Est. Annual Conservation Credit Diversion Allocation						11,651
Accrued Conservation Credit Diversion Allocation						11,651
Total Diversion Allocation						199,768
District Allotment Balance						22,245
EOY Allocation Balance						**33,896**

- In some years it has not been applied at all

Effect of ACE Credit Applied at the End of the Year

When ACE Credit is added on to EPCWID's Allocation at the end of the year:

- EPCWID cannot make use of it in current year
- It is included in EPCWID's Carryover account to following year
- It increases paper water in EPCWID's Carryover account
- It reduces the part of Useable Water available for Current-Year Allocation the following year
- It reduces EBID's Allocation the following year
- It may increase the likelihood of a Carryover Transfer to EBID, but that possibility depends on EPCWID's water use

Summary of ACE Credit Issue

- ACE Credit rewards EPCWID for mitigating a problem largely caused by Texas
- Application of the ACE Credit harms EBID

11. Effects of Carryover on EBID and New Mexico

- EBID's Allocation is now so low it can make little use of Carryover.
- EPCWID's Allocation in full-supply years is much higher than its demand, and so it can carry over large amounts of unused Allocation.
- Under the 2008 OA, Carryover plus water needed to deliver it is subtracted from Usable Water before performing Current-Year Allocation.
- Carryover accounts are never reduced for evaporation and may include paper water.
- EPCWID's large Carryover accounts have acted to reduce Current Year Supply and the amount of water allocated to EBID.

Carryover is a New Feature of Project Allocation and Accounting

- As late as 2007 Reclamation's Project Manager, Bert Cortez, declared:

"The practice for nearly 100 years of Project operations was that any unreleased storage water or unused diversion Allocation from either district went back into the Project supply to be allocated anew the next year"

And Dr. King wrote for EBID:

"Carryover of unused Allocation by individual districts from one year to the next of either delivery or diversion was never included in the management of the Rio Grande Project prior to 2006. Implementing carryover in the Allocation procedure for the Project would be a substantial change in the Allocation of Project Water, which would in turn have a substantial impact on Project operations and hydrology"

Since 2006 EBID's Allocation Has Been Too Low to Accumulate Much "Unused Allocation" to Carryover

Table A.13. EBID Allocation and Charged Delivery Summary 2006 - 2019

Year	Current-Year Allocation AF	Carryover from Previous Year AF	Transfer from EPCWID AF	Total Allocation AF	Total Charged Diversions AF	Unused Allocation AF	Mexican Adjust-ment AF	Potential Carryover to Next Year AF
2006	211,385	0	0	211,385	211,841	-456	0	-456
2007	310,894	623	0	311,517	302,665	8,852	0	8,852
2008	324,990	0	0	324,990	329,294	-4,304	0	-4,304
2009	268,077	-4,304	82,044	345,817	305,475	40,342	0	40,342
2010	255,257	40,342	10,271	305,870	282,082	23,788	-3,774	20,014
2011	57,090	20,014	0	77,104	59,771	17,333	-1	17,332
2012	118,300	17,333	0	135,633	133,060	2,573	0	2,573
2013	54,438	2,573	0	57,011	54,002	3,009	0	3,009
2014	104,651	3,009	0	107,659	99,007	8,652	0	8,652
2015	161,940	8,653	0	170,593	143,404	27,189	-2,586	24,603
2016	156,310	24,602	0	180,912	175,199	5,713	-2,487	3,226
2017	267,523	3,226	0	270,749	259,510	11,239	0	11,239
2018	114,419	11,239	0	125,958	127,487	-1,529	0	-1,529
2019	203,933	-1,529	75,333	277,737	191,462	86,275	0	86,275

EPCWID's Allocation Has Been Higher than Its Demand in Full Supply Years, Allowing Substantial Carryover

Table A.14. EPCWID Allocation and Charged Delivery Summary 2006 - 2018T

Year	Current-Year Allocation + ACE Credit	Carryover from Previous Year	Transfer to EBID	Total Allocation	Total Charged Diversions	Unused Allocation	Mexican Adjust-ment	Potential Carryover to Next Year
	AF	AF	AF	AF	AF	AF	AF	AF
2006	241,657	0		241,657	177,183	64,474	0	64,474
2007	367,291	36,200		403,491	278,252	125,239	0	125,239
2008	405,073	106,982		512,055	279,173	232,882	0	232,882
2009	402,159	232,882	-82,044	552,997	320,083	232,914	0	232,914
2010	309,515	232,914	-10,271	532,158	304,937	227,221	-2,874	224,347
2011	43,466	224,347		267,813	258,772	9,041	-1	9,040
2012	132,935	9,042		141,977	136,380	5,597	0	5,597
2013	41,446	5,597		47,043	53,530	-6,487	0	-6,487
2014	106,590	-6,487		100,103	97,418	2,685	0	2,685
2015	197,629	2,685		200,314	165,872	34,442	-1,969	32,473
2016	235,908	32,473		268,381	216,309	52,072	-1,893	50,179
2017	401,842	50,179		452,021	249,919	202,102	0	202,102
2018	143,038	202,102		345,190	280,674	64,516	0	64,516
2019	399,655	64,466	-75,333	388,787	155,872	232,915	0	232,915

Part of the reason EPCWID's Charged Diversions are as low as they have been is that EPCWID is **not charged for** its diversion and use of ~24,000 AF/yr of EPWU effluent in the El Paso Valley

In the D3 Allocation Process, Current Year Allocation is Reduced to Ensure Total Carryover Can be Delivered

- The amount of "Usable Water for Current Year Allocation" is Usable water minus "Carryover Obligation"
- "Carryover Obligation" is usually even higher than total Carryover

Rio Grande Project Diversion Allocations (Data as of Oct. 31, 2011)		
8	Total Usable Water Available for Release	426,821
9	Carryover Obligation using Estimated Diversion Ratio	281,459
10	Total Usable Water Available for Current Year Allocation	145,362
11	EBID Allocation Balance (Previous Year)	20,015
12	EPCWID Allocation Balance (Previous Year)	224,348
26	Diversion Ratio	0.868

Total Carryover equals 244,362 AF

In 2010 – 2011 the "Paper Water" Problem Became Evident

- Carryover exceeded Usable Water in Storage as of 10/15/2010
- When "Carryover Obligation" is included, 62,846 AF of winter inflows went to satisfy "Carryover" and "Carryover Obligation." These inflows were thus not available for Current Year Allocations.
- EBID's Current Year Allocation in 2011 was only 57,090 AF.

Table D.4. 2010 – 2011 Example of New Inflow to Reservoir Needed to Fulfill Existing Carryover Accounts and Obligation

2010 - 2011 Example of when Carryover Accounts Required Additional Inflows

		Storage, Carryover and Credit Conditions as of October 15 2010	Storage, Carryover and Credit Conditions as of January 1, 2011
Total Water in Reservoir Storage	(AF)	386,735	497,789
CO Compact Credit	(AF)	800	2,700
NM Compact Credit	(AF)	100,500	164,700
San Juan Chama Water	(AF)	60,796	64,250
Usable Water In Storage	(AF)	224,639	266,139
EBID 2010 Unused Allocation (Carryover from 2010 to 2011)	(AF)	20,014	
EPCWID 2010 Unused Allocation (Carryover from 2010 to 2011)	(AF)	224,348	
Total Carryover (Carryover from 2010 to 2011)	(AF)	244,362	
Diversion Ratio	(unitless)	0.98	0.85
2011 Carryover Obligation (divide total Carryover by 2011 Diversion Ratio	(AF)		287,485
Inflows after October 15 required to fulfill Carryover Obligation			62,846

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Summary of Carryover Issue

- It is a new feature of the Project (fully implemented starting 2007)
- It largely and substantially benefits EPCWID
- EBID's Allocations are too low to accumulate much Carryover
- Carryover Accounts can contain "paper water"
- Carryover is not reduced to account for evaporation
- Carryover reduces water available for Current Year Allocation to the detriment of EBID

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12. Net Effect of 2008 OA on EBID and New Mexico

- D3 Reduces Allocation to EBID
  - Reduces aquifer recharge from canal seepage
  - Increases need for groundwater pumping to meet demand
- Groundwater levels in Rincon and Mesilla valleys decline further
  - Drain flows decrease
  - River losses increase
- Further reduction in Project performance
- Further reduction in EBID's Allocation

Net Result: Vicious Cycle

(Double Whammy/Positive Feedback Loop as stated by Dr. Phil King)

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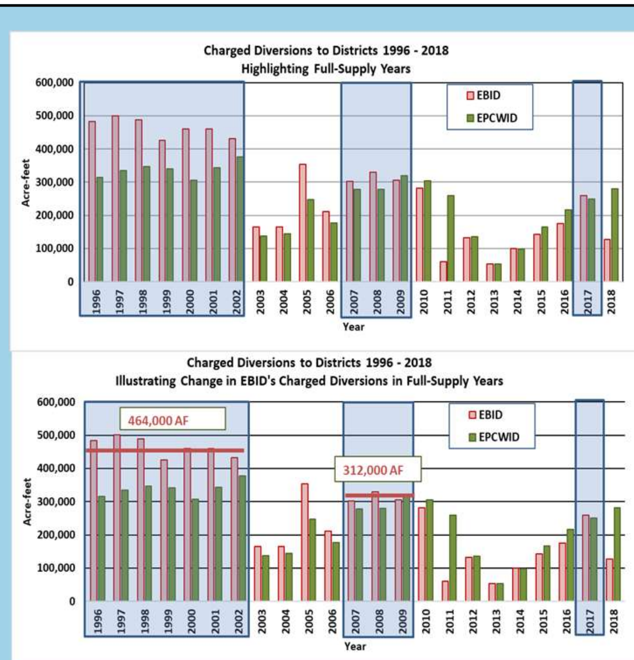
EBID's Full-Supply Allocation and Diversion Has Been Greatly Reduced

Reduced Project diversion causes reduction in canal seepage, historically a major source of recharge to the aquifers of the Rincon and Mesilla Valleys

With a reduced Allocation, farmers need to pump more groundwater to grow their crops



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Reduced Aquifer Recharge and Increased Pumping

Dr. Phil King calls this a "Double Whammy"

Barroll estimates the aquifer water budget in the Rincon and Mesilla valleys is worse off by at least 100,000 AF in many years

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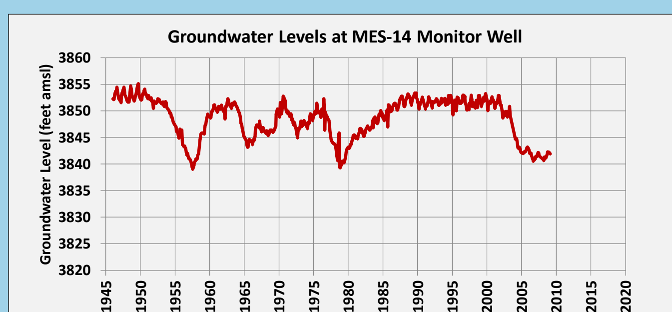
Historical Groundwater Conditions in Rincon and Mesilla Valleys

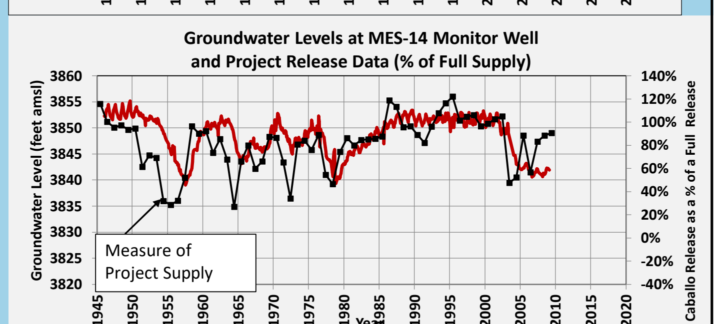
Groundwater levels fluctuated with Project Supply.

Groundwater levels

- Dropped during low-supply years
- Recovered during full-supply years

Aquifer was resilient





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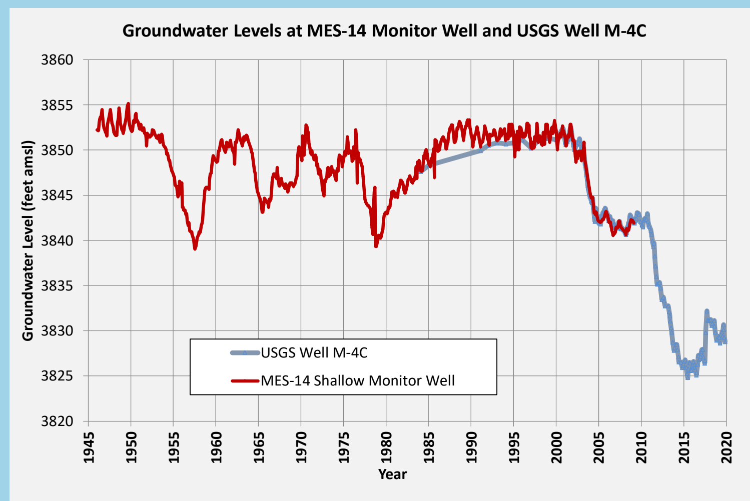
More Recently, under D3 Allocation:

Groundwater levels

- Drop during low-supply years
- Do not recover during full-supply years



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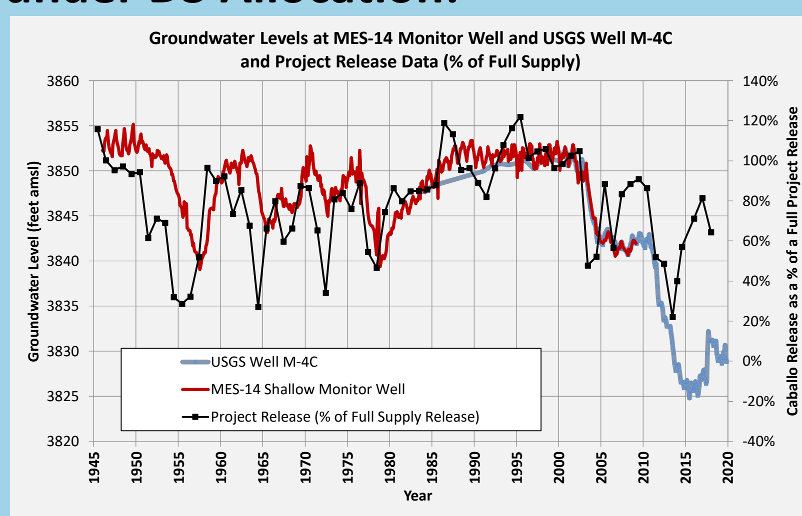
More Recently, under D3 Allocation:

Groundwater levels

- Drop during low-supply years
- Do not recover during full-supply years



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Vicious Cycle (Positive Feedback Effect)

- Project performance deficit leads to reduced EBID Allocation
- Reduced EBID Allocation leads to increased aquifer stress (less recharge and more groundwater pumping)
- Increased aquifer stress leads to lower groundwater levels
- Lower groundwater levels lead to lower drain flows and increased seepage loss from Rio Grande
- Lower drain flows/increased losses make Project performance worse

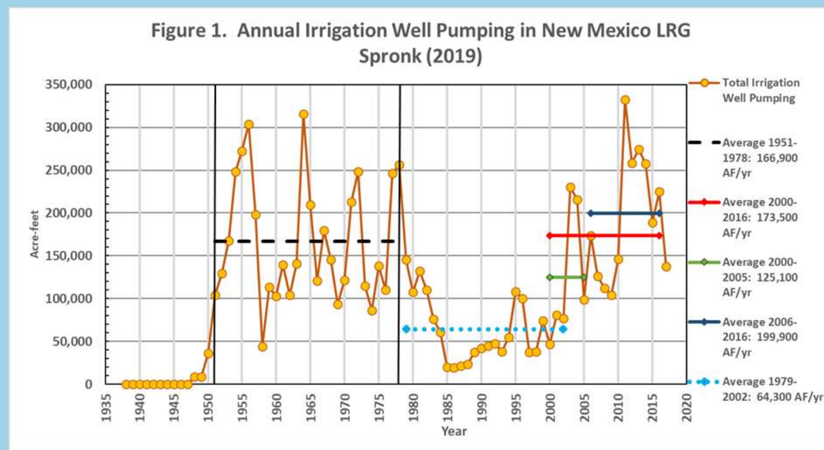
13. US Claim: D3 Reallocation is Necessary to Offset NM Pumping on EPCWID and Protect EPCWID's Project Supply Against Excessive NM Pumping

- US provides no technical analysis to quantify the effect of NM pumping on Project Supply or EPCWID deliveries
- New Mexico pumping has not greatly increased since D2 Period
- As demonstrated earlier, a significant part of the apparent discrepancy between current Project performance and historical Project performance is caused by factors other than New Mexico pumping

Irrigation Pumping in New Mexico

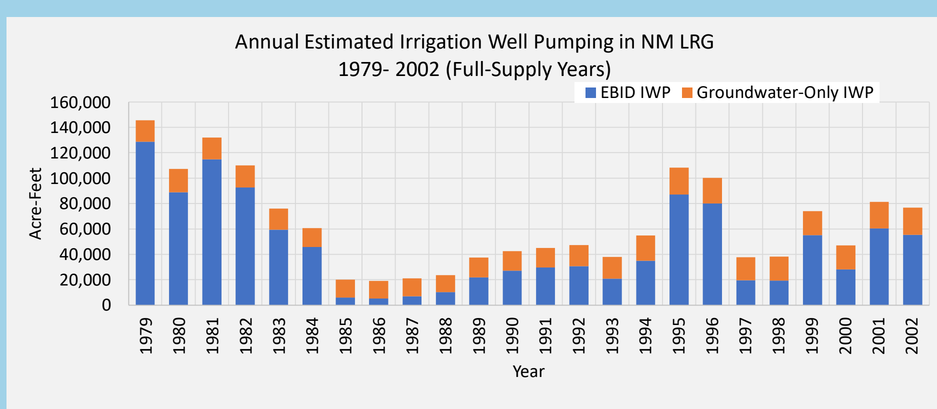
New Mexico irrigation well pumping (IWP) is high in recent years. Historically IWP was high during dry years in the D2 period.

In recent years NM IWP is aggravated by decrease in EBID's allocation under 2008 OA.



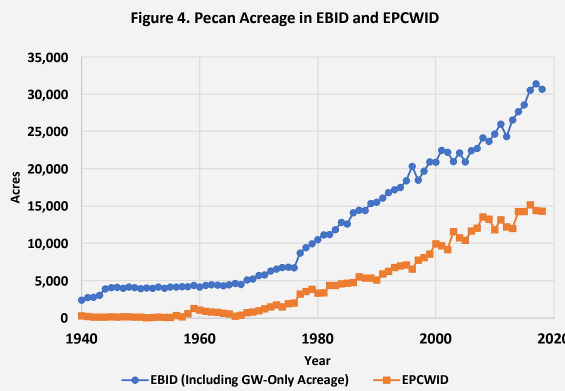
Estimated Irrigation Well Pumping in New Mexico During Project Full-Supply Years 1979 - 2002

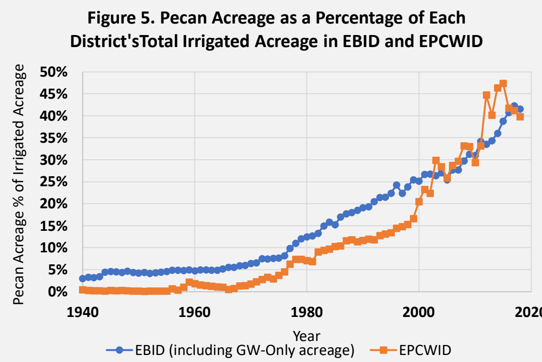
New Mexico has approximately 6,000 acres irrigated with groundwater-only (non-EBID).
There are EBID farmers who use some groundwater, regardless of surface water supply



Acreage of High-Water-Use Crops Have Increased in Both Texas and New Mexico

In both Districts, pecans are now about 40% of irrigated acres





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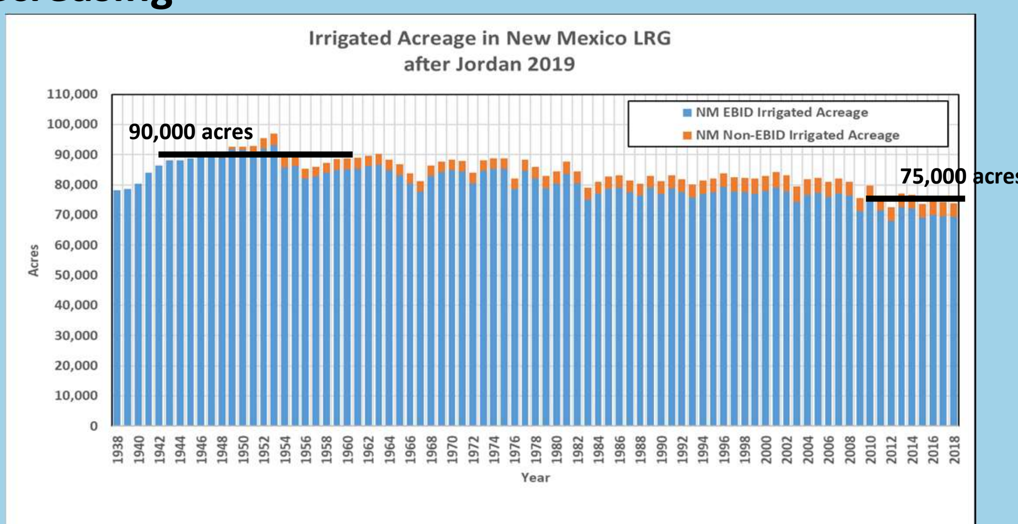
Total Irrigated Acreage in NM LRG Has Been Decreasing



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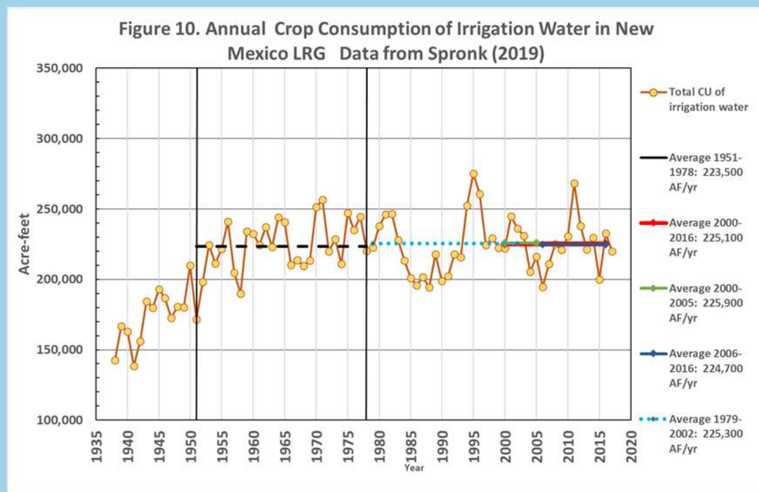
Estimated Net Irrigation Depletions in New Mexico Have Not Increased Since 1950's



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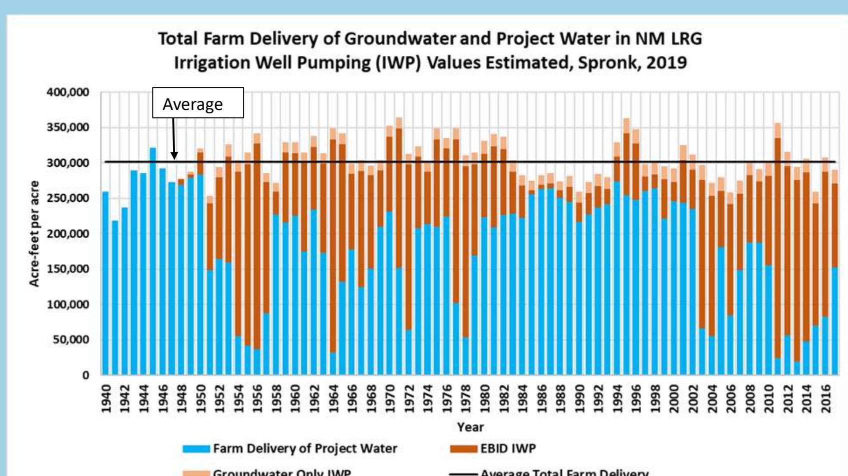
Estimated Farm Application of Irrigation Water in New Mexico (GW + SW) Has not Increased



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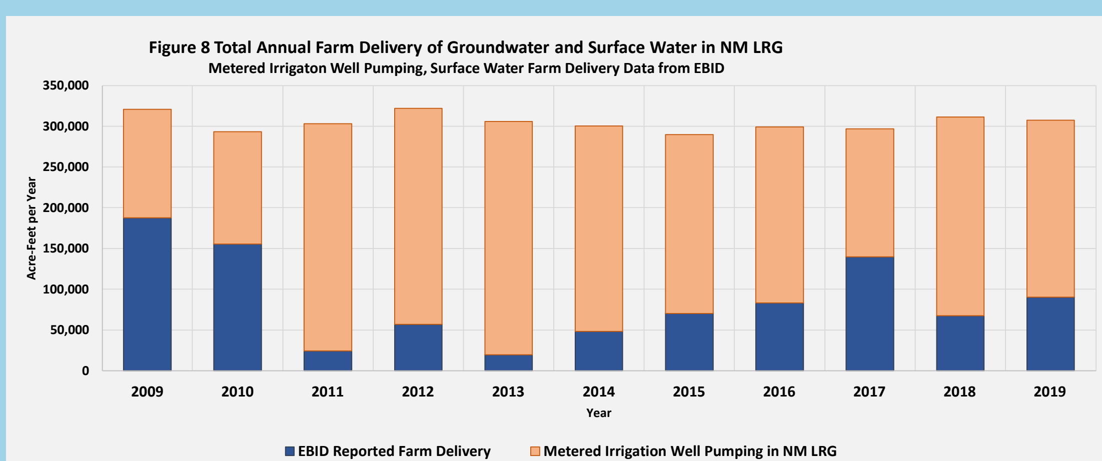
US_MSJ_00001096

New Mexico Total Farm Delivery Data
Meter Data and Reported EBID Farm Deliveries

Year	Project Allocation to EBID	Surface Water Delivered/ Charged to EBID Canal Headings	EBID Reported Farm Delivery	Metered Irrigation Well Pumping	Total Farm Delivery of Water (GW + SW)	Irrigated Acreage	Average Farm Delivery per irrigated acre	Assessed acreage	Average Farm Delivery per assessed acreage
	Project Accounting Records	Project Accounting Records	EDID Board Meeting Minutes	NM OSE Water Master Records		Intera 2019			
	Acre-Feet	Acre-Feet	Acre-Feet	Acre-Feet	Acre-Feet	Acres	Acre-Feet /Acre	Acres	Acre-Feet /Acre
2008	324,990	329,294	187,899	133,000	320,899	81,061	4.0	90,640	3.5
2009	345,817	305,475	187,694	133,000	320,694	75,607	4.2	90,640	3.5
2010	305,870	282,082	155,417	137,600	293,017	79,669	3.7	90,640	3.2
2011	77,104	59,771	24,149	279,000	303,149	76,002	4.0	90,640	3.3
2012	135,633	133,060	57,014	265,000	322,014	72,524	4.4	90,640	3.6
2013	57,011	54,002	19,711	286,000	305,711	77,199	4.0	90,640	3.4
2014	107,659	99,007	48,135	252,000	300,135	76,771	3.9	90,640	3.3
2015	170,593	143,404	70,416	219,400	289,816	73,616	3.9	90,640	3.2
2016	180,912	175,199	83,103	216,000	299,103	74,884	4.0	90,640	3.3
2017	270,749	258,954	139,589	157,000	296,589	74,218	4.0	90,640	3.3
2018	125,958	127,487	67,366	244,000	311,366	73,849	4.2	90,640	3.4
2019	277,737	191,462	90,134	217,000	307,134	74,000	4.2	90,640	3.4
Averages					305,802		4.0		3.4

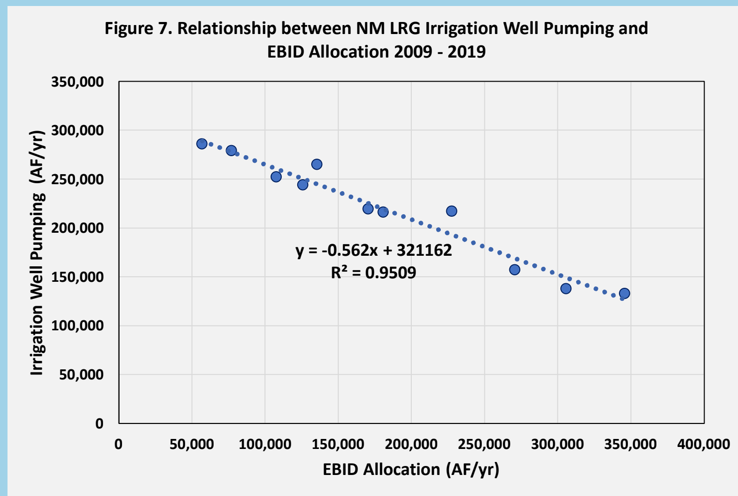
Estimated Values: 2008 Irrigation well pumping set equal to metered 2009 irrigation well pumping. 2019 Irrigated Acreage set to reflect levels in recent years.

Total Farm Delivery (SW + GW) Has Been Stable



Irrigation Well Pumping in New Mexico is Totally a Function of Surface Water Supply

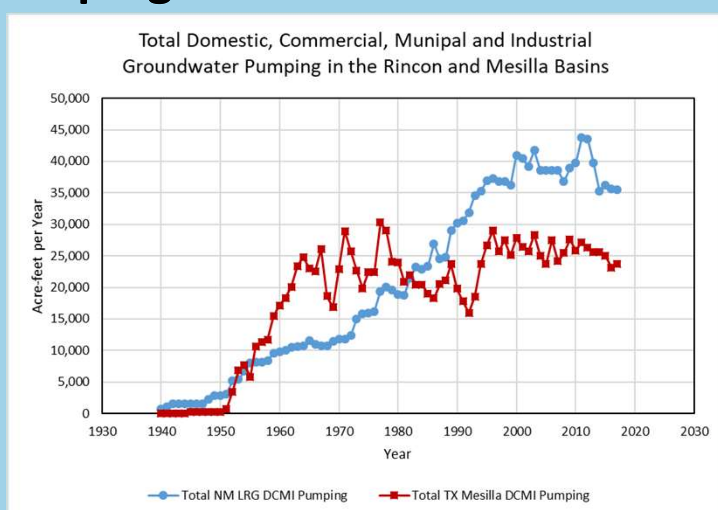
- Correlation between IWP and EBID Allocation is almost perfect.
- $R^2 = 0.95$
- NM's recent high groundwater pumping (since 2006) is almost certainly aggravated by the reduction in Allocation caused by D3 Allocation



Non-Irrigation Pumping in Rincon-Mesilla Basins

New Mexico DCMI (Domestic, Commercial, Municipal, Industrial) pumping leveled off in about 2000. Total amount is about 40,000 AF/yr.

Texas DCMI pumping in the Mesilla Basin is about 25,000 AF/yr.



14. Neither TX nor US Refute Barroll Analysis Showing:

- Before 2006 EBID and EBID farmers were entitled to order 57% of US Project Supply.
- Before 2006 the actual distribution of Project Supply between the Districts was approximately 57% to EBID and 43% to EPCWID.
- Starting in 2006 there was a large reduction in the share of Project Supply allocated to EBID, and the share of water EBID received.
- The large reallocation that began in 2006 is due to the new D3 Allocation method plus Carryover
  - D3 Allocation reduces EBID's Allocation for all negative departures in Project performance from historical levels defined by the D2 Curve.
- A significant part of the negative departure from D2 is caused by changes in Project Accounting and other factors not related to New Mexico.

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15. Neither TX nor US Refute Barroll Analysis Showing:

- EBID's Allocation is now so low that it is impossible for EBID to take advantage of Carryover.
- EPCWID has been able to create large Carryover accounts from its unused Allocation in full-supply years. Part of the reason EPWID can accumulate large amounts of unused Allocation is because it can now use El Paso municipal effluent in the El Paso Valley free of charge.
- Carryover is never reduced for evaporation and can include paper water. EPCWID's large Carryover account can reduce the amount of water available for Current Year Allocation, and thus the amount of water allocated to EBID.

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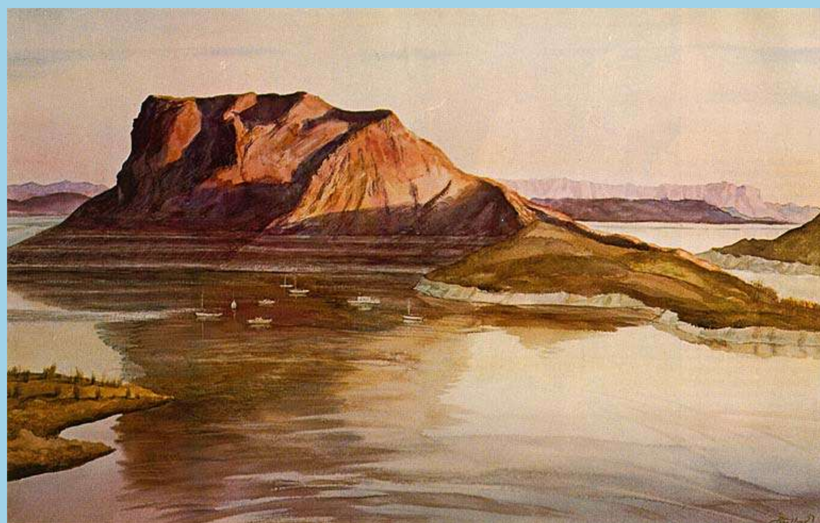

usbr.gov/museumproperty/art/hurd.html

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NO. 141, ORIGINAL ACTION
IN THE
SUPREME COURT OF THE UNITED STATES

TEXAS V. NEW MEXICO AND COLORADO

SUPPLEMENTAL REBUTTAL EXPERT REPORT OF MARGARET BARROLL, PH.D.
JULY 15, 2020

PREPARED FOR:
STATE OF NEW MEXICO

Margaret Barroll

MARGARET BARROLL, PH.D.

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Summary Opinions and Conclusions

In this Supplemental Report, I summarize results of certain runs of the revised Integrated Lower Rio Grande Model ("ILRGM") to further support the opinions I express in my 2019 Expert Report and 2020 Expert Rebuttal.

The questions that I use the ILRGM model results to address are:

1) What are the impacts of New Mexico's groundwater pumping on the amount of water allocated and delivered to Texas through the Rio Grande Project?

2) What are the impacts of D3 Allocation and the 2008 OA on the amount of water allocated and delivered to New Mexico by the Project?

3) How do the impacts of New Mexico's groundwater pumping on Texas compare with the amount of water re-allocated away from EBID and New Mexico under the 2008 OA?

4) What has been the impact of changes in Project operations and accounting in the El Paso Valley on the amount of water allocated and delivered to New Mexico by the Project?

5) How would Project allocation and delivery differ if the conditions existing during the D2 period (1951 – 1978) had continued to the present day?

My analysis consists of comparisons of Project allocation between different model runs, and comparison of Project diversions between model runs. In general, a District's diversion amounts are driven by and constrained by the amounts it is allocated. As a result, analysis of modeled allocations and diversions usually show similar trends, with minor differences in quantity and in detail. Typically, I look at both types of results in order to understand the model results more fully.

RUN 3 SUMMARY:

The impacts of New Mexico groundwater pumping are calculated by comparing a run of the ILRGM in which **all historical New Mexico groundwater pumping was turned off (Run 3)** to the historical Base Run (Run 1)**.** The resulting impacts occurring in 1980 through 2017 are as follows:

- There is no impact on the allocation of Project Supply to EPCWID or EBID for the full-supply years 1980 – 2002.

- There are limited impacts to EPCWID in the years 2003 through 2005 when all of New Mexico's pumping is turned off in Run 3. The cumulative total impacts to the Districts occurring during 2003 – 2005 are:

- An increase of EPCWID's allocation totaling 117,000 AF over all three years 2003, 2004 and 2005
- An increase of EPCWID's net diversion for all three years totaling 80,000 AF
- An increase of EBID's allocation for all three years totaling 151,000 AF
- An increase of EBID's net diversion for all three years totaling 146,000 AF

- The impacts simulated for 2006 – 2017 are dominated by the imposition of D3 + Carryover from the 2008 Operating Agreement, which resulted in significantly increased groundwater pumping by EBID farmers. As a result, the simulated impacts are larger than those that would have occurred if the 2008 OA had never been implemented. During these years, 2006-2017, New Mexico is shorted Project surface water.

RUN 11 SUMMARY:

The impacts of 2008 Operating Agreement ("D3 + Carryover") on the amount of Project water allocated and delivered to New Mexico can be calculated both from an analysis of actual Project Allocation and Diversion data, and by the analysis of outputs from the ILRGM (Run 11 versus Run 1 comparison).

- Analysis of historical allocation and diversion data shows that EBID's Allocations and Diversions after 2006 fall short of a 57% share of Project Supply by approximately 600,000 AF over the period 2006 through 2019.

- EBID's average annual shortfall from 57% is 50,000 AF each year starting in 2006. This is a first-order analysis (i.e. a conservatively low estimate without reallocation and re-operation) that does not include the actual changes in Project performance that would occur, and supply that would result from a significant change in allocation, such as a return to 57:43 Allocation.

- The actual effects of reallocation **are** simulated by the ILRGM. Using the ILRGM, I calculate that the impacts of 57:43 (or D1/D2) Allocation during 2006 – 2017, as compared with historical/actual D3 Allocation + Carryover during that time. The ILRGM impacts are as follows:
  - EBID's simulated D1/D2 Allocations are 1,218,000 AF higher than its Allocation under D3 + Carryover.[1] This indicates that on average EBID is allocated 103,000 AF less each year because of the 2008 Operating Agreement.

[1] This is cumulative total of differences over the 2006 – 2017 period, comparing D2 Allocation with Current-Year Allocation under D3 + Carryover.

- EBID's total simulated diversions under D1/D2 Allocation are 1,238,000 AF higher than under D3 + Carryover. This indicates that on average EBID receives 103,000 AF less Project Water each year because of the 2008 Operating Agreement.

- EPCWID's D1/D2 Allocations during 2006 – 2017 are a total of 185,000 AF lower than EPCWID's Allocations under D3 + Carryover for the same period.[2] This is an average of 15,000 AF/yr additional allocation to EPCWID under the 2008 Operating Agreement.

- EPCWID's total net diversions under D1/D2 Allocation are 336,000 AF lower than under D3 + Carryover. This is an average of 28,000 AF/yr of additional Project water to EPCWID.

The large magnitude of the EBID impacts calculated when comparing D1/D2 Allocation v. D3 + Carryover primarily results from two different factors:

1) Direct reallocation of water away from EBID under 2008 Operating Agreement, including the effects of the large amounts of EPCWID Carryover, and

2) Hydrologic effects of the increases in New Mexico groundwater pumping and decreases in aquifer recharge caused by the 2008 Operating Agreement. These aquifer impacts reduce Project performance (reduce the Diversion Ratio), reduce Project Supply, and thus further reduce EBID's allocation under the D3 Allocation method (i.e. "the vicious cycle").

Comparison of the results described above shows that the reduction in EBID's allocation and diversion caused by the 2008 Operating Agreement (D3 + Carryover) is much larger than the effect of New Mexico groundwater pumping on EPCWID in the years leading up to the adoption of D3 + Carryover. This finding directly refutes contentions by United States witnesses:

- Dr. Ferguson (2019) on page 5 states that "Under the D3 Method, EBID foregoes a portion of its annual diversion allocation to **offset** the impacts of groundwater pumping in New Mexico on Project allocations and deliveries to EPCWID."

- Dr. King (2019) on page 7 states: "The intended impact of the 'D3 Allocation method' is to **offset** the impacts of groundwater pumping in New Mexico on EPCWID."

Dr. Ferguson and Dr. King claim the 2008 Operating Agreement was intended to "offset" the impacts of New Mexico's pumping on the Project deliveries, yet both have acknowledged that no quantification of potential impacts from groundwater pumping was ever done during the development of the 2008 Operating Agreement. The ILRGM Run 11 prepared by New Mexico proves that the 2008 Operating Agreement significantly reduced EBID's yearly allocation and this reduction is not an appropriate offset for impacts from groundwater pumping. In sum, the analyses I have presented demonstrate that the actual impact of New Mexico groundwater pumping on

[2] This is cumulative total of differences over the 2006 – 2017 period, comparing D2 Allocation with Current-Year Allocation under D3 + Carryover.

EPCWID is **far less** than the amount of Project Supply that has been reallocated away from EBID under the 2008 Operating Agreement (D3 + Carryover).

RUN 15 SUMMARY:

Furthermore, as described in Section 5 of this Supplement, changes in Project operations and Project accounting in the El Paso Valley since the D2 period (1951- 1978) have also had a large negative impact on EBID's Project Supply. If these changes were rolled back, there would be a considerable benefit to New Mexico (see Runs 15).

- If the relatively recent ACE Credit were eliminated, and EPCWID were again charged for its diversion and use of EPWU wastewater treatment plant discharges into the Project, the ILRGM calculates the result would be a cumulative total increase in Project diversions to EBID's of 470,000 AF over the period 2000 – 2017, and an average increase of 36,000 AF/yr from 2006 through 2017.

- Alternatively, if EPCWID were required to divert El Paso Valley drain flows, as they had done historically, and were charged for such diversions, the ILRGM calculates an increase in EBID's allocation by a cumulative total of 471,133 AF, and an cumulative increase in Project diversions to EBID of 458,000 AF over the period 2000 - 2017.

- Both sets of issues were addressed in a combination run that eliminated the ACE Credit, charged EPCWID for its diversion and use of wastewater treatment plant discharges and utilized El Paso Valley drain returns in the ILRGM (Run 15). The results of this run show a total increase of 880,000 AF to EBID Project diversions from 2000 through 2017.

RUN 16 SUMMARY:

Other analysis using the ILRGM (Run 16, described in Section 6 of this supplement) shows that if Project allocation methods and the operations and accounting within Texas after 1978 had remained consistent with the D1/D2 period (1951-1978), EBID would have been allocated and would have received more Project Supply in recent years than they have actually received.

- Specifically, if the US had required EPCWID to use drain returns as it did historically, charged EPCWID for use of wastewater discharged into the EPCWID system, and kept the historical operations at D1/D2, the result reflect the historical Project operations and eliminates the inequities the US has forced on New Mexico through improper Project accounting and improper Project allocation.

1 Introduction

This supplement incorporates and summarizes the results of certain "runs" of the New Mexico Integrated Lowe Rio Grande Model ("ILRGM") as they relate to and help quantify some of the issues raised in my earlier expert reports in this litigation: Barroll (2019) and Barroll Rebuttal (2020). These issues include the impacts of New Mexico groundwater pumping, and the impacts of D3 Allocation and the 2008 Operating Agreement ("2008 OA") which incorporates both D3 Allocation + District Carryover accounts

In this report "D3 + Carryover" will be used a shorthand to refer to the allocation method that was initially adopted in 2006, and formalized in the 2008 Operating Agreement, that includes both D3 Allocation and District Carryover accounts.

In general, this supplement addresses the following questions based on results from the latest version of the ILRGM:

1) What are the impacts of New Mexico's groundwater pumping on the amount of water allocated and delivered to Texas through the Rio Grande Project ("Project")?
2) What is the impact of D3 Allocation and the 2008 OA on the water allocated and delivered to New Mexico by the Project?
3) How do the impacts of New Mexico's groundwater pumping on Texas compare with the amount of water re-allocated away from EBID and New Mexico under the 2008 OA?
4) What has been the impact of changes in Project operations and accounting in the El Paso Valley on EBID's share of Project Supply?
5) How would Project allocation and delivery differ if the conditions existing during the D2 period (1951 – 1978) had continued to the present day?

The rebuttal report filed July 15, 2020 by Gregory K. Sullivan and Heidi M. Welsh, Spronk Water Engineers, Inc. ("Spronk (2020)") presents the New Mexico ILRGM, and documents a number of base runs and test runs made with the ILRGM over an historical time period from 1940 through 2017. The ILRGM simulates the groundwater systems of the Rincon, Mesilla and Hueco Bolson/El Paso Valley, and also actively simulates the allocation and distribution of water by the Rio Grande Project.

The irrigation system operations associated with the Project comprises the largest and most complex part of the ILRGM system. The operations part of the ILRGM calculates the allocation of Project Supply,[3] and the delivery of that Project Supply in response to irrigation demands and the Mexican delivery schedule; and the delivery of a portion of EPCWID's allocation to the City of El Paso. Irrigation well pumping is then calculated through a comparison of irrigation demands (specified irrigated acreage and per-acre-water requirements) and the delivery of Project surface water to farms. The impacts of surface water distribution and groundwater pumping on the groundwater system are simulated in the two groundwater models of the ILRGM (one for the Mesilla and Rincon basins, the other for the Hueco Bolson), and key outputs from these groundwater models are fed back into the operations model of the ILRGM. The operation rules recalculate the Project allocation if necessary, and recalculate the reservoir releases required to obtain the associated deliveries of Project deliveries.

[3] Many of the terms using in this Supplement are defined in the glossary of Barroll (2020) starting on page 80.

The advantage of this integrated modeling approach is that it allows New Mexico to build on the stream depletion calculations produced by a groundwater model, and simulate how these streamflow depletions would translate into impacts on Project allocation, Project operations, and Project deliveries during the irrigation season.

The Base Run of the ILRGM is Run 1, a historical run that simulates

- Historical hydrologic inputs (including inflows to Elephant Butte, which constitute the ultimate source of most of the water in the system),
- Historical water demands (irrigated acreages and crop demands),
- Historical groundwater pumping,
- Historical Project operations through time,
- Historical allocation methods from 1940 through 2017, including the adoption of D3 + Carryover in 2006, formalized in the 2008 Operating Agreement.

A number of hypothetical alternative runs have been performed in which modified groundwater pumping and/or alternative Project operation and accounting scenarios are simulated for the same time period, and same hydrologic inputs, as the Base Run. The impacts of these modifications on Project allocation and deliveries can be quantified by comparing the pertinent alternative run to the Base Run. All of these are fully documented in Spronk (2020). In this supplement I analyze pertinent parts of the output data from certain ILRGM runs.

2 Run 3 versus Run 1: Net Effect of All New Mexico Groundwater Pumping

Run 3 is an alternative run which is set up the same as the Base Run (Run 1) except for the fact that all groundwater pumping in New Mexico has been turned off. Comparison of Run 3 to Run 1 allows us to quantify the impacts of all New Mexico pumping on the hydrologic system and on Project allocations and deliveries.

In Run 3 all non-irrigation pumping in New Mexico is set to zero, and wastewater treatment plant returns and urban deep percolation associated with that pumping are set to zero, eliminating all associated depletions. Irrigation well pumping in New Mexico is also set to zero, and aquifer recharge associated with irrigation return flow is reduced accordingly. The net result is a lower amount of irrigation consumptive use, which each year is automatically set to the amount that could be sustained with surface water only.

The elimination of New Mexico groundwater pumping causes a reduction in loss from the Rio Grande, some reduction in canal seepage, and an increase in drain flows in the Rincon and Mesilla Valleys. The model simulates these effects and also calculates how Project performance, Project allocation, and releases from Project storage would change as a result of these changes in hydrologic conditions.

Comparison of Run 1 and Run 3 allows us to isolate the net effects of New Mexico groundwater pumping, and quantify those impacts. A summary of this comparison is documented in Spronk (2020) and the supporting documents associated with that report. In this section I present analysis of the model output from these runs, starting from the year 1980, approximately when Reclamation began allocating water to the EBID and EPCWID ("the Districts") instead of allotting water to Project farmers directly.[4] To be consistent with Spronk (2020) I provide these results in the form of graphs and tables in which the impact of pumping is calculated as Run 3 minus Run 1, and represent **the change in Project allocation and diversions that would result from turning off all New Mexico pumping.**

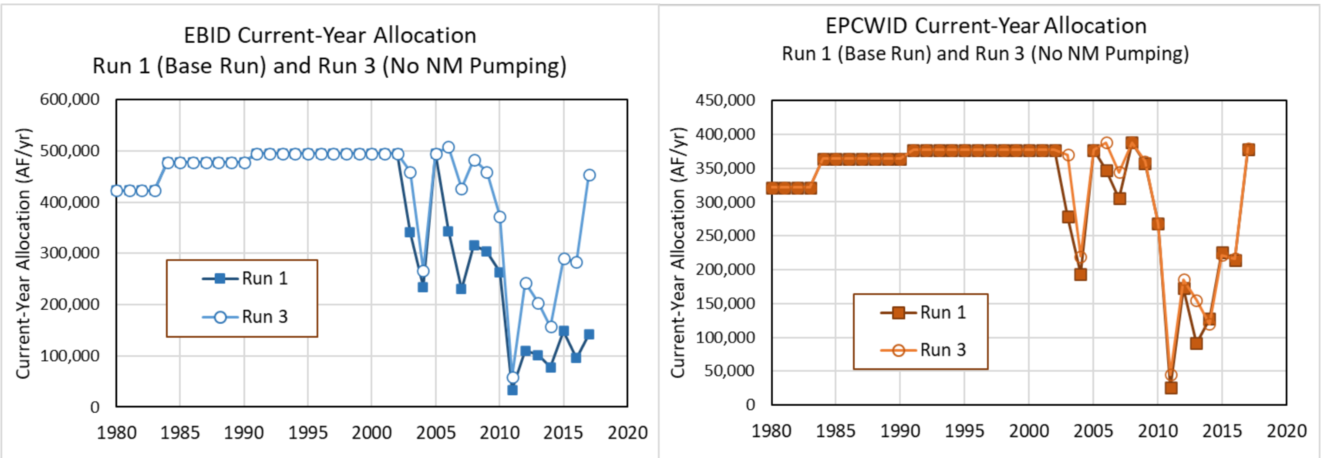
2.1 Current-Year Allocation

This Section deals with the simulated impact of New Mexico groundwater pumping on Project Allocation; that is, the impact of New Mexico pumping on the amounts of Project Supply each District was entitled to order each year under historical allocation procedures.

Figure 1 shows each Districts' Current-Year Allocation (excluding Carryover) for the years 2006 – 2017 simulated for Run 1 (historical pumping and Project operations) and Run 3 (no New Mexico pumping, and resulting Project operations).

[4] Results from earlier times, and a more complete documentation of these model runs and results can be found in Spronk (2020).

Figure 1. Simulated Current-Year Allocations to Districts, Runs 1 and 3



The Project historically enjoyed full supply conditions from 1979 – 2002, and the ILRGM simulates full-supply allocation in those years in both the Base Run and Run 3. As shown in Figure 1, New Mexico pumping has no impact on Project allocation during those years. Starting in 2003, the Project has less than a full supply in many years, and during this period New Mexico groundwater pumping has had an effect on Project Allocation. Figure 2 shows the difference between the allocations to each District in Run 1 and Run 3, and these values are tabulated in Table 1 for the years 2003 – 2017.

In general, turning off pumping during the full supply years reduces the releases from Caballo necessary to meet demands. As long as there is already sufficient water in reservoir storage, this practice has no effect on annual Project allocation. In effect, during full-supply conditions, reductions in groundwater pumping that impact Project efficiency cause "accretions" to reservoir storage.

If the reservoir spills, as it did in the mid 1980's and mid-1990's, earlier accretions to reservoir storage manifest as an increase in the amount of water spilled. Reservoir storage immediately after the spill would not reflect any of those earlier storage accretions. In effect, after a spill, the reservoir "resets."

When a series of full-supply years is ended by low-supply conditions as happened in 2003, then the storage accretions that occurred since the last spill manifest as a greater amount of water in storage at the beginning of that first low-supply year than would have occurred otherwise. (The amount of storage increase is impacted by reservoir evaporation, which is higher when reservoir levels are higher.) Under less-than-full-supply conditions, this increase in reservoir storage results in greater allocations in that first dry year. This is the effect the ILRGM Run 3 simulates in 2003 and 2004.

Figure 2. Simulated Difference in Current-Year Allocations to Districts, Runs 1 and 3: Net Impact of All New Mexico Groundwater Pumping

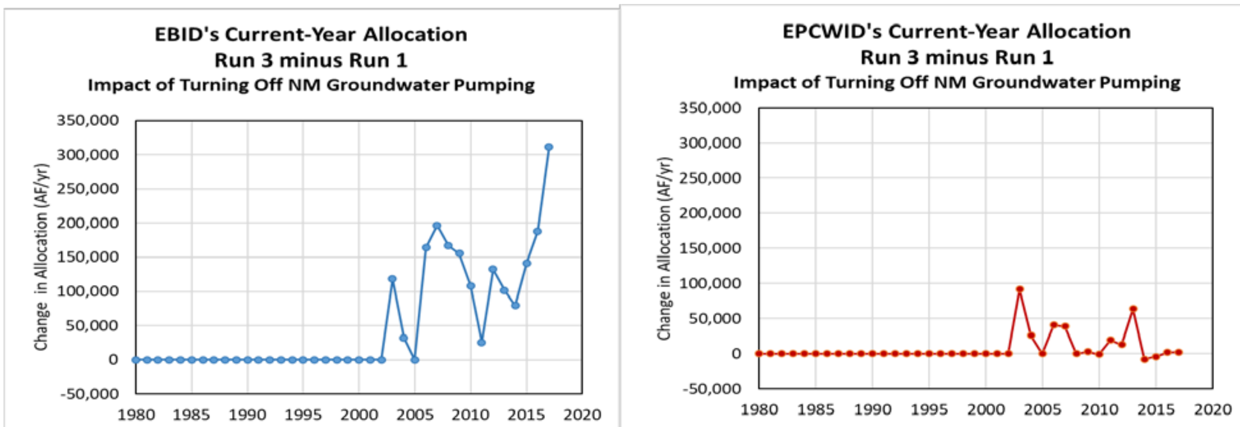


Table 1. Simulated Current-Year Allocations to Districts, Runs 1 and 3: Net Impact of Turning Off All New Mexico Groundwater Pumping

Current-Year Allocations to EBID and EPCWID Comparison of Run 3 and Run 1, Net Impact of Turning Off New Mexico Groundwater Pumping						
	EBID			EPCWID		
	Run 1	Run 3	Run 3 - Run 1	Run 1	Run 3	Run 3 - Run 1
Year	AF	AF	AF	AF	AF	AF
2003	341,165	459,359	118,194	278,116	369,713	91,596
2004	234,774	267,299	32,525	193,878	219,828	25,950
2005	494,979	494,979	0	376,862	376,862	0
2006	343,239	507,468	164,229	347,542	388,192	40,650
2007	230,031	427,069	197,039	305,167	343,917	38,749
2008	316,148	483,073	166,925	388,192	388,192	0
2009	303,662	458,928	155,266	357,470	360,138	2,668
2010	263,891	372,316	108,425	268,731	267,759	-972
2011	33,619	59,197	25,578	25,596	45,071	19,474
2012	110,596	243,258	132,662	172,242	185,207	12,965
2013	101,912	203,868	101,955	91,165	155,217	64,052
2014	77,693	156,904	79,211	127,555	119,461	-8,094
2015	148,876	290,234	141,358	225,858	221,672	-4,186
2016	95,409	283,590	188,181	214,548	216,279	1,732
2017	141,763	453,437	311,674	377,309	379,667	2,358

The data in Table 1 indicate that the cumulative impact of New Mexico's groundwater pumping on EPCWID's Current-Year Allocation in the years 2003 through 2005 (the years that led up to the adoption of D3 Allocation in 2006) totaled 117,500 AF.[5] In order to calculate the effect of New Mexico pumping on the amount of water EPCWID would actually receive, I analyze the simulated diversions in Section 2.2.

[5] 117,546 AF is the sum of 91,596 AF from 2003 plus 25,950 AF from 2004.

The later impacts shown in Figure 2 and Table 1, for the years 2006 through 2017, reflect the increase in New Mexico irrigation well pumping caused by the implementation of 2008 Operating Agreement (D3 + Carryover), and its reduction in EBID's allocation. Furthermore, these differences do not reflect the beneficial effect of D3 Allocation itself has on EPCWID's allocation compared with previous allocation methods, which would only have allocated EPCWID 43% of the Project Supply.[6] (See Section 4 for this analysis.)

Table 1 shows that turning off all New Mexico groundwater pumping also has a net positive impact on EBID's Current-Year Allocation in 2003 and 2004, the years leading up to the adoption of D3 + Carryover. The change in reservoir level simulated at the beginning of 2003 (described above) impacts EBID's Allocation as well as ECPWID's. The total impact of turning off New Mexico groundwater pumping increases EBID's allocation in the years 2003 – 2005 by a cumulative total of 151,000 AF. Starting in 2006, the net impact of New Mexico groundwater pumping on EBID's allocation grows dramatically. This reflects two related factors:

1) Irrigation well pumping by EBID farmers in the Base Run is systematically higher starting in 2006 because D3 Allocation has systematically reduced EBID's Project share of surface water Supply to account for all negative departures from the D2 Curve (Barroll (2019) and (2020)).
2) Negative departures from D2 and reductions in EBID's allocation in the Base Run are further aggravated by the increased EBID farm pumping required to grow crops under low D3 Allocations.

2.2 Net River Headgate (RHG) Diversions

This Section presents the simulated effects of New Mexico groundwater pumping on the Districts' Net River Headgate (RHG) Diversions of Project Water[7]. The Net RHG Diversions shown here are the net amount that each District is simulated to have diverted over each calendar year, and these values are calculated as the total canal heading diversions (including EPWU diversions for municipal supply), less any by-pass water (El Paso Valley Carriage in New Mexico, and Ascarate wasteway flow in the El Paso Valley), with an adjustment to assign part of the diversions at Mesilla Dam to EPCWID[8]. In general, RGH Diversions are greater than the Districts' Charged Diversions, in part due to the diversions occurring outside of the Caballo Release season (which are not included in Charged Diversions), diversion of water spilled from reservoir storage, and due the effect of to Project Accounting credits. In this section I analyze RHG diversions instead of Charged Diversions in order to ensure that all potential impacts to EPCWID's irrigation supply caused by New Mexico pumping are considered.

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[6] In this report, when I refer to each District's allocated or diverted percentages of Project Supply, I am referring to the Project Supply that is allocated to, or diverted by the Districts, exclusive of the Mexican delivery.

[7] Some Project Diversions accounted for in both the Charged Diversions and RHG diversions are not actually made from the "River", that is from the bed of the Rio Grande. EPCWID now diverts water from the American Canal and American Canal Extension, and it is those diversion amounts which are used in Project Accounting and in Spronk's (2020) calculation of FHG diversions.

[8] Neither EPCWID's Charged Diversions or the RHG diversions analyzed here include the diversion and use of EPWU wastewater discharged directly into the ACE and Riverside Canal, which Dr. Blair refers to as "District Water" but not "Project Water" (Blair, A.W., 2001, "Sources and Quantity of Rio Grande Project Water Available for Conversion to Uses Other than Irrigation under the Proposed Third-Party Implementing Contract among EPCWID, the City of El Paso, and the United States", Exhibit D of Contract No. 01-Wc-40-6760.)

Figure 3 shows the simulated Net RHG diversions for both Run 1 and Run 3 for each District. Figure 4 shows the difference between the two runs for each District, which represents the simulated impact of New Mexico pumping on each District's RHG Diversion. These data are tabulated in Table 2.

Figure 3. Simulated Net RHG Diversions, Runs 1 and 3

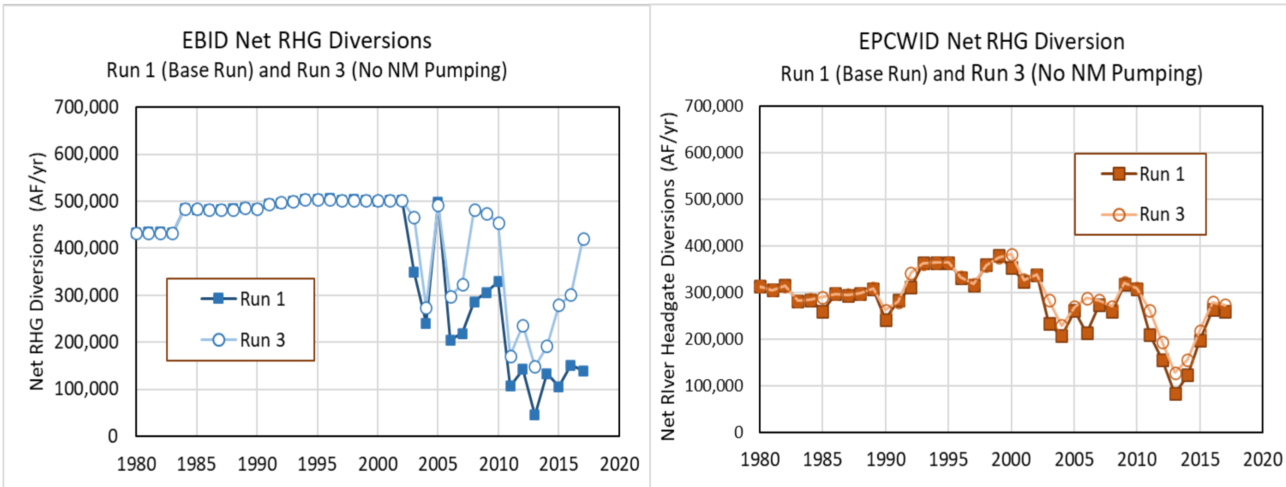
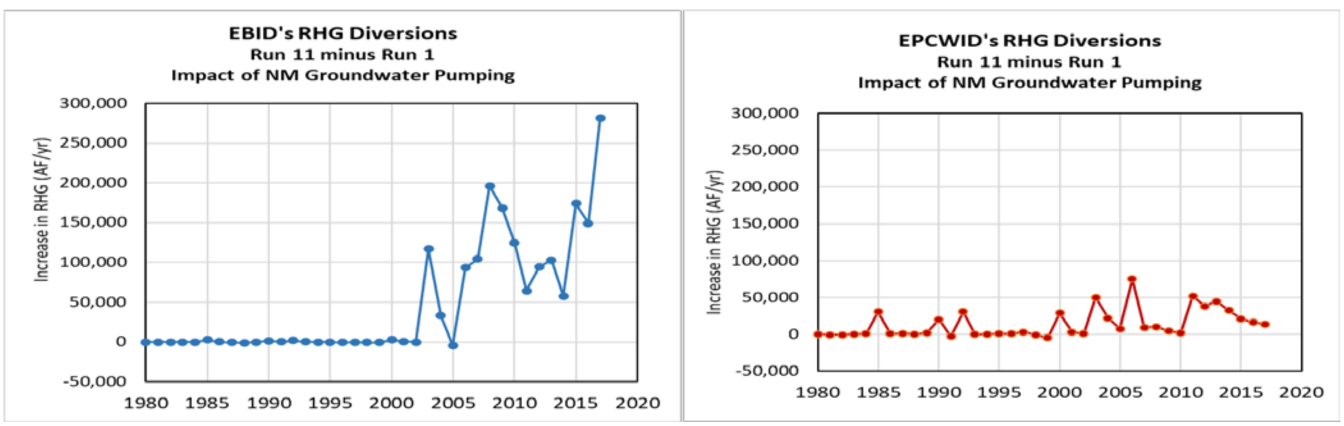


Figure 4. Simulated Differences in Net RHG Diversions, Runs 1 and 3: Net Impact of Turning Off All New Mexico Groundwater Pumping



The results tabulated in Table 2 show that the simulated increase in EBID diversions associated with turning off New Mexico groundwater pumping totals 146,000 AF for the years 2003 through 2005, the years leading up to the 2006 adoption of D3 + Carryover (then formalized as the 2008 Operating Agreement). The corresponding increase in EPCWID diversions for the years 2003 through 2005 totals 80,000 AF.

As before (Section 2.1), the net large impacts of New Mexico groundwater pumping on EBID's diversions that are simulated starting in 2006 represent the larger amounts of groundwater EBID farmers must pump to supply their crops due to decreased surface water Supply under D3 +

Carryover. Similarly, the changes simulated in EPCWID's diversions from 2006 forward in also reflect the effects of New Mexico's increased groundwater pumping under D3 Allocation.

Table 2. Simulated Net RHG Diversions, Runs 1 and 3: All NM GW Pumping

Net RHG Diversions of Project Supply by EBID and EPCWID Comparison of Run 3 and Run 1, Net Impact of Turning Off All New Mexico Groundwater Pumping						
	EBID			EPCWID		
Year	Run 1	Run 3	Run 3 - Run 1	Run 1	Run 3	Run 3 - Run 1
1980	433,268	432,912	-356	312,744	313,037	293
1981	433,653	433,252	-401	305,805	305,274	-531
1982	433,560	433,219	-341	314,541	313,644	-896
1983	432,113	431,915	-198	281,781	281,797	16
1984	484,460	484,156	-304	284,146	285,019	873
1985	481,345	484,178	2,833	259,657	290,065	30,407
1986	482,482	482,664	182	296,550	297,128	578
1987	482,109	481,487	-622	293,682	294,661	979
1988	483,503	482,368	-1,135	297,322	297,642	320
1989	486,906	486,560	-347	307,160	308,546	1,386
1990	483,559	484,878	1,318	241,462	261,827	20,365
1991	493,976	494,135	159	283,327	280,350	-2,977
1992	495,794	497,629	1,836	311,210	341,732	30,522
1993	499,413	499,580	167	362,563	362,137	-426
1994	503,220	503,052	-168	363,544	363,555	10
1995	503,878	503,561	-318	363,488	364,026	538
1996	505,168	504,675	-494	332,227	332,978	750
1997	501,401	501,132	-269	315,117	317,860	2,743
1998	503,068	502,665	-403	358,655	357,777	-877
1999	502,372	501,951	-420	379,902	375,097	-4,805
2000	499,831	502,594	2,763	353,006	381,694	28,688
2001	500,880	501,377	497	323,888	326,998	3,110
2002	501,146	501,101	-45	337,603	338,184	581
2003	348,354	465,374	117,019	233,194	283,442	50,248
2004	240,730	273,818	33,088	206,563	228,701	22,138
2005	496,896	492,623	-4,273	261,182	268,711	7,529
2006	204,657	297,827	93,171	212,909	287,837	74,928
2007	218,167	322,389	104,222	273,894	283,034	9,140
2008	286,285	482,221	195,936	260,100	270,178	10,078
2009	306,158	474,593	168,435	317,032	321,196	4,164
2010	329,193	453,604	124,411	306,683	308,666	1,983
2011	106,982	171,231	64,249	209,232	261,066	51,834
2012	141,861	236,042	94,181	155,465	193,700	38,235
2013	44,996	147,969	102,972	82,838	127,603	44,765
2014	133,721	191,594	57,873	122,924	155,556	32,632
2015	105,521	279,585	174,064	196,717	217,629	20,911
2016	151,458	300,499	149,040	262,606	278,910	16,305
2017	139,049	420,627	281,578	259,271	272,898	13,626

2.3 Summary and Conclusions

The ILRGM results show that impacts of **turning off all New Mexico groundwater pumping** on the Districts' allocation and diversion for the years 1980 through 2017 are as follows:

- There is no impact on the allocation of Project Supply to EPCWID or EBID for the full-supply years 1980 – 2002.
- There are limited impacts to EPCWID in the years 2003 through 2005 when all of New Mexico's pumping is turned off in Run 3. The cumulative total impacts to the Districts occurring during 2003 – 2005 are:
  - An increase of EPCWID's allocation totaling 117,000 AF over these three years 2003, 2004 and 2005
  - An increase of EPCWID's net diversion over these three years totaling 80,000 AF
  - An increase of EBID's allocation over these three years totaling 151,000 AF
  - An increase of EBID's net diversion over these three years totaling 146,000 AF
- The impacts simulated for 2006 – 2017 are dominated by the imposition of D3 + Carryover from the 2008 Operating Agreement, which resulted in significantly increased groundwater pumping by EBID farmers. As a result, the simulated impacts are larger than those that would have occurred if the 2008 OA had never been implemented. During these years, 2006-2017, New Mexico is shorted Project surface water.

3 Historical District Allocations and Deliveries: Departure from 57:43

In Barroll Rebuttal (2020) I performed analysis of the reported Current-Year Allocations to, and Diversions by, the Districts from 2006 through 2019, to calculate the amount by which EPCWID Current-Year Allocation exceeds 43% of the total Current-Year Allocation to the Districts. Essentially, this analysis is a conservatively low, first-order estimate of the effects of D3 Allocation and the 2008 Operating Agreement on EBID.

This Allocation calculation is shown below as Table 3. The departure from 57:43 allocation is here calculated by taking the total amount allocated to the Districts each year and reallocating that amount 57% to EBID and 43% to EPCWID.

In the first columns of Table 3, reported Current-Year District Allocations (from Reclamation records) are tabulated and summed. 43% of that total is calculated. The final column represents the amount by which EPCWID's actual Current-Year Allocation exceeded 43% of the whole. The total amount by which EPCWID's Current-Year Allocation has exceeded 43% over the period 2006 through 2019 is approximately 693,000 AF. This calculation is a "zero-sum game" in that any increase to EPCWID's allocation above 43% is equal to the amount by which EBID's allocation falls short of 57%. Therefore, this analysis provides a first order estimate that EBID's Allocation has been reduced by a total 693,000 AF in period 2006 – 2019.

Table 3. Reported Current-Year Allocation Data: Departure from 57:43, 2006-2017

(Rebuttal Table 9) EPCWID Current-Year Reported Allocation in Excess of 43% of the Total Current-Year Allocation to Districts					
	Current-Year Allocation from Reclamation Records				
	EBID	EPCWID (Including ACE Credit)	Total Current-Year Allocation to Districts	43% of District Allocation	EPCWID Allocation in Excess (+) of 43%
Year	AF	AF	AF	AF	AF
2006	211,385	241,657	453,042	195,831	45,826
2007	310,894	367,291	678,185	293,151	74,140
2008	324,990	405,073	730,063	315,576	89,497
2009	268,077	402,159	670,236	289,715	112,444
2010	255,257	309,515	564,772	244,127	65,388
2011	57,090	43,466	100,556	43,466	0
2012	118,300	132,935	251,235	108,598	24,337
2013	54,438	41,446	95,884	41,447	-1
2014	104,651	106,590	211,241	91,311	15,279
2015	161,940	197,629	359,569	155,427	42,202
2016	156,310	235,908	392,218	169,539	66,369
2017	267,523	401,842	669,365	289,338	112,504
2018	114,419	116,437	230,856	99,789	16,648
2019	203,933	205,952	409,885	177,176	28,776
Total					**693,408**

A similar analysis of reported Charged Diversions (or Allocation Charges) to each District during 2006 through 2019 is shown below as Table 4. The total amount by which EPCWID's Charged Diversions exceeds 43% of total District diversions is 531,000 AF, and conversely EBID's total Charged Diversions are 531,000 AF below 57% for the period 2006 - 2017.

Table 4. Reported Charged Diversion Data: Departure from 57:43, 2006-2017

(Rebuttal Table 10) EPCWID Reported Charged Diversions in Excess of 43% of Total District Diversions					
	Charged Diversions from District Accounting Records				
	EBID	EPCWID	Total Charged Diversions	43% of Total District Charged Diversions	EPCWID Diversion in Excess of 43%
Year	AF	AF	AF	AF	AF
2006	211,841	177,183	389,024	168,159	9,024
2007	302,665	278,252	580,917	251,106	27,146
2008	329,294	279,173	608,467	263,015	16,158
2009	305,475	320,083	625,558	270,402	49,681
2010	282,082	304,937	587,019	253,744	51,193
2011	59,771	258,772	318,543	137,693	121,079
2012	133,060	136,380	269,440	116,468	19,912
2013	54,002	53,530	107,532	46,482	7,048
2014	99,007	97,418	196,425	84,906	12,512
2015	143,404	165,872	309,276	133,687	32,185
2016	175,199	216,309	391,508	169,232	47,077
2017	259,510	249,919	509,429	220,205	29,714
2018	127,487	280,674	408,161	176,431	104,243
2019	194,510	155,872	350,382	151,455	4,417
Total					**531,389**

The data in Table 4 do not include the amounts of EPWU wastewater discharged into EPCWID's conveyances and used by EPCWID farmers without any Project accounting charge. (EPWU operates the City of El Paso's municipal water system.)[9]

Table 5 is a re-analysis of the diversion data so as to include this uncharged EPWU wastewater. The amount included is the reported discharge of EPWU wastewater into EPCWID conveyances in the El Paso Valley during the Caballo release season (the time period for which Project Charges are now computed).

[9] EPWU is El Paso Water Utilities. For more detail on the issue of EPWU wastewater in the El Paso Valley, see Barroll Rebuttal (2020) Section R7.

As shown in Table 5, EPCWID's total diversions (including wastewater) are 708,000 AF greater than 43% of the total District diversions. Conversely, EBID's total diversions are 708,000 AF less than 57% of the total District diversions (including all wastewater).

Table 5. Reported Diversion Data including EPWU Wastewater in the El Paso Valley: Departure from 57:43, 2006-2017

(Rebuttal Table 11.) EPCWID Diversion (including Wastewater) in Excess of 43% of Total District Diversions						
	Charged Diversions from District Accounting Records		Reported during Release Season			
	EBID	EPCWID	EPCWID Uncharged Use of Wastewater	Total District Diversions (including wastewater)	43% of Total Diversions	EPCWID Diversion in Excess of 43%
Year	AF	AF	AF	AF	AF	AF
2006	211,841	177,183	29,888	418,912	181,078	25,993
2007	302,665	278,252	29,773	610,690	263,976	44,050
2008	329,294	279,173	30,949	639,416	276,393	33,729
2009	305,475	320,083	26,992	652,550	282,070	65,005
2010	282,082	304,937	25,629	612,648	264,822	65,744
2011	59,771	258,772	21,382	339,925	146,935	133,219
2012	133,060	136,380	21,566	291,006	125,790	32,157
2013	54,002	53,530	6,962	114,494	49,491	11,001
2014	99,007	97,418	14,442	210,867	91,149	20,711
2015	143,404	165,872	17,488	326,764	141,246	42,113
2016	175,199	216,309	24,814	416,322	179,958	61,164
2017	259,510	249,919	21,855	531,284	229,652	42,122
2018	127,487	280,674	***20,000***	428,161	185,076	115,598
2019	194,510	155,872	***20,000***	370,382	160,101	15,771
Total						**708,377**
Estimated Values						

As described in Barroll Rebuttal (2020, page 47), this is a first order analysis. This analysis does not incorporate the effects of the improvement in hydrologic conditions that would result from the increase in EBID's allocation and the application of additional surface water within EBID. This improvement would tend to increase drain flows and reduces seepage losses, increasing the Project Diversion Ratio and further increasing EBID's Allocation. As such, this analysis probably understates the amount by which EBID's allocation would increase if Project Supply water were divided more equitably. Furthermore, the Allocation calculation does not incorporate the likely changes in total reservoir releases and subsequent changes in Usable Supply that would result from changes in allocation. In order to calculate the effect of both of these second order factors, it is necessary to use an integrated model, such as the ILRGM. The results of that analysis are in Section 4.

3.1 Summary and Conclusions

Analysis of reported Project allocation and diversion data provides a conservative estimate of how much water has been reallocated away from EBID as a result of D3 + Carryover, compared to EBID's historical 57% share of Project Supply.

This analysis shows for the period 2006 through 2019:

- EBID's Current-Year Allocations under D3 + Carryover fall short of 57% of the Current-Year Allocation to the Districts by a total of 693,000 AF. On average EBID's Current-Year Allocation falls short of 57% by 50,000 AF each year.

- EBID's Charged Diversions under D3 + Carryover fall short of 57% of District Charged Diversions by a total of 531,000 AF, or an average of 38,000 AF each year.

- If EPCWID's uncharged diversion and use of EPWU wastewater in the El Paso Valley is included in the diversion calculation, then EBID's share of diversions falls short of 57% by a total of 708,000 AF, or an average of 50,000 AF each year.

4 Run 11 versus Run 1: Net Effect of D3 Allocation Compared with D1/D2 (57:43) Allocation

Run 11 is an alternative run, which is set up the same as the Base Run (Run 1) except for the fact that the Project allocation method is not changed to D3 + Carryover in 2006[10]. Instead, Run 11 continues to apply D1/D2 Allocation throughout the 2006 to 2017 period. Comparison of Run 11 to Run 1 allows us to quantify the impacts of D3 Allocation and the 2008 OA on Project operations and deliveries relative to a 57:43 allocation split of Project Supply implemented through D1/D2 Allocation[11]. This analysis with the ILRGM not only calculates the immediate reallocation of water on Project allocation and distribution, but also calculates the resulting impacts on the hydrologic system, how those impacts change Project performance, and then how those changes in Project performance further change Project allocation and distribution.

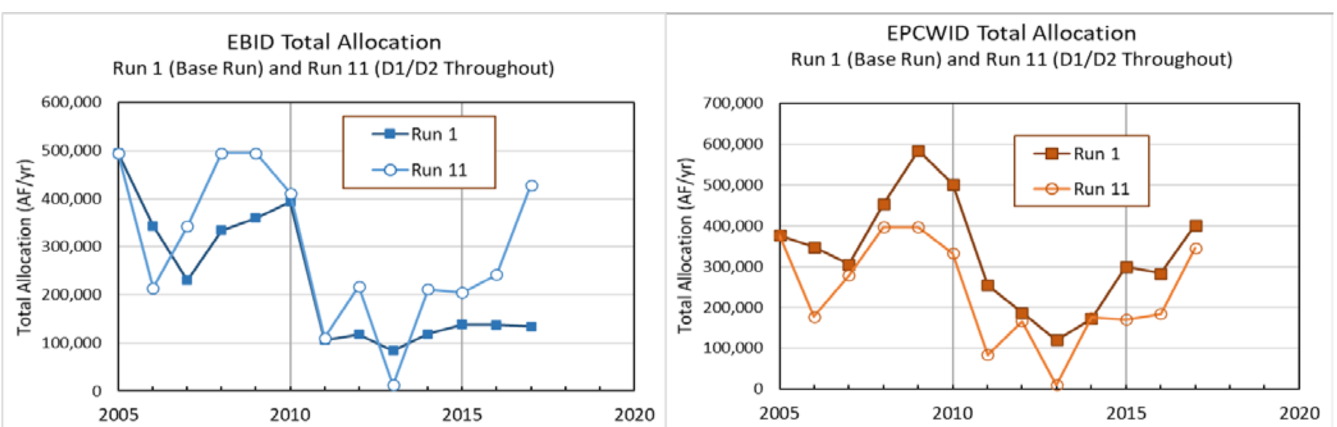
In this section I present analysis of the model output from these runs starting from the year 2005, just before the two model runs diverge. To be consistent with Spronk (2020), these results are presented in the form of graphs and tables showing Run 11 minus Run 1. These results represent the change in allocation or diversion caused by **returning to D1/D2 (57:43) Allocation.**

4.1 Total Allocation

Figure 5 shows the Total Allocation (including Carryover) to each District, for the time period 2005 – 2017, for Run 1 (the Base Run) and for Run 11. I show these graphs to illustrate the effects of Carryover, especially for EPCWID in low-supply years.

In general, EBID's Total Allocation is higher in Run 11 (the D1/D2 run) than in Run 1, as would be anticipated in a return to 57:43 Allocation. Conversely, EPCWID's Total Allocation is lower in Run 11 than in Run 1, as would be anticipated both because of EBID's increased Run 11 allocation, and subsequent greater water use; and also because in Run 11 EPCWID is not able to accumulate Carryover for use in low-supply years.

Figure 5. Total Allocation to Districts, Runs 1 and 11



[10] The Base Run implements D3 Allocation in 2006 and Carryover in 2008.
[11] A description of the D1/D2 Allocation method, the D3 Allocation method, and Carryover under the 2008 OA can be found in Barroll (2019).

4.2 Current-Year Allocation

Current-Year Allocation results for each District from Runs 1 and 11 are plotted in Figure 6.

Figure 6. Current-Year Allocations to Districts, Runs 1 and 11

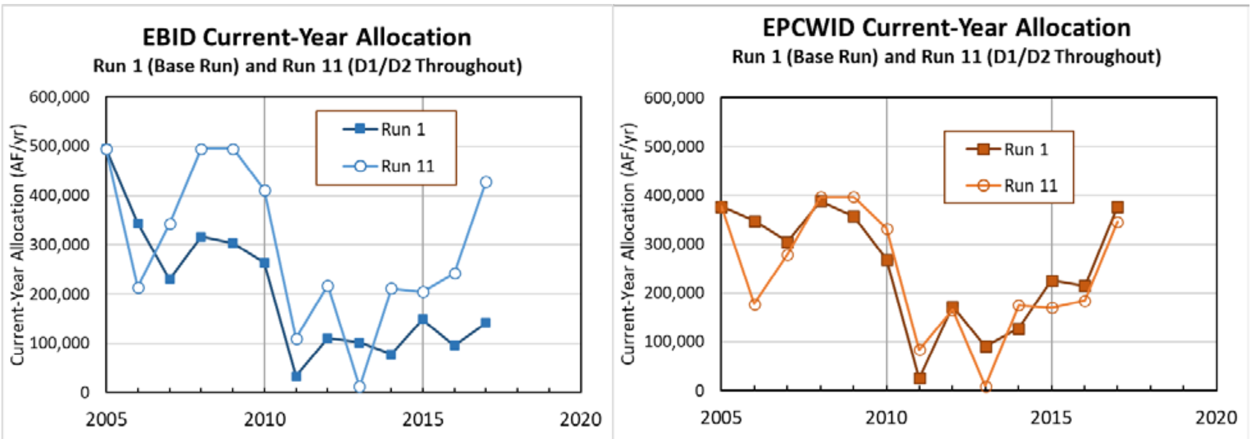


Figure 7 shows the difference in Current-Year Allocation results for each District, and Table 6 tabulates Current-Year Allocation results for each District. As shown in Figures 6 and 7 and in Table 6, the effects of a return to D1/D2 (57:43) Allocation are predominantly positive for EBID, with a cumulative total 1.2 million AF of increased allocation. This means that the net effect of the implementation of D3 + Carryover has been a reduction in EBID's allocation by 1.2 million AF over the 12 years from 2006 through 2017.

The effect of a return to D1/D2 are predominantly negative for EPCWID, and with a total reduction in Current-Year Allocation of 0.2 million AF. This means that the net effect of the implementation of D3 + Carryover has been an increase in EPCWID's allocation by 0.2 million AF over 12 years from 2006 through 2017, 1/6th (one-sixth) of the amount by which EBID's allocation was reduced. That is to say: the large deficit to EBID caused by D3 + Carryover results in only a modest benefit to EPCWID.

Figure 7. Difference in Current-Year Allocation in Districts, Runs 1 and 11: Net Impact of Implementing D1/D2 Allocation 2006-2017 instead of D3 Allocation + Carryover

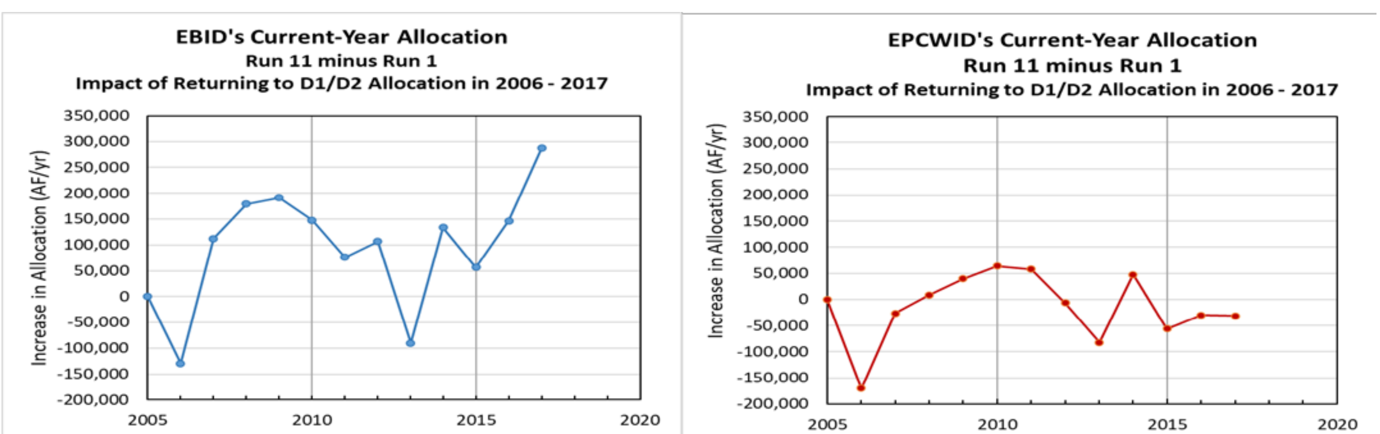


Table 6. District Current-Year Allocations, Runs 1 and 11: Net Impact of Implementing D1/D2 Allocation 2006-2017 instead of D3 + Carryover

Current-Year Allocations Comparison of Run 11 and Run 1,						
	EBID			EPCWID		
	Run 1	Run 11	Run 11 - Run 1	Run 1	Run 11	Run 11 - Run 1
Year	AF	AF	AF	AF	AF	AF
2005	494,979	494,979	0	376,862	376,862	0
2006	343,239	213,722	-129,517	347,542	177,227	-170,315
2007	230,031	342,432	112,401	305,167	278,852	-26,315
2008	316,148	494,979	178,831	388,192	396,914	8,722
2009	303,662	494,979	191,317	357,470	396,914	39,444
2010	263,891	411,577	147,686	268,731	332,739	64,007
2011	33,619	109,903	76,284	25,596	83,676	58,080
2012	110,596	217,598	107,002	172,242	165,671	-6,571
2013	101,912	12,076	-89,837	91,165	9,194	-81,971
2014	77,693	211,461	133,769	127,555	175,347	47,792
2015	148,876	205,078	56,203	225,858	169,975	-55,882
2016	95,409	242,209	146,800	214,548	184,409	-30,139
2017	141,763	428,909	287,145	377,309	346,148	-31,161
Sum			**1,218,084**			**-184,309**

4.3 Net RHG Diversions

In this section I quantify the impact of D3 Allocation plus Carryover on the Districts' RHG Diversions by comparing results from Runs 1 and 11.

Figure 8 plots the RHG Diversion results for each District for the period 2005 – 2017 from Runs 1 and 11. Figure 9 plots the difference in RHG Diversions between the two runs, showing the net effect of Allocation method on how much water the District are simulated to divert at their canal headings.

Figure 8. Net RHG Diversions, Runs 1 and 11

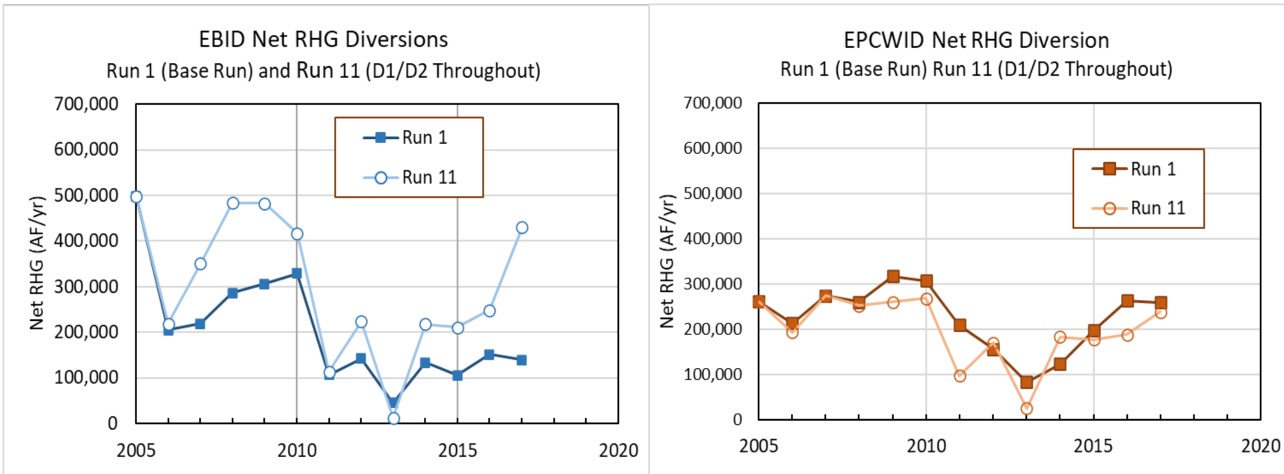
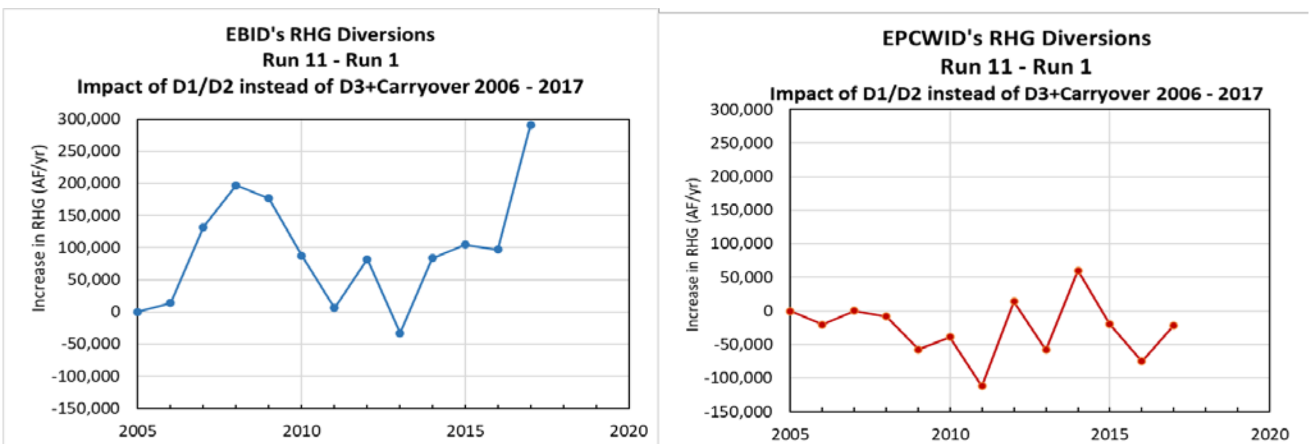


Figure 9. Difference in Net RHG Diversions: Runs 1 and 11, Net Impact of Implementing D1/D2 Allocation 2006-2017 instead of D3 Allocation + Carryover



The results plotted in Figures 8 and 9 show that EBID diverts considerably more water under the D1/D2 Allocation (57:43) than under D3 + Carryover. Conversely EPCWID diverts less water under D1/D2 Allocation than under D3 + Carryover.

The RHG Diversion results from Runs 1 and 11 are tabulated in Table 7. In summary, the ILRGM calculates that under D1/D2 Allocation, EBID would have diverted approximately 1.2 million acre-feet more than under D3 + Carryover, while EPCWID would have diverted 0.3 million acre-feet less. **Again, the net effect of the 2008 OA is to reduce EBID's water supply by a large amount (approximately 103,000 AF/yr on average since 2006), in order to obtain a relatively small increase in the supply to EPCWID (approximately 30,000 AF/yr on average since 2006).**

Table 7. Simulated Net RHG Diversions, Runs 1 and 11: Net Impact of Implementing D1/D2 Allocation 2006-2017 instead of D2 Allocation + Carryover

Net RHG Diversions of Project Supply by EBID and EPCWID Comparison of Run 11 and Run 1, Net Impact of Implementing D1/D2 Allocation 2006 – 2017 instead of D3 Allocation and 2008 OA						
	EBID			EPCWID		
Year	Run 1	Run 11	Run 11 - Run 1	Run 1	Run 11	Run 11 - Run 1
2005	496,896	496,894	-2	261,182	261,206	24
2006	204,657	218,610	13,953	212,909	192,687	-20,222
2007	218,167	350,089	131,922	273,894	274,228	334
2008	286,285	483,276	196,991	260,100	251,975	-8,125
2009	306,158	482,700	176,542	317,032	259,628	-57,404
2010	329,193	416,550	87,358	306,683	267,755	-38,928
2011	106,982	113,324	6,342	209,232	97,184	-112,048
2012	141,861	223,567	81,706	155,465	169,687	14,222
2013	44,996	12,062	-32,934	82,838	25,167	-57,670
2014	133,721	217,430	83,709	122,924	182,916	59,991
2015	105,521	210,353	104,832	196,717	177,029	-19,688
2016	151,458	248,208	96,749	262,606	187,797	-74,808
2017	139,049	430,254	291,204	259,271	237,844	-21,428
Totals			**1,238,371**			**-335,752**

4.4 Simulated Total Project Supply Amounts

The results in Table 7 indicate that more total water is delivered to and diverted by the Districts under D1/D2 Allocation than under D3 + Carryover, even though both model runs have the same annual inflows to Elephant Butte Reservoir supplying the Project. Essentially, D1/D2 Allocation allows more water in total to be delivered to the Project canal headings downstream than the 2008 Operating Agreement does, for the same total amount of Reservoir inflow. **This result is a natural outcome from the general principal in irrigation systems that when more water is applied to lands upstream, there is more opportunity for "recycling", by which the same water is diverted 2 or 3 times as it passes to downstream diversion points as return flow.**[12]

In the Lower Rio Grande, the extra water provided to EBID also improves aquifer conditions in the upper Project by reducing groundwater pumping, reducing seepage losses from the main stem of the Rio Grande, and improving drain flows. The total reduction in seepage losses and increase in drain flows contributes to the total amount of water the Project can deliver, thereby improving the delivery performance or delivery efficiency of the Project.

[12] Other factors contribute to this difference in the total Project Supply delivered to the Districts: both total reservoir evaporation and Mexican deliveries are different between these two runs.

This is illustrated by the Project Diversion Ratios from the two model runs. (The Diversion Ratio is a measure of Project delivery performance, and is defined as the total annual Charged Diversions of Project Water divided by the annual release of Project water from Storage.) Figure 10 is a plot of the simulated Diversion Ratios simulated for Runs 1 and 11, and Table 8 provides a tabulation of these values. Figure 10 shows that Run 11, in which D1/D2 Allocation is applied from 2006 – 2017, typically has a higher Diversion Ratio, which is consistent with a higher total Project diversion per quantity of Reservoir release.

Figure 10. Simulated Diversion Ratios in Run 1 and Run 11

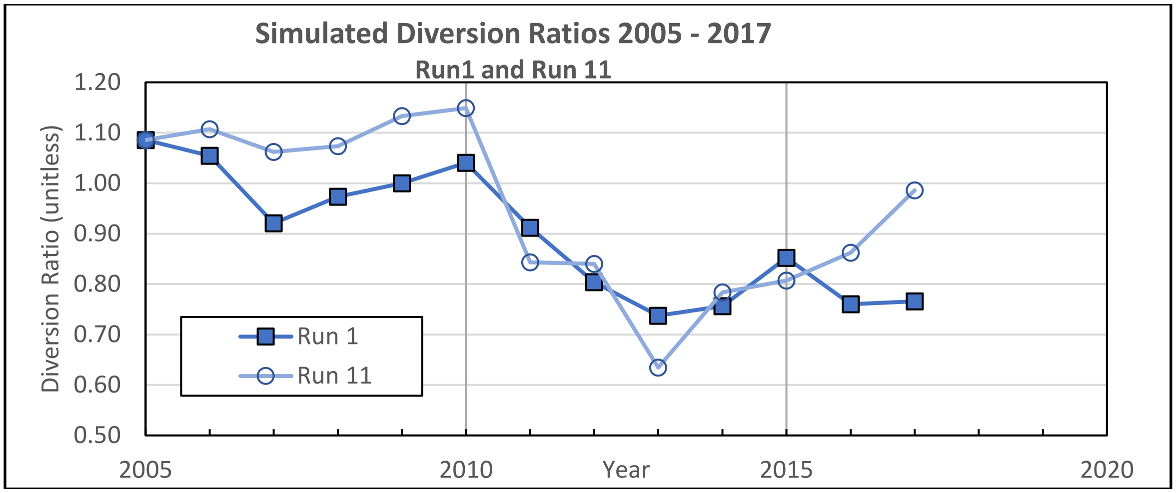


Table 8. Simulated Diversion Ratios, Run 1 and Run 11, 2005-2017

Simulated Diversion Ratios, Run 1 and Run 11					
Year	Run 1	Run 11	Year	Run 1	Run 11
2005	1.09	1.09	2012	0.80	0.84
2006	1.05	1.11	2013	0.74	0.63
2007	0.92	1.06	2014	0.76	0.78
2008	0.97	1.07	2015	0.85	0.81
2009	1.00	1.13	2016	0.76	0.86
2010	1.04	1.15	2017	0.77	0.99
2011	0.91	0.84			

4.5 Summary and Conclusions

In 2006, the Rio Grande Project made a substantial change in its allocation procedure, adopting D3 Allocation and District carryover accounts. The effects of this re-allocation are calculated by comparing Run 11, which implements D1/D2 (57:43) Allocation in 2006 through 2017, to Run 1, in which D3 + Carryover Allocation is implemented in those years.

The impacts during the years 2006 – 2017 resulting from this re-allocation are as follows:

- The cumulative total of EBID's simulated D1/D2 Allocations during 2006 – 2017 are 1,218,000 AF higher than EBID's simulated Current-Year Allocations under D3 + Carryover. This indicates that on average EBID is allocated 103,000 AF less each year because of the 2008 Operating Agreement.

- The cumulative total of EBID's simulated diversions under D1/D2 Allocation during 2006 – 2017 are 1,238,000 AF greater than EBID's simulated diversions under D3 + Carryover. This indicates that on average EBID receives 103,000 AF less Project Water each year because of the 2008 Operating Agreement.

- EPCWID's D1/D2 Allocations are a cumulative total of 185,000 AF lower than EPCWID's Current-Year Allocations under D3 + Carryover. This is an average of 15,000 AF/yr additional allocation to EPCWID under the 2008 Operating Agreement.

- EPCWID's net diversions under D1/D2 Allocation are a cumulative total of 336,000 AF lower than under D3 + Carryover. This is an average of 28,000 AF/yr of additional Project water to EPCWID.

These results show that the adoption of the 2008 Operating Agreement (D3 Allocation + Carryover) had significant negative impacts on the amount of Project Water EBID was allocated and diverted. The large magnitude of the EBID impacts primarily results from two different factors:

1) Direct reallocation of water away from EBID under 2008 Operating Agreement, including the effects of the large amounts of EPCWID Carryover, and

2) Hydrologic effects of the increases in New Mexico groundwater pumping and decreases in aquifer recharge caused by the 2008 Operating Agreement. These aquifer impacts reduce Project performance (reduce the Diversion Ratio), reduce Project Supply, and thus further reduce EBID's allocation under the D3 Allocation method (i.e. "the vicious cycle").

5 Runs 15, 15a, 15b, and 15c (Run 15 et al.): Early EPCWID Operations

Run 15 et al. are hypothetical runs that are identical to the historical base run (Run 1) except that changes in accounting, operations and pumping are implemented in the El Paso Valley. Runs 15, 15a and 15b modify EPCWID operations and accounting in the later parts of these model runs, to more consistently reflect operations and Project Accounting in the El Paso Valley as they occurred in earlier years, prior to the 2008 OA and prior to the change in accounting that occurred in 1979.

5.1 Run 15a: Charges for All EPWU Wastewater and Elimination of ACE Credit

Run 15a changes Project Accounting so that EPCWID is charged for the diversion and use of all wastewater discharged from the City of El Paso in the El Paso Valley ("EPV Wastewater") during the Caballo release season, including wastewater discharged into EPCWID conveyances.[13] Run 15a also eliminates the relatively recent ACE Credit, which awards EPCWID extra allocation as a reward for mitigating delivery inefficiencies that were in part caused by Texas groundwater pumping.[14]

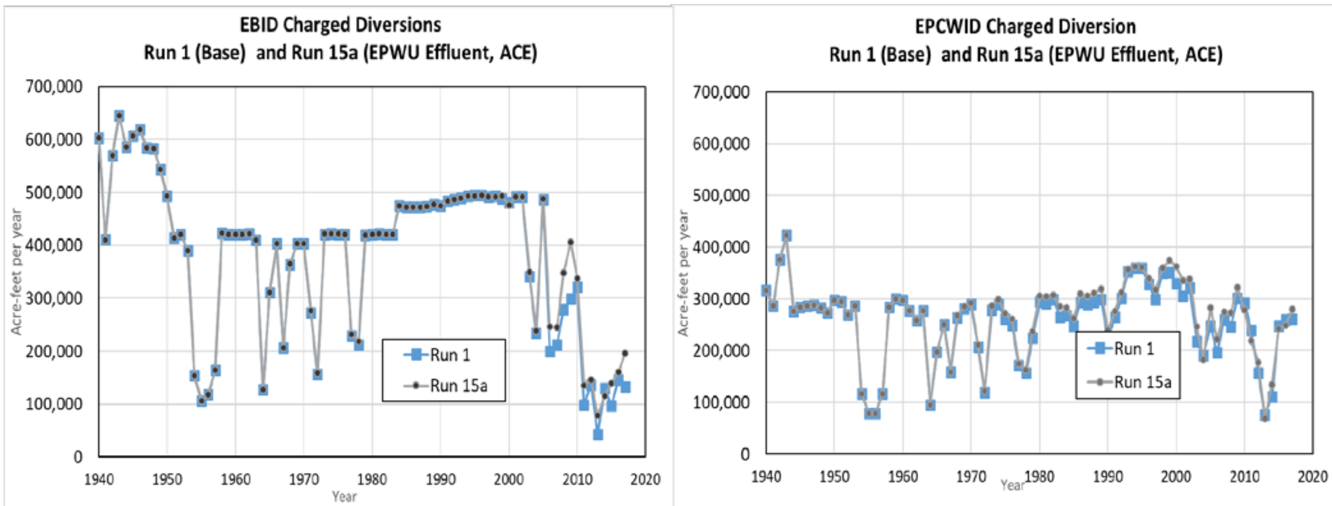
The accounting in Run 15a is more consistent with earlier Project operations and accounting. From the earliest days of the Project until 1967 all of El Paso's wastewater was discharged into the Rio Grande above Riverside Dam, and the diversion of this water at Riverside was included in the accounting of Project Supply.[15] The ACE Credit did not exist until 2003, and was instituted to reward the ACE bypass of the Rio Grande seepage that itself was largely caused by Texas and Mexican groundwater pumping. Aside from these accounting changes, Run 15a is the same as Run 1 (the historical base run) and a comparison of these runs allows us to isolate the effects of the accounting anomaly that allows EPCWID to use El Paso wastewater (which largely consists of Project return flow[16]) free of charge, and the ACE Credit.

The simulated Charged Diversions from Run 1 (the Base Run) and Run 15a are plotted in Figure 11 for the entire simulation period, 1940 – 2017.

[13] For more complete discussion of El Paso Valley wastewater issues, see Barroll (2020), Section R7.
[14] For more complete discussion of the ACE, see Barroll (2020), Section R8.
[15] Starting in 1967, part of El Paso's wastewater was discharged into the Riverside Canal at a location below the gage at which the Riverside diversion are measured, and so this wastewater was not included in accounting of Project Supply. Starting in 1999, Haskell R Street wastewater (which previously discharged to the Rio Grande and was accounted Project Supply) was intercepted by the American Canal Extension, and from that time forward EPCWID has been allowed to divert and use that water without charge.
[16] Barroll (2020), Section R7.

Figure 11 shows that these accounting changes have little to no impact on EBID's diversions before 2006, and that starting in 2006 they tend to increase EBID's Charged Diversions. EPCWID's Charged Diversions for Run 15a show a small increase starting in approximately 1980, reflecting the fact that in Run 15a EPCWID is being charged for the diversion and use of EPWU wastewater, which in Run 1 it is using free of charge.

Figure 11. Simulated Charged Diversions, Runs 1 and 15a, 1940-2017



Simulated Charged Diversions for the period 2000 through 2017 are plotted in Figure 12 and tabulated in Table 9. Table 9 shows that the benefits to EBID of charging EPCWID for all EPWU wastewater and eliminating the ACE Credit are substantial, as EBID's diversions from Run 15a are considerably higher than Run 1. EBID's Charged Diversions in Run 15a are greater in every year, and the total increase in EBID's Charged Diversions in this period is 470,000 AF. EPCWID's Run 15a Charged Diversions are also somewhat higher but this is largely because in Run 15a EPCWID is charged for the diversion and use of EPWU wastewater, while in Run 1 EPCWID still diverts and uses the wastewater but is not charged for it.

Figure 12. Charged Diversions, Runs 1 and 15a, 2000-2017

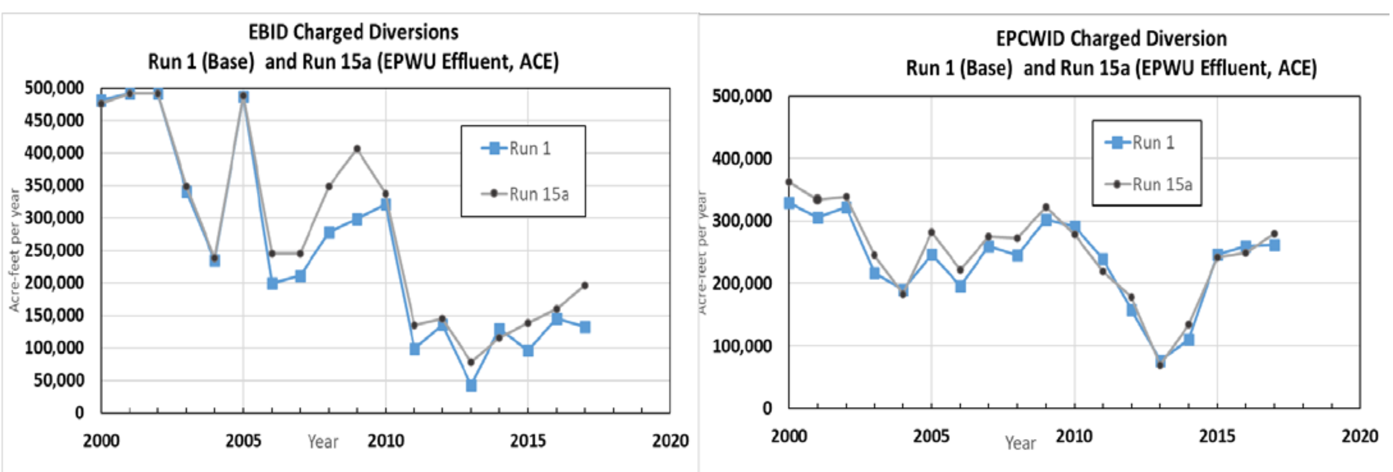


Table 9. Simulated Charged Diversions, Runs 1 and 15a: EPV Wastewater and ACE Credit

Charged Diversions to Districts: Run 1 and Run 15a; 2006 – 2017						
	EBID Charged Diversions			EPCWID Charged Diversions		
	Run 1	Run 15a	Run 15a - Run 1	Run 1	Run 15a	Run 15a - Run 1
Year	AF	AF	AF	AF	AF	AF
2000	481,143	475,780	-5,363	329,682	362,989	33,307
2001	491,744	491,752	8	306,054	334,700	28,646
2002	491,796	491,796	0	321,794	338,646	16,852
2003	340,912	348,669	7,756	217,108	245,860	28,752
2004	234,605	237,967	3,362	190,306	182,563	-7,743
2005	486,958	488,059	1,101	246,933	282,603	35,670
2006	199,360	245,500	46,139	195,503	221,915	26,412
2007	211,626	245,129	33,504	259,806	274,926	15,120
2008	278,630	348,110	69,480	246,057	272,910	26,853
2009	298,781	406,616	107,835	302,148	322,049	19,901
2010	321,683	337,479	15,797	291,560	279,091	-12,469
2011	98,467	135,530	37,062	239,594	219,706	-19,889
2012	135,800	145,364	9,564	157,542	177,653	20,111
2013	42,538	78,503	35,965	76,014	69,641	-6,373
2014	129,599	115,676	-13,923	110,806	133,801	22,995
2015	96,739	138,893	42,154	246,835	241,502	-5,333
2016	145,167	160,476	15,309	259,694	249,302	-10,391
2017	132,611	196,475	63,863	261,451	279,419	17,967
Total			**469,849**			**230,576**

Review of these results (and the more complete set of results in Spronk (2020)) indicates that these accounting factors (ACE Credit and EPWU wastewater charges) have little impact on EBID until the advent of D3 Allocation + Carryover. This is because D3 Allocation reduces EBID's allocation for any reduction in the Diversion Ratio, and the Diversion Ratio is calculated using Charged Diversions. As a result, any reduction in Charged Diversions (including those due to accounting credits) automatically reduces EBID's D3 Allocation (Barroll (2020), Table 3).

Furthermore, Carryover causes these factors to have additional negative impacts on EBID. Prior to the implementation of Carryover, the effect of Allocation Credits and uncharged diversions on EPCWID's Allocation would disappear at the end of each year when all unused allocation returned to the common supply of water available for the next year's allocation. Under Carryover, EPCWID's unused allocation is carried over into the following year, and converted into Carryover Obligation that is sequestered out of the Usable Supply before any allocation to EBID can occur (Barroll (2020), Sections R6 and R9). **In recent years, part of EPCWID's unused allocation results from not being charged for the use of EPWU wastewater in the El Paso Valley and from the ACE Credit.**

5.2 Run 15b: EPCWID Utilization of El Paso Valley (EPV) Drain Flows

Run 15b is identical to Run 1, except that it changes EPCWID operations and Project Accounting so that 1) EPCWID diverts and uses drain flow from the River Drain system[17] when available, adjusting its reservoir demand accordingly, and 2) EPCWID is charged in Project Accounting for the diversion and use of this drain flow.

This diversion of EPV drain flows and Project charges associated with those diversion are consistent with earlier Project operations and accounting. Prior to 1938, the River Drain (and other drains as well) discharged into the Rio Grande above the Tornillo heading,[18] which was at that time the last diversion heading in the Rio Grande Project. This drain flow is here referred to collectively as "EPV drain flow". This drain water was diverted at the Tornillo Canal heading, and it was accounted as Project Supply.

Following the Rectification of the Rio Grande in the Fabens area in 1938, the drain system near Fabens was re-routed so that water from the River Drain (and its tributary, the Middle Drain) could be diverted into the Riverside Canal Extension, which now supplied the Tornillo Canal heading. Any drain flow not diverted was routed to the Fabens Waste Drain. Reclamation records from 1945 until about 1980 show diversions of up to 30,000 AF/yr from the River Canal into the Riverside Canal Extension, and Project Records indicate that these diversions are included in the Reclamation Water Distribution Reports that form the basis of the D2 Curve.[19] That is, such diversions were accounted as part of Project Supply. Other drains in this area were routed directly into the Fabens Waste Drain.

Post-1978 Project Accounting does not include any term for the diversion of El Paso Valley drain flows, and there is no evidence that EPCWID has diverted drain flow in the Fabens area for many years. Nevertheless, these drain flows were a historical source of Project Supply, both in the years leading up to the Rio Grande Compact and during the D2 period. Run 15b provides an estimate of how much drain flow could have been diverted by ECPWID near Fabens throughout the model run. Comparison of Run 15b and Run 1 provides an estimate of the effect of El Paso drain flow on the distribution of Project Supply if diverted and charged to EPCWID.

The ILRGM simulates all of the drains above Fabens as one, so in order to simulate diversion of only the flows from the River Drain system the simulated diversion amount diverted is capped at 70% of the total simulated drain flow above Fabens.

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[17] The Middle Drain discharges into the River Drain below the River Drain's gaging point, and so the gaged flows of both drains are available for diversion into the Riverside Canal Extension at Fabens.

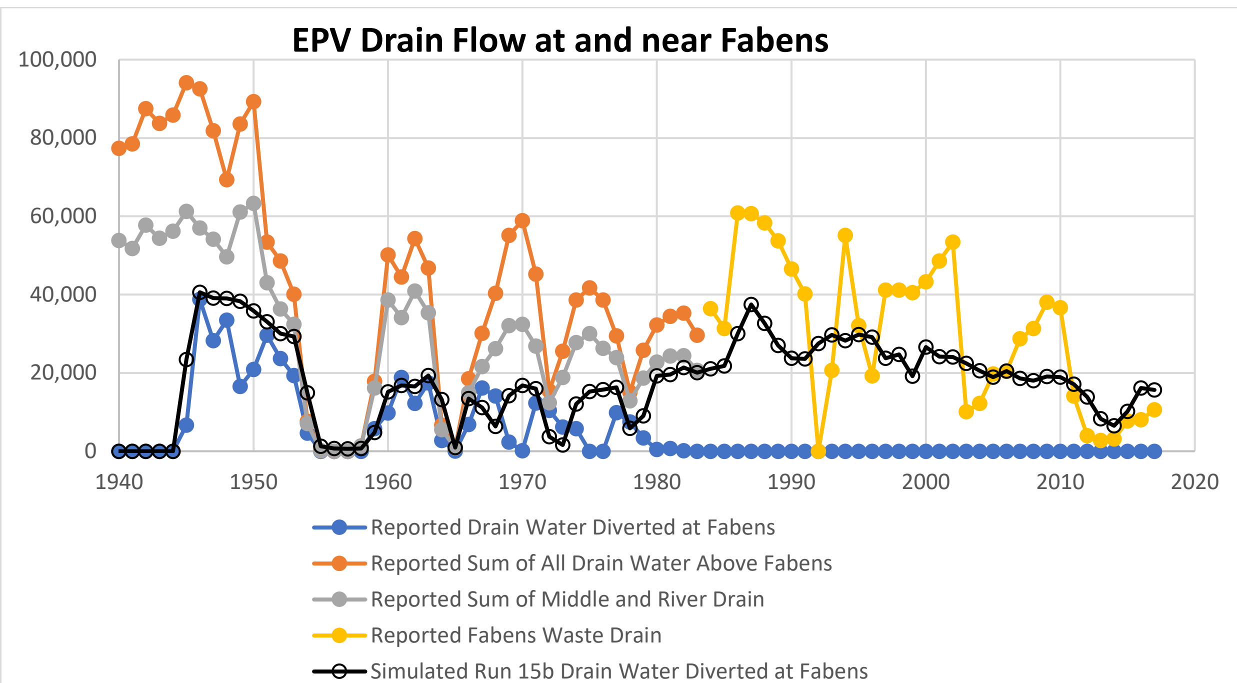
[18] The Tornillo heading was built in 1923 for the stated purpose of capturing Project return flows. "[T]he site of this heading [Tornillo] furnishes the means to collect a large amount of recovered and developed water of the project for use in the Tornillo area, and for sale to the Hudspeth Counting Irrigation District below the project limits." 1923 Project History, Chapter 1, Introductory and General, page 5.

[19] Barroll (2019), Section 5.2.2 and Appendix C.

A comparison of the historical reported drain flows near Fabens[20], historical diversions of drain flow at Fabens, and the simulated diversion of drain flow at Fabens from Run 15b, is provided in Figure 13. These data show:

1) The actual reported diversion of drain flow at Fabens during the 1940s through the 1970's is reasonably represented by Run 15b. In a number of years, the model simulates somewhat higher drain flow diversions, representing the availability of more drain flow than was actually diverted.
2) In approximately 1980, the diversion of drain flow at Fabens appears to have ceased, even though the flows measured in the Fabens Waste Drain indicates that the drains above Fabens were still flowing.
3) Run 15b of the model simulates diversion of drain flow roughly consistent with the actual availability of drain flow as measured in the Fabens Waste Drain through approximately 2011, after which the Run 15b simulates diversion of more drain flow than was likely available historically. This may either be a reflection of a less than perfect calibration of drain flow, or may be a result of better general hydrologic conditions in Run 15b compared with historical conditions due to diversion and use of EPV drain flows during the 1980's, 1990's and 2000's.

Figure 13. Drain Flows Near Fabens, Reported Diversion of Drain Flow at Fabens, and Simulated Diversion of Drain Flow Near Fabens (Run 15b)



[20] Following the Rectification of the Rio Grande all of the El Paso Valley drains above Fabens were routed into the Fabens Waste Drain, with the exception of the flow from the River Drain which was diverted into the Riverside Canal Extension. The El Paso Valley drains above Fabens were measured separately until 1984, after which the resulting flow in the Fabens Waste Drain was measured.

Differences between Runs 1 and 15b (in which EPV drain flow is utilized) become noticeable in approximately the year 2000. Current-Year Allocation results from Runs 1 and 15b for the period 2000 through 2017 are plotted in Figure 14 and Tabulated in Table 10.

These results show that in the year 2003 allocations for both EBID and EPCWID are significantly higher in Run 15b than Run 1. This happens because during full-supply years that preceded 2003 (the late 1990's and early 2000's), EPCWID's use of EPV drain flow in Run 15b resulted in EPCWID calling for less water from reservoir storage. By the end of 2002, the last full-supply year, reservoir storage in Run 15b is significantly greater than in Run 1. Greater reservoir storage allows larger 2003 allocations in the Run 15b.

Starting in 2006, EBID is also allocated substantially more water in Run 15b than in Run 1. This suggests that the improvement in Project Performance caused by the use of EPV drain flows resulted in a higher Diversion Ratio and higher consequent allocation to EBID.

Figure 14. Simulated Current-Year Allocation, Runs 1 and 15b, 2000-2017

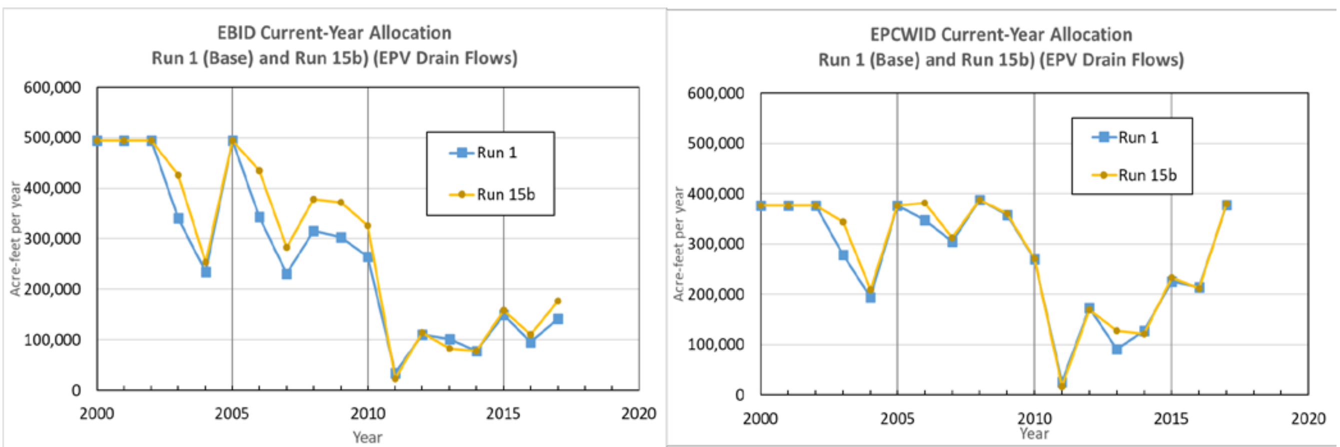
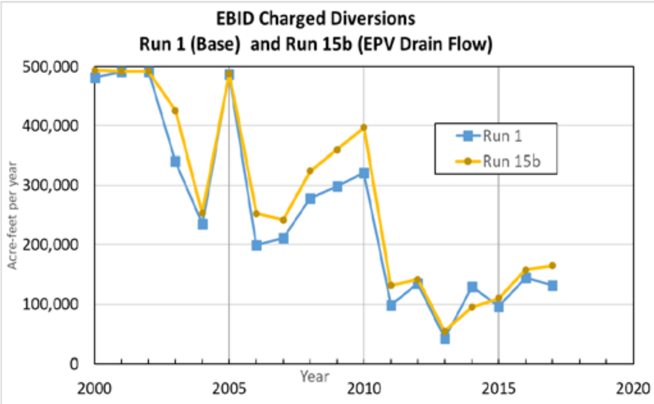


Table 10. Simulated Current-Year Allocation, Runs 1 and 15b: Net Impact EPV Drain Flow Diversion and Accounting

Current-Year Allocation to Districts: Run 1 and Run 15b; 2005 - 2017						
	EBID Allocation			EPCWID Allocation		
	Run 1	Run 15b	Run 15b - Run 1	Run 1	Run 15a	Run 15b - Run 1
Year	AF	AF	AF	AF	AF	AF
2000	494,979	494,979	0	376,862	376,862	0
2001	494,979	494,979	0	376,862	376,862	0
2002	494,979	494,979	0	376,862	376,862	0
2003	341,165	426,059	84,894	278,116	344,102	65,986
2004	234,774	253,133	18,359	193,878	208,556	14,678
2005	494,979	494,979	0	376,862	376,862	0
2006	343,239	434,590	91,351	347,542	381,353	33,810
2007	230,031	282,929	52,898	305,167	312,428	7,261
2008	316,148	377,721	61,573	388,192	388,192	0
2009	303,662	371,621	67,958	357,470	359,598	2,128
2010	263,891	326,185	62,294	268,731	270,444	1,712
2011	33,619	22,226	-11,393	25,596	16,922	-8,674
2012	110,596	114,120	3,525	172,242	169,063	-3,179
2013	101,912	82,519	-19,393	91,165	126,584	35,419
2014	77,693	77,710	18	127,555	120,251	-7,303
2015	148,876	158,299	9,423	225,858	233,146	7,288
2016	95,409	109,862	14,453	214,548	210,890	-3,657
2017	141,763	176,937	35,174	377,309	380,239	2,930
Total			**471,133**			**148,398**

Charged Diversions from Runs 1 and 15b for the years 2000 through 2017 are plotted in Figure 15 and tabulated in Table 11. EPCWID's Charged Diversions in Run 15b are generally slightly larger than in Run 1, while EBID's Charged Diversions in Run 15b are significantly larger than in Run 1**. This means that the EBID would get a significant benefit if EPCWID were to divert, and be charged for diverting, EPV drain flows.** Table 11 shows that EBID's total cumulative Charged Diversions since the year 2000 might have been as much as 460,000 AF greater if EPCWID had diverted, and been charged for the diversion of, EPV drain flows since the mid-1990's. (Benefits to Project Storage accruing prior to the last reservoir spill in the mid-1990's would have been wiped out by the spill.)

Figure 15. Simulated Charged Diversions, Runs 1 and 15b, 2000-2017



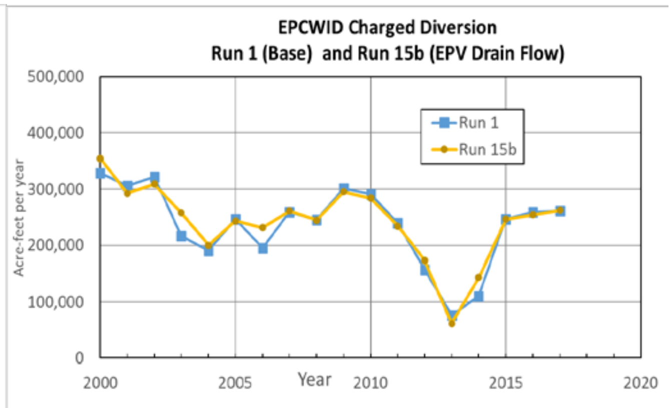


Table 11. Simulated Charged Diversions, Runs 1 and 15b: EPV Drain Flow, 2000-2017

Charged Diversions to Districts: Run 1 and Run 15b; 2005 - 2017						
	EBID Charged Diversions			EPCWID Charged Diversions		
	Run 1	Run 15b	Run 15b - Run 1	Run 1	Run 15b	Run 15b - Run 1
Year	AF	AF	AF	AF	AF	AF
2000	481,143	493,534	12,392	329,682	354,372	24,690
2001	491,744	492,335	591	306,054	292,757	-13,297
2002	491,796	491,892	96	321,794	309,518	-12,276
2003	340,912	425,431	84,518	217,108	257,586	40,478
2004	234,605	253,186	18,581	190,306	200,092	9,786
2005	486,958	487,921	963	246,933	243,445	-3,488
2006	199,360	252,272	52,912	195,503	231,466	35,963
2007	211,626	241,884	30,258	259,806	261,285	1,480
2008	278,630	324,317	45,687	246,057	244,430	-1,628
2009	298,781	359,884	61,103	302,148	295,716	-6,432
2010	321,683	396,987	75,305	291,560	284,053	-7,507
2011	98,467	131,665	33,198	239,594	234,631	-4,964
2012	135,800	142,075	6,274	157,542	173,437	15,895
2013	42,538	54,434	11,896	76,014	61,566	-14,448
2014	129,599	95,137	-34,462	110,806	143,288	32,482
2015	96,739	110,147	13,408	246,835	246,500	-335
2016	145,167	158,440	13,273	259,694	254,551	-5,143
2017	132,611	165,176	32,564	261,451	262,530	1,079
Total			458,558			92,335

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5.3 Run 15: Combined EPCWID Accounting Run: EPCWID Utilization of EPV Drain Flows, Charged for Use of EPV Wastewater, and Elimination of ACE Credit

Run 15 combines both of the modifications from Run 15a and Run 15b. That is, in Run 15 the ACE Credit is eliminated, all EPWU wastewater in the El Paso Valley that is delivered to EPCWID during the Caballo release season is charged to ECPWID in Project accounting, and drain flow at Fabens is diverted by EPCWID and charged to ECPWID in Project accounting. The results of this combined run are shown for the years 2000 through 2017 in Table 12. These results show a large benefit to EBID, totaling 880,000 AF, if EPCWID's operations (diverting EPV drain flow) and accounting (Project charges for EPV drain flow and use of all EPWU wastewater) were modified so as to be more consistent with earlier – and more equitable – Project operations and accounting.

Table 12. Simulated Charged Diversions, Runs 1 and 15 (Combined Run), 2000-2017

Charged Diversions to Districts: Run 1 and Run 15; 2005 - 2017						
	EBID Charged Diversions			EPCWID Charged Diversions		
	Run 1	Run 15	Run 15b - Run 1	Run 1	Run 15	Run 15b - Run 1
Year	AF	AF	AF	AF	AF	AF
2000	481,143	492,848	11,705	329,682	375,121	45,439
2001	491,744	492,329	586	306,054	332,242	26,188
2002	491,796	491,891	95	321,794	328,811	7,017
2003	340,912	427,935	87,023	217,108	283,510	66,402
2004	234,605	256,925	22,320	190,306	196,560	6,255
2005	486,958	487,881	923	246,933	283,943	37,010
2006	199,360	276,328	76,967	195,503	247,084	51,581
2007	211,626	275,157	63,531	259,806	286,397	26,592
2008	278,630	388,601	109,971	246,057	271,064	25,006
2009	298,781	452,336	153,555	302,148	316,245	14,097
2010	321,683	362,660	40,978	291,560	278,567	-12,993
2011	98,467	155,351	56,884	239,594	227,319	-12,275
2012	135,800	153,000	17,200	157,542	175,687	18,145
2013	42,538	88,867	46,329	76,014	75,281	-733
2014	129,599	147,909	18,309	110,806	109,867	-938
2015	96,739	148,888	52,149	246,835	233,473	-13,362
2016	145,167	168,777	23,609	259,694	256,086	-3,607
2017	132,611	230,944	98,333	261,451	282,792	21,341
Total			**880,466**			**301,164**

Table 12 also shows that EPCWID would have, on average, higher Charged Diversions if these operational and accounting changes were made. This increase in Charged Diversion probably largely reflects the fact that under the model scenario EPCWID is now being **charged** for its historical use of EPWU wastewater, thus increasing its Charged Diversion.

Note that the net impacts from Run 15a and Run 15b do not add up to the net impacts from the combined Run 15. This result occurs because the ILRGM is a non-linear model that simulates the existing non-linearities in Project allocation and operations. For example, when Project storage levels (in the reservoirs) are low, and Project allocations are relatively low, an increase in reservoir storage can increase the Project allocations. However, once a District's allocation has been increased to its full-supply amount, further increases in Project storage will not cause increases in that District's allocation. This change in response is "non-linear" (that is, the response is not directly proportion to the causal factor), and a model that simulates this correctly will also be non-linear.

5.4 Summary and Conclusions

If the relatively recent ACE Credit were eliminated, and EPCWID were again charged for its diversion and use of EPWU wastewater treatment plan discharges into the Project, the ILRGM calculates the result would be a cumulative total increase in EBID's Project diversions of 470,000 AF over the period 2000 – 2017. The annual impacts become larger starting in 2006, the year D3 Allocation + Carryover is implemented in the Base Run. Impacts average 36,000 AF/yr from 2006 through 2017. Increases in EPCWID's Charged Diversions are also simulated, a total of 230,000 AF from 2000 to 2017, but this increase is largely a result of EPCWID being charged for the EPCWID wastewater it has recently been using without charge.

If EPCWID were required to divert El Paso Valley drain flows, as they had done historically, and were charged for such diversions, the ILRGM calculates an increase in EBID's allocation by a cumulative total of 471,133 AF, and an increase in EBID Project diversions by a cumulative total of 458,000 AF over the period 2000 - 2017. EPCWID's simulated allocations and Charged Diversions would also have been larger. Current-Year Allocations would have been larger by a cumulative total of 148,000 AF and Charged Diversions by a cumulative total of 92,000 AF. These increases are simulated because the diversion and use of El Paso Valley drain flows would constitute an increase of Project Supply above current levels.

Both sets of issues were addressed in a combination run that eliminated the ACE Credit, charged EPCWID for its diversion and use of wastewater treatment plant discharges and utilized El Paso Valley drain returns in the ILRGM (Run 15). The results of this run show a total increase of 880,000 AF to EBID Project diversions from 2000 through 2017.

6 Runs 16 and 16a: Conjunctive Management at D1/D2 Period Levels

At the direction of New Mexico's legal counsel, I have worked with New Mexico expert Greg Sullivan to describe two scenarios that are consistent with my Opinions related to the D1/D2 Allocation and the Project operations and accounting procedures in place during the D1/D2 time period (1951 – 1978). Mr. Sullivan then coordinated with other New Mexico experts to simulate those scenarios using New Mexico's ILRGM for the historic period from 1940 to 2017. The Spronk Rebuttal Report (2020) provides a description of the scenario specifications and the results of the modeling analyses along with high-level observations of the results. In this Supplemental Report, I describe the basis for the scenarios (Run 16 and Run 16a) and offer some observations of the results.

6.1 Model Results

Runs 16 and 16a are hypothetical runs that simulate the hydrologic history of the Project area through 2017, in which

- Project Supply is allocated 57:43 using the D1/D2 Allocation method through 2017,
- The operational and accounting principles described in Run 15 are implemented through 2017, and
- Groundwater use to the levels occurring during the D2 Period (1951-1978) is incorporated.

In essence Runs 16 and 16a are simulations that extend earlier Rio Grande Project operations (including diversion of El Paso Valley drain flows), earlier Project accounting (including charges for the diversion of EPWU wastewater and El Paso Valley drain flows), and 57:43 Project allocation, until the present time. In addition, pumping limitations are imposed so that irrigation pumping levels cannot exceed the level occurring during the D2 time period (Run 16 and 16a) and non-irrigation well pumping is limited to the maximum amount occurring during the D2 time period (Run 16a). The only difference between Runs 16 and 16a is that in Run 16a non-irrigation well pumping (municipal, industrial, etc.) is also limited, with the limit set equal to the maximum amount diverted for those uses during the D2 Period.

Table13 provides a summary of how key model parameters are set for Run 1 and Runs 16 and 16a.

Table 13. Summary Description of Settings for Runs 1, 16, and 16a

Summary of Runs 1, 16, and 16a			
	Run 1	Run 16	Run 16a
NM Irrigation Well Pumping	Historical, calculated based on crop demand and SW shortage	10-year average limited to 166,866 AF/yr, calculated as in Run 1	10-year average limited to 166,866 AF/yr, calculated as in Run 1
TX Irrigation Well Pumping	Historical, calculated based on crop demand and SW shortage	10-year average limited to 70,783 AF/yr	10-year average limited to 70,783 AF/yr
NM Non-Irrigation Well Pumping	Same as occurred historically	Same as occurred historically	Limited to maximum of D2 period: 20,993 AF/yr
TX Non-Irrigation Well Pumping	Same as occurred historically	Same as occurred historically	Limited to maximum of D2 period: 30,264 AF/yr in Mesilla basin, 89,979 AF/yr in Hueco bolson
Irrigated Acreage and Irrigation Water Requirements	Same as occurred historically	Same as occurred historically	Same as occurred historically
Project Allocation Method	57:43 through 2005, D3 in 2006 & 2007, D3+Carrover 2008-2017	57:43 using D1/D2 Method	57:43 using D1/D2 Method
EPWU Wastewater	Diversion and use EPWU wastewater discharged in El Paso Valley not charged to EPCWID	EPCWID charged for diversion and use of EPWU wastewater during Caballo Release Season	EPCWID charged for diversion and use of EPWU wastewater during Caballo Release Season
EPV Drain Flow	No charge for use of El Paso Valley drain flow after 1978	EPCWID diverts and is charged for diverting available drain flow in El Paso Valley	EPCWID diverts and is charged for diverting available drain flow in El Paso Valley
ACE Credit	ACE Credit implemented starting 2003, historical values	ACE Credit eliminated	ACE Credit eliminated

Because both Run 16 and 16a simulate 57:43 Allocation through 2017, EBID's allocation does not suffer the dramatic reduction in 2006 caused by D3 Allocation (as actually occurred, see Barroll (2019), Section 8), and New Mexico irrigation well pumping is not artificially inflated as a result. Also, in both runs EPCWID is charged in Project Accounting for all diversion and use of drain flow in the El Paso Valley during the Caballo release season, the ACE Credit is eliminated, and EPCWID diverts and is charged for use of El Paso Valley drain flow. These changes improve EBID's allocation and diversion of Project Supply in many years, especially (as shown in Section 5 of this report) since the year 2003. This improvement of EBID's Project Supply further reduces the need for irrigation well pumping in New Mexico. As a result, in Runs 16 and 16a, New Mexico irrigation well pumping never reaches the limits described in Table 13. EPCWID does not reach those limits either, because of the large reduction in EPCWID's irrigation water demand since the D2 Period (1951 – 1978).

Figure 16 is a plot of the annual Current-Year Allocations for EBID and EPCWID for the years 2000 through 2017 for Run 16 and 16a. Figure 17 is a plot of the Charged Diversions for EBID and EPCWID for the years 2000 through 2017 for Run 16 and 16a.

Figure 16. Simulated Current-Year Allocations, Runs 1, 16 and 16a

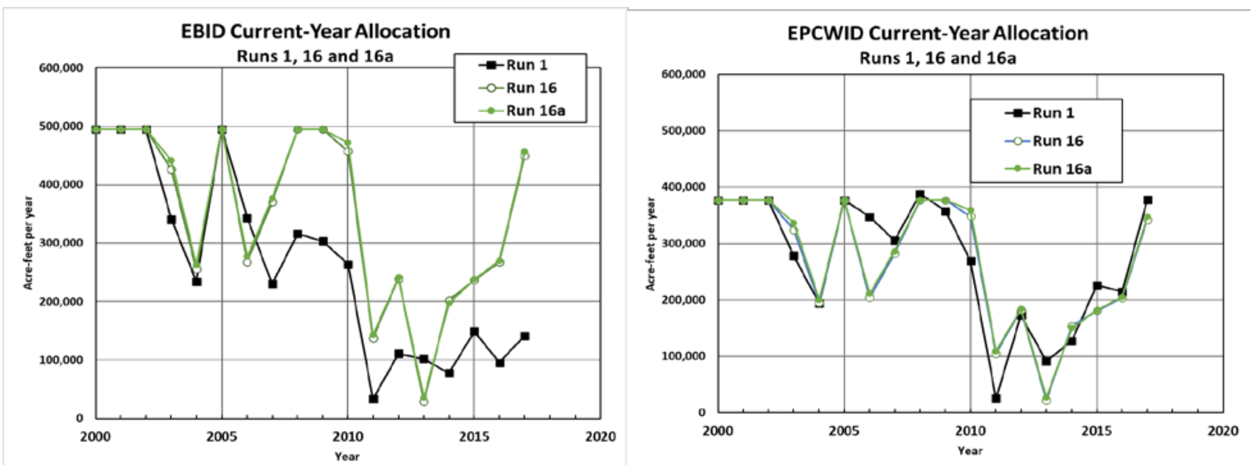
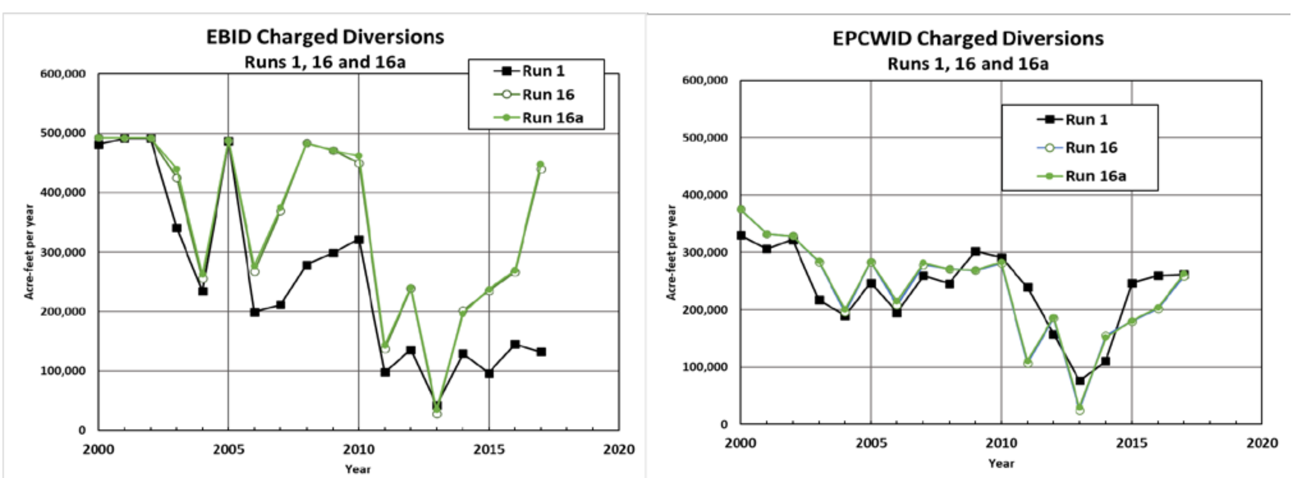


Figure 17. Simulated Charged Diversions, Runs 1, 16 and 16a



Figures 16 and 17 show almost no difference between the results from Runs 16 and 16a. This indicates that the factors that differ between the runs (that is: New Mexico non-irrigation well pumping reaching approximately 40,000 in Run 16 and remaining at 20,000 AF/yr in Run 16a) have little impact on the model results. In part this is likely caused by the fact that **much of New**

Mexico's non-irrigation well pumping is effectively offset by wastewater returns to the Rio Grande which are accounted as Project Supply when diverted downstream (see Barth Rebuttal, 2020). This small impact is also probably related to the fact that non-irrigation well pumping in the New Mexico part of the LRG is quite small compared with other stresses, such as irrigation well pumping.

Figure 16 also shows that EBID's allocations and Charged Diversion are considerably higher in Run 16 (and 16a) than they are for Run 1, while EPCWID's allocation and diversions in Run 16 are sometimes higher, and sometimes lower, but generally not greatly different that those in Run 1. These differences in diversion are quantified in Table 14. Over the 18-year period from 2000 through 2017, EBID diverts a total 1,620,000 AF more in Run 16 than it did in the Base Run (Run 1). Conversely, EPCWID diverts 39,000 less in Run 16 than it did in the Base Run. This shows that the reallocation involved in the 2008 OA does not greatly benefit EPCWID compared to what it would have diverted if D1/D2 conditions still applied (including the Run 15 EPCWID operational and accounting changes). EBID, on the other hand would have benefitted greatly if 57:43 allocation had been maintained and EPCWID had been operated and its diversions accounted for, as had been the case during the D1/D2 Period.

Table 14. Simulated Charged Diversions, Runs 1 and 16, 2000-2017

Charged Diversions to Districts, Runs 1 and 16 (D1/D2 Condition Runs)						
	EBID Charged Diversions			EPCWID Charged Diversions		
	Run 1	Run 16	Run 16 - Run 1	Run 1	Run 16	Run 16 - Run 1
2000	481,143	492,739	11,596	329,682	375,090	45,408
2001	491,744	492,324	580	306,054	332,195	26,141
2002	491,796	491,891	95	321,794	328,814	7,020
2003	340,912	425,454	84,542	217,108	283,336	66,228
2004	234,605	255,608	21,003	190,306	195,609	5,304
2005	486,958	487,885	927	246,933	283,691	36,759
2006	199,360	267,685	68,325	195,503	207,908	12,405
2007	211,626	369,990	158,364	259,806	278,182	18,376
2008	278,630	483,791	205,161	246,057	271,102	25,044
2009	298,781	471,418	172,636	302,148	268,942	-33,206
2010	321,683	450,155	128,473	291,560	280,760	-10,800
2011	98,467	137,620	39,152	239,594	106,967	-132,627
2012	135,800	239,315	103,515	157,542	185,744	28,202
2013	42,538	28,416	-14,122	76,014	25,001	-51,013
2014	129,599	202,114	72,514	110,806	155,354	44,549
2015	96,739	235,254	138,515	246,835	180,242	-66,593
2016	145,167	266,750	121,583	259,694	201,779	-57,915
2017	132,611	440,497	307,886	261,451	258,450	-3,002
Sum			**1,620,743**			**-39,722**

6.2 Summary and Conclusions

Runs 16 and 16a simulate a continuation of the conditions existing during the D2 Period (1951 – 1978) into the present day. The model modifications that were implemented to simulate Project allocation, accounting, and operations during the D2 period are:

1) D1/D2 Allocation applied through 2017
2) Post-1978 irrigation well pumping limited, on average, to the average levels occurring during the D2 Period
3) (Post-1978 Non-irrigation well pumping limited to the maximum level occurring during the D2 Period: Run 16a only.)
4) ACE Credit eliminated
5) EPCWID charged for its diversion and use of EPWU wastewater in the El Paso Valley throughout the Run
6) Continued diversion and use of El Paso Valley drain flows by EPCWID throughout the Run

In fact, the pumping constraints did not impact the simulated irrigation well pumping in Runs 16 or 16a for either New Mexico or Texas. Texas's irrigation demands have decreased substantially since the D2 period, and the Project modifications made for Runs 16 and 16 did not change that. For New Mexico, the allocation, accounting, and operational modifications applied in these runs, such as D1/D2 Allocation, increased EBID's share of Project Water enough to reduce New Mexico's total need for irrigation well pumping below average D2 levels.

The non-irrigation well pumping limitation in Run 16a had no impact on Texas' non-irrigation well pumping after 1978, but that constraint did limit New Mexico non-irrigation well pumping to approximately 20,000 AF/yr.

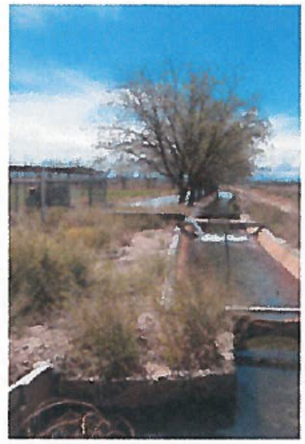
Figures 16 and 17 show almost no difference between the results from Run 16 and Run 16a, suggesting that the impact of post-1978 non-irrigation pumping increases have small impact on Project allocation and diversions.

Comparison of Run 1 and Run 16 shows that under Run 16 (D1/D2 conditions through present) EBID is allocated and diverts more water than under actual historical conditions. EPCWID's allocation and diversion under D1/D2 conditions are sometimes higher and sometimes lower than under actual historical conditions.

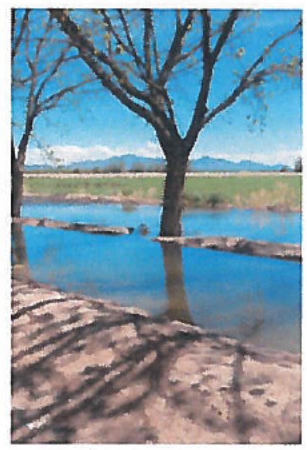
In summary, if Project allocation methods and the operations and accounting within Texas had remained consistent with the D2 Period (1951-1978), EBID would be have been allocated and received more Project Supply in recent years than they have received, New Mexico farmers would have pumped less groundwater, and EPCWID's allocation and delivery of Project Supply would have been little different than under D3 + Carryover.

Consumptive Use of Applied Water in the Rincon, Mesilla, El Paso and Juarez Valleys in the Rio Grande Basin







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For the State of New Mexico
In the Matter of:
State of Texas v. State of New Mexico and State of Colorado
No. 141, Original
Before the United States Supreme Court

October 2019

Consumptive Use of Applied Water in the Rincon, Mesilla, El Paso and Juarez Valleys in the Rio Grande Basin

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Abbreviations, Acronyms and Symbols

Symbol	Definition	Common Unit
AE	Application Efficiency	
ASABE	American Society of Agricultural and Biological Engineers	
ASCE	American Society of Civil Engineers	
AW	Available Soil Water	General use
AWC	Available Waterholding Capacity	mm, m m^{-1}, in., $in.ft^{-1}$
AWiFS	Advanced Wide Field Sensor	
AWS	Automatic Weather Station	
CDL	Crop Data Layer	
CGDD	Cumulative Growing Degree Days	^oC-d
CIR	Consumptive Irrigation Requirement	
CLU	Common Land Unit	
c_p	Specific Heat at constant pressure	kJ kg^{-1} $^oC^{-1}$
CR	Capillary Rise	mm d^{-1}, mm h^{-1}, in. d^{-1}
CU	Consumptive Use	mm d^{-1}, mm h^{-1}, in. d^{-1}
d	Zero Plane Displacement of wind profile	cm, m
DEM	Digital Elevation Model	
DoY	Day of year	
E	Evaporation	General use
E	Evaporation, depth and rate	mm d^{-1}, mm h^{-1}, in. d^{-1}, mm mo^{-1}, in. $mo.^{-1}$
e	Water Vapor Pressure in air	kPa
e_a	Actual Vapor Pressure	kPa
e_s	Saturation Vapor Pressure	kPa
EBID	Elephant Butte Irrigation District	
EPCWID	El Paso County Water Improvement District #1	
ET	Evapotranspiration	General use
ET	Evapotranspiration rate	mm d^{-1}, mm h^{-1}, in. d^{-1}
ET_{act}	Actual Evapotranspiration	mm d^{-1}, mm h^{-1}, in. d^{-1}
ET_{aw}	evapotranspiration of applied water	mm d^{-1}, mm h^{-1}, in. d^{-1}
ET_c	ET from a particular crop	mm d^{-1}, mm h^{-1}, in. d^{-1}
ET_o	ET from a well-watered Grass reference crop	mm d^{-1}, mm h^{-1}, in. d^{-1}
ET_oF	Crop Coefficient or Fraction of Grass Reference ET developed based on ET_o	
ET_{pot}	Potential Evapotranspiration	mm d^{-1}, mm h^{-1}, in. d^{-1}
ET_{pr}	ET of Precipitation	mm d^{-1}, mm h^{-1}, in. d^{-1}
ET_r	ET from a well-watered Alfalfa reference crop	mm d^{-1}, mm h^{-1}
ET_rF	Crop Coefficient or Fraction of Alfalfa Reference ET developed based on ET_r	
ET_{ref}	Reference Evapotranspiration, general	mm d^{-1}, mm h^{-1}
ETM+	Enhanced Thematic Mapper Plus	
EWRI	Environmental and Water Resources Institute of ASCE	

Symbol	Definition	Common Unit
f_c	Fraction of Ground Cover by crop or vegetation canopy	0 – 1.0
FAO-56	Food and Agriculture Org. Irrig. and Drain. Paper 56	
FSA	Farm Service Agency	
FWS	Free-Water Surface	
G	Heat Flux Density to the Ground	MJ m^{-2} d^{-1}, MJ m^{-2} h^{-1}, W m^{-2}
g	Acceleration of Gravity	m s^{-2}
GIS	Geographic Information System	
GPS	Global Positioning System	
GO	Groundwater Only	
G_{sc}	Solar Constant	MJ m^{-2} h^{-1}, W m^{-2}
GW	Groundwater	
h	Height of Vegetation	cm, m
H	Heat Flux Density to the Air	MJ m^{-2} d^{-1}, MJ m^{-2} h^{-1}, W m^{-2}
Hudspeth	Hudspeth County Conservation & Reclamation District #1	
ICUC	Irrigation Consumptive Use Coefficient	decimal or %
IE	Irrigation Efficiency	decimal or %
IRS-P6	Indian Remote Sensing RESOURCESAT-1	
ISC	Interstate Stream Commission	
J	Day of the Year	
Juarez	Juarez Valley Irrigation District	
k	von Karman's Constant	
K_c	Crop coefficient general (not the same as the Blaney-Criddle K)	decimal
K_{cb}	Crop Coefficient (basal), in general, with soil water not limiting transpiration, but the soil surface is visually dry. When soil water is not limiting, K_{cb} is referred to as a potential K_{cb}, otherwise, it is referred to as an actual K_{cb}.	decimal
K_{cm}	Mean, or Single, Crop Coefficient	decimal
K_e	Evaporation Coefficient to adjust for increased evaporation from the soil	decimal
K_o	Adjustment to minimum temperature used to estimate dewpoint temperature	^oC, K
K_s	Water Stress Coefficient	decimal, 0-1.0
K_{sat}	Saturated Hydraulic Conductivity	
LAI	Leaf-Area Index	General use
LRG	Lower Rio Grande	
L1T	Landsat Level-one, Terrain-corrected image	
LU	Land Use	
MAD	Management Allowed Depletion	decimal or %
MAE	Maximum Application Efficiency	decimal or %
METRIC	Mapping ET at High Resolution with Internalized Calibration	
MODIS	Moderate Resolution Imaging Spectroradiometer	
NASA	National Aeronautics and Space Administration	
NASS	National Agricultural Statistics Service	

Symbol	Definition	Common Unit
NCEI	National Centers for Environmental Information, administered by NOAA	
NCSS	National Cooperative Soil Survey	
NDVI	Normalized Difference Vegetation Index	decimal
NDWI	Normalized Difference Water Index	decimal
NED	National Elevation Dataset	
NEH	National Engineering Handbook	
NLCD	National Land Cover Database	
NMISC	New Mexico Interstate Stream Commission	
NMOSE	New Mexico Office of the State Engineer	
NMSU	New Mexico State University	
NOAA	National Oceanic and Atmospheric Administration	
NRCS	Natural Resources Conservation Service	
P	Atmospheric Pressure	kPa
Pr	Precipitation	mm, in.
PM	Penman-Monteith	General use
q	Specific Humidity	Kg kg^{-1}
QC	Quality Control	
R_a	Exoatmospheric (extraterrestrial) Solar Radiation on a horizontal surface	MJ m^{-2} d^{-1}, MJ m^{-2} h^{-1}, W m^{-2}
r_a	Aerodynamic Resistance of vertical movement of Heat and Vapor in the near-surface air layer	s m^{-1}
RAW	Readily Available Water in the root zone	mm, in.
REW	Readily Evaporable Water from soil	mm, in.
RGP	Rio Grande Project	
RH	Relative Humidity	%
RMSE	Root mean square error	
R_n	Net Short-wave and Long-wave Radiation	MJ m^{-2} d^{-1}, MJ m^{-2} h^{-1}, W m^{-2}
R_s	Solar Radiation at the surface on a horizontal plane	MJ m^{-2} d^{-1}, MJ m^{-2} h^{-1}, W m^{-2}
r_s	Surface Resistance (generally a bulk canopy resistance)	s m^{-1}
R_{so}	Solar Radiation on a cloudless day	MJ m^{-2} d^{-1}, MJ m^{-2} h^{-1}, W m^{-2}
SCS	Soil Conservation Service	
SEB	Surface Energy Balance	
SLC	Scan Line Corrector on Landsat 7	
SSURGO	Soil Survey Geographic Database	
SW	Surface Water	
T	Temperature	°C, K, °F
T	Transpiration	
t	Time	s, h, d
TAW	Total Available Water in the root zone	mm, in.
TEW	Total Evaporable Water of the upper 0.12 layer of soil (evaporation layer)	mm, in.
T_{dew}	Dewpoint Temperature of the air	^{o}C, K
TM	Thematic Mapper	
T_{max}	Daily Maximum Air Temperature	°C, K

Symbol	Definition	Common Unit
T_{min}	Daily Minimum Temperature	°C, K
T_s	Surface temperature	°C, K
T_w	Wet bulb temperature of the air	^oC, K
u_z	Horizontal wind speed at height z	m s^{-1}, km d^{-1}
USDA	United States Department of Agriculture	
USGS	United States Geological Survey	
VPD	Vapor Pressure Deficit	kPa
Z	Elevation in air above ground surface or Elevation above mean sea level	cm, m
z_{om}	Roughness Length, momentum	cm, m
z_{ov}	Roughness Length, heat and water vapor	cm, m
α	Shortwave Albedo	decimal
ρ	Air Density	Kg m^{-3}
Θ	Volumetric Soil Water Content	decimal or %

Assignment

Pursuant to direction of legal counsel representing the State of New Mexico in the United States Supreme Court Case *Texas v. New Mexico and Colorado*, No. 141, Original, I was asked to compile and review applicable documentation and data necessary to perform the technical analyses described in this expert report. Professional staff and employees of Davids Engineering, under my direct supervision and direction, provided assistance in this work. I served as the primary author of the report and am responsible for the documentation, data, methodology, results and opinions contained herein. My curriculum vitae is provided in Appendix 11.

Dr. Richard Allen reviewed and endorses the data, documentation, analyses, results and opinions contained in this report. Dr. Allen also performed his review and work under the direction of legal counsel representing the State of New Mexico in this case. Dr. Allen's curriculum vitae is provided in Appendix 12.

Summary of Qualifications for Bryan P. Thoreson

1. My name is Bryan P. Thoreson. I am a registered Civil Engineer in California and Washington and principal engineer at Davids Engineering, Inc. in Davis, CA, where I have been employed since 1997. I have 25 years of professional experience as a civil engineer specializing in agricultural water consumptive use and water balance analyses.
2. My education includes Bachelor of Science and Master of Science degrees in Agricultural Engineering from South Dakota State University, and a Doctoral degree in Agricultural and Biosystems Engineering from the University of Arizona.
3. Prior to working at Davids Engineering, Inc., I worked for Imperial Irrigation District initially as an assistant engineer and then as an engineer from 1994 through 1997.
4. In December 2003, I became a shareholder at Davids Engineering, Inc.
5. I have completed more than 20 consumptive use and water balance analyses for irrigation and water districts.
6. Davids Engineering is being compensated for my work on this assignment at a rate of $196 per hour.
7. My professional resume, including publications authored in the previous 20 years, is included in Appendix 11.

Summary of Qualifications for Richard Glen Allen

1. My name is Richard Glen Allen. I am a registered Civil Engineer in Idaho. I am a full professor of water resources engineering in the Department of Soil and Water Science at the University of Idaho, where I have been employed since 1998. I am also the owner and principal of Evapotranspiration Plus, LLC and Allen Engineering companies. I have 42 years of professional experience as an irrigation engineer and civil engineer specializing in irrigation systems design and management, agricultural water consumptive use and water balance analyses and in satellite-based remote sensing of water consumptive use.
2. My education includes a Bachelor of Science degree in Agricultural Engineering from Iowa State University, a Master of Science degree in Agricultural Engineering from the University of Idaho, and a Ph.D. in Civil Engineering from the University of Idaho.
3. Prior to employment at the University of Idaho, I was an assistant professor, associate professor and full professor in the Department of Biological and Irrigation Engineering at Utah State

University from 1985 to 1998. Prior to that, I was an assistant professor in the Department of Civil Engineering at Iowa State University from 1983 to 1985. Prior to that, I was a research associate at the University of Idaho Research and Extension Center at Kimberly, Idaho from 1977 to 1983.

4. I was lead author on the United Nations Food and Agriculture Organization Irrigation and Drainage Paper 56: "Crop Evapotranspiration – Guidelines for computing crop water requirements" that serves as an international practice's standard
5. I was coauthor of the 1990 and 2016 American Society of Civil Engineers Manual no. 70: "Evaporation, Evapotranspiration and Irrigation Requirements" that serves as a national practice's standard
6. I have been lead author on 29 technical research completion reports related to consumptive use, evapotranspiration and irrigation water management.
7. I have authored or coauthored more than 160 papers in refereed journals and book chapters related to evapotranspiration, irrigation water requirements, irrigation system design, and remote sensing of evapotranspiration.
8. My company Evapotranspiration Plus, LLC is being compensated for my work on this assignment at a rate of $188 per hour.
9. My professional resume, including publications authored, is included in Appendix 12.

I. Consumptive Use Determination Overview

Purpose

In the context of agriculture, consumptive use is defined as "the part of water withdrawn that is evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise removed from the immediate water environment" (ASCE, 2016). Consumptive use primarily encompasses all water that is evaporated from soil and crop surfaces and all water that is transpired by crops (i.e., carried through plant tissue from the roots to stomata, or pores, in the leaves). Most field crops dry to a very low moisture content approaching harvest, so the volume of water incorporated into crop biomass is small and therefore typically neglected. As such, consumptive use is often considered approximately equal to crop evapotranspiration (ET_c). ET_c rates vary between individual crops, soil surface coverage conditions, and surrounding weather and climate conditions.

Consumptive use includes the use of water from precipitation and from irrigation. Consumptive use of applied water, or irrigation water, varies over time primarily due to variability in water supply conditions, weather patterns and crop types.

The purpose of this study was to accurately determine consumptive use of irrigation water in the Rincon, Mesilla, El Paso and Juarez Valley Study Area by evaluating historical crop areas, soil characteristics, weather conditions, agricultural practices, and other factors that have affected consumptive use over time.

This section provides an overview of the analyses used to estimate consumptive use of irrigation water – also referred to as evapotranspiration of applied water (ET_{aw}) – for irrigated lands in the Study Area under full water supply (full supply) conditions. ET_{aw} is estimated by first determining ET_c of crops in the Study Area under full supply conditions, and then apportioning ET_c between evapotranspiration of precipitation (ET_{pr}) and ET_{aw}. "Full supply" is generally understood to mean that available water supplies are sufficient to fully satisfy crop irrigation water demands for all irrigated lands. This report does not determine consumptive use under conditions of deficit irrigation, nor does it report consumptive use of municipal and industrial water use.

The Study Area includes the irrigated lands that extend along both banks of the Rio Grande from below Caballo Reservoir in New Mexico to Fort Quitman, Texas and that lie primarily within the boundaries of the Elephant Butte Irrigation District (EBID) in the Rincon and Mesilla Valleys in New Mexico, the El Paso County Water Improvement District #1 (EPCWID) in the lower Mesilla and El Paso Valleys in Texas, Hudspeth County Conservation & Reclamation District #1 (Hudspeth) in the El Paso Valley in Texas (collectively the US Districts) and the Juarez Valley Irrigation District (Juarez) in the Juarez Valley in Mexico. The Study Period considered in this analysis spans 1938 through 2018.

Overview of Methodology

This subsection provides a brief overview of the methodology used to estimate consumptive use of irrigation water. Additional detail regarding each step in this methodology is provided in the subsections that follow.

Introduction

As defined above, consumptive use is generally equivalent to evaporation (E) and crop transpiration (T), together referred to as crop evapotranspiration (ET_c) (**Equation 1-1**). ET_c encompasses evapotranspiration of all water available to crops from precipitation, irrigation and, in some cases, from shallow groundwater. The portion of ET_c that is satisfied by precipitation is typically referred to as ET of precipitation (ET_{pr}), or effective precipitation. The portion of ET_c that is satisfied by applied irrigation water is typically referred to as ET of applied water (ET_{aw}), or consumptive use of irrigation water. ET_{aw} is the variable of interest in this study; it is calculated by estimating ET_c and apportioning the total ET_c between ET_{pr} and ET_{aw} (**Equation 1-2**).

$$ET_c = Crop\ Transpiration + Evaporation \quad \textbf{(Eq. 1-1)}$$

$$ET_c = ET_{aw} + ET_{pr} \quad \textbf{(Eq. 1-2)}$$

Categories of ET_c

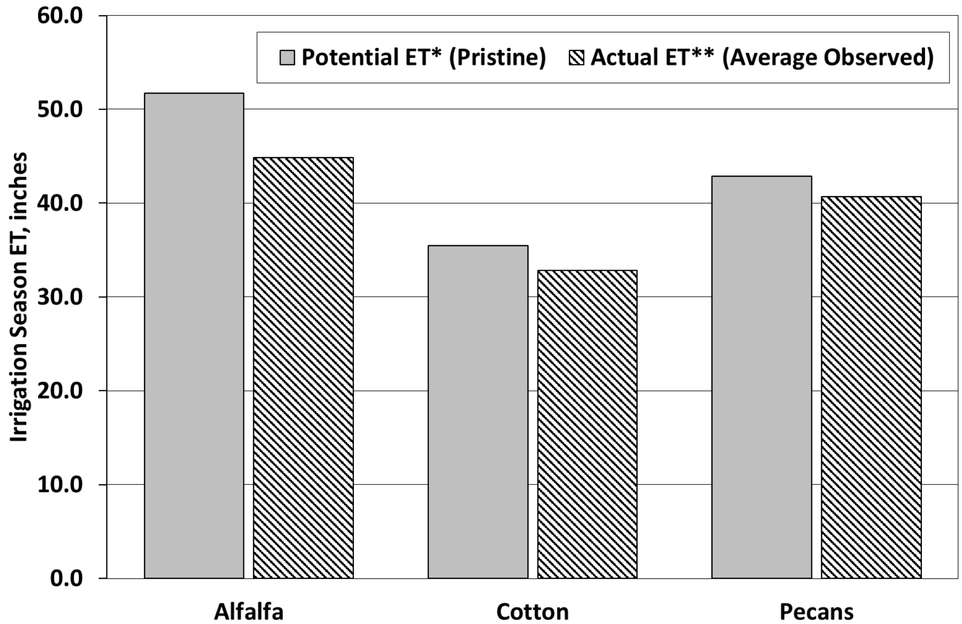
There are three categories of ET_c discussed in this report. The first is potential crop ET_c, which represents the highest potential evapotranspiration rate that could be achieved by the crop assuming ideal or "pristine" conditions with regard to water availability and crop health (ASCE, 2016).

The next is actual ET_c, which is the actual rate of evapotranspiration that occurs under actual field conditions (ASCE, 2016) in the Rincon, Mesilla, El Paso and Juarez Valleys. In years when water supplies are sufficient to fully satisfy crop irrigation water demands, actual ET_c represents consumptive use under full supply conditions. Actual ET_c cannot generally be measured directly, particularly over a large region such as the Study Area. In this report "actual ET_c" refers to ET_c computed by the METRIC (Mapping Evapotranspiration at high Resolution using Internalized Calibration) surface energy balance (described in the following section) or using crop coefficients derived from METRIC, as that is considered the most accurate method available to calculate actual ET_c over a large area. This computed value of actual ET_c represents the average ET_c across all fields containing a specific type of crop. Because of the differences between "pristine" and actual conditions, potential ET_c may be higher than actual ET_c and is generally not representative of average crop conditions (ASCE, 2016) across the Study Area (**Figures 1-1 and 1-2**).

The third and final category of ET_c discussed in this report is calculated ET_c, or ET Demands ET_c. This is the ET_c value calculated in this report following the crop coefficient – reference crop ET standard method using the ET Demands Root Zone water balance model (both described below). ET Demands ET_c is calibrated for consistency with actual ET_c determined by METRIC during key full supply years and represents an accurate estimate of consumptive use under actual crop conditions in the Study Area.

Standard Methods for Estimating ET_c

Two standard methods used to estimate ET_c in this study are the crop coefficient – reference crop ET method and the satellite-based surface energy balance method.



* Potential ET calculated based on 70th percentile Kc values (typical of pristine conditions) derived by METRIC analyses for all crop-specific areas in EBID in 2008.

** Actual ET of all crop-specific areas based on METRIC analyses for EBID in 2008.

Figure 1-1. Comparison between Potential ET (Pristine Conditions) and Actual ET (Average Observed Conditions) of Crops in New Mexico (EBID) during the 2008 Irrigation Season (March-October).

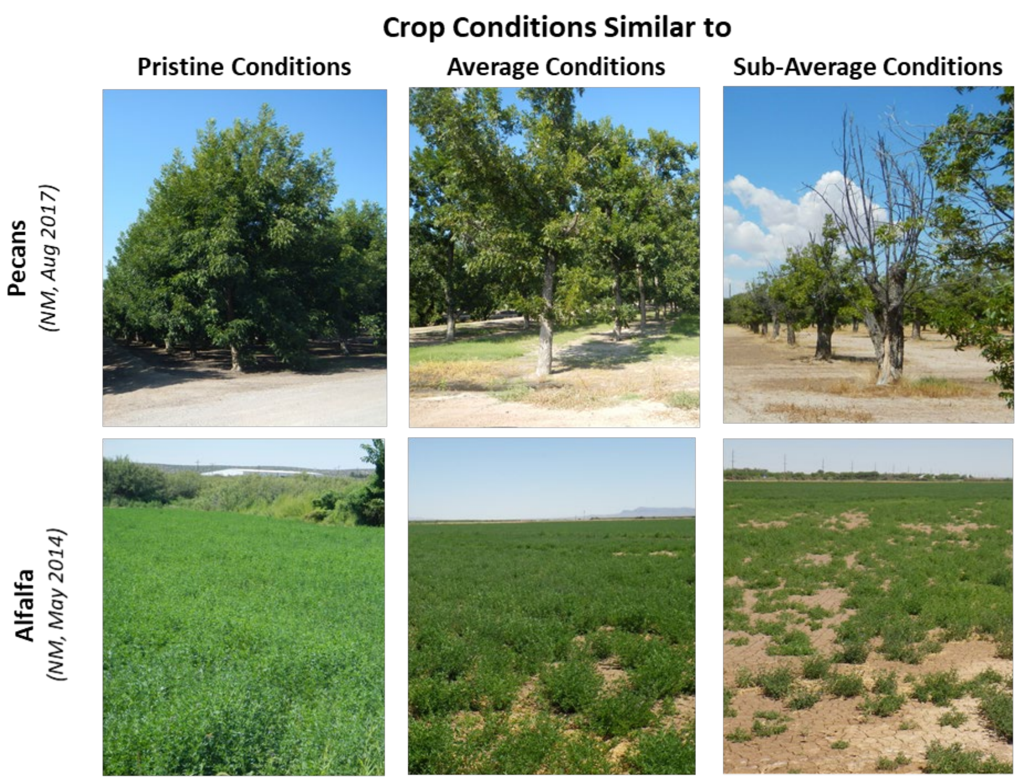


Figure 1-2. Comparison of pecan and alfalfa crops grown under conditions similar to pristine, average, and sub-average conditions, as observed in New Mexico (pecan images from August 2017, alfalfa images from May 2014).

In the crop coefficient – reference crop ET method, ET is calculated for a reference crop under local weather conditions and is then extrapolated and adjusted to other crops using local crop-specific "crop coefficients" (ASCE, 2016). A crop coefficient (K_c) is defined as "the ratio of evapotranspiration occurring with a specific crop at a specific stage of growth [ET_c] to reference crop evapotranspiration at that time [ET_{ref}]" (ASCE, 2016) and can be represented as ET_c/ET_{ref}. This method is widely accepted and used throughout the western United States and in similar arid, irrigated regions worldwide and has been extensively applied in irrigation water management and irrigation scheduling. Since the late 1990s, the method has been standardized through technical committee discussions, as reported in the Food and Agriculture Organization of the United Nations (FAO) Report Number 56 (FAO-56) (Allen, et al., 1998) and American Society of Civil Engineers Manual 70 (ASCE, 2016). The method has proven to produce accurate, robust, consistent results, and is relatively straightforward to apply (ASCE, 2016). A description of how this method is used is provided in the following paragraphs.

Another method to estimate ET_c that has been developed during the last 25 years is a surface energy balance using satellite imagery data. Surface energy balance methods can be used in tandem with the crop coefficient – reference crop method to improve accuracy of results. One widely accepted energy balance model is METRIC (Mapping Evapotranspiration at high Resolution using Internalized Calibration). The METRIC energy balance model is a widely accepted, widely applied (Serbina and Miller 2014), and accurate, ±5 to ±15% method when applied by expert users, (Allen, et al., 2011). METRIC is a surface energy balance-based group of algorithms that represents the best available science. However, executing it accurately requires an experienced expert and more time and resources than the crop coefficient – reference crop ET method, which has, traditionally, been more widely used. In this study, the two methods have been combined to achieve the benefits of both. In key years representing full supply conditions, METRIC is used to locally calibrate crop coefficients to improve local accuracy of crop consumptive use estimates. The METRIC model employs the key physical concept that transformation of liquid water to vapor via the ET process requires and consumes substantial amounts of energy (about 590 calories per cubic centimeter of water). The energy used for the ET process originates from the sun and atmosphere and provides an upper limit on expected ET rates. The METRIC model computes a balance of net radiation influx (R_n) to an area of interest and partitions that into sensible heat (H) transferred from the ground or vegetation surface to the air, heat conducted to the ground (G), and energy consumed through ET. The calculation process is driven using data from satellite imagery coupled with meteorological data from ground-based weather stations (**Figure 1-3**).

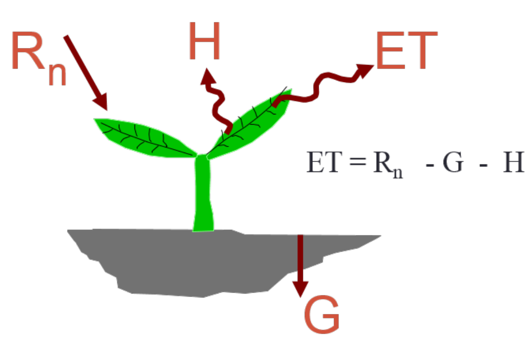


Figure 1-3. METRIC Energy Balance for Calculating ET (Allen, 2015).

The METRIC model has been in existence and under development since 2000 and has been widely applied in the states of Idaho, California, Oregon, Nevada, New Mexico, Montana, Wyoming, Colorado, Texas and Nebraska for a broad range of purposes. Those purposes include those where it is critical to estimate actual ET_c over large spatial areas, such as for water rights administration, water balances from field to regional scales, and ground-water model development. Many applications of METRIC, both in the western United States (Wyoming, Idaho, Nevada, Colorado and California) and internationally (Australia and Morocco), are summarized in Serbina and Miller (2014). General accuracy of ET_c estimated by METRIC has been estimated to be ±5 to ±15% when applied by expert users (Allen et al., 2011). The actual ET_c results from METRIC include evaporation and transpiration from ET_{aw} and ET_{pr}. The METRIC methodology has been widely vetted with more than 40 refereed journal publications.

Procedure for Estimating and Calibrating ET_c

In this study, the crop coefficient – reference crop ET method was used to estimate ET_c for the Study Area for 1938 through 2018. METRIC was used to estimate ET_c for three selected years to collect actual crop coefficient information over the entire Study Area that was then used to calibrate a local crop coefficient for each crop for use with the crop coefficient – reference crop ET method as described below.

In the crop coefficient – reference crop ET methodology, ET_c is estimated for various crops across the Study Area and for their differing growth stages over time using two locally-defined parameters: reference crop ET (ET_o here) and a crop coefficient (K_c) (**Equation 1-3**).

$$ETc = ET_O \times K_c \quad \textbf{(Eq. 1-3)}$$

First, the crop ET of a defined reference crop surface is calculated for 1938 through 2018 following accepted methods and using local, quality-controlled weather data from weather stations representative of the Study Area. In this study, the standardized Penman-Monteith (PM) methodology using the clipped cool season grass reference as described by the Food and Agricultural Organization (FAO-56 - Allen et al., 1998) and the ASCE Task Committee Report on the Standardized Reference Evapotranspiration Equation (ASCE-EWRI, 2005) was used to determine daily grass reference ET (ET_o). The PM method "is recommended as the sole standard method" by FAO-56 for estimating reference crop ET, providing "strong likelihood of correctly predicting ET_o in a wide range of locations and climates [with] provision for application in data-short situations" (Allen et al., 1998). ASCE (2016) makes similar recommendations on applying the ASCE Standardized Penman-Monteith reference method in preference to all other reference ET methods.

Next, the ET_o timeseries is adapted to other crops and their differing growth conditions, water requirements, and cultivation practices using crop coefficient (K_c) curves. A dual crop coefficient approach was used in this study (ASABE, 2007 and ASCE, 2016) to distinguish evaporation from precipitation and evaporation from applied irrigation water to provide more accurate estimation of the ET_{aw} and ET_{pr} components of ET_c. In this approach, the crop coefficient is divided into a basal crop coefficient (K_{cb}) that is used to estimate the crop transpiration component of ET_c, and into an evaporation coefficient (K_e) that is used to estimate evaporation following wetting events (**Equations 1-4, 1-5 and 1-6**).

$$K_c = K_{cb} + K_e \quad \textbf{(Eq. 1-4)}$$

$$K_{cb} = \frac{Crop\ Transpiration}{ET_o} \quad \textbf{(Eq. 1-5)}$$

$$K_e = \frac{Evaporation}{ET_o} = 1.05 \quad \text{during wetting (ASCE,2016)} \qquad \textbf{(Eq. 1-6)}$$

The K_{cb} contains a small portion of residual evaporation from soil beneath crops (Wright 1982; Allen et al., 1998; ASCE 2016). In this study, K_{cb} values were developed from and calibrated using the three years of actual ET_c calculated by the METRIC satellite imagery-based energy balance analyses of actual crop water use across the Study Area. This methodology was selected as the most accurate, most consistent, and most dependable method and means to produce actual ET_c results that are spatially representative of the water use of agriculture in the Study Area.

For each crop, daily K_c values were developed for 2008 (a year representing "full supply" conditions) based on actual ET_c estimates from fields developed by the METRIC surface energy balance model using data from the Landsat satellite. The Normalized Difference Vegetation Index (NDVI), a quantitative index relating changes in crop canopy cover that serves as an indicator of crop-specific growth characteristics, was used to guide development of the time-basis for K_{cb} values from the METRIC-derived K_c values by providing information on the stage of crop canopy development.

Following the development of K_{cb} values for 2008 (a "full supply" project year), these values and other parameters were calibrated through an iterative process until they produced ET_c estimates that were within at least 10% accuracy for estimating actual ET_c calculated by METRIC for EBID in 2002 (a "full supply" year) and 2013 (a "limited supply" year). Years 2002 and 2013 were used as independent checks on the K_{cb} calibration developed using year 2008 and for error assessment.

Operation of ET Demands to Estimate ET_{aw}

Next, the crop coefficient – reference crop ET methodology was implemented in the ET Demands Root Zone water balance model using a daily calculation time step (ASCE, 2016 and ASABE, 2007) to apportion ET_c between ET_{pr} and ET_{aw}.

A daily root zone water balance is a generally accepted methodology that is widely used to estimate the portion of ET_c met by precipitation (ET_{pr}) and by irrigation (ET_{aw}) by accounting for daily inflows to and outflows from the root zone (ASCE, 2016 and ASABE, 2007). For this study, the ET Demands Root Zone model (referred to as the ET Demands model) was selected because it calculates total ET from the crop coefficient – reference crop ET method and has been widely applied to compute consumptive water use and to study the potential effects of climate change on agricultural water demands (Allen and Robison, 2009 and Allen and Huntington, 2010, Allen and Huntington, 2015, and Reclamation, 2015). Additionally, ET Demands follows the dual crop coefficient approach to more accurately account for crop transpiration and evaporation resulting from rainfall and local irrigation practices. ET Demands employs a thermal basis for estimating the rate of crop development for most crops so that effects of warmer or cooler conditions during spring and early summer that impact the rate of crop and ET development are captured (Reclamation, 2015). The daily timestep of the ET Demands model provides substantially greater accuracy than the use of monthly timesteps through its ability to follow day-to-day variation in ET extractions from soil and deep percolation fluxes through and below the root zone after (Bauer and Vaccaro, 1987; Willis et al., 1997; Allen et al., 1998; Bethune et al. 2008).

Operation of the ET Demands model (and root zone water balance models in general) requires information on weather, soils, basal crop coefficients, and other crop data as described in **Figure 1-4** below. The root zone water balance model calculates outputs including ET_c, ET_{pr}, ET_{aw}, runoff of precipitation, tailwater, and deep percolation following standardized methodologies based on known or calculated flows into and out of the root zone. The ET Demands model calculates all inflows and outflows uniquely for each different crop on a per area (per acre) basis. Total consumptive use of irrigation water can therefore be summarized across an area of interest, such as the Study Area, by multiplying the appropriate ET Demands model results (ET_{aw} volume per acre, by crop) across the historical acreage of each crop in that area.

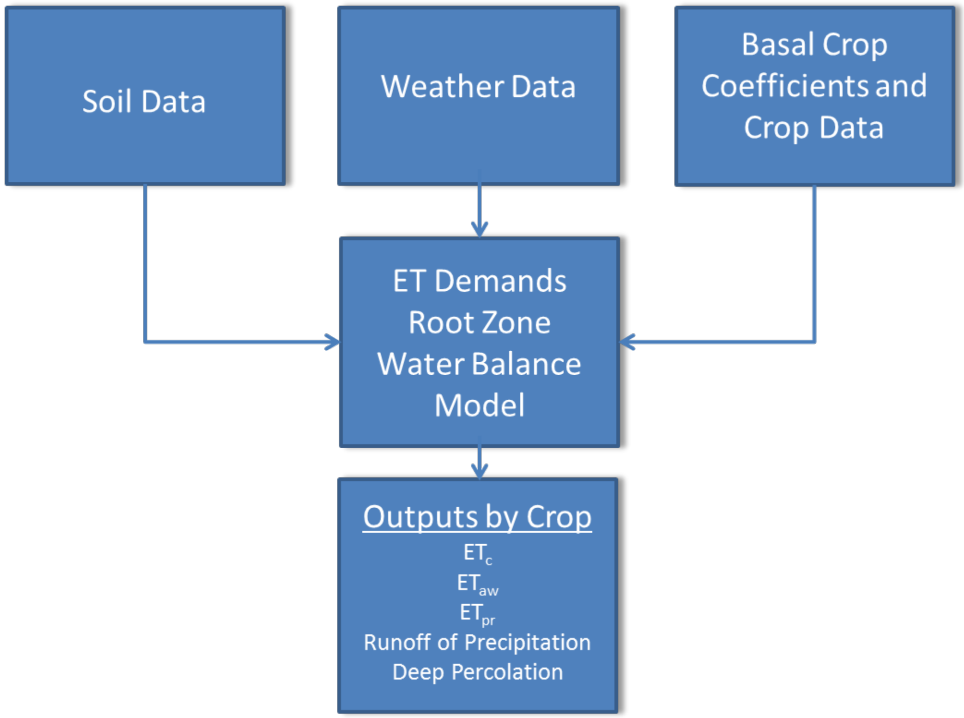


Figure 1-4. Schematic Representation of Data Inputs to and Outputs from the ET Demands Daily Root Zone Water Balance Model (ET Demands).

As described above, the basal crop coefficients used in ET Demands were developed for local conditions based on weather data and 2008 energy balance ET_c estimates (**Figure 1-5**). Crop coefficients and other crop data were calibrated to local conditions within the Study Area using remotely sensed energy balance ET_c estimates and local observations of crop plant and harvest dates and irrigation practices (**Figure 1-6**).

Finally, the ET_{aw} outputs from ET Demands (volume per acre, by crop) were multiplied by the corresponding crop acreage to estimate ET_{aw} volumes by crop (**Figure 1-7**). ET_{aw} volumes by crop were then summed to obtain the total consumptive use of irrigation water for irrigated lands.

Figure 1-8 provides an example of the process used to calculate consumptive use of irrigation water for cotton fields in EBID on one day in August 2008. A similar process was followed to calculate daily consumptive use of irrigation water for all crops in all regions of the Study Area during the entire period between 1938 and 2018.

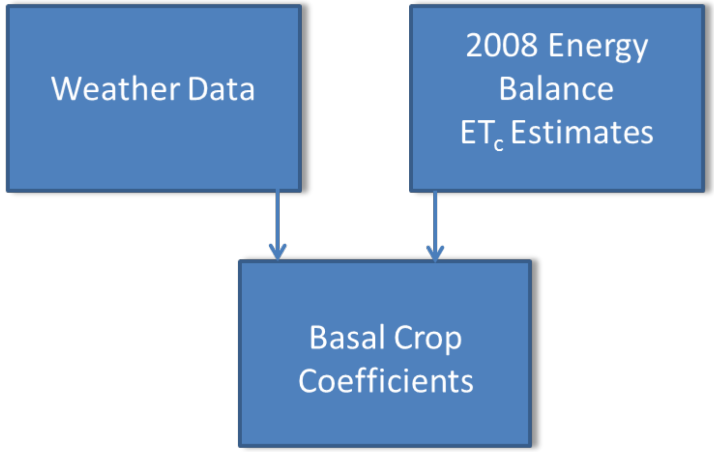


Figure 1-5. Schematic Representation of Local Crop Coefficient Development for the ET Demands Model.

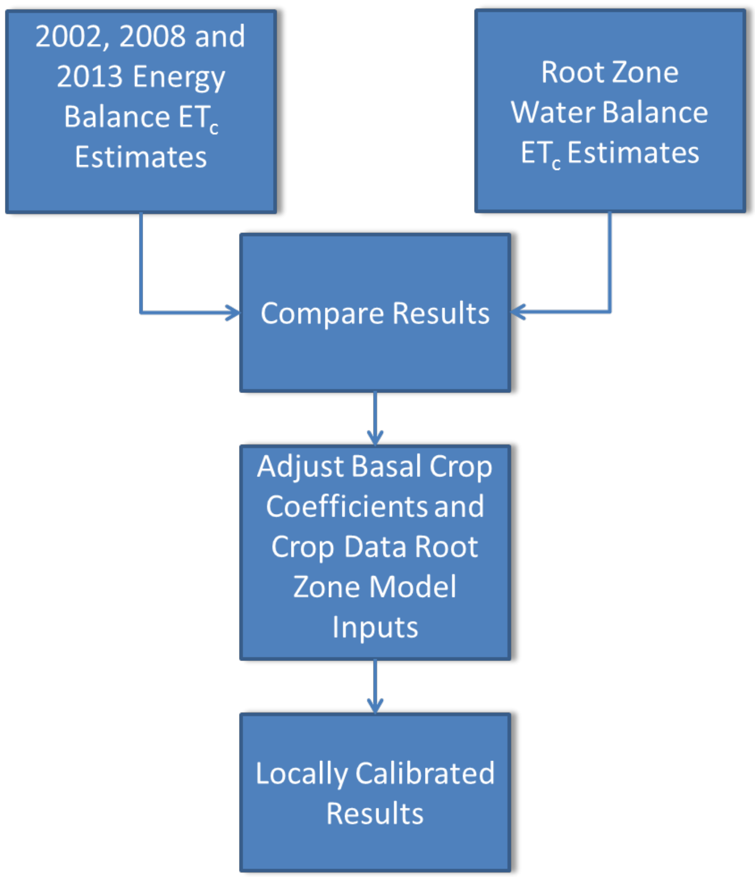


Figure 1-6. Schematic Representation of Local Calibration of ET Demands Model.

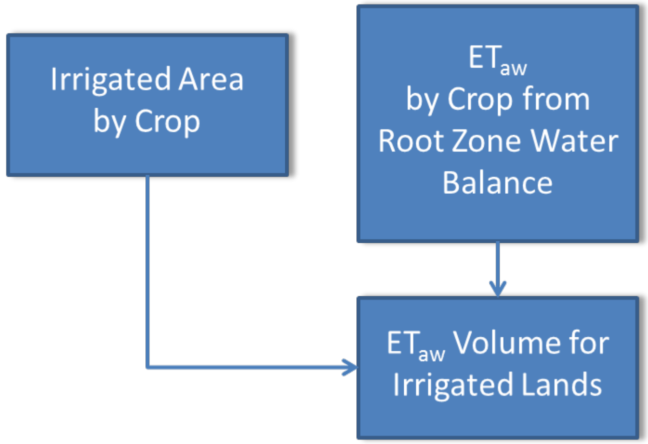


Figure 1-7. Schematic Representation of Calculation of ET_{aw} Volume for Irrigated Lands.

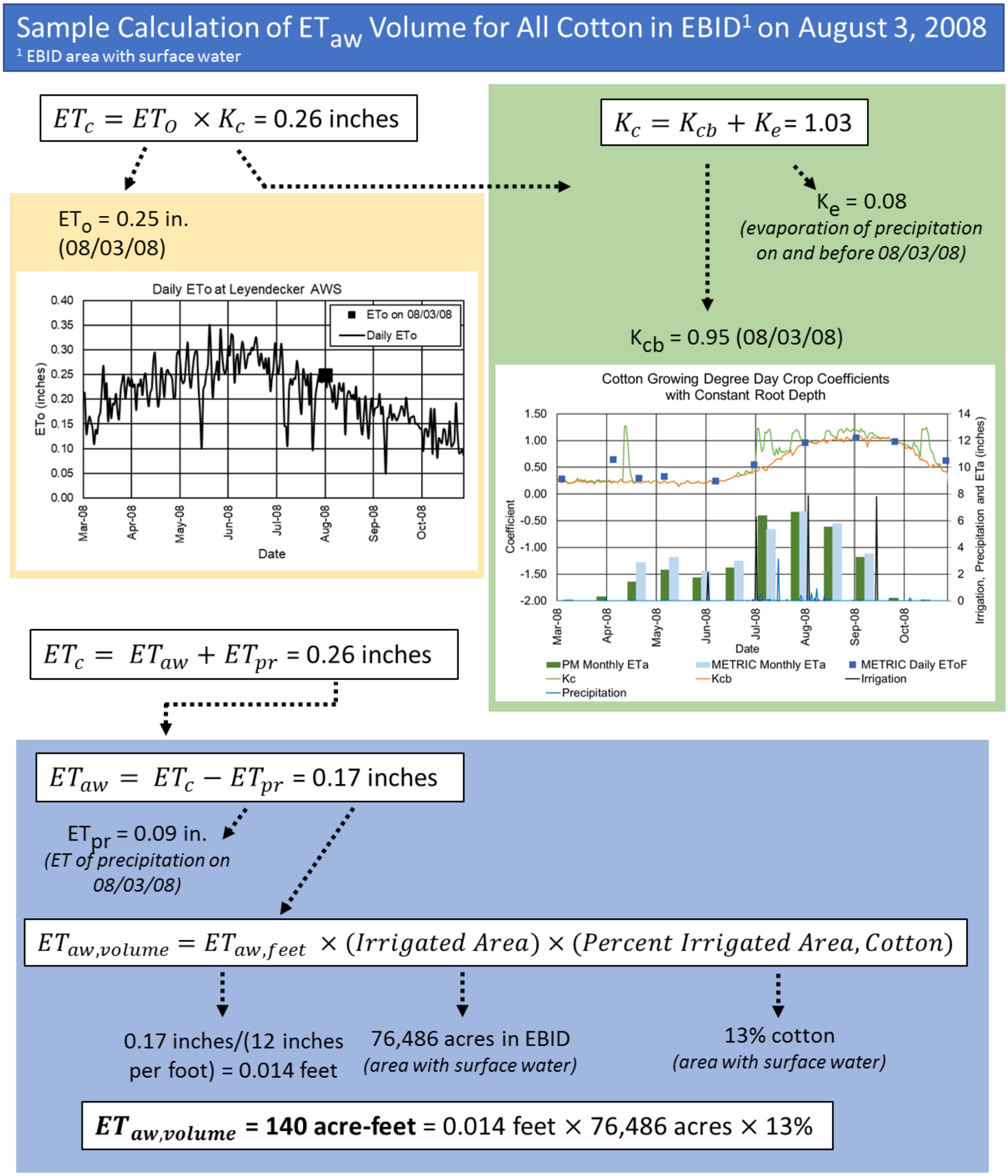


Figure 1-8. Example of Process Used to Calculate Consumptive Use of Irrigation Water for Cotton in EBID (With Surface Water) on August 3, 2008.

The following subsections briefly summarize the scientifically sound methodologies widely adopted by engineers, crop and irrigation experts that were used in our applications to develop the weather, soils, and basal crop coefficients and other crop data required by the ET Demands root zone model. Details regarding the development of METRIC ET_c estimates, operation of the ET Demands root zone model, and determination of crop irrigated areas are also briefly summarized.

The full detailed procedures and results of each step in the procedure are provided in the remaining sections of this report.

Soil Data

Soil infiltration characteristics are required in the ET Demands model to estimate surface runoff from precipitation. Additionally, soil water holding properties are required to simulate representative irrigation frequencies and applied water amounts which are used to calculate total depth of evaporation per wetting event.

Information about soil collected by the National Cooperative Soil Survey, which is published for natural resource planning and management in the Soil Survey Geographic (SSURGO) database (SSURGO, 2014), was the basis for the analysis of soil characteristics. The data are available as maps and tables. The maps outline areas called map units, which represent the most precise spatial delineation of soil characteristics publicly available. Each map unit describes soil characteristics of the components (soil series) including physical properties, interpretations, and productivity.

Soil textures throughout the Study Area were found to consist predominately of loams, which have approximately equal percentages of clay, silt, and sand, and medium intake rates and water holding capacities. The detailed methodology and results for determining the soil characteristics used in the root zone water balance model are described in Section 2.

Weather Data

Producing accurate estimates of ET_c using the crop coefficient – reference crop ET methodology requires accurate and representative weather data (ASCE, 2016). The standardized Penman-Monteith (PM) methodology as described by the Food and Agricultural Organization (Allen et al., 1998), the ASCE Task Committee Report on the Standardized Reference Evapotranspiration Equation (ASCE-EWRI, 2005) and ASCE Manuals and Reports on Engineering Practice No. 70 (ASCE 2016) is a scientifically sound and widely accepted methodology for determining daily reference ET. The PM methodology requires solar radiation, air temperature, vapor pressure and wind speed data. Additionally, the ASCE Task Committee Report and ASCE (2016) recommend methodologies for estimating required inputs to the standardized equation when measured data are unavailable. The task committee report standardizes the ASCE PM methodology for application to a full-cover alfalfa reference (ET_r) and to a clipped cool season grass reference (ET_o). For this work, the clipped cool season grass reference was selected because it is commonly reported by automated weather stations (AWS) and commonly used in New Mexico and Texas.

Among all weather stations considered, the Leyendecker Automatic Weather Station (AWS) was selected to represent the Rincon and Mesilla Valleys, and the Art Ivey AWS was selected to represent the El Paso and Juarez Valleys. **(Figure 1-9)**

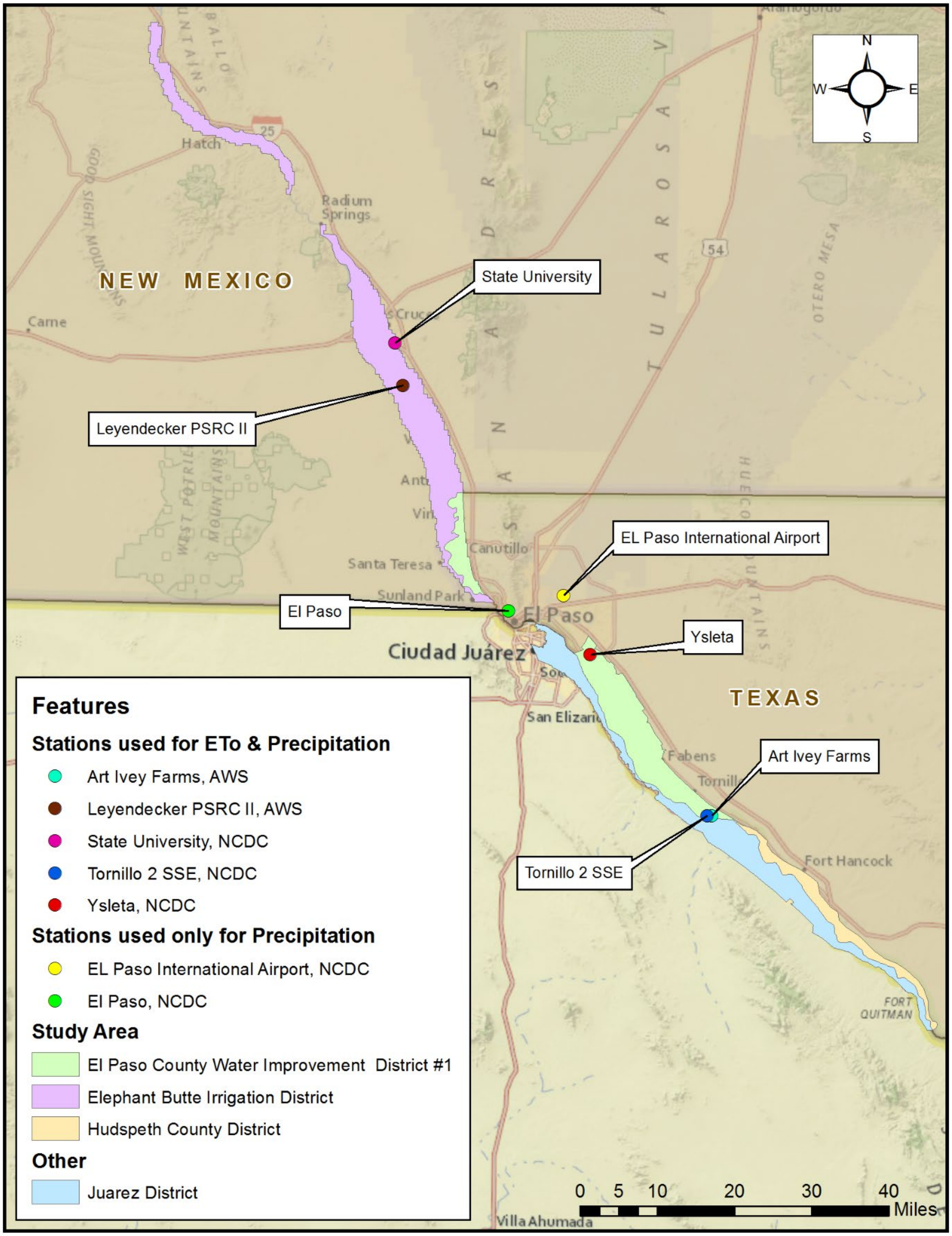


Figure 1-9. Weather Station Used in the Analysis.

The Leyendecker station is located in an agricultural area about 20 miles south of Las Cruces, and was judged to be the most representative station for irrigated areas in New Mexico due to its location interior to and surrounded by agricultural areas with more open areas of low-growing agricultural crops and fewer trees and buildings within 500 feet of the weather station as compared to other AWS stations in the Mesilla Valley. During years when data were unavailable from Leyendecker, the New Mexico State University (NMSU) weather station operated by the National Oceanic and Atmospheric Administration (NOAA) was used.

The Art Ivey station is located approximately 3.75 miles southeast of Tornillo in El Paso County, Texas, and was found to have the most complete record of weather data in the Texas region and relatively extensive areas of agriculture surrounding it. During years when data were unavailable, other stations in the Tornillo and Ysleta areas of El Paso County were used.

Weather data from the selected weather stations were reviewed for missing data, discontinuities in instrument readings (such as those resulting from dust and debris on sensors) and other problems that can affect weather data accuracy. When necessary, data were corrected with estimates of missing data or by replacing inaccurate sensor readings following accepted scientific procedures, as described in Section 3 of this report and following Allen (1996), Allen, et al, (1998), ASCE-EWRI (2005) and ASCE (2016). Hourly weather data obtained from the AWS stations were evaluated using the University of Idaho Ref-ET and QAQC program (Allen 2013). This program, developed by Dr. Richard G. Allen, provides standardized calculation of reference ET and graphical outputs of weather data parameters for analysis and applies quality control (QC) measures according to the guidelines specified in Appendix-D of the ASCE Task Committee Report on the Standardized Reference Evapotranspiration Equation (ASCE-EWRI, 2005).

For the time periods when AWS weather data are not available (before 1985 and 2004, in Rincon and Mesilla, and El Paso Valleys, respectively), standardized recommended methodologies (Allen, et al, 1998; ASCE-EWRI, 2005; and ASCE, 2016) were utilized for estimating solar radiation, vapor pressure, and wind speed and the estimated parameters were used with measured temperature data from the NMSU weather station to calculate ET_o. Over the last 20 years, calculating ET_o utilizing a physically based equation and estimating missing or unmeasured data using tested standardized procedures (Allen, et al, 1998; ASCE-EWRI, 2005; Pereira et al., 2015; ASCE, 2016) has become widely accepted and a consensus has formed among ET estimation professionals that this method is reasonable and technically sound. An inventory of weather stations, quality control of weather data from the stations selected and methodology used to estimate missing parameters are described in Section 3.

Basal Crop Coefficients and Other Crop Data

Producing accurate estimates of ET_c using the crop coefficient – reference crop ET methodology requires basal crop coefficients and other crop data (ASCE, 2016). Other crop data includes crop planting and harvest dates, crop root depths and crop irrigation parameters.

Basal crop coefficients estimate crop transpiration, are used with root zone water balances to account for evaporation from precipitation and irrigation events (ASCE, 2016), and vary with crop development to relate the effects of leaf area and plant growth stage to ET_o. Changes due to increasing leaf area and growth stage are accounted for either by varying the crop coefficient with the plant's age or with other parameters indicative of the plant's growth, such as temperature. Crop coefficients are typically developed by researchers by relating ET_o to measurements of crop water use under nearly ideal growing conditions (good fertility, adequate water supply, good plant health, good management, etc.), or potential ET, which do not necessarily represent actual growing conditions in commercial agriculture. Thus, under commercial growing conditions, crop water use is typically less than estimates based on research-based crop coefficients, especially over large areas, because less than ideal growing conditions typically exist at some locations (Allen et al., 2005a; Burt et al., 2002; and Skaggs and Samani, 2005). To ensure that the crop coefficient-reference crop methodology produced actual ET_c results that are representative of commercial growing conditions in the Study Area, basal crop coefficients were developed based on actual ET_c estimates for 2008 from the satellite-based METRIC™ energy balance model. The 2008 estimates from METRIC represent hundreds of fields over all crop types and thereby quantify variation in ET_c among fields and with location in the Study Area that generally has the effect of reducing average ET_c for commercial growing conditions below pristine research conditions. Development of the local basal crop coefficients used in the ET Demands model to determine total crop water use in the Study Area is described in detail in Section 6.

Energy Balance ET_c Estimates

METRIC is a widely used (Serbina and Miller 2014) and accurate (Allen, et al., 2011) surface energy balance algorithm. A detailed description of METRIC can be found in Allen et al. (2007a, b; 2010). METRIC represents the best available science to locally calibrate crop coefficients to improve crop consumptive use estimates and is a recent advance that is gaining wide acceptance. Many applications of METRIC, both in the western United States (Wyoming, Idaho, Nevada, Colorado and California) and internationally (Australia and Morocco), are summarized in Serbina and Miller (2014). An important advantage of the energy balance methodology is that it inherently accounts for factors that cause actual ET_c under commercial growing conditions to be less than ET_c under ideal conditions (referred to earlier in this report as potential ET_c). METRIC utilizes spectral raster images from the visible, near infrared, and thermal infrared energy spectrum to compute the energy balance resulting in estimates of actual ET_c on a pixel-by-pixel[1] basis. General accuracy of ET_c estimated by METRIC has been estimated to be ±5 to ±15% when applied by expert users (Allen et al., 2011). The 2008 growing season METRIC ET_c results for EBID were used to develop crop coefficients, and results from 2002, 2008 and 2013 growing seasons were used to calibrate the ET Demands model to local conditions within the Study Area. The METRIC methodology and results are documented in four **METRIC Reports**: one each for 2002 and 2013 and one for New Mexico in 2008 and one for Texas and Mexico in 2008.

ET Demands Root Zone Water Balance Model

As described above, a daily root zone water balance is a generally accepted and widely used methodology to estimate the portion of crop water consumption met by precipitation, often referred to as effective precipitation (ASCE, 2016 and ASABE, 2007). A root zone water balance model accounts for inputs to the root zone (irrigation, rain, and capillary rise) and outputs from the root zone (evapotranspiration, runoff, and deep percolation) (**Figure 1-10**). The daily root zone water balance model assumes regular irrigation occurs when required to refill the root zone soil moisture that is depleted by estimated crop evapotranspiration. Rainfall and runoff were modeled in ET Demands based on precipitation data, irrigation frequency, and crop-soil surface characteristics, including slope, vegetation coverage, and soil type. Deep percolation (the infiltration of water into the groundwater

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[1] A single raster element in a computer image that has a constant value across its domain. In Landsat images, a pixel has dimensions of 30 m x 30 m.

system) was modeled based on soil characteristics as well as rainfall and irrigation events at the soil surface.

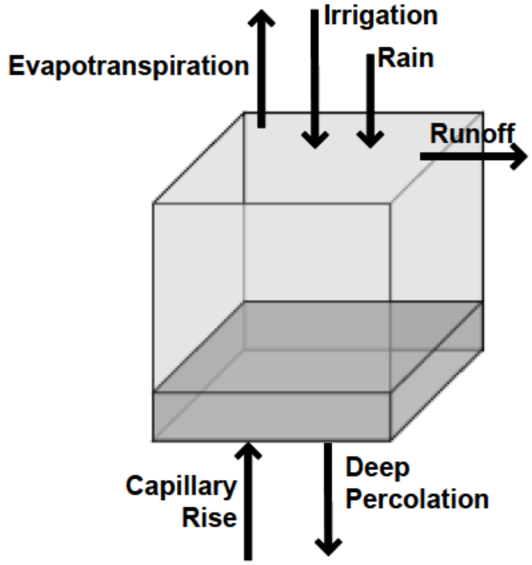

Figure 1-10. ET Demands Model Root Zone Water Balance Following FAO-56 Root Zone Water Balance. Modified from Allen et al. (1998).

The ET Demands model was chosen because it or earlier derivatives has been widely applied to compute consumptive water use (Allen and Robison, 2009 and Allen and Huntington, 2010, and Allen and Huntington, 2015) to study potential effects on agricultural water demands and use associated with climate change (Reclamation, 2015). Another important consideration was the model's use of the dual crop coefficient approach, which uses basal crop coefficients and separate soil evaporation coefficients to more accurately account for evaporation resulting from rainfall and irrigation events, the pattern of which varies from year-to-year. The simulated daily ET_{aw} values for each crop were aggregated into monthly values for each District. The monthly ET_{aw} multiplied by the irrigated area in each District represents the consumptive use of irrigation water under full supply conditions. The ET Demands model provided results for the Study Area for 1938 through 2018. The ET Demands input parameters and calibration results are described in detail in Section 7.

Irrigated Area by Crop

As previously described, the ET_{aw} per acre for each crop is multiplied by the acreage of the crop to produce the ET_{aw} volume by crop. The United States Bureau of Reclamation (Reclamation) has published an annual "Summary Statistics, Water, Land and Related Data" report based on crop census data reported by Reclamation projects (Jachens and Albertson, 1999). Districts receiving water from Reclamation projects were required to complete annual acreage reports on Reclamation Crop and Data Forms 7-316 and 7-2045 summarizing the area that receives surface water from those projects. These Reclamation reports serve as the primary basis for the historical irrigated crop area compilations. However, generally, these reports only account for cropping on lands receiving water from Reclamation projects. Thus, crops irrigated solely with groundwater are typically not included in these reports. To ensure that all irrigated crop area in the Study Area is accounted for, regardless of irrigation water source, a remote sensing application was developed and applied by INTERA. The application uses the Normalized Difference Vegetation Index (NDVI) at selected times during the irrigation season to identify irrigated lands (Intera, 2014). NDVI is a commonly used indicator of vegetation health and vigor, and establishing threshold values of NDVI and their trends during the growing season to differentiate between irrigated and non-irrigated lands in arid environments has been shown to be scientifically sound and is generally accepted (Melton, et al. 2015; Jordan and Barroll, 2013; and Clark et al., 2014). Validation of this remote sensing-based process through comparison with the results of a ground-based field survey conducted in 2016 is summarized in Section 4.

Nine crops representing about 95 percent of the area irrigated in the Study Area were selected to represent crop groups. Each crop reported in the area was assigned to one of the nine crop groups, so that 100 percent of the irrigated area in the Study Area was evaluated every year. Assignments of crops to crop groups was based on similarity of water use characteristics. The methodology used to develop total irrigated area and the area of each of the nine crop groups in each year are described in detail in Section 5.

Opinions

This section summarizes the findings of analyses supporting consumptive use determination under full supply conditions between 1938 and 2018 for the Study Area. Consumptive use of irrigation water is approximately equivalent to ET_{aw} and varies over time in the Study Area due primarily to variability in water supply conditions and crop types within the districts.

To achieve accurate ET_{aw} estimates, the ET Demands root zone model was used to compute a daily water balance tracing all inflows and outflows from the root zone. This model was selected because it accurately calculates the consumptive water use (Allen and Robison, 2009 and Allen and Huntington, 2010, and Allen and Huntington, 2015). The model has also been used to study potential effects on agricultural water demands and use associated with climate change (Reclamation, 2015).

The ET Demands model requires inputs of irrigation, precipitation, soil parameters, and ET of a reference surface (ET_o in this Study, representing a clipped cool season grass reference crop). The model then computes rainfall and runoff based on precipitation data, irrigation frequency, and crop-soil surface characteristics, including slope, vegetation coverage, and soil type; deep percolation based on soil characteristics, as well as rainfall and irrigation events at the soil surface; and ET_c for specific crops in the Study Area. To calculate ET_c and apportion it into separate ET_{pr} and ET_{aw} components, the model calculates a daily root zone water balance and uses the basal crop coefficient with the widely accepted "crop coefficient – reference crop ET" methodology (Allen, et al., 1998) (ASCE, 2016).

The ET Demands root zone model was developed and calibrated through a multi-step process involving analyses to accurately assign and determine:

- Soils and relevant soil characteristics in the Study Area (Section 2)
- Daily values of reference evapotranspiration and precipitation in the Study Area (Section 3)
- Annual irrigated crop areas in the Study Area (Sections 4 and 5)
- Locally calibrated basal crop coefficients used to estimate actual ET_c in the Study Area (Section 6)
- The ET Demands root zone model used to apportion ET_c between ET_{pr} and ET_{aw} (Section 7)
- Historical consumptive use estimates for the Study Area (monthly values between 1938 and 2018) (Section 8)

Opinions: Soils and relevant soil characteristics in the Study Area

Soil analyses conducted with information from the Soil Survey Geographic (SSURGO) database (SSURGO, 2014) found similar soil textures within the three US Districts. Loamy soils cover much of the Study Area, accounting for 87-100% of the total area in each US District. Average area-weighted soil parameters were calculated and used to characterize root zone soil in the Study Area (**Table 1-1**). Key parameters of interest include saturated hydraulic conductivity (K_{sat}); a measure of water movement through saturated soil), hydrologic soil group (alphabetical soil classification by Natural Resource Conservation Service identifying soil runoff potential, from lowest potential (A) to highest potential (D)); and available waterholding capacity (AWC; a measure of the potential water volume held in the soil that is available to crops). Although SSURGO soil data are not available for Mexico, the primary factors that determine soil type and soil characteristics – topography, soil parent material, time for soil formation, regional climate, and vegetation – were determined to be similar between Juarez and the US Districts. Thus, the average area weighted values for soil characteristics in the El Paso Valley on the east bank of the Rio Grande were used for the soils in Mexico on the west bank of the Rio Grande. Soils in all regions of the Study Area have similar AWC characteristics and generally lower runoff potential (hydrologic soil groups A and B) with correspondingly higher infiltration potential (K_{sat} greater than 1 in/hr).

Table 1-1. K_{sat}, Hydrologic Soil Group and AWC Inputs to ET Demands for Each Subarea within the Study Area.

Study Area-Subarea	Area (Acres)	K_{sat} (in/hr)	Hydrologic Soil Group	AWC (in/ft)	Area, Percent
Rincon Valley (EBID)	19,311	5.96	A	1.63	10%
Mesilla Valley (EBID and EPCWID)	74,814	4.83	B	1.72	40%
El Paso Valley (EPCWID)	39,924	1.55	B	1.76	22%
El Paso Valley (Hudspeth)	15,144	6.09	A	1.79	8%
Juarez Valley (Mexico)	36,323	2.14	B	1.77	20%
Total	185,517	NA	NA	NA	100%

Opinions: Daily values of reference evapotranspiration and precipitation in the Study Area

Daily precipitation data and reference evapotranspiration for a clipped cool season grass reference crop (ET_o) were developed from representative weather station measurements in the Study Area. Annual precipitation and ET_o data for 1938-2018 are presented in Appendix 3A.

Following visual inspection of all-weather stations in the New Mexico Study Area region, the Leyendecker Automated Weather Station (AWS) was found to be the most representative station for irrigated areas in New Mexico because of its location interior to and surrounded by irrigated agricultural areas and a greater abundance of low growing crops that permitted open flow of wind over the station. This site is located in an agricultural area about 20 miles south of Las Cruces. During years when data were unavailable from Leyendecker AWS, the New Mexico State University (NMSU) weather station data were used.

In Texas, visual inspection and data review determined the Art Ivey Farms AWS site within EPCWID to have the most complete weather data record and to be the most representative station for Texas irrigated areas, also because of its proximity to irrigated agricultural land. The Art Ivey Farms AWS site is located approximately four miles southeast of the town of Tornillo in El Paso County. During years when data were unavailable from Art Ivey Farms AWS, other stations in the Tornillo and Ysleta areas of El Paso County were used.

Quality control and quality assessment protocols were followed, and necessary adjustments were performed for hourly AWS data and daily NOAA data. Generally, some solar radiation records at both the Leyendecker and Art Ivey AWS sites were found to be artificially low and required adjustment for consistency with computed clear sky envelopes of solar radiation on cloudless days (R_{so}; the maximum R_s value that should be achieved on cloud-free days). The air temperature and humidity data at both sites were found to be consistent and did not need adjustment. Some periods of consistently low wind speed data required minor adjustment for consistency with nearby station data during short periods at both sites.

For the time periods when AWS weather data were not available, the standardized recommended methods (Allen, et al, 1998 and ASCE-EWRI, 2005) for estimating solar radiation, dewpoint temperature, and wind speed were utilized. These estimates resulted in ET_o values that were not significantly different from ET_o calculated from measured parameters (within 3 percent).

Following quality control and quality assessment of all-weather data, daily precipitation and ET_o timeseries were developed as inputs for the ET Demands model. The average annual ET_o for 1938 through 2018 was 63.2 (1,604 mm) and 63.5 inches (1,614 mm) in New Mexico and Texas, respectively. The 81-year average annual precipitation from 1938 to 2018 was 8.88 (226 mm) and 8.67 inches (220 mm) in New Mexico and Texas, respectively.

Opinions: Validation of Remote Sensing Based Processes Used to Classify Irrigation Status and Crop Type

The 2016 NMOSE survey found 21,196 acres out of 24,295 acres surveyed, or about 87.2 percent, to be irrigated in 2016. In comparison, the NDVI methodology to identify irrigated fields found 20,705 acres out of 24,295 acres observed, or 85.2 percent, to be irrigated. The NDVI methodology under estimated the irrigated area by two percent. This is well within the expected confidence range of the respective methodologies (generally plus or minus 5 percent). Therefore, no adjustment was made to these estimates based on the 2016 verification study.

The CDL methodology to identify irrigated fields underestimated the irrigated area by 2.3 percent, finding 20,590 acres out of 24,295 acres, surveyed, or 84.7 percent, to be irrigated and is also within the expected confidence range of these methodologies.

The overall accuracy of the 2016 CDL methodology to identify the nine crop groups adjusted based on the best estimate of the proportion of crop areas in the Study Area was 85.5 percent with a 95 percent confidence interval of plus or minus one percent.

Opinions: Development of Annual Irrigated Crop Areas for 1938 through 2018

Over time, there has been an overall decline in irrigated acreage in the Study Area with some variability among the Districts, as summarized below.

For example, EBID irrigated area with access to surface water averaged about 72,800 acres from 2004 through 2018 and has been generally declining since the early 1950s, when it averaged 93,100 acres.

Irrigated area within and in the vicinity of EBID with access to groundwater only (no access to surface water) averaged about 4,700 acres from 2004 through 2018 and in recent years has been generally declining after a peak at about 5,500 acres in 2000.

EPCWID irrigated area averaged about 36,400 acres from 2004 through 2018 and has been generally declining since the early 1950s, when it averaged 66,700 acres.

Hudspeth irrigated area averaged about 9,500 acres from 2004 through 2016 compared to irrigated areas between about 14,000 and 16,000 acres in the 80's and 90's.

Juarez irrigated area averaged about 33,800 acres from 2004 through 2018 and has been generally declining in recent years since its peak of 54,000 in 1986.

Since the early 1950s, the predominant crop has generally shifted from cotton to pecans in both EBID and EPCWID.

In EBID, the alfalfa crop acreage has remained about the same while it has decreased in EPCWID.

In Hudspeth, the main crop has remained cotton with some decrease in alfalfa since the early 1950s.

The main crop in Juarez remains cotton with an increase in alfalfa acreage from the early 1950s to the 1980s. Pecan area has been increasing in recent years, but still is considerably less than cotton and alfalfa.

Opinions: Development and Local Calibration of Basal Crop Coefficients

The K_{cb} curves are parameterized to represent average local conditions and stress levels across the entire population of fields in the Study Area. While these K_{cb} curves have the same general shape as published "book", or potential, K_{cb} curves for "pristine" crops, it is important to note that many individual fields have ET rates that vary from the "book" K_{cb}. These K_{cb} curves reflect influences of incidental water stress, wetness of exposed soil, and the resulting transpiration and evaporation rates. These curves better represent local conditions than "book" K_{cb} curves.

Basal crop coefficients can be developed from METRIC-derived crop coefficients and NDVI values that are based on standard procedures and that are reflective of the level of ET of applied water obtained through local irrigation and crop management practices. These basal crop coefficients can be used with a calibrated ET Demands root zone model to estimate ET of applied water. These basal crop coefficients used together with a calibrated ET Demands model and climate data result in reliable full supply ET_c and ET_{aw} estimates for all year types including years with less than full supply, ever though, the actual ET_c and ET_{aw} may be less than the full supply ET_c and ET_{aw} for years with less than a full water supply. That reduction is made in the farm water budget model.

Opinions: Local Calibration and Results of ET Demands

When used in the ET Demands root zone water balance model, locally calibrated basal crop coefficients based on 2008 METRIC actual ET for EBID yield and expected estimates of Study Area ET_c and ET_{aw} under "full supply" conditions.

Over the entire Study Area, ET Demands ET_c estimates are one, four and eight percent higher than the METRIC ET_c results in 2002, 2008 and 2013, respectively. All years are within the 10 percent calibration objective with the limited supply year of 2013 having the greatest difference.

Five of the six subareas had ET Demands total ET_c estimates within plus or minus three percent of the METRIC total ET_c estimates in 2002, the 24th consecutive full supply year. The one area (irrigated lands in New Mexico with access to groundwater only) that was not within three percent had higher ET Demands total ET_c compared to METRIC ET_c, which was found to be related to less intensive agricultural management practiced in this area. Overall, the ET Demands total ET_c estimates (representing ET_c under full supply) are higher than the METRIC total ET_c estimates (representing actual ET_c) in all areas in 2013 (a limited supply year), reflecting the expected changes in consumptive use with changes in water supply. ET Demands ET_c estimates are slightly higher in all but one area in 2008 and in all but two areas in 2002, which were full supply years. The ET Demands estimates were within three percent of the METRIC ET estimates in all areas and years having ET Demands total ET_c estimates were lower than the METRIC total ET_c estimates.

In New Mexico, the actual ET_c estimated for full supply conditions varied in its comparison to METRIC-derived estimates of actual ET_c, depending on the water sources available. ET Demands estimated total ET_c for EBID irrigated lands having access to surface water and groundwater to average 3.3 percent higher than the METRIC total actual ET_c estimates for 2002, 2008 and 2013. For the irrigated lands in New Mexico having access to groundwater only, the ET Demands total ET_c averaged 33 percent higher than the METRIC total actual ET_c estimates for 2002, 2008 and 2013. Reasons for the departure between ET Demands ET_c and METRIC actual ET_c are apparently due to suboptimal agricultural and irrigation practices in the groundwater only area.

The ET Demands total ET_c for the EPCWID irrigated lands in the Mesilla Valley averaged nine percent higher than the METRIC total actual ET_c estimates for 2002, 2008 and 2013. The ET Demands total ET_c for the EPCWID irrigated lands in the El Paso Valley averaged 1.7 percent more than the METRIC total actual ET_c estimates for 2002, 2008, and 2013.

In Hudspeth, the ET Demands total ET_c for the irrigated lands averaged 18.3 percent higher than the METRIC total actual ET_c estimates for 2002, 2008 and 2013.

In Juarez, the ET Demands total ET_c for irrigated lands averaged 3.7 percent higher than the METRIC total actual ET_c estimates for 2002, 2008 and 2013.

The crop coefficients used to calculate ET_c in the ET Demands model have been developed based on best practices using locally-derived calibration to the 2008 METRIC results. When the crop coefficients are used to estimate ET_c representing full water supply for 2002 and 2013, the differences between the ET Demands results and METRIC results are slightly greater than those found in 2008, but are well within generally accepted ET modeling results. Thus, the comparisons with METRIC results demonstrate that the full supply ET_c estimates developed using ET Demands and locally calibrated crop coefficients are reproducible and can be relied upon for conducting water balance and consumptive use analyses.

Opinions: Historical Consumptive Use Estimates

A reduction of five percent applied to the alfalfa and cotton ET_{aw} for the 1938 to 1953 period, reducing linearly from 1954 to zero reduction in 1970 is reasonable to accurately account for historical improvements in agricultural practices that include plant density and yield, and that have impacted ET_{aw}. ET_{aw} from 1970 through 2018 does not require adjustment.

Opinions: Irrigation Consumptive Use Coefficient

The ICUC estimates developed here and listed in **Table 1-2** and **Table 9A-1** are district-wide, annual values expressing consumption of irrigation water given irrigation performance when surface water supply is limiting. These average values reflect a large variability across the many fields of the Study Area. Notably, under conditions of limited surface water supply, growers apply additional management actions that may increase on-farm efficiencies that are reflected in increased ICUC values. Thus, in years having sufficient water supplies, the actual district-wide ICUC is less than the ICUC estimates described in this report. In addition, ICUC has changed over time with changes in on-farm practices. The main changes noted in the Study Area have been improved land leveling technologies and lining of head ditches. These on-farm improvements are reflected in the adjustments to ICUC estimates for earlier years.

Table 1-2. ICUC Values for Each Irrigation Unit for 1938 through 2018.

Years	EBID, EPCWID and Hudspeth	Comment
1984 to 2018	76%	Calculation of ICUC is based on METRIC and ET Demands results and reported farm deliveries and groundwater pumping in EBID
1983	75%	One percent per year increase in ICUC as fields are laser leveled over a five-year period
1982	74%	
1981	73%	
1980	72%	
1955 to 1979	71%	Calculated ICUC minus five percent (laser leveling improvement has not occurred during this period, leveling has been improved and farm ditches lined compared to 1938 through 1950)
1954	70%	One percent per year increase in ICUC due to improved leveling and farm ditch lining over a five-year period
1953	69%	
1952	68%	
1951	67%	
1938 to 1950	66%	Calculated ICUC minus ten percent (five percent for improved leveling and farm ditch lining from 1951 through 1954 and five percent for laser leveling from 1980 through 1983))

Opinions: Bare Ground Evaporation from Groundwater

Bare ground evaporation from groundwater is an important outflow from the groundwater system and depends primarily on climatic demand and depth to groundwater. Evaporation flux curves have been developed to estimate bare ground evaporation from groundwater for groundwater modeling. These curves have a maximum evaporative flux, termed the potential bare ground evaporation from groundwater, that represents the maximum potential bare ground evaporation from groundwater that can occur when groundwater levels are close to the ground surface. The rate and depth to groundwater at which this occurs varies based on climatic demand, precipitation, and soil texture. When the depth to groundwater is below this level, the bare ground evaporation is limited by the rate of capillary rise from the groundwater table to the evaporative layer.

II. Soils and Relevant Soil Characteristics

Purpose

The purpose of this section is to describe the soils and relevant soil characteristics found within the irrigated lands in the Rio Grande Valley from below Caballo Reservoir, New Mexico to Fort Quitman, Texas. Soil infiltration characteristics and available waterholding capacities (AWC) both affect crop consumptive use and are needed in the ET Demands root zone model to estimate evapotranspiration of applied water (ET_{aw}). The standard accepted practice for including soil effects on consumptive use in root zone water balance modeling is to develop crop-soil groups comprised of combinations of the most common crops and soil textures in an irrigated area. This section describes soil characteristics and other related information from published sources available in the public domain for soils in the Study Area and the methods used to determine soil infiltration and AWC for use in the ET Demands root zone model.

Methodology

The soils information assembled and methods for determining soil parameters are described in the following sections.

ET Demands

The primary objective of the ET Demands root zone water balance model is to estimate the ET_{aw} and ET_{pr} components of ET_c. Soil infiltration characteristics and AWC values are used to quantify water availability to crops in the model. Key parameters of interest include saturated hydraulic conductivity (K_{sat}; a measure of water movement through saturated soil) and available waterholding capacity (AWC); a measure of the potential water volume held in the soil that is available to crops).

Specifically, saturated hydraulic conductivity is used to determine a soil's hydrologic soil group – an alphabetical soil classification by the Natural Resource Conservation Service that identifies a group of soils having similar runoff potential under similar precipitation and land cover conditions, from lowest potential (A) to highest potential (D). Based on the hydrologic soil group, a curve number is selected for use with the USDA-NRCS curve number method for estimating precipitation runoff. Soil AWC values are used by the ET Demands model to estimate irrigation schedules, which are then used to estimate evaporation losses from the soil and deep percolation from the root zone (Allen and Robison 2009).

Soil Data

The Soil Survey Geographic Database (SSURGO) contains information about soil in the United States collected by the National Cooperative Soil Survey (NCSS). The NCSS is a nationwide partnership of federal, regional, state, and local agencies and private entities and institutions that cooperatively investigates, inventories, documents, classifies, interprets, disseminates, and publishes information about soils. The United States Department of Agriculture-Natural Resources Conservation Service (USDA-NRCS), formerly known as the Soil Conservation Service (SCS), organizes the NCSS and publishes scientifically sound and accepted standards for conducting soil surveys and classifying soils.

The database is available on the internet (SSURGO, 2014). Soils information is available for most areas in the United States including New Mexico and Texas. The information in the database was gathered by physical land and soil observance and collecting and analyzing soil samples (SSURGO, 2014). The database contains information on soil characteristics that was initially provided in bound hard copy soil survey publications. The soil maps are used in natural resource planning and management activities. Information available from the database includes soil infiltration characteristics, AWC, and other data necessary for plant consumptive use analyses and other water resource engineering applications.

The SSURGO database contains scientifically accepted and technically sound information on soils within the Study Area in New Mexico and Texas. The information is available as tables or as maps. Areas of soils with similar characteristics are displayed on the maps and are called map units. Each map unit is an area comprised of similar classes of soils present at the surface and within specific depth layers. The soil bulk density and the percentage of sand, clay and organic matter were obtained from the SSURGO database for each soil map unit within the Study Area. Based on the percentage of sand and clay, USDA textural classes were assigned to each soil map unit. Soils data for the Study Area in Mexico are not available in the SSURGO database.

The saturated hydraulic conductivity (K_{sat}) and AWC values obtained from the SSURGO database for each layer of each map unit were used to develop soil infiltration and AWC parameters, respectively, for each soil texture class. The procedures used to estimate these soil parameters are described in the next section.

Soil Infiltration and AWC Estimates

The distribution of soil particle size in the soil is an important factor governing soil infiltration and AWC (Soil Survey, 1993). Infiltration is defined as "the downward entry of water through the soil surface into the soil" (ASABE, 2007). Soil texture, a parameter that affects the soil infiltration rate, is defined by the weighted proportion of particles less than two millimeters in diameter. Ranging in size from largest to smallest, the three classes of particles are called "sand", "silt" and "clay". Additionally, soils are often grouped into broader classes of texture referred to generally as "sandy", "loamy" and "clayey" soils (Soil Survey, 1993). Sandy and clayey soils have sand and clay, respectively, as the predominant particles. Loamy soils have a relatively even mixture of sand, silt and clay or predominantly silt particles. Sandy, loamy and clayey soils are also commonly called coarse, medium and fine soils, respectively. Generally, sandy soils have the lowest AWC and highest K_{sat} because the coarse grains cannot be packed closely together leaving relatively large, well connected spaces that do not retain water, allowing water to flow through and drain under the force of gravity to the water table. Loamy soils have the highest AWC and lower K_{sat} because the medium size grains contain spaces for water, but these spaces are not as well connected as they are in the coarse soils. Thus, water cannot drain as quickly through the spaces. Compared to sandy and loamy soils, clayey soils have smaller spaces between particles and the spaces are the least connected. Therefore, the fine soils have the slowest water movement. Because the smaller spaces hold on to the water more tightly than loamy soils, clayey soils have a slightly lower AWC than many loamy soils.

To determine ET_{aw}, it is necessary to estimate the amount of precipitation that contributes to evapotranspiration (ET). This requires estimates of the total amount of precipitation, the amount that runs off the land and is not captured within the soil moisture profile, and the amount that is stored in the root zone and used to satisfy crop ET. To estimate the amount of precipitation that runs off, information about the soil's infiltration characteristic is used to determine the hydrologic soil group. To estimate the amount of precipitation that is stored in the soil, the soil's AWC is needed. The following paragraphs describe how these soil parameters are developed from the SSURGO database.

Determine Area-weighted Ksat

The hydrologic soil group is determined by the infiltration rate of the surface layer of the soil (NEH, 2009). SSURGO provides information on infiltration rates as low and high values of K_{sat} for each soil layer comprising a map unit. The low and high values of K_{sat} for the surface soil layer were averaged together to obtain a midpoint K_{sat} estimate of infiltration in inches per hour for each map unit. Following the methodology of Allen and Robison (2009), the average K_{sat} values for each map unit were multiplied by 0.85 to adjust for the logarithmic nature of the NRCS permeability ranges. The resulting K_{sat} values for the surface layer of each map unit were averaged, weighted by the areal extent of each map unit, for each of the three general soil textures (sandy, loamy, and clayey), for four subareas of the Study Area (the Rincon and Mesilla Valleys, the area of EPCWID in the El Paso Valley and the area of Hudspeth).

Determine Area-weighted AWC

For the AWC, a depth-weighted average is calculated for each map unit. First, the published minimum and maximum AWC for each soil layer comprising a map unit from SSURGO are averaged. Next, using the average AWC for each layer of a map unit, a weighted average was calculated based on each reported layer thickness down to 48 inches. A depth of 48 inches was selected as a reasonable maximum depth to use for the determination of AWC because it is near the midpoint of range of maximum effective root depths for the crops in the Study Area, which range from 31 to 71 inches. Additionally, the SSURGO AWC information was often not available for layers deeper than 48 inches for this area. So, if a layer extended below 48 inches, only the thickness above 48 inches was used in the calculations. For map units having depths less than 48 inches, the maximum published soil depth was used. The result is a weighted average AWC for each map unit. The resulting AWC values for each map unit were averaged, weighted by the areal extent of each map unit, for each of the three general soil textures, for four subareas of the Study Area (the Rincon and Mesilla Valleys, the area of EPCWID in the El Paso Valley and the area of Hudspeth). The resulting area averaged AWC values for the top 48 inches are used together with the maximum effective root depth for the crop to calculate the available water that can be stored in the root zone for each crop regardless of the crop's root zone depth.

Results

Soil Textures by Crop

Tables 2-1, 2-2 and 2-3 summarize the general soil texture groupings (loamy, sandy and clayey soils) of USDA soil texture classes by crop in EBID, EPCWID and Hudspeth, respectively. Loamy, sandy and clayey soils comprise 88, nine and three percent of the irrigated area in EBID, respectively (**Table 2-1**). In EPCWID, loamy, clayey and sandy underlie 88, 11 and one percent of the irrigated area, respectively (**Table 2-2**). In Hudspeth, with the exception of a few small areas of sandy soils that represent statistically negligible acreage, the irrigated area is comprised of loamy soils (**Table 2-3**). Soil textures in all three districts are predominately loamy, containing relatively equal percentages of clay, silt and sand. Detailed soil texture data were not available for the area in Mexico. Approximately 88 percent of all crops are on loamy soils with the remaining crop areas dispersed between sandy and clayey in the same general proportion that the soils are found in the Study Area. In other words, no crop is primarily grown on a single soil texture. Given the distributed nature of crops across soil textures and the predominance of loamy soils, it is reasonable to calculate and to use weighted averages of K_{sat} (infiltration rate) and AWC with all crops within geographically defined sub areas of the Study Area.

Table 2-1. General Soil Texture Areas by Crop* in Elephant Butte Irrigation District Areas with Access to Surface Water.

General Soil Texture	Cotton	Pecans	Alfalfa Hay	Chile (Peppers)	Corn, Sweet Corn, and Silage	Onions	Wheat and Small Grains	Miscellaneous Vegetables	Irrigated Pasture	Total, acres	Total, Percent
Loamy	10,487	23,823	14,483	3,503	5,735	793	752	486	5,527	65,589	88%
Sandy	651	2,653	1,804	412	448	58	19	49	668	6,762	9%
Clayey	459	748	140	95	225	0	19	24	243	1,953	3%
Total	11,596	27,224	16,427	4,011	6,407	851	789	559	6,439	74,303	100%

*The crop in each field with access to surface water for 2008 was determined from a ground-based crop survey for EBID (NMOSE, 2011).

Table 2-2. General Soil Texture Areas by Crop* in El Paso County Water Improvement District #1.

General Soil Texture	Cotton	Pecans	Alfalfa Hay	Chile (Peppers)	Corn, Sweet Corn, and Silage	Onions	Wheat and Small Grains	Miscellaneous Vegetables	Irrigated Pasture	Total, acres	Total, Percent
Loamy	12,988	9,137	2,621	0	93	99	4,630	42	2,173	31,783	88%
Clayey	1,832	570	116	0	47	38	1,076	0	202	3,881	11%
Sandy	73	88	25	0	0	0	20	0	48	253	1%
Total	14,893	9,795	2,763	0	140	137	5,725	42	2,422	35,918	100%

*The crop in each field for 2008 was determined from the geospatial crop data layer (CDL) from the United States Department of Agriculture National Agricultural Statistics Service (USDA NASS, 2014) for EPCWID.

Table 2-3. General Soil Texture Areas by Crop* in Hudspeth County Conservation & Reclamation District #1.

General Soil Texture	Cotton	Pecans	Alfalfa Hay	Chile (Peppers)	Corn, Sweet Corn, and Silage	Onions	Wheat and Small Grains	Miscellaneous Vegetables	Irrigated Pasture	Total, acres	Total, Percent
Loamy	9,726	73	1,014	0	332	0	835	0	440	12,420	100%
Sandy	14	0	0	0	1	0	0	0	2	17	0%
Clayey	0	0	0	0	0	0	0	0	0	0	0%
Total	9,739	73	1,014	0	334	0	835	0	442	12,436	100%

*The crop in each field for 2008 was determined from the geospatial crop data layer (CDL) from the United States Department of Agriculture National Agricultural Statistics Service (USDA NASS, 2014) for Hudspeth.

Soil Parameters by Subarea

The soil parameters reported by SSURGO for each soil layer in each map unit and averaged as described in the methodology section are reported by general soil texture for four subareas of the Study Area in **Tables 2-4, 2-5, 2-6, and 2-7**. The weighted average Ksat and AWC values in these tables were computed using specific soil textures (for example, clay loam) based on spatial and depth distributions. The irrigated area underlain by loamy soils varied from 87 percent in the Rincon Valley to 99 percent in Hudspeth. The area weighted average of K_{sat} ranged from 1.55 inches per hour in EPCWID in the El Paso Valley to 6.09 inches per hour in Hudspeth in the El Paso Valley. The AWC area weighted average value varied from 1.63 inches per foot in the Rincon to 1.79 inches per foot in Hudspeth.

Table 2-4. SSURGO Soil Characteristics and Parameters by General Soil Texture in the Rincon Valley area (Elephant Butte Irrigation District).

General Soil Texture	Area (Acres)	K_{sat} (in/hr)	AWC (in/ft)	Area, Percent
Loamy	16,870	4.61	1.72	87%
Sandy	2,136	17.40	0.98	11%
Clayey	305	0.22	1.62	2%
Total/weighted average	19,311	5.96	1.63	100%

Table 2-5. SSURGO Soil Characteristics and Parameters by General Soil Texture in the Mesilla Valley (Elephant Butte Irrigation District and El Paso County Water Improvement District).

General Soil Texture	Area (Acres)	K_{sat} (in/hr)	AWC (in/ft)	Area, Percent
Loamy	66,036	3.51	1.79	88%
Sandy	5,997	21.52	0.93	8%
Clayey	2,782	0.19	1.63	4%
Total/weighted average	74,814	4.83	1.72	100%

Table 2-6. SSURGO Soil Characteristics and Parameters by General Soil Texture in the El Paso Valley (El Paso County Water Improvement District).

General Soil Texture	Area (Acres)	K_{sat} (in/hr)	AWC (in/ft)	Area, Percent
Loamy*	35,433	1.54	1.77	89%
Sandy	321	22.05	0.94	1%
Clayey	4,171	0.08	1.68	10%
Total/weighted average	39,924	1.55	1.76	100%

*For loamy soil, Ksat typically varies from 0.40 in/hr to 4.00 in/hr (USDA-NRCS).

Table 2-7. SSURGO Soil Characteristics and Parameters by General Soil Texture in the El Paso Valley (Hudspeth County Water Improvement District).

General Soil Texture	Area (Acres)	K_{sat} (in/hr)	AWC (in/ft)	Area, Percent
Loamy	15,044	5.96	1.80	99%
Sandy	100	26.30	0.54	1%
Clayey	0	NA	NA	0%
Total/weighted average	15,144	6.09	1.79	100%

The National Engineering Handbook (NEH), Chapter 7, (2009) provides a table for selecting a hydrologic soil group for use with the USDA-NRCS curve number method based on soil depths to a water impermeable layer and K_{sat} values. With soil depths to a water impermeable layer greater than 40 inches and an area weighted average K_{sat} greater than 1.42 inches per hour and less than 5.67 inches per hour in the Mesilla Valley and the area of EPCWID in the El Paso Valley, hydrologic soil group B was selected as the input to ET Demands for these areas. For the Rincon Valley and the area of Hudspeth in the El Paso Valley, with an area-weighted average Ksat greater than 5.67 inches per hour, hydrologic soil group A was selected.

Soil Parameters in Mexico

As previously stated, SSURGO soil data are not available for Mexico. Topography, soil parent material, time for soil formation, regional climate and vegetation are the primary factors that determine the type and characteristics of soils in an area (Soil Survey Staff, 1993). In Mexico, these factors are similar to the factors in the US Districts. Additionally, the average area-weighted K_{sat} and AWC values for soils on the east and west sides of the Rio Grande in the Mesilla Valley south of Las Cruces were compared and found to be similar (**Tables 2-8 and 2-9**). Thus, the average area weighted values for the soils in the El Paso Valley on the east bank of the Rio Grande (**Table 2-10**) will be used to represent the soils in Mexico on the west bank of the Rio Grande.

Table 2-8. SSURGO Soil Characteristics and Parameters by General Soil Texture in the US Districts in the Mesilla Valley South of Las Cruces on the East Side of the Rio Grande.

General Soil Texture	Area (Acres)	K_{sat} (in/hr)	AWC (in/ft)	Area, Percent
Loamy	13,376	3.96	1.81	88%
Sandy	1,466	18.84	0.91	10%
Clayey	312	0.19	1.63	2%
Total/weighted average	15,154	5.32	1.78	100%

Table 2-9. SSURGO Soil Characteristics and Parameters by General Soil Texture in the US Districts in the Mesilla Valley South of Las Cruces on the West Side of the Rio Grande.

General Soil Texture	Area (Acres)	K_{sat} (in/hr)	AWC (in/ft)	Area, Percent
Loamy	29,781	2.81	1.78	90%
Sandy	1,708	28.81	0.94	5%
Clayey	1,699	0.17	1.64	5%
Total/weighted average	33,188	4.01	1.73	100%

Table 2-10. SSURGO Soil Characteristics and Parameters by General Soil Texture in the El Paso Valley area of El Paso County Water Improvement District and Hudspeth County Water Improvement District for use on the West Bank of the Rio Grande in Juarez Valley in Mexico.

General Soil Texture	Area (Acres)	K_{sat} (in/hr)	AWC (in/ft)	Area, Percent
Loamy	50,477	2.15	1.78	92%
Sandy	421	21.70	0.92	1%
Clayey	4,171	0.08	1.68	8%
Total/weighted average	55,069	2.14	1.77	100%

Opinions

Soil analyses conducted with information from the Soil Survey Geographic (SSURGO) database (SSURGO, 2014) found similar soil textures within the three US Districts. Loamy soils cover much of the Study Area accounting for 87-100% of the total area in each US District. Based on these soil textures, average area-weighted soil parameters were calculated and used to characterize root zone soil in the Study Area (**Table 2-11**). Key parameters of interest include saturated hydraulic conductivity (K_{sat}); (a measure of water movement through saturated soil), hydrologic soil group (alphabetical soil classification by the Natural Resource conservation service identifying soil runoff potential, from lowest potential (A) to highest potential (D)), and available waterholding capacity (AWC, a measure of the potential water volume held in the soil that is available to crops). Although SSURGO soil data are not available for Mexico, the primary factors that determine soil type and soil characteristics—topography, soil parent material, time for soil formation, regional climate, and vegetation – were determined to be similar between Juarez and the US Districts. Thus, the average area weighted values for soil characteristics in the El Paso Valley on the east bank of the Rio Grande were used for the soils in Mexico on the west bank of the Rio Grande. Soils in all regions of the Study Area have similar AWC characteristics and generally lower runoff potential (hydrologic soil groups A and B) with correspondingly higher infiltration potential (K_{sat} greater than 1 in/hr).

Table 2-11. K_{sat}, Hydrologic Soil Group and AWC Inputs to ET Demands for Each Subarea within the Study Area.

Study Area-Subarea	Area (Acres)	K_{sat} (in/hr)	Hydrologic Soil Group	AWC (in/ft)	Area, Percent
Rincon Valley (EBID)	19,311	5.96	A	1.63	10%
Mesilla Valley (EBID and EPCWID)	74,814	4.83	B	1.72	40%
El Paso Valley (EPCWID)	39,924	1.55	B	1.76	22%
El Paso Valley (Hudspeth)	15,144	6.09	A	1.79	8%
Juarez Valley (Mexico)	36,323	2.14	B	1.77	20%
Total	185,517	NA	NA	NA	100%

III. Daily Reference Evapotranspiration and Precipitation

Purpose

The purpose of this section is to describe the development of daily reference evapotranspiration (ET_{ref}) and precipitation values for 1938 through 2018 for use to determine consumptive use of irrigation water in the Study Area. Estimating water depletions resulting from irrigated agriculture requires information on weather and crop areas irrigated.

This section describes the methodology for developing ET_{ref} and precipitation records, the results and the findings.

Methodology

Scientifically sound and widely accepted methods for determining consumptive use of irrigation water utilize daily ET_{ref} determined using the standardized ASCE Penman-Monteith (PM) method as described by the ASCE Task Committee Report on the Standardized Reference Evapotranspiration Equation (ASCE-EWRI, 2005). The PM method requires measurements or best estimates of incoming solar radiation (R_s), air temperature (T_a), relative humidity (RH) and wind speed (W_s) at hourly or daily time steps. The Task Committee Report standardizes the ASCE PM method for application to a full-cover alfalfa reference (ET_r) and to a clipped cool season grass reference (ET_o). The clipped cool season grass reference is widely used throughout the western United States and was selected for this application. Additionally, the Task Committee Report provides recommended methods for estimating required inputs to the standardized equation when measured data are unavailable. The remainder of this section describes an inventory of weather stations and available data, weather data quality control, and the methods used to estimate ET_o.

Weather Data Inventory

Weather data from irrigated areas are needed to develop estimates of consumptive use of irrigation water. Automatic Weather Stations (AWS) provide measurements of R_s, T_a, RH and W_s over hourly or shorter periods that are used to compute ET_o. AWS data are often available from state extension services and weather station networks. Prior to the advent of the AWS, National Oceanic and Atmospheric Administration (NOAA) stations recorded daily minimum and maximum air temperatures and daily precipitation. Data from these NOAA stations are available from the National Centers for Environmental Information (NCEI), formerly the National Climatic Data Center (NCDC).

In recent years, several gridded climate data sets have become available for public use. Daymet and PRISM (Parameter-elevation Relationships on Independent Slopes Model) are two of the more well-known data sets. The gridded estimates are developed by a collection of algorithms that interpolate and extrapolate from daily meteorological observations at available weather stations. Generally, the gridded estimates do not include all necessary parameters to calculate ET_o. PRISM[2] provides estimates for precipitation, daily maximum air temperature, daily minimum air temperature and daily average dewpoint temperature determined by interpolating between weather stations based on the physiographic similarity of the station to the grid cell.

[2] http://www.prism.oregonstate.edu/ accessed on May 18, 2014.

For developing ET_o values to use in determining crop water depletions, it is important that the weather local environment in which the data are collected represents that of irrigated agriculture. This is because calculated potential ET from irrigated areas in arid regions is generally lower than that calculated using weather data collected from surrounding non-irrigated areas (example: weather stations at airports). The evaporation process tends to both cool and humidify the near-surface boundary layer over irrigated fields. This cooling and humidifying effect tends to reduce estimated ET rates, including the reference ET estimate, and should be considered when selecting weather stations and data for calculating reference ET. Weather stations used to develop the gridded data are from both irrigated and non-irrigated areas. For narrow corridors of agriculture like the Rio Grande study area, this is especially true. For this reason, AWS inside the irrigated area are the preferred source for weather data to calculate ET_o for use in determining consumptive use of irrigation water rather than a hybrid type of gridded data set.

A complete inventory of weather stations both inside and near irrigated areas was conducted to select the most appropriate weather station, or stations, for the historical crop water consumptive use analysis. Selected stations were visited and site conditions assessed for additional data quality assurance.

Weather Data Quality Control

Accurate estimation of consumptive use of irrigation water requires accurate and representative weather data. Weather data from each station were reviewed and corrected when necessary, following vetted and accepted, scientific procedures (Allen, et al 1996, Allen, et al, 1998, ASCE-EWRI, 2005 and ASCE, 2016). Hourly data obtained for the AWS stations were quality checked using the University of Idaho Ref-ET and quality analysis and quality control (QAQC) program[3] (Allen 2013). This program provides graphical outputs of weather data parameters for analysis and application of quality control methods according to the guidelines specified in Appendix-D of the ASCE Task Committee Report on the Standardized Reference Evapotranspiration Equation (ASCE-EWRI, 2005). Quality control procedures applied to R_s, T_a, RH and W_s are briefly described in the following sections.

Solar Radiation

Solar radiation data were quality controlled by plotting measured R_s and computed clear sky envelopes of solar radiation on cloudless days (R_{so}) for hourly or daily time steps (Allen, et al 1996, Allen, et al, 1998, ASCE-EWRI, 2005 and ASCE, 2016). Recommended equations for R_{so} that include the influence of sun angle, turbidity, atmospheric thickness, and precipitable water were used (Allen, et al 1996 and ASCE, 2016). The measured R_s is expected to reach the clear sky envelope on cloud-free days. On cloudy or hazy days, the measured R_s will not reach the clear sky envelope. Measured R_s values that consistently fall substantially above or substantially below the curve on what appear to be cloudless days indicate improper calibration or other problems, such as the presence of dust, bird droppings or something else on the sensor. When values for R_s were found to be consistently more than 3% above or below R_{so} on clear days, all values for R_s were adjusted by dividing R_s by the average value of R_s/R_{so} for clear days. Adjustment ratios were calculated at intervals of 60-day groupings for daily data and 30 day periods for hourly data. The values resulting from these adjustments were carefully reviewed to confirm reasonableness of the adjustments.

[3] REF-ET for Windows ver. 3.1.15 downloaded on May 15, 2013 from http://extension.uidaho.edu/kimberly/2013/04/ref-et-reference-evapotranspiration-calculator/

Air Temperature

Air temperature is the simplest weather parameter to measure and the parameter most likely to be of high quality (Allen, et al 1996, Allen, et al, 1998, ASCE-EWRI, 2005 and ASCE, 2016). Nevertheless, daily maximum and minimum air temperatures were plotted together vs. time, and extreme values were compared against historical extremes. Temperatures that consistently exceed the recorded extremes for a region may indicate a problem with the sensor.

Relative Humidity

Daily maximum and minimum relative humidity values were plotted and examined for values chronically lower than five to ten percent and values that were consistently over 100 percent (Allen, et al 1996, Allen, et al, 1998, ASCE-EWRI, 2005 and ASCE, 2016). Additionally, relative humidity was checked on days having recorded rainfall to confirm that the measured maximum RH values approached 90 to 100 percent. Where necessary, reasonable adjustments such as setting all values above 100 percent equal to 100 percent were made.

Wind Speed

Wind speed records were plotted and visually inspected for consistently low wind speed values (Allen, et al 1996, Allen, et al, 1998, ASCE-EWRI, 2005 and ASCE, 2016). Low wind speeds can indicate dirty or worn anemometer bearings that precede total failure of the anemometer. Any period of more than thirty days having wind speeds below 1.0 meters per second was compared to available nearby stations and, if the wind speed at the nearby station did not indicate a similar period of unusually low wind speeds, wind speed data were adjusted using ratios that were based on the nearby station.

ET_o Estimates

Over the last 20 years, it has become widely accepted, and has become a consensus within the ET estimation community, that utilizing a physically based equation with estimation of missing or unmeasured data using tested standardized procedures (Allen, et al, 1998 and ASCE-EWRI, 2005) is technically sound. For the time periods when AWS weather data were not available, including the historical periods back to year 1938, the standardized recommended methods (Allen, et al, 1998 and ASCE-EWRI, 2005) for estimating solar radiation, dewpoint temperature, and wind speed were utilized as described below.

Solar Radiation

The standardized procedures recommended by FAO-56 (Allen et al, 1998) and ASCE-EWRI (2005) estimate solar radiation from daily minimum and maximum air temperatures using an equation such as the Hargreaves-Samani (1982) equation:

$$R_s=0.16*(T_{max}-T_{min})^{0.5}\ R_a \qquad \textbf{(Eq. 3-1)}$$

Where R_s is estimated daily solar radiation, MJ m^{-2} d^{-1}, R_a is exoatmospheric radiation (also known as extraterrestrial radiation), MJ m^{-2} d^{-1}, T_{max} is the daily maximum air temperature, ^oC, T_{min} is the daily minimum air temperature, ^oC. R_s estimated by **Equation 3-1** must be limited to less than or equal to the value of R_s that is expected to occur under clear sky conditions.

ASCE (2016) also recommends the solar radiation estimation procedure developed by Thornton and Running (1999) for estimating daily solar radiation across the United States.

$$R_s= R_{so} *\{1-0.9*exp[-B*(T_{max}-T_{min})^{1.5}]\} \qquad \textbf{(Eq. 3-2)}$$

where R_{so} is theoretical solar radiation on a clear day, MJ m^{-2} d^{-1}, B is an empirical fitting coefficient, T_{max} is the daily maximum air temperature, ^oC, T_{min} is the daily minimum air temperature, ^oC. The Thornton-Running method uses a $T_{max} – T_{min}$ technique similar to the Hargreaves-Samani method, but with a differently shaped function of T_{max} and T_{min} that is automatically asymptotic to the R_{so} curve so that no post-clipping of R_s is required. Thornton-Running (1999) presented a "universal" function for B for use across the U.S.:

$$B_{T\text{-}R}= 0.031 + 0.201*exp[-0.185*(\Delta T_{month})$$ (**Eq. 3-3**)

where the subscript "T-R" indicates the use of the "universal" function for B for use across the U.S and ΔT_{month} is the difference in long term average values for T_{max} and T_{min} on a monthly basis. One value of ΔT_{month} is required for each month for each location of application.

Root mean square error (RMSE) is often used to evaluate how closely estimates compare with measured data. For this study, the RMSE was used to select the method for estimating solar radiation when measured solar radiation data were not available. The RMSE of the Thornton-Running method and the Hargreaves-Samani equation were calculated for the monthly and daily time periods that Ysleta and Tornillo temperature data overlaps with Art Ivey measured solar radiation. The equation with the lowest RMSE (i.e. providing estimates that are closest to measured data) was selected to estimate the solar radiation during the time period when measurements were not available.

Dewpoint Temperature

The dewpoint temperature, T_{dew}, is defined as the temperature at which air, when cooled, becomes saturated with water vapor, and condensation occurs, forming dew. When the air temperature is at the dewpoint, the relative humidity (RH) is, by definition, 100 percent. Because the Ysleta and the Tornillo NCEI weather stations measure only T_{max}, T_{min} and precipitation, the dewpoint temperature for these stations was estimated according to the FAO 56 (Allen et al, 1998), ASCE-EWRI (2005) and ASCE (2016) standard procedures by applying monthly offsets between daily minimum air temperature and dewpoint temperature developed from analysis of local AWS weather data sets.

The Texas ET network provided hourly relative humidity for the Art Ivey AWS for years 2004 and 2006 to 2012. To determine the offset, K_o, for calculating dewpoint temperature from the minimum temperature (**Equation 3-4**), the dewpoint temperature was computed based on daily maximum relative humidity using equations 37, 41 and D.7 from ASCE-EWRI (2005) (**Equations 3-5, 3-6 and 3-7** below).

$$T_{dew}=T_{min} - K_o$$ (**Eq.3-4**)

with K_o determined on a monthly basis during the period of weather data overlap as:

$$e_s=0.6108exp((17.27*T_{min})/(T_{min}+237.7))$$ (**Eq. 3-5**)

$$e_a=(RH_{max}/100)*e_s$$ (**Eq. 3-6**)

$$T_{dew} =((116.91+237.3*ln(e_a))/(16.78-ln(e_a))$$ (**Eq. 3-7**)

$$K_o= T_{min} - T_{dew}$$ (**Eq. 3-8**)

where e_s is the saturation vapor pressure in kPa, T is the temperature in ^oC, e_a is the actual vapor pressure in kPa and RH_{max} is the daily maximum relative humidity in percent. Daily values for K_o were averaged over each month to develop a table of twelve-monthly values as recommended by ASCE (2016). The use of the RH_{max} and T_{min} pairing in **Equations 3-5 and 3-6** is recommended by ASCE-EWRI (2005) and ASCE (2016). Because the Ysleta NOAA station was surrounded by urban areas during the time of the overlap period, 2004 to 2009, with the Art Ivey AWS station, the Tornillo NOAA station was used to determine the K_o offset.

Wind Speed

Wind speed was estimated for each NOAA station by using the mean monthly values for wind speed developed from nearby AWS stations in Texas and New Mexico, respectively as recommended by the standardized methods (Allen et al., 1998, ASCE-EWRI, 2005 and ASCE, 2016).

ET_o Variance with Estimated Weather Parameters

When ET_o is calculated with some weather parameters estimated, the variance of the resulting population may be less than that of the true underlying population. For example, wind speeds vary from day to day, but the wind speed estimates used here are mean monthly values, as previously described. This may result in reduced variation in the ET_o estimates (Allen et al., 1998).

To assess the impact of estimating solar radiation, dewpoint temperature and wind speed, the ET_o calculated from these estimated weather data were compared to the ET_o calculated using the full suite of measured weather parameters from the nearby AWS station.

Results

This section describes the results of an inventory of weather stations and available data, weather data quality control, and ET_o estimates.

Weather Station Inventory

In New Mexico, an evaluation of weather stations by Allen (2009) determined the Leyendecker station, located in an agricultural area south of Las Cruces, to be the most representative station for the New Mexico irrigated areas. In large irrigated agricultural areas, weather data from within the irrigated area is the preferred data source as temperature and humidity are both influenced by evapotranspiration (Allen et al., 1998, and ASCE, 2016). Following visual inspection and comparison with other weather stations, Leyendecker was judged to be most acceptable for calculating ET_o rates that are representative of agricultural consumptive use of irrigation water due to its location interior to and surrounded by agricultural areas and with more areas of open fetch in the weather station vicinity than AWS stations nearer to Las Cruces, for better air flow.

The Leyendecker AWS is located about 20 miles south of Las Cruces and started collecting data on January 1, 1985. Before this, the State University, NCDC, (or NMSU) station provided the most suitable record. That station began collecting temperature and precipitation data in 1896 (as the Agricultural College Station) and was moved to its present location on the NMSU campus on the edge of Las Cruces in 1959. The NMSU station was used for the years before the Leyendecker station was operating and for two years (1991 and 1992) that Leyendecker data were not available. **Figure 3-1** shows the location of the weather stations selected in the Study Area. **Table 3-1** lists the stations and time periods used for the New Mexico weather data.

Table 3-1. New Mexico Weather Data Time Series Summary for the period 1936 – 2018.

Weather Station	Start Date	End Date	Comment
NMSU	Jan. 1, 1936	Dec. 31, 1984	NOAA
Leyendecker	Jan. 1, 1985	Dec. 31, 1990	AWS
State University, NCDC	Jan. 1, 1991	Dec. 31, 1992	Leyendecker data unavailable.
Leyendecker	Jan. 1, 1993	Dec. 31, 2008	AWS (January 1993 air temperatures estimated using NMSU temperatures)
Leyendecker PRSC II*	Jan. 1, 2009	Dec. 31, 2018	AWS

*The Leyendecker PRSC II station was installed in 2009 and was collocated with the original Leyendecker station for several years. The PRSC II station used newer sensors and was therefore adopted over the older original station.

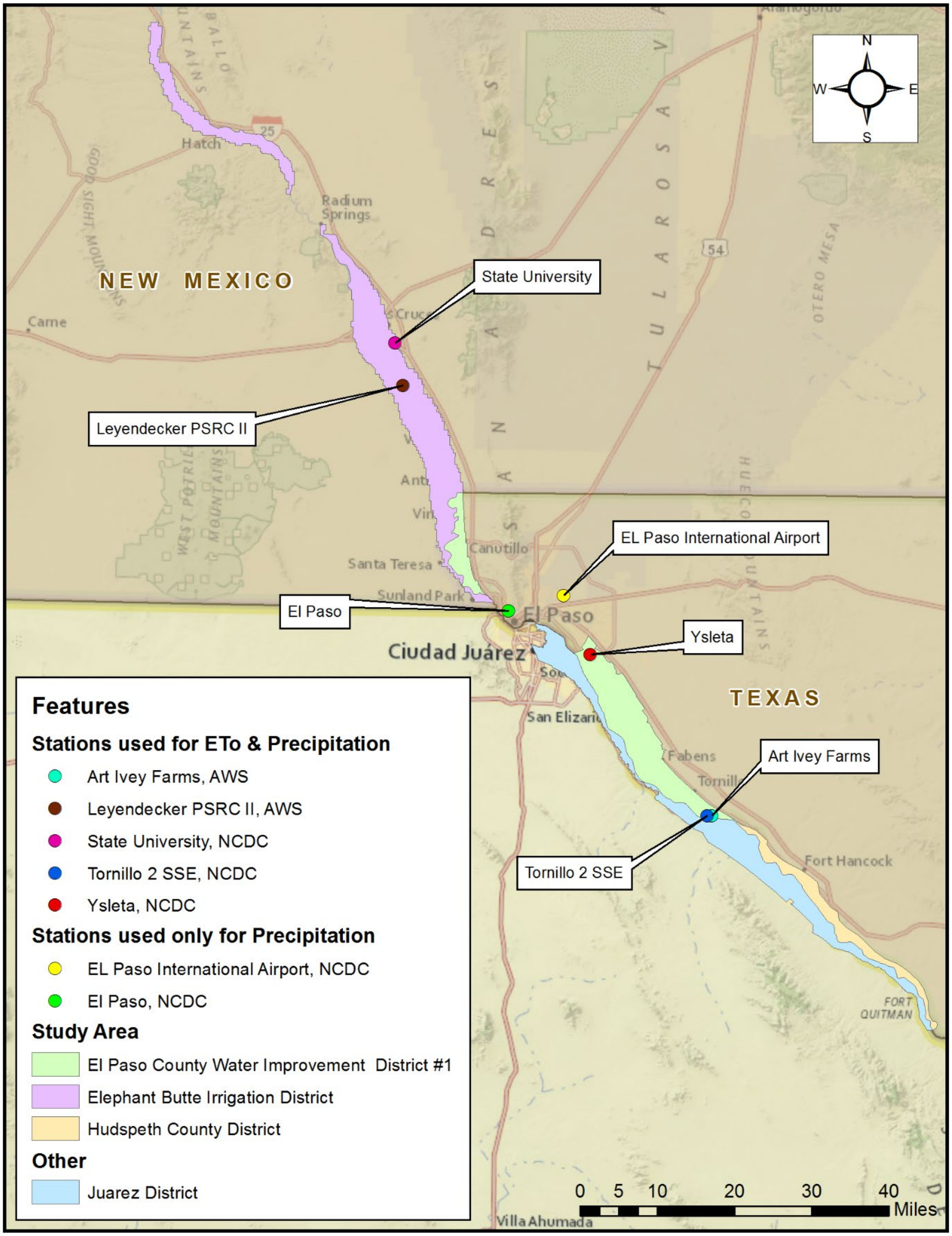

Figure 3-1. Weather Station Used in the Analysis.

In Texas, within EPCWID, the Art Ivey Farms and Tirres Farms sites were found to be located in agricultural settings that best represented the Study Area. The Art Ivey Farms AWS had the most complete record and was located approximately 3.75 miles southeast of the town of Tornillo in El Paso County, Texas at approximate latitude N31.404 degrees, and longitude W106.047 degrees. Latitude and longitude were determined by visually locating the site using Google Earth.

Because the Art Ivey AWS did not begin collecting and recording data until early 2004, NOAA weather stations were used to extend the daily ET_o time series back to 1938. The longest NOAA station data record was at Ysleta, which was discontinued in 2009 and is now located within the city of El Paso. The Tornillo NOAA station is located southeast of the town of Tornillo, only a few miles from the Art Ivey AWS. However, this station did not begin collecting data until 1981. The Tornillo station was used to fill in missing days in the Art Ivey record because an aridity analysis determined that the Tirres Farms station was in an arid environment. For 2013 to 2018, the only available weather data for Texas were at Pebble Hills Park and Westside Sports Complex. Both of these stations are located in urban areas with poor air flow due to limited fetch in the weather station vicinity. An analysis and comparison of the data from these stations to the Art Ivey and the Leyendecker PRSC II station indicated that the Leyendecker PRSC II station, even though it is located in New Mexico, provides the most representative ET_o for the irrigated agricultural areas in Texas and Mexico of the available weather stations for 2013 to 2018. Given the limitations of the available weather data, the daily ET_o time series was developed based on the best available station at any given time (**Table 3-2**).

Table 3-2. Texas ET_o Data Time Series Summary of Sources Used for the Period 1936 – 2018.

Weather Station	Start Date	End Date	Comment
NMSU adjusted	Jan. 1, 1936	Jan. 31, 1939	Adjusted based on overlap with Ysleta/Tornillo data
Ysleta	Feb. 1, 1939	June 30, 1981	Only station available inside irrigated area
Tornillo	Jul. 1, 1981	Dec. 31, 2003	Inside irrigated area, during this time Ysleta is likely becoming urbanized.
Art Ivey	Jan. 1, 2004	Dec. 31, 2004	AWS
Tornillo	Jan. 1, 2005	Dec. 31, 2005	No data at Art Ivey
Art Ivey	Jan. 1, 2006	Dec. 23, 2006	AWS
Tornillo	Dec. 24, 2006	Apr. 16, 2007	Only station inside irrigated areas
Art Ivey	Apr. 17, 2007	Dec. 31, 2007	AWS
Tornillo	Jan. 1, 2008	Jan. 10, 2008	Only station inside irrigated areas
Art Ivey	Jan. 11, 2008	Dec. 15, 2008	AWS
Tornillo	Dec. 16, 2008	Dec. 31, 2008	Only station inside irrigated areas
Art Ivey	Jan. 1, 2009	Dec. 30, 2012	AWS
Leyendecker PRSC II	Dec. 31, 2012	Dec. 31, 2018	AWS No station inside Texas irrigated areas

Weather Data Quality Control

Hourly checks and necessary adjustments performed on AWS station data and daily checks and necessary adjustments performed on NOAA data are described in the following sections.

Daily data were obtained from the NCEI web site for the NOAA stations nearest to the available AWS having data for periods from 1938 up to when the AWS record began. These data were selected to develop the complete daily record (**Table 3-3**). The daily air temperature and precipitation data at these stations were reviewed for missing days and other data errors and appropriate corrections and estimates were made using accepted procedures.

Table 3-3. NOAA Data Stations.

Station Name	State	Record Start Date	Record End Date	No. of Days
STATE UNIVERSITY NM US	NM	1/1/1936	12/31/2018	30,316
TORNILLO 2 SSE TX US	TX	7/1/1981	11/30/2012	11,476
YSLETA TX US	TX	2/1/1939	9/30/2009	25,426

Solar Radiation

Leyendecker AWS solar radiation data were generally of good quality until the last few years of the record. Between 2011 and 2019, the R_s measurements began to fall below the estimated R_{so} curve in a trend suggestive of sensor inaccuracy. The distance below the R_{so} curve continued to increase through the end of 2016. The R_s data were adjusted by dividing by a ratio that continually decreased from 2011 through the end of 2016. The ratio was calculated for approximately 180-day periods and progressively decreased from 0.98 during the second half of 2011 to 0.83 in the first half of 2016. The ratio increased to 0.91 for the second half of 2016. The R_s measurements in 2017 and 2018 were closer to the estimated R_{so} curve than in 2016, but remained slightly lower in both years. During this period, a ratio between 0.89 and 0.97 with an average of 0.92 was used to adjust the R_s data.

Art Ivey and Tirres AWS solar radiation data appear to be of good quality. During spring of 2008 and 2009 and 2011, midday measurements often rose to about 10% above the estimated R_{so} curve, during pre-monsoon periods when the humidity was very low. One reason for R_s data to lie above correct levels might be a tipping of the pyranometer towards the south. R_s data for Art Ivey were adjusted for year 2008 by dividing by a ratio that linearly increased from 1.00 on day of year (DoY) 70 to 1.09 on DoY 110 and remained at 1.09 until DoY 135, when the ratio linearly reduced to 1.00 on DoY 200. Reference ET was recomputed following the adjustment. A ratio of 1.00 means that no adjustment to measured data was needed. Similar adjustments were made to years 2009 – 2012.

Air Temperature

Leyendecker AWS air temperature data were consistent and followed expected values and behavior. No adjustments were made.

Art Ivey and Tirres AWS air temperature data were consistent and followed expected values and behavior. No adjustments were made.

Relative Humidity

Leyendecker AWS humidity data for all years appeared to be reasonable and expected, when assessed using the procedures previously described. Dewpoint temperatures were generally associated with daily minimum air temperature, with RH at night commonly about 60% in spring before the monsoon period and then approaching 100% during the monsoon period of late spring through summer. No adjustments to humidity data were made.

Art Ivey and Tirres AWS humidity data for all years appeared to be reasonable and expected, when assessed using the procedures described. Dewpoint temperatures were generally associated with daily minimum air temperature, with RH at night commonly about 60% in spring before the monsoon period and then approaching 100% during the monsoon period of late spring through summer. No adjustments to humidity data were made.

Wind Speed

Leyendecker AWS wind speed data were generally reasonable and followed expected ranges and patterns, with lower values during nighttime and higher values during the day. However, at the end of July of 2014 the wind speed measurements decreased significantly and many values were missing. A double mass plot comparing valid windspeed data from the Leyendecker and Fabien-Garcia weather stations was developed. Data from the Fabien-Garcia station were used without adjustment based on the double mass comparison to fill the missing measurements and measurements at the Leyendecker station that were below the threshold for the 2014-2016-time period.

The Art Ivey hourly wind speed data were relatively complete. However, many nighttime wind speed values dropped to zero even though daytime values were as high as 6 m/s. The trend toward zero values seems to increase with time in the record. This may suggest a fatiguing of anemometer bearings (ASCE-EWRI 2005). To calculate ET_o, all hourly wind speed values less than 0.5 m/s were set to 0.5 m/s, following the recommendation in ASCE-EWRI (2005) to represent a floor on wind movement and equilibrium boundary layer stability effects in the Penman-Monteith equation.

ET_o Estimates

For the time periods when AWS weather data were not available, the standardized recommended methods (Allen, et al, 1998 and ASCE-EWRI, 2005) for estimating solar radiation, dewpoint temperature, and wind speed were utilized with the results described below.

Solar Radiation

To determine which equation provided a better fit to available measured solar radiation data, the Thornton-Running method and Hargreaves-Samani equation were both used to estimate solar radiation based on the daily air temperature extremes from the available weather stations. These estimates were then compared to the quality controlled measured solar radiation from available AWS data through a ratio of estimated R_s to measured R_s. A value closer to 1.0 indicates closer fit of estimated R_s to measured R_s.

Comparison between the average annual ratio of estimated R_s from NMSU NOAA station temperature data and measured R_s from the Leyendecker AWS indicated that the solar radiation estimated by the Hargreaves-Samani equation more closely matched the measured solar radiation during the overlapping time period than did the Thornton-Running method (**Table 3-4**).

For the shorter overlap between Ysleta NOAA and Art Ivey AWS, the average annual ratio of estimated R_s to measured R_s from the Thornton-Running method (**Equations 3-2 and 3-3**) indicated that the Thornton-Running estimated solar radiation more closely matched measured solar radiation (**Table 3-4**).

Table 3-4. Annual Ratios of Estimated Solar Radiation Based on Air Temperatures to Measured Solar Radiation.

Stations Compared	Period	Ratio of estimated R_s to measured		Number of Days*
		Thornton-Running (Eq. 3-2 and 3-3)	Hargreaves-Samani (Eq. 3-1)	
NMSU-Leyendecker	1985-2014	1.09	1.00	9,962
Ysleta-Art Ivey	2004-2009	1.03	0.95	1,596

*The ratio was only computed for days with both measured temperature and measured solar radiation at the respective sites.

Among the New Mexico weather stations, the Hargreaves-Samani equation had a lower root mean square error (RMSE) compared to the Thornton-Running method (**Table 3-5**), again indicating closer fit between the Hargreaves-Samani estimated R_s and the measured R_s at Leyendecker AWS. This may be due to the generally lower minimum temperatures noted at Leyendecker and Leyendecker PRSC II due to the generally better siting as compared to the Texas weather stations. Thus, for irrigated lands in New Mexico the Hargreaves-Samani equation was used to estimate solar radiation at the NMSU NOAA station for time periods without measured solar radiation.

Among the Texas weather stations, the Thornton-Running universal function had an equal or lower RMSE at Ysleta and Tornillo, indicating better agreement with the measured solar radiation at Art Ivey AWS (**Table 3-5**). Additionally, the Thornton-Running universal function had a similar RMSE to those found in calibrated functions (Allen and Robinson, 2009 (page 83)). Thus, the universal function was selected for use to estimate solar radiation at those two NOAA stations for time periods without measured solar radiation.

Table 3-5. RMSE values (MJ m^{-2} d^{-1}) for Daily Estimates of Solar Radiation for the Thornton-Running Universal Function Method and the Hargreaves-Samani Equation.

Station Compared	R_s (Thornton-Running)	R_s (Hargreaves-Samani)	n – Number of Measurements
NMSU-Leyendecker	2.4	2.2	9,962
Ysleta-Art Ivey	3.54	3.66	1,596
Tornillo-Art Ivey	2.93	3.16	2,753

Dewpoint Temperature

The values to calculate K_o for the NMSU weather station (**Table 3-6**) are estimated as the minimum temperature from NMSU NOAA station minus the dewpoint temperature calculated from the reported temperature and relative humidity data from Leyendecker AWS using **Equations 3-5, 3-6 and 3-7**. Although the results are larger than the typical values of 2 to 5 °C found for irrigated agricultural areas, ASCE (2016) notes that K_o may have values of five to ten °C under extremely dry conditions of the American Southwest. In Texas, the Tornillo NOAA station was used to determine the K_o offset. The monthly K_o shown in **Table 3-6** is estimated as the minimum temperature from Tornillo NOAA station minus the dewpoint temperature calculated from the reported temperature and relative humidity data from Art Ivey AWS using **Equations 3-5, 3-6 and 3-7**.

Table 3-6. Mean Monthly Values for the K_o Offset, °C, for use in Equation 3-4 for Estimating Daily Average Dewpoint Temperature at NOAA stations in New Mexico and Texas.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
New Mexico--NMSU	4.3	5.4	8.1	9.6	10.7	10.6	8.1	6.1	5.5	3.7	4.4	3.9
Texas--Tornillo	0.7	2.8	5.1	7.1	5.1	3.8	0.8	-0.6	-1.7	-2.5	-1.3	-1.6

Wind Speed

Table 3-7 lists the mean monthly wind speed values used for each NOAA station as estimated for each station by using the mean monthly value for wind speed from the nearby Leyendecker AWS in New Mexico and Art Ivey and Tirres AWS in Texas. These monthly values bracket the global average wind speed of 2 m s^{-1} reported in the FAO-56 guidelines (Allen et al., 1998).

Table 3-7. Mean Monthly Wind Speed Values, m s^{-1} at 2m Height, for Estimating Daily ET_o at NCEI Stations in New Mexico and Texas

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
New Mexico (NMSU) from Leyendecker	1.67	1.97	2.28	2.26	1.93	1.72	1.63	1.38	1.42	1.39	1.48	1.50
Texas (Ysleta & Tornillo) from Art Ivey and Tirres	1.63	2.12	2.24	2.35	1.84	1.50	1.36	1.17	1.19	1.14	1.30	1.56

ET_o Variance with Estimated Weather Parameters

To assess the impact of estimating solar radiation, dewpoint temperature and wind speed int ET_o estimates, the ET_o estimates were compared to the ET_o calculated using the full suite of measured weather parameters from the nearby AWS station. The statistics comparing the ET_o calculated with measured weather parameters to the ET_o calculated for the nearby NOAA station using measured air temperature and estimated solar radiation, wind speed and dewpoint temperature are shown in **Tables 3-8 through 3-10**.

Table 3-8. Statistics Comparing the ET_o Calculated with Measured Weather Parameters at Art Ivey to the ET_o Calculated with Temperature for Ysleta*.

Site	Mean mm/day	Ratio of mean ET_o	Std. Dev. mm/day	Coeff of Variation	RMSE, mm/day
Art Ivey Measured	4.74	----	2.07	0.44	----
Ysleta Estimated	4.70	0.99	2.02	0.43	1.03
Difference	0.04			0.01	
*For the period 1/1/2004-9/30/2009 (1,596 days)					

Table 3-9. Statistics Comparing the ET_o Calculated with Measured Weather Parameters at Art Ivey to the ET_o Calculated with Measured Air Temperature for Tornillo and Leyendecker*.

Site	Mean mm/day	Ratio of mean ET_o	Std. Dev. mm/day	Coeff of Variation	RMSE, mm/day
Art Ivey Measured	4.62	---	2.04	0.44	----
Tornillo Estimated	4.47	0.97	1.91	0.43	0.83
Leyendecker Measured	4.52	0.98	2.00	0.44	0.77
Diff Art Ivey - Tornillo	0.15			0.01	
Diff Art Ivey - Leyendecker	0.10			0.00	

*For the period 1/1/2004-11/30/2012 (2,753 days)

Table 3-10a. Statistics Comparing the ET_o Calculated with Measured Weather Parameters at Leyendecker to the ET_o Calculated with Air Temperature for NMSU*.

Site	Mean mm/day	Ratio to meas. params	Std. Dev. Mm/day	Coeff of Variation	RMSE, mm/day
Leyendecker Measured	4.29	---	2.01	0.47	----
NMSU Estimated	4.41	1.03	1.87	0.42	0.82
Difference	-0.12			-0.89	

*For the period 1/1/1985-4/22/2014 (9,973 days)

Table 3-10b. Statistics Comparing the ET_o Calculated with Measured Weather Parameters to the ET_o Calculated with Air Temperature for Leyendecker and NMSU*.

Site	Mean mm/day	Ratio to meas. params	Std. Dev. Mm/day	Coeff of Variation	RMSE, mm/day
Leyendecker Measured	4.51	---	1.86	0.41	---
NMSU Estimated	4.52	1.00	2.00	0.44	0.79
Difference	-0.01			-0.03	

*For the period 1/1/2004-9/30/2009 (2,753 days)

The statistical summaries show that the ratios of ET_o calculated with all parameters other than temperatures estimated to the ET_o calculated from all measured parameters is close to 1.00. This indicates relatively high accuracy and consistency in the estimation of secondary parameters using the ASCE methods. The days in the overlap period between the NMSU and Leyendecker stations total nearly four times that for the Art Ivey-Tornillo overlap. This greater overlap is likely the reason that the coefficient of variation is 0.05 lower for the ET_o from calculated as compared to from estimated parameters. The ratio between the ET_o from calculated parameters to ET_o from measured parameters is also likely affected by the greater overlap period with greater range in ET_o values. RMSE values ranged from 0.79 to 1.03 mm per day. This is typical of the increase for individual days found with other data sets, and the RMSE drops significantly when ET_o values are averaged over five-day periods when applied to estimate ET during typical irrigation intervals. Similar results were obtained when averaged over seven-day intervals. Additionally, the application of the ASCE-PM at NOAA stations with estimated parameters is congruent with the application of the same ASCE-PM equation to the New Mexico and Texas AWS weather data sets when all required parameters are measured and available.

ET_o Results Summary

The average annual ET_o for 1938 through 2018 was 63.2 inches (1,604 mm) and 63.5 inches (1,614 mm) in New Mexico and Texas, respectively. It is not surprising that the average annual ET_o record is this close, given that the weather data are from weather stations that are all located in or near agricultural areas near Las Cruces, New Mexico and near Tornillo, Texas and that the Tornillo station is less than 90 miles southeast of Las Cruces. The four-year period, 2008 through 2012, having full weather data sets from Art Ivey in Texas and Leyendecker II in New Mexico averages two and five percent above the longer term 1936-2016 average, respectively. Also, noteworthy is the higher ET_o at Leyendecker II compared to Leyendecker, though these estimates cover different periods of record. It should be noted that there is a three-year period from 1994 to 1996 where the Leyendecker ET_o also averaged 66.2 inches compared to the 66.2 inch four-year average at Leyendecker II. Interestingly, the 2013 Leyendecker II ET_o was about eight percent lower than the recent (2013 through 2016) three-year average and, at 60.9 inches, corresponds closely with the 1982-2003 Leyendecker average. This indicates that the differences in the average ET_o values computed from the weather data collected at the various stations (**Table 3-11**) is most likely due to natural and expected variability in the record.

Table 3-11. Comparison of Full Year Annual Average Totals for ET_o for the Time Period of Data Available in New Mexico and Texas. All Units in Inches.

Averages	Art Ivey	Leyendecker	Leyendecker PSRC II	State University	Tornillo	Ysleta	New Mexico	Texas
1936-1939				62.6			62.6	62.6
1940-1980				64.0		63.3	64.0	63.3
1982-2003		60.9		63.3	63.2	64.9	61.4	63.2
2008-2012	64.9		66.2	64.4	63.0		65.6	64.6
1936-2013				63.6			63.0	63.4
1938-2018							63.2	63.5

Annual ET_o totals for the complete 1938 to 2018 record for the New Mexico and Texas areas of the project are included in **Appendix 3A**.

Precipitation Results Summary

The longest NOAA station data record for precipitation and air temperature was at Ysleta, which began on February 1, 1939 and was discontinued in 2009. The location of the discontinued station is now within the city of El Paso. Prior to the beginning of the Ysleta record, the precipitation record at the El Paso Texas NOAA weather station was used. After the Ysleta weather station was discontinued, the El Paso International Airport NOAA weather station was used for precipitation in Texas (**Table 3-12**). Additionally, the El Paso International Airport NOAA weather station record was used to fill in missing data in the Ysleta NOAA station precipitation record. In New Mexico, an evaluation of weather stations (Allen, 2009) selected the State University NOAA weather station as having the best precipitation record for the New Mexico irrigated area. Missing data at this station were filled in with data from the nearby Leyendecker AWS weather station.

Table 3-12. Summary of Data Time Series Periods used for Texas and New Mexico Precipitation Data.

State	NOAA Weather Station	Begin Date	End Date	Total Days
New Mexico	STATE UNIVERSITY NM US	1/1/1936	12/31/2018	30,316
Texas	EL PASO TX US	1/1/1936	1/31/1939	1,127
Texas	YSLETA TX US	2/1/1939	9/30/2009	25,810
Texas	EL PASO INTERNATIONAL AIRPORT TX US	10/1/2009	12/31/2018	3,379

The 81-year average precipitation from 1938 to 2018 was 8.88 (226 mm) and 8.67 inches (220 mm) in New Mexico and Texas, respectively (**Table 3-13**). The annual precipitation in New Mexico varied from 3.45 to 19.60 inches over the 81-year period. In comparison, the minimum annual precipitation in Texas was slightly higher at 3.57 inches and the maximum was nearly 3 inches less at 16.78 inches. As shown by the difference column, the minimum and maximums did not occur in the same year for the two states. In one year, the reported Texas precipitation was 4.93 inches *greater* than the New Mexico precipitation total. Conversely, in another year, the reported New Mexico precipitation was 6.85 inches greater than the Texas precipitation. The annual precipitation totals are included in **Appendix 3A**.

Table 3-13. Texas and New Mexico Annual Precipitation Statistics for 1938-2018.

Parameter	New Mexico	Texas	Difference, NM-TX*
Average, inches	8.88	8.67	0.21
Minimum, inches	3.45 (1970)	3.57 (1956)	-4.93 (2008)
Maximum, inches	19.60 (1941)	16.78 (1974)	6.85 (1969)
No. of Years	81	81	81

*Calculated each year and then summarized.

Opinions

Daily precipitation data and reference evapotranspiration for a clipped cool season grass reference crop (ET_o) were developed from representative weather station measurements in the Study Area. Annual precipitation and ETo data for 1938 through 2018 are presented in Appendix 3A.

Following visual inspection of all-weather stations in the New Mexico Study Area region, the Leyendecker Automated Weather Station (AWS) was found to be the most representative station for irrigated areas in New Mexico because of its location interior to and surrounded by irrigated agricultural areas and a greater abundance of low growing crops that permitted open flow of wind over the station. This site is located in an agricultural area about 20 miles south of Las Cruces. During years when data were unavailable from Leyendecker AWS, the New Mexico State University (NMSU) weather station was used.

In Texas, visual inspection and data review found the Art Ivey Farms AWS site within EPCWID to have the most complete weather data record and to be the most representative station for Texas irrigated areas also because of its proximity to irrigated agricultural land. The Art Ivey Farms AWS site is located approximately four miles southeast of the town of Tornillo in El Paso County. During years when data were unavailable from Art Ivey Farms AWS, other stations in the Tornillo and Ysleta areas of El Paso County were used.

Quality control and quality assessment protocols were followed and necessary adjustments were performed for hourly AWS data and daily NOAA data. Generally, some solar radiation record at both the Leyendecker and Art Ivey AWS sites were found to be artificially low and required adjustment for consistency with computed clear sky envelopes of solar radiation on cloudless days (R_{so}, the maximum Rs value that should be achieved on cloud-free days). The air temperature and humidity data at both sites were found to be consistent and not need adjustment.   Some periods of consistently low wind speed data required minor adjustment for consistency with nearby station data during short periods at both sites.

For the time periods when AWS weather data were not available, the standardized recommended methods (Allen, et al, 1998 and ASCE-EWRI, 2005) for estimating solar radiation, dewpoint temperature, and wind speed were utilized. These estimates resulted in ET_o values that were not significantly different from ET_o calculated from measured parameters (within 3 percent).

Following quality control and quality assessment of all-weather data, daily precipitation and ET_o timeseries were developed as inputs for the ET Demands model. The average annual ET_o for 1938 through 2018 was 63.2 (1,604 mm) and 63.5 inches (1,614 mm) in New Mexico and Texas, respectively. The 81-year average annual precipitation from 1938 to 2018 was 8.88 (226 mm) and 8.67 inches (220 mm) in New Mexico and Texas, respectively.

IV. Validation of Remote Sensing Based Processes Used to Classify Irrigation Status and Crop Type

The New Mexico Interstate Stream Commission (NMISC), New Mexico Office of the State Engineer (NMOSE) and INTERA Inc. (INTERA) have developed and utilized a Normalized Difference Vegetation Index (NDVI) remote sensing methodology using Landsat satellite data to classify agricultural fields as irrigated or non-irrigated. This methodology is important to crop consumptive use investigations as it helps to delineate total irrigated crop acreage over time and across large areas for which land use data may be incomplete or only sporadically available. The methodology has been applied along the Rio Grande in the Rincon, Mesilla and El Paso Valleys in New Mexico and Texas. Jordan and Barroll (2013) describe two previous accuracy assessments (or validations) of the remote sensing methodology in New Mexico using: 1) 2006 ground-based observations from approximately 100 fields in the Mesilla Valley in New Mexico and 2) 2008 ground-based crop survey data collected by NMOSE. The NMOSE conducted a third validation in 2016 to further assess the reliability of the methodology under current field conditions.

The United States Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) has developed and provided the Cropland Data Layer (CDL) datasets available for the Study Area in 2008 through 2018. The CDL is a raster, geo-referenced, crop-specific land cover data layer. The CDL has a ground resolution of 30 meters, though before 2010, the resolution was 56-meters. The CDL is produced using satellite imagery from Landsat 5 TM sensor, Landsat 7 ETM+ sensor, and the Indian Remote Sensing RESOURCESAT-1 (IRS-P6) Advanced Wide Field Sensor (AWiFS) collected during the growing season. The 2016 field survey also is an opportunity to validate the CDL in the LRG.

Methodology

The 2016 ground-truthing exercise and validation survey followed the steps recommended for sample-based field verification studies as described by Gilbert (1987) and for a statistically representative selection of a stratified, random sample as described by Stehman and Milliken (2007). The methodology describes the objectives, area of interest, physical environment, information to be collected, quality assurance protocols, field sampling designs and planned statistical analyses.

Objectives

The two main objectives of the 2016 validation were to:

1. Assess and verify the accuracy of the remotely sensed NDVI methodology for classifying a field as irrigated or non-irrigated in the LRG and
2. Assess and verify the accuracy of the remotely sensed National Agricultural Statistics Service (NASS) Crop Data Layer (CDL) for classifying crop types in the LRG.

The 2016 validation calculated the overall accuracy (number of fields correctly classified divided by total number of fields sampled) and 95 percent confidence interval of the remotely sensed classifications for the following classifications of fields:

- irrigated or non-irrigated
- total crop area
- each crop type

Three field surveys were conducted for the 2016 validation, scheduled at different times during the crop season. The protocol followed during the field surveys is briefly summarized in the following sections and described in more detail in **Appendix 4A**. For each survey, field information was collected with a GIS/GPS computer system with drop down boxes to standardize the information to enable validation of each of the three classifications listed above. Additionally, irrigation method, crop growth stage and production stage were observed for each field to support consumptive use determinations.

A stratified, random sample of fields was developed to achieve a 95 percent confidence interval on the overall accuracy of the classifications listed above through direct observation during the field survey. The fields were randomly selected and stratified with respect to geographic region and field size, as described in detail below. Fields less than five acres were not considered for the random sample. The survey results were compared to a 2016 NDVI based analysis of irrigated acreage that used the Jordan and Barroll (2013) method to classify fields as irrigated or non-irrigated.

Area of Interest

The geographic area for the 2016 validation survey was primarily within the boundaries of the Elephant Butte Irrigation District (EBID) in New Mexico, the El Paso County Water Improvement District #1 (EPCWID); and Hudspeth County Conservation & Reclamation District #1 (Hudspeth) in Texas. The Study Area extends from Caballo Dam in New Mexico to Ft. Quitman, Texas.

Physical Environment

Agricultural fields in the Study Area are generally located on valley lowlands next to the Rio Grande. The agricultural fields typically are level or have gentle slopes generally conducive to surface irrigation methods. Fields less than five acres in size comprise 63 percent of the total number of fields, but only 16 percent of the irrigated land area. Average field sizes are smaller in the Mesilla Valley averaging 5.3 acres compared to 6.2, 8.6 and 13.3 acres in Rincon, EPCWID and Hudspeth, respectively.

Data Collected

During each of the three surveys, the following parameters were observed for each selected field: evidence of irrigation; crop type and growth/development stage; and irrigation method. Evidence of irrigation included observation of: ongoing irrigation events; signs of a recently completed irrigation event (such as wet soil or ditches); presence of irrigation facilities (head ditches, field borders, etc.); presence and vigor of crop. Crop type was also recorded. Irrigation method was classified as drip, sprinkler, basin, border or furrow. Additional information collected for pecan fields included: approximate tree height, tree structure, and approximate groundcover. Descriptions of the field survey teams, GIS processes, and field survey procedures, including GIS and crop ID manuals and handbooks, are described in **Appendix 4A**.

Quality Assurance Protocols

GPS coordinates were recorded at the point of observation of each sampled field to confirm that the correct field was observed, and that the same field polygon delineation was used for the ground survey data collection and the remote sensing based irrigated versus non-irrigated classification. Digital data entry forms were developed to minimize data entry errors. Additionally, the data collected each day were reviewed at the end of the day to ensure that complete and clear information was recorded for all fields visited. Each field team developed tables summarizing the number of fields and total area for each observed parameter. The teams met briefly and discussed the day’s observations. If data were determined to be missing on any field, or other unusual circumstances were noted (for example: observed irrigation on bare ground in July), the field was revisited within the next two weeks.

After completion of each of the three surveys, summary tables of field parameters were developed and reviewed. In addition, after the second and third surveys, field parameters for the current and prior surveys were compared and any implausible changes or inconsistencies (for example, a field that was observed to have bare ground in April and mature pecans in July) were flagged, and the field revisited within the next two weeks.

Other Validation Studies

The NMOSE performed a comprehensive ground survey of crops in the LRG in New Mexico in 2008. All fields were observed in the spring and summer of 2008 and then again in the spring of 2009. Selected fields were observed again in the fall of 2008. This field study was completed to determine irrigated area and cropping patterns for the Lower Rio Grande Basin Adjudication. Based on the 2008 and 2009 data, Jordan and Barroll (2013) found an overall accuracy of 90 percent for the NDVI method of classifying agricultural fields as irrigated or non-irrigated.

Stehman and Milliken (2007) assessed the accuracy of crop classifications for fields in the areas irrigated with Colorado River water downstream of Hoover Dam. They used a random sampling plan stratified by agricultural field size within four geographically separate irrigated areas. The total area sampled was about five percent of the total irrigated area. The results of the accuracy analysis were used to estimate the effect of crop classification error on evapotranspiration estimates.

Melton, et al. (2015) used a remote sensing NDVI methodology to classify agricultural fields as fallow or irrigated in California's Central Valley. They performed one accuracy assessment based on confidential Farm Services Agency (FSA) data and a second accuracy assessment based on monthly ground surveys. The ground surveys recorded observations of fields along eight east to west transects across the Central Valley. Data collected included information on crop presence or absence, crop type, crop height, visual estimates of canopy cover, soil condition, and observations of evidence of irrigation, weed control, or other field maintenance. Digital photographs and GPS readings were collected at each field survey site. Overall accuracy was calculated as the percent of fields correctly classified as fallow or irrigated.

Field Sampling Designs

The 2016 validation was based on a probability sample of fields. The sample was designed with the objective to develop a 95 percent confidence interval on the overall accuracy of classifying agricultural fields as irrigated or non-irrigated. Standard accepted practices use a stratified, random sample of fields (Gilbert, 1987; Stehman and Milliken, 2007 and Congalton and Green, 2009). Fields were defined as consisting of a single crop and selection is stratified by field area within each of four geographic regions. The field polygon data, revised in 2016 to reflect current field configurations, was used to develop the sampling plan. As previously noted, field polygons less than five acres in size represent 63 percent of the total number of fields, but only 16 percent of the total field area. These fields are predominately rural ranch parcels (i.e. ranchettes), or "hobby" farmers and were not included in the survey.

First, the total sample size required to estimate the overall accuracy with a 95 percent confidence was determined. Since the population of irrigated and non-irrigated fields was unknown when the sample were selected, the total sample size was estimated by determining the sample size required to estimate the average field size to within one acre with 95 percent confidence using the prespecified margin of error method described by Cochran (1977) as described by Gilbert (1987). The sample size was estimated to be 475 fields or six percent of the total fields available. The ground survey was planned to sample a total of 1,200 fields to ensure that a sufficient number of fields were sampled.

Next, four geographic regions were used as the upper level strata of the stratified random sample, with each region representing similar, but separate physical environments:

- Rincon Valley
- Mesilla Valley
- El Paso Valley, and
- Hudspeth.

The total sample is allocated to the regional strata proportionally using the Neyman allocation (Cochran, 1977). The Neyman allocation minimizes the variance and, in this case, results in sample sizes in each regional strata approximately proportional to the total field area in each region.

The population of fields within each geographic region is similar. These populations are highly skewed, with large numbers of small fields (less than 5 acres each), but the greatest total area is represented by fields between 11 and 23 acres each (**Figure 4-1**). The highest accuracy from samples for skewed populations is obtained by setting an upper stratum that is fully (100 percent) sampled (Hidiriglou, 1986). In addition to the upper strata, three additional field size strata, unique for each region, were developed based on the cumulative area of the population of fields in each region using the cumulative square root of the frequency method (Cochran, 1977). All fields in the upper strata were selected for the sample. As for the regions, the Neyman allocation was used to allocate the remaining region sample among the three remaining field size strata. The fields in the remaining strata were assigned a random number by a random number generator and the lowest random numbers were selected. Additionally, in Texas, because access to fields not near public roads is restricted, the fields with the lowest random numbers that are also near public roads were selected.

Statistical Analysis

Well established and widely accepted accuracy assessment methods (Gilbert, 1987; Stehman and Milliken, 2007, Congalton and Green, 2009, and Rossiter, 2014) were used to evaluate the accuracy of irrigated field identification by the NDVI remote sensing methodology and to evaluate the accuracy of CDL crop mapping by crop class. Summary tables were prepared assessing the accuracy of field classification as irrigated by the NDVI methodology and by the CDL crop mapping.

A 95 percent confidence interval was prepared for the overall accuracy of field identification as irrigated. Additionally, 95 percent confidence intervals were calculated for each crop evaluated. The analysis followed standard accuracy assessment principles and practices described by Congalton and Green (2009) and Rossiter (2014).

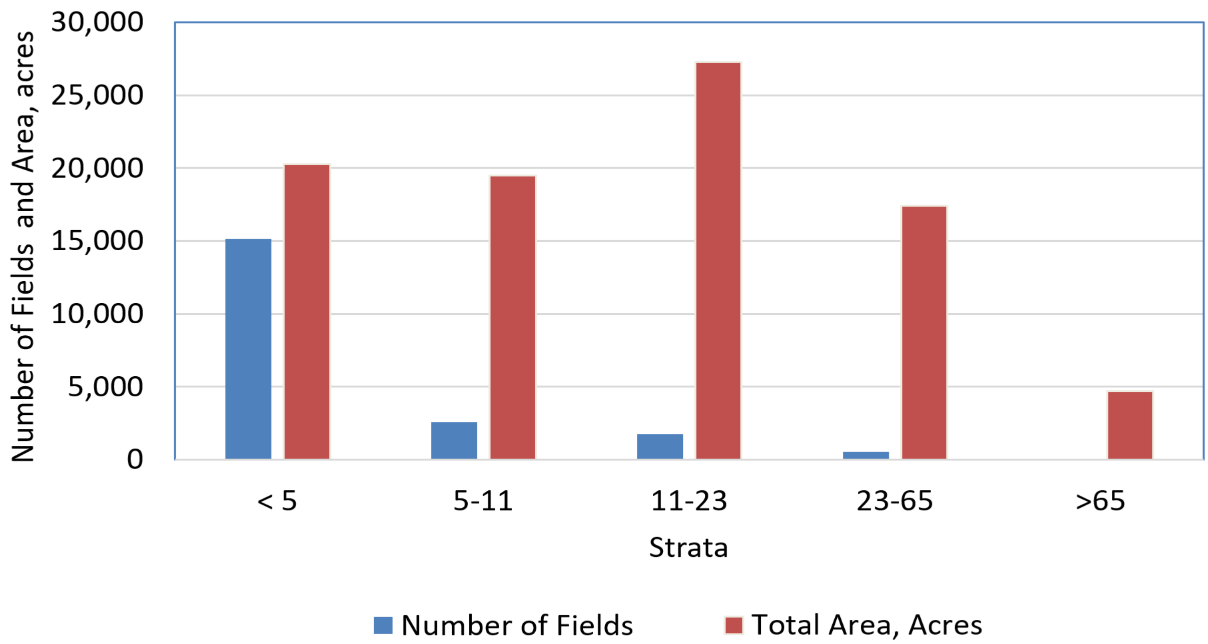

Figure 4-1. Sample Distributions of Number of Fields and Field Area Based on Mesilla Valley Field Population.

Results

The survey found 21,196 acres out of 24,295 acres observed, or about 87.2 percent, to be irrigated in 2016 (**Table 4-1**). The NDVI methodology to identify irrigated fields found 20,705 acres of the 24,295 acres observed, or 85.2 percent, to be irrigated. The NDVI methodology under estimated the irrigated area by two percent. The irrigated field classification using the USDA NASS Cropland Data Layer results can also be grouped into irrigated and not irrigated fields for comparison to the ground-based survey. The CDL methodology found 20,590 acres out of 24,295 acres observed, or 84.7 percent, to be irrigated. The CDL methodology under estimated the irrigated area by 2.5 percent.

The estimated divergence of the NDVI and CDL methodologies from the ground-truth verification study results is considered to be well within the expected confidence range of the respective methodologies (generally ±2 to 10 percent for NDVI (Wardlow and Egbert, 2005; Ozdogan et al, 2005; and Taufik et al, 2016) and for CDL (Luman and Tweddale, 2008)). Therefore, no adjustment was made to these estimates based on the 2016 verification study.

Table 4-1. Irrigated Area Field Observation Results Compared to NDVI Results

Irrigation Status	Area by Survey, Acres	Area by NDVI, Acres	Area by CDL, Acres
Irrigated	21,196	20,705	20,590
Not Irrigated	3,099	3,590	3,705
Total	24,295	24,295	24,295
Percent Irrigated	87.2%	85.2%	84.7%

The NDVI methodology misidentified a limited amount of irrigated area as not irrigated due primarily to two situations:

1. The interval between the early summer Landsat image date and fall Landsat image date in 2016 was long enough for some crops, when managed for a quick turn-around, to have low NDVI in both the early summer and fall Landsat images. Some varieties of corn, cotton, and chile can be managed this way. Since the Landsat date images vary from year to year (primarily driven by clouds on the date of the image), the occurrence of this problem may or may not occur in a given year.
2. Young pecan trees with little green vegetation have a low NDVI score.

Considering the accuracy of identifying all crop areas, the overall accuracy by the CDL remote sensing methodology is 85.5 percent (**Table 4-2**). When calculating the confidence interval, the observed proportions in the crop survey were considered to be the best estimate of the overall proportions of each crop in the study area for the calculation of a 95 percent confidence interval. The overall accuracy of 85.5 percent had a 95 percent confidence interval of plus or minus one percent. This narrow confidence range is primarily due to the large sample survey of 14 percent of the total agricultural area within the Study Area.

The CDL correctly identified more than 90 percent of the observed areas for alfalfa hay, cotton, not irrigated and water and pecans. These are the three crops with the greatest area observed in the crop survey. The CDL had the most difficulty correctly identifying irrigated pasture and miscellaneous vegetables. Although the CDL only correctly identified 85.5 percent of the crops, the 14.5 percent of the area with incorrectly identified crops did have a crop identified and thus water consumption was calculated for that 14.5 percent of the area also.

Table 4-2. Survey Observed Crop Areas Correctly Identified by the CDL.

Crop	Crop Survey Total Area, Acres	CDL Area Correctly Identified, Acres	CDL Correctly Identified, Percent
Alfalfa Hay	1,679	1,528	91.0%
Chile (Peppers)	359	148	41.2%
Corn, Sweet Corn, and Silage	762	634	83.2%
Cotton	3,976	3,867	97.3%
Irrigated Pasture	642	10	1.6%
Miscellaneous Vegetables	156	24	15.4%
Not Irrigated and Water	3,099	2,792	90.1%
Onions	261	195	74.7%
Pecans	12,463	11,348	91.1%
Wheat and Small Grains	897	234	26.1%
Total Areas, Acres	24,294	20,780	85.5%

Opinions

The 2016 NMOSE survey found 21,196 acres out of 24,295 acres surveyed, or about 87.2 percent, to be irrigated in 2016. In comparison, the NDVI methodology to identify irrigated fields found 20,705 acres out of 24,295 acres observed, or 85.2 percent, to be irrigated. The NDVI methodology under estimated the irrigated area by two percent. This is well within the expected confidence range of the respective methodologies (generally plus or minus 5 percent). Therefore, no adjustment was made to these estimates based on the 2016 verification study.

The 2016 CDL methodology to identify irrigated fields found 20,590 acres out of 24,295 acres, surveyed, or 84.7 percent, to be irrigated. The CDL methodology under estimated the irrigated area by 2.3 percent and is also within the expected confidence range of these methodologies.

The overall accuracy of the CDL methodology to identify the nine crop groups adjusted based on the best estimate of the proportion of crop areas in the Study Area was 85.5 percent with a 95 percent confidence interval of plus or minus one percent.

V. Development of Annual Irrigated Crop Areas for 1938 through 2018

Purpose

The purpose of this section is to document the development of annual irrigated crop areas for 1938 through 2018 in the Study Area for the purpose of calculating annual volumes of evapotranspiration of applied water (ET_{aw}). The total irrigated area was developed by INTERA (2018) and provided to Davids Engineering to determine the irrigated area of each crop.

This section describes an inventory of available sources of information on irrigated crop areas in the Study Area, and the methodology used to define crop categories, the results of the analysis, and findings. Supporting information is appended and referenced where applicable.

Available Irrigated Crop Area Information

Table 5-1 lists and summarizes key information pertaining to the various sources of irrigated crop data available within the Study Area. The various data sources are briefly described in the following sections.

District Crop Reports Submitted to Reclamation

The United States Bureau of Reclamation (Reclamation) publishes an annual report of "Summary Statistics, Water, Land and Related Data" based on crop census data reported by Districts receiving Reclamation project surface water supplies (Jachens and Albertson, 1999). Districts complete annual crop acreage reports using Reclamation Crop and Data Forms 7-316 and 7-2045, which document the area of each crop that receives surface water. These reports generally include only the crops irrigated by surface water and generally exclude any crops irrigated exclusively with groundwater. However, in certain years from 1948 through 1959, crop and irrigated acreage for fields irrigated with groundwater only were reported in Reclamation reports. The most recent crop reports available for the Study Area are for 2010. Davids Engineering (2015) compiled available Reclamation Crop Reports for 1971 through 2010 and 1938 through 1975, respectively. The annual District crop reports are available for the period from 1938 through 2010 and generally provide the most consistent and reliable estimates of areas of crops irrigated by surface water supplied by the Districts.

New Mexico Office of the State Engineer Crop Survey

The New Mexico Office of the State Engineer (NMOSE) conducted ground surveys of crops in EBID in 2008. The survey included three field visits in the spring, summer and fall of 2008 and one visit in the spring of 2009. The crops observed in each field during each of the four field visits were assigned to field polygons in a GIS database. Field observers were trained and the data were subjected to rigorous review and quality control. These surveys provide a comprehensive representation of ground-based crop data in EBID and provide a basis of comparison to other crop data sources.

Table 5-1. Summary of Crop Data Sources

Crop Data Source	Description	Comments
District Crop Reports Submitted to Reclamation.	Report area by crop receiving surface water from the district in each year. Double cropped area is included twice, once in each crop category.	Only includes cropped area receiving district surface water, with some exceptions from 1937 to 1959.
NMOSE crop survey	Extensive field survey with spatial information on crop locations for EBID only.	None.
NASS Cropland Data Layer	Crops identified by satellite algorithms, accuracy varies by crop generally improving from year to year, includes spatial information on crop locations.	Accuracy on minor crops is relatively low.
Remotely Sensed NDVI Irrigated Area Analysis	INTERA: Evaluation and Analysis of Rio Grande Project Irrigated Acreages (2018 Estimates of irrigated areas based on satellite (Landsat) NDVI values with spatial information on location of irrigated area; identifies orchards (mostly pecans) in 1976, 1996, 2004, and 2010; includes areas irrigated by groundwater that are not found in district crop reports to Reclamation. Includes Juarez Irrigation District.	Only identifies irrigated area; crop type is mostly unknown, except for orchards (mostly pecans) in four select years.
NM OSE Hydrographic Survey	Map of tracts within New Mexico that potentially have irrigation water rights, including information on the source of irrigation water available to each tract. ESRI shapefile format.	Does not identify crop type. Some uncertainty with field boundaries containing developed area (houses, shops, roads, etc.)
Carreno 1957*	Irrigated acres within Juarez Valley Irrigation District from 1938-1947.	Methodology and accuracy unknown.
Groundwater Conditions and Resources in El Paso/Juarez Valley IBWC 1989	Cropped and irrigated acres within Juarez Valley Irrigation District from 1950-1984.	Methodology and accuracy unknown.
El Servicio de Informacion Agroalimentaria y Pesquera (SIAP)	Cropped and irrigated acres within Juarez Valley Irrigation District from 1999 to 2017. (2018 not available as of June 2019, estimated as 2017 irrigated areas)	Methodology and accuracy unknown.
County Crop Reports	Contain total acres in a given county with no spatial information.	Crop areas include areas both inside and outside the Study Area with no information separate the area inside the study area from the area outside the study area.
USDA Ag Census	Contain total acres by crop in a given county with no spatial information.	Crop areas include areas both inside and outside the Study Area with no information separate the area inside the study area from the area outside the study area.

* Estudio Geohidrologico Preliminar Del Valle De Juarez Y Zonas Comarcanas, Edo. De Chihuahua.

National Agricultural Statistics Service Crop Data Layer

The Cropland Data Layer (CDL) datasets are developed and published by the United States Department of Agriculture (USDA) National Agricultural Statistics Service (NASS). The CDL is a raster, geo-referenced, crop-specific land cover data layer. Beginning in 2010 the CDL is based on a spatial resolution of 30 meters; and for 2008 and 2009 is based on a resolution of 56-meters. The CDL is produced using satellite imagery from the Landsat 5 Thematic Mapper (TM) sensor, Landsat 7 Enhanced Thematic Mapper Plus (ETM+) sensor, and the Indian Remote Sensing RESOURCESAT-1 (IRS-P6) Advanced Wide Field Sensor (AWiFS) collected during the growing season, or seasons, of interest. Additional data sources sometimes used to improve classification accuracy include the United States Geological Survey (USGS) National Elevation Dataset (NED), the USGS National Land Cover Database 2001 (NLCD 2001), and the National Aeronautics and Space Administration (NASA) Moderate Resolution Imaging Spectroradiometer (MODIS) Normalized Difference Vegetation Index (NDVI) composite images. The MODIS images have a spatial resolution of 250 meters.

Agricultural crop classification training and validation data are derived from the Farm Service Agency (FSA) Common Land Unit (CLU) Program. Non-agricultural land cover classification training and validation is derived from NLCD 2001 data. Metadata files describing all imagery, ancillary data, and training and validation data used to generate each state's CDL are available at: https://nassgeodata.gmu.edu/CropScape/.

Complete CDL land use coverages for New Mexico and Texas are available for 2008 through 2018. The CDL datasets have varying accuracy in the identification of crops that generally depends on the specificity of the crop to be identified, as documented in the metadata provided with the CDL data (USDA, 2014). In other words, the more specific the crop identification is (apples versus pecans, for example, as compared to orchards versus field crops), the less accurate the results. The most recent CDL data layer evaluated from NASS is for 2013 for both New Mexico and Texas.

CDL crop classification procedures are still accepted, but should be deferred to higher-resolution classifications when available. CDL datasets are available for 2008 through 2018 for areas within the United States and every year in early February, the most recent completed year is added to the dataset.

Remotely Sensed NDVI Irrigated Area Analysis

INTERA (2014 and 2018) used the Normalized Difference Vegetation Index (NDVI), a commonly used measure of vegetation greenness (a surrogate for vegetation health and vigor), to identify irrigated crop areas in Landsat images of the Study Area. Urban greenery and native vegetation were eliminated through the use of digital coverages that define historical agricultural fields. Additionally, INTERA used data from the NMOSE Hydrographic Survey to differentiate New Mexico lands supplied by groundwater only, in contrast to lands that also have access to surface water. Lands irrigated with groundwater only are not included in District crop reports.

Delineating irrigated areas in arid environments using NDVI calculated from Landsat data has been shown to be scientifically sound and is an accepted procedure (Melton, et al. 2015; Jordan and Barroll, 2013; Clark et al., 2014; and others). When possible, other data sources are used to verify the irrigated area and crop area estimates developed.

Methodology

The methodology for estimating irrigated crops areas for EBID, EPCWID, Hudspeth and Juarez is described in this section.

A total of 35 different crops are identified in the historical crop records for the Study Area, including several major crops and many minor crops based on acreage. An appropriate and reasonable accepted practice (ASCE, 2016, p. 365) is to group into a smaller number of crop categories based on similarity in factors that influence crop water use and applied water requirements, including growing season, cultural practices and water requirements. The nine crop categories defined are the same for all parts of the Study Area, although not all crops are present in all areas in all years. Each of the individual crops was placed in one of the nine crop categories.

The various irrigated crop data sources were assessed for consistency and reliability, revealing that District crop reports provide the most complete, consistent and reliable basis for establishing irrigated crop areas over time. However, recognizing that the District crop reports have certain limitations, adjustments were made to provide a more accurate representation of irrigated crop history. In particular, as previously noted, the District crop reports only account for crops supplied with surface water supplied by Reclamation, and generally do not account for crops irrigated with groundwater only. When one crop follows another crop on the same area in the same year, a practice known as double-cropping, the area is reported to have the first crop. The methodology used to develop the crop coefficient (described in Section 5) includes the second crop where it exists.

In some years, slight differences between the total cropped acreage in some valleys and the irrigated area received from INTERA were observed. Therefore, the total irrigated crop areas determined from adjusted District crop reports were adjusted to match the irrigated area received from INTERA, while preserving the proportion of acres in the nine crop groups.

For Juarez, three technical reports and the NDVI analysis of Landsat imagery were available. Similar to the US Districts, total reported Juarez crop areas were slightly different than the irrigated areas received from INTERA. In all cases, the total irrigated crop areas from the available reports were adjusted to match the irrigated area received from INTERA, while preserving the proportion of acres in the crop groups.

Results

The irrigated crop areas from the data sources described in the previous section and the estimates of total irrigated crop areas are described in the following sections.

Crop Groups

Reclamation Crop Reports have acreage for up to 35 different crops in EBID, EPCWID, and Hudspeth. The 35 individual crops were each assigned to one of nine crop groups with similar growing seasons, cultural practices and water requirements as indicated in appendices B through F of ASCE (2016). These nine primary crop groups represent 94, 96, and 92 percent of the total irrigated area in EBID, EPCWID, and Hudspeth, respectively (**Tables 5-2, 5-3, and 5-4 for the period 1975 through 2010 as an illustrative example**). With the area of each remaining crop assigned to one of these groups, 100 percent of the area in each district is included every year that is evaluated. The nine crop categories defined are the same for all parts of the Study Area, although not all crops are present in all areas in all years. A list of detailed crop types included in the Reclamation crop reports as reported by Davids Engineering and corresponding crop group assignments for calculating ET are provided in **Appendix 5A**.

Table 5-2. EBID Primary Crops 1975 through 2010 and Crop Groups.

Crop Group	1975-2010 Minimum Area, acres[1]	1975-2010 Minimum Year	1975-2010 Maximum Area, acres[1]	1975-2010 Maximum Year	1975-2010 Average Area, acres	Average Area, %	Cumulative Average Area, %
Cotton	6,743	2009	31,697	1975	18,410	24%	24%
Pecans	6,436	1976	23,097	2010	15,716	20%	44%
Alfalfa Hay	12,123	1989	19,096	1985	15,593	20%	64%
Miscellaneous Vegetables	3,270	1995	13,640	2004	7,403	9%	73%
Chile (Peppers)	2,415	2006	11,554	1985	6,586	8%	82%
Corn, Sweet Corn, and Silage	671	1987	9,959	1999	5,995	8%	89%
Wheat and Small Grains	254	2003	14,389	1976	3,799	5%	94%
Onions	2,695	1981	5,184	1993	3,690	5%	99%
Irrigated Pasture	467	1998	4,026	1987	903	1%	100%
Total					78,095	100%	

[1]The year the minimum or maximum occurred is in provided in parenthesis.

Table 5-3. EPCWID Primary Crops 1975 through 2010 and Crop Groups.

Crop Group	1975-2010 Minimum Area, acres[1]	1975-2010 Minimum Year	1975-2010 Maximum Area, acres[1]	1975-2010 Maximum Year	1975-2010 Average Area, acres	Average Area, %	Cumulative Average Area, %
Cotton	8,733	1976	32,390	1979	22,562	48%	48%
Pecans	1,508	1975	13,566	2008	6,980	15%	63%
Alfalfa Hay	3,585	2005	12,542	1977	6,727	14%	78%
Wheat and Small Grains	0	2000	15,242	1976	2,961	6%	84%
Corn, Sweet Corn, and Silage	81	2007	7,913	1976	2,886	6%	90%
Miscellaneous Vegetables	40	2010	3,387	1999	1,514	3%	94%
Irrigated Pasture	87	2009	4,289	1993	1,452	3%	97%
Chile (Peppers)	0	2009	2,785	1994	792	2%	98%
Onions	0	2009	1,722	1994	705	2%	100%
Total					46,579	100%	

[1]The year the minimum or maximum occurred is in provided in parenthesis.

Table 5-4. Hudspeth Primary Crops 1975 through 2010 and Crop Groups.

Crop Group	1975-2010 Minimum Area, acres[1]	1975-2010 Minimum Year	1975-2010 Maximum Area, acres[1]	1975-2010 Maximum Year	1975-2010 Average Area, acres	Average Area, %	Cumulative Average Area, %
Cotton	2,782	1976	16,377	1989	9,779	72%	72%
Alfalfa Hay	450	1989	3,721	1976	1,315	10%	82%
Irrigated Pasture	0	1998	4,126	1975	995	7%	89%
Chile (Peppers)	0	1975	2,440	1992	509	4%	93%
Corn, Sweet Corn, and Silage	0	1976	2,106	2001	419	3%	96%
Miscellaneous Vegetables	0	1975	1,695	1992	282	2%	98%
Wheat and Small Grains	0	1978	1,714	1975	254	2%	100%
Onions	0	1975	218	1993	24	0%	100%
Pecans	0	1975	58	2003	22	0%	100%
Total					13,600	100%	

[1]The year the minimum or maximum occurred is in provided in parenthesis.

Crop Areas

The annual distribution of crop areas for EBID, EPCWID and Hudspeth were calculated from District Crop Reports for the years 1938-2010. (District Crop Reports were not available for EPCWID and Hudspeth for 2009; the average of 2008 and 2010 data was used for that year.) Crops listed in District Crop Reports were assigned to one of nine crop groups with similar growth characteristics and cultural practices as described previously and detailed in **Appendix 5A**. First the reported crop acreages for each District were compiled for each year, for each crop group. Annual crop distributions for each district were calculated by dividing the area in each crop group by the total cropped area in each District. The sums of the crop group distributions for each year add up to 100% for each District. The annual crop distribution percentages were used to estimate irrigated crop areas in model sub regions within each District.

For years 2011-2018, crop distributions for EBID, EPCWID and Hudspeth were determined using the NASS CDL reported crop acres and the procedure described in the previous paragraph.

Estimates of the crop distribution for New Mexico groundwater only fields were developed according to the following steps:

- 'Pecan' acreage from 1938 to 2018 was estimated using the following sources:
  - Intera 'Pecan' identification, available for the following years: 1976, 1996, 2004, and 2010.
  - Reclamation reports were used for the following years: 1937, 1939, 1945-1956, and 1959.
  - The New Mexico field survey was used for the area in New Mexico in 2008.
  - The remaining years were estimated by linear interpolation between adjacent years.

- The percentages of all crop groups, except for 'Pecans' (described above) were based on the 2008 New Mexico field survey.
- The percentages from foregoing step were applied, to all years to determine annual irrigated acreage by crop group from 1938 to 2018.

Estimates of the crop distribution for Juarez were developed for years with NDVI data by preserving the proportional area representing each crop group across the total cropped area in the Juarez determined from NDVI analysis. For the years before the NDVI analysis was available, the crop areas reported in the available reports were used.

Crops listed in District Crop Reports were assigned to one of nine crop groups with similar growth characteristics and cultural practices as described previously and detailed in **Appendix 5A**. The total irrigated area for EBID - SW (surface water), EBID - GO (groundwater only), EPCWID, Hudspeth and Juarez are provided in **Appendix 5B**. Annual irrigated crop areas by crop group are provided in **Appendix 5C** and **Appendix 5D** for each District. The acreages by crop group for the last 81 years (1938 through 2018) are shown in **Figures 5-1 through 5-5** for EBID - SW (surface water), EBID - GO (groundwater only), EPCWID, Hudspeth and Juarez, respectively. Agricultural land use classes that are not irrigated are not included in the analysis and not assigned to a crop group.

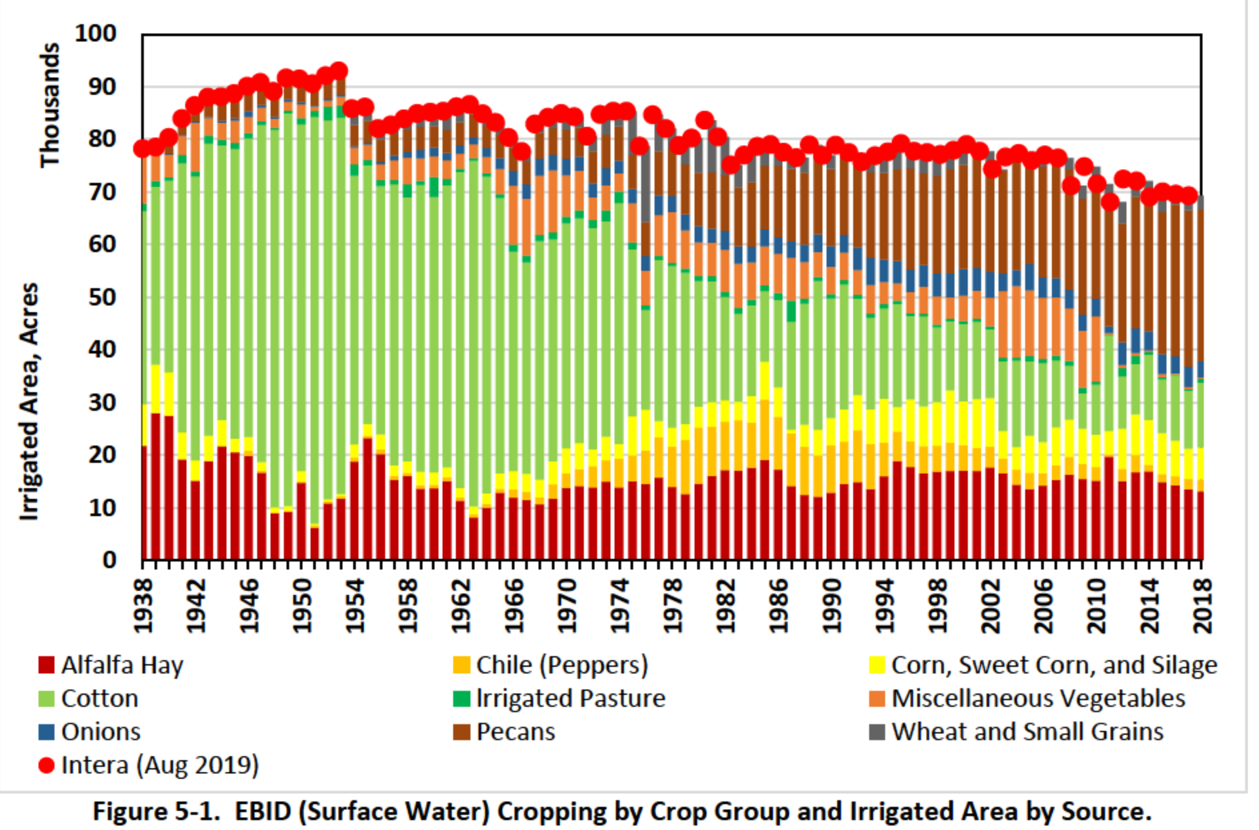

Figure 5-1. EBID (Surface Water) Cropping by Crop Group and Irrigated Area by Source.

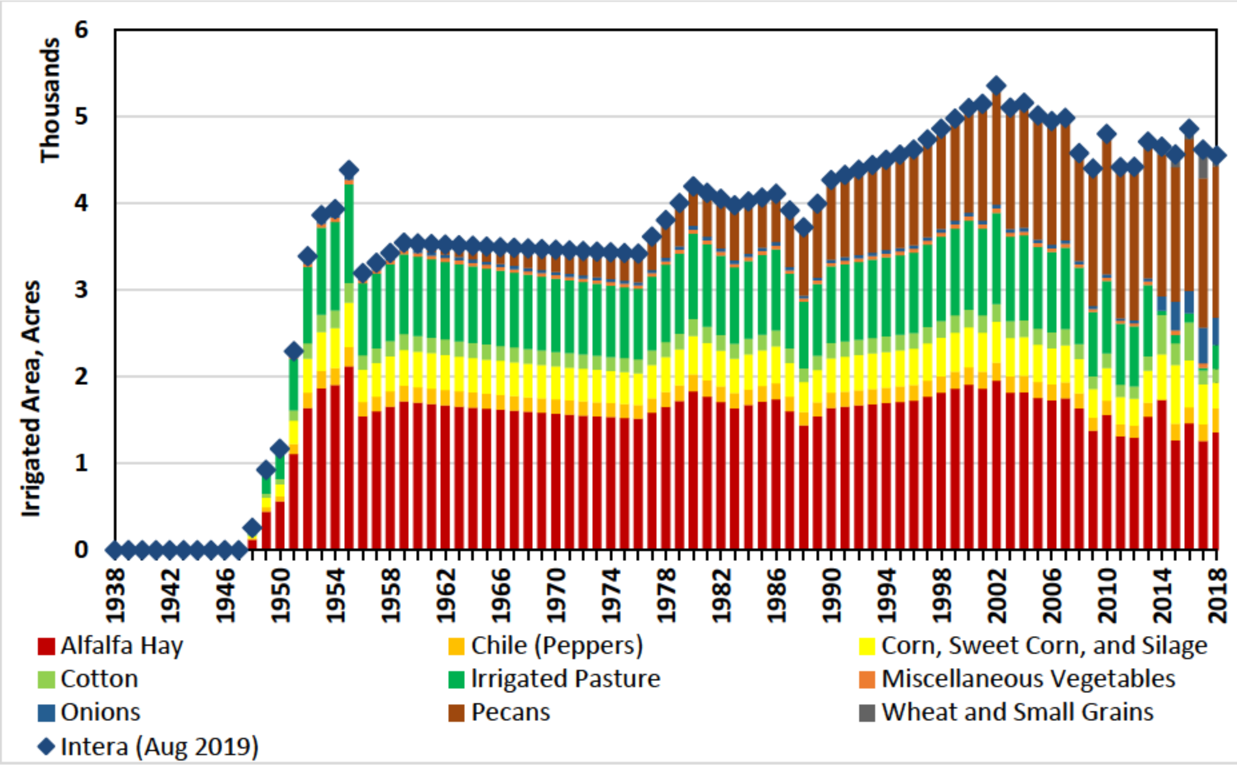

Figure 5-2. EBID (Groundwater Only) Cropping by Crop Group and Irrigated Area by Source.

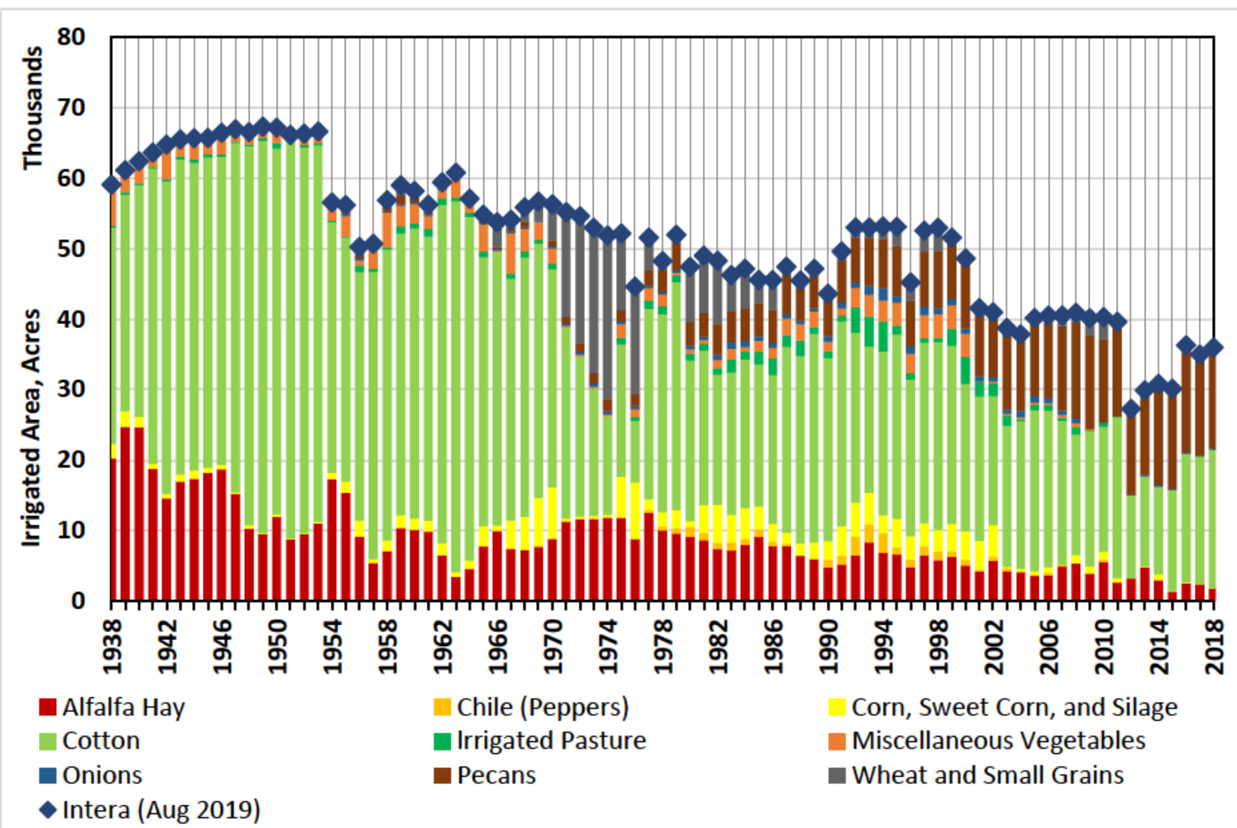

Figure 5-3. EPCWID Cropping by Crop Group and Irrigated Area by Source.

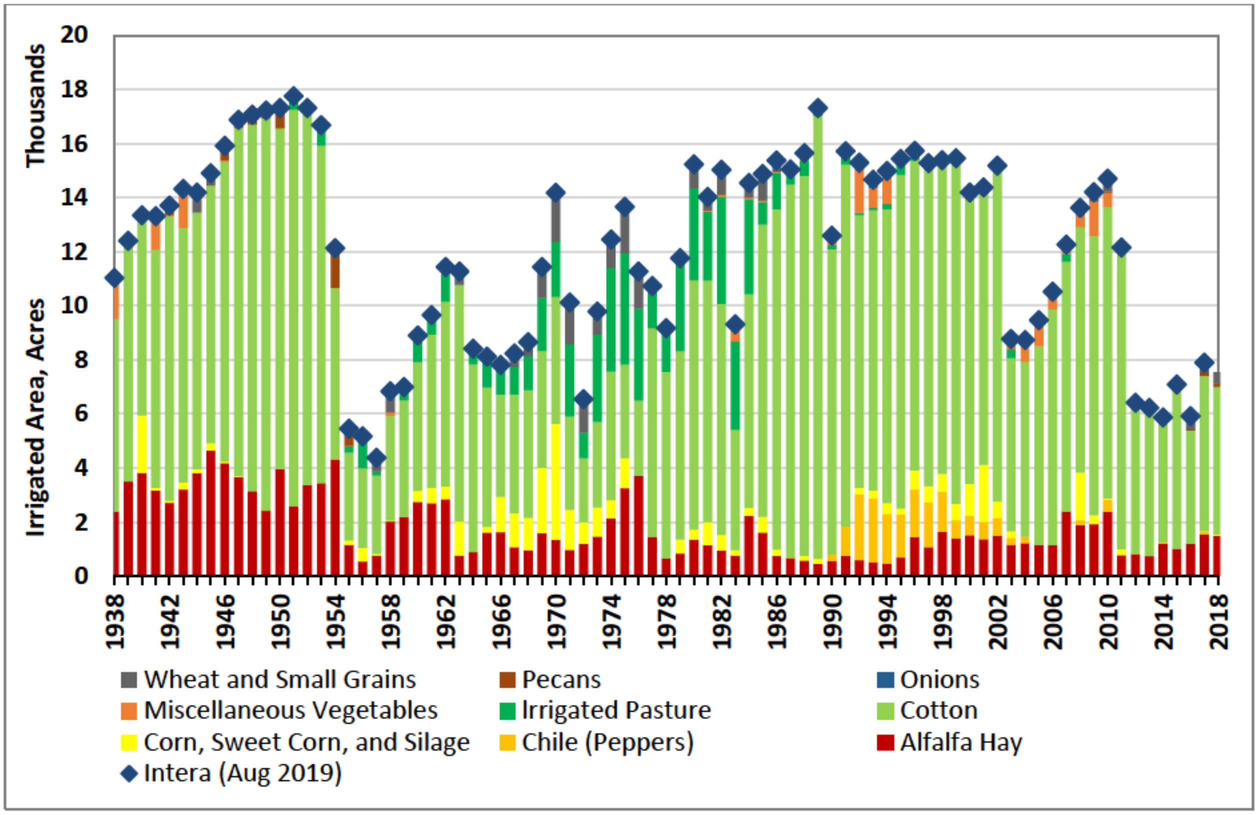

Figure 5-4. Hudspeth Cropping by Crop Group and Irrigated Area by Source.

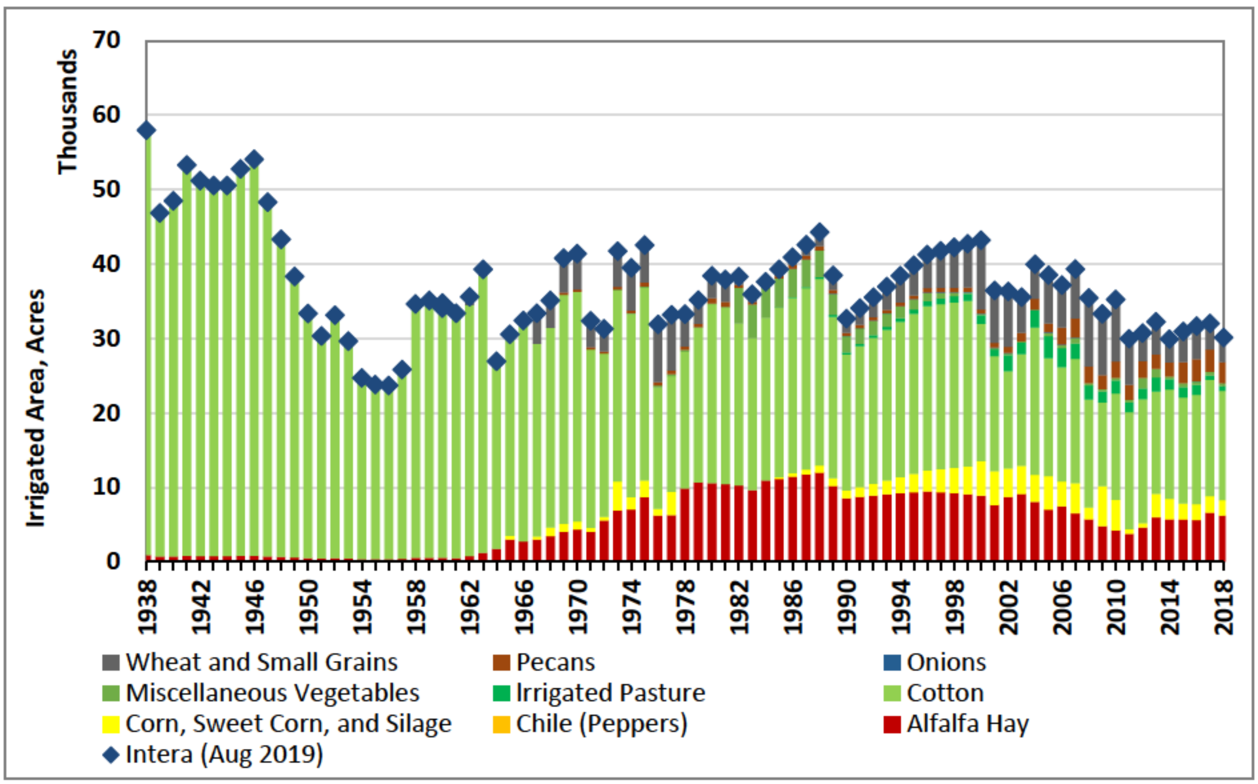

Figure 5-5. Juarez Cropping by Crop Group and Irrigated Area by Source.

Opinions

Over time, there has been an overall decline in irrigated acreage in the Study Area with some variability among the Districts, as summarized below.

For example, EBID irrigated area with access to surface water averaged about 72,800 acres from 2004 through 2018 and has been generally declining since the early 1950s, when it averaged 93,100 acres.

Irrigated area within and in the vicinity of EBID with access to groundwater only (no access to surface water) averaged about 4,700 acres from 2004 through 2018 and in recent years has been generally declining after a peak at about 5,500 acres in 2000.

EPCWID irrigated area averaged about 36,400 acres from 2004 through 2018 and has been generally declining since the early 1950s, when it averaged 66,700 acres.

Hudspeth irrigated area averaged about 9,500 acres from 2004 through 2016 compared to irrigated areas between about 14,000 and 16,000 acres in the 80’s and 90’s.

Juarez irrigated area averaged about 33,800 acres from 2004 through 2018 and has been generally declining in recent years since its peak of 54,000 in 1986.

Since the early 1950s, the predominant crop has generally shifted from cotton to pecans in both EBID and EPCWID.

In EBID, the alfalfa crop acreage has remained about the same while it has decreased in EPCWID.

In Hudspeth, the main crop has remained cotton with some decrease in alfalfa since the early 1950s.

The main crop in Juarez remains cotton with an increase in alfalfa acreage from the early 1950s to the 1980s. Pecan area in Juarez has been increasing in recent years, but still is considerably less than cotton and alfalfa.

VI. Local Calibration of Basal Crop Coefficients

Purpose

The purpose of this section is to describe the methodology used to develop basal crop coefficients for use in the ET Demands root zone water balance model, including the data analyzed and the results. The ET Demands model is used to estimate consumptive use of irrigation water, often referred to as evapotranspiration (ET) of applied water (ET_{aw}), under full water supply (full supply) conditions for irrigated lands in the Study Area. “Full supply” is generally understood to mean that available water supplies are sufficient to fully satisfy irrigation water demands for all lands irrigated. This ET_{aw} can be viewed as an average of the variability in ET_{aw} that occurs among fields under full supply conditions. This variability is attributed to variations within individual fields due to soil water availability, irrigation management, salinity effects, crop disease, and other non-water supply factors. This section describes the methodology used to develop basal crop coefficients and the results.

Methodology

The development of basal crop coefficients described in this section is the first step in a four-step process (**Figure 6-1**) to calibrate ET Demands results to remotely sensed surface energy balance ET estimates. The objective of the calibrated model is to estimate ET_c when under full supply conditions and to apportion ET_c between ET of precipitation (ET_{pr}) and ET_{aw}. To this end, the objective of the calibration process is to develop crop season ET results from the ET Demands model that are within 10 percent of the energy balance ET estimates. Ten percent is a reasonable goal that can be achieved with reasonable effort given typical errors in ET measurement and estimation methods as reported by Allen, et al (2011). The final three steps in the process involve comparing ET results from ET Demands to three years of remotely sensed ET results and are described in the following section describing ET Demands calibration.

In the first calibration step, basal crop coefficients were developed based on actual consumptive use of crops cultivated within the Study Area, as estimated by METRIC analyses. Following the procedure described in this section, these basal crop coefficients were derived from spatial METRIC analyses of irrigated lands in EBID during 2008.

In the second, third, and fourth calibration steps, crop consumptive use characteristics were first provided as inputs to the ET Demands model based on the 2008 METRIC analysis. Then, the resulting ET estimates from the ET Demands model were compared back to METRIC ET estimates from 2008, 2013, and 2002. Years 2002 and 2008 represent approximately full supply conditions in the Study Area, the conditions considered in this report. The third year, 2013 was selected to validate the methodology’s accuracy during a limited supply year. At each step, if the ET results from ET Demands were not within 10 percent of the METRIC ET estimates, the crop inputs to the ET Demands model were revised and the calibration step was repeated again. At the conclusion of this calibration process, ET results from ET Demands were within 10 percent of METRIC ET estimates across the Study Area during 2008, 2013, and 2002.

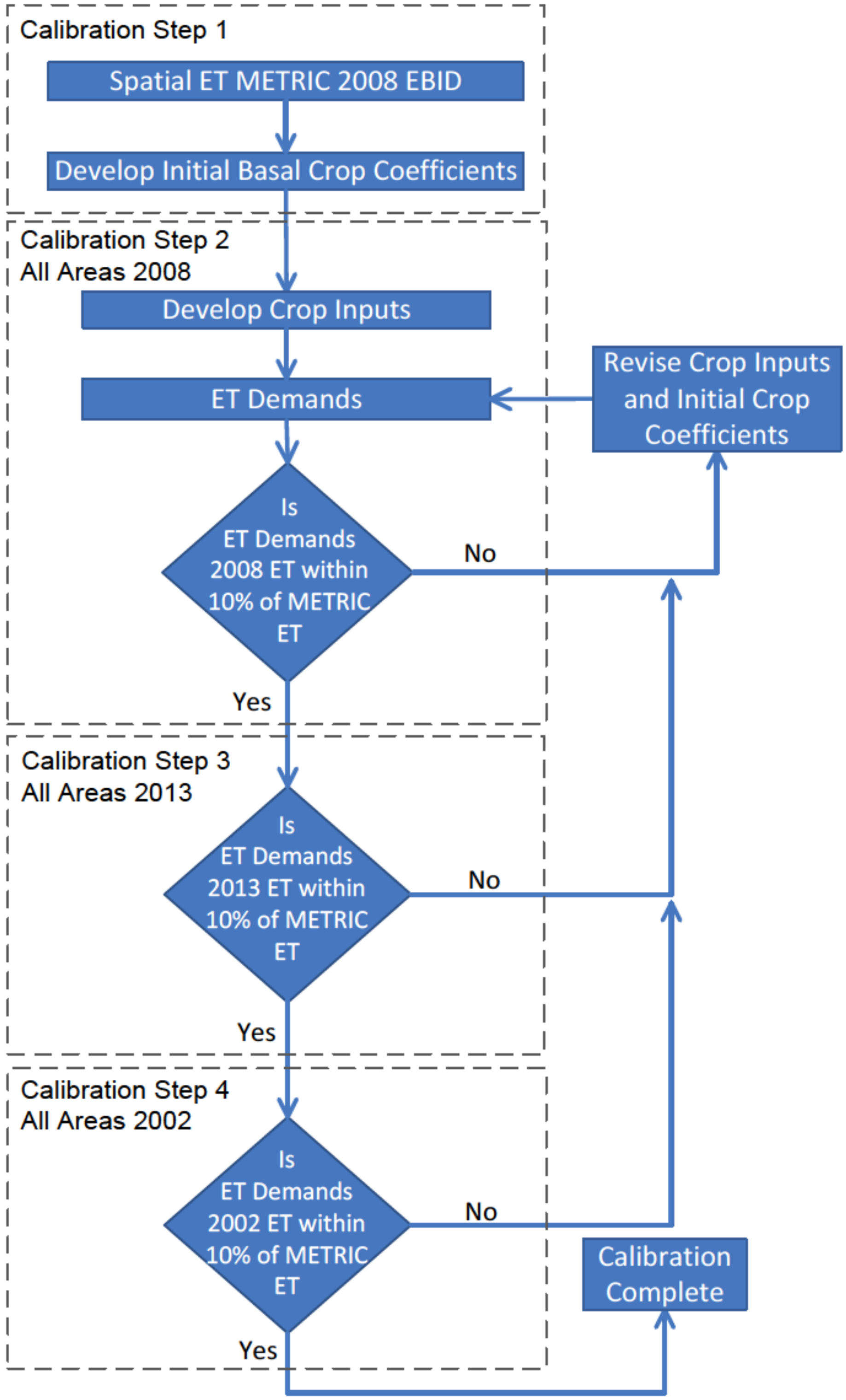

Figure 6-1. ET Demands Calibration Process Including Development of Basal Crop Coefficients

The basal crop coefficients developed for this analysis differ from the basal crop coefficients reported in research reports and technical practice manuals like Allen, et al (FAO 1998), ASABE (2007) and ASCE (2016) in two important ways:

1. These are historical basal crop coefficients that reflect “actual” local conditions in commercial agriculture under full supply conditions at a District-wide scale in contrast to basal crop coefficients used to determine “potential” consumptive use under idealized conditions. As such, they represent the best estimates of the actual ET that occurred under full water supply or would have occurred if a full water supply had been available, taking into account all factors that impact crop growth and ET, including water availability, water quality, pest and disease infestations.
2. These basal crop coefficients represent the average of numerous fields compared to typically reported crop coefficients that are developed from, and for use on, a single field at a uniform stage of development. Each remotely sensed snapshot used in their development consists of many fields at different stages of growth, depending on planting date and management.

Because of these two important differences from typically reported basal crop coefficients, the basal crop coefficients developed for this work tend to be somewhat lower and begin earlier and end later than typically reported crop coefficients. The curves begin earlier and end later because they include the earliest and latest actual planted fields in contrast to curves based on a predefined plant date.

The crop coefficient-reference ET method for estimating crop ET, spatial cropping information, spatial ET_{act}, reference ET (ET_{ref}) and crop coefficient (K_c) curves supporting basal crop coefficient development are described. The last section describes the methodology for determining basal crop coefficients.

Crop Coefficient – Reference ET Method

Crop ET is estimated using the crop coefficient – reference ET method, which generally involves multiplying ET_{ref} by crop-specific and time varying coefficients, crop coefficients (K_c). The method has proven to be accurate, robust, consistent, and relatively straightforward to apply (ASCE, 2016) and is widely accepted and used throughout the western United States and in similar arid, irrigated regions worldwide. Additionally, the method has been standardized through the FAO-56 (Allen, et al., 1998) and ASCE-EWRI (2005) conventions and has a long record of successful application in irrigation water management and irrigation scheduling. In this case, basal crop coefficients were derived from mean crop coefficients developed from actual crop ET estimates for the EBID area generated from satellite-based surface energy balance analyses, as described in the following paragraphs.

The K_c varies by crop and the stage of crop development and relates the ET of a specific crop or land cover class to the ET_{ref}. As the growing season progresses, plants grow and develop and the fraction of land covered by vegetation changes, causing the K_c to change. Precipitation and irrigation change the wetness of the soil adjacent to the crop also leading to changes in K_c. Two approaches for estimating ET values that are scientifically accepted and commonly applied are the single crop coefficient approach and the dual crop coefficient approach (Allen et al., 1998 and ASCE, 2016). The single crop coefficient approach accounts for total evaporation and transpiration from precipitation and irrigation averaged over time into a single, “mean” crop coefficient (K_{cm}). The dual crop coefficient approach separates the crop coefficient into a “basal” crop coefficient (K_{cb}) that accounts for plant transpiration and some residual evaporation from soil, and a second coefficient accounting for soil evaporation (K_e) occurring following soil wetting. The dual crop coefficient approach was chosen to develop ET_{aw} estimates because it allows for separate and more precise accounting for evaporation and transpiration resulting from rainfall and irrigation. The dual crop coefficient approach requires a daily computational time step.

ET_{act} can be estimated from a surface energy balance (Allen, 2003; Bastiaanssen, 2005; Cassel, 2006; Thoreson, 2009). By computing ET from the energy consumed by evaporation of water from soil and plant surfaces, the surface energy balance inherently accounts for the effects of salinity, deficit irrigation, disease, poor plant stands, and other field conditions that typically cause ET_{act} to be less than potential (ET_{pot}) on a field, farm, or district scale. Thus, ET generated from satellite-based surface balances better represents local management practices and water availability. Mapping ET at high Resolution with Internalized Calibration (METRIC) is a widely used and accepted surface energy balance methodology with numerous applications, both in the western US (Wyoming, Idaho, Nevada, Colorado and California) and internationally (Australia, Spain, Portugal, China and Morocco), some of which are described in Serbina and Miller (2014). METRIC uses spectral radiances recorded by satellite-based sensors, including a thermal sensor, along with ground-based weather data to solve the energy balance at the Earth's surface, yielding spatially distributed estimates of ET_{act} from vegetation and land surfaces. ET_{act} is computed for each pixel in a multispectral satellite image by applying energy balance physics. Daily results are provided for each satellite image. Time-integrated monthly, seasonal and annual totals are generated for multiple images across a crop growing season or year by developing crop coefficient curves that are used to estimate ET_{act} throughout the season, including on days between satellite images. METRIC ET_{act} estimates have been validated extensively in irrigated agriculture environments (Allen, et al., 2007a and Singh and Senay, 2016). A detailed description of METRIC is provided by Allen, et al. (2007b).

For this analysis, the METRIC daily results have been used to provide information on the timing of crop coefficient development throughout the growing season. To develop K_{cm} values for individual crops and crop groups, the crop in each field on the image date must be known. The source for this information is described in the following section.

Spatial Cropping Information

In 2008, the crop in each field was determined from a ground-based crop survey for EBID and the geospatial crop data layer (CDL) from the United States Department of Agriculture National Agricultural Statistics Service (USDA NASS) for EPCWID and Hudspeth. In 2013, the crop in each field was assigned based on the CDL for EBID, EPCWID and Hudspeth. The following paragraphs briefly describe these two data sources. Data identifying the crop in the field was not available for Juarez in any of the three years.

The New Mexico Office of the State Engineer/Interstate Stream Commission (NMOSE/ISC) staff identified the crop that was present in each EBID field during four field visits, including the spring, summer and fall of 2008 and the spring of 2009. The purpose of the field visits was to characterize the complex cropping patterns in EBID (Longworth, 2011). The use of a geographic information system (GIS) linked to the Global Positioning System (GPS) located each field and stored the crop identified as growing in the field providing the crop location information needed to support the development of crop coefficients from METRIC. The 2008 EBID crop survey results are summarized in **Table 6-1**.

The CDL is a GIS raster layer and the only data available for EPCWID and Hudspeth in 2008 and 2013 and for EBID in 2013. A GIS raster layer contains an independent value for each pixel in the data layer. The 2008 CDL for New Mexico and Texas utilized multiple satellites to estimate the crop type for each 56-meter square pixel. Fields contain many pixels, so it is possible that not all pixels within each field are assigned the same crop classification. Generally, the crop classification of the majority of pixels within a field is assigned to the entire field. Details of the method used to assign one crop to each field from the CDL pixels within the field boundaries are described in **Appendix 6A**.

Table 6-1. EBID 2008 Major Crop Types, Number of Field Polygons, and Acres Represented (NMOSE/NMISC Ground Survey).

Crop Category	Field Area (acres)	Number of Fields	Average Area per field (acres)
Pecans	28,643	3,612	8
Alfalfa Hay	17,529	1,700	10
Cotton	11,727	721	16
Irrigated Pasture	7,205	2,505	3
Corn, Sweet Corn, and Silage	6,701	417	16
Chile (Peppers)	4,118	360	11
Onions	872	50	17
Wheat and Small Grains	816	54	15
Miscellaneous Vegetables	593	104	6
Total:	78,204	9,523	8.2

Spatially Distributed ET_{act}

Spatially distributed ET_{act} was calculated for the Study Area for 2008 using the METRIC energy balance algorithm (Allen Engineering, 2008 and ET Plus, 2014). Because of the availability of a ground-based crop survey identifying crops in the field, only EBID METRIC results were used for developing K_{cb} values. METRIC solves the energy balance at the Earth's surface for ET using data collected by satellite and weather stations. METRIC first determines the available energy from the Sun and atmosphere (net radiation, R_n), then calculates two of the three significant energy uses (1) heating of the ground surface (soil heat flux, G), and (2) heating of air at the surface (sensible heat flux, H). Then, the energy used to evapotranspire water (the third significant use of energy) is calculated as the difference between the available energy from the Sun and the amount of energy used to heat the ground surface and the air. METRIC ET_{act} estimates have been validated extensively in agricultural environments. A detailed description of METRIC is provided by Allen, et al. (2007a,b). Daily, monthly and seasonal estimates of ET_{act} were developed for each 30-meter satellite pixel within the Study Area.

Reference ET

Quality-controlled weather data from the Leyendecker Automatic Weather Station (AWS) were used to calculate alfalfa reference ET (ET_r) and ET_o for the EBID area.

Mean Crop Coefficients Derived from METRIC Results

METRIC results provide mean crop coefficients for each pixel based on ET_r. Prior to beginning the crop coefficient analysis, the METRIC mean crop coefficients based on ET_r were converted to mean crop coefficients based on ET_o by multiplying by the ratio of ET_o to ET_r on the day of each image. This ratio was provided with the METRIC results. To facilitate the analysis of K_{cm} over time, the data were organized in a Microsoft Access database containing field-specific and date-specific K_{cm} and Normalized Difference Vegetation Index[4] (NDVI) values.

The database for analysis of K_{cm} values was created by overlaying EBID, EPCWID and Hudspeth field polygon layers over crop coefficient and NDVI raster images. Data were extracted using ArcMap's spatial analyst tool and organized in a database. **Appendix 6A** describes the detailed step by step

[4] An index sensitive to changes in crop canopy cover.

process of extracting the data using ArcMap to develop the database. The EBID data was used to develop the crop coefficients.

Estimation of Basal Crop Coefficients

The K_{cm} discussed in the preceding section includes evaporation from the soil which depends on the stage of crop development and the wetting frequency and depth from irrigation and rainfall. To obtain more accurate estimates of ET and effective precipitation, a dual crop coefficient and a daily root zone model (ASABE, 2007 and ASCE, 2016) is used. The dual crop coefficient approach requires a basal crop coefficient (K_{cb}), crop transpiration divided by ET_o, to estimate transpiration and an evaporation coefficient (K_e) to estimate evaporation following wetting events. For each crop and image date, to relate K_{cb} to crop vegetative development, K_{cb} was estimated based on the average NDVI of fields in EBID. A relationship between NDVI and K_{cb} was developed for each crop based on observed field scale relationships between NDVI and ET_oF[5] from the 2008 METRIC results. Four methods of defining the relationship between NDVI and K_{cb} (Tasumi, et al., 2006 and Er-Raki, et al., 2007) were considered:

Method 1: $$k_{cb} = 1.2 \times NDVI \qquad \textbf{(Eq. 6-1)}$$

Method 2: $$k_{cb} = 1.4 \times NDVI \qquad \textbf{(Eq. 6-2)}$$

Method 3: $$k_{cb} = m \times NDVI + b \qquad \textbf{(Eq. 6-3)}$$

Method 4 (Er-Raki): $$k_{cb} = k_{cb,max}\left[1 - \left(\frac{NDVI_{max} - NDVI}{NDVI_{max} - NDVI_{min}}\right)^{1.56}\right] \qquad \textbf{(Eq. 6-4)}$$

These four methods were compared against average METRIC ET_oF and NDVI results to select an appropriate method that most accurately reflected average crop growth conditions observed in fields across the Study Area.

In **Equation 6-3**, m represents the slope of a linear relationship between NDVI and k_{cb} and is calculated as $\frac{k_{cb,max} - k_{cb,min}}{NDVI_{max} - NDVI_{min}}$, where $k_{cb,max}$ is the maximum expected value of K_{cb} among a population of fields and occurs at $NDVI_{max}$ (maximum expected NDVI), and $k_{cb,min}$ is the minimum expected value of K_{cb} (set as zero, which occurs when no transpiring vegetation is present) among a population of fields and occurs at $NDVI_{min}$ (NDVI value corresponding to bare soil). The intercept, b, is then calculated as $b = k_{cb,max} - m \times NDVI_{max}$. **Equation 6-4** represents a curvilinear relationship between NDVI and K_{cb} as described by Er-Raki et al. (2007). In **Equations 6-3 and 6-4**, the minimum allowable value of K_{cb} was set to zero for the time before the crop is planted and prior to emergence.

Average METRIC ET_oF, NDVI, and estimated K_{cb} for EBID cotton fields in 2008 based on each method (**Equations 6-1 through 6-4**) are shown in **Figure 6-2**. Similar graphs were prepared for all crops in the Study Area. Results for individual image dates are connected by a smoothed line, essentially equivalent to a cubic spline. The METRIC ET_oF results correspond to a combination of evaporation and transpiration, with evaporation representing all of the ET early in the growing season (note impacts of pre-irrigation in the March, April, and May images), and transpiration representing most of the ET during mid-season (July, August, and September). During peak season, it is expected that the K_{cb} would be approximately equal to ET_oF due to full or nearly full shading of the soil surface by the crop, limiting

[5] Grass reference ET fraction, synonymous with K_{cm} and generally refers to K_{cm} values from METRIC results.

evaporation. Prior to planting, it is expected that K_{cb} would be approximately zero as no crops would be available to transpire.

Based on review of these crop season graphs, **Equation 6-4** (the Er-Raki method) was selected to estimate the basal crop coefficient corresponding to each image date. This methodology was chosen because it results in a K_{cb} value at peak season equal to the average ET_oF, while producing K_{cb} values of zero prior to planting, accurately reflecting the trend of crop evapotranspiration throughout the year.

As indicated in the figure, the methodologies of **Equations 6-1 and 6-2** result in K_{cb} values of approximately 0.15 to 0.20 early in the season, when vegetation is not believed to be present, and the K_{cb} would be expected to be near zero. Additionally, K_{cb} values from **Equations 6-1 and 6-2** reach approximately 0.85 to 1.00 during mid-season, which is substantially less than the average ET_oF of approximately 1.05. During peak season, it is expected that the K_{cb} would be approximately equal to ET_oF due to full or nearly full shading of the soil surface by the crop, limiting evaporation. **Equation 6-3** results in a K_{cb} of zero prior to planting but reaches only approximately 0.9 at peak season.

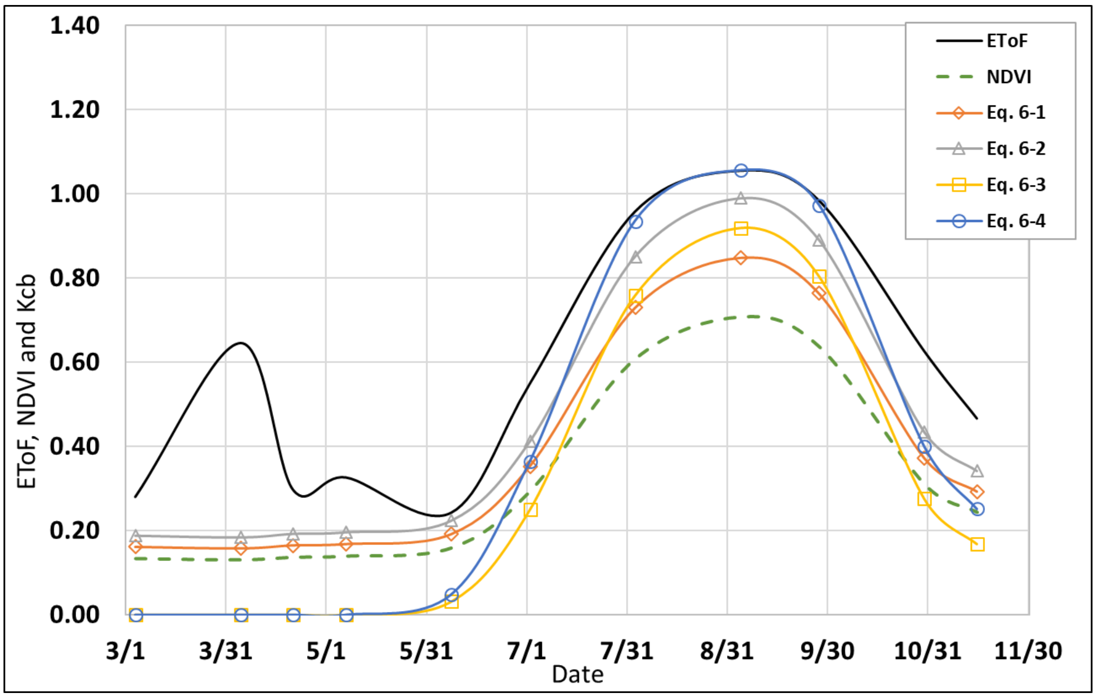

Figure 6-2. 2008 Average ET_oF, NDVI, and K_{cb} Estimates for EBID Cotton.

The following steps were completed for each crop to parameterize **Equation 6-4**:

1. Review relationships between NDVI and ET_oF.
2. Combine the distributions of average field NDVI and ET_oF values for image dates occurring during the primary growing season (June to September) on a single scatter plot.
3. Iteratively revise the initial parameters used in **Equation 6-4** until the resulting basal crop coefficient curve fits the METRIC results for the image dates corresponding to full cover.

Results

Crop coefficient curves based on the METRIC results are discussed and the results of the three steps followed to develop a K_{cb} curve from METRIC using the Er-Raki equation for cotton are described in the following sections.

K_{cm} Curves

Figure 6-3 is an example K_{cm} curve from the METRIC results that includes evaporation from rainfall and irrigation and shows how K_{cm} varies with time for about 600 fields identified as cotton by the NMOSE ground-based crop survey. Mean and median values of K_{cm} were determined for all cotton fields on each image date and then plotted. Plots of mean and median values of K_{cm} on each image date for all fields for each crop are included in **Appendix 6B**.

METRIC ET estimates combined with field polygons and crop information for each field in the Study Area make it possible to develop crop coefficients that represent local conditions. Variability in ET from field to field as seen in the METRIC results is typical of most irrigated areas. This variability is due to a number of factors including difference in planting dates, soil conditions, irrigation management, and plant health. METRIC observes this variability for the particular historical conditions that existed in the year of the METRIC analysis. Limitations of the METRIC are that it takes considerable time and experience, and is limited to recent years when Landsat images are available. The crop coefficients developed from this information represent the mean ET that would occur under full supply conditions, recognizing that some individual fields will have ET greater and others less than the computed mean ET value.

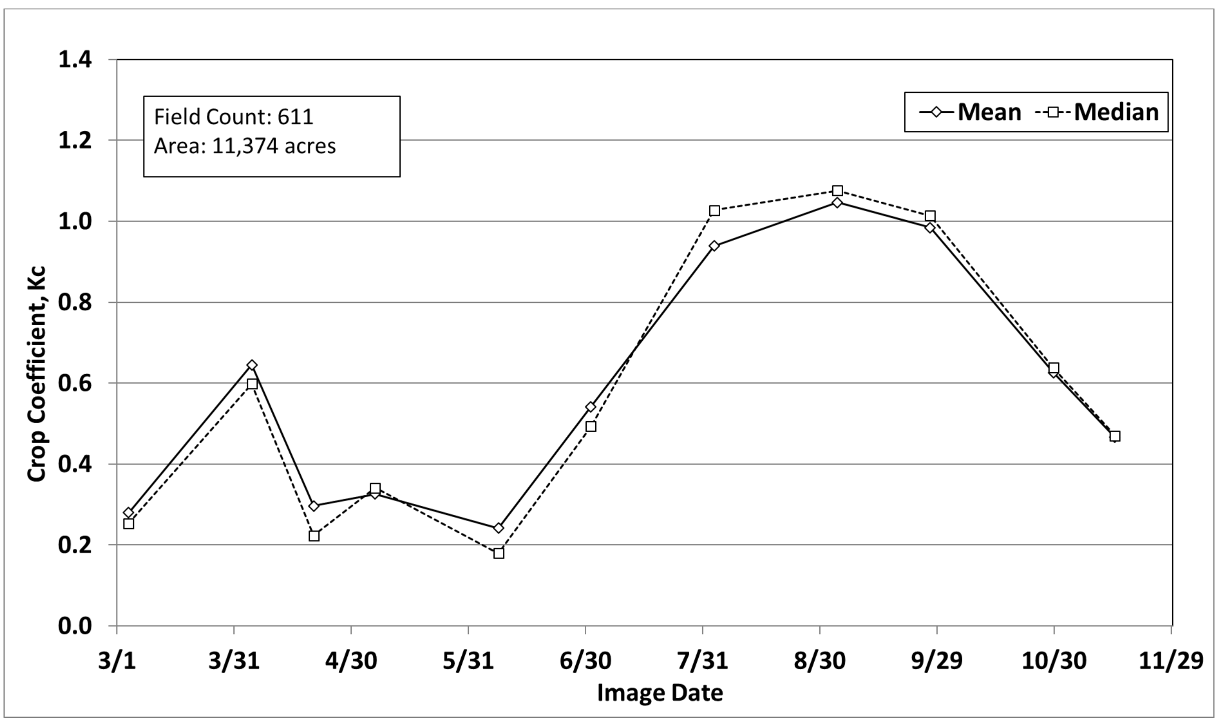

Figure 6-3. 2008 METRIC - Derived Crop Coefficients (ET_c/ET_o) for Fields Identified with Cotton by NM Field Survey.

NDVI Curves

The Normalized Difference Vegetation Index (NDVI) is sensitive to changes in crop canopy cover. **Figure 6-4** is an example of how NDVI changes with time for cotton fields in EBID. Comparing **Figures 6-3 and 6-4** side-by-side, pre-irrigation and approximate green up time can be detected. The relatively high K_c values (**Figure 6-3**) in early April are due to high evaporation resulting from pre-irrigation of many fields at that time. The mean and median NDVI for the same time period is low indicating there is little green vegetation, or cotton growth, present. Field observations, literature review and interviews with local growers confirm that nearly all cotton fields pre-irrigate during a one to two-week period in late March and early April to assist in seed germination. After planting between mid-April and mid-May the NDVI begins to slowly increase and by early July most fields have NDVI between 0.2 and 0.4 (**Figure 6-4**). Crop coefficients and NDVI decline around the same time as plants become mature and harvest approaches.

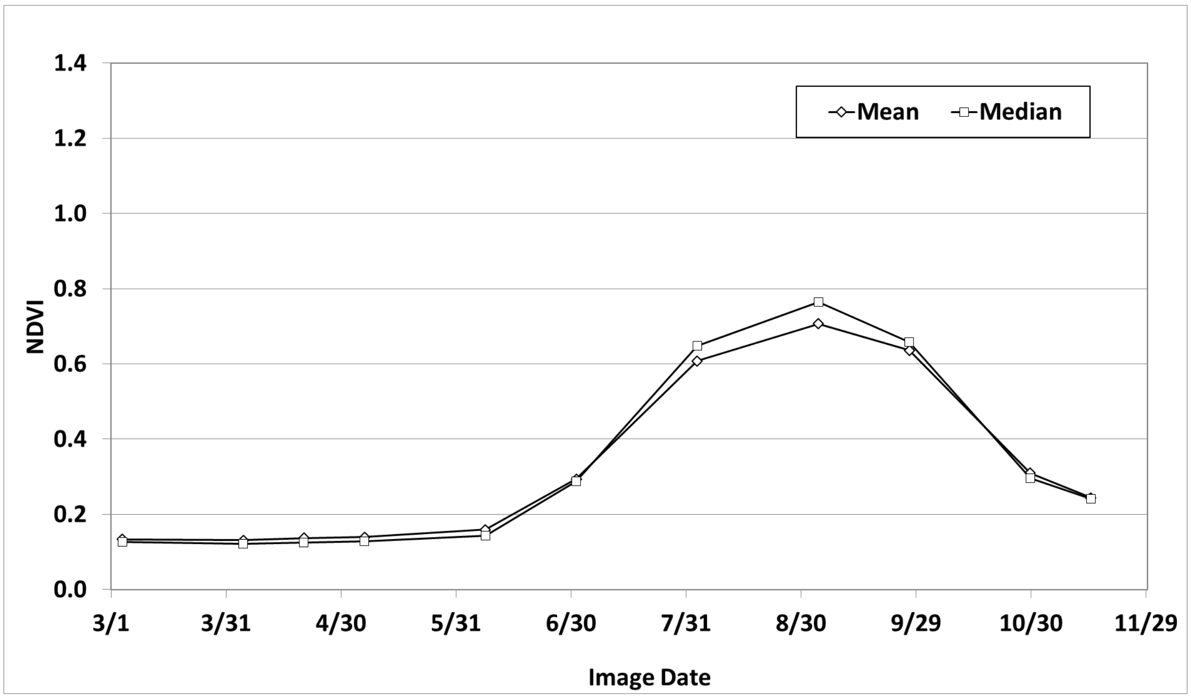

Figure 6-4. NDVI for Fields Identified to have Cotton by NM Field Survey.

Relationships between NDVI and ET_oF

The relationships between NDVI and ET_oF for cotton are shown in **Figure 6-5** for eight image dates from May 7 to November 15, 2008. In each graph, average NDVI for individual fields is shown on the x-axis, and average ET_oF is shown on the y-axis.

The majority of fields have an NDVI of 0.1 to 0.15 in the May image and 0.1 to 0.2 in the June image, suggesting little or no presence of green vegetation. The wide variability in ET_oF denotes differences in soil wetness and resulting evaporation rates resulting from early season irrigations or precipitation. Fields with greater NDVI have green vegetation present, with the "base" of the ET_oF distribution representing the relationship between K_{cb} and NDVI (see notes in **Figure 6-5.1 and 6-5.3**). As the growing season progresses, transpiration becomes the dominant component of ET, as indicated in **Figure 6-5.4 and 6-5.5**, with fields with greater NDVI having a greater K_{cb} (and ET_oF). Close to and following harvest in October and November, NDVI and ET_oF values tend to decrease and are again largely influenced by evaporation.

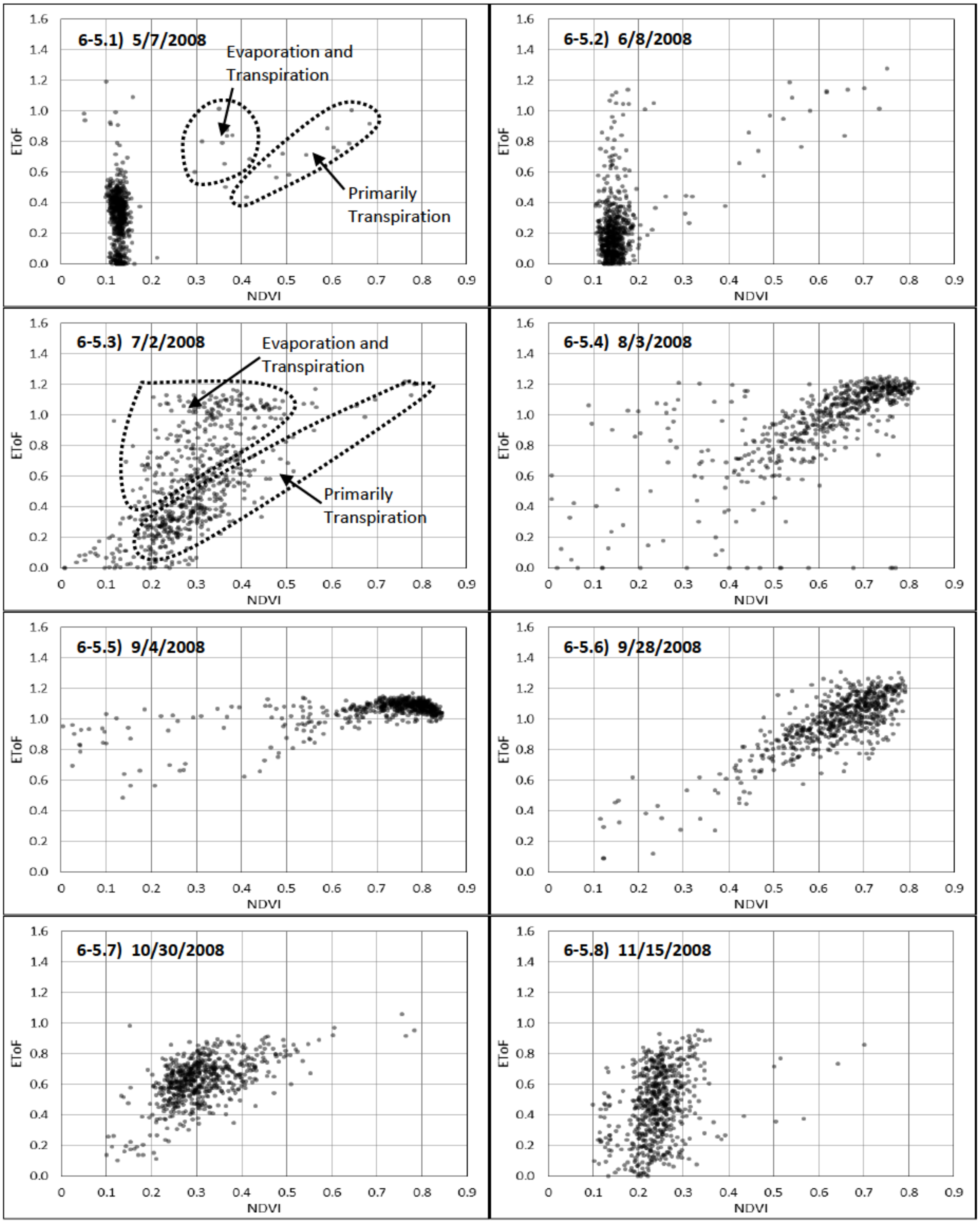

Figure 6-5. NDVI and ET_oF for EBID Cotton Fields, May 7 to November 15, 2008.

The relationships between NDVI and ET_oF for the remaining crops are shown in **Appendix 6C** for image dates for the 2008 growing season. The annual crop NDVI generally follows a pattern similar to cotton with low NDVI and ET_oF varying from low to high for dry and wet soil conditions, respectively, early in the season. As the growing season progresses, NDVI and ET_oF increase as the crop shades the soil and transpiration becomes dominant. Following harvest, NDVI values decrease and ET_oF depends on soil moisture conditions. Alfalfa and pasture have less variability in ET_oF at the low NDVI values because these crops shade the soil year round limiting evaporation.

Combined Distributions of Average Field NDVI and ET_oF Values

To parameterize K_{cb} through **Equations 6-3 and 6-4**, first the distributions of average field NDVI and ET_oF values for image dates occurring during the primary growing season (June to September) were combined on a single scatter plot (**Figure 6-6** and **Appendix 6D**). $NDVI_{min}$, which corresponds to a k_{cbmin} value of zero, was estimated to be 0.14. $NDVI_{max}$ and k_{cbmax} were estimated to be 0.85 and 1.15, respectively. Variability in ET_oF at a given value of NDVI results from factors including primarily differences in wetness of exposed soil and resulting evaporation rates and minor differences in water stress among fields. The average ET_oF value at upper values of NDVI (e.g. above 0.7) is reflective of average stress levels among the population of fields.

Iterative Refinement of K_{cb} Parameters

Parameters selected from review of single scatter plots similar to **Figure 6-6** for each crop group were then used with the Er-Raki equation (**Equation 6-4**) to estimate basal crop coefficients reflective of the population of fields. These initial parameter values varied by crop within narrow ranges and were iteratively revised until the resulting basal crop coefficient curve fit the METRIC results for the image dates corresponding to full cover (**Figure 6-7**). The curve labeled ASCE 2016 is the K_{cb} for cotton found in Appendix D of the ASCE Manual 70, Evaporation, Evapotranspiration, and Irrigation Water Requirements. This K_{cb} is for "well-managed" crops and is often referred to as a potential K_{cb}. The K_{cb} curves have the same general shape. Although the K_{cb} values averaged across large numbers of fields are slightly less than the "book", or potential, K_{cb}, it is important to note that many individual fields have ET_oF values equal to, or even slightly greater than the "book" K_{cb}.

Parameters for All Crops

$NDVI_{min}$ and $NDVI_{max}$ and $K_{cb,min}$ and $k_{cb,max}$ were selected for each of the nine crop groups for the ET Demands model. $NDVI_{min}$ and $NDVI_{max}$ were selected to be 0.14 and 0.85, respectively for each crop[6]. $K_{cb,min}$ and $k_{cb,max}$ were selected to be 0.00 and 1.15 for each crop, respectively, with the exception of pecans, for which $k_{cb,max}$ was selected to be 1.05. This lesser value of $k_{cb,max}$ was selected so the resulting basal crop coefficient curve fit the METRIC results for the image dates corresponding to full cover. Information on the age of the pecan trees was only available for EBID in 2008, so the young pecan orchards are included in the average METRIC ET_oF results to allow use of the crop coefficient when information on pecan tree age is not available.

[6] The $NDVI_{min}$ represents bare ground before the crop emerges, so it is the same for each crop. Although the $NDVI_{max}$ can vary slightly by crop, for the crop groups chosen, the observed value on the NDVI graphs was 0.85.

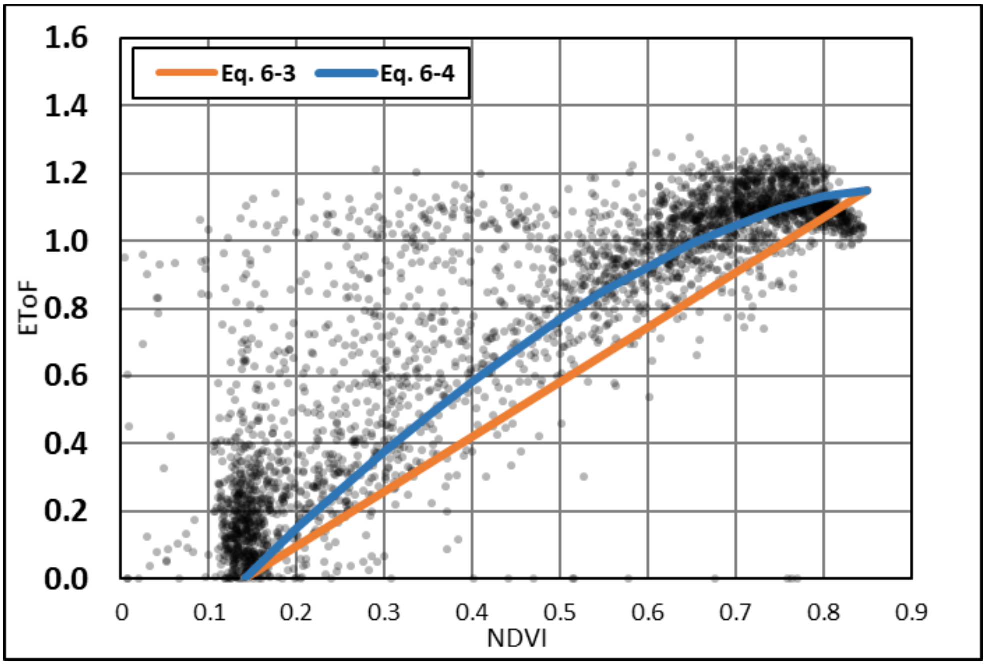

Figure 6-6. NDVI, ET_oF, and Estimated Relationships of K_{cb} to NDVI for EBID Cotton Fields, June 4 to September 28, 2008.

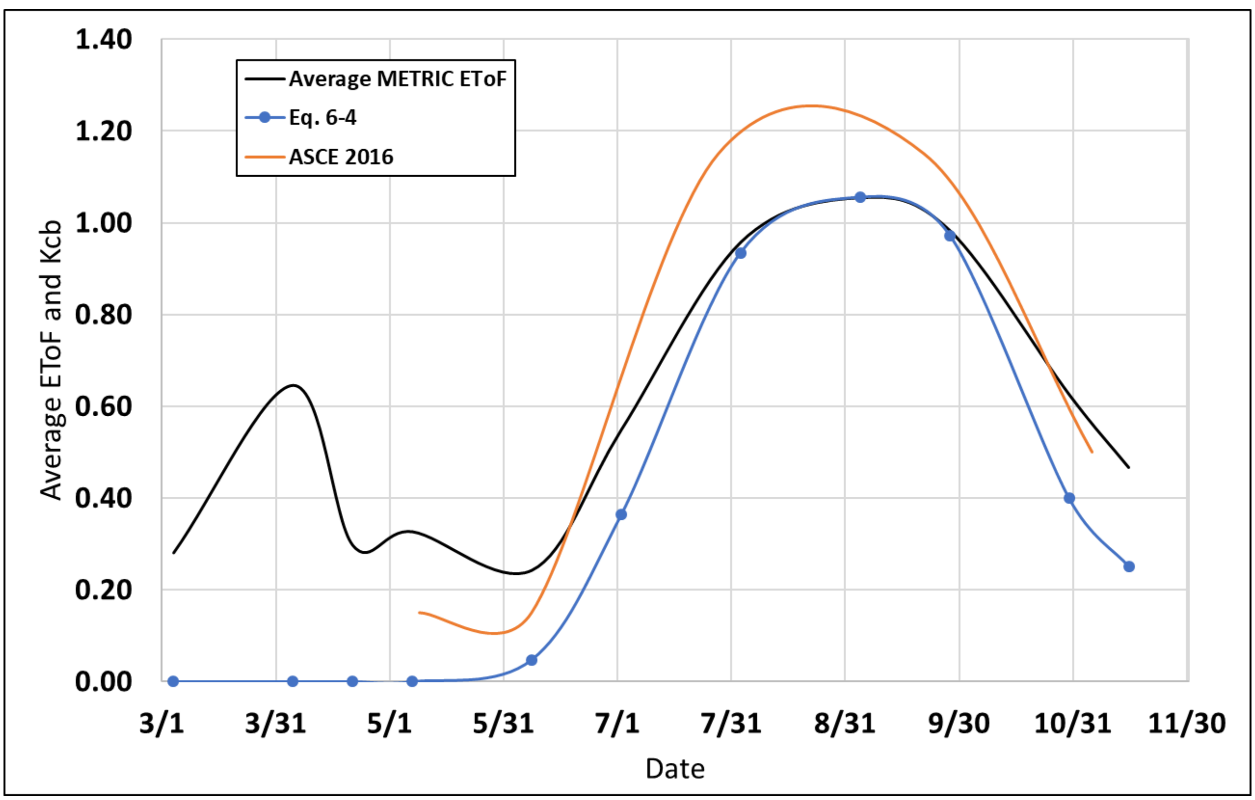

Figure 6-7. 2008 ET_oF and K_{cb} Estimates for EBID Cotton

For alfalfa, the METRIC average ET_oF values, average NDVI values, and estimated K_{cb} values represent an average of alfalfa fields in EBID during 2008. In each image these average values include fields at all stages of development from just after cutting to just before cutting. To parameterize ET Demands for alfalfa, a representative, individual field was simulated including specific hay cutting cycles. Within the ET Demands, K_{cb} values were calculated on a daily basis based on Cumulative Growing Degree Days (CGDD). Two relationships between CGDD and K_{cb} were estimated, one for the period from initial growth to full cover prior to the first cutting, and one for all subsequent cuttings following Allen and Robison (2009). The timing of cuttings was based on the actual CGDD accumulated, and thus varied slightly from year to year. Within ET Demands, the K_{cb} value is set to zero following a killing frost every year according to daily temperature data from Leyendecker Automatic Weather Station (AWS) for EBID.

Average ET_oF, NDVI, and K_{cb} estimates for each image date are provided for each of the eight crops other than cotton in **Figure 6-8**. The average ET_oF values include evaporation and thus are generally greater than the K_{cb} values early in the crop season when evaporation occurs from the soil. Later in the season, when the soil is nearly, or in some cases, completely shaded the K_{cb} curve is much closer to the average ET_oF values.

Opinions

The K_{cb} curves are parameterized to represent average local conditions and stress levels across the entire population of fields in the Study Area. While these K_{cb} curves have the same general shape as published "book", or potential, K_{cb} curves for "pristine" crops, it is important to note that many individual fields have ET rates that vary from the "book" K_{cb}. These K_{cb} curves reflect influences of incidental in water stress, wetness of exposed soil, and the resulting transpiration and evaporation rates. These curves better represent local conditions than "book" K_{cb} curves.

Basal crop coefficients can be developed from METRIC-derived crop coefficients and NDVI values that are based on standard procedures and that are reflective of the level of ET of applied water obtained through local irrigation and crop management practices. These basal crop coefficients can be used with a calibrated ET Demands root zone model to estimate ET of applied water. These basal crop coefficients used together with a calibrated ET Demands model and climate data result in reliable full supply ET_c and ET_{aw} estimates for all year types including years with less than full supply, even though, the actual ET_c and ET_{aw} may be less than the full supply ET_c and ET_{aw} for years with less than a full water supply. That reduction is made in the farm water budget model.

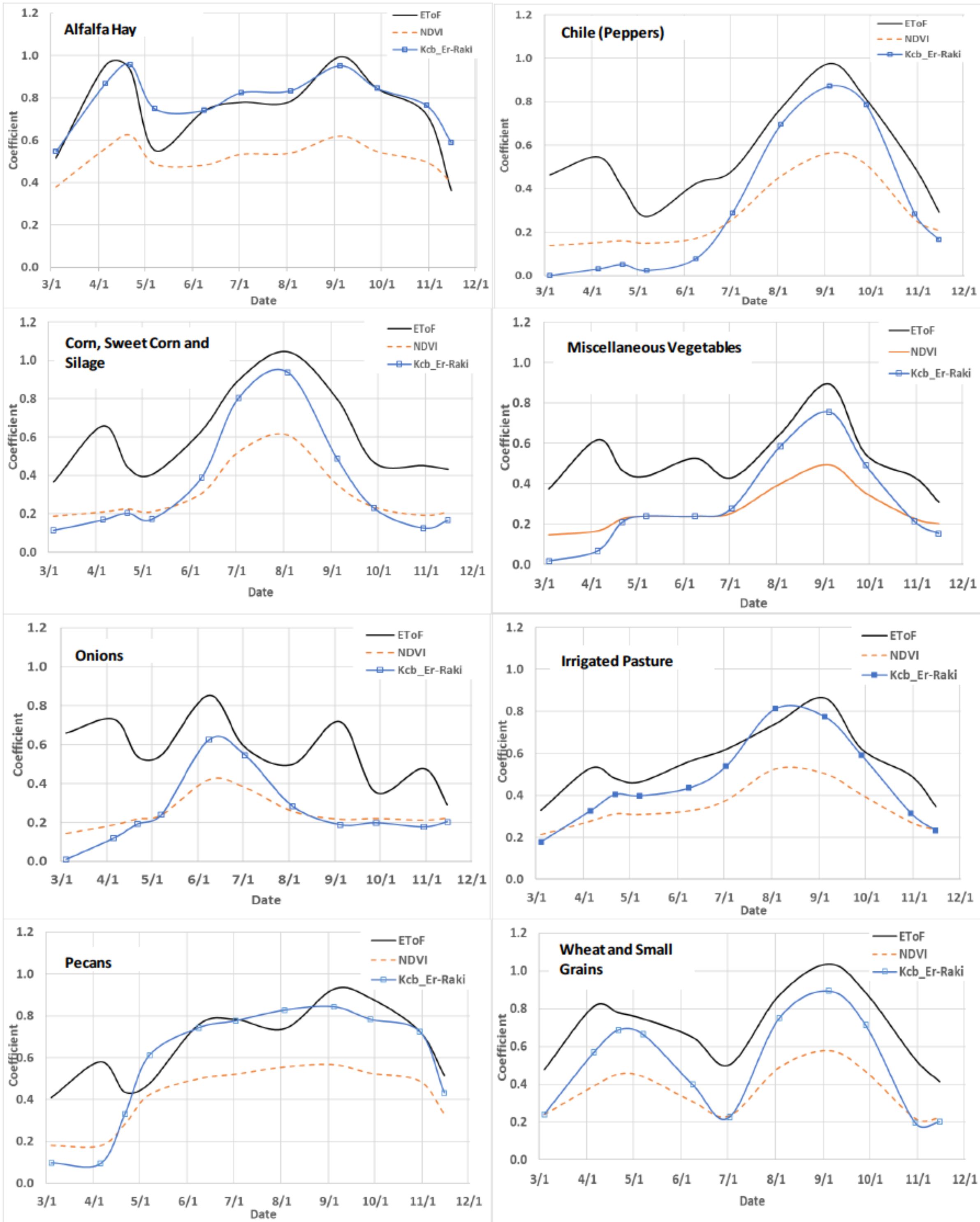

Figure 6-8. Average NDVI, ET_oF, and Basal Crop Coefficients for EBID Crops, 2008.

VII. ET Demands Local Calibration and Results

Purpose

The purpose of this section is to describe the local calibration of the daily root zone water balance model, ET Demands, and results for actual crop evapotranspiration (ET_c) and ET of applied water (ET_{aw}) for the irrigated lands in the Study Area. This section describes the ET Demands calibration methodology, results, and findings.

Methodology

Local calibration of basal crop coefficients comprises the second, third, and fourth steps in a four-step process (**Figure 7-1**) to calibrate ET Demands results to remotely sensed surface energy balance ET estimates. The objective of the calibration process is to develop crop season ET estimates in the ET Demands model that are reliable and within 10 percent of the energy balance ET estimates for six subareas of the Study Area (defined later). The first step in the calibration process involves developing basal crop coefficients from remotely sensed ET results and is described in Section 6 of this report.

As described previously, in the second, third, and fourth calibration steps, crop consumptive use characteristics were first provided as inputs to the ET Demands model based on the 2008 METRIC analysis. Then, the resulting ET estimates from the ET Demands model were compared back to METRIC ET estimates from 2008, 2013, and 2002. These years were selected as 2008 and 2002 represented approximately full supply conditions in the Study Area, the conditions considered in this report. The third year, 2013 was selected to validate during a limited supply year. At each step, if the ET Demands estimates were not within 10 percent of the METRIC ET estimates, the crop inputs to the ET Demands model were revised and the calibration step was repeated again. At the conclusion of this calibration process, ET Demands estimates were within 10 percent of METRIC ET estimates across the overall Study Area during 2008 and 2002.

This section includes a short description of the surface energy balance ET_c estimates, ET Demands model, methods used in ET Demands calibration, and the methods for comparing ET Demands model ET_c estimates to METRIC ET_c estimates from 2008, 2013 and 2002.

Surface Energy Balance ET_c Estimates

As described previously, the METRIC surface energy balance model was used to develop locally accurate ET estimates for the Study Area and served as a reference for ET Demands during the calibration process. An important advantage of the energy balance methodology used by METRIC is that it inherently accounts for factors that cause ET_c under commercial growing conditions to be less than ET_c under ideal conditions (sometimes referred to as potential ET). METRIC utilizes spectral raster images from the visible, near infrared, and thermal infrared energy spectrum to compute the energy balance resulting in estimates of ET_c on a pixel-by-pixel[7] basis. General accuracy of ET_c estimated by METRIC has been shown to be ±5 to ±15% when applied by expert users (Allen et al., 2011). The 2008 growing season METRIC ET_c results for EBID were used to develop crop coefficients and results from 2002, 2008 and 2013 growing seasons were used to calibrate the ET Demands model to local conditions within the Study Area.

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[7] A single raster element in a computer image that has a constant value across its domain. In Landsat images, a pixel has dimensions of 30 m x 30 m.

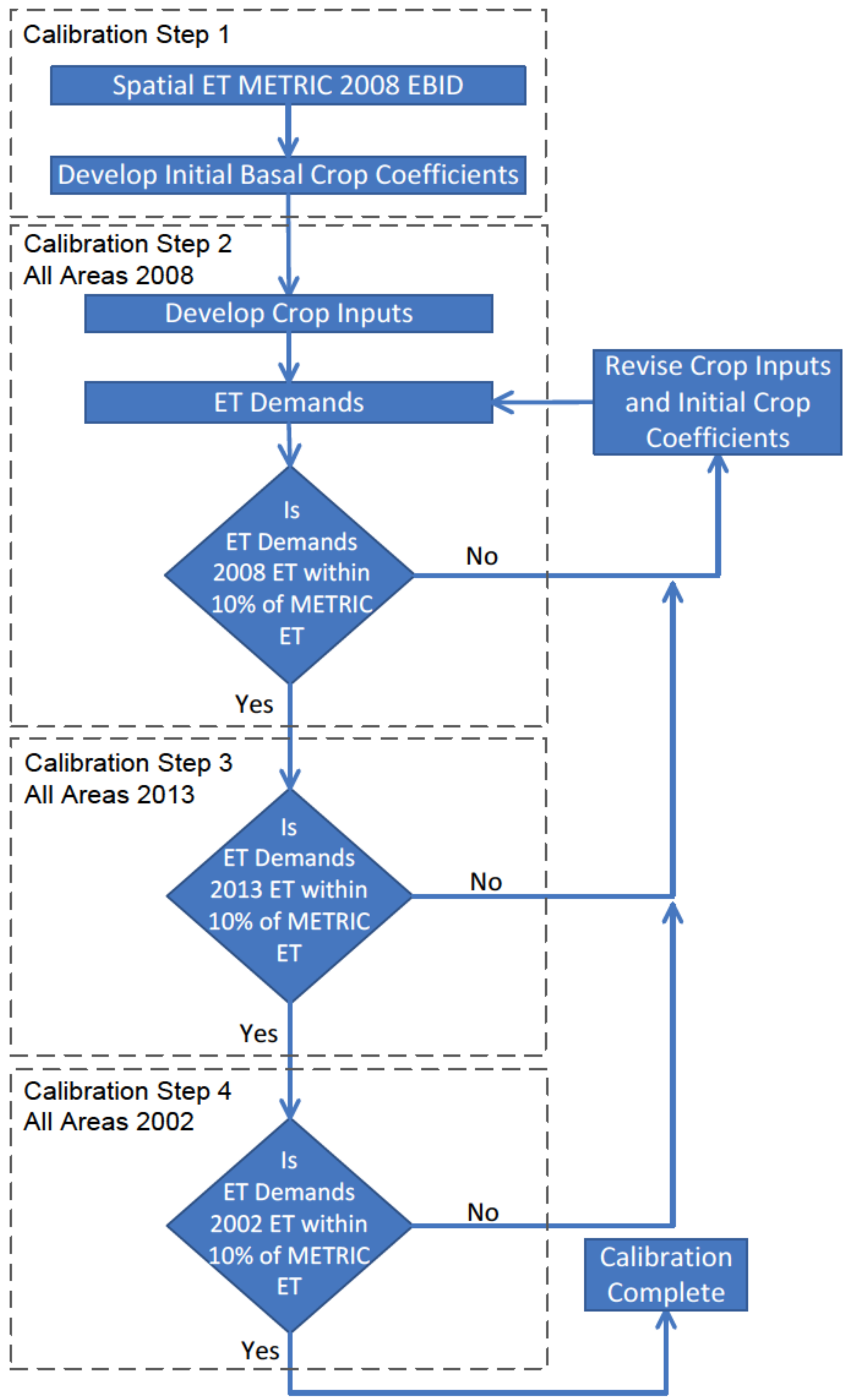

Figure 7-1. Schematic Describing Calibration of the ET Demands Model

ET Demands Model

The ET Demands model utilizes weather, crop and soil information to calculate a daily root zone water balance (**Figure 7-2**). Inflows to the root zone include rain, applied irrigation water and capillary rise; outflows include evapotranspiration (ET_c), runoff, and deep percolation. Rainfall and runoff are modeled in ET Demands based on precipitation data, irrigation frequency assumptions, and crop-soil surface characteristics, including slope, vegetation coverage, and soil type. Capillary rise (the flux of groundwater toward the soil surface) and deep percolation (the infiltration of water into the groundwater system) are both modeled based on soil characteristics as well as rainfall and irrigation events at the soil surface.

Weather inputs to the model include daily rainfall, reference evapotranspiration (ET_o) and temperature. Crop inputs include crop coefficients, maximum root depths, and planting and harvest dates. Soil inputs include available water holding capacity and hydrologic group.

On a daily time step, ET_o is multiplied by the dual crop coefficients, one to quantify crop transpiration and the other to quantify evaporation of water from wet soil surfaces following rainfall and modeled irrigation events (Allen and Robison, 2009). Daily crop transpiration and evaporation are then summed to obtain daily ET_c. This approach accounts separately for evaporation and transpiration, thereby accounting for the influence of the timing and magnitude of rainfall and irrigation events on evaporation. The daily calculation is performed continuously, both during and outside the growing season, to quantify ET_c, ET_{pr} and ultimately ET_{aw}.

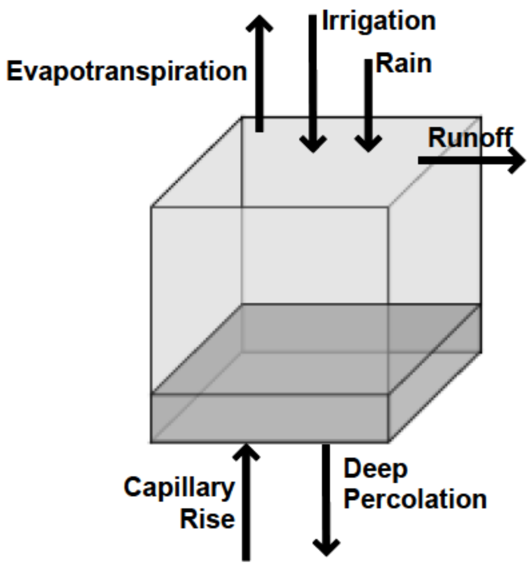

Figure 7-2. ET Demands Model Root Zone Water Balance Following FAO-56 Root Zone Water Balance. Modified from Allen et al. (1998).

The ET Demands model also generates daily estimates of applied irrigation water, surface runoff of rainfall and deep percolation (the drainage of soil water by gravity below the effective depth of the root zone). Capillary rise was assumed to be negligible because irrigation water was applied by the model before the root zone dried to the point where significant capillary rise would occur. These estimates are used along with daily ET_c estimates to calculate a daily root zone water balance for each crop and soil type combination, thereby accounting for consumptive water use in the entire Study Area. The following sections describe the weather, crop, and soil information required for computing ET_o, ET_c, and ET_{aw} in the ET Demands model.

Weather Inputs

Reference ET is calculated using the standardized short (0.12 m tall) grass reference ET equation (ASCE-EWRI 2005, ASCE 2016). The weather data used for calculating ET_o, including the weather stations reviewed and selected, and the data review and quality control procedures applied, as previously addressed. The Leyendecker Automatic Weather Station (AWS) was selected to represent the Rincon and Mesilla Valleys, and Art Ivey AWS was selected to represent the El Paso and Juarez Valleys. As previously described in detail in the weather data section, weather data, including rainfall records, were reviewed and accepted practices (EWRI ASCE, 2005 and ASCE, 2016) applied to fill data gaps and address other data anomalies. The result from this process was two daily time series of ET_o, temperature and rainfall for 1938 through 2018 for input to the ET Demands model.

Crop Inputs

Crop inputs include basal crop coefficient parameters (see Section 6), crop planting and harvest dates, crop root depths and crop irrigation parameters. For most crops, the start date and duration of growing season were determined uniquely for each year to account for weather variability from one year to the next. The basal crop coefficient (K_{cb}) curves were expressed on relative time scales or relative thermal unit scales (ASCE, 2016), so that the curves reflect differences in crop growing conditions from year-to-year. The end of each growing season was based on the maturation of the crop as predicted by cumulative growing degree days (CGDDs), local observed maturation dates, or by the occurrence of a killing frost. Beginnings of growing seasons were generally estimated using a 30-day running average mean air temperature ending on the start date. One of four methods can be selected in ET Demands to express the daily changes to the K_{cb} curve as the season progresses: 1) percent time from planting to harvest; 2) percent time from planting to effective full cover, with this ratio extended until termination; 3) percent time from planting to effective full cover and then days after full-cover; and 4) percent CGDDs from planting to effective full cover, with this ratio extended until termination. The method chosen can vary depending on the crop and the method chosen for each crop is described in the results subsection.

For this analysis, daily changes to the K_{cb} curves progressed according to CGDDs and their relationship to local growth stage lengths. The initial basis for the crop coefficient curve and other crop-inputs were adopted from Allen (2009) and adjusted during the calibration process to fit the METRIC ET_c results and local observations from the literature and personal observations.

ET demands uses the FAO-56 method (Allen, et al. 1998) for estimating evaporation from and computing a daily water balance for the top 10 cm of soil (the soil surface) following rainfall and irrigation events. The evaporation rate is reduced as the soil surface dries. Water stored between the soil surface and the bottom of the root zone is available for uptake and transpiration by the crop. Irrigations are scheduled in ET Demands when the daily water balance indicates that the water remaining in the root zone has reached a management allowed depletion[8] (MAD). Rooting depth and MAD values are defined by crop type and crop development stage (**Figure 7-2**). Irrigations are simulated in the model in the manner that is typically used for surface irrigation, as described in the following sentences. When the soil moisture within the root zone is reduced to the MAD, irrigation is triggered, with the applied water equal to the depth required to fill the root zone to field capacity, the soil moisture level above which water drains

[8] The management allowed depletion (*MAD*) is defined as the management planned percentage of the available soil water (between field capacity and the lower limit of extractable water) that is depleted between irrigations (ASCE, 2016).

from the root zone due to gravity, plus 10 percent. The additional 10 percent is a factor of safety often added to ensure that the crop is fully irrigated and that it does not increase the calculated crop ET.

Soil Inputs

Available Waterholding Capacities (AWC) and permeabilities (K_{sat}) were determined based on a GIS analysis of information from the National SSURGO soils database covering the Study Area (SSURGO, 2014). This analysis is described in Section 2. About 85 percent of the soils within each area were found to have AWC and K_{sat} in relatively narrow ranges, thus, single weighted average values were selected to represent all soils occurring within each Valley, except for the El Paso Valley which was divided into areas for EPCWID and Hudspeth. Runoff of rainfall was estimated using the widely used USDA-NRCS Curve Number method (ASCE, 2016), with antecedent moisture determined from the daily soil surface water balance in the ET Demands model. Evaporation occurring during the nongrowing periods for each crop group was calculated by assigning one of the following three soil surface conditions that provide different degrees of regulation of potential evaporation rates: (1) bare soil, (2) mulched soil (wheat and small grains) or (3) dormant sod (pasture).

ET Demands Calibration

The initial development of basal crop coefficients (k_{cb}) from METRIC ET results for 2008 is described in detail in a separate report. (This is illustrated as Calibration Step 1 in **Figure 7-1**.) The next three steps to calibrate ET Demands (Calibration Steps 2 through 4 in **Figure 7-1**) involve an iterative process of setting crop parameters in ET Demands, and then comparing the ET Demands crop ET results to the METRIC ET results for years 2008, 2013 and 2002. By computing ET from the energy consumed by evaporation of water from soil and plant surfaces, the surface energy balance of METRIC inherently accounts for the effects of salinity, deficit irrigation, disease, poor plant stands, and other field conditions that typically cause ET_{act} to be less than potential (ET_{pot}) on a field, farm, or district scale. Thus, ET generated from satellite-based surface balances represents local management practices and water availability. METRIC ET_{act} estimates have been validated extensively in irrigated agriculture environments (Allen, et al., 2007a,Singh and Senay, 2016, French, et al., 2015, He et al., 2017 and Madugundu et al., 2017). Sections describing pre-season evaporation coefficient estimates and maximum crop coefficient estimates follow.

Pre-Season Evaporation Coefficient Estimates

The ET Demands model triggers irrigation events when available soil moisture has been depleted by crop use to certain user-specified levels referred to as the MAD. In actual practice, growers often irrigate bare fields prior to planting certain crops. These irrigations are referred to as pre-irrigations and are used for a variety of purposes, including leaching salts from the root zone, conditioning soil for bed forming operations, establishing conditions favorable for seed germination, and establishing deep soil moisture. For crops known to typically have pre-irrigations, such as cotton, pre-season evaporation coefficients were estimated to match observed average crop coefficient values from METRIC during pre-season periods. For each crop, the pre-season evaporation coefficient was initially set equal to the average observed METRIC ET_oF[9] value for the image dates starting with March and before planting. Then, the initial evaporation coefficients were iteratively adjusted until a pre-irrigation was triggered in ET Demands at approximately the time that typical pre-irrigations are actually observed and the ET Demands monthly ET was approximately equal to the monthly METRIC ET.

[9] Grass reference ET fraction, synonymous with K_{cm} and generally refers to K_{cm} values from METRIC results.

Maximum Crop Coefficient Estimates

ET Demands requires the setting of a maximum limit on the crop coefficient value (k_{cmaxo}) for each crop to prevent overestimation of k_e and the ET Demands simulated crop coefficient following rainfall and simulated irrigation events. The k_{cmaxo} ensures that the dual crop coefficient does not result in transpiration and evaporation values that exceed the available energy (ASCE, 2016). For each crop, values for k_{cmaxo} were iteratively adjusted (always downward) until crop ET calculated by ET Demands approximately equaled crop ET from METRIC. The k_{cmaxo} values determined through this calibration and used in the ET Demands model are not the same as the maximum k_c values observed in the METRIC data and are not the same as the k_{cmaxo} described in ASCE (2016). Rather, the adjusted k_{cmaxo} as used here is used to calibrate modeled conditions representing a hypothetical field with crop ET equal to the average ET obtained from METRIC for each crop. It is recognized that fields having higher and lower ET rates and volumes exist in the population of fields planted to each crop, but are represented, on average, by the average field.

Initial k_{cmaxo} values were estimated as the maximum of the average crop coefficient value for a given crop from all METRIC image dates. These values were adjusted iteratively for each crop until the 2008 growing season ET_c from the ET Demands model agreed with 2008 METRIC ET_c within approximately ten percent. The resulting values were used in ET Demands and the ET_c results compared to the METRIC ET_c results as described in the results section.

ET Demands to METRIC ET Comparisons

Three years were chosen for METRIC remote sensing analyses to provide a basis for developing and calibrating crop coefficients for the Study Area for use with the ET Demands root zone water balance model. The initial calibration used the 2008 year because of the availability of the NMOSE ground survey in EBID to identify crops in fields and because it was a "full supply" project year. Next, the water short year 2013 was selected to confirm that crop coefficients developed from the full supply year (2008) would result in ET Demands actual ET_c estimates equal to or greater than the METRIC actual ET_c for 2013. Finally, a second full supply year, 2002, was chosen to confirm that the crop coefficients developed from one full supply year (2008) would result in ET_c estimates equal to or greater than the METRIC actual ET_c for a different full supply year (2002).

METRIC ET_c results were aggregated to produce an average depth of ET_c over all irrigated areas and are described as METRIC total ET_c. Similarly, ET Demands results were aggregated and reported as the average depth of ET_c over all irrigated areas and are described as ET Demands total ET_c. Delineation of irrigated areas was based on a Normalized Difference Vegetation Index (NDVI) analysis completed by Intera in April 2016 (Intera, 2018), which identifies irrigated fields in 2002, 2008 and 2013 throughout the Study Area. Fields classified as "Irrigated Agriculture" or "Possible Irrigated Agriculture" were considered to be irrigated areas.

Monthly METRIC ET_c results were extracted for the area remaining after applying a buffer (Clark, et al., 2007) to account for field edge effects. Using the monthly METRIC results, the average depth of ET_c was calculated for all irrigated fields as identified by the NDVI analysis. The ET Demands total ET_c was calculated by multiplying the ET Demands ET_c for each crop by the irrigated area of that crop. Irrigated areas by crop for each of the six areas described below are provided in the crop distribution report. The METRIC total ET_c estimates and the ET Demands total ET_c estimates were compared for 2008, 2013 and 2002 for the following six separate areas of the Study Area:

1. EBID irrigated lands with access to both surface water and groundwater (combined water source),
2. Irrigated lands with access to only groundwater (groundwater only water source) in New Mexico (about 60 percent this area is in close proximity to, but outside of, the EBID boundary, and the remaining 40 percent is within the EBID boundaries),
3. Subset of EPCWID irrigated lands with access to surface water in the Mesilla Valley,
4. Subset of EPCWID irrigated lands with access to surface water in the El Paso Valley,
5. Hudspeth irrigated lands with access to surface water in the El Paso Valley, and
6. Juarez irrigated lands with access to surface water in the Juarez Valley with ET Demands results.

For each annual comparison, when the ET Demands total ET_c was within ten percent of the METRIC total ET_c, individual crop ET values were reviewed to identify the crop(s) requiring crop input data adjustments. Input parameters were adjusted to achieve ET demands model ET_c agreement with METRIC ET_c results for the identified crops using consistent and standard model calibration methods. Selection of input parameters to adjust was based on review of monthly ET_c data for identified crops and determination of the parameters that most impacted deviations from monthly METRIC results. The objective of calibration is to develop ET Demands total ET_c results as the upper limit of ET_c under full water supply conditions. This requires that ET Demands total ET_c results be, on average, equal to the METRIC total ET_c in the Study Area for full water supply years and equal to, or greater than, METRIC total ET_c for less than full water supply years. Thus, when the ET Demands total ET_c for all six areas for all three years was either greater than the METRIC total ET_c or within ten percent less than the METRIC total ET_c, the goal of local calibration was considered to have been accomplished. The farm budget model, described in a separate report compares the surface water supply to ET Demands results and if the surface water supply is insufficient, the consumptive use estimates are reduced by the farm budget model. Finally, all ET Demands and METRIC ET results were reviewed for all individual crop groups for years 2008 and 2013 (the years with crop locations known) to ensure that the ET Demands estimates for each individual crop were also within 10 percent of METRIC ET results. This was done to ensure that any large shifts in crop areas did not reduce the overall ET estimation accuracy.

Results

The final crop inputs and maximum crop coefficient estimates arrived at through calibration for each crop, and used in the ET Demands model, are discussed in the first two of the three subsections in this section. The last subsection describes the ET Demands and METRIC ET comparison for the ending calibration for 2008, 2013 and 2002 for each of the six areas of the Study Area described above. Crop by crop comparisons are provided in **Appendix 7A** for 2008 and 2013, the years where spatial crop information is available.

Crop Inputs

The crop inputs resulting from the calibration of the ET Demands total ET_c results to the METRIC total ET_c results are summarized in **Tables 7-1 and 7-2**. The initial crop inputs were obtained from the literature, corroborated by personal observations during field trips. The calibrated crop inputs were within the ranges noted in the literature and also corroborated by personal observations during field trips to the area. The curve type and value used to estimate when the crop coefficient starts, effective cover is reached and when the crop is harvested together with the dates in 2008 when the development stage of the crop coefficient began and the harvest date for each of the nine crops are provided in **Table 7-1**.

Table 7-1. Crop Coefficient Types Used in ET Demands and Values Used to Specify Growth Stages in Crop Coefficient Curves.

Crop	Curve Type	Crop Coefficient Curve Value (K_c)		
		Initiation	Effective Cover	Termination
Alfalfa Hay	CGDD*	370	850	900 **
Chile (Peppers)	CGDD	110	1990	2780
Corn, Sweet Corn, and Silage	CGDD	230	1240	2550
Cotton	CGDD	110	930	2100
Irrigated Pasture	Date	1-Mar	4-Aug	1-Dec
Miscellaneous Vegetables	Date	1-Mar	4-Aug	1-Dec
Onions	Date	1-Mar	4-Aug	1-Dec
Pecans	Date	1-Mar	4-Aug	1-Dec
Wheat and Small Grains	Date	1-Mar	4-Aug	1-Dec

*Cumulative Growing Degree Days (CGDD) in °Celsius-days.
**CGDD for single cutting cycle.

Table 7-2. MAD, Rooting Depths and Non-Growing Period Land Uses by Crop Used in the ET Demand Model.

Crop	Management Allowable Depletion (%)		Initial Rooting Depth, ft	Maximum Rooting Depth, ft	Non-growing Period Land Condition
	Initial and Development	Midseason and Late			
Alfalfa Hay	60	60	2.3	5.9	Bare
Chile (Peppers)	60	50	1.3	3.3	Bare
Corn, Sweet Corn, and Silage	60	50	1.1	3.9	Bare
Cotton	60	60	5.9	5.9	Bare
Irrigated Pasture	60	50	3.3	3.3	Sod
Miscellaneous Vegetables	60	50	1.3	3.9	Bare
Onions	40	40	2.6	2.6	Bare
Pecans	50	50	3.3	3.6	Bare
Wheat and Small Grains	60	50	1.3	5.2	Mulch

Maximum Crop Coefficients

For each crop, the k_{cmaxo} establishes an upper limit during the estimation of k_e following rainfall and simulated irrigation events, thus, ensuring that the dual crop coefficient does not result in transpiration plus evaporation values that exceed the available energy (ASCE, 2016). Values for k_{cmaxo} were set during calibration and were adjusted iteratively until the 2008 growing season ET Demands ET_c results for each crop for agreed with METRIC ET_c results within approximately ten percent. The resulting values were used in ET Demands and the ET_c results compared to the METRIC ET_c results. Because 2002 ET Demands ET was less than the METRIC ET_c in the 2002 for EPCWID and Hudspeth, the k_{cmaxo} values for cotton and alfalfa, the two main crops in those areas, were adjusted upward from 1.15 to 1.20 to allow the ET Demands ET to increase. The adjusted values were used in ET Demands and the results were again compared to the METRIC ET_c results with the ET Demands ET results three percent lower than the METRIC ET with the new calibration for these two crops. Calibrated k_{cmaxo} values by crop are summarized in **Table 7-3**.

Table 7-3. Estimated $k_{c,maxo}$ Values for Each Crop in ET Demands.

Crop Group	ET Demands $k_{c,maxo}$
Alfalfa	1.2
Chile (Peppers)	1.1
Corn	1.2
Cotton	1.2
Miscellaneous Vegetables	1.5
Onion	1.2
Pasture and Hay	1.1
Pecans	0.9
Wheat and Other Small Grains	1.2

Comparison of Calibrated ET Demands to METRIC Results

This section describes the comparison of METRIC total ET_c to the ET Demands calibrated model total ET_c for 2002, 2008 and 2013. Comparisons are made for each of the six geographic areas described in the Methodology section. As described in the methodology section, 2002 and 2008 were full supply years and 2013 was a water short (less than full supply) year. Although both 2002 and 2008 were full supply years, the total supply in 2002 was somewhat greater than in 2008. Additionally, 2002 was the last year of 23 consecutive full supply years, whereas 2008 was preceded by five years with less than full supply.

In 2002, the calibrated ET Demands total ET_c for all areas, except the area in New Mexico with access to only groundwater, were within five percent of the METRIC total ET_c (**Table 7-4**). The ET Demands total ET_c in 2002 was greater than the 2002 METRIC total ET_c for four of the six areas considered (**Table 7-4**). In the remaining two areas – the EPCWID Irrigated Lands in the El Paso Valley and the Hudspeth area – the ET Demands total ET_c was three percent less than the METRIC total ET_c. The close agreement between the calibrated ET Demands total ET_c and METRIC total ET_c suggests that the calibrated basal crop coefficients and related crop inputs derived during the calibration are representative of the Study Area as a whole. From this, it can be deduced that the influences of drought, salinity and other stress factors on ET_c are similar between EBID, for which the basal crop coefficients were developed, and the other parts of the Study Area, except for the area in New Mexico having access to only groundwater.

Table 7-4. Comparison of Total ET_c (Total of ET_{aw} and ET_{pr}) from METRIC and ET Demands for the 2002 March through October Irrigation Season.

Area	Total Irrigated Area (acres)	METRIC Total ET_c (inches)	ET Demands Total ET_c (inches)	% Difference*
EBID Irrigated Lands with Access to SW and GW	79,164	38.0	38.2	1%
Irrigated Lands in New Mexico with Access to Only GW	5,556	30.5	39.4	29%
EPCWID Irrigated Lands in the Mesilla Valley	4,746	35.4	36.1	2%
EPCWID Irrigated Lands in the El Paso Valley	36,295	37.6	36.4	-3%
Hudspeth Irrigated Lands in the El Paso Valley	15,220	33.4	32.5	-3%
Juarez Irrigated Lands in the Juarez Valley	36,323	37.6	38.8	3%
Total, All	177,304	37.1	37.4	1%
Total, New Mexico	84,720	37.5	38.3	2%
Total, Texas	56,261	36.3	35.3	-3%
Total, Mexico	36,323	37.6	38.8	3%

*(ET Demands - METRIC)/(METRIC)

**Irrigated area using groundwater only that is in close proximity to EBID, but mostly outside the district

The ET Demands total ET_c in 2008 was greater than the 2008 METRIC total ET_c for all areas except for the EPCWID area in the El Paso Valley, which was three percent less than the METRIC total ET_c results (**Table 7-5**). For three of the six areas, the ET Demands total ET_c was more than ten percent greater than the METRIC total ET_c. As for 2002, the area in New Mexico with access to only groundwater had the greatest difference, with the ET Demands total ET_c being 31 percent higher than the METRIC total ET_c. Hudspeth had the next largest difference with the ET Demands total ET_c being about 27 percent higher than the METRIC total ET_c. As the METRIC total ET_c represents the best available science to calculate actual ET_c from satellite imagery, the lower value of METRIC total ET_c indicates that a full water supply for the irrigated area was either not available to Hudspeth in 2008, or that a full water supply was not effectively distributed within Hudspeth to supply potential crop water needs. Published "book," or potential, crop coefficients would overestimate ET_c in years having less than full supply, since they generally exceed the METRIC-derived crop coefficients calibrated for the ET Demands model applications.

In both 2002 and 2008, average METRIC total ET_c for EPCWID irrigated lands in the El Paso Valley were within one inch of the METRIC total ET_c for EBID irrigated lands with access to both surface water and groundwater. The close correspondence between METRIC total ET_c estimates and the ET Demands results across the Study Area as a whole helps to support the validity of this methodology in consistently and accurately representing crop consumptive use in full supply years.

In 2013, a year with less than full supply, the ET Demands total ET_c was greater than the METRIC total ET_c for all areas and more than 10 percent greater for four of the six areas (**Table 7-6**). As in 2002 and 2008, the area in New Mexico having access to only groundwater had the greatest difference with the ET Demands total ET_c 39 percent higher than the METRIC results. Again, as in 2008, Hudspeth had the next largest difference with the ET Demands total ET_c 31 percent higher than the METRIC total ET_cWhile the differences between the ET Demands results and METRIC results for 2013, a less than full water supply year, are slightly greater than those found in 2002 and 2008, they are well within 10 percent accuracy across the Study Area as a whole. Thus, the comparisons with METRIC results demonstrate that the ET_c estimates developed using ET Demands and these calibrated crop coefficients are accurate and can be relied on for further analyses.

Table 7-5. Comparison of Total ET_c (Total of ET_{aw} and ET_{pr}) from METRIC and ET Demands for the 2008 March through October Irrigation Season.

Area	Total Irrigated Area (acres)	METRIC Total ET_c (inches)	ET Demands Total ET_c (inches)	% Difference*
EBID Irrigated Lands with Access to SW and GW	77,730	39.0	40.4	4%
Irrigated Lands in New Mexico with Access to Only GW	4,898	30.3	39.7	31%
EPCWID Irrigated Lands in the Mesilla Valley	3,940	33.9	37.9	12%
EPCWID Irrigated Lands in the El Paso Valley	36,967	38.2	37.0	-3%
Hudspeth Irrigated Lands in the El Paso Valley	13,632	28.3	36.0	27%
Juarez Irrigated Lands in the Juarez Valley	35,463	36.9	38.4	4%
Total, All	172,630	37.2	38.8	4%
Total, New Mexico	82,628	38.5	40.4	5%
Total, Texas	54,539	35.4	36.8	4%
Total, Mexico	35,463	36.9	38.4	4%

*% Difference = (ET Demands - METRIC)/(METRIC)

Table 7-6. Comparison of total ET_c (Total of ET_{aw} and ET_{pr}) from METRIC and ET Demands for the 2013 March through October Irrigation Season.

Area	Total Irrigated Area (acres)	METRIC Total ET_c (inches)	ET Demands Total ET_c (inches)	% Difference*
EBID Irrigated Lands with Access to SW and GW	73,684	37.4	39.3	5%
Irrigated Lands in New Mexico with Access to Only GW	5,066	27.8	38.6	39%
EPCWID Irrigated Lands in the Mesilla Valley	3,536	32.9	37.4	14%
EPCWID Irrigated Lands in the El Paso Valley	26,451	34.1	37.7	11%
Hudspeth Irrigated Lands in the El Paso Valley	6,160	26.5	34.7	31%
Juarez Irrigated Lands in the Juarez Valley	32,235	35.6	37.0	4%
Total, All	147,132	35.5	38.2	8%
Total, New Mexico	78,750	36.8	39.3	7%
Total, Texas	36,147	32.7	37.2	14%
Total, Mexico	32,235	35.6	37.0	4%

*% Difference = (ET Demands - METRIC)/(METRIC)

Irrigated Lands in New Mexico with Access to Only Groundwater

The ET Demands total ET_c for irrigated lands in New Mexico with access to only groundwater ranged from 29 to 39 percent higher than the METRIC ET_c. This is because total ET_c is less from the irrigated lands in New Mexico with access to only groundwater than it is for the irrigated areas with access to both surface water and groundwater. ET Demands and METRIC analyses were carefully reviewed and these analyses were found to be correct. Although this area represents less than four percent of the Study Area, additional analyses were conducted to confirm lower ET from the irrigated areas having access to groundwater only and to understand why the METRIC ET_c was lower for this area. Initially, a detailed review of the METRIC analysis by crop, soil and within each field was completed. Also, NDVI, a related indicator of ET, was reviewed for this area and compared to the other areas. These comparisons supported the METRIC ET_c results of lower ET_c from the irrigated lands in New Mexico with access to only groundwater, but did not provide insight into why the crops from this area had, on average, lower ET_c. In August 2017, a field trip was organized to visit selected groundwater-only irrigated lands to visually confirm lower ET_c on fields. Approximately 31 irrigated fields were selected for visual inspection based on professional judgement. These fields represented a cross section of the crops, soils and locations of the irrigated fields with access only to groundwater in the study area.

LRG Water Master Ryan Serrano put together a package for 23 fields that included a map of the field, the water rights summary, and the meter pumping summary sheet. The fields were inspected for factors that have been found to impact ET_c: proximity of irrigated land to groundwater well, the effort/diligence expended (i.e. commercial farming v. hobby farm), irrigation infrastructure and proximity to other fields with surface water supplies. Eighteen fields were inspected over two days. The inspection was continued until the number of fields was determined adequate to accomplish the purpose of confirming that many fields had low ET_c. The field inspection determined that the aforementioned average 33 percent difference appears to be a combination of farming effort, sparse stands, poor crop health and stressed crops, depending on the field. Each field had a unique factor or combination of factors contributing to reduced ET_c and some fields had full ET_c.

Lumping all the irrigated lands in New Mexico together results in ET Demands ET_c results greater than the METRIC ET_c results by two, five and seven percent in 2002, 2008 and 2013, respectively. These are all within the ten percent calibration goal. Thus, although the ET Demands ET_c results are slightly greater than the METRIC ET_c results in New Mexico, separate crop coefficients were not developed, and the result is slightly greater actual ET_c than if the irrigated lands with access to groundwater had separate crop coefficients.

ET_{aw} Results

Because METRIC results provide the total ET_c that is derived from both precipitation and applied water, the total ET_c results from the calibrated model are compared to METRIC during the calibration process. Ultimately, the objective of the calibrated ET Demands model is to estimate ET of applied water, ET_{aw}, under "full supply" conditions (when water supplies are not limiting). To do so, the ET Demands model first estimates ET_c, which has been calibrated to the METRIC results, and then apportions ET_c between ET_{pr} and ET_{aw} for the Study Area. This section describes the ET_{aw} results for the three years and six areas used in the calibration process.

ET_{aw} in 2002 (**Table 7-7**) ranged from 25.5 to 34.1 inches for Hudspeth and irrigated lands in New Mexico having access to only groundwater, respectively. ET_{pr} in the EBID irrigated area and the EPCWID irrigated lands in the Mesilla Valley ranged from 5.1 to 5.3 inches. In the El Paso and Juarez Valleys, ET_{pr} ranged from 7.0 to 7.1 inches.

Table 7-7. Average ET_c, ET_{aw} and ET_{pr} for 2002

Area	Total Irrigated Area (acres)	ET Demands Total ET_c (inches)	ET Demands Total ET_{aw} (inches)	ET Demands Total ET_{pr} (inches)
EBID Irrigated Lands with Access to SW and GW	79,164	38.2	32.9	5.3
Irrigated Lands in New Mexico with Access to Only GW	5,556	39.4	34.1	5.3
EPCWID Irrigated Lands in the Mesilla Valley	4,746	36.1	30.9	5.1
EPCWID Irrigated Lands in the El Paso Valley	36,295	36.4	29.3	7.0
Hudspeth Irrigated Lands in the El Paso Valley	15,220	32.5	25.5	7.0
Juarez Irrigated Lands in the Juarez Valley	36,323	38.8	31.7	7.1

ET_{aw} in 2008 (**Table 7-8**) ranged from 23.0 to 32.4 inches for Hudspeth and irrigated lands in New Mexico with access to only groundwater, respectively. ET_{pr} in the EBID irrigated area and the EPCWID irrigated lands in the Mesilla Valley ranged from 7.0 to 8.0 inches. In the El Paso and Juarez Valleys, ET_{pr} ranged from 10.9 to 13.0 inches.

Table 7-8. Average ET_c, ET_{aw} and ET_{pr} for 2008

Area	Total Irrigated Area (acres)	ET Demands Total ET_c (inches)	ET Demands Total ET_{aw} (inches)	ET Demands Total ET_{pr} (inches)
EBID Irrigated Lands with Access to SW and GW	77,730	39.7	31.9	7.9
Irrigated Lands in New Mexico with Access to Only GW	4,898	40.4	32.4	8.0
EPCWID Irrigated Lands in the Mesilla Valley	3,940	37.9	30.9	7.0
EPCWID Irrigated Lands in the El Paso Valley	36,967	37.0	26.1	10.9
Hudspeth Irrigated Lands in the El Paso Valley	13,632	36.0	23.0	13.0
Juarez Irrigated Lands in the Juarez Valley	35,463	38.4	26.4	11.9

ET_{aw} within the Study Area in 2013 is provided in **Table 7-9** below.

Table 7-9. Average ET_c, ET_{aw} and ET_{pr} for 2013

Area	Total Irrigated Area (acres)	ET Demands Total ET_c (inches)	ET Demands Total ET_{aw} (inches)	ET Demands Total ET_{pr} (inches)
EBID Irrigated Lands with Access to SW and GW	73,684	38.6	33.2	5.4
Irrigated Lands in New Mexico with Access to Only GW	5,066	39.3	33.7	5.5
EPCWID Irrigated Lands in the Mesilla Valley	3,536	37.4	32.1	5.2
EPCWID Irrigated Lands in the El Paso Valley	26,451	37.7	31.3	6.4
Hudspeth Irrigated Lands in the El Paso Valley	6,160	34.7	27.0	7.7
Juarez Irrigated Lands in the Juarez Valley	32,235	37.0	29.9	7.2

In all three years, the lowest ET Demands ET_{aw} was in Hudspeth and the highest was in the irrigated lands in New Mexico having access only to groundwater.

Opinions

When used in the ET Demands root zone water balance model, locally calibrated basal crop coefficients based on 2008 METRIC actual ET for EBID yield reasonable and expected estimates of Study Area ET_c and ET_{aw} under "full supply" conditions.

Over the entire Study Area, ET Demands ET_c estimates are one, four and eight percent higher than the METRIC ET_c results in 2002, 2008 and 2013, respectively. All years are within the 10 percent calibration objective with the limited supply year of 2013 having the greatest difference.

Five of the six subareas had ET Demands total ET_c estimates within plus or minus three percent of the METRIC total ET_c estimates in 2002, the 24th consecutive full supply year. The one area (irrigated lands in New Mexico with access to groundwater only) that was not within three percent had higher ET Demands total ET_c compared to METRIC ET_c, which was found to be related to less intensive agricultural management practiced in this area. Overall, the ET Demands total ET_c estimates (representing ET_c under full supply) are higher than the METRIC total ET_c estimates (representing actual ET_c) in all areas in 2013 (a limited supply year), reflecting the expected changes in consumptive use with changes in water supply. ET Demands ET_c estimates are slightly higher in all but one area in 2008 and in all but two areas in 2002, which were full supply years. The ET Demands estimates were within three percent of the METRIC ET estimates in all areas and years having ET Demands total ET_c estimates lower than the METRIC total ET_c estimates.

In New Mexico, the actual ET_c estimated for full supply conditions varied in its comparison o METRIC-derived estimates of actual ET_c depending on the water sources available. ET Demands estimates total ET_c for EBID irrigated lands having access to surface water and groundwater to average 3.3 percent higher than the METRIC total actual ET_c estimates for 2002, 2008 and 2013. For the irrigated lands in New Mexico having access to groundwater only, the ET Demands total ET_c averaged 33 percent higher than the METRIC total actual ET_c estimates for 2002, 2008 and 2013. Reasons for the departure between ET demands ETc and METRIC actual ETc are apparently due to suboptimal agricultural and irrigation practices in the groundwater only area.

The ET Demands total ET_c for the EPCWID irrigated lands in the Mesilla Valley averaged nine percent higher than the METRIC total actual ET_c estimates for 2002, 2008 and 2013. The ET Demands total ET_c for the EPCWID irrigated lands in the El Paso Valley averaged 1.7 percent more than the METRIC total actual ET_c estimates for 2002, 2008, and 2013.

In Hudspeth, the ET Demands total ET_c for the irrigated lands averaged 18.3 percent higher than the METRIC total actual ET_c estimates for 2002, 2008 and 2013.

In Juarez, the ET Demands total ET_c for irrigated lands averaged 3.7 percent higher than the METRIC total actual ET_c estimates for 2002, 2008 and 2013.

The crop coefficients used to calculate ET_c in the ET Demands model have been developed based on best practices using locally-derived calibration to the 2008 METRIC results. When the crop coefficients are used to estimate ET_c representing full water supply for 2002 and 2013, the differences between the ET Demands results and METRIC results are slightly greater than those found in 2008, but are well within generally accepted ET modeling results. Thus, the comparisons with METRIC results demonstrate that the full supply ET_c estimates developed using ET Demands and locally calibrated crop coefficients are reproducible and can be relied upon for conducting water balance and consumptive use analyses.

VIII. Historical Consumptive Use Estimates

Overview

ET Demands model results for the consumptive use of irrigation water from irrigated lands under full water supply (full supply) conditions have been calibrated to local conditions using surface energy balance results for 2002, 2008 and 2013. The ET Demands calibrated inputs have been used to estimate consumptive use of irrigation water under “full supply conditions” for 1938 through 2013. “Full supply conditions” is generally understood to mean that available water supplies are sufficient to fully satisfy irrigation water demands for all lands irrigated.

Crop varieties, cultivation practices and irrigation management has changed over the 1938 to 2018 study period. The Rio Grande Project Histories, historical photographs and agricultural extension and research publications are important sources of information about the crop and irrigation management practices during this time period. These information sources were reviewed to assess the differences in agricultural practices that potentially affect ET_{aw} that are likely to have occurred under “full supply” conditions during the 1938 to 1970-time period as compared to the more recent time period. The time period 1938 through 1970 (early period) was chosen because after this time the crop mix began to diversify, moderating the dominant planting of cotton and alfalfa. This section compares and contrasts important agricultural practices and yield with those of the more recent 1970 to 2013-time period (recent period), and describes the adjustments applied to ET_{aw}.

Historical Consumptive Use Estimates

The Rio Grande Joint Investigation (RGJI) defines consumptive use (or evapotranspiration) as “the sum of the volumes of water used by the vegetative growth of a given area in transpiration or building of plant tissue and that evaporated from adjacent soil, snow, or intercepted precipitation on the area in any specified time” (RGJI, 1938). This definition includes evapotranspiration of precipitation (ET_{pr}). The values reported by the RGJI below were estimated based on the “...so-called integration method; that is, based on all available experience and judgment, unit values of consumption (acre-feet per acre) are assigned to the various classes of vegetative and other cover, taking into account the location of the latter within the basin with respect to altitude and latitude.” The depletions from the METRIC-calibrated ET demands root zone model differ only slightly from RGJI results for the Rincon, Mesilla and El Paso Valleys. The ET Demands results for 1936 are 0.3 acre-feet per acre, or 14 percent, higher than the RGJI estimates for cotton (**Table 8-1**). For alfalfa hay, the ET Demands results for 1936 are 0.1 acre-feet per acre, or 4 percent, lower than the RGJI estimates.

Table 8-1. Comparison of Joint Investigation Consumptive Use Estimates to ET Demands ET_{aw} Results (all values are in acre-feet per acre).

Location	Cotton		Alfalfa	
	Rio Grande Joint Investigation (1936)	ET Demands	Rio Grande Joint Investigation (1936)	ET Demands
Rincon Valley (in Sierra and Dona Ana Counties)	2.5	2.8	4.0	3.9
Mesilla Valley in New Mexico and Texas	2.5	2.8	4.0	3.9
El Paso division, Rio Grande project	2.5	2.7	4.2	3.9
Hudspeth County Conservation and Reclamation District No. 1	2.5	2.7	4.2	3.9

NA = Not Available

Historical Agricultural Practices and Yields

Between 1938 and 1970 cotton was grown on more than 60 percent of the area irrigated in the Rio Grande Project (Reclamation Crop Reports, 1938-1970). Alfalfa and cotton together during this period accounted for between 80 and 90 percent of the crops irrigated in Elephant Butte Irrigation District (EBID), El Paso County Water Improvement District #1 (EPCWID), Hudspeth County Conservation & Reclamation District #1 (Hudspeth) and Juarez Valley Irrigation District (Juarez) (**Figures 8-1, 8-2, 8-3 and 8-4**). The reduction in irrigated areas beginning approximately in 1953, and shown in all four major geographic areas in **Figures 8-1 through 8-4**, was due to a drought that reduced water supplies in the Rio Grande Project. Given the dominance of cotton and alfalfa as the primary crops during this period, first cotton and then alfalfa will be discussed in the following sections.

Cotton

Over 40 historical agricultural extension and research reports that included information on cotton agricultural practices were reviewed. The reports reviewed are listed and illustrative photos are provided in **Appendix 8A**. Although most of these reports focused on the Mesilla Valley, New Mexico, eight of the reports reported on research trials in the El Paso Valley, Texas. The agricultural practices documented in these reports from the El Paso Valley were generally consistent with the practices in the nearby Mesilla Valley, so review results were summarized into one combined table (**Table 8-2**). Reported seed rates ranged from 12 to 40 pounds per acre in the 1920 through 1970-time period compared to 25 pounds per acre now. The research publications reported more irrigations applying smaller amounts with each irrigation compared to the present era. Although lower seed rates could indicate lower ET, the thinning practices and final stand density are more important to the ET_{aw}. In general, agricultural practices are very similar during the two-time periods. With regards to fertilizer practices, the historical trials showed little response to fertilizer other than manure. Contrast this with the current recommended extension practice to apply 120 pounds of Nitrogen and 50 pounds of P_2O_5 fertilizer per acre. This is likely due to current, improved cotton varieties having improved ability to respond to higher nutrient availabilities and to be less prone to become rank under water and fertilizer abundant conditions.

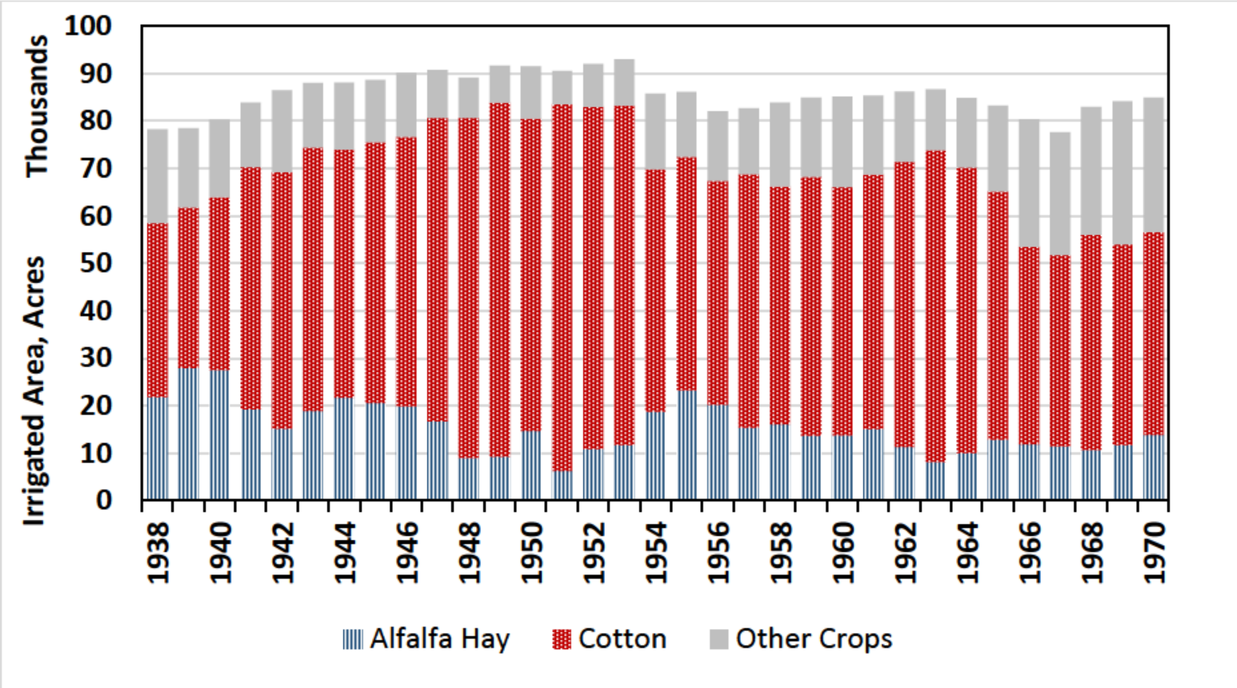

Figure 8-1. EBID major crops 1938 through 1970.

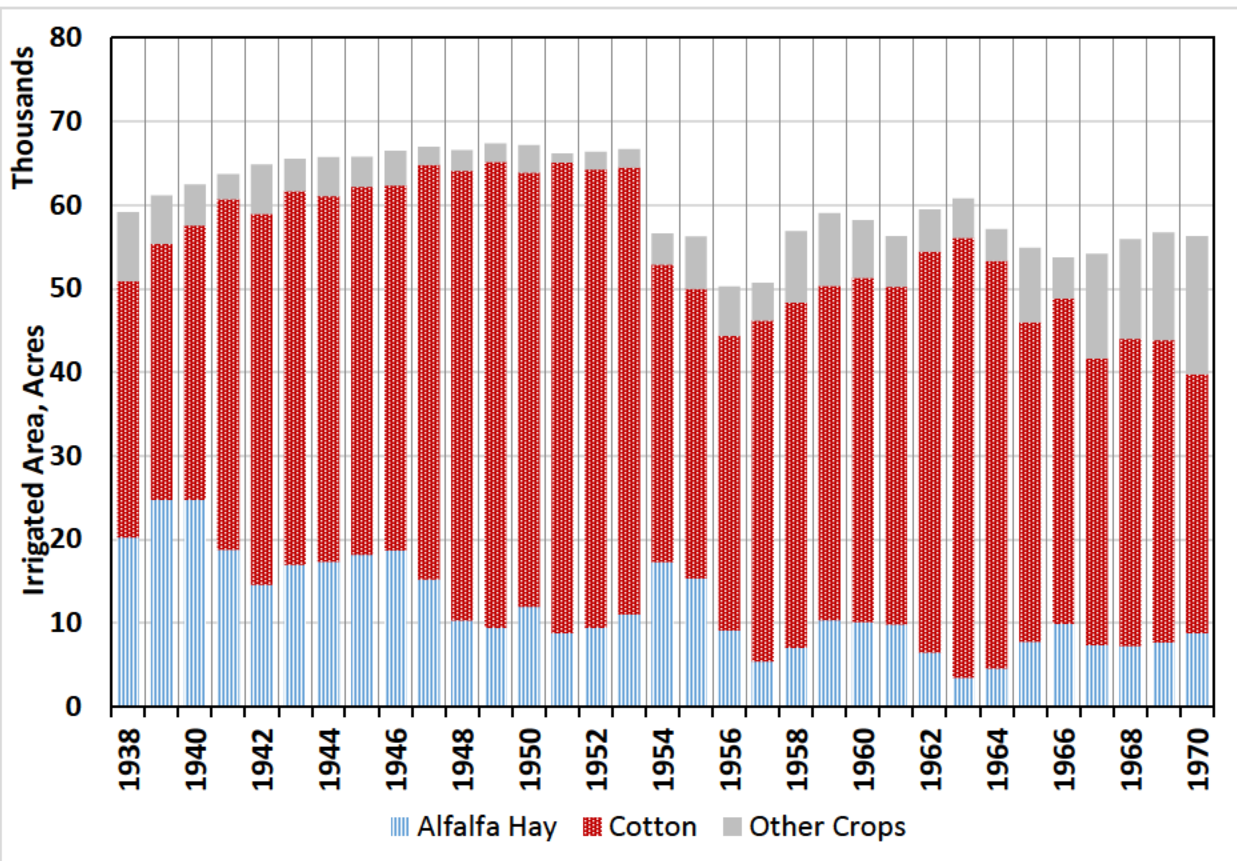

Figure 8-2. EPCWID major crops 1938 through 1970.

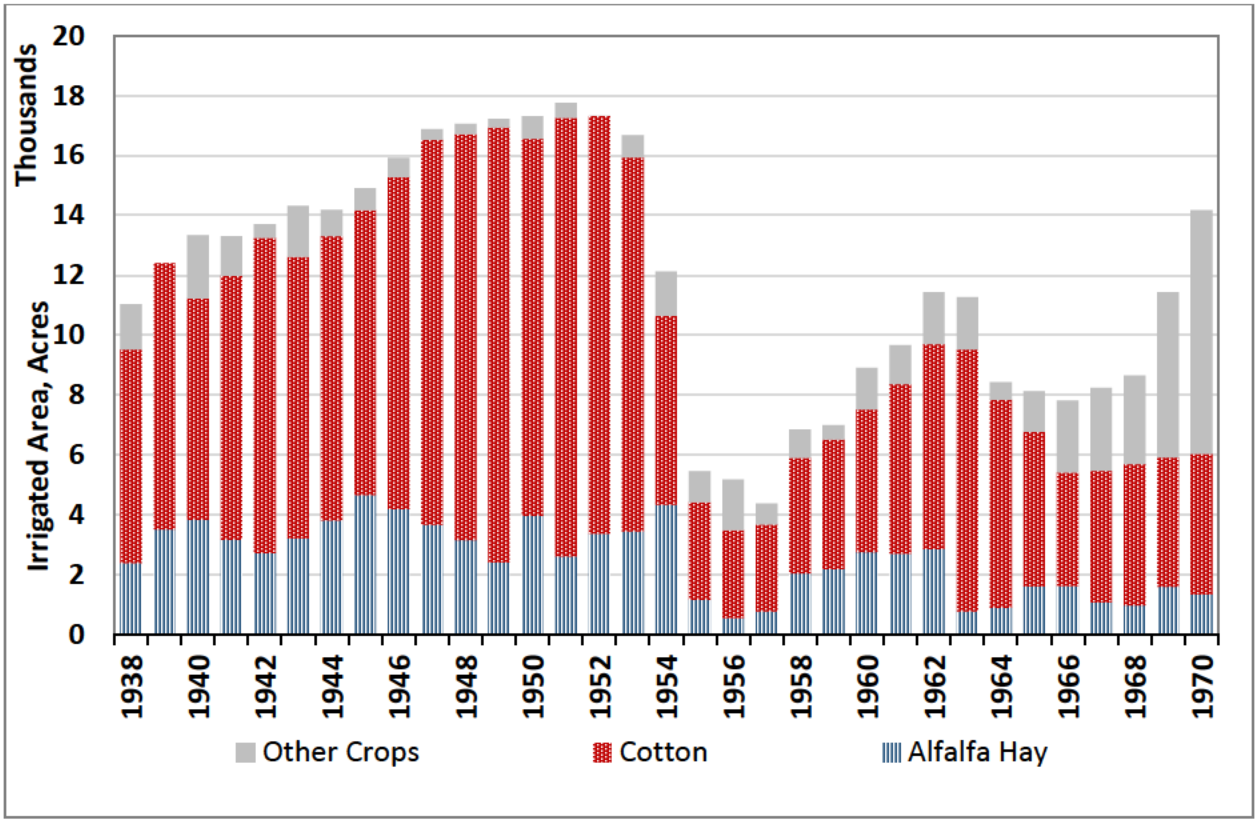

Figure 8-3. Hudspeth major crops 1938 through 1970.

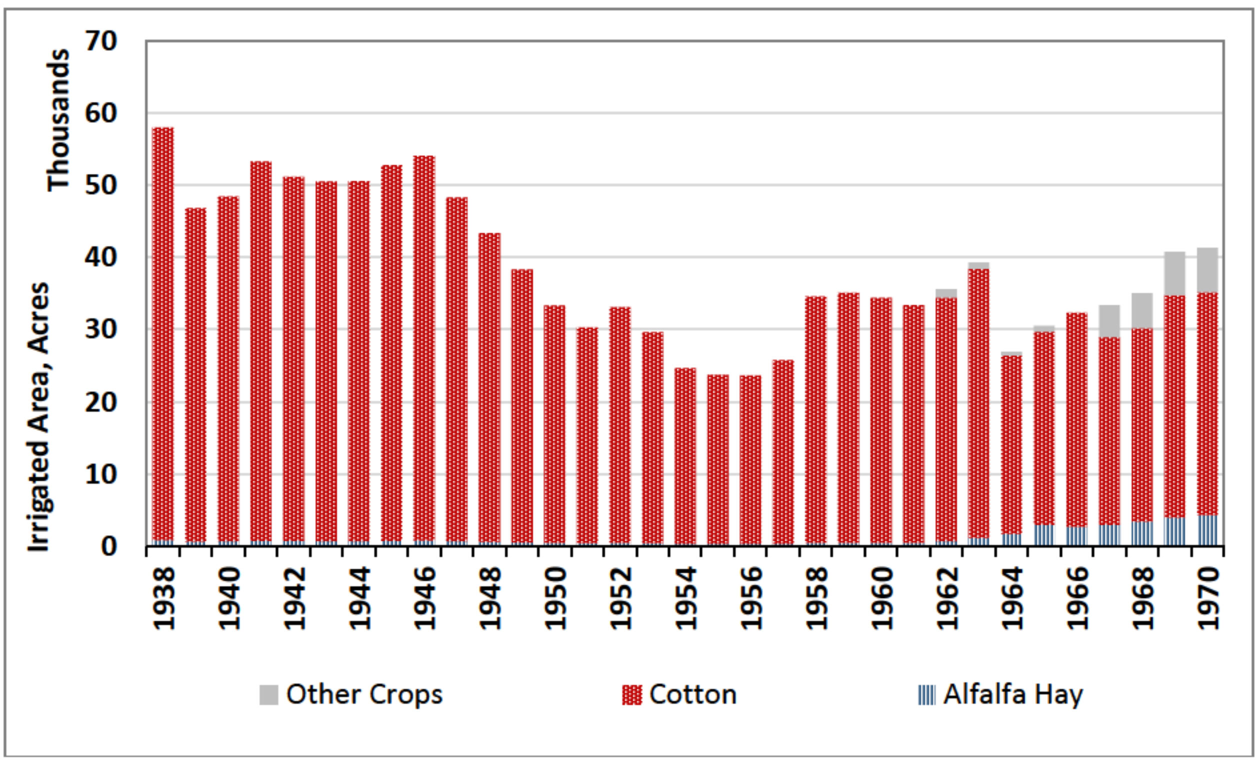

Figure 8-4. Juarez major crops 1938 through 1970.

Table 8-2. Summary of Reported Cotton Agricultural Practices in Mesilla Valley, New Mexico and El Paso Valley, Texas.

Cultural Practice	Historical Practices Early Period (1920* through 1970)		Current Practices**
	Minimum	Maximum	
Planting Dates	4/14	5/28	April 15-30
Row Spacing, inches	36	42	40
Seed Rate, lbs/acre	12	40	25
Plant Spacing, inches	3	20	
Pre-irrigation	A pre-irrigation late March/early April is standard practice.		Late March or Early April
No. of irrigations	3	8	4
Irrigation applied, inches***	15	35	33
Fertilizer	Most trials show little response to fertilizer other than manure.		120 lbs N, 50 lbs P_2O_5

*Some historical reports available beginning in 1920.
**Current practices from personal observation, Zhang (2015) and Cost and Return Study Dona Ana County (2003).
***Irrigation applied amounts obtained from research trials.

Reclamation reports crop areas and yields for upland and long staple (Pima) cotton for lint, in bales per acre, and for seed in tons per acre. This information is collected from water users each year by Reclamation staff on Form 7-332 and compiled on Form 7-316 (Reclamation, 1917). These crop reports indicate that cotton yields increased from the 1920s through the 1960s (**Figure 8-5**). The yields began decreasing again in the late 1960s back to the yield levels of the 1930s. Similar statewide cotton yield trends during the late 1960s were reported by Lansford, et al. (1987). Yield data from the National Agricultural Statistics Service (NASS) shows that yield began increasing again in the 1980s. Lansford, et al. (1987) attribute the yield increase to improved crop varieties, the decline that followed in the early 1960s to climatic factors (primarily lower temperatures during the growing season) and the subsequent rebound due to improved varieties.

Alfalfa Hay

Over 20 historical agricultural extension and research reports that included information on alfalfa agricultural practices were reviewed. The reports reviewed are listed and illustrative photos provided in **Appendix 8B**. Although most of these reports focused on the Mesilla Valley, one report reported on research trials in the El Paso Valley. The agricultural practices documented in these reports from the El Paso Valley were generally consistent with the practices in the nearby Mesilla Valley, so review results were summarized into one combined table (**Table 8-3**). With the exception of fertilizer practices, noted in the bottom row, the practices are fairly consistent throughout that time period and with current practices. The historical trials showed little response to fertilizer. Contrast this with the current recommended extension practice, which is to apply 35 pounds of Nitrogen and 90 pounds of Phosphorous fertilizer per acre. This is likely due to current, improved varieties having improved ability to respond to higher nutrient availabilities.

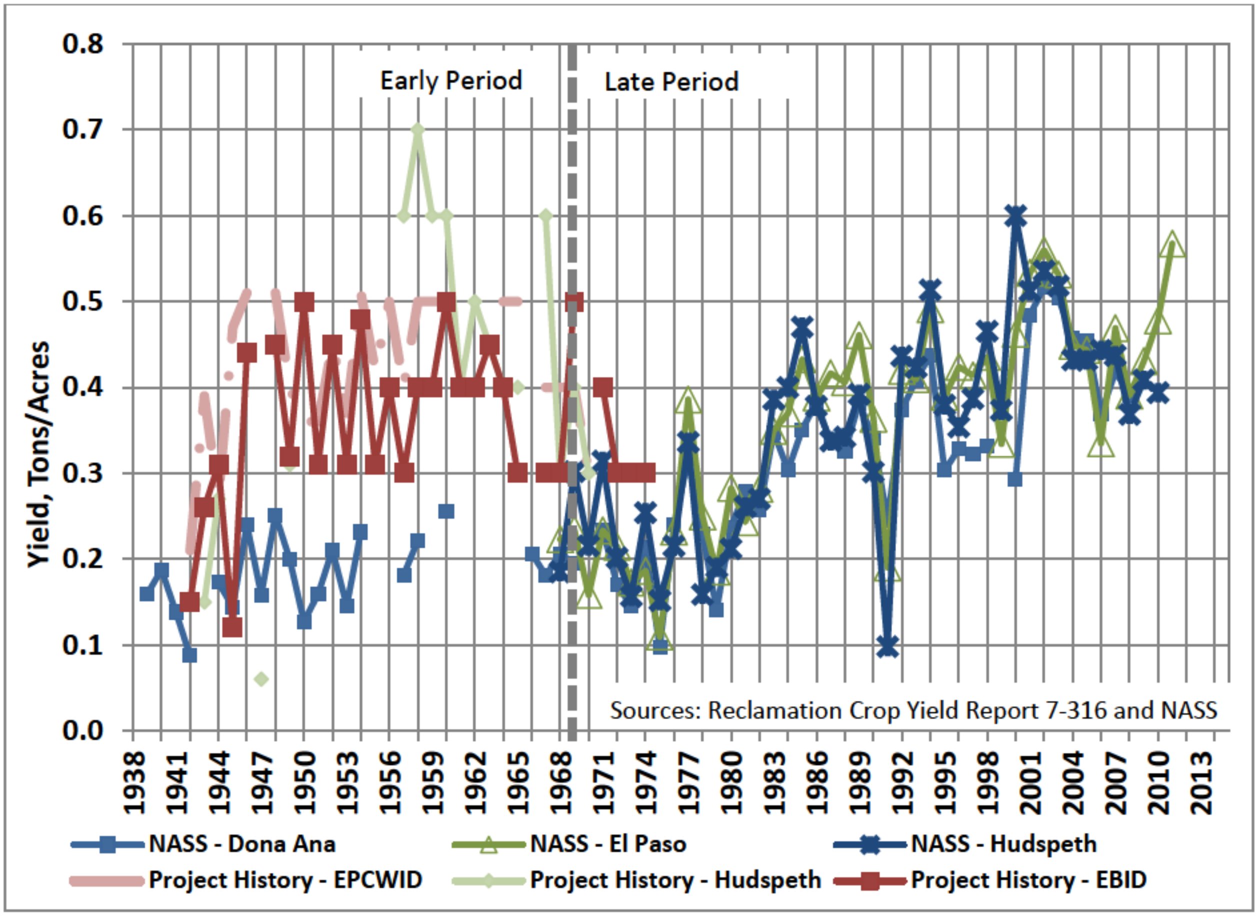

Figure 8-5. Average cotton yields in the project 1938 through 2013

Table 8-3. Summary of Reported Alfalfa Agricultural Practices in Mesilla Valley, New Mexico and El Paso Valley, Texas.

Cultural Practice	Based on Extension Bulletins Published in 1923, 1931, 1940 and 1943. Min	Max	Current Practices*
Number of cuttings	4	6	5
First Cutting Date	10-Apr	7-Jun	1-May
Second Cutting Date	20-May	17-Jul	
Third Cutting Date	15-Jul	9-Sep	
Fourth Cutting Date	18-Aug	18-Oct	
Fifth Cutting Date	10-Oct	16-Oct	1-Oct
No. of irrigations	9	14	10
Irrigation applied, inches	46	52	60
Fertilizer	Vary	Vary	35 lbs N, 90 lbs P
Yield Data (tons/acre)	5.5	7.6	6.5 to 8.0

*Current practices from personal observation, and Cost and Return Study Dona Ana County (2003).

Reclamation crop reports for the project indicate that alfalfa yields ranged from about 3.5 to 4.5 tons per acre from the 1930s through the late 1950s (**Figure 8-6**). In the late 1950s through the early 1960s, alfalfa yields increased to about 5 tons per acre, staying at about that level through the early 1970s. In the early 1970s, yields increased again to about 6 to 6.5 tons per acre by the early 1980s. These trends are similar to statewide yield trends reported in Lansford, et al. (1987), but the actual yields are higher, as would be expected from an irrigated area and somewhat longer growing season compared to other parts of the state reported in Lansford, et al. (1987). Yield data from the NASS shows that average yields in Dona Ana, El Paso and Hudspeth County remain between 6.5 and 7.5 tons per acre with a few years above 8 tons per acre between 2000 and 2015. Lansford, et al. (1987) attribute the yield increases in the late 1950s and early 1970s to improved varieties.

Summary of Key Differences between Early and Late Periods

Available historical photos, agricultural practices and yield were reviewed for the early period, 1938 through 1970, for cotton and alfalfa to consider the need to adjust ET_{aw} during this time period.

Cotton

Historical photos

- Photos are mostly from research publications and are generally of poor quality (**Appendix 8A**)
- Cotton density looks similar to modern densities

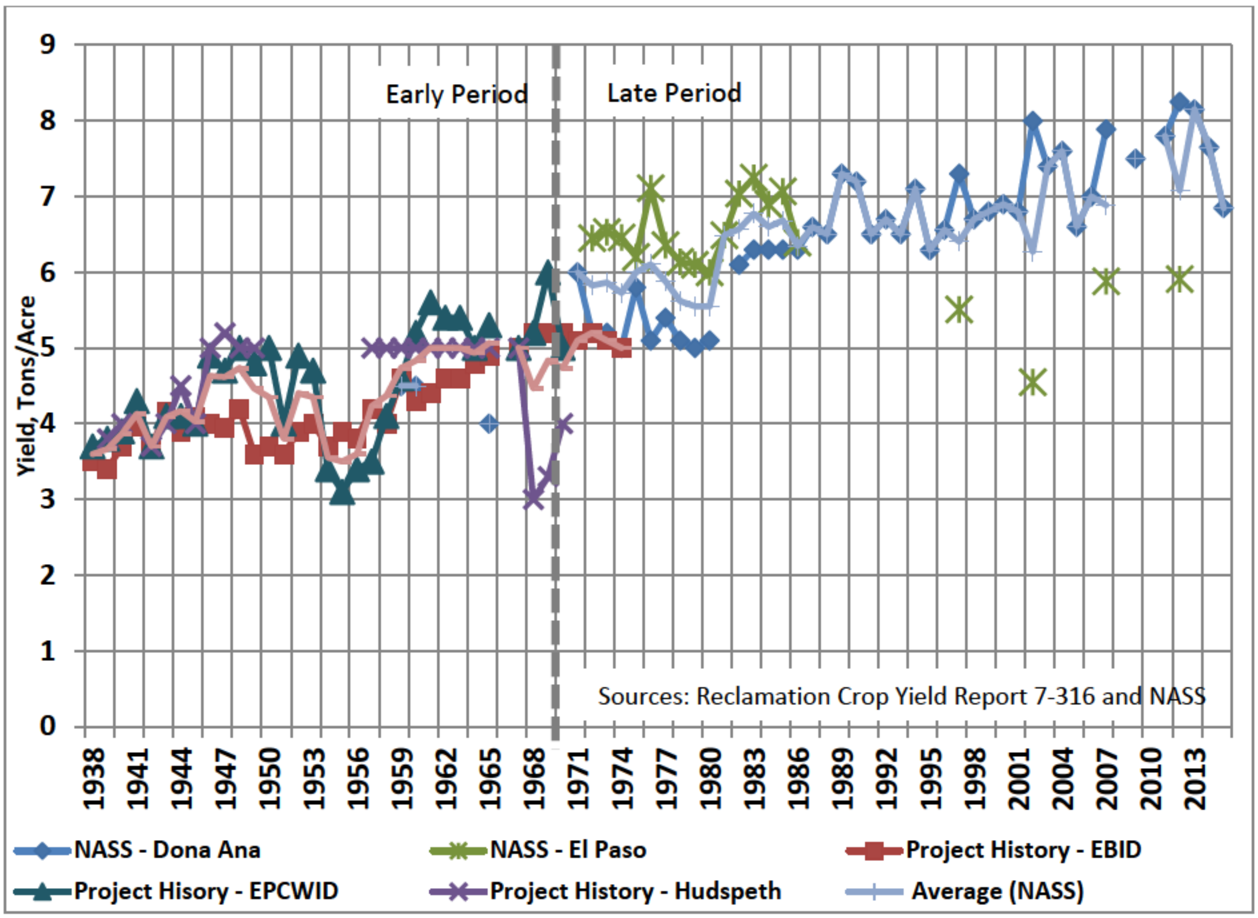

Figure 8-6. Average alfalfa yields in the project 1938 through 2013.

Agricultural Practices

- Modern seed rate is 25 pounds per acre compared to 15 to 20 pounds in the earlier time period
- **Table 8-4** summarizes agricultural practices that impact the plant population in the field and the volume of water available to the cotton plant. Comparing the 1938 to 1970 to the 1971 to 2013-time period, relevant agricultural practices for the 1938 to 1970 period were slightly lower compared to the recent period.

Table 8-4. Summary of Changed Agricultural Practices That Impact Crop ET and Estimates of Cotton ET.

Cultural Practice/ET_c Estimate	Early Period (1938 to 1970)	Recent Period (1981-2013)	Early Period Relative to Recent Period
Row Spacing, inches	40	40	Same
Seed Rate, lbs/acre	18	25	Lower
Irrigation applied, inches	25	33	Lower

Yield

- Cotton yield has varied over this time period primarily due to variety changes and cool summers (Lansford, et al., 1981).

Alfalfa

Historical photos

- Photos are mostly from research publications and are generally of poor quality (**Appendix 8B**)
- Alfalfa density looks similar to modern densities

Agricultural Practices

- Modern seed rate is 20 pounds per acre compared to 18 to 20 pounds in the earlier time period
- Most growers take 6 cuttings now with some growers taking 7 cuttings compared to an average of 5 cuttings in the earlier time period. Many growers cut sooner now compared to the earlier period to increase the protein in the hay. This is especially desirable for hay fed to dairy cows.
- **Table 8-5** summarizes agricultural practices that impact the water consumption of the alfalfa hay crop. Comparing the 1938 to 1970 to the 1971 to 2013-time period, relevant agricultural practices for the 1938 to 1970 period were slightly lower compared to the recent period.

Yield

- Alfalfa yield has generally increased with average yields ranging between six and seven tons per acre from 1980 to 2015 compared to average yields ranging from 3.5 to 5 tons per acre for the 1938 to 1970-time period. Because alfalfa yield is primarily dry matter, the yield is strongly related to the crop ET.

Table 8-5. Summary of Changed Agricultural Practices That Impact Crop ET and Estimates of Alfalfa ET.

Cultural Practice/ET_c Estimate	Early Period (1938 to 1970)	Recent Period (1971-2013)	Early Period Relative to Recent Period
Number of Cuttings	5	6	Lower
Yield, tons per acre	5.5	7.6	Lower
Irrigation applied, inches	46 to 52	60	Lower

Opinions

A reduction of five percent applied to the alfalfa and cotton ET_{aw} for the 1938 to 1953 period, reducing linearly from 1954 to zero reduction in 1970 is reasonable to accurately account for historical improvements in agricultural practices that include plant density and yield, and that have impacted ET_{aw}. ET_{aw} from 1970 through 2018 does not require adjustment.

IX. Irrigation Consumptive Use Coefficient

Purpose

The purpose of this section is to estimate the Irrigation Consumptive Use Coefficient (ICUC) under conditions of limited surface water supply, which is used to determine groundwater pumping before records became available. Burt, et al. (1997) defined the ICUC as the ratio of volume of irrigation water consumptively used to the quantity of the total volume of irrigation water applied minus the change in storage of irrigation water, both in a specified period of time and expressed as a percentage. Under conditions of limited surface water supply, the total volume of applied water (both surface water and groundwater) can be estimated as the evapotranspiration of applied water (ET_{aw}), often referred to as consumptive use of applied water, divided by the ICUC. Given the volume of surface water applied in a defined area, the groundwater pumping required to meet irrigation requirements can be calculated as the total volume of applied water minus the surface water applied.

Methodology

This section describes the methodology for estimating ICUC in each district for 1938 through 2018. First, irrigation performance measures are discussed and explanation is given for the selection of ICUC to estimate groundwater pumping under limited water supply conditions. The methodology used to calculate district-wide ICUC under conditions of limited surface water supply is then described for EBID. This is followed by description of the methodology used to extrapolate the ICUC values to the other districts and then the methodology to extrapolate the ICUC values to past years.

Irrigation Performance Measures

Many definitions have been proposed for Irrigation Efficiency (IE) and other irrigation performance measures. In 1997, Burt et al. (1997) reported on the results of the American Society of Civil Engineers (ASCE) Task Committee on Defining Irrigation Efficiency and Uniformity. This report, presented as a peer-reviewed technical article in the Journal of Irrigation and Drainage Engineering, describes seven irrigation performance indicators. Four indicators are used to characterize single irrigation event performance, while three – including ICUC and IE – are used to characterize overall project management over some time interval, such as an irrigation season or on an annual basis. More fundamentally, the report describes a peer-reviewed and widely accepted scientific and technical framework and approach to determine the appropriate irrigation performance indicator for a defined purpose.

In addition to ICUC, three of the most commonly used efficiency terms are IE, application efficiency (AE) and distribution uniformity (DU). AE and DU are used to evaluate efficiency for a single field, or sometimes smaller unit, and for a single irrigation event. Because a district-wide efficiency term is needed to estimate district-wide groundwater pumping volumes, only the ICUC and IE indicators, which can be applied to a field, farm, district, project, or basin are appropriate in this investigation.

Burt, et al. (1997) defined IE as the percentage of volume of irrigation water *beneficially* used relative to the total volume of irrigation water applied (**Equation 9-1**). The total volume of irrigation water applied is equal to the volume of irrigation water applied minus the change in storage of irrigation water. Irrigation water beneficially used can be either consumed or not consumed. For example, water used to leach salts from the root zone is beneficially used, but is not consumed; rather, it percolates below the root zone. Thus, IE requires quantification of all beneficial uses and an estimate of the change in storage of irrigation water to calculate the volume of irrigation water applied (**Equation 9-2**). However, the total volume of irrigation water beneficially used is not always quantified or easily estimated across an area as extensive as the Study Area.

$$IE = \frac{volume\ of\ irrigation\ water\ beneficially\ used}{volume\ of\ irrigation\ water\ applied - change\ in\ storage\ of\ irrigation\ water} \cdot 100$$ (**Eq. 9-1**)

$$volume\ of\ irrigation\ water\ applied = \frac{volume\ of\ irrigation\ water\ beneficially\ used}{IE} \cdot 100 + change\ in\ storage\ of\ irrigation\ water$$ (**Eq. 9-2**)

The ICUC, first described by Jensen (1993), is an alternative efficiency term that quantifies the percentage of irrigation water *consumed* relative to the total volume of irrigation water applied. This performance indicator is used to characterize overall project management and is calculated for a selected area and time interval, commonly for a complete irrigation season (**Equation 9-3**). Compared to irrigation water beneficially used, the volume of irrigation water consumptively used (ET_{aw}) is more readily quantified and estimated over large areas and extended time periods based on reference evapotranspiration derived from local weather and climate data and locally-calibrated crop coefficients. Thus, ICUC is a more appropriate term to use in this basin-scale study over an extended period of time.

$$ICUC = \frac{volume\ of\ irrigation\ water\ consumptively\ used}{volume\ of\ irrigation\ water\ applied - change\ in\ storage\ of\ irrigation\ water} \cdot 100$$ (**Eq. 9-3**)

Because the ICUC performance indicator quantifies *consumed* water as a percentage of irrigation water applied (applied water), the total volume of applied water can be determined by dividing ET_{aw} by the ICUC, multiplying by 100 and adding the change in storage of irrigation water (**Equation 9-4**).

$$volume\ of\ irrigation\ water\ applied = \frac{ETaw}{ICUC} \cdot 100 + change\ in\ storage\ of\ irrigation\ water$$ (**Eq. 9-4**)

When calculated for an entire irrigation season, the change in storage of irrigation water is often assumed to be zero. The volume of irrigation water stored in the root zone is generally low at both the beginning and end of the irrigation season. At the end, growers stop irrigating prior to harvest so that the fields and crops will be dry for harvest. At the beginning, storage of irrigation water is also low because no irrigation water has been applied since the end of the preceding irrigation season. For the Study Area, Hulsman (1983) concludes that the change in storage in the root zone over the irrigation season is near zero. Thus, the total volume of applied water can be calculated simply as the ETaw divided by the ICUC and multiplied by 100 (**Equation 9-5**).

$$volume\ of\ irrigation\ water\ applied = \frac{ETaw}{ICUC} \cdot 100$$ (**Eq. 9-5**)

Once the total volume of applied water is determined, the volume of groundwater pumped can be determined by subtracting the volume of surface water applied from the total volume of applied water (Equation 9-6).

$$volume\ of\ groundwater = volume\ of\ irrigation\ water\ applied - volume\ of\ surface\ water$$ (**Eq. 9-6**)

Likewise, ICUC for an entire irrigation season can be calculated from the total volume of applied water and ET_{aw} when values of both are available (**Equation 9-7**).

$$ICUC = \frac{ETaw}{volume\ of\ irrigation\ water\ applied} \cdot 100 \qquad \textbf{(Eq. 9-7)}$$

ICUC Calculations

To calculate ICUC (**Equation 9-7**), the volume of irrigation water consumptively used by crops (also referred to as ET_{aw}) and the volume of irrigation water applied over the time period selected must be known. These volumes must be specific to the area and time period considered. These data are only available for EBID and nearby irrigated lands with access only to groundwater during the period 2009 through 2016, when Reclamation Crop and Data Forms 7-316 and 7-2045 are available and contain sufficient information regarding applied irrigation water. Additionally, ICUC changes between years depending on water availability and related irrigation practices. Thus, to use ICUC to estimate groundwater pumping in years with limited surface water supply, the ICUC must be calculated during years with limited surface water supply. Data sources and calculations related to these considerations are described below.

ET_{aw}

ET_{aw} is based on crop coefficients developed from remotely sensed energy balance ET analyses for 2008 and calibrated through review of 2002 and 2013 METRIC results. The crop coefficients and resulting ET_{aw} volumes from the METRIC analysis and ET Demands root zone model were developed to represent full water supply conditions. Development of these values is described in detail in the Consumptive Use of Applied Water in the Rincon, Mesilla, El Paso and Juarez Valleys of the Rio Grande Report.

Volume of Irrigation Water Applied

The volume of irrigation water applied is based on EBID reports of total annual farm delivery volume provided to Reclamation. Beginning in 2008, the state of New Mexico required growers to measure and report the volume of groundwater pumped. The first full year with measurements of groundwater pumped was 2009. Thus, the years 2009 through 2016 include the best and most complete measurements of farm deliveries including groundwater pumping and estimates of the ET_{aw} demand for use in a district-wide annual ICUC analysis.

Limited Surface Water Supply

Growers generally prefer surface water when it is available because it is less expensive than groundwater because of pumping costs. When surface supplies are limited, growers implement additional management actions that, within limits, result in an increase in the ICUC. Thus, the ICUC used to calculate groundwater pumping is calculated for years with limited surface water supplies. Limited surface water supplies within the Study Area are generally defined as years having less than three acre-feet per acre of surface water available. For years that meet these criteria, the ICUC was calculated for EBID and nearby irrigated lands with access to only groundwater as the ET_{aw} divided by the total volume of water applied (equal to measured farm head gate deliveries plus measured groundwater pumped).

Extrapolate EBID ICUC Values to other Districts

The EBID ICUC values calculated for the period 2009 through 2016 were then extrapolated for all other districts in the Study Area having insufficient data to calculate separate district-specific ICUC values. Similarities and differences between EBID, EPCWID, Hudspeth and Juarez were evaluated with regards to factors affecting on-farm surface irrigation efficiencies. When districts were found to be dissimilar to EBID, the findings of these analyses were used to develop an adjustment factor for the ICUC calculated for EBID to account for differences in the physical and management situations in the other districts. Methodologies used to evaluate these similarities and differences are described for irrigation methods, field slopes, soils, field size, and water ordering and delivery flexibility in the following paragraphs.

Irrigation Methods

Irrigation methods are an important factor affecting ICUC values. In the US Districts, irrigation methods were identified from crop survey data. Crop survey data were unavailable in Juarez, so irrigation methods were assumed to be similar to methods in EPCWID and Hudspeth based on the similarity in terrain, soils, and cropping between these districts.

In 2008, the New Mexico Office of the State Engineer (NMOSE) conducted a ground crop survey by mapping and visual inspection to identify crops and irrigation methods in all irrigated fields in EBID (Longworth, 2011). A second crop survey[10] in 2016 identified crops and irrigation methods in a random sample of fields in EBID, EPCWID and Hudspeth. The random sample included 822 fields in EBID (covering 23 percent of the irrigated area), 279 fields in EPCWID (covering 14 percent of the irrigated area), and 112 fields in Hudspeth (covering 36 percent of the irrigated area). These surveys found that most fields in the Study Area are irrigated by surface irrigation methods. The three main surface irrigation methods observed – border, furrow and basin – are summarized below:

1. Border, or border strip, irrigation consists of a sloping strip of land that is level widthwise across the strip and bounded by borders so as to prevent water from spreading laterally (Burt et al, 2000). Water is released into the upper end of the strip and spreads longitudinally by gravity downslope along the strip. Border irrigation is generally used to irrigate alfalfa, pasture, grain and pecans in the Rio Grande Project area.
2. Furrow irrigation consists of a small, sloping channel in the soil between the crop rows (Burt et al, 2000). Water is released at the upper end of the furrow and flows downslope to the end of the field. Furrow irrigation is used to irrigate row crops, such as corn, cotton and miscellaneous vegetables.
3. Basin irrigation consists of a level, or nearly level, area of land bounded by dikes (Burt et al, 2000). Water is released into the basin and remains ponded until all the water infiltrates into the soil. Basin irrigation is generally used to irrigate alfalfa, pasture, grain and pecans in the Rio Grande Project area.

A few fields in the Study Area are irrigated by drip/micro irrigation. Drip/micro irrigation refers to irrigation methods in which water is delivered directly to small areas adjacent to plants through applicators, often simply small holes spaced along a pipe or tube delivering water (Burt et al, 2000).

Field Slopes

In the US Districts, ArcMap's 'Slope' tool was used to convert elevations from digital elevation model (DEM) datasets obtained from the National Map Viewer (USGS, 2017) to slopes. First, the DEM data were mosaicked to cover all the US Districts. DEM data for the Juarez area in Mexico were not available. Therefore slopes in Juarez were assumed to be similar to slopes in the US Districts based on their similarity in terrain. Next, the DEM data were resampled to a spatial resolution of 30 square meters using the cubic convolution method and reprojected in the NAD_1983_UTM_Zone_13N projection system[11]. After using the 'Slope' tool to convert the DEM elevation data to slopes, the slope data were extracted by field using ArcMap's 'Zonal Statistics as Table' tool with the Intera (2017) fields coverage.

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[10] The survey methodology and results are described in detail in the Consumptive Use of Applied Water in the Rincon, Mesilla, El Paso and Juarez Valleys of the Rio Grande Report.

[11] Spatial coordinate projection systems are used to project locations on the Earth's surface to a two-dimensional Cartesian coordinate system. Each projection system relies on a spheroid to represent the approximately spherical

Soils

The Soil Survey Geographic Database (SSURGO) contains information about soil in the United States collected by the National Cooperative Soil Survey (NCSS). The NCSS is a nationwide partnership of federal, regional, state, and local agencies and private entities and institutions that cooperatively investigates, inventories, documents, classifies, interprets, disseminates, and publishes information about soils. The United States Department of Agriculture-Natural Resources Conservation Service (USDA-NRCS), formerly known as the Soil Conservation Service (SCS), organizes the NCSS and publishes scientifically sound and accepted standards for conducting soil surveys and classifying soils.

The SSURGO database is available on the internet and contains scientifically accepted and technically sound information on soils that was formerly provided in printed soil survey publications (SSURGO, 2014). Soils information is available for most areas in the United States, including New Mexico and Texas. The information in the database was gathered by observing the land and soil and collecting and analyzing soil samples (SSURGO, 2014). Soil maps in the database are commonly used in natural resource planning and management activities nationwide. Information available from the database includes soil infiltration characteristics, available waterholding capacity (AWC), and other data necessary for plant consumptive use analyses and other water resource engineering applications.

To characterize soils within the Study Area, the United States Department of Agriculture (USDA) textural classes were determined based on the percentage of sand and clay observed in the SSURGO database soil maps. The saturated hydraulic conductivity (K_{sat}) and AWC values were also obtained from SSURGO to characterize soil infiltration and AWC parameters, respectively, for each soil texture class. The procedures used to estimate these soil parameters are described in more detail in the Soils section of the Consumptive Use of Applied Water in the Rincon, Mesilla, El Paso and Juarez Valleys of the Rio Grande Report. Soil data for the portion of the Study Area in Mexico were not available in the SSURGO database, but were assumed to be similar to soils in the US Districts based on the similarity in soils on the west and east side of the Rio Grande in the Mesilla Valley.

Field Size and Head Ditch Lining

Field sizes were reviewed based on the most recent available field boundaries developed in GIS by Intera (2017) from aerial photographs. A head ditch is an irrigation ditch in a farm field from which irrigation water is diverted into furrows or border strips. Head ditches are often lined with concrete to reduce seepage into the ground. Information on head ditch lining was obtained from the Rio Grande Project Histories.

Water Ordering and Delivery Flexibility

Customer water ordering procedures and flexibility in the flow rate, duration, and timing of water deliveries together dictate the ability of irrigators to match water deliveries to individual fields' water needs and physical characteristics. To achieve high ICUC values, a district's flexibility in providing accurately timed water deliveries of requested flow rates and durations is important. Recent publications describing the districts' water ordering and delivery procedures were reviewed to assess similarities and differences among districts' abilities to support high ICUC values.

Extrapolate ICUC Values to Past Years

The calculated EBID ICUC values and the estimated ICUC values for all other districts were extrapolated to past years before 2009 and after 2016, when sufficient data were not available to calculate ICUC. The

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surface of the Earth. For additional information, see http://resources.esri.com/help/9.3/arcgisengine/dotnet/89b720a5-7339-44b0-8b58-0f5bf2843393.htm.

ICUC values were extrapolated to years beyond 2009 to 2016 by adjusting for changes in the two main factors affecting ICUC values that have changed over time: irrigation methods and on farm irrigation system improvements. Historical information regarding each factor was extracted from the Rio Grande Project Histories and early research publications' descriptions of the Study Area. The Rio Grande Histories include annual reports by Reclamation summarizing Rio Grande Project operations for the years 1912 through 1988.

Results

The following sections present the results of the ICUC calculation for the EBID area; the evaluations of irrigation methods, field slopes, soils, field sizes, water ordering, and delivery flexibility used to extrapolate the EBID ICUC values to other districts; and the review of historical documents used to extrapolate the ICUC estimates to earlier years.

EBID ICUC Calculations

ICUC was calculated for EBID for 2009 through 2016. All eight years were considered to have limited surface water supplies, because the farm deliveries per irrigated area with access to surface water was less than three acre-feet per acre in all years, varying from 0.30 to 2.64 acre-feet per acre (**Table 9-1**). When the farm deliveries are combined with the available pumping data and the irrigated area with access to only groundwater are included, the total applied water increased to 3.68 acre-feet per acre or more in all eight years, exceeding limited supply conditions. Thus, it is reasonable to assume that groundwater pumping supplied enough water to meet the full ET demand of crops in EBID. The ICUC was calculated to range from 69 to 87 percent with an average of 76 percent (**Table 9-2**). The highest ICUC of 87 percent occurred in 2011, the year with the maximum reference ET in the 1936 to 2018 time period. The minimum ICUC of 69 occurred in 2015, a year of relatively low reference ET and irrigated area.

Extrapolate ICUC Estimates to other Districts

Similarities and differences between EBID, EPCWID, Hudspeth and Juarez were evaluated with regards to factors affecting on-farm surface irrigation efficiencies. These evaluations were used, if needed, to develop an adjustment factor for the EBID ICUC to reflect differences in the physical and management situations in the other districts. Results of the methodologies used to evaluate similarities and differences in irrigation methods, field slopes, soils, field sizes, and water ordering and delivery flexibility are described in the following paragraphs.

Table 9-1. Annual Surface Water Deliveries and Groundwater Pumping for EBID for years with GW Pumping Measurements.

Year	Farm Deliveries (Surface Water), acre-feet*	Groundwater Pumping, acre-feet	EBID SW Irrigated Area, Acres	GW Only NM Irrigated Area, Acres	Farm Deliveries (Surface Water) per acre, feet	Total Applied Water per acre, feet
2009	187,694	131,000	71,210	4,397	2.64	4.22
2010	155,416	138,000	74,875	4,794	2.08	3.68
2011	24,149	279,000	71,592	4,411	0.34	3.99
2012	53,756	265,000	68,110	4,415	0.79	4.40
2013	21,817	286,000	72,494	4,706	0.30	3.99
2014	39,999	252,000	72,124	4,646	0.55	3.80
2015	70,416	219,000	69,057	4,559	1.02	3.93
2016	86,023	216,000	70,031	4,853	1.23	4.03

*2012-2014 Estimated based on 2011 delivery efficiency and 2016 Estimated based on 2015 delivery efficiency

Table 9-2. Annual ICUC Calculation for EBID for Years with Complete Water Delivery Measurements.

Year	Farm Deliveries (Surface Water), acre-feet*	Groundwater Pumping, acre-feet	Total Applied Water, acre-feet	ET of Applied Water, acre-feet	ICUC
2009	187,694	131,000	318,694	224,999	71%
2010	155,416	138,000	293,416	233,114	79%
2011	24,149	279,000	303,149	265,048	87%
2012	53,756	265,000	318,756	235,228	74%
2013	21,817	286,000	307,817	220,958	72%
2014	39,999	252,000	291,999	224,483	77%
2015	70,416	219,000	289,416	198,768	69%
2016	86,023	216,000	302,023	229,880	76%
Average =					76%

*2012-2014 estimated based on 2011 delivery efficiency and 2016 estimated based on 2015 delivery efficiency

Irrigation Methods

The 2008 ground survey of crops and irrigation methods in EBID completed by NMOSE staff (Longworth, 2011) found that combined border and basin irrigation (recorded as "flood" in the database) was the most prevalent irrigation method used on 78 percent of the fields. Furrow irrigation was the next most prevalent method used on 19 percent of the fields, while sprinkler and drip irrigation together were used on just under three percent of the fields. The 2016 survey[12] visited a random sample of 822 fields in EBID covering 23 percent of the irrigated area and found 75 percent of the sampled fields used the border or basin irrigation method (often referred to locally as flood irrigation). The furrow irrigation method was used on 22 percent of the sampled fields and drip or sprinkler irrigation was used on four percent of the sampled fields. This survey also observed and identified irrigation methods on a random sample of 279 and 112 fields in EPCWID and Hudspeth, respectively covering 14 and 36 percent of the irrigated area. In EPCWID, the survey found 50 percent of the sampled fields using border or basin and

[12] The survey methodology and results are described in detail in the Consumptive Use of Applied Water in the Rincon, Mesilla, El Paso and Juarez Valleys of the Rio Grande report.

50 percent of the sampled fields using furrow irrigation methods. In Hudspeth, the survey found 35 percent of the sampled fields using border or basin and 65 percent of the fields using furrow irrigation methods. The greater percentage of furrow irrigation found in EPCWID and Hudspeth is consistent with the greater percentage of irrigated cotton acreage found in EPCWID and Hudspeth compared to EBID. No drip or sprinkler irrigation was observed in EPCWID or Hudspeth. Based on the similarity in terrain, soils and cropping in Juarez, the irrigation methods are assumed to be similar to those in EPCWID and Hudspeth. Given the similarity in irrigation methods across the districts, an ICUC adjustment factor for irrigation method differences across districts is not needed.

Field Slopes

Irrigated areas in the Study Area are generally located on the valley lowlands with gentle slopes next to the Rio Grande. Additionally, nearly all the fields in the US Districts have been laser leveled to uniform and precise slopes. As part of a 1980 to 1982 study on irrigation efficiency, Hulsman (1983) measured slopes on 16 irrigated fields in EBID with nine different crops and all fields had slopes less than 0.2 percent. The DEM analysis described earlier also found that 70, 59, and 65 percent of the fields in EBID, EPCWID and Hudspeth, respectively, had slopes equal to or less than 0.5 percent. The topography in the US Districts and Juarez is similar, thus field slopes in Juarez are likely similar to those observed in the US Districts. Given the similarity in field slopes across all districts, an ICUC adjustment factor for field slope differences is not needed.

Soils

Soil textures within fields have important effects on irrigation performance. A soils analysis was completed using the SSURGO database compiled by NCSS (SSURGO, 2014) and is documented in a Soils section of the Consumptive Use of Applied Water in the Rincon, Mesilla, El Paso and Juarez Valleys of the Rio Grande Report. Sample results of that analysis are briefly summarized in Table 3 below. Soil textures in the three districts are generally similar and comprised of loamy Soils. Five textures – clay loam, loam, sandy loam, sandy clay loam, and silt loam – together comprise 88, 85, and 100 percent of the area cropped in EBID, EPCWID and Hudspeth, respectively. Detailed soil texture data are not available for the Juarez District in Mexico, but are assumed to be similar to the US Districts based on the similarity in soils on the west and east side of the Rio Grande in the Mesilla Valley.

As indicated in **Table 9-3**, the K_{sat} values in EBID and Hudspeth are greater compared to those measured in EPCWID and estimated for Juarez, but the soils are predominantly loamy in all districts with similar AWC values. Given the similarity in soil texture and AWC values across the districts, an ICUC adjustment factor for soil differences is not needed.

Table 9-3. K_{sat}, and AWC Values for the Study Area.

District	Ksat (in/hr)	AWC (in/ft)
EBID	5.69	1.65
EPCWID*	1.98	1.75
Hudspeth	6.09	1.79
Juarez	2.14	1.77

*In general loamy soils in the El Paso Valley portion of EPCWID contain higher percentages of clay than those in the Mesilla and Rincon Valleys resulting in lower K_{sat} values. This value is a weighted average that includes both the portion of EPCWID in the Mesilla Valley and the portion in the El Paso Valley.

Field Size and Head Ditch Lining

Field sizes are predominately in the 20 to 50-acre category in all districts, with 44, 48 and 49 percent of the fields in EBID, EPCWID and Hudspeth, respectively, falling within this range based on the Intera (2016) field boundaries. Field sizes tend to be slightly smaller in EBID, where the average field size is 19.0 acres compared to 24.1 and 25.7 acres in EPCWID and Hudspeth, respectively. Field sizes in Juarez are similar to those in the US Districts. Per the Rio Grande Project Histories, nearly all field ditches have been concrete lined since the 1950s in all Districts. The field sizes in the three US Districts and Juarez are similar and an adjustment factor related to field size is not needed. Since nearly all field ditches were lined over a two to three-year period during the drought in the early 1950s, an ICUC adjustment factor for differences in field ditch lining is also not needed.

Water Ordering and Delivery Flexibility

EBID typically delivers water within three days of an order being placed by a grower (DeMouche, 2004). EPCWID typically delivers water within three or sometimes four days of an order being made (EPCWID, 2017). Information on water ordering and delivery procedures for Hudspeth and Juarez was not found, but they are assumed to be similar to EBID and EPCWID practices based on similarity in regional agricultural practices, irrigation methods, and cropping. As the water ordering and delivery constraints in the districts are considered similar, an ICUC adjustment factor for water ordering and delivery flexibility differences is not needed.

Summary

As discussed above, the factors that affect ICUC in the Study Area are similar between all the Districts. As such, the ICUC is not expected to be different between the US Districts and Juarez due to these factors. Thus, the ICUC calculated for EBID does not require adjustment, and use of the EBID ICUC value for all districts is reasonable.

Extrapolate ICUC Estimates to Other Years

The calculated EBID ICUC values used for all districts during 2009 through 2018, as described above, were finally extrapolated to past years before 2009 when sufficient data were not available to calculate ICUC directly. These values were adjusted for changes in irrigation methods and on farm irrigation system improvements, as identified from historical documents.

The Rio Grande Project Histories (annual reports by Reclamation summarizing Rio Grande Project operations for the years 1912 through 1988) describe the main irrigation methods in use and improvements that occurred in the Study Area. With respect to the surface irrigation methods that are most common in the Study Area, the two practices described in the histories that have the greatest effect on ICUC values are improved land leveling with “bulldozers and carryalls” in the 1940s and 1950s, and the lining of field ditches in the 1950s. Additionally, with the advent of laser leveling practices in the 1970s and 1980s, fields in the project were leveled with increased uniformity and precision of field grades. Most fields receive touch up leveling every year or two.

Laser leveling has been estimated to increase on-farm efficiency by about five to ten percent (Daubert and Ayer, 1982) and was quickly adopted by most growers in the Study Area in the early 1980s. The average EBID ICUC value of 76 percent from 2009 through 2016 is therefore recommended for calculating total water deliveries and corresponding groundwater pumping in years with limited surface water supply between 1984 and 2018 (**Table 9-4**). Common use of laser leveling practices began in about 1980 and by 1984 laser leveling was used by most fields in the Study Area. This improvement led to an estimated increase in efficiency of five percent. Between 1955 and 1979, prior to the use of laser leveling, the calculated ICUC is estimated to be reduced five percent from 76 to 71 percent (Table 4). During the transition period between 1980 and 1983, the district-wide ICUC is estimated to increase by one percent each year, from 72 to 74 percent.

The other significant change in surface irrigation practices was triggered by the drought in the early 1950s (Reclamation, 1951). Due to the limited surface water supply, head ditches were lined throughout the Study Area and improved land leveling practices using bulldozers and carryalls were adopted. Together, these improvements are estimated to have increased the district-wide ICUC by five percent. Prior to 1950, the district-wide ICUC is estimated to be reduced five percent from 71 to 66 percent (**Table 9-4**). During the assumed five-year transition period when the improvements were taking place (1951 to 1954), the district-wide ICUC is assumed to increase by one percent each year from 67 to 70 percent.

Table 9A-1 provides a full summary of the annual ICUC values by district between 1938 and 2018. These values were ultimately used to estimate groundwater pumping before records became available.

Opinions

The ICUC estimates developed here and listed in **Table 9-4** and **Table 9A-1** are district-wide, annual values expressing consumption of irrigation water given irrigation performance when surface water supply is limiting. These average values reflect a large variability across the many fields of the Study Area. Notably, under conditions of limited surface water supply, growers apply additional management actions that may increase on-farm efficiencies that are reflected in increased ICUC values. Thus, in years having sufficient water supplies, the actual district-wide ICUC is less than the ICUC estimates described in this report. In addition, ICUC has changed over time with changes in on-farm practices. The main changes noted in the Study Area have been improved land leveling technologies and lining of head ditches. These on-farm improvements are reflected in the adjustments to ICUC estimates for earlier years.

Table 9-4. ICUC Values for Each Irrigation Unit for 1938 through 2018.

Years	EBID, EPCWID and Hudspeth	Comment
1984 to 2018	76%	Calculation of ICUC based on METRIC and ET Demands results and reported farm deliveries and groundwater pumping in EBID
1983	75%	One percent per year increase in ICUC as fields are laser leveled over a five-year period
1982	74%	
1981	73%	
1980	72%	
1955 to 1979	71%	Calculated ICUC minus five percent (laser leveling improvement has not occurred during this period, leveling has been improved and farm ditches lined compared to 1938 through 1950)
1954	70%	One percent per year increase in ICUC due to improved leveling and farm ditch lining over a five-year period
1953	69%	
1952	68%	
1951	67%	
1938 to 1950	66%	Calculated ICUC minus ten percent (five percent for improved leveling and lined farm ditches from 1951 through 1954 and five percent for laser leveling from 1980 through 1983

X. Bare Ground Evaporation from Groundwater

Purpose

The purpose of this section is to describe the development of the parameters used to calculate bare ground evaporation in the groundwater models encompassing the Rio Grande Valley from below Caballo Reservoir, New Mexico, to Fort Quitman, Texas. Groundwater in the Study Area is simulated by two groundwater models, the Rincon/Mesilla and Hueco groundwater models, that generally cover the New Mexico and Texas model areas, respectively.

Evaporation from bare ground is a necessary element of consumptive use of water in a groundwater model. Water that evaporates from bare ground can come from precipitation or from shallow groundwater that is made available at the ground surface through capillary rise. This process is limited by the depth to groundwater. Maddock, et al. (2005) describes a methodology used by a groundwater model to estimate evaporation of groundwater from bare ground that requires potential evaporation from groundwater, the rate of capillary rise as a function of depth to groundwater (called the transpiration flux curve for vegetation and referred to as the evaporation flux curve in this document) and an extinction depth. This section briefly describes an accepted scientific method to determine the potential bare ground evaporation from groundwater, the evaporation flux curve, and the extinction depth that accurately simulates bare ground evaporation in the Study Area.

Methodology

The following sections describe the methodology used to determine the potential bare ground evaporation from groundwater, the evaporation flux curve and the extinction depth.

Potential Bare Ground Evaporation from Groundwater

Potential evaporation is defined as "the rate of evaporation from a surface when all surface interfaces are wet or from a free water surface, so that there is no surface restriction on the rate" (ASCE, 2016). Potential evaporation from groundwater is calculated as the potential evaporation (assuming a continuously wet soil surface with water supplied by precipitation and groundwater) minus the evaporation from precipitation. This calculation accounts for evaporation from precipitation when available, so that the remaining water that is evaporated represents the potential groundwater that could be evaporated if the water table is at, or near, the ground surface and supplies water for evaporation through capillary rise. This potential evaporation from groundwater is limited by the availability of groundwater as defined by the evaporation flux curve in the next section.

An accepted method to determine total evaporation and the evaporation from precipitation is to use a daily root zone water balance model that uses the Food and Agricultural Organization 56 (FAO 56) model to estimate evaporation from a bare ground surface (FAO, 1998 and ASCE, 2016). Mutziger, et al (2006) evaluated the FAO 56 model using seven data sets from the literature. Their root zone water balance results suggested a model accuracy of about +/-15 percent.

For this study, the ET Demands Root Zone model (referred to as the ET Demands model) was selected because it has been widely applied to compute consumptive water use and to study the potential effects of climate change on agricultural water demands (Allen and Robison, 2009 and Allen and Huntington, 2010, Allen and Huntington, 2015, and Reclamation, 2015). ET Demands utilizes the FAO 56 method for estimating evaporation from bare, wet ground and follows a dual crop coefficient approach, using basal crop coefficients to more accurately account for evaporation resulting from rainfall and local irrigation practices.

The reference ET (ET_o) and precipitation data developed for the analysis were based primarily on the Leyendecker and Art Ivey weather stations in the New Mexico and Texas model areas simulated by the Rincon/Mesilla and Hueco groundwater models, respectively.

Following the ASCE (2016) methodology for determining bare ground evaporation, the potential bare ground evaporation is calculated by multiplying the ET_o by an evaporation coefficient, K_e, equal to 1.2, as recommended by technical publications (ASCE, 2016). Each month will have a different potential bare ground evaporation depending on ET_o for that month. To estimate bare ground evaporation from precipitation, an ET Demands model run was completed for bare ground with precipitation as the only water source (i.e. with no irrigation water or groundwater available for evaporation). The potential bare ground evaporation from groundwater was calculated as the potential bare ground evaporation minus the bare ground evaporation from precipitation.

Evaporation Flux Curve

The transpiration flux curve provides information on how the transpiration flux changes as the depth to groundwater changes (Maddock, 2005). For bare ground, this curve can be called an evaporation flux curve. Groundwater can contribute to evaporation from bare ground when the water table is at, or near, the land surface. As water is consumed by bare ground evaporation, groundwater from the water table can rise through capillary action into the effective evaporation layer of soil, from which evaporation occurs. This process is referred to as "capillary rise." The rate of capillary rise depends on the soil texture, the depth to the water table, and the soil water content of the upper soil profile (ASCE, 2016). The following sections describe the methodology for determining the soil textures underlying the bare ground in the two model areas, the regression equations describing capillary rise in each soil texture, and the use of those equations to estimate the evaporation flux curve.

Soils

Bare ground soil textures in the Rincon/Mesilla model area were determined based on the riparian sub-areas defined as 'bare' ground in the groundwater model and the soil textures found in these sub-areas in the Soil Survey Geographic (SSURGO, 2014) database.

Inputs to the Rincon-Mesilla groundwater model delineate the riparian corridor and subdivide it into discrete sub-areas with attributes quantifying the percent of bare ground and vegetation in each. The 2004 snapshot of the riparian corridor totals 13,099 acres, of which 10,036 acres are bare ground. The Rio Grande River located in the riparian corridor (which is identified as 'bare ground') was excluded from this analysis by applying a 50-meter buffer from approximately the centerline of the river. Only those sub-areas having at least 80 percent 'bare' ground and outside of the 50-buffer from the Rio Grande centerline, totaling 6,500 acres, were included when identifying primary soil textures in areas of bare ground. The soils in this snapshot are generally representative of the soils in the 'bare' ground model areas through time.

Bare ground soil textures in the Hueco model were also determined based on the sub-areas defined as 'bare' ground in the groundwater model and the Soil Survey Geographic (SSURGO) database. The SSURGO database contains information about soil in the United States collected by the National Cooperative Soil Survey (NCSS). The NCSS is a nationwide partnership of federal, regional, state, and local agencies and private entities and institutions that cooperatively investigates, inventories, documents, classifies, interprets, disseminates, and publishes information about soils. The United States Department of Agriculture-Natural Resources Conservation Service (USDA-NRCS), formerly known as the Soil Conservation Service (SCS), organizes the NCSS and publishes scientifically sound and accepted standards for conducting soil surveys and classifying soils.

The SSURGO database is available on the internet and contains scientifically accepted and technically sound information on soils that was formerly provided in printed soil survey publications (SSURGO, 2014). Soils information is available for most areas in the United States, including New Mexico and Texas. The information in the database was gathered by observing the land and soil and collecting and analyzing soil samples (SSURGO, 2014). Soil maps in the database are commonly used in natural resource planning and management activities nationwide. Information available from the database includes soil infiltration characteristics, available waterholding capacity (AWC), and other data necessary for plant consumptive use analyses and other water resource engineering applications.

The soil survey only covers the portion of the Hueco model within the United States (north of the Rio Grande). Similar to the Rincon/Mesilla model, the Hueco model specifies the percent 'bare' ground within each 10-acre sub-area. There are 13,323 acres (excluding Juarez) of 'bare' ground identified in the portion of the alluvial corridor of the Hueco model north of the Rio Grande. Only those 10-acre areas containing at least 80 percent 'bare' ground and located within the United States were included in the analysis to identify primary soil textures in areas of bare ground.

Capillary Rise Equations

Regression equations (**Eq. 10-1**) are available to estimate capillary rise based on depth to groundwater for each soil texture. These equations are based on simulations using UPFLOW (Raes and deProost, 2003 and Raes 2004), a software tool that estimates capillary rise using an analytical technique based on Brutsaert (1982).

$$CR = a_f * d_w \hat{} b_f \quad \text{(Eq. 10-1)}$$

In these equations, CR is capillary rise in millimeters per day (mm/day), d_w is the depth to groundwater from the ground surface in meters (m), and a_f and b_f are regression parameters (unitless) (**Table 10-1**). The resulting capillary rise is converted to inches per day. The effective evaporation surface layer was assumed to be dry and have a depth of four inches, per accepted methods given the Study Area climate and soil conditions (ASCE 2016).

Table 10-1. Regression Parameters for Capillary Rise (millimeters per day) in Dry Soil to the Soil Surface for Evaporation (Reproduced from ASCE 2016) for the Three Most Common Bare Ground Soil Textures.

Groundwater Model	Soil	a_f	b_f	R^2*
Rincon/Mesilla	Sandy Loam	0.94	-3.02	0.99
Rincon/Mesilla	Loamy Sand	1.89	-2.85	0.99
Rincon/Mesilla	Sand	1.44	-2.98	1.00
Hueco	Loam	4.32	-2.45	0.99
Hueco	Sand	1.44	-2.98	1.00
Hueco	Clay Loam	0.27	-1.54	0.99

*Regression coefficient of determination for the associated regression parameters.

Evaporation Flux Curve

The evaporation flux curve is developed from the capillary rise equation discussed in the previous section in two steps. First, the depth to groundwater (d_w) is plotted on the y-axis and the evaporation flux, or capillary rise (CR), is plotted on the x-axis. Second, at the groundwater depths where the evaporation flux is greater than the potential bare ground evaporation from groundwater calculated above, the evaporation flux is set equal to the potential bare ground evaporation from groundwater.

Results

The following sections describe the results of the methodologies above for the potential bare ground evaporation from groundwater, the evaporation flux curve, and the extinction depths in the Rincon/Mesilla and Hueco model areas.

Potential Bare Ground Evaporation from Groundwater

Sample monthly values for ET_o, potential bare ground evaporation, precipitation, bare ground evaporation from precipitation, and potential bare ground evaporation from groundwater are presented in **Table 10-2** for the 2008 Rincon/Mesilla groundwater model year. Daily ET Demands model results are summed by month for presentation in the table. **Appendices 10A and 10B** provide monthly values for 1938 through 2018 for the Rincon/Mesilla and Hueco groundwater model areas, respectively.

Evaporation Flux Curve

The following sections describe the soil textures found to underlie bare ground in the two model areas, as well as the capillary rise and evaporation flux curves developed for these soils.

Soils

Sandy loam, loamy sand, and sand together underlie 89 percent of bare ground in the Rincon/Mesilla model area (**Table 10-3**) based on soil textures underlying the riparian corridor sub-areas that are at least 80% bare ground and outside a 50-meter buffer of the Rio Grande centerline.

Table 10-2. Potential* Bare Ground Evaporation from Groundwater for the Rincon/Mesilla Model for 2008, all Values are in Inches.

Month	Leyendecker ET_o, in	Potential Bare Ground Evaporation, in	Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in**
1	2.7	3.3	0.0	0.0	3.3
2	3.9	4.6	0.2	0.2	4.5
3	5.8	7.0	0.0	0.0	7.0
4	7.0	8.3	0.0	0.0	8.3
5	8.0	9.6	0.0	0.0	9.6
6	8.5	10.2	0.1	0.1	10.1
7	7.0	8.4	5.0	2.1	6.4
8	6.3	7.5	2.5	2.1	5.4
9	5.0	6.1	0.8	0.8	5.3
10	3.9	4.7	0.3	0.3	4.4
11	2.7	3.3	0.4	0.4	2.9
12	2.3	2.8	0.1	0.1	2.7
Totals	63.1	75.8	9.3	5.9	69.8

*Assumes groundwater remains near the ground surface so a water supply is continuously available for evaporation.

**Results for Potential Bare Ground Evaporation from Groundwater differ from the calculation of Potential Bare Ground Evaporation minus Bare Ground Evaporation from Precipitation by 0.1 inch in February and July due to rounding.

Table 10-3. Soil Textures in Riparian Sub-Areas that are at Least 80% Bare Ground within the Rincon/Mesilla Model Area.

Texture	Area*, Acres	Percent of Sample, %
sandy loam	2,689	41%
loamy sand	1,565	24%
sand	1,544	24%
Subtotal	5,798	89%
loam	506	8%
silt loam	91	1%
clay loam	59	1%
sandy clay loam	47	1%
clay	0	0%
Total	6,500	100%

***includes areas from riparian corridor outside 50-meter buffer of Rio Grande centerline with 80% or greater bare ground.**

Loam, sand, and clay loam together underlie 83 percent of bare ground in the Hueco model north of the Rio Grande (**Table 10-4**) based on soil textures underlying the 10-acre sub-areas that are at least 80% bare ground.

Table 10-4. Soil Textures in Sub-Areas that are at Least 80% Bare Ground within the Hueco Model Area.

Texture	Area*, Acres	Percent of Sample, %
loam	2,124	33%
sand	1,918	30%
clay loam	1,255	20%
Subtotal	5,297	83%
loamy sand	324	5%
sandy loam	285	4%
silt loam	214	3%
clay	147	2%
silty clay loam	72	1%
sandy clay loam	1	0%
Total	6,340	100%

*Includes the area of all 10-acre sub-areas from the Texas alluvial corridor with at least 80% bare ground and within the United States.

Capillary Rise Equations in Bare Ground Evaporation

The rate of capillary rise, or evaporation flux, from groundwater to the ground surface was calculated as a function of depth to the groundwater table using the regression equation identified in **Eq. 1** and the regression parameters identified in **Table 10-1**. Curves were developed to calculate evaporation flux for dry conditions and the three most common soil textures underlying bare ground in the riparian sub-areas along the Rio Grande in the Rincon/Mesilla and Hueco model areas. **Table 10-5** shows an example of the evaporation flux (in inches per day, in/day) from groundwater calculated for increasing depth to the groundwater table (in feet, ft) in June 2008. For the Hueco groundwater model, soils data from Mexico were not available, so soils were assumed to be similar to the soils on the Texas side of the Rio Grande.

Fluxes to the evaporation layer for the three main soil textures in the Rincon/Mesilla model area are similar (**Figure 10-1**). The three main soil textures in the Hueco model area have a wide range in fluxes to the evaporation layer, but the average flux is similar to the average flux from the soils in the Rincon/Mesilla model area (**Figure 10-2**).

Evaporation Flux Curve

Figure 10-3 shows the evaporation flux curve for bare ground in the Rincon/Mesilla model area during June 2008, showing a potential bare ground evaporation from groundwater rate of up to 0.337 inches per day that corresponds to 10.1 inches of total potential evaporation during that month (**Table 10-2**). Below the point of intersection of the potential bare ground evaporation from groundwater with the evaporation flux curve, bare ground evaporation from groundwater is limited by the depth to the groundwater table. **Table 10-5** provides the evaporation flux to the surface as the depth to groundwater increases by increments of 0.5 feet in June 2008.

Table 10-5. Evaporation Flux from Groundwater to the Surface Evaporation Layer for a Bare Ground and Dry Soil Condition as a Function of the Soil Texture and Depth to Groundwater for the Rincon/Mesilla and Hueco Models in June 2008.

Depth to Groundwater, ft	Evaporation Flux, in/day				Evaporation Flux, in/day			
	Rincon/Mesilla Groundwater Model				Hueco Groundwater Model			
	Sandy Loam	Loamy Sand	Sand	Average	Loam	Sand	Clay Loam	Average
0.26*	0.362	0.362	0.362	0.362	0.366	0.366	0.366	0.366
0.50	0.362	0.362	0.362	0.362	0.366	0.366	0.193	0.308
1.00	0.362	0.362	0.362	0.362	0.366	0.366	0.066	0.266
1.50**	0.362	0.362	0.362	0.362	0.366	0.366	0.035	0.256
2.00	0.165	0.305	0.248	0.239	0.366	0.248	0.023	0.212
2.50	0.084	0.161	0.127	0.124	0.331	0.127	0.016	0.158
3.00	0.048	0.096	0.074	0.073	0.212	0.074	0.012	0.099
3.50	0.030	0.062	0.047	0.046	0.145	0.047	0.010	0.067
4.00	0.020	0.042	0.031	0.031	0.105	0.031	0.008	0.048
4.50	0.014	0.030	0.022	0.022	0.078	0.022	0.007	0.036
5.00	0.010	0.022	0.016	0.016	0.061	0.016	0.006	0.027
5.50	0.008	0.017	0.012	0.012	0.048	0.012	0.005	0.022
6.00	0.006	0.013	0.009	0.010	0.039	0.009	0.004	0.017
6.50	0.005	0.011	0.007	0.008	0.032	0.007	0.004	0.014
7.00	0.004	0.009	0.006	0.006	0.027	0.006	0.003	0.012
7.50	0.003	0.007	0.005	0.005	0.022	0.005	0.003	0.010
8.00	0.003	0.006	0.004	0.004	0.019	0.004	0.003	0.009
8.50	0.002	0.005	0.003	0.003	0.017	0.003	0.002	0.007
9.00	0.002	0.004	0.003	0.003	0.014	0.003	0.002	0.006
9.50	0.001	0.004	0.002	0.002	0.013	0.002	0.002	0.006
10.00	0.001	0.003	0.002	0.002	0.011	0.002	0.002	0.005

*Maximum depth to groundwater at which evaporation flux equals the potential bare ground evaporation from groundwater in the Hueco model.
**Maximum depth to groundwater at which evaporation flux equals the potential bare ground evaporation from groundwater in the Rincon-Mesilla model.

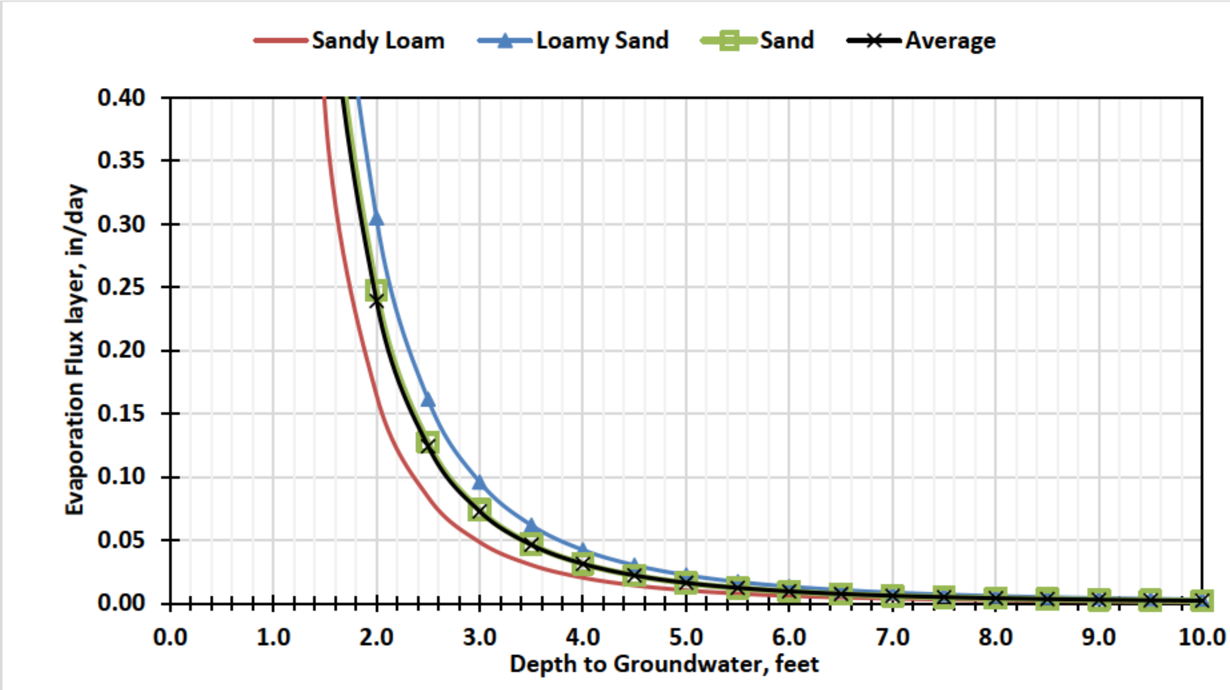

Figure 10-1. Capillary Rise, or Evaporation Flux, from Groundwater to the Surface Evaporation Layer for a Bare Ground and Dry Soil Condition as a Function of the Soil Texture and Depth to Groundwater in the Rincon/Mesilla Model Area.

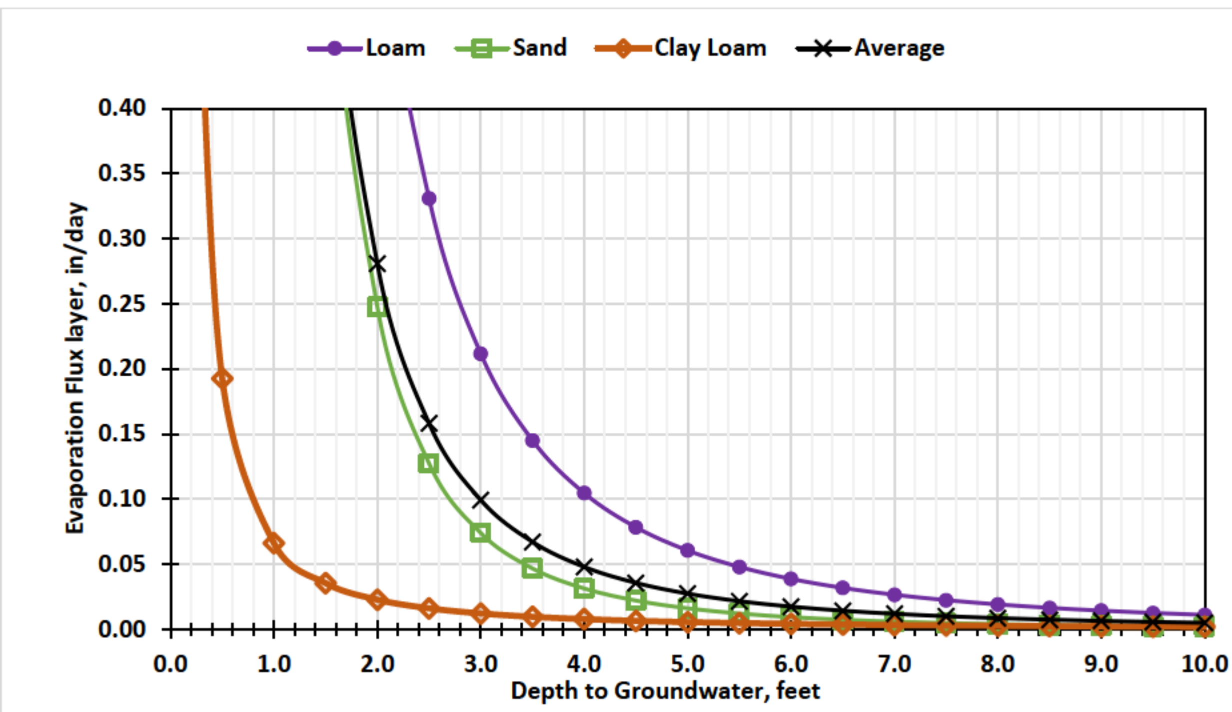

Figure 10-2. Capillary Rise, or Evaporation Flux, from Groundwater to the Surface Evaporation Layer for a Bare Ground and Dry Soil Condition as a Function of the Soil Texture and Depth to Groundwater in the Hueco Model Area.

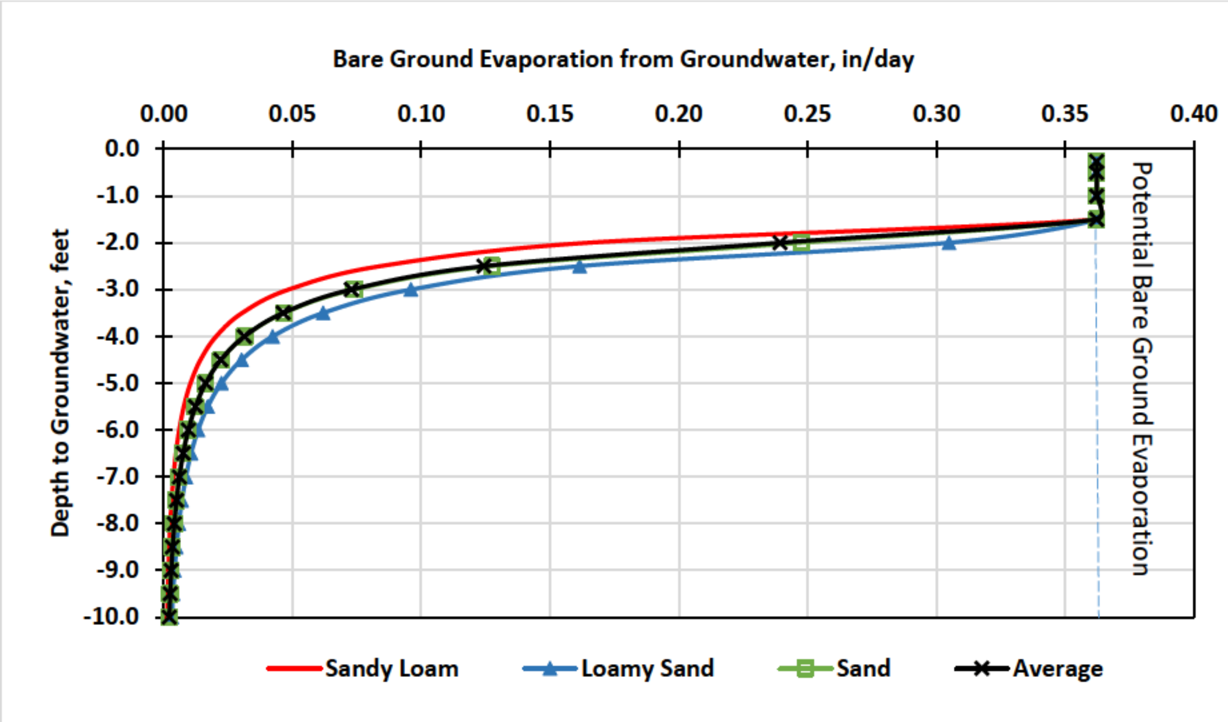

Figure 10-3. The Evaporation Flux from Bare Ground as a Function of the Soil Texture and Depth to Groundwater in the Rincon/Mesilla Groundwater Model Area for June 2008.

As described above, the potential bare ground evaporation from groundwater in a given month varies depending on ET_o and precipitation, thus the point at which the curve becomes vertical is different in each month. Monthly values are provided in Appendices 10A and 10B for the Rincon/Mesilla and Hueco model areas, respectively.

Extinction Depth

For all soil textures, the flux to the effective surface evaporation layer becomes increasingly closer to zero at 7 and 9 feet below the surface for the Rincon/Mesilla and Hueco models, respectively. The point where the flux begins to change by 0.001 inch per day for each 0.5 feet of decrease in depth to the groundwater is approximately the point at which the capillary rise is two percent of the potential evaporation. Thus, 7 and 9 feet below the surface is recommended for the extinction depth for the Rincon/Mesilla and Hueco models, respectively. The recommended extinction depths are summarized in **Table 10-6**.

Table 10-6. Recommended Extinction Depths by Region for Bare Ground Evaporation.

Region	Land cover	Extinction Depth, ft
Rincon/Mesilla	Bare Soil	7
Hueco	Bare Soil	9

Opinions

Bare ground evaporation from groundwater is an important outflow from the groundwater system and depends primarily on climatic demand and depth to groundwater. Evaporation flux curves have been developed to estimate bare ground evaporation from groundwater for groundwater modeling. These curves have a maximum evaporative flux, termed the potential bare ground evaporation from groundwater, that represents the maximum potential bare ground evaporation from groundwater that can occur when groundwater levels are close to the ground surface. The rate and depth to groundwater at which this occurs varies based on climatic demand, precipitation, and soil texture. When the depth to groundwater is below this level, the bare ground evaporation is limited by the capillary rise from the groundwater table to the evaporative layer.

XI. Technical Rebuttal of Expert Reports

Introduction

The purpose of this report is to provide a rebuttal to the following expert reports disclosed by Texas:

- Expert report of Dr. Joel E. Kimmelshue of Land IQ, LLC, titled *Land use Classification and Consumptive Use estimates for the Rincon, Mesilla, and El Paso Valley from 1936 to 2018* (henceforth referred to as the *Land IQ Report*).
- Expert report of Mr. Staffan W. Schorr and Dr. Colin P. Kikuchi of Montgomery & Associates, Inc., titled *Water Budget Estimates in Support of Groundwater Model Development: Rincon and Mesilla Basins, New Mexico, Texas, and Northern Mexico, 1938 through 2016* (henceforth referred to as the *Montgomery & Associates Report*).

The rebuttal of each report is presented in the order given above. Each rebuttal is organized by topic to summarize and critique major elements of each report. Each section includes a technical evaluation with supporting information to support the rebuttal opinions, followed by a statement of the New Mexico technical experts' opinions.

In summary, the use of potential crop coefficients rather than average, actual crop coefficients, as recommended by standard, recommended procedures (ASCE, 2016 and ITRC, 2019) for historical water balance analyses, leads to an overestimation of crop consumptive use by Land IQ. This overestimate, compounded by use of non-standard procedures for the soil water budget by Montgomery & Associates leads to a gross overestimation of the pumping necessary to meet consumptive use requirements.

Technical Rebuttal of Land IQ Report

This rebuttal centers on technical critiques of the methodologies to support land use classification and consumptive use estimation in the *Land IQ Report,* as well as the lack of clarity and detail provided therein. The report lacks sufficient documentation or data to support the opinions tendered by Dr. Kimmelshue.

Each of these critiques and objections is identified below under the applicable sections, by topic. Each section begins with a technical evaluation with supporting information to support the rebuttal opinions and concludes with a summary of the New Mexico technical experts' opinions.

Agricultural Land Use

In general, the *Land IQ Report* lacks sufficient detail to thoroughly explain how the land use classification analysis was completed. The level of detail provided in the disclosed report does not allow for replication or evaluation of each step within the procedure, and does not support the opinions tendered by Dr. Kimmelshue. Additionally, the time step of data used to define annual land use acreage (approximately one year per decade for agricultural land) is inadequate to accurately represent annual land use changes and does not fully utilize the abundance of data available in other years, such as annual reports from the U.S. Bureau of Reclamation, aerial photography, and remote sensing-based land use information.

Annual Land Use Analyses

Technical Evaluation

The technical experts for Texas state that they developed a spatial land use database for the period 1936-2018 based on image analyses (maps, aerial photos, and/or satellite imagery) and annual crop reports. Agricultural land use maps were developed approximately once per decade between 1936-2018 (more frequently since 2006), and riparian land use maps were developed for four years (Exhibit 45 lists 1955, 2005, 2014 and 2016). These generated maps were used with annual crop reports and field survey data to interpolate to annual land use datasets.

The agricultural land use maps identify spatial crop distribution. Prior to 1986, field-level crop classification was estimated from aerial photos and crop reports (1955, 1966, 1975) and from Rio Grande Joint Investigative Report maps and survey tables (1936). At minimum, these data sources were used to determine whether or not fields were irrigated. Beginning in 1986, a random forest classification algorithm was used to classify crop types from imagery (1986, 1996, 2006, 2011, 2014, 2016, 2018).

Depending on available data sources, between 5 and 34 individual crops and land use classes were identified in each of the years above. The annual land use analysis methodologies described in the report provide only high-level information on image sources and incomplete descriptions of classification algorithm procedures.

Opinion

The *Land IQ Report* lacks clear and sufficient information necessary to confirm the accuracy of the land use classification procedures, which are central to estimating consumptive use:

- **Classification accuracy of the crop classification algorithm**: Classification algorithms require training data. In random forest algorithms, such as those used in the *Land IQ Report*, error is closely related to the size of training/test data sets, the number of variables and categories used, and the tunable parameters that govern the random forest's development (Breiman, 2001; Tang, Garreau, and von Luxburg, 2018). Additionally, standard methodologies require training data to be from the year of analysis and indicate that observed field data from the same year produces the best accuracy. LandIQ had only field data available for training in 2014 and in 2018. In 2016, the LandIQ report states that the 2014 field data were used. Using field data from an earlier year is reasonable for a crop like pecans that can be expected to be the same two years later. However, it is not clear what LandIQ did for annual crops that may be different in 2016. For earlier years, the LandIQ report states that photo interpretation was used to crops for training sites. Reduced accuracies can be expected in the years when observed field data from that year are not available. While the Texas technical expert mentions using a random forest algorithm and preparing an "accuracy assessment," no details or results, such as the "accuracy assessment matrix," are given to evaluate the methodology's fitness except to say that "accuracies…are consistently in the mid-90s percentage or higher." (*Land IQ Report*, p. 9). This is not supported by any of the exhibits provided in the *Land IQ Report*. In a supplemental disclosure, accuracy assessments for 2014 and 2018 were provided.
    - *"After the random forest classification was completed, an accuracy assessment was performed with the independent validation sites. The resultant accuracy assessment matrix provides information on the overall accuracy as well as the accuracy of individual crop types."* (*Land IQ Report*, p. 15, 19, 24)

- **Criteria used to evaluate the classification accuracy**: As with the classification "accuracy assessment" described above, the Texas technical experts mention evaluating fields with "low probability values" and correcting these with photo-interpretation. No quantitative metrics are given to identify the source of these values or how these values were defined.
    - *"Fields with low probability values were inspected and evaluated against the imagery. When a low probability was identified, based on expert photo-interpretation, the class label was corrected*." (*Land IQ Report*, p. 15, 19, 25)
- **Photo-interpretation techniques and corrections**: The Texas technical experts state that they corrected crop classification of fields with "low probability" through "expert photo-interpretation," but no detail is given for the number of corrections necessary and no description is provided of the corrections that were made. The methodology applied to correct erroneous data and/or add data to incomplete datasets was not described, nor was the prevalence of fields that required further inspection or the "textural cues" (beyond "row structure" and "some plant structures") that were used to make these corrections.
    - *"The high resolution of the aerial imagery provided textural cues that were correlated to crop type. Row structures and even some plant structures could be discerned, allowing for a high level of discrimination between crop types during the review/editing phase."* (*Land IQ Report*, p. 15, 19, 25)
- **Specific image dates evaluated** (**Table 11-1**): This detail is foundational to interpreting the validity of the crop distribution maps. Specific dates correspond only to specific times during the growing season (specific stages of crop development) and to specific weather conditions, which can each impact the classification algorithm. Ideally, images are evaluated throughout the growing season to confirm crop coverage and consistency in image dates from year to year is highly desirable for consistency in classification.

Table 11-1. Sample Data Sources Table, 2018 Land Use Analysis (*Land IQ Report*, page 14).

	Imagery	Date	Resolution	Color
Rincon	Planet Labs Landsat 8 Google Earth	Multiple dates Multiple dates Multiple dates	5 m 30 m Various	Natural Color Multispectral Natural Color
Mesilla	Planet Labs Landsat 8 Google Earth	Multiple dates Multiple dates Multiple dates	5 m 30 m Various	Natural Color Multispectral Natural Color

- **Time step of land use data evaluated:** Land use changes from year to year as different areas are irrigated, different crops are cultivated, and riparian corridors grow or shrink. The *Land IQ Report* identifies 11 years (about one per decade between 1936-2018) in which agricultural land use maps were developed using available spatial data and crop reports. In the remaining years without spatial data, agricultural land use was linearly interpolated from these maps. In the riparian corridor, the *Land IQ Report* identifies only ten total years in which riparian land use was mapped by Land IQ or the Papadopulos Report (2008). Riparian land use in other years was assumed to be equal to a neighboring mapped year. These time steps are deemed inadequate to accurately capture the changeability in land use.

Validation of Procedures with Field Surveys (Ground-truthing)

Technical Evaluation

The technical experts for Texas state that in 2018 and 2014, field data were collected to serve as the basis for crop land use classification. These field data ("ground truth data") were used as training data for classification efforts. When ground truthing was conducted, the *Land IQ Report* states that "nearly a week each time was spent collecting anywhere from 3,200 to nearly 4,000 individual field data points depending on the year and season" (*Land IQ Report*, p. 9).

In August 2018, ground truth data were collected for summer crops in all three valleys. These data were stratified by crop type and divided into training and validation data for classification efforts to support development of the 2018 agricultural land use map (*Land IQ Report*, p. 15).

In June 2014, ground truth data were collected for summer crops in all three valleys. These data were also stratified by crop type and divided into training and validation data for classification efforts to support development of the 2016 and 2014 agricultural land use maps (*Land IQ Report*, p. 19, 24). Additional ground-truth data were collected for fall annuals during September 2014, and were similarly used to support development of just the 2014 agricultural land use map (*Land IQ Report*, p. 24).

Opinion

The field survey sampling design, sampling procedures, and other necessary information to elucidate how the field data were collected were not provided. Specific dates when data were collected, and information on which fields were sampled were not provided. Additionally, no clear description is given to state how these field data were used in crop classification, or to show how the proportional land use areas determined from the field study compare to the spatial land use database.

Field surveys play a primary role in confirming the reliability of crop classification methodologies under current field conditions. Field surveys and ground-truthing exercises should explicitly follow steps recommended for sample-based field verification studies (such as those described by Gilbert (1987)) and evaluate a statistically representative selection of a stratified, random sample of fields pre-determined following standard protocols (such as those described by Stehman and Milliken (2007)).

Specifically, a description of the field survey should outline the objectives, area of interest, physical environment, information to be collected, quality assurance protocols, field sampling designs, and planned statistical analyses. This information is not provided with the *Land IQ Report*.

El Paso Valley Irrigated Area Review

The irrigated area data received from Land IQ was found in the acreage tab of six Excel spreadsheets with consumptive use analyses by region. The Excel files contain cropped acreages, various factors applied to CUP+ crop ET and crop ET estimates. Below is a list of the Excel files provided by region/subregion:

1. Excel files
    a. ElPaso_ConsumptiveUse.xlsx Acreage tab labeled as showing areas for "El Paso Valley, Tx"
        i. EPCWID1_ConsumptiveUse.xlsx Acreage tab labeled as showing areas for "EPCWID1"

    ii. Hudspeth_ConsumptiveUse.xlsx Acreage tab labeled as showing areas for "Hudspeth"

b. MesillaAndRincon_ConsumptiveUse.xlsx Acreage tab labeled as showing areas for "Mesilla and Rincon Valleys"
    i. Mesilla_ConsumptiveUse.xlsx Acreage tab labeled as showing areas for "Mesilla"
    ii. Rincon_ConsumptiveUse.xlsx Acreage tab labeled as showing areas for "Rincon"

Technical Evaluation

Based on the comparisons described in the remainder of this section, it appears that Land IQ also included the portion of EPCWID within Mesilla Valley in the El Paso Valley irrigated areas in some years; thereby, incorrectly increasing the irrigated area of EPCWID lands in the El Paso Valley. Land IQ provided Excel files summarizing irrigated area and crop ET by region and subregion. Based on the use of "EPCWID1" in the spreadsheet name and the title in row one of the acreage tab, one would expect that the irrigated areas in this spreadsheet are for all of EPCWID including the areas in the Mesilla Valley. **Figure 11-1** shows that the irrigated area determined by Intera closely matches the irrigated area determined by Land IQ when the Intera irrigated areas include the portion of EPCWID that is in the Mesilla Valley. **Figure 11-2** shows that the irrigated area for Hudspeth, which is included in the El Paso Valley, determined by Intera closely matches the irrigated area determined by Land IQ. Based on the use of "ElPaso" in the spreadsheet name and the use of "El Paso Valley, Tx" in the title in row one of the acreage tab, one would expect that the irrigated areas in this spreadsheet are for only the EPCWID irrigated area in Texas plus the irrigated area in Hudspeth. However, the irrigated acres in the "ElPaso" spreadsheet are the sum of the irrigated area in the Excel files "EPCWID1" and "Hudspeth." Additionally, **Figure 11-3** shows that the irrigated areas determined by Intera and sent to (DE) closely match the irrigated areas determined by Land IQ when these irrigated areas include the portion of EPCWID that is in the Mesilla Valley. Correspondingly, the irrigated areas determined by Land IQ are greater than the irrigated areas determined by Intera when these irrigated areas do not include the portion of EPCWID that is in the Mesilla Valley.

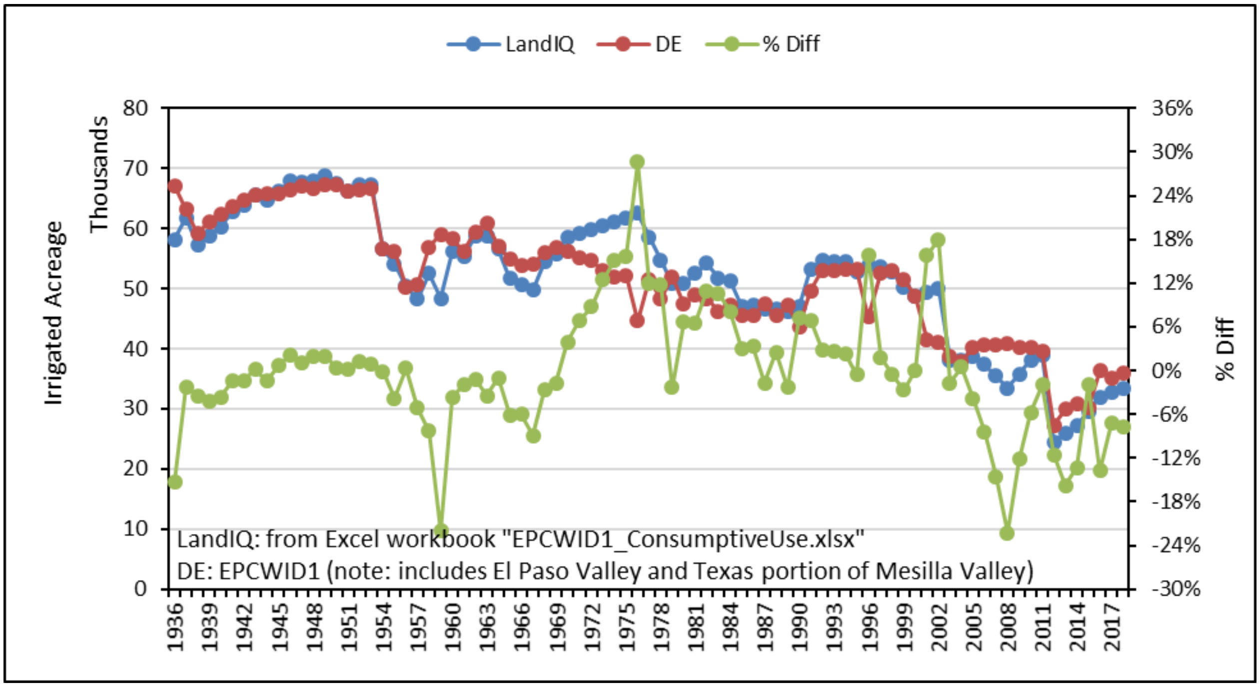

Figure 11-1. Irrigated Acreage for EPCWID1.

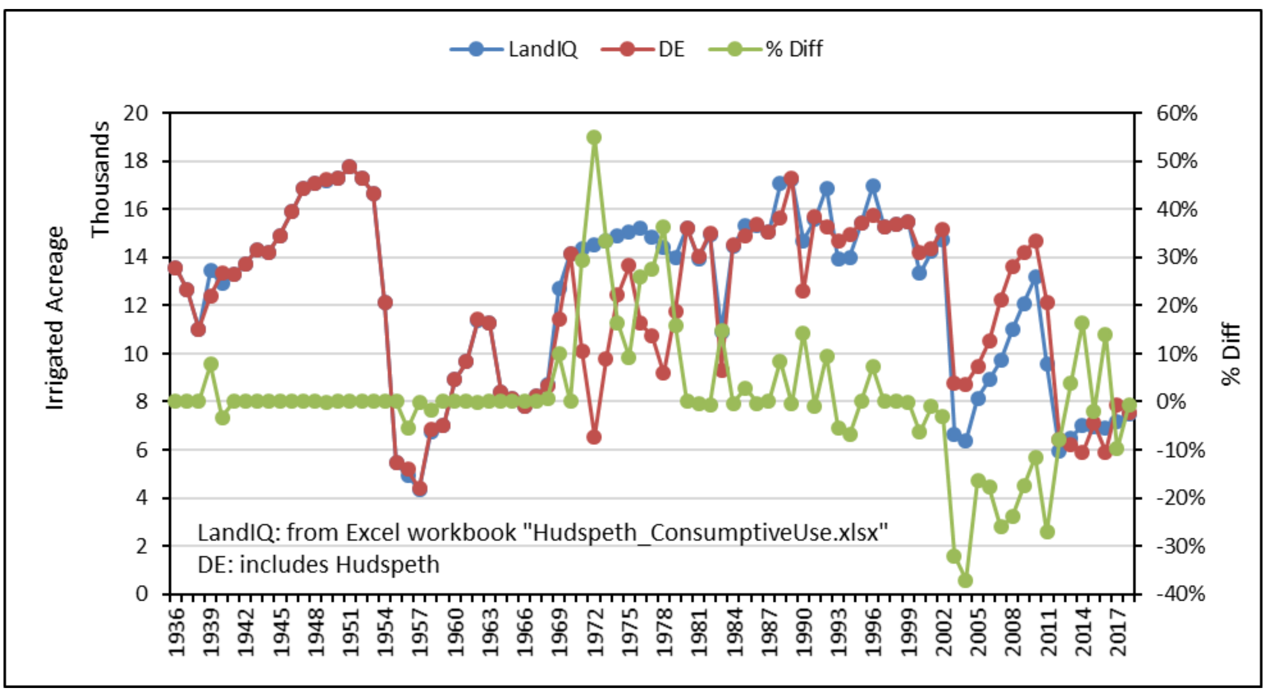

Figure 11-2. Irrigated Acreage for Hudspeth.

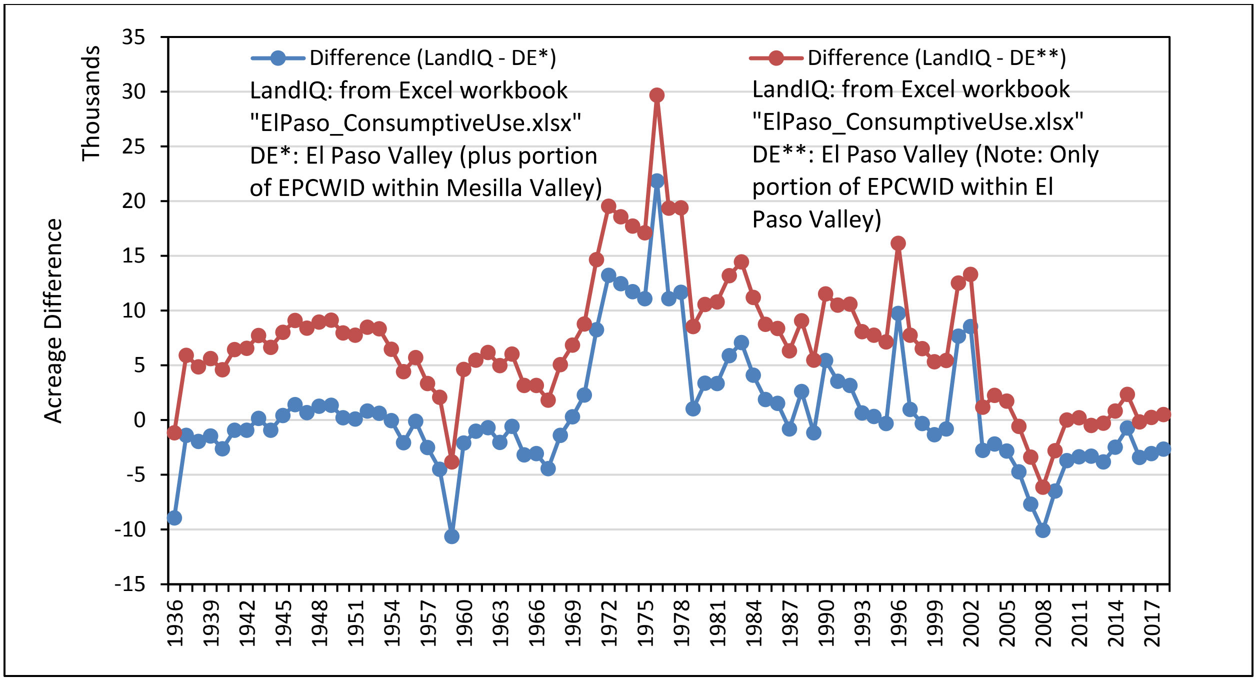

Figure 11-3. Irrigated Acreage for El Paso Valley, Tx.

Opinion

Exhibit 40 in the Land IQ Expert Report clearly indicates that the portion of EPCWID1 in Mesilla Valley was assigned to the Mesilla Valley as service areas 5, 6 and 13. The Land IQ Expert Report does not include a similar exhibit for the El Paso Valley. However, as described in the above technical evaluation, it appears that Land IQ included the portion of EPCWID1 within Mesilla Valley in the El Paso Valley irrigated areas.

Additionally, in the Land IQ Expert Report Agricultural Land Use opinions on page 11, three opinions on the irrigated areas of selected crops in the El Paso Valley have areas different than the areas in the ElPaso_consumptiveUse spreadsheet received as noted below:

- Alfalfa in the El Paso Valley has generally decreased from 16,649 **(17,409 acres in spreadsheet received)** acres in 1936 to 3,105 **(3,270 acres in spreadsheet received)** acres in 2018.
- Cotton in the El Paso Valley increased from 44,501 **(47,718 acres in spreadsheet received)** acres in 1936 to approximately 56,622 acres **(71,275 acres in spreadsheet received)** in 1951 and then decreased to 19,161 **(matched acres in spreadsheet received)** acres in 2018.
- Pecans in the El Paso Valley increased from essentially 0 **(446 acres in spreadsheet received)** acres in 1936 to 15,412 **(matched acres in spreadsheet received)** acres in 2018

Crop Area Review

Technical Evaluation

The spatial crop area data received from Land IQ was found to contain three columns of crop category information, one each for spring, summer and fall. When the crop areas were summed, if, for example, a field had alfalfa as the crop in the spring column and cotton as the crop in the summer column, the area for that field appears to have been counted both in the alfalfa and in the cotton areas. Although unlikely, it is possible that a field may have been alfalfa in the spring and converted to cotton in the summer. However, with the area in both alfalfa and cotton, the same field has consumptive use calculated for both alfalfa for March through December and for cotton for April through November.

Opinion

The methodology described above that LandIQ uses to include double cropped areas in the consumptive use totals double counts fields if the crop season defined for the two crops overlaps. A more correct way to account for double cropping is to count the field only once and to develop a crop coefficient that continues for the entire irrigation season and includes both crops sequentially.

Pecan Spacing and Age Analysis

Technical Evaluation

The stated purpose of the analysis is to determine whether orchards planted more recently have more trees per acre. The report states: "Especially in earlier years of an orchard (until the canopy closes in), it should be expected that more trees per acre will result in more consumptive use as compared to older, less dense orchards. This positive conclusion allows for the assumption of escalation of pecan consumptive use in more recent years." Although it seems reasonable that more trees per acre will result in more consumptive use, no studies are cited and no proof is offered to support this claim. Additionally, the report does not describe how the age of each pecan orchard was established even though this is the first step in the analysis.

The section focuses on the increased density of trees in recent years among the randomly selected orchards that were examined. However, the "Spacing Results" section describes the occurrence of some "alternately spaced orchards" between the 1980s and 1990s that were thinned from 30 foot spacing down to 60 foot spacing between trees in alternate rows. Exhibit 36 generally shows average tree density varying between 35 and 50 trees per acre for orchards planted between 1988 and 2006 (including alternately spaced orchards) while orchards planted after 2006 have an average tree density of just under 60 trees per acre. This section concludes by stating that: "Older orchards tend to have more widely spaced trees, while younger orchards tend to have tighter spacings."

The pecan age analysis results in Exhibit 38 generally show that the area of pecans planted in years between 1985 and 2018 varied from a few hundred to just over 2,000 acres.

Opinion

The *Land IQ Report* fails to support the conclusion that more trees per acre will result in more consumptive use. Furthermore, after making this conclusion, the supporting files provided by Land IQ fail to account for any differences in consumptive use between older and younger orchards.

The report states that this "allows for the assumption of escalation of pecan consumptive use in more recent years." However, the calculations in the spreadsheets provided by Land IQ use the same crop coefficient during the 1968 through 2018 time period to represent pecan consumptive use and use an irrigation and production adjustment of 1.00. Thus, the pecan consumptive use is not escalated in the analysis prepared by Land IQ due to the decreased spacing. More importantly, the pecan crop coefficient that was used is for mature trees and is NOT adjusted downward to account for the area of young trees. The pecan consumptive use is too high because it erroneously assumes that all of the pecan trees are mature.

Riparian Land Use and Classification

Technical Evaluation

During development of their spatial land use database, the Texas technical experts determined the relative cover of different riparian vegetation classes through analysis of images with geospatial techniques, and then calibrated these results to a historical study of vegetation cover change by Papadopulos (2008) that was informed by ground level survey data.

The Texas technical experts delineated riparian corridors (comprised of "riparian polygons") for 1955, 2005, and 2014 using digital mapping techniques and photo interpretation of images collected in June 1955, August 2005, June/July/August 2014, and May/June/August 2016.

The riparian corridor in 2014 (the "baseline") was assessed using NDVI-based classification to determine the relative cover of three land cover classes, or plant functional groups (PFGs) in each riparian polygon: riparian trees, riparian shrubs, and bare ground. In intervening years, the relative coverage of vegetation and bare ground in each polygon were adjusted in increments of 5% to account for differences in canopy cover of trees or shrubs determined from imagery in 2005 (and presumably 1955).

The accuracy of the riparian land use was evaluated by comparing the total extent of riparian area mapped by the Texas experts in 1955 and 2005 to the extent mapped by Papadopulos in 1955 and 2004, respectively, and by comparing the relative total vegetation and bare ground areas mapped by the Texas experts and Papadopulos in 2005 and 2004, respectively. Differences in the total vegetation area between these sources were used to calibrate the baseline coverage of vegetation in 2014.

Regarding the estimation of land cover using the vegetation index NDVI, on page 79 the report states: "This difference is expected and due to the common overestimation of Cover using NDVI values (pixel-based) compared with field survey data. The Papadopulos (2008) report had the benefit of field survey data to verify and measure riparian vegetation cover in 2004. Therefore, the tabular 2014 total vegetation cover values were reduced by 159% to calibrate the 2014 NDVI-based cover observations to 2004 field-based observations in the Papadopulos (2008) report."

No explanation is given regarding why the NDVI-based methods overestimated vegetation cover by 159%. The reason for the flaw caused by using NDVI is not described. It is noted in most modern literature[13] that NDVI generally has a close, nearly 1:1 correspondence with fraction of ground cover. Therefore, the 2.59 ratio of NDVI-estimated cover to actual cover is unexpected and surprising, and suggests a substantial flaw in the vegetation cover analysis. No documentation is provided to explain this large, unexpected departure between estimated and actual ground cover, or to explain why the NDVI-based procedure overestimates ground cover if it was initially calibrated to known data. In addition, no description is provided for how Papadopulos (2008) measured riparian vegetation cover in 2004.

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[13] For example, Jiang, Z., Huete, A.R., Chen, J., Chen, Y., Li, J., Yan, G. and Zhang, X., 2006. Analysis of NDVI and scaled difference vegetation index retrievals of vegetation fraction. Remote sensing of environment, 101(3), pp.366-378; Verger, A., Martínez, B., Camacho-de Coca, F. and García-Haro, F.J., 2009. Accuracy assessment of fraction of vegetation cover and leaf area index estimates from pragmatic methods in a cropland area. International Journal of Remote Sensing, 30(10), pp.2685-2704; and Glenn, E.P., Huete, A.R., Nagler, P.L. and Nelson, S.G., 2008. Relationship between remotely-sensed vegetation indices, canopy attributes and plant physiological processes: What vegetation indices can and cannot tell us about the landscape. Sensors, 8(4), pp.2136-2160.

In exhibit 48 on p. 79, it is not explained why there was so much bare ground determined for riparian areas. The physical reason or cause is not provided. Riparian areas are typically defined as areas having close proximity to surface water or to shallow ground water. Under these conditions, vegetation usually prospers and extensive areas of bare soil are not found to occur. No explanation is given for why bare ground is considered to be riparian. Is it due to proximity to a stream or drain where water flow or human intervention discourages vegetative growth?

Opinion

To calibrate the riparian land use analysis, the *Land IQ Report* uses erroneous comparisons between land use analysis results from different years. Specifically, calibration is made by comparison between the Land IQ analysis for 2005 and the Papadopulos analysis for 2004. However, these years are not necessarily equivalent. Calibration based on comparisons between different years is difficult at best, requires information supporting the "equivalence" of the years, and likely resulted in inaccurate riparian land use classifications.

Riparian vegetation growth depends, in part, on river flows and changes depending on Rio Grande flows in the years and months prior to the analysis. For example, leading up to the Papadopulos analysis in 2004, flows along the Rio Grande upstream of the Study Area remained below 1,200 CFS most days between October 2000 and December 2004, with the exceptions of several days in May/June 2001 and April/May 2004[14]. Lower flows provide less water to support riparian vegetation, potentially explaining the higher bare ground coverage observed by Papadopulos in 2004. Between the Papadopulos analysis for 2004 and the Land IQ analysis for August 2005, Rio Grande flows at the same site exceeded 3,500 cubic feet per second nearly every day between mid-April and the end of June 2005. These higher flows could have several consequences, providing more water to support expanded vegetation growth or potentially washing away riparian vegetation. Either impact would affect vegetation areas in August 2005. It is likely that riparian vegetation coverages would have been different between 2004 and August 2005.

On p. 80, the *Land IQ Report* states: "Photo-interpretation of the 2005 and 2014 high-resolution aerials showed little to no detectable change in the relative PFG composition between 2005 and 2014 in the riparian areas." However, the report does not describe how the photo-interpretation was conducted to show little to no detectable change in PFG composition. No description is given regarding the assumptions and means for analyzing the 4-band aerial photo images.

Confidence in the accuracy of the Land IQ estimates of riparian vegetation coverage is substantially reduced by the large estimation bias in their NDVI-based method. This suggests that Land IQ should redevelop their NDVI-based method for estimating vegetation amount, and increase use of literature-based approaches and findings. In addition, for image pixels that may have had some open water intermixed with vegetation, no description is given pertaining to the impact of negative NDVI caused by open water on lowering the pixel-wide NDVI.

Page 76 of the *Land IQ Report* states that "Bare Ground**:** Includes areas that are bare year-round and areas that may have seasonal vegetation cover (dominated by annual grasses and other herbaceous vegetation (the life cycle of which is driven by rainfall events and not due to deeper rooted perennial

[14] Based on 15-minute discharge, in cubic feet per second (CFS), reported at USGS Station 08358400, Rio Grande Floodway at San Marcial, NM.

transpiration)." Evaporation of water from bare ground following rainfall is an important part of the water balance for these areas and this is not discussed in the *Land IQ Report*. It is not explained why areas that may have seasonal vegetation cover such as annual grasses was not classified as annual grasses, and an appropriate ET estimate assigned.

No documentation is provided, nor justification given, that "the Herbaceous Riparian PFG is both insignificant from a consumptive water use perspective given its limited extent and relatively shallow rooting morphology." (p. 76).

Consumptive Use Estimates

As with its documentation of the land use classification analyses, the *Land IQ Report* lacks sufficient detail to thoroughly explain how consumptive use estimates were developed. The level of detail provided in the disclosed report and accompanying materials does not allow for replication or evaluation of the steps to achieve the final consumptive use estimates. Furthermore, the ETo_adjustment tab in the spreadsheets provided for the Texas area applied Blaney-Criddle adjustment factors to the Hargreaves-Samani reference ET estimates output during years with limited data availability, which is incorrect usage.

Although Land IQ uses the crop coefficient-reference crop methodology, they do not reference the most recent and up-to-date description of the methodology found in the second edition of the American Society of Civil Engineers Practice Manual 70 (ASCE, 2016). Additionally, as described in the following sections, the weather station selection is poor for representing weather conditions over agricultural areas and weather data quality control is inadequate. In addition, the ET calculation procedure often does not use locally-based or calibrated crop coefficients. Based on the information presented in the *Land IQ Report*, the best available information and the best available science has not been used to quantify the consumptive use estimates. The following sections on preparing weather station data, crop irrigation season parameters, consumptive use estimates, and yield analyses describe specific areas where the best available information and the best available science were not used.

Weather Station Selection

Technical Evaluation

Producing accurate estimates of ET using the crop coefficient and reference crop ET methodology requires accurate and complete weather data from representative stations (ASCE, 2016). These data are necessary to calculate the consumptive use of water from cropland and riparian vegetation. The standardized Penman-Monteith (PM) methodology has been recognized as the preferred "gold standard" for ET estimation by the Food and Agricultural Organization (Allen et al., 1998), in the ASCE Task Committee Report on the Standardized Reference Evapotranspiration Equation (ASCE-EWRI, 2005) and in ASCE Manual 70 (ASCE, 2016).

The PM methodology requires solar radiation, air temperature, vapor pressure and wind speed data. Importantly, the ASCE Task Committee Report and Manual 70 provide explicit recommendations regarding methodologies used to estimate the required inputs to the standardized equation when measured data are missing, incorrect, or generally unavailable. Ultimately, the weather data that are used to develop reference ET estimates for determining crop water requirements must be representative of irrigated agriculture under equivalent weather and climate conditions as compared to the Study Area (Allen et al., 1998). Stringent quality assessment and quality control (QA/QC) methods must be employed, as described in the ASCE 2005 report and ASCE Manual 70.

In presenting the factors used to evaluate all available weather stations in the vicinity of the Study Area, the Texas technical experts list several generally accepted parameters recommended for consideration by ASCE (2016), including “location/distance to agriculture fields, immediate surroundings (e.g. irrigated surface vs. vacant lot), measured values (preference for stations that have required data supporting the PM calculation for ET_o), and data reliability and consistency” (*Land IQ Report*, p. 86). However, in presenting the preferred weather stations chosen by Land IQ, no clear explanation or results are given to describe how these factors were compared and supported the ranking of preferred stations. Land IQ is basing calculation of ET_o upon weather stations that do not represent the best sites and upon data that have not been subject to stringent QA/QC methods.

Opinion

The weather stations selected by Land IQ and, thus, the weather data relied upon in calculating ET_o are not the most representative sites for the agricultural conditions in the area. In addition, the data that are used were not subject to stringent QA/QC methods. The use of weather data from sites that are not the most representative and that were not subject to QA/QC methods results in inaccurate calculations of ET_o and subsequently consumptive use by Texas.

The reasons for selecting the weather stations shown in Exhibit 52 are not provided in the report. Our review of weather stations in the Study Area indicates that many of the stations selected in the *Land IQ Report* are not the best stations for the reasons presented in **Table 11-2**.

Weather Data Quality Assurance and Quality Control (QAQC)

Technical Evaluation

As described above, the careful selection of an appropriately located and representative weather station is a crucial step in assuring the suitability of weather data for estimating consumptive use. To confirm the quality of the data from selected weather stations, several quality assurance (QA) and quality control (QC) measures are recommended in the ASCE Task Committee Report on the Standardized Reference Evapotranspiration Equation (ASCE-EWRI, 2005) and in ASCE Manual 70 (ASCE, 2016).

Central to these QA and QC measures is the determination of inaccurate or missing data, and subsequent correction or estimation of these values. Neglecting this process can result in inaccurate or incomplete ET estimates.

For example, the year 2000 is the first year with complete weather data available to calculate the PM equation at the Fabian Garcia weather station. In that year, the annual reference ET rate reported and used by the Texas technical experts increased nearly half a foot over prior years (**Figure 11-4**). Review of the weather data from that station following standard, recommended procedures shows that the measured solar radiation data exceeded the clear sky solar radiation (the theoretical maximum solar radiation striking the earth's surface from a cloudless sky) in the winter/spring and fall/winter of that year (**Figure 11-5**), apparently due to sensor or data collection error. When these data are corrected following standard, recommended procedures, the solar radiation values are reduced to expected levels (**Figure 11-6**) and the reference ET decreases from 5.98 feet to 4.78 feet, a reduction of 20%.

Table 11-2. Summary of Weather Stations Selected in the *Land IQ Report* and the Reasons these Stations are not Representative.

Date Range	Valley	Station Selected as "Most Desirable" in *Land IQ Report* (Exhibit 52)	Reason Station Not Representative
2017-2018	EPCWID1/Hudspeth	*No station listed in Exhibit 52*	*No station listed in Exhibit 52*
2007-2011	EPCWID1/Hudspeth	Tirres	Environment less representative of reference conditions compared to Art Ivey based on an aridity assessment of the reported weather data
1962-1977	EPCWID1/Hudspeth	Fabens	Vegetated areas surrounding Ysleta are more representative of the agricultural area during this period.
1936-1950	EPCWID1/Hudspeth	Socorro	Vegetated areas surrounding Ysleta are more representative of the agricultural area during this period.
2015-2018	Rincon/Mesilla	*No station listed in Exhibit 52*	*No station listed in Exhibit 52*
2001-2014	Rincon/Mesilla	Fabian Garcia	Environment is less representative of reference conditions compared to Leyendecker PRSC II based on visual inspection of the two stations. The Fabian Garcia station is impacted by close-by trees, orchards and residential development that reduce wind speed.
1944-2000	Rincon/Mesilla	Las Cruces, NM	Environment less representative of reference conditions compared to Leyendecker and NMSU weather stations based on visual inspection of the two stations regarding fetch of transpiring vegetation within 200 m and openness regarding close-by orchards and buildings.

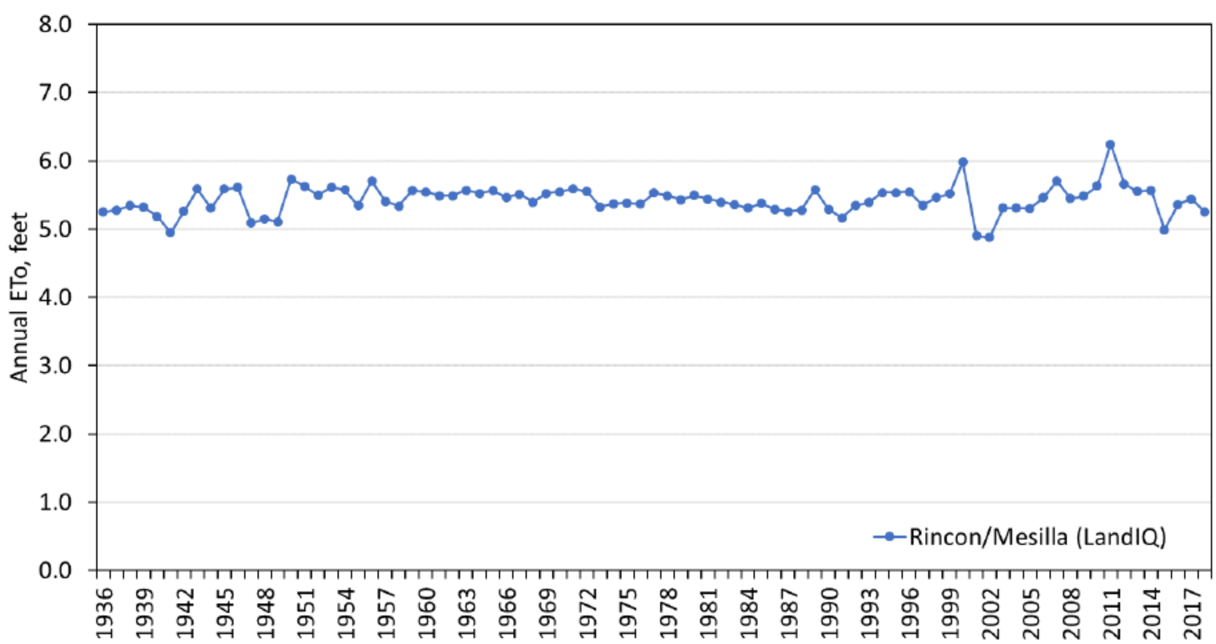

Figure 11-4. Land IQ Reference ET for the Rincon/Mesilla Valleys (note large increase in 2000).

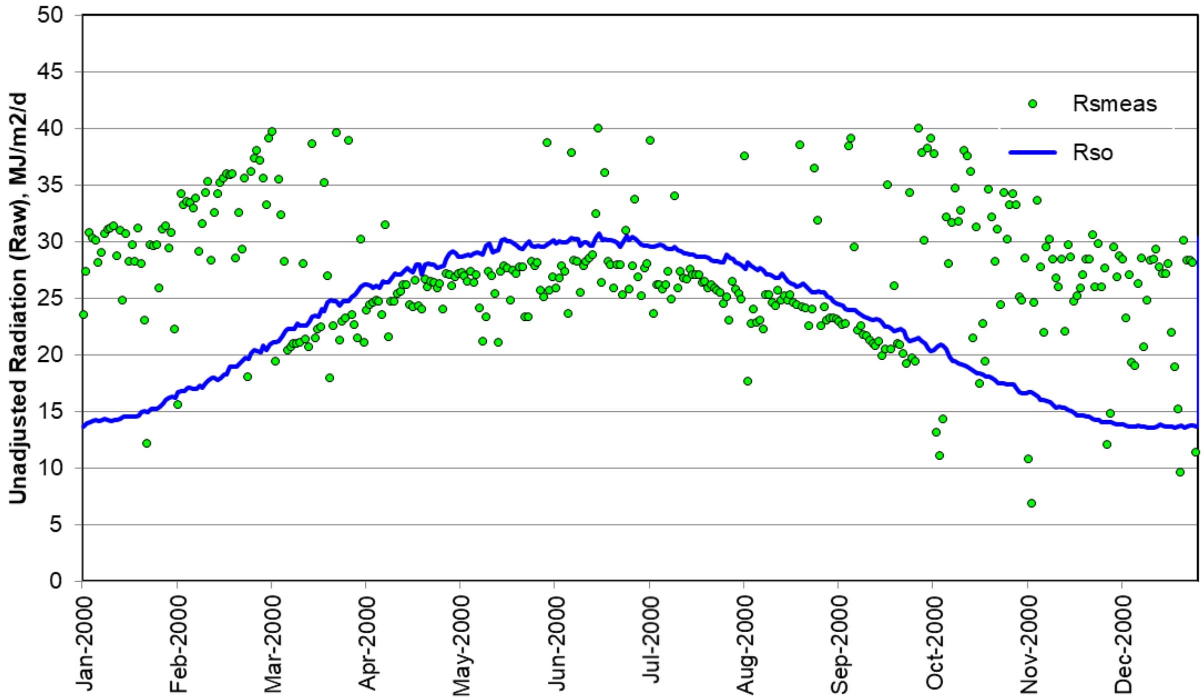

Figure 11-5. Fabian Garcia Weather Station Unadjusted (Raw) Solar Radiation Data, 2000, as utilized by Texas experts. The blue line (Rso) represents the theoretical maximum solar radiation expected under clear-sky (no clouds) conditions.

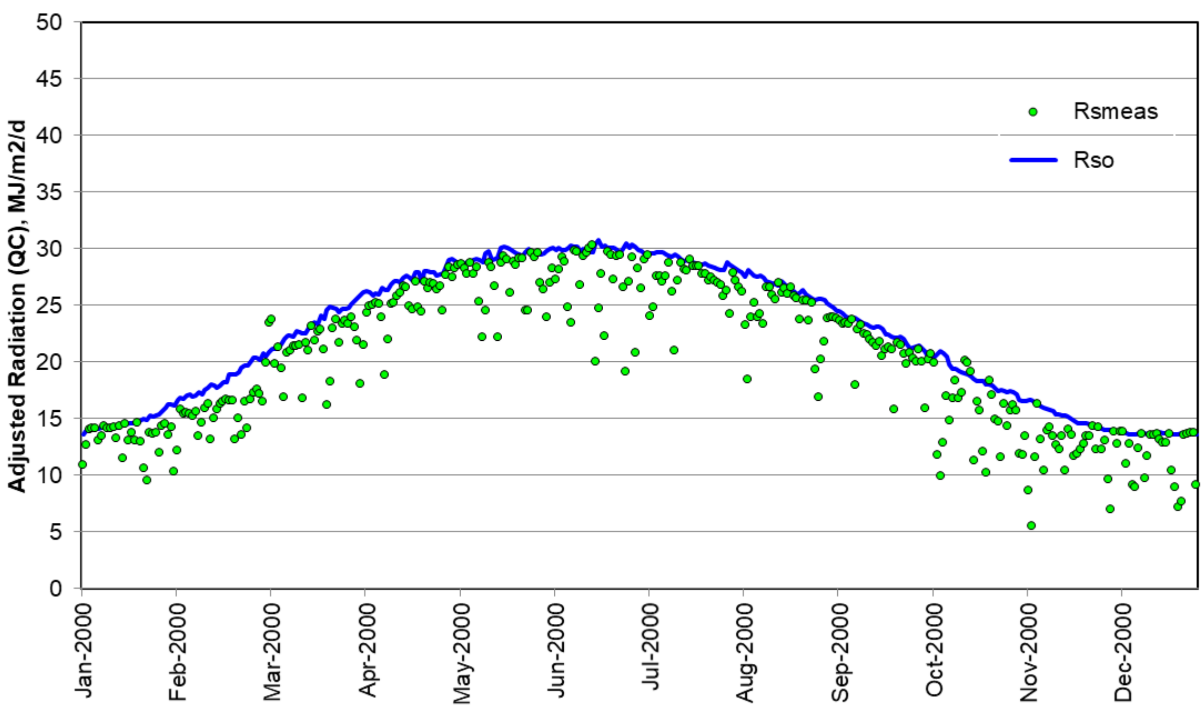

Figure 11-6. Fabian Garcia Weather Station Adjusted (QC) Solar Radiation Data Following Adjustment using Standard, Recommended Procedures of ASCE-EWRI (2005) and ASCE (2016).

Opinion

The *Land IQ Report* does not provide sufficient information on their weather data QA/QC measures to evaluate the quality of data that were used by the Texas team to develop the reference ET_o data used to compute crop consumptive use. Review of the weather input data described in the preceding section indicates that the QA/QC of the weather data did not follow standard, recommend procedures (ASCE-EWRI, 2005, and ASCE, 2016). Standard, recommended QA/QC analysis techniques (ASCE-EWRI, 2005, and ASCE, 2016) should always be utilized to ensure the accuracy and representativeness of solar radiation, air temperature, wind speed, and humidity data and all necessary corrections made to adjust inaccurate data.

Reference ET Equations

Technical Evaluation

Central to the *Land IQ Report's* estimates of consumptive use within the Study Area is the methodology used to estimate ET. ET encompasses all water that is consumptively used either through evaporation from the soil or crop surface or as transpiration through the plant tissue. ET rates vary between individual crops, soil surface coverage conditions, and surrounding weather and climate conditions. ET rates can also vary with the type of irrigation that is used due to the frequencies of irrigation and consequent soil evaporation events and the extent of surface wetted by the particular irrigation system.

When following standard procedures (ASCE, 2016), reference ET is calculated for a known reference surface using local weather data and is then adjusted to other individual crops based on specific crop coefficients that vary throughout the growing season. This is referred to as the "crop coefficient – reference crop ET" methodology.

At present, the PM method "is recommended as the sole standard method" for estimating reference ET, providing "strong likelihood of correctly predicting ET_o in a wide range of locations and climates [with] provision for application in data-short situations" (Allen et al., 1998). The aforementioned ASCE Task Committee report and the recently published second edition of ASCE Manual 70 (ASCE, 2016) also recommend the PM method in the form of the ASCE Standardized Penman-Monteith method. ASCE (2005 and 2016) recommend employment of the PM method with estimation of missing humidity, wind and solar radiation data when only air temperature data are available. The employment of the PM method under all conditions, including those when only air temperature data are available, is recommended by ASCE over the Hargreaves-Samani method and Blaney-Criddle methods.

The *Land IQ Report* utilizes the PM methodology when sufficient weather data are available for its application. However, when available data are insufficient for the PM, the *Land IQ Report* states that the "…Blaney-Criddle ET calculation method was used…" (page 88). However, notes on the ET_o adjustment tabs in the spreadsheets disclosed by the Texas technical experts indicate that prior to the years 2000 and 2004 in New Mexico and Texas, respectively, two separate methodologies are used to estimate reference ET for the New Mexico and Texas regions of the Study Area. For the Rincon and Mesilla Valleys (EBID and the small area of EPCWID in the Mesilla Valley), the Hargreaves-Samani methodology is used to estimate ET_o. For the El Paso Valley (Hudspeth and the area of EPCWID1 not in the Mesilla Valley), the note in row states: "Values used to Scale Blaney Criddle ETo prior to 2000 to Penman Monteith." This seems to indicate that the Blaney-Criddle method is used to estimate ET_o. However, the Blaney-Criddle method does not provide an ET_o estimate. Also, sufficient data to use the PM equation is not available until 2004 in the El Paso Valley, not 2000 as stated in the note. According to the spreadsheets, a monthly ET_o adjustment factor is applied to the ET_o calculated from the Hargreaves-Samani and Blaney-Criddle equations. The report states that: "In years that the Penman-Monteith data were available, however, both methods were calculated in order to compare methods and generate adjustment factors for earlier years where only Blaney-Criddle could be used." Presumably these adjustment factors are monthly averages from the years of overlap, however, no further description of the methodology was provided and the input data and results of the calculation have not been provided.

Notably, the Texas technical experts state that the CUP+ program released by the California Department of Water Resources (CDWR) was used to generate ET_o estimates, but the program documentation states that it calculates ET_o using the Hargreaves-Samani methodology when the data provided are not sufficient to calculate the PM ET_o.

Per an additional data request prior to the deposition, Land IQ provided additional information on the ET_o adjustment factors in the form of a spreadsheet with two tabs. One tab contained adjustment factors used in the Rincon, Mesilla and RinconandMesilla spreadsheets that appeared to be an exact copy of the ET_o adjustment tab included in those spreadsheets. However, in the other tab containing adjustment factors used by the EPCWID1, Hudspeth and El Paso Valley spreadsheets, the note at the top of the sheet was changed from the previous sheets to indicate that these adjustment factors were for the Hargreaves-Samani equation, but the adjustment factors were unchanged. Thus, it is not clear which methodology was used to calculate ET_o and the adjustment factors used in the EPCWID1, Hudspeth and El Paso Valley spreadsheets, and why the same adjustment factors apply equally to the Hargreaves-Samani and Blaney-Criddle methods in the El Paso Valley.

Opinion

Use of different reference ET equations to estimate reference ET during the years when all the parameters for the PM equation are not available leads to incongruencies between reference ET estimates for areas within New Mexico and areas within Texas.

ASCE Manual 70 (ASCE, 2016), Allen et al. (1998) and ASCE-EWRI (2005) recommend that for the time periods when sufficient weather data are not available, reference ET should be calculated by first using standard methodology to estimate the missing weather parameters, then employing the estimated weather parameters in the standardized PM equation. Standard methodologies are able to incorporate variation in regional wind speed over time based on regional wind speed data and variation in relative humidity over time in some proportion to reported air temperature. These variations drive ET_o estimates by the PM equation to increase accuracy of ET_o estimates from year to year as compared to Hargreaves-Samani and Blaney-Criddle equations that have no knowledge of year to year or month to month variation in regional wind speed or relative humidity and their impact on ET_o.

Crop Coefficient Values and Derivation

Technical Evaluation

Crop coefficients are foundational to calculating the consumptive use of water from agricultural land and riparian vegetation using the reference ET and crop coefficient methodology. Crop coefficients *must* be derived from, and calibrated to, local, observed crop growth characteristics within the Study Area to accurately account for crop consumptive water use in that area. Furthermore, the magnitudes of crop coefficients, when used for water balance estimates, must be derived from, or calibrated to, local measurements or estimates of actual (not potential) consumptive use.

In the section "Water Use of Mesilla Valley Crops" (*Land IQ Report*, p. 82-86), the *Land IQ Report* identifies some sources used as the basis for crop coefficients of chilis, onions, and lettuce crops in the

Mesilla Valley, and qualitatively describes “reasonable” crop coefficient adjustments to account for changes in crop ET in historical years (from 1936 to approximately 1985, with continued adjustment for a few crops into the 1990s).

The sources given for these crop coefficients include published crop coefficients from the New Mexico Climate Center and FAO Irrigation and Drainage Paper 56 (Allen et al., 1998). However, the crop coefficient curves are neither given nor described in the report. The sources of crop coefficients for other crops and other regions in the Study Area are also not clearly identified. Following the deposition, additional information was received that provided sources for the crop coefficients. Many of the crop coefficients provided were the default crop coefficients, in terms of magnitude, and were applied with default planting and harvest dates and with default growing season lengths that came with the CUP+ program released by the California Department of Water Resources (CDWR). California is a large state that spans over 1,000 miles from north to south. The crop coefficients, the planting and harvest dates, and the growing season durations developed for application in California can be substantially different from conditions of southern New Mexico and western Texas.

The *Land IQ Report* bases its historical crop coefficients and crop coefficient adjustments on a brief and inconclusive evaluation of literature on crop water use associated with differing irrigation methods and crop yields. The sources identified by the *Land IQ Report* for each crop are discussed below. Following this evaluation, the report repeatedly concludes that: “adjusting crop coefficient[s] downward going back in time in the study period is a reasonable approach to estimate consumptive use throughout the study period” (*Land IQ Report* pp. 83, 85, 86). However, the quantitative basis for this adjustment is not described and, more importantly, the basis for the unadjusted California crop coefficients used for recent history (about 1985 through 2018) is not established. The following sections briefly discuss the sources for the crop coefficients used by Land IQ (as indicated in *Kc_Values_and_Sources_20190924.xlsx*) given for each crop in approximate order from greatest to least irrigated area in 2018.

Pecans

Information provided by Land IQ indicates that the crop coefficients for pecans originate from “Evapotranspiration of flood-irrigated pecans” (Sammis, Mexal, and Miller, 2004) and the work of Samani et al. (2012).

The study by Sammis, Mexal, and Miller reports on daily ET measurements for 5.1 hectares of mature pecan orchards (21 year old stand) located in the Rio Grande floodplain in New Mexico near Las Cruces. ET was calculated from the net surface energy balance measured at a tower located in the middle of the orchard during 2001 and 2002. Notably, this work calculates grass reference evapotranspiration using Penman’s equation per the methodology specified in Sammis et al. (1985). This methodology differs from the standardized PM methodology, and consequently results in different ET_o values. Thus, the crop coefficients derived with the Penman ET_o equation must be adjusted prior to use with ET_o calculated with the standardized PM equation to account for differences between the two ET_o methods.

In reference to the work of Samani et al., Land IQ notes that the crop coefficients for pecans are “listed under stone fruit in FAO 56.” However, a separate analysis by Taylor et al. (2017) argues that “pecans should not be grouped under stone fruit” and that models such as the pecan monthly water use simulator developed by Samani et al. “may not always give acceptably accurate ET values outside of the area in which they were calibrated.” Suitable crop coefficients should be calculated based on the same ET_o methodology with which they will be used (i.e., the standardized PM methodology) and should be calibrated to local conditions. Additionally, the Sammis Kc was developed for well-managed mature trees and therefore not appropriate for application to immature trees or poorly managed trees.

Alfalfa

The crop coefficient used by Land IQ for alfalfa crops is estimated from FAO Irrigation and Drainage Paper 24 (FAO 24) and research from the University of California, as communicated through Dr. Richard Snyder at the University of California in Davis, CA (UC Davis).

The alfalfa crop coefficient is constant and equal to the mean K_c value given for alfalfa in a dry climate with light to moderate wind (FAO 24, p. 45). Notably, this reference describes crop coefficients that are used to calculate ideal, potential crop water requirements (FAO 24, p. 1: "Crop water requirements are defined here as 'the depth of water needed to meet the water loss through evapotranspiration…of a disease-free crop, growing in large fields under non-restricting soil conditions including soil water and fertility and achieving full production potential under the given growing environment'."). This definition describes ideal conditions, which are characterized by potential ET. Because some of the alfalfa crops are affected by water stress, disease, restrictive soil conditions, or other factors leading to reduced ET, these crop coefficient values overestimate the actual ET of the average alfalfa crop in the Rincon, Mesilla and El Paso Valleys.

Cotton

The crop coefficients used by Land IQ for cotton are adjusted from the K_c values given in FAO 56 according to the Kc values given in CUP+ and the consumptive use of cotton reported in a study by Ahadi, Samani, and Skaggs (2013).

The initial and end of season Kc values equal those of cotton as reported in FAO 56. For mid-season, Land IQ states that the peak Kc value is estimated to be "not as high as 1.15-1.20" (as in FAO 56), and "not as low as CUP+ (0.95)" (note in *Kc_Values_and_Sources_20190924.xlsx*). Neither FAO 56 nor CUP+ provide local information for southern New Mexico or western Texas conditions. The K_c values provided in FAO 56 are representative of ideal conditions for "non stressed, well-managed crops in subhumid climates" (FAO 56, Table 12), whereas the source of the default crop coefficients given in CUP+ is unclear. Presumably, they were developed for simulating crop water requirements across California.

Onions

The crop coefficients used by Land IQ for onions are taken from CUP+. The source of the default crop coefficients given in CUP+ is unclear, though presumably they were developed for simulating crop water requirements across California., a large state spanning diverse climate regions. The crop coefficients developed for application in California are likely different than what might be expected in southern New Mexico and western Texas due to likely differences in plant density, row spacing, watering practices and lengths of growing seasons.

Corn

The crop coefficients used by Land IQ for corn are taken from CUP+, with adjustment to match the end of season Kc value given in FAO 56. Neither FAO 56 nor CUP+ provide local information from southern New Mexico or western Texas. The K_c values provided in FAO 56 are representative of ideal conditions for "non stressed, well-managed crops in subhumid climates" (FAO 56, Table 12), whereas the source of the default crop coefficients given in CUP+ is unclear, though presumably they were developed for simulating crop water requirements across California.

Chilis

The crop coefficients used by Land IQ for chilis are taken from New Mexico crop information provided by the New Mexico Climate Center (NMSU, 1996), which is based on the work of Saddiq (1983). On p. 83, the *Land IQ Report* states that the crop coefficients from the New Mexico Climate Center were adjusted "for lower yields in historical crops." However, no documentation supporting the derivation of and application of the adjustments to ET "for lower yields" is provided. In addition, the basis for the "crop coefficients from the New Mexico Climate Center (1996)" is not provided beyond the source's reference to Saddiq (1983). If those coefficients applied were derived based on Penman's equation per the methodology specified in Sammis et al. (1985), they should be adjusted to the PM ET_o basis prior to use with PM ET_o developed by *Land IQ.*

Pasture

The crop coefficient used by Land IQ for irrigated pasture is taken from FAO 24 and communication with Dr. Richard Snyder at UC Davis.

The pasture crop coefficient is constant and equal to the mean K_c value given for "grass for hay" in a dry climate with light to moderate wind (FAO 24, p. 45). As described above, FAO 24 provides crop coefficients that are used to calculate ideal, potential crop water requirements (FAO 24, p. 1: "Crop water requirements are defined here as 'the depth of water needed to meet the water loss through evapotranspiration…of a disease-free crop, growing in large fields under non-restricting soil conditions including soil water and fertility and achieving full production potential under the given growing environment'."). This definition describes ideal conditions, which are characterized by potential ET. These crop coefficient values overestimate the actual ET of average crops because some crops are affected by water stress, disease, restrictive soil conditions, or other factors that reduce water use below the potential ET described by these crop coefficients.

Hay

The crop coefficient used by Land IQ for hay crops are estimated based on the crop coefficients for alfalfa reduced by a value of 0.1 throughout the growing season. As described above, the alfalfa crop coefficients represent ideal, potential ET conditions and overestimate the actual ET of crops that are affected by water stress, disease, restrictive soil conditions, etc. The same concerns with alfalfa crop coefficients apply to hay as well. Furthermore, the basis for the 0.1 K_c value reduction from the alfalfa crop coefficients is not given.

Cole/Leafy Greens

The crop coefficients used by Land IQ for cole and leafy greens were based on crop coefficients reported for lettuce through communication with Dr. Richard Snyder at UC Davis. The lettuce crop coefficient is constant and presumably developed for application in California, a large state spanning diverse climate regions. The crop coefficients developed for application in California are likely different than what might be expected in southern New Mexico and western Texas.

Grain, Grapes, Legumes, Melons/Squash, Root Crop, Tomatoes, and Turf

The crop coefficients used by Land IQ for grain, grapes, legumes, melons/squash, root crop, tomatoes, and turf are taken from CUP+. The default crop coefficients given in CUP+ were developed for simulating crop water requirements across California, a large state spanning diverse climate regions. The crop coefficients developed for application in California are likely different than what might be expected in southern New Mexico and western Texas.

Asparagus

The crop coefficients used by Land IQ for asparagus are taken from the K_c values given in FAO 56. The K_c values provided in FAO 56 are representative of ideal conditions for "non stressed, well-managed crops in subhumid climates" (FAO 56, Table 12). These conditions may not be representative of actual agricultural fields in southern New Mexico or western Texas.

Irrigated Annuals and Miscellaneous/Other

The crop coefficient used by Land IQ for irrigated annuals and other miscellaneous crops were estimated to be equal to the crop coefficients for chilis. Therefore, the same concerns with chili crop coefficients listed above applies for these crops as well.

Opinion

The *Land IQ Report* provides insufficient information to understand the basis for the crop coefficients used in the Study Area and to support their usage. For most crops and regions of the Study Area, this information is neither described nor provided in the Report. For the three crops (chilis, onions, lettuce) in the Mesilla Valley that the report does provide crop coefficient sources, these crop coefficients are gleaned from published literature, and are seemingly not calculated specifically for observed crop growth in the Study Area. This is confirmed by the documentation of crop coefficient sources provided by Land IQ since the initial disclosures.

To provide the most accurate estimates of consumptive use, crop coefficient curves should ideally represent average local conditions and crop water use across the entire population of fields in the Study Area (ASCE, 2016). Published crop coefficient curves from technical literature and manuals ("book" crop coefficient curves) generally represent growing conditions of idealized "well-managed" crops and do not reflect local differences in irrigation practices, soil conditions, and resulting transpiration and evaporation rates among fields. As described in the technical evaluation above, the Mesilla Valley crop coefficients referenced by the *Land IQ Report* (the *Land IQ Report* does not discuss the differences between potential and actual crop coefficients) represent potential water use rather than actual water use. It is important to note that individual fields often have ET rates that vary from the "book" crop coefficient curves (Tasumi et al. 2005, 2006 and Tasumi and Allen 2007, Singh and Irmak 2009). Locally derived and calibrated crop coefficient curves reflect local differences in water stress, wetness of exposed soil, and resulting transpiration and evaporation rates and are necessary to correctly calculate consumptive use (Allen et al., 1998; ASCE 2016). Land IQ used published crop coefficients developed to represent potential crop water use (as evident by their use of the term potential daily evapotranspiration (PET)), rather than locally derived and calibrated, actual crop coefficient curves as recommended for standard practice (ASCE, 2016).

The *Land IQ Report* only discusses total ET. The ET of applied water (ET_{aw}) and ET of precipitation (ET_{pr}) components of ET_c must be discussed, as the ET_{aw} is required to determine consumption of applied water.

Monthly Adjusted Agricultural Consumptive Use and Yield Analysis

Technical Evaluation

On page 88, the *Land IQ Report* states that PET was "adjusted for irrigation and production differences across time" using an adjustment factor that "takes into account improvements in irrigation efficiency, land leveling, and increased yields/biomass." This adjustment factor was "employed for many of the crop types (dominated by cotton and alfalfa) based on yield records and image analysis," including comparison between reported yield in the JIR and crop reports, and comparison between historical

(1955) and recent (2014) photographs (shown in Exhibit 53). No clear explanation is given to describe how these comparisons were used to arrive at a quantitative "Irrigation and Production Factor."

Similarly, on page 88 the report states: "This factor reduces the PET of crops in historical years because the overall yield, vigor, density and consistency of growth were proven (through historical yield records and image analysis) to be less in previous years. As a result, the consumptive use was correspondingly less. An adjustment factor was employed for many of the crop types (dominated by cotton and alfalfa) based on yield records and image analysis." No documentation is provided to support the notion that all increases in ET have come from an increase in yield, which implies that some increases in yield cannot have come from a larger harvestable yield/biomass ratio that is unrelated to factors that affect ET, such as leaf area or ground cover. Increases in harvestable yield and biomass ratio are common to nearly all modern crops, even with the same amount of ground cover and ET[15]. This is especially the case for cotton where harvestable yield has increased substantially over time.

With regards to chilis, page 83 of the *Land IQ Report* states: "the crop coefficient from 1996 represents relatively high yielding crops compared to today's crops." No documentation is provided to support this statement. Furthermore, page 83 states: "current crops are even higher yielding, but may also be more water efficient, and likely don't need more water." No documentation is provided to support this statement that current crops may be more water efficient. No indication is given as to what has changed with modern crops to cause this. Similar documentation and justification are needed for onion and lettuce crops also. The section on chilis concludes on page 83 by going on to state: "Therefore, adjusting the crop coefficient downward going back in time in the study period is a reasonable approach to estimate consumptive use throughout the study period."

The onion section concludes with very similar statement at the top of page 85. Again, documentation is not provided to support downward adjustment in time as a reasonable approach, and to support proportionality between crop yield and crop ET. The statement does not show congruency with the previous three bullets from that section on chilis.

Documentation is also needed for adjustment to other crops, including lettuce. The lettuce section, presumably discussing the "cole/leafy greens" crop coefficient, concludes with the following two bullets and the statement about adjusting crop coefficients:

- "the crop coefficients used to estimate lettuce and cabbage ET are likely applicable
- Current crops may be higher yielding, but likely don't use much more water than crops grown during the time period when crop coefficients were developed.

Therefore, adjusting the crop coefficient downward going back in time in the study period is a reasonable approach to estimate consumptive use throughout the study period."

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[15] For example: Barbieri, P., Echarte, L., Della Maggiora, A., Sadras, V.O., Echeverria, H. and Andrade, F.H., 2012. Maize evapotranspiration and water-use efficiency in response to row spacing. Agronomy journal, 104(4), pp.939-944. and
Howell, T.A., 2001. Enhancing water use efficiency in irrigated agriculture. Agronomy journal, 93(2), pp.281-289. and for rainfed corn and soybeans:
Egli, D.B., 2008. Comparison of corn and soybean yields in the United States: Historical trends and future prospects. Agronomy journal, 100(Supplement_3), pp.S-79.

The second bullet and the concluding statement contradict with the bullet stating that “current crops may be higher yielding, but don’t use much more water…” and compared to a concluding statement that states that adjusting crop coefficients, and thus water use, going back in time is reasonable.

Opinion

The methodology used in the *Land IQ Report* does not provide any clear justification or metric for quantifying the proposed Irrigation and Production Factor. Little crop yield information is provided except for chilis, onions, and lettuce in the Mesilla Valley, and those values are provided in differing units that cannot be directly compared without additional information. No quantitative analysis is described in the report to support the proposed Irrigation and Production Factors. Following the deposition, spreadsheets were provided with yield data and graphs, but no description of how the reduction factor used relates to yield and consumptive use was provided.

The *Land IQ Report* states “Visual evidence of these crop growth differences can also be clearly seen when comparing image resources from different decades (Exhibit 53).” No quantitative analysis of the images is described to support the proposed Irrigation and Production Factors. Furthermore, there is no description of how the fields were selected and no analysis describing the number of fields with clear evidence of crop growth differences. It seems simply by chance that four fields with reduced growth in 1955 could be found and compared to 2014. Also, the subjective comparison of higher resolution color images from 2014 to black and white images from 1955 biases the comparison.

The comparison should be for a pre-determined random sample of fields to eliminate any of bias of the analyst in selecting fields that appear most different, and clear criteria should be used to consistently identify cropping and irrigation status, and to quantify parameters of crop growth characteristics that are used to compute a PET adjustment factor. Both images should be black and white (the minimum information available between the two pictures) to prevent subjective effects on the evaluation of consumptive use.

Growing Season Duration

Technical Evaluation

In the supporting spreadsheets accompanying the *Land IQ Report*, consumptive use is calculated for each crop during a growing season that begins on the same season start date for each crop and progresses to the harvest date (season end date) (**Table 11-3**).

Table 11-3. Summary of Growing Season for Predominant Crops in the Rincon and Mesilla Valleys (over 1,000 ac) from the *Land IQ Report* Supporting Files.

Crops (over 1,000 ac, per *Land IQ Report*)	Season Start Date	Season End Date
Alfalfa	3/1	12/1
Chile/ Peppers	4/1	10/1
Corn/ Silage	5/1	11/15
Cotton	4/15	11/30
Onions	11/1	6/1
Pasture	3/1	10/31
Pecans/ Other Trees	3/1	11/30

Source: *MesillaAndRincon_ConsumptiveUse* file, Land IQ, LLC Supporting Files and *Kc_Values_and_Sources_20190924.xlsx provided following the deposition*.

Opinion

No evidence is given to support the selection of the growing season start and end dates chosen for each crop. While the growing season can be defined based on local observed planting and crop maturation dates, the approaches applied are rigid and do not reflect year-to-year changes in weather and temperature. More generally accepted approaches (ASCE, 2016) base the beginning and progression of the growing season on air temperature or via cumulative growing degree days (CGDDs). The end of a growing season for annual perennial crops should be defined by air temperature, by CGDDs or by the occurrence of a killing frost. FAO-56 (Allen et al. 1998) strongly recommends basing starts and ends of growing periods on local observations.

Riparian Water Consumption

Technical Evaluation

Page 108 of the *Land IQ Report* states: "Evapotranspiration rates are available from literature resources and studies relevant to the study area for these three PFGs." The literature sources used to support this statement are not cited. Page 108 of the report goes on to state: "Evapotranspiration (ET) rates depend on several factors including the characteristics of the plant community (including species identity, height and age, vegetation health), stand densities, site conditions such as depth to groundwater and salinity, temperature and precipitation (Tamarisk Coalition 2009, Johns 1989)." However, documentation on how the factors in the statement were quantified in estimating ET for riparian vegetation is not provided.

Page 108 also states: "Using relative tree cover estimates from Papadopulos (2008) for those three tree groups for each of the years of analysis, an average riparian tree ET was developed." No documentation is provided describing how the average riparian tree ET was quantified using relative tree cover.

Page 110 of the *Land IQ Report* states: "Annual ET rates for the Cottonwood-Willow riparian vegetation community were selected by reviewing Allen et al. (2005), which calculated average annual ET (mm) for Cottonwood (1380 mm) and Willow (1283 mm) for a study area in the Middle Rio Grande River Basin, with 2002 Imagery and a satellite based energy balance calculation method using Landsat Imagery. The selected rate was 0.47 m/year." No description, evidence, nor documentation supporting the decision to estimate cottonwood-willow ET as 0.47 m/year as compared to the substantially larger 1331 mm (1.33 m/year) as found by Allen et al. (2005) is provided. The difference between these two values is 180 percent.

Page 110 also states: "An ET rate of 0.5 m/year was selected for Mesquite." The ET rate of 0.5 m/year for mesquite is opposed by values in Exhibit 64 of the *Land IQ Report* that are higher than this rate. No discussion supporting 0.5 m/year is provided.

Opinion

Little evidence or documentation is provided to support the selection of water consumption amounts for riparian systems. The approach is far from a mechanistic approach that considers influences of weather (evaporative demand), wetting frequency, vegetation density, and vegetation health. Rather, broad estimates of water consumption are put forward based on literature values obtained from different climates and different types of riparian conditions.

Nongrowing season water consumption

Technical Evaluation

As described above, the supporting fields accompanying the *Land IQ Report* calculate consumptive use for each crop during a growing season defined by the start and end dates in **Table 11-3**. Outside of this season, the apparent calculated monthly consumptive use is zero.

Opinion

Consumptive use, or evapotranspiration (ET), encompasses all water that is consumptively used either through evaporation from the soil or crop surface or transpiration through the plant tissue. Consumptive use includes the use of water from precipitation and from irrigation. Consumptive use rates vary between individual crops throughout the year based on soil surface coverage conditions and surrounding weather and climate conditions. Outside of the growing season, the consumptive use rates may be low, but they will not equal zero for crops that remain in the field (e.g. pecans and other trees), particularly during precipitation events. Additionally, pre-season irrigation of certain crops, such as cotton, is an important consumptive use of water outside the growing season. Excluding these elements of consumptive water use results in inaccurate results.

Summary

In summary, the methodologies provided in the *Land IQ Report* are generally not clear, are not well documented nor justified, and often do not adhere to standard and accepted procedures. Conclusions regarding crop coefficient adjustments are especially unfounded, as are the weather stations selected to develop weather data for calculating reference evapotranspiration. Additionally, as was demonstrated, weather data QA/QC did not follow standard, recommended quality control procedures as described in the second edition of ASCE Practice Manual 70 (ASCE, 2016) and other widely accepted reference materials. Most importantly, the use of potential crop coefficients rather than average, actual crop coefficients, as recommended by standard, recommended procedures (ASCE, 2016 and ITRC, 2019) for historical water balance analyses, leads to an overestimation of crop consumptive use. This overestimate, compounded by use of non-standard procedures for the soil water budget (as discussed later in this report), leads to a gross overestimation of the pumping necessary to meet consumptive use requirements.

Technical Rebuttal of Montgomery & Associates Report

This rebuttal centers on technical critiques of the methodologies used in the soil water balance and of the related opinions presented in the *Montgomery & Associates Report*. As described, these methodologies do not accurately reflect actual conditions observed on irrigated fields in the Study Area, nor do they adhere to standard and accepted soil water balance practices as described in the second edition of ASCE Practice Manual 70 (ASCE, 2016) and other widely accepted reference materials.

Each of these critiques and objections is identified below under the applicable sections, by topic. Each section concludes with a summary of the New Mexico technical experts' opinions and describes the key areas of disagreement with information to support the rebuttal opinions.

Montgomery & Associates Opinions

Technical Evaluation

On page 9 of the Montgomery & Associates Report, Dr. Kikuchi highlights that "Crop consumptive use simulated using the soil water balance model matches crop consumptive use reported in Dr.

Kimmelshue's report very closely, with average percent discrepancy less than 0.01%." Although this comparison is written in the opinion that it validates the soil water balance model results, later in the report it becomes clear that there is insufficient evidence and justification, as the Land IQ estimates were used as targets of calibration.

Opinion

Page 42 of the *Montgomery & Associates Report* specifies that the monthly model was calibrated using the adjusted crop evapotranspiration rates provided by Land IQ. Thus, the fact that the soil water balance results match the Land IQ results does not serve as a validation of the accuracy of the soil water balance compared to local conditions in the Study Area. Indeed, the same problems with the Land IQ ET estimates, such as the overestimation caused by using potential rather than average, actual crop coefficients for actual conditions observed in the Study Area (see above) apply to the soil water balance results as well.

Soil Water Balance Model

The documentation of the soil water balance model in the *Montgomery & Associates Report* reveals several key incongruities with standard and accepted soil water balance practices. The choices in methodologies likely impede the ability of the model to accurately simulate actual conditions observed in the Rincon and Mesilla Valleys.

The following sections describe the water balance time step and model calibration efforts used in the *Montgomery & Associates Report*. Each section highlights specific areas where the best available information and the *best available science* were not used.

Soil Water Balance Time Step

Technical Evaluation

The soil water balance model developed by Montgomery & Associates "tracks soil moisture within the maximum extent of irrigated agricultural lands of the Rincon and Mesilla basins on a monthly time step" (*Montgomery & Associates Report*, p. 19). Ultimately, the soil water balance is used to "estimate agricultural groundwater pumping and deep percolation" between 1938 and 2016 (p. 19). On page 25, the report describes using the water stress model developed by Allen, et al. (1998) that requires a daily time step, and then incorrectly applies the model on a monthly time step.

Opinion

Standard practices for developing a root zone soil water balance require a daily time step (Allen et al., 1998, ASCE 2016). The monthly time step used for developing the soil water balance is typically used for simulating larger-scale groundwater inflows and outflows, but a daily time step is necessary to accurately simulate the inflows, outflows, and change in storage within the root zone that impact crop water stress (ASCE 2016).

A daily time step aligns more closely with the time scale of events impacting soil moisture exchange and crop consumptive use, such as irrigation and precipitation events and daily crop development. Consequently, a daily model is capable of tracking soil moisture more realistically. Importantly, a monthly model cannot track soil moisture correctly because within the monthly time step irrigation water generally needs to be applied more than once and deep percolation fluxes vary daily and may last only five to ten days.

Monthly models do not capture all of these exchanges and can therefore misrepresent or understate or overstate changes in soil water storage and other flow paths (e.g. consumptive water use). For example, in the Montgomery & Associates soil water balance results, average monthly soil moisture drops below the permanent wilting point of some crops during some months and remains above field capacity (FC; the maximum amount of water that a well-drained soil can hold) in other months. Both scenarios are wholly unrealistic, i.e. physically impossible. Soil moisture exceeding FC can occur briefly (i.e., for a few days) in a typical field, but the excess water will drain through deep percolation soon after (Bauer and Vaccaro, 1987; Willis et al., 1997; Allen et al., 1998; Bethune et al. 2008).

Furthermore, the monthly time step does not clearly describe specific planting/harvest dates or irrigation dates (or volumes on those dates). These events are all critically important to estimating stages of crop development, water stress and consumptive water use in the beginning and ending months of the season.

Model Calibration

Technical Evaluation

As indicated on pg. 42 of the *Montgomery & Associates Report*, the monthly model "was calibrated to match available historic data as closely as possible" and "consisted of adjusting surface runoff of applied water" and "soil moisture uniformity parameters within reasonable ranges to simultaneously match historic data and conceptual trends." The data used to calibrate the monthly model include the adjusted crop evapotranspiration rates provided by Land IQ ("accounting for observed historical trends in crop yield"), metered groundwater pumping at registered irrigation wells, and estimates of on-farm irrigation efficiency.

Opinion

It is not clear that the calibration described above was sufficient to accurately represent observed conditions in the Rincon and Mesilla Valleys. Rather, the calibration suggests that the soil water balance results were effectively predetermined to target the Land IQ consumptive use estimates (which overestimate consumptive use for the Rincon and Mesilla Valleys, as stated in the opinions in the previous section).

As described, the calibration appears to be partly subjective (calibration "to simultaneously match historic data and conceptual trends") and does not use sufficient historic data to address all concerns with accuracy in a monthly model. The adjustment of surface runoff of applied water ("tailwater") to match ET and metered groundwater pumping effectively ignores potential changes in deep percolation, a significant flow path in the soil water balance.

Model Inputs and Methodologies

Several key inputs and methodologies used in the Montgomery & Associates soil water balance model do not reflect the soil characteristics, soil moisture conditions, or crop water stress characteristics observed in the Rincon and Mesilla Valleys.

The following sections describe the assumptions used by Montgomery & Associates to route precipitation inputs through the model and to select soil, irrigation, and water stress characteristics. Each section highlights specific areas where the best available information and the *best available science* were not used.

Soil Analysis

Technical Evaluation

Soil properties used in the soil water balance model are described in Section 2.1.3.4 of the *Montgomery & Associates Report*. The Soil Survey Geographic Database (SSURGO) is given as the source for determining the distribution of soil classes in the Rincon and Mesilla Valleys, which dominantly include clay loam, loam, and loamy sand soils (collectively 70% of the basins). However, following this analysis, "a loam soil was chosen as the representative soil type for the soil water balance analysis" (p. 38-39). Loam soil characteristics were used in the farm soil water balances in both the Rincon and Mesilla Valleys.

Opinion

The extent of the soil analysis is wholly inadequate to characterize the entirety of the Rincon and Mesilla Valleys. Despite the similarity in their expression as "loam" type soils, each of the soil types identified by the Texas technical experts refers to a classification that covers a spectrum of soils. The physical characteristics of clay loam, loam, and loamy sand soils can be quite varied depending on the precise relative composition of sand, clay, and organic matter in each. For example, in the work of Saxton and Rawls (2006) the saturated hydraulic conductivity of these soils can range from nearly 97 mm/hr for loamy sand soils to just 4.3 mm/hr for clay loam (assuming 2.5% organic matter by weight). Likewise, the soil moisture available to plants varies substantially, from 7% by volume in loamy sand to 14% by volume in clay loam. These differences matter, both to actual crops in the field, the flow and distribution of water in the soil, and to a model simulating the soil water balance to determine crop consumptive use.

Lumping all soils into one "loam" category does not accurately reflect the distribution of soils across agricultural land in the Rincon and Mesilla Valleys and the hydraulic behavior of those soils. A more accurate approach for defining soil characteristic inputs for the model would be to conduct a more extensive analysis of the SSURGO data, which is readily available in the public domain, to identify the distribution and percent composition of soil types in each region and then calculating area-weighted soil characteristics to represent each of these soils. It is not clear why this approach was not used in the *Montgomery & Associates Report*. The use of a single soil type and characteristics invalidates the representativeness of parameters determined for the Montgomery & Associates soil water balance model.

Precipitation Routing

Technical Evaluation

As described on page 31 of the *Montgomery & Associates Report*, the monthly soil water balance model simulates surface runoff of precipitation using the Soil Conservation Service (SCS) curve number method. The same curve number value of 85 is used to simulate all agricultural land (cropped and non-cropped) in both the Rincon and Mesilla Valleys. This value is based on curve number values for hydrologic soil group C, corresponding to the loam soil chosen as the representative soil type for both valleys in the soil water balance analysis.

Effective precipitation in the soil water balance model was calculated "using empirical equations adopted by the U.S. Bureau of Reclamation (USBR) […that are] recommended for arid and semi-arid regions" (p. 32).

Opinion

The methodology used by the Texas technical experts to simulate surface runoff of precipitation does not follow best practices for several reasons. First, the standardized approach for estimating surface runoff of precipitation, as recommended by the American Society of Civil Engineers (ASCE), is to use a daily root zone water budget model (ASCE, 2016). As described previously, the monthly soil water balance is unable to accurately simulate daily changes in soil moisture and precipitation that are central to accurately estimating surface runoff. Second, curve number values are to be selected to specifically simulate soil surface characteristics influenced by the soil type and by the crops that are grown in the soil. The Texas technical experts' application of the same curve number to simulate the entirety of both the Rincon and Mesilla Valleys is unlikely to accurately capture the runoff characteristics of different soils and crops across both valleys. A more structured and analytical approach to calculate area-weighted soil parameters and curve numbers using SSURGO data is a more standard and recommended approach.

The reason for selecting the empirical USBR method to calculate effective precipitation is unclear. As with the simulation of surface runoff of precipitation, a daily root zone water budget model is recommended for estimating effective precipitation to account for changes in soil water content, precipitation amounts and ET demands that all vary daily (ASCE, 2016).

Field Irrigation and Non-Uniform Moisture Distribution

Technical Evaluation

In the soil water balance model described in the *Montgomery & Associates Report*, surface irrigation is simulated assuming non-uniform moisture distribution along the lengths of fields, with some portions of fields receiving disproportionately more water than others. As indicated on pg. 22 of the *Montgomery & Associates Report*, "the soil water balance model explicitly accounts for irrigation non-uniformity by distributing the monthly volume of irrigation water – derived from both surface and groundwater – over the field according to a common model for the distribution of infiltration over furrow- or basin-irrigated fields (Karmeli, 1978; Warrick, 1983)." The report asserts that the model "…represents continuous reduction in infiltration rates moving from the field inlet to the end of the field." On p. 21, the report also asserts that in these areas that receive more water, "crop consumptive use demands are fully satisfied" while other portions of the field that receive disproportionately less water "are characterized by smaller rates of crop consumptive use."

The supporting evidence given for these statements is the historical aerial imagery analysis by Land IQ, which "demonstrated the effects [of] non-uniform water application on crop growth during the 1950s, prior to improvements in land-leveling technologies and their subsequent adoption in the Rincon and Mesilla basins" (*Montgomery & Associates Report*, p. 21-22).

As discussed above, the *Land IQ Report* remedies the perceived differences in crop consumptive use demands resulting from "irrigation and production differences" over time through PET adjustment using an "Irrigation and Production Factor" (*Land IQ Report*, p. 88). However, the quantitative basis for this adjustment factor is unclear.

Opinion

The soil water budget model developed in this report incorrectly assumes that the entire reduction in consumptive use assumed by Land IQ is due to non-uniform moisture distribution. To correct this, the Land IQ irrigation and production adjustment factors are applied to most crops in the Rincon and Mesilla Valleys from 1936 through the 1970s and 1980s.

While the quantitative basis for this adjustment factor is unclear, it serves to substantially reduce the ET_c of surface irrigated crops in earlier years. In recent years, the lack of any adjustment factor implies that these crops are achieving full PET – the highest potential evapotranspiration rate that can be achieved, assuming ideal or "pristine" conditions with regard to crop health, soil, climate, water availability, etc. PET is not necessarily equivalent to ET under full supply conditions (in which water supply is not limited). In the field, actual conditions of crop health, soil, and climate observed in the Study Area can affect crop stress and consumptive use, even when sufficient water supply is available across an entire field. Because of the differences between "pristine" and actual conditions, PET is generally higher than actual ET_c and is generally less representative of average crop conditions across a large area (**Figure 11-7**).

These assumptions result in physically impossible monthly average soil moisture conditions both in the 1930s and 1940s and between 2006 and 2018. In the 1930s to 1940s, the low ET values provided by Land IQ require the average soil moisture at the end of the field to be below the crops' wilting points. If the average soil moisture was below wilting point for an entire month, the crop in that area would die.

On the other hand, from 2006 through 2018 the average soil moisture across the entire field is consistently above field capacity. As described earlier, soil moisture above field capacity will drain to equal the field capacity within a few days. It is physically impossible for the soil moisture to remain above field capacity, on average, for an entire month unless the groundwater levels are so high that the root zone is water logged. Even if these high average soil moisture conditions were possible, the crop health in that area would suffer due to the lack of oxygen in the root zone as a result of water filling all pores in the soil, and ET would be reduced.

Additionally, the "analysis" mentioned in the *Montgomery & Associates Report* was described in the Land IQ deposition not as an "analysis," but as "an example" of a few selected fields. To support the assertions made in the *Montgomery & Associates Report,* the ends of these sample fields that are farthest from the inlets should generally show poor crop growth. This is not always the case.

Finally, the assertion that the model "…represents continuous reduction in infiltration rates moving from the field inlet to the end of the field" misrepresents the model. The model represents a reduction in infiltration volumes (often referred to as depths) between the field inlet and field end. These differences in volume are generally the result of different opportunity times for water to infiltrate, or enter the ground, rather than differences in infiltration rates.

(Other disagreements with the aerial imagery analysis cited as support for these soil water balance modeling assumptions are described above in the Land IQ rebuttal section "Monthly Adjusted Agricultural Consumptive Use and Yield Analysis.")

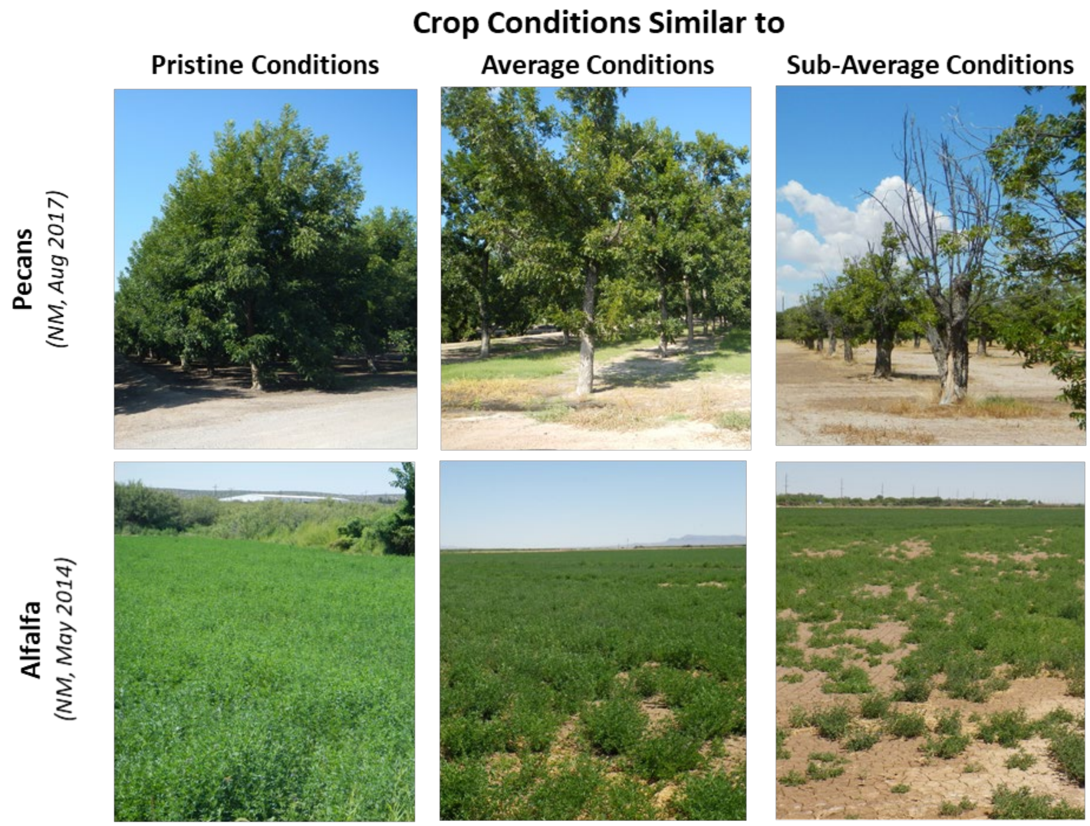

Figure 11-7. Comparison of pecan and alfalfa crops grown under conditions similar to pristine, average, and sub-average conditions, as observed in the New Mexico region of the Study Area (pecan images from August 2017, alfalfa images from May 2014).

Water Stress

Technical Evaluation

On p. 25-26 of the *Montgomery & Associates Report*, a simple model is given for computing actual ET (AET) that adjusts the ET of a well-watered grass reference crop (ET_o) by a crop coefficient (K_c) and a water stress coefficient (K_s) to account for crop-specific water use requirements under potential soil water stress conditions. FAO Irrigation and Drainage Paper 56 (Allen et al., 1998) is given as the reference for this model and for the methodology to compute K_s.

Opinion

Chapter 8 of FAO Irrigation and Drainage Paper 56 states: "The estimation of K_s requires a daily water balance computation for the root zone." However, the methodology applied in the *Montgomery & Associates Report* instead estimates and applies K_s on a monthly time step which contradicts the guidelines in FAO 56. As described in the previous section, the use of a coarse monthly time step can lead to inaccurate estimates of soil moisture changes due to daily root zone inflows and outflows that cannot be accounted for using a monthly timestep, which in turn leads to potential inaccuracies in all calculated or estimated flows in the soil water balance.

Non-Crop Season ET

Technical Evaluation

The Montgomery & Associates Report states on page 26 that actual ET (AET) in cropped areas is calculated as a function of reference ET (ET_o), a crop coefficient (K_c), and a water stress coefficient (K_s), whereas "AET in the non-cropped area is defined as bare soil evaporation."

Opinion

Modeling agricultural fields as bare ground during the non-crop season is not an accurate approach for all crop types or field conditions. For example, permanent crops such as pecans and grapes remain in the ground throughout the year, and their ET is consequently much different than that from bare ground. Likewise, plants and plant materials can remain in the field between harvest and planting and can suppress evaporation from soil (Allen et al., 1998). While ET from these surfaces will not be the same as crop ET during the growing season, these ET rates will still likely not equal ET of bare ground.

Summary

In summary, the monthly timestep that Montgomery & Associates used to develop the soil water balance for the Rincon and Mesilla Valleys does not adhere to best practices for root zone soil water balance modeling. Furthermore, the model calibration process appears to have been driven to match the Land IQ consumptive use estimates (which overestimate the consumptive use for the Rincon and Mesilla Valleys, as discussed in the Land IQ rebuttal opinions), effectively predetermining the results of the soil water balance analysis. The calibration also problematically neglects potential changes in deep percolation, a significant flow path, while adjusting runoff of applied water to match ET and metered groundwater pumping values.

The procedures and assumptions underlying the soil water balance model inputs are also problematic. The Texas technical experts' estimation of water stress-related ET adjustment factors does not obey the underlying assumptions of the standard methodology they used, which require daily or shorter timestep, and also understates water stress conditions in recent years. The soil analysis and methodologies for routing precipitation through the model are also inadequate to accurately characterize different soil and crop surface characteristics across the Rincon and Mesilla Valleys.

These combined characteristics of the model result in unrealistic soil moisture estimates during some months and calls into question the accuracy of the model's consumptive use estimates and subsequent estimates of groundwater pumping.

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Appendix 2A. Glossary of Consumptive Use Terms

The definitions below are primarily based on definitions established in publications of the American Society of Civil Engineers (ASCE), American Society of Agricultural and Biological Engineers (ASABE) and Food and Agriculture Organization (FAO). Glossary terms with an asterisk (*) are copyrighted by the American Meteorological Society (2015) and used with permission, via ASCE Manual 70, published in 2016. Page numbers are included when a definition is not found in the referenced document's glossary. Some definitions have been modified (added words are in italics font and removed words are in strikethrough font) here to improve their precision and clarity. A few selected terms that are additionally defined in the Rio Grande Joint Investigation 1938 have been included at the end of this glossary.

Actual Crop Coefficient (ET_oF): The ratio of **Actual Evapotranspiration** to reference evapotranspiration for a specified crop and time period. Sometimes abbreviated K_c. Also referred to as the Fraction of Grass Reference ET_o (ET_oF). Any reduction in K_c due to water stress or other factors such as reduced density, disease, or salinity are encapsulated into the actual crop coefficient. (ASCE, 2016).

Actual Evapotranspiration (ET_{act}): The ET rate that occurs under actual field conditions, often used interchangeably with the term crop ET (ET_c). ET_{act} is important because it is the historical actual consumption of water that affects hydrologic responses and water balances, including groundwater system behavior. (ASCE, 2016)

Alfalfa Reference ET Fraction (ET_rF): The fraction of alfalfa reference ET_r as calculated by the standardized ASCE-EWRI Penman-Monteith equation (ASCE-EWRI, 2005). ET_rF is calculated as the ratio of the computed instantaneous ET from each pixel to the reference ET_r computed from weather data where ET_r is for the standardized 0.5 m tall alfalfa reference at the time of the image. (Allen et al., 2007, p. 389)

Available Waterholding Capacity (AWC): The portion of water in a soil that can be readily absorbed by plant roots. It is the amount of water released between in situ field capacity and permanent wilting point. (ASABE, 2007)

Basal Crop Coefficient (K_{cb}): A crop coefficient representing primarily the transpiration component of ET and a small evaporation component from soil that is visually dry at the surface. Basal crop coefficients are used in soil water modeling to provide more accurate estimates of crop ET on a daily basis. (ASCE, 2016)

Beneficial Use: That part of water withdrawn that supports the production of crops: food, fiber, oil, landscape, turf, ornamentals, or forage. Water consumed to achieve an agronomic objective is beneficial. The major beneficial uses are crop ET and water needed for improving or maintaining soil productivity, that is, salt removal. (Burt, et al., 1997)

Capillary Fringe*: A shallow zone of soil above a water table that is nearly saturated by capillary action in the smaller pore spaces. (ASCE, 2016)

Consumptive Use Fraction (CUF): The fraction of water withdrawn from a surface or ground water source that is evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise removed from the immediate water environment. (ASCE, 2016).

Consumptive Irrigation Requirement (CIR): The potential ET for a crop required for full production, including incidental evaporation losses from soil, **in excess of the effective Precipitation**. In other words, the irrigation water needed for full water supply under perfect distribution *uniformity* (no losses (100% efficiency)). Sometimes called crop irrigation requirement. ASCE (2016) uses the synonymous term Net Irrigation Water Requirement (NIWR) with definition: NIWR is the amount of soil water that must be made up to complete the potential ET requirement and avoid undesirable water stress. (ASCE, 2016, p. 435)

Consumptive Use* (CU): That part of water withdrawn that is evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise removed from the immediate water environment (also referred to as water consumed). Water consumed may be defined as beneficial if there are economic or environmental benefits or non-beneficial if there are no direct economic or environmental benefits. (ASCE, 2016)

Crop Coefficient*(K_c): The ratio of evapotranspiration occurring with a specific crop at a specific stage of growth to reference crop evapotranspiration ~~at~~ *during* that time *period,* usually denoted by the symbol Kc (Not the same as K used in the Blaney-Criddle method). (ASCE, 2016)

Crop Water Requirement*: The depth of water needed to meet evapotranspiration of a disease-free crop, growing in large fields under nonrestricting soil conditions and achieving full production potential in a given growing environment. (ASCE, 2016)

Deep Percolation*: The drainage of soil water by gravity below the maximum effective depth of the root zone. (ASCE, 2016)

Depletion: Net rate of water use from a stream or groundwater aquifer for beneficial and non-beneficial uses. For irrigation or municipal uses, the depletion is the headgate or well-head diversion less return flow to the same stream or groundwater aquifer. (ASCE, 2016)

Dewpoint*: The temperature to which a given parcel of air must be cooled at constant pressure and at constant water vapor content until saturation occurs, or the temperature at which saturation vapor pressure of the *air* parcel is equal to the actual vapor pressure of the contained water vapor (ASCE, 2016).

Effective Precipitation*: Precipitation that remains on the foliage or in the soil that is available for evapotranspiration, and reduces the withdrawal of soil water by a like amount. (ASCE, 2016)

Grass Reference ET Fraction (ET_oF): The fraction of clipped grass reference ET_o as calculated by the standardized ASCE-EWRI Penman-Monteith equation (ASCE-EWRI, 2005) and representing the relative amount of ET in terms of fraction of grass reference ET occurring from any particular pixel of a satellite image. Typical ranges for ET_oF are 0 to 1.4. ET_oF is synonymous with the crop coefficient as used with a clipped grass reference basis. (ASCE, 2016).

Evaporation*(E): The physical process by which a liquid or solid is transformed to the gaseous state which in irrigation; usually is restricted to the change of water from liquid to gas. (ASCE, 2016)

Evaporation Coefficient (K_e): A coefficient to account for evaporation from the soil surface following rainfall or irrigation. A maximum value of approximately 1.2 is recommended when using clipped grass reference ET. (ASCE, 2016, p. 230 and 235)

Evapotranspiration* (ET): The combined processes by which water is transferred from the earth's surface to the atmosphere; evaporation of liquid or solid water plus transpiration from plants. (also see consumptive use). (ASCE, 2016)

Fetch*: (Also generating area) The length of ~~fetch~~ *upwind* area, measured in the direction of the wind from the site in question*, that has similar vegetation and water availability as the local surroundings of a weather or ET measurement.* (ASCE, 2016)

Field Capacity: The amount of water remaining in a soil when the downward water flow due to gravity becomes negligible. (ASABE, 2007)

Infiltration: The downward entry of water through the soil surface into the soil. (ASABE, 2007)

Irrigation Consumptive Use Coefficient (ICUC): The ratio of volume of irrigation water consumptively used to the total volume of irrigation water applied minus the change in storage in the root zone *(a defined volume)*, both in a specified period of time and expressed as a percentage. (Burt, et al., 1997)

Irrigation Efficiency (IE): The ratio of volume of irrigation water beneficially used to the total volume of irrigation water applied minus the change in storage in the root zone *(a defined volume)*, both in a specified period of time and expressed as a percentage. (Burt, et al., 1997)

Irrigation Water Requirements*: The quantity of water exclusive of *effective* precipitation that is required for various beneficial uses, particularly evapotranspiration. (ASCE, 2016)

Management Allowed Depletion (MAD): The desired soil water deficit at the time of irrigation; can vary with crop growth stage. (ASABE, 2007)

Mean Crop Coefficient (K_{cm}): A crop coefficient where the time-averaged effects of evaporation from the soil surface (from rainfall or irrigation) are included in the crop coefficient value. (ASCE, 2016, p. 268 and 273)

METRIC: Mapping Evapotranspiration at high Resolution using Internalized Calibration. METRIC is a satellite-based image-processing tool *developed by the University of Idaho* for calculating ET as a residual of the energy balance at the Earth's surface. (Allen et al. 2007, p. 380)

NDVI: Normalized Difference Vegetation Index is a dimensionless, radiometric measure that indicates relative abundance and activity of green vegetation. NDVI is estimated from two shortwave bands typically measured by satellites: the red band (~0.6-0.7 µm) and the near infrared band (~0.7-1.3 µm). Typically, NDVI varies between 0.1 and 0.8, with the higher value indicating dense vegetation and values less than about 0.2 associated with soil and rock that is void of vegetation. NDVI is generally negative for water, snow and clouds. (Jensen, 2007, p. 382 and ASCE, 2016, p. 552, Allen et al., 2007, p. 384)

Nonconsumptive Use: That part of water withdrawn that is not evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise removed from the immediate water environment. Water withdrawn that is not consumed may be recoverable for further use or *may be* non-recoverable or lost to further use ~~such as~~ *due to* flows to saline sinks or flows to the sea. (ASCE, 2016)

Permanent Wilting Point: The soil water content below which plants cannot ~~readily~~ *sufficiently* obtain water and will permanently wilt. Sometimes called *permanent wilting percentage, fifteen-atmosphere percentage,* or *lower limit*. It is estimated as the soil moisture content at about –1.5 MPa matric potential. (ASABE, 2007)

Pixel: A two-dimensional picture element that is the smallest nondivisible element of a digital image. *In Landsat images, a pixel has dimensions of 30 m x 30 m.* (Jensen, 2007, p. 194)

Potential Crop Coefficient (K_{pot}): The ratio of ET_{pot} to ET_o. The potential, or upper limit on ET for a particular crop, in other words, representing a pristine, well-watered condition. (ASCE, 2016, p. 267).

Potential Evapotranspiration* (ETpot): The rate at which water, if available, would be removed from *wet* soil and plant surfaces, expressed as the rate of latent heat transfer per unit area or an equivalent depth of water. (ASCE, 2016)

Preplant Irrigation: Irrigation applied prior to seeding *of annual crops or greenup of perennial crops*. Sometimes called *preirrigation.* (ASABE, 2007)

QAQC: Quality Assessment (QA) and Quality Control (QC) of data; in the case of weather data, where data are compared against relevant physical extremes, using statistical techniques to identify extreme or anomalous values; and comparing data with neighboring stations. Current ASCE procedures compare weather data, visually, to theoretical values in the case of solar radiation, and compare dewpoint temperature to air temperature, in the case of humidity. (Allen, 2008, p. 192-193)

Reference ET (ET_{ref}, ET_o or ET_r): The ET rate from a reference surface closely resembling an extensive surface of dense, actively growing vegetation having a specified uniform height and surface resistance, not short of soil water, and representing ET from an expanse of at least 100 m of the same or similar vegetation. **ET_o** refers to reference ET from a short crop, having an approximate height of 0.12 meter, generally approximated by a clipped, cool-season grass. **ET_r** refers to reference ET from a tall crop, with an approximate height of 0.50 meter, generally approximated by full-cover alfalfa. In the case of ET_r, reference ET represents the near maximum possible ET as dictated by weather conditions (temperature, wind, humidity, sunshine) and the vegetation surface. (ASCE, 2016, p. 197-198)

Root Zone: The layer of soil that plant roots readily penetrate and in which the predominant root activity *and water extraction* occurs. (ASABE, 2007)

Soil Water: Water present in the soil pores (also called soil moisture, which would include water vapor). (ASCE, 2016)

Soil Water Capacity: The quantity of water that a soil can hold and make available to most plants, usually defined as water held between –33 kPa and –1500 kPa matric potential; the amount of water stored in the soil at field capacity. Also called *available water capacity*. (ASABE, 2007)

Solar Radiation* (R_{so}): The total electromagnetic radiation emitted by the sun. (ASCE, 2016)

Surface Energy Balance (SEB): The surface energy balance relates to the various ways in which net radiation, Rn, is balanced by the inputs or outputs of energy from nonradiative parameters. The vertical energy balance at the soil or water surface, or at the "effective surface" of a crop, is the sum of sensible heat flux to or from the air *(H)* and soil (or water) *(G)*, latent heat *(LE)*, net radiation *(Rn)*, and other miscellaneous fluxes. The energy balance of land and water surfaces…is expressed as…Rn = LE + H + G, *so that LE = Rn – G – H*. (ASCE, 2016, p. 59-60)

Transpiration* (T): The process by which water in plants is transferred as water vapor to the atmosphere. (ASCE, 2016)

Vapor Pressure*: The partial pressure of water vapor in the atmosphere. (ASCE, 2016)

Water Stress Coefficient (K_s): A dimensionless coefficient dependent on available soil water. The value for K_s is 1 unless available soil water limits transpiration, in which case it has a value less than 1.0. (ASCE, 2016, p. 268).

Water Use: Water that is used for a specific purpose such as domestic use, irrigation, or industrial processing. *It includes both consumptive and nonconsumptive components.* (ASCE, 2016)

Appendix 2B. Rio Grande Joint Investigation, 1938 Selected Consumptive Use Terms

Consumptive Use (Evapotranspiration) – The sum of the volumes of water used by the vegetative growth of a given area in transpiration or building of plant tissue and that evaporated from adjacent soil, snow, or intercepted precipitation on the area *during* ~~in~~ any specified time *period*. (Rio Grande Joint Investigation, 1938 (page 88))

Depletion (Stream-flow depletion) – The amount of water which annually flows into a valley, or onto a particular land area (I), minus the amount which flows out of the valley or off from the particular land area (R) is designated "stream-flow depletion" (I-R) and is usually less than *or equal to* the consumptive use and is distinguished from consumptive use in the Rio Grande studies. (Rio Grande Joint Investigation, 1938 (page 326))

Appendix 2C. Glossary References

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Appendix 3A. Annual ET_o and Precipitation Results

Table 3A-1. New Mexico Annual ET_o and Precipitation Results

Year	ET_o, inches	Precipitation, inches
1938	63.3	9.3
1939	62.8	5.8
1940	61.4	9.2
1941	58.7	19.6
1942	62.0	9.8
1943	65.6	7.6
1944	62.8	9.3
1945	66.3	5.8
1946	66.2	7.1
1947	60.2	6.1
1948	60.5	5.2
1949	60.4	9.0
1950	67.6	5.4
1951	66.2	5.1
1952	64.6	6.2
1953	66.1	3.8
1954	65.7	5.8
1955	63.1	7.3
1956	67.0	4.8
1957	63.3	9.4
1958	62.6	14.0
1959	65.1	6.0
1960	64.9	7.7
1961	63.9	10.1
1962	64.1	6.4
1963	64.9	6.1
1964	64.7	3.6
1965	64.8	8.3
1966	63.9	9.9
1967	64.8	8.4
1968	63.3	13.2
1969	64.2	11.9
1970	65.1	3.4
1971	65.1	5.8
1972	65.2	12.2
1973	62.8	9.1

Table 3A-1. New Mexico Annual ET_o and Precipitation Results

Year	ET_o, inches	Precipitation, inches
1974	63.0	13.8
1975	63.3	8.1
1976	63.0	7.8
1977	64.6	8.8
1978	63.8	14.8
1979	63.6	9.4
1980	63.9	8.1
1981	63.4	9.7
1982	63.2	7.9
1983	62.3	7.3
1984	62.3	13.8
1985	60.7	12.6
1986	57.5	13.0
1987	59.7	9.2
1988	60.1	11.3
1989	61.9	9.0
1990	58.1	9.6
1991	60.6	14.7
1992	62.2	11.1
1993	61.6	9.3
1994	66.2	8.2
1995	66.4	7.7
1996	65.8	6.1
1997	59.4	10.5
1998	59.1	7.2
1999	59.7	9.2
2000	61.3	10.0
2001	60.2	5.3
2002	60.4	7.6
2003	61.1	5.5
2004	59.9	13.2
2005	60.3	10.9
2006	62.3	14.2
2007	58.4	10.3
2008	63.1	9.3
2009	64.1	8.8
2010	64.3	9.4
2011	69.9	6.9
2012	66.5	5.5

Table 3A-1. New Mexico Annual ET_o and Precipitation Results

Year	ET_o, inches	Precipitation, inches
2013	60.8	6.4
2014	64.2	8.3
2015	61.5	12.6
2016	66.4	8.5
2017	66.6	11.6
2018	65.2	9.4

Table 3A-2. Texas Annual ET_o and Precipitation Results

Year	ET_o, inches	Precipitation, inches
1938	62.9	8.3
1939	64.1	6.0
1940	62.7	5.5
1941	59.2	14.2
1942	61.8	9.8
1943	63.1	6.2
1944	61.4	8.3
1945	63.4	5.3
1946	63.6	5.3
1947	63.8	5.2
1948	64.1	4.6
1949	62.3	8.3
1950	65.2	6.3
1951	64.1	5.6
1952	63.7	6.7
1953	64.3	4.0
1954	65.4	5.1
1955	63.2	6.2
1956	65.6	3.6
1957	62.3	7.1
1958	61.8	15.6
1959	64.0	3.8
1960	63.2	8.0
1961	62.9	5.7
1962	62.1	9.4
1963	63.2	5.2
1964	62.5	4.6
1965	62.6	7.1
1966	62.0	11.6

Table 3A-2. Texas Annual ET_o and Precipitation Results

Year	ET_o, inches	Precipitation, inches
1967	63.5	5.2
1968	62.5	14.0
1969	64.8	5.1
1970	63.0	6.0
1971	63.9	6.4
1972	64.4	13.2
1973	63.2	6.6
1974	63.6	16.8
1975	63.4	6.7
1976	62.0	10.1
1977	64.2	9.1
1978	63.0	10.7
1979	64.2	8.2
1980	66.3	8.4
1981	65.8	10.0
1982	64.8	10.0
1983	63.4	8.7
1984	63.8	14.5
1985	63.1	9.1
1986	61.5	13.9
1987	61.2	9.9
1988	62.8	9.0
1989	64.3	7.5
1990	61.4	13.9
1991	60.4	14.0
1992	61.1	11.9
1993	62.1	8.0
1994	64.5	8.5
1995	64.0	8.0
1996	65.4	10.1
1997	62.1	14.1
1998	63.7	8.1
1999	64.1	5.7
2000	65.2	6.7
2001	63.5	3.7
2002	64.1	10.1
2003	64.5	6.0
2004	68.0	14.8
2005	62.4	12.7

Table 3A-2. Texas Annual ET_o and Precipitation Results

Year	ET_o, inches	Precipitation, inches
2006	67.1	13.1
2007	62.3	11.2
2008	63.4	14.2
2009	62.5	9.8
2010	62.7	6.7
2011	69.6	5.3
2012	64.6	6.0
2013	60.8	9.5
2014	64.2	8.6
2015	61.5	12.1
2016	66.4	9.3
2017	66.6	10.1
2018	65.2	8.4

Appendix 4A. Field Survey Protocol

Equipment and Material

Each two to three-person team required a laptop, a Global Positioning System (GPS) unit with appropriate software, an automobile power cord and converter, and a standalone ArcMap license. The WUCB has 4 laptops (if all staff can participate) and the ISC has 3 GPS units.

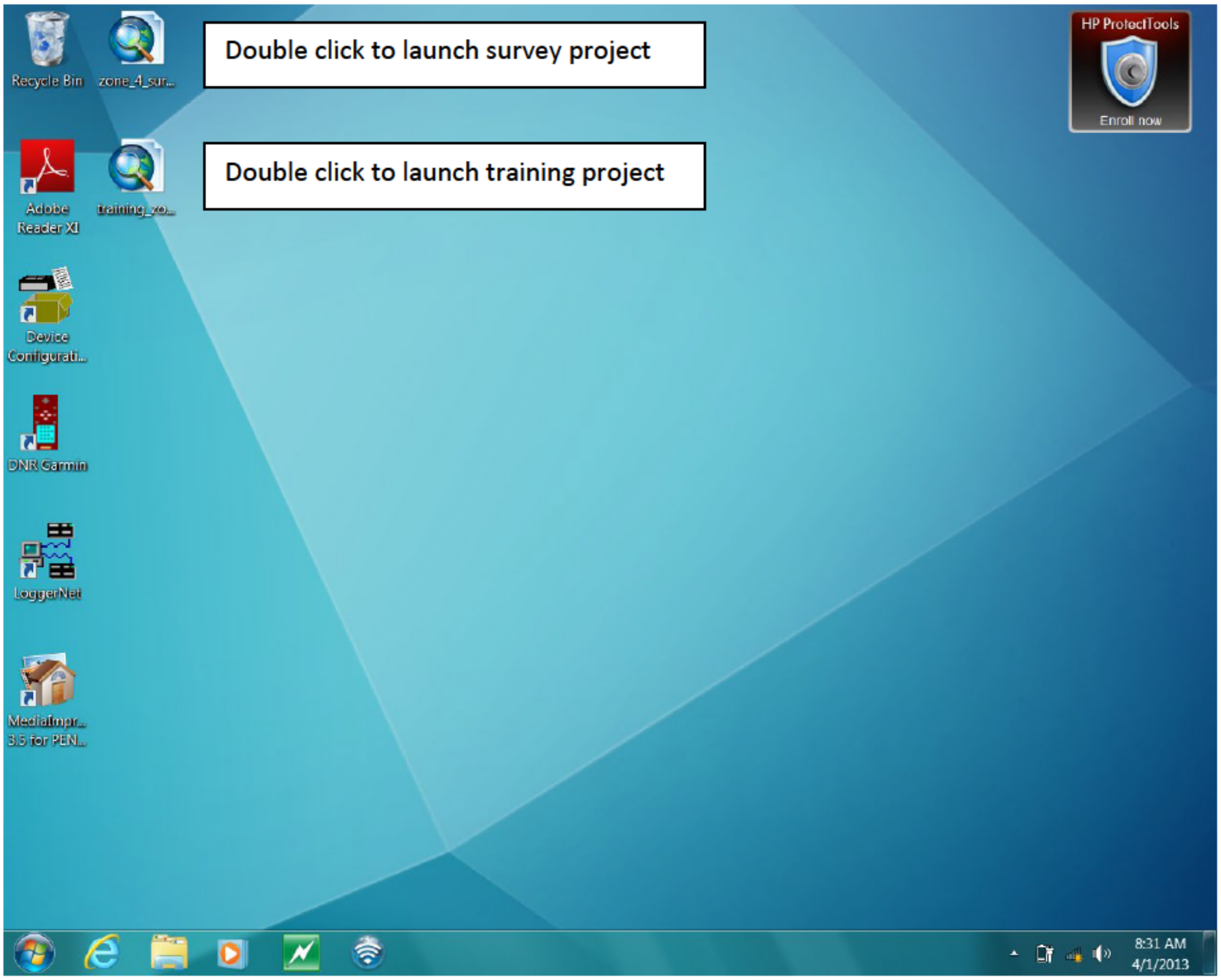
GIS

The GIS consisted of a base polygon layer from INTERA (2016) with drop downs for irrigation (yes/no), irrigation method, crop type, growth stage, field condition, and basic comments, as well as an open field where additional comments could be added. The Geodatabases were loaded onto the laptops. Garmin GPS units were attached to the computers, and Minnesota Department of Natural Resources freeware software was used to connect the Garmins to ArcGIS.

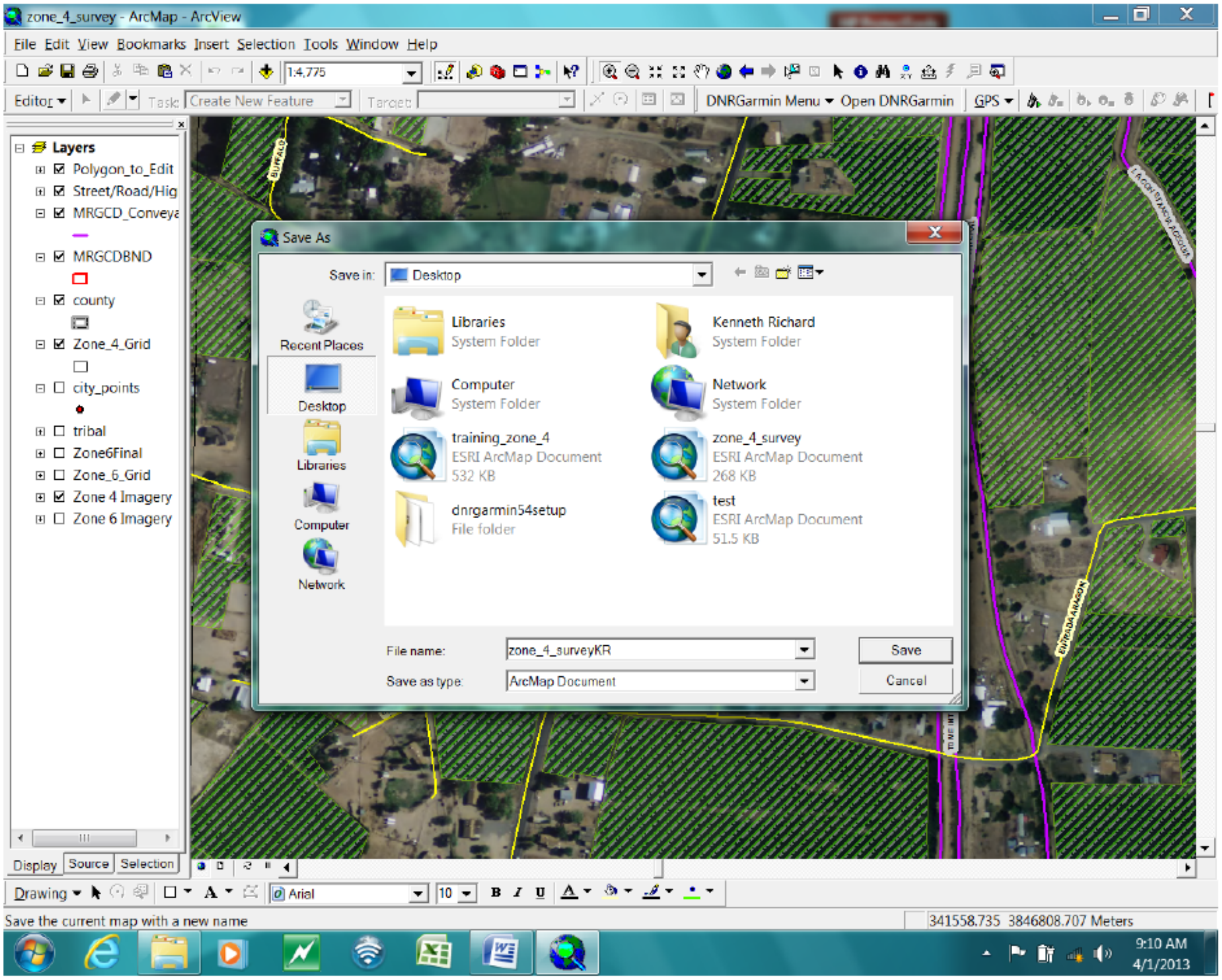
Each team had one person skilled in GIS applications using the laptop and following the detailed steps described below to start the project at the beginning of each day, log the data observed for each field and close out the project at the end of the day.

Starting your project and GPS unit in order to start collecting data.

- Log into computer and double click on Training_zone_# icon in order to practice or Zone_#_Survey for the actual survey project.

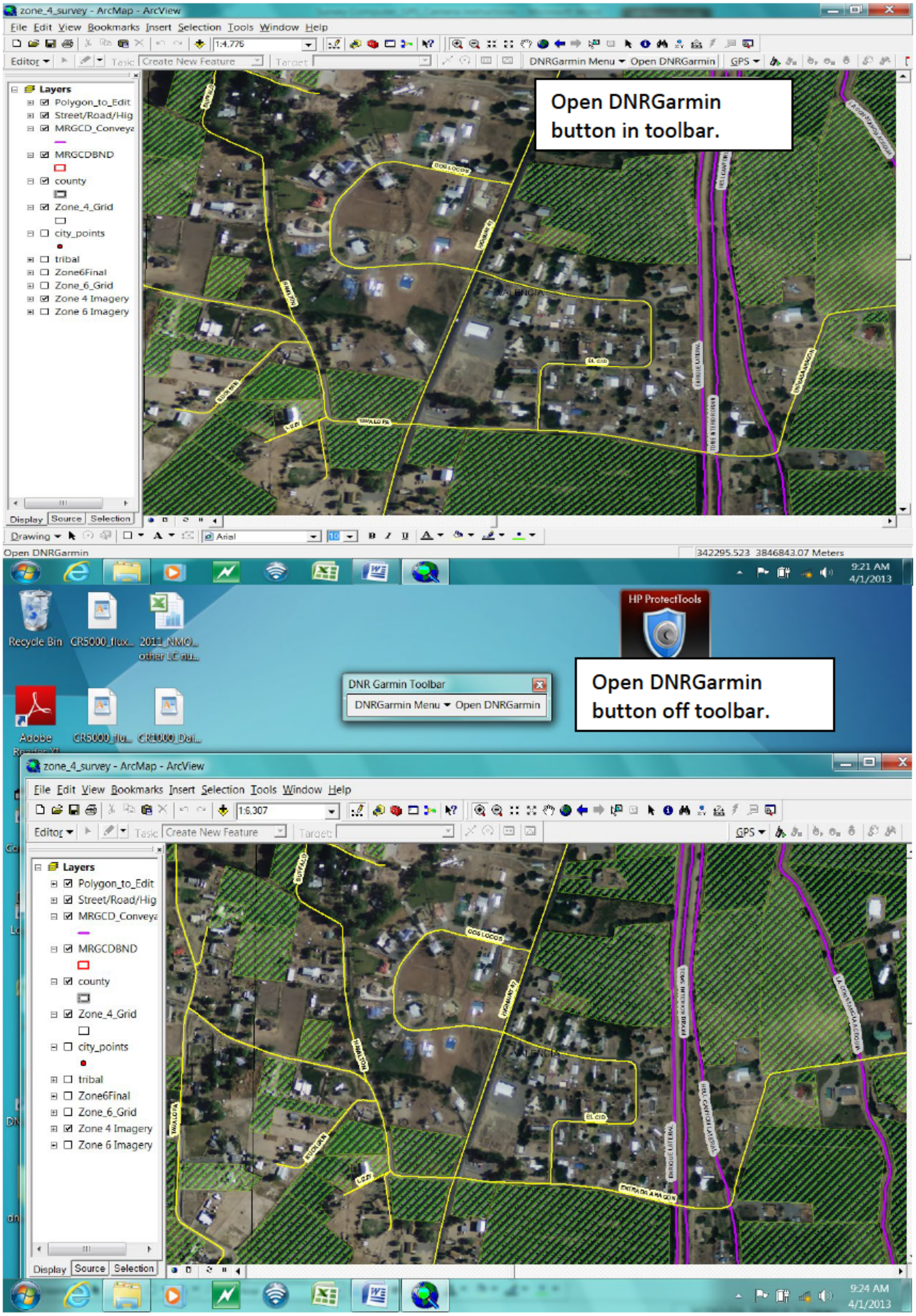


- Save projects immediately as project name plus users initials to desktop. This will allow individual users to create a working project that best fits their needs (line or polygon color). Each person who enters the GIS data may want to save their own project or the team may want to use one project for everyone.

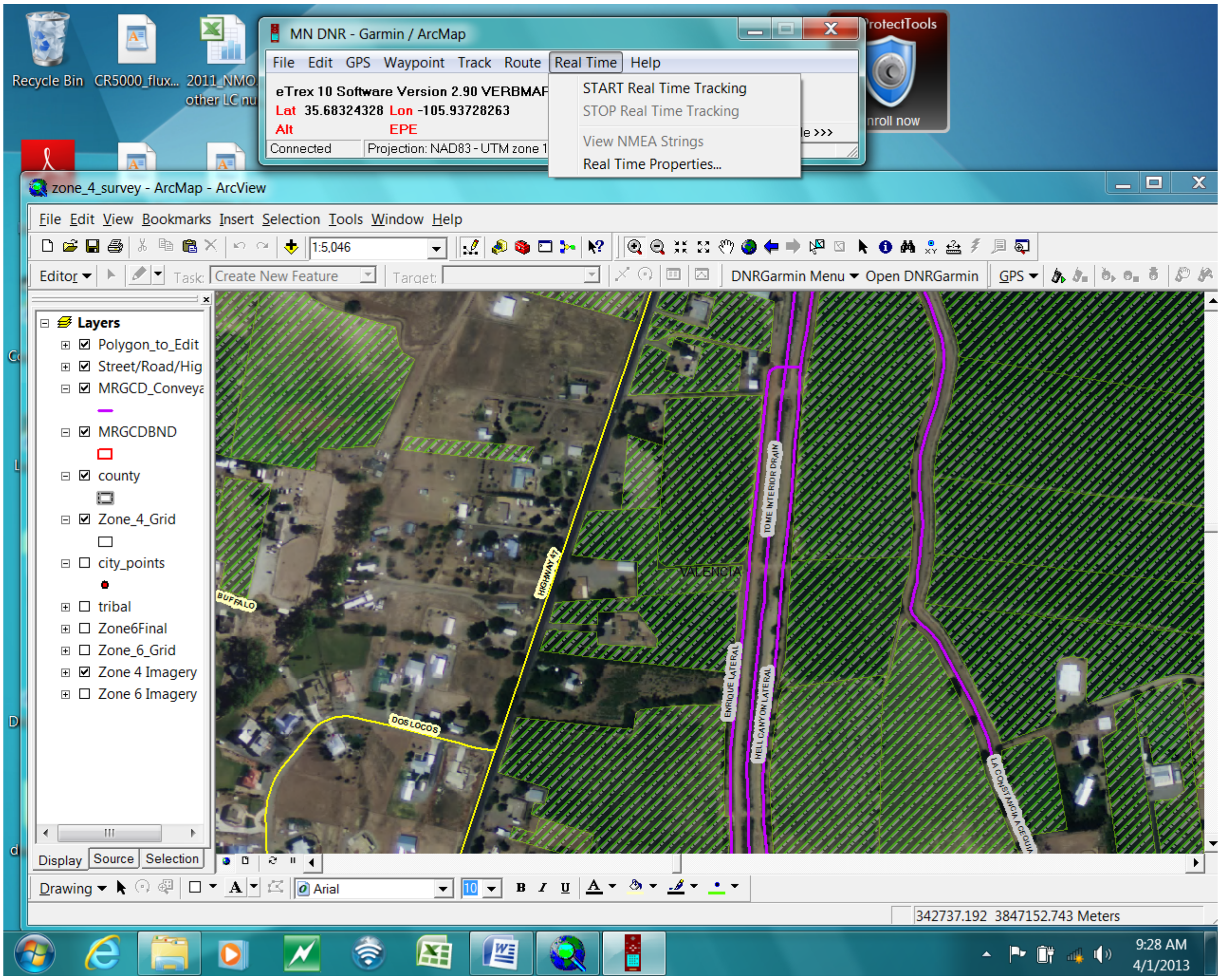


- Once the project is saved, turn on the Garmin GPS etrex 10. The on/off button is located next to the word "light".
- Turn over the unit and lift the rubber flap above the steel loop. Plug the provided cable into the port. Plug the USB side of the cable into the Laptop's front left USB port.
- Look at the Garmin screen and it should say "USB cable detected. Would you like to go to Mass Storage." No should be highlighted black. Select the highlighted "No" by pushing straight down on the navigation bar (toggle switch) located above the Garmin screen to the right.

- Find the "Open DNRGarmin" located either on your ARCGIS toolbar or as a separate toolbar off the ARCGIS Window. See below.


Open DNRGarmin button in toolbar.
Open DNRGarmin button off toolbar.
DNR Garmin Toolbar
DNRGarmin Menu
Open DNRGarmin

- The Garmin should automatically connect once the Open DNRGarmin is clicked. Below you can see active location data in the Lat Lon spaces. Select the Real Time drop down menu and select "Start Real Time Tracking." "MNDNR – Garmin" and "Real Time Window" windows will open.

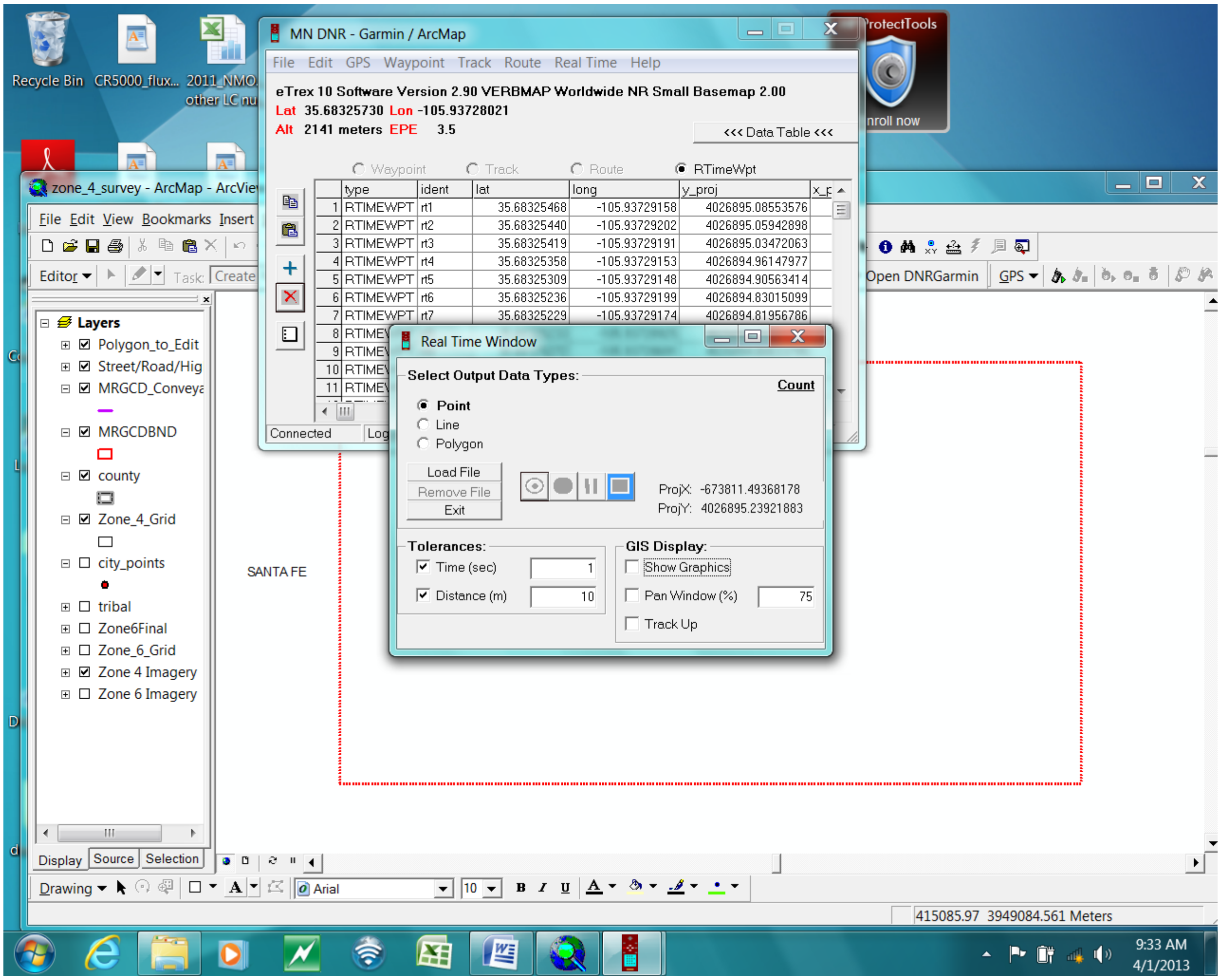


- Based on past surveys, there is a recommendation to change settings to what is seen below.
  - Leave "Select Output Date Types" as point.
  - Select both "Time" and "Distance" and populate with 1 second and 10 meters respectively.
  - Uncheck all "GIS Display"
    - Show Graphics: leaves a trail of markers indicating where you've been in the .mxd. These obstruct the map & are not easily deleted.
    - Pan Window: auto pans to your place in the .mxd. The percentage indicates how big the window (red dashed line) is within the View. Most people have found this annoying or difficult to work with, however it could be useful temporarily if you lose your place.
    - Track Up: orients ArcMap so that "up" is the direction you are traveling rather than north. This causes ArcMap to refresh often, which removes the layers so

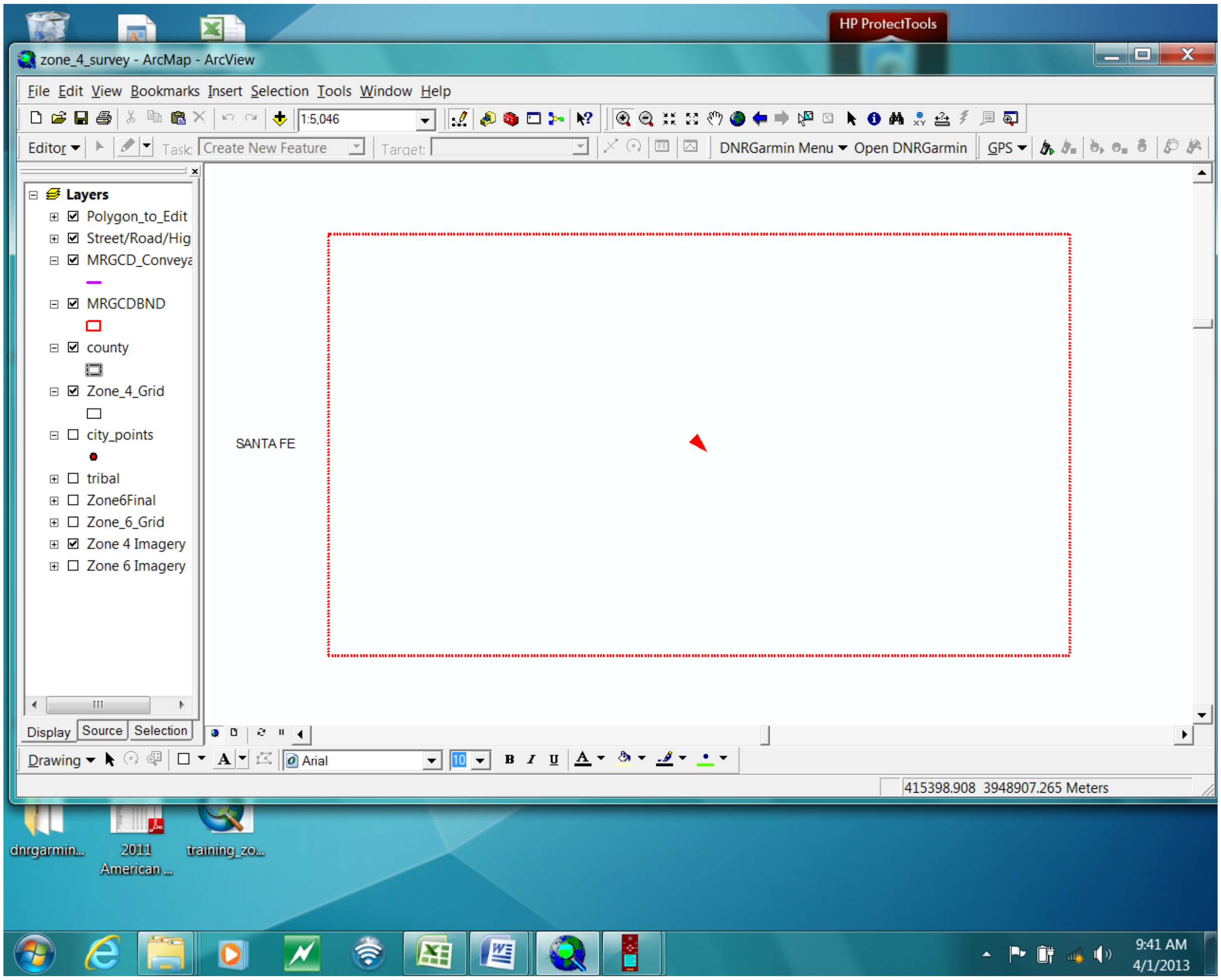
that you can’t see them & you can’t select a polygon. It’s better to keep north up. There will be an arrow that will show you in what direction you are traveling.

  - Minimize both DNRGarmin windows.

- If issues arise with the GPS unit and or software, repeat initial start up and or try another USB port on the left side of the computer.



- You will see a red triangle which is the current location being shown in ARCGIS.

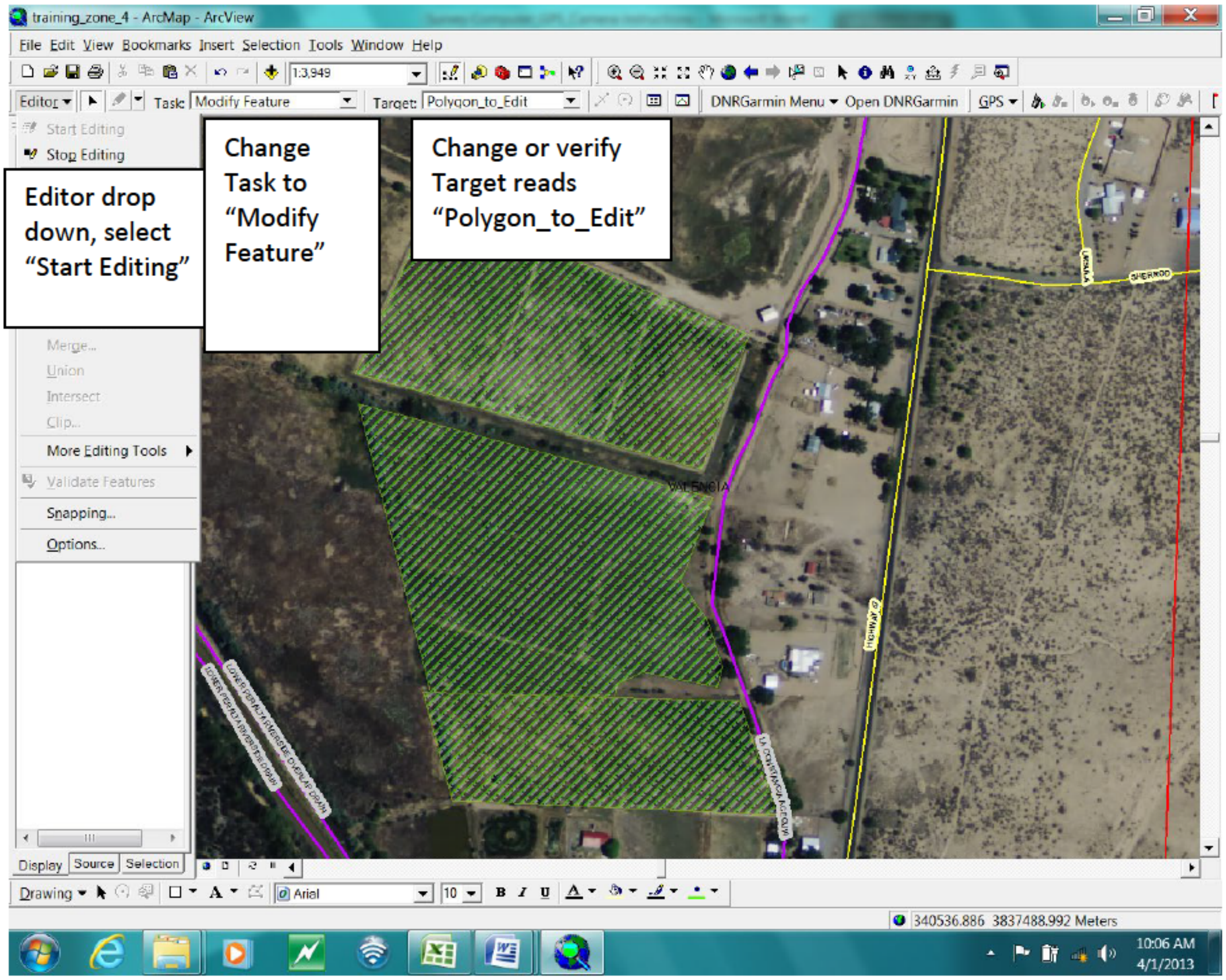


- When done for the day, close the 2 DNRGarmin windows and unhook the GPS unit. Once the GPS unit is unplugged from the computer, it will shut off by itself.

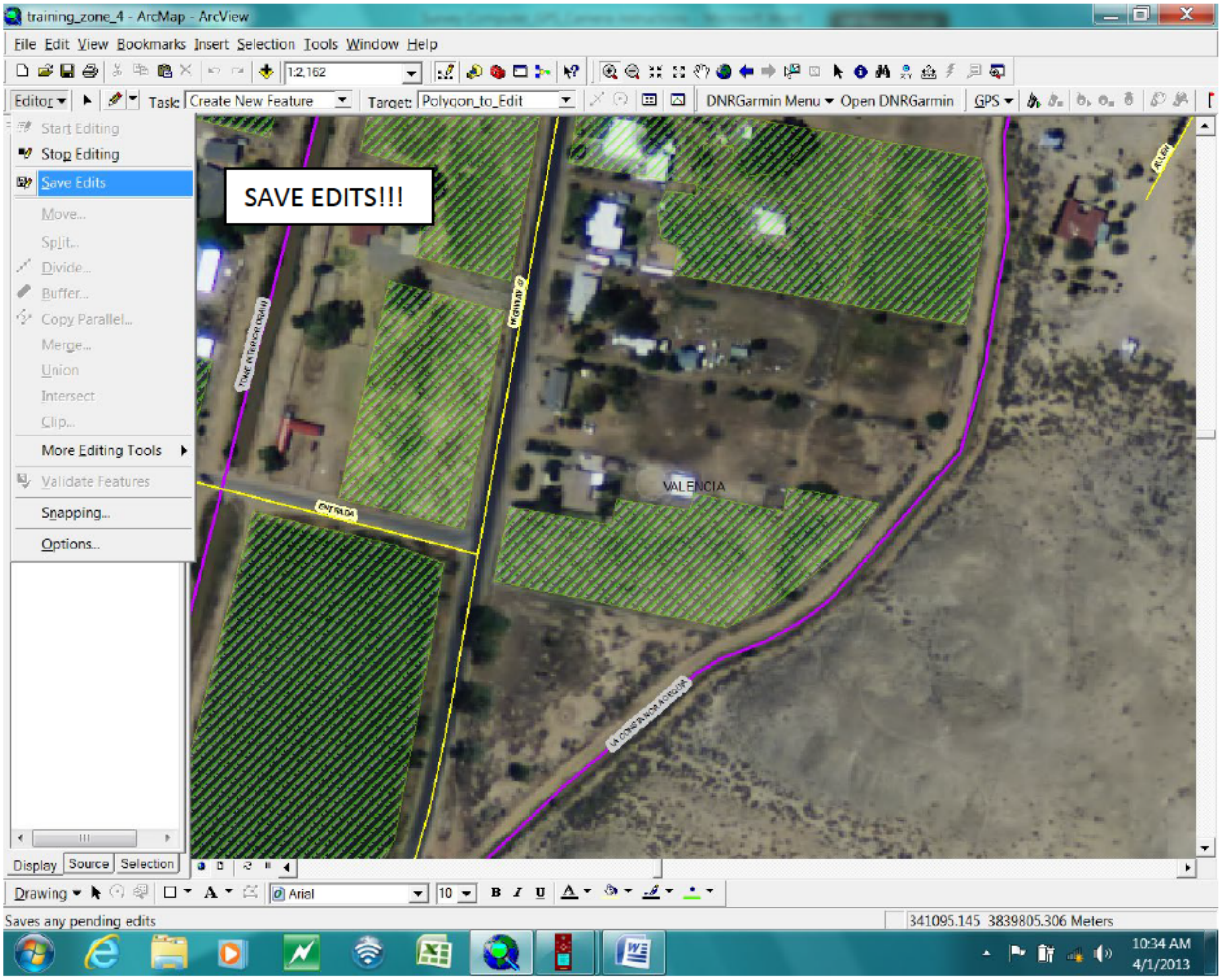
Collection of Crop Data - Populating the GIS projects - Logging changes into the provided Mapbook.

- The Mapbook contains map sheets for the assigned zone. The map sheets represent approximately a 1 mile by ¾ mile area. Mapbooks are used to:
  - Split fields that are shown as one polygon but contain separate crop types. Split the field with the provided Sharpie and write crop types associated with new field boundaries.
  - If a large agricultural field does not have polygon (there should not be any), draw a field boundary and write crop type on page.
  - Mark any page with changes with provided tabs.
  - List everyone's task in the Mapbook
    - List GIS person
    - Mapbook Person
    - Driver

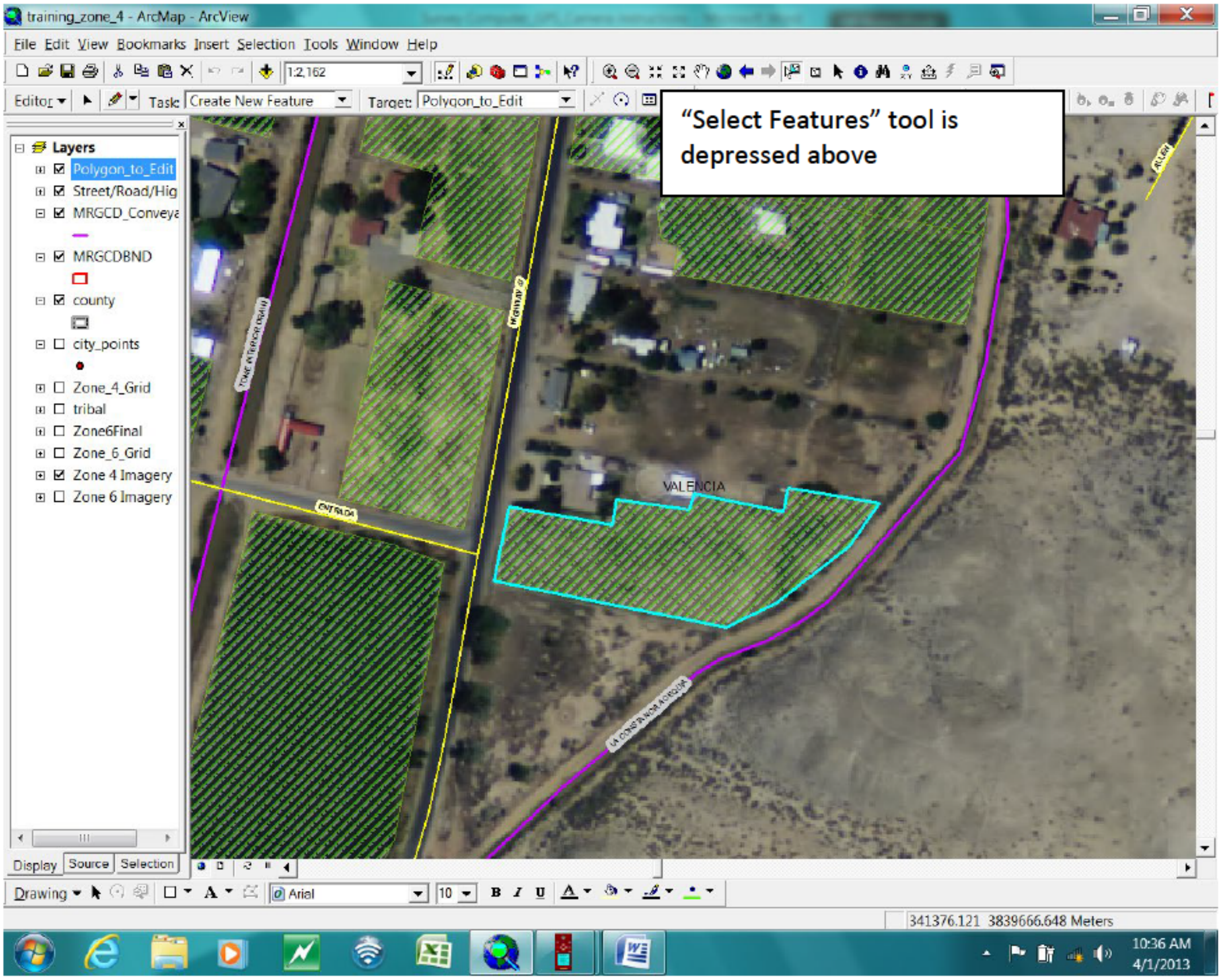
    - If assignments are changed list on Mapbook page when the change occurred.
- At the beginning of each day, find your farthest south Mapbook page and location in the GIS and start collection from the point and collect data moving north.
- To start collecting GIS data under the "Editor" drop down menu, select "Start Editing". The areas represented on the intial project with green hatched polygons need to be collected.
    - Change Task to "Modify Feature" and verify Target reads ""Polygon_to_Edit"



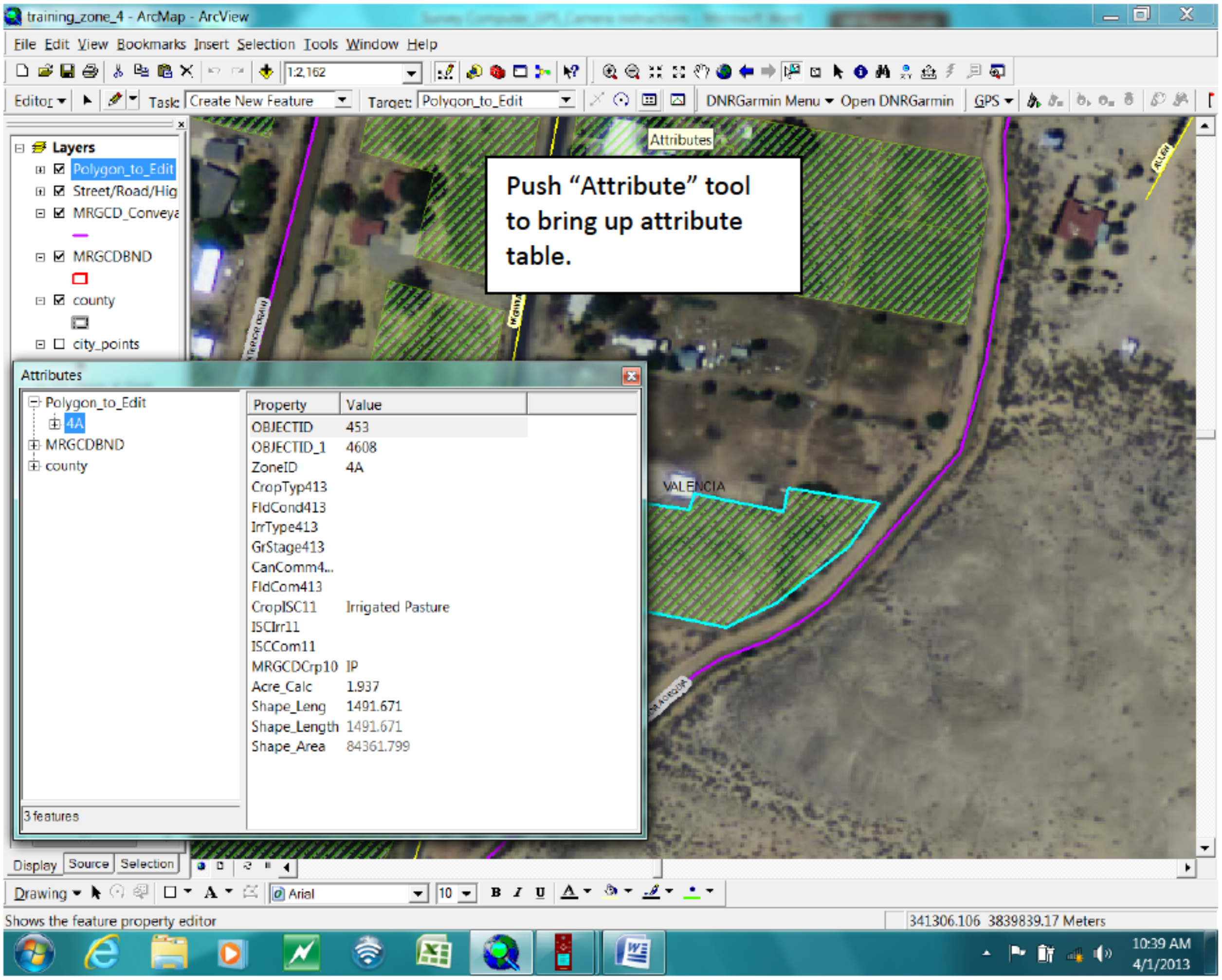
- Start continually saving your updates once you begin collecting data. Changes should be saved every few minutes.



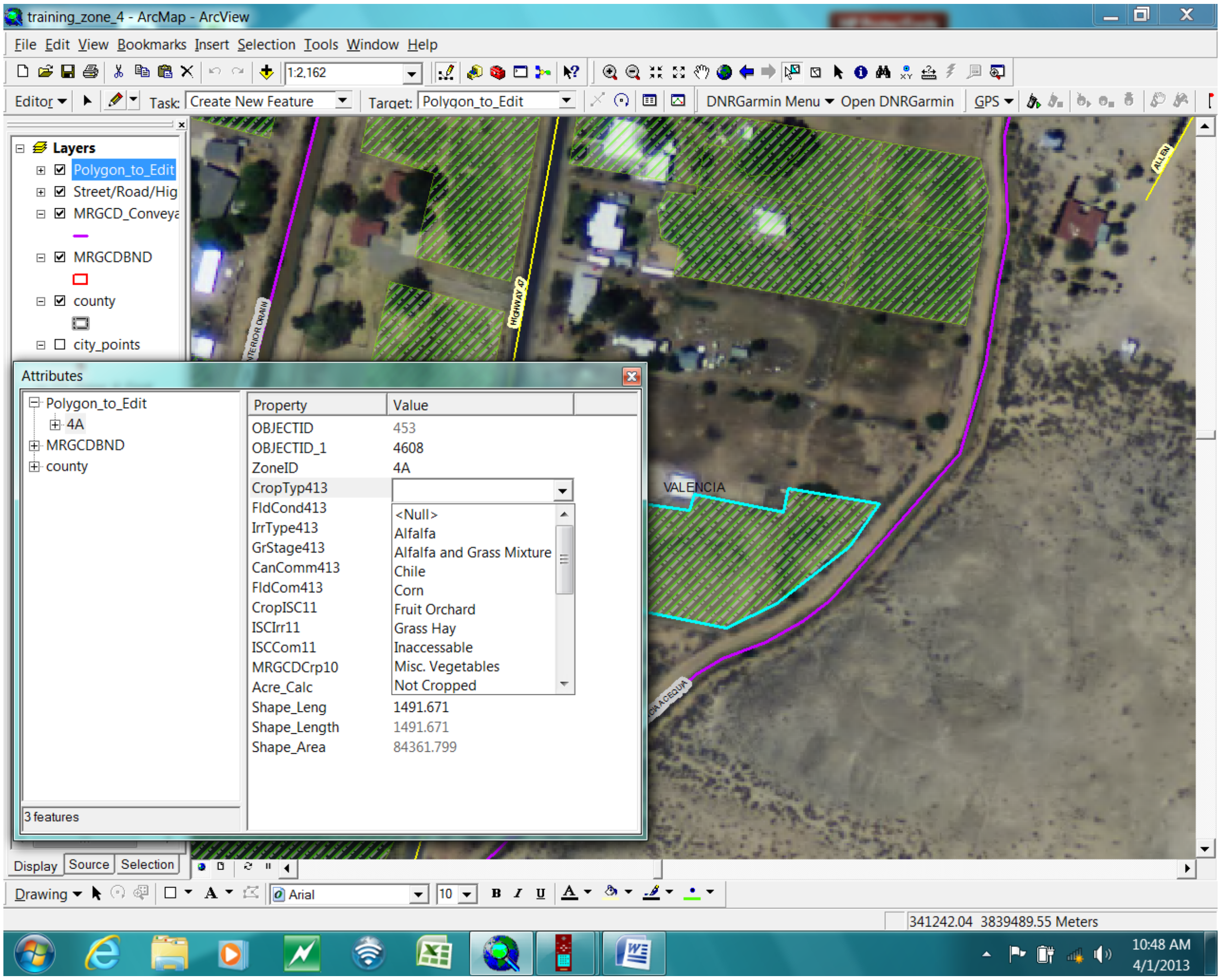
- **Use the "Select Features" tool to choose polygon to update.**



- **After selecting polygon, press attribute table to update polygon attributes.**



- XXXXX413 indicate attributes to be collected on this survey. Below is an example of the drop down menus under the XXXXX413 fields that will be collected on this survey. The only XXXXX413 field that does not have a drop down menu is FieldCom413. This is a space to type field notes into.

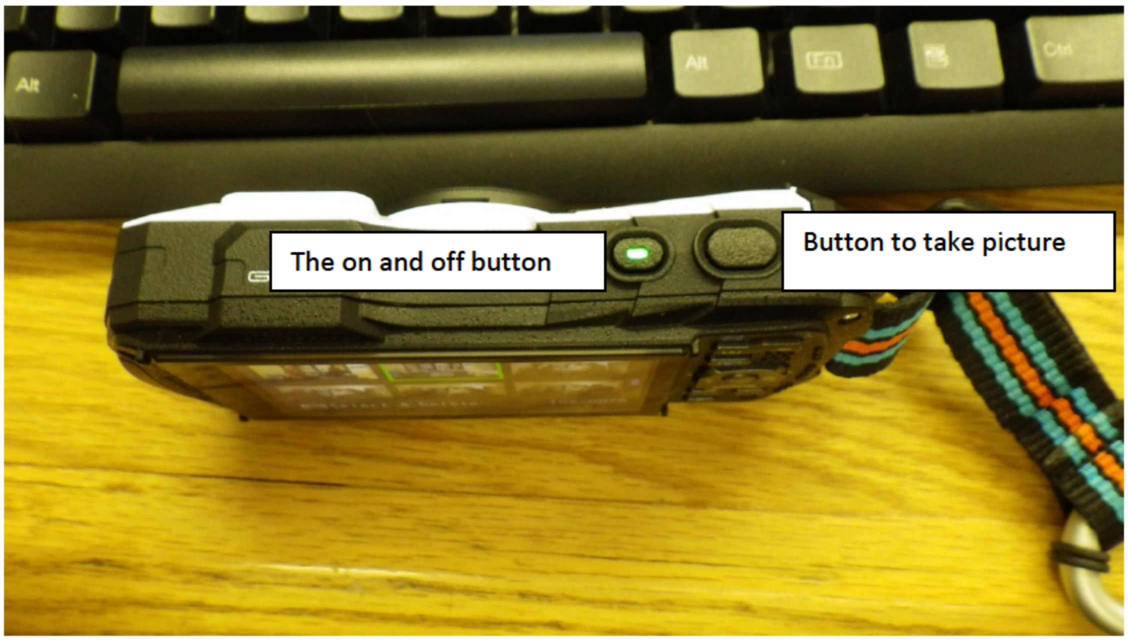


- The following is an explanation of the attribute table above and what must be populated. Only populate or change things that have a XXXXX413 at the end.
  - OBJECTID - ARCGIS field – **Do not change**
  - OBJECTID_1 – **Do not change**
  - ZoneID - **Do not change**
  - CropTyp413 – Populate, dropdown menu Crop Type
    - ALWAYS POPULATE
  - FildCond413 - Populate, dropdown menu Field Condition.
    - ALWAYS POPULATE
  - IrrType413 - Populate, dropdown menu Irrigation Type
    - Populate if irrigation type is visible
  - GrStage413 - Populate, dropdown menu Growth Stage
    - ALWAYS POPULATE unless field is not an agricultural field
  - CanComm413 - Populate, dropdown menu Canned Comments
    - Populate if appropriate
  - FldCom413 - Populate, type into space provided

    - Populate if appropriate
  - Acre_Calc - **Do not change**, Field GIS calculated acreage
  - Shape_Leng - **Do not change**
  - Shape_Length - **Do not change**
  - Shape_Area - **Do not change**

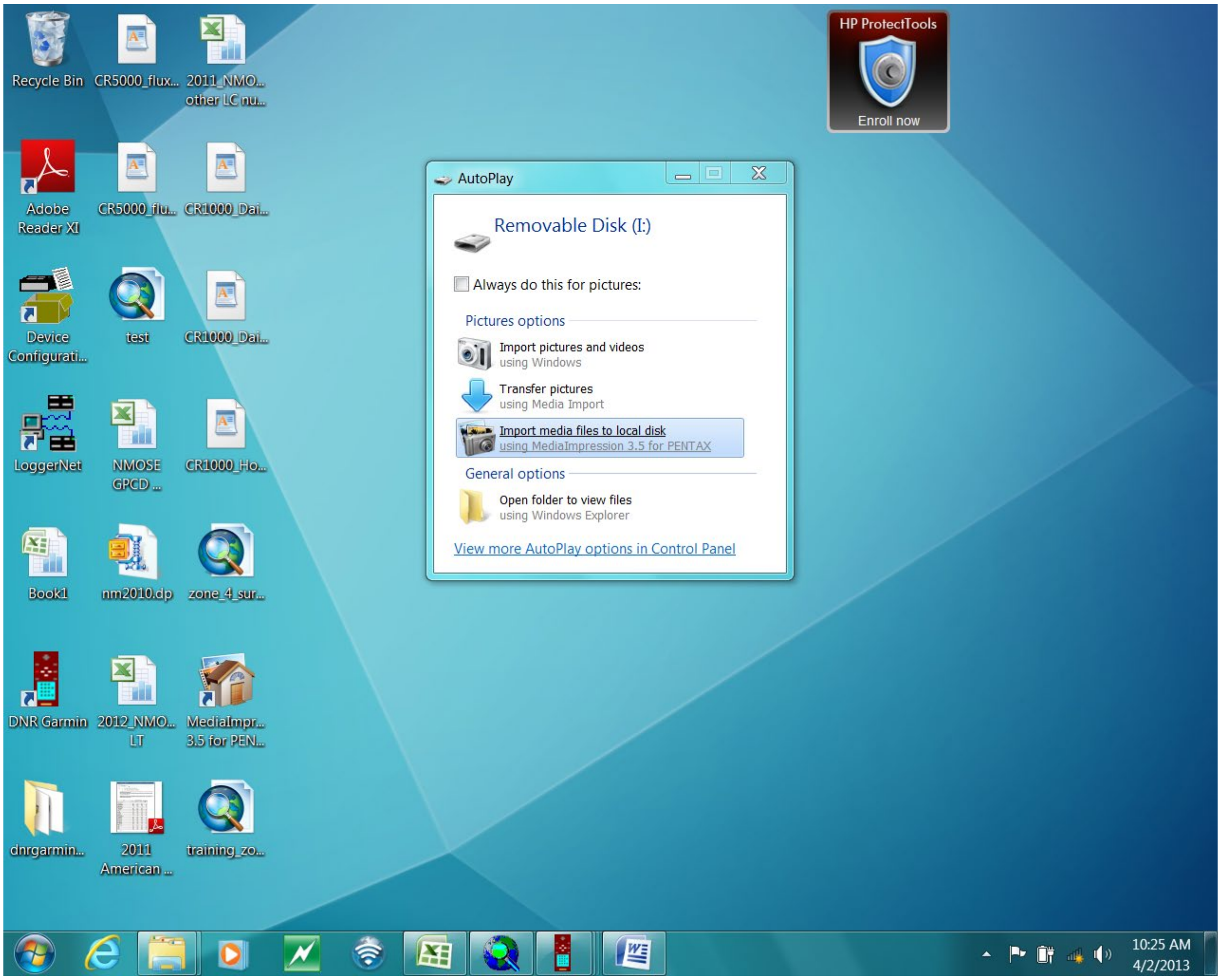
Camera Operation and Uploading Images to Laptop if Memory Card is Full and How to Populate a Photo into the GIS attribute Table

- Turning the camera on and taking a picture. See Below

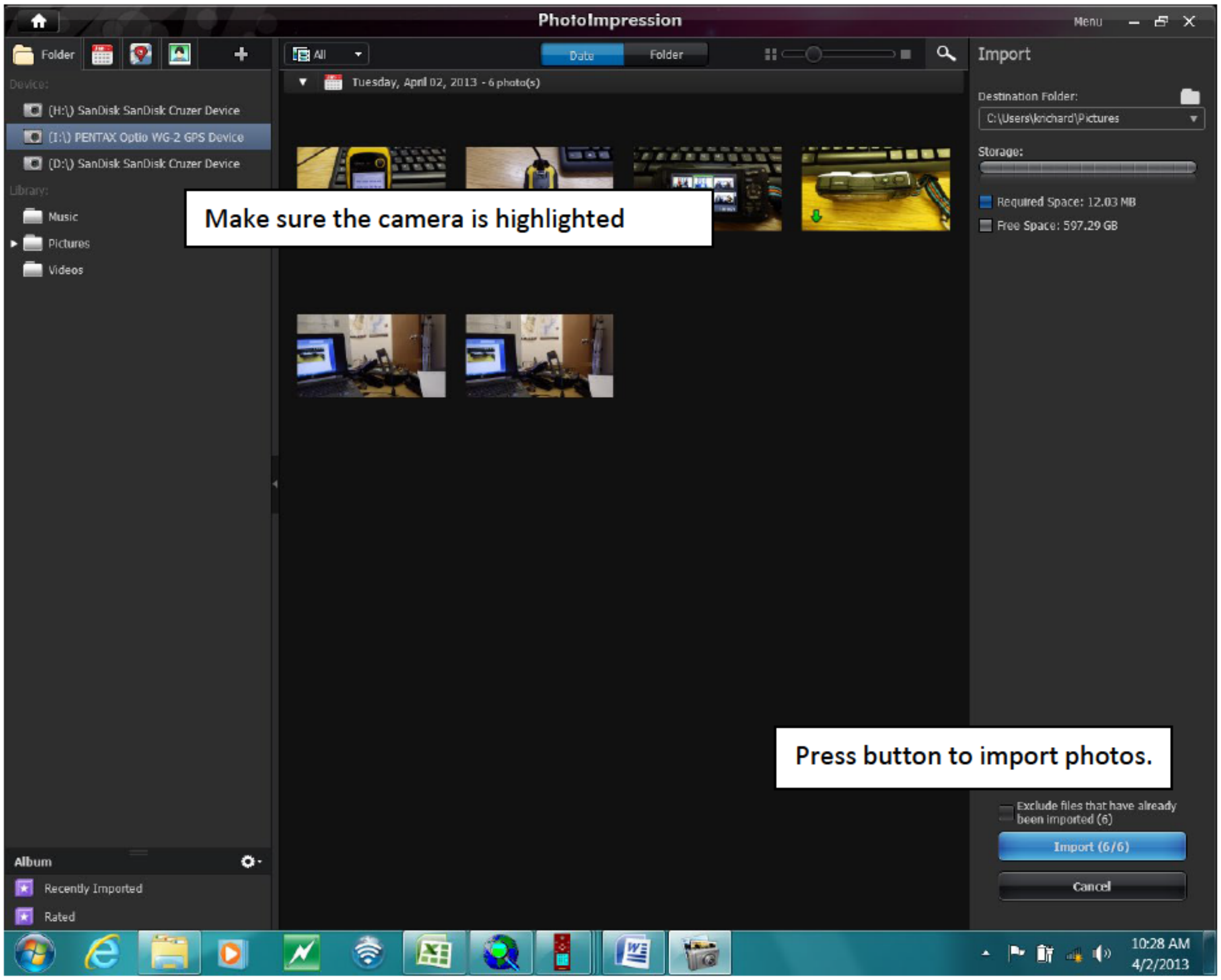


- The first push of the button to take a picture will set the photo and a harder push actual takes the picture. Take a few practice shots.
- Identifying the number associated with the picture to enter into GIS FldCom413 field in the attibute table
  - After taking photo, push the blue play button below the W
  - Push the W to get to the screen below
  - Navigate by using the controller around the okay button
  - Below the photo highlighted with the green border is the number 106-0076
  - Pressing the blue play button below the W will bring you back to the screen to take another picture

- Only take pictures if there is a crop present and if it can't be identified
    - In the CanComm413 attribute field choose "Photo"
    - In the FldCom413 attribute field type the number associated with the photo
- Remember to shut the camera off when not using it to conserve the battery
- If the camera memory card is full connect the provided camera cable to a USB port, the camera holds approximately 50 photos
    - The below menu will pop up
    - Choose "Import Media Files to Local Disk", "MediaImpression 3.5 for PENTAX"



- The screen below will pop up, make sure that the camera is chosen on the left side menu
    - Import photos by pressing button on button right



- To delete photos follow the above steps to determine the number associated with the photo and press the delete button. This button is above the garbage pail and below the word **menu**. See below.

Field Survey Procedure

Fields surveyed were five acres or larger in size. Before beginning each survey, staff training was conducted with a prepared crop ID manual and instructions regarding each category of data being collected.

As noted previously, in order to identify irrigation and crop types, three field surveys were performed: a spring survey, a summer survey, and a fall survey. The survey area was broken into sections based on the samples determined. The field survey teams consisted of a driver/crop identifier, and a GIS person/navigator. Survey participants included Water Use and Conservation Bureau staff, ISC staff, and Las Cruces Water Rights District Office staff.

Appendix 5A. Assignment of Specific Crops to Crop Groups

Table 5A-1. Assignment of Reported Crops to Crop Groups

Crop Reported	Crop Group	Crop Reported by
Alfalfa	Alfalfa Hay	Reclamation
Alfalfa Hay	Alfalfa Hay	Reclamation
Almonds	Pecans	Reclamation
Apples	Pecans	Reclamation
Apricots	Pecans	Reclamation
Asparagus	Miscellaneous Vegetables	Reclamation
Barley	Wheat and Small Grains	Reclamation
Beans	Corn, Sweet Corn, and Silage	Reclamation
Beets	Corn, Sweet Corn, and Silage	Reclamation
Berries	Miscellaneous Vegetables	Reclamation
Black Eyed Peas	Miscellaneous Vegetables	Reclamation
Broccoli	Miscellaneous Vegetables	Reclamation
Cabbage	Miscellaneous Vegetables	Reclamation
Cantaloupes	Miscellaneous Vegetables	Reclamation
Carrots	Miscellaneous Vegetables	Reclamation
Cauliflower	Miscellaneous Vegetables	Reclamation
Celery	Miscellaneous Vegetables	Reclamation
Cereal	Wheat and Small Grains	Reclamation
Cherries	Pecans	Reclamation
Chile (Peppers)	Chile (Peppers)	Reclamation
Citrus	Pecans	Reclamation
Clover	Irrigated Pasture	Reclamation
Clover Seed	Irrigated Pasture	Reclamation
Corn	Corn, Sweet Corn, and Silage	Reclamation
Cotton	Cotton	Reclamation
Cotton (Egypt)	Cotton	Reclamation
Cotton (Upland)	Cotton	Reclamation
Cropland Not harvested	Miscellaneous Vegetables	Reclamation
Cucumbers	Miscellaneous Vegetables	Reclamation
Dates	Pecans	Reclamation
Eggplant	Miscellaneous Vegetables	Reclamation
Famgard*	Miscellaneous Vegetables	Reclamation
Field	Corn, Sweet Corn, and Silage	Reclamation
Figs	Pecans	Reclamation
Flax	Miscellaneous Vegetables	Reclamation
Flaxseed	Miscellaneous Vegetables	Reclamation
Flowers	Miscellaneous Vegetables	Reclamation

Table 5A-1. Assignment of Reported Crops to Crop Groups

Crop Reported	Crop Group	Crop Reported by
Forage	Alfalfa Hay	Reclamation
Fruit	Pecans	Reclamation
Gardens	Miscellaneous Vegetables	Reclamation
Grapes	Pecans	Reclamation
Green Beans	Miscellaneous Vegetables	Reclamation
Hay	Alfalfa Hay	Reclamation
Hops	Miscellaneous Vegetables	Reclamation
Irrigated Pasture	Irrigated Pasture	Reclamation
Lawn	Irrigated Pasture	Reclamation
Lettuce	Miscellaneous Vegetables	Reclamation
Melons	Miscellaneous Vegetables	Reclamation
Mixed Fruit	Miscellaneous Vegetables	Reclamation
Mint	Miscellaneous Vegetables	Reclamation
Misc	Corn, Sweet Corn, and Silage	Reclamation
Mustard	Miscellaneous Vegetables	Reclamation
Nursery	Miscellaneous Vegetables	Reclamation
Nuts	Pecans	Reclamation
Oats	Wheat and Small Grains	Reclamation
Okra	Miscellaneous Vegetables	Reclamation
Olives	Pecans	Reclamation
Onion Seeds	Onions	Reclamation
Onions	Onions	Reclamation
Oranges	Pecans	Reclamation
Orchard	Pecans	Reclamation
Other	Corn, Sweet Corn, and Silage	Reclamation
Other Acreage	Corn, Sweet Corn, and Silage	Reclamation
Other Crop	Corn, Sweet Corn, and Silage	Reclamation
Other Forage	Alfalfa Hay	Reclamation
Other Hay	Alfalfa Hay	Reclamation
Pasture	Irrigated Pasture	Reclamation
Peaches	Pecans	Reclamation
Peanuts	Corn, Sweet Corn, and Silage	Reclamation
Pears	Pecans	Reclamation
Peas	Miscellaneous Vegetables	Reclamation
Pecans	Pecans	Reclamation
Peppermint	Miscellaneous Vegetables	Reclamation
Plums	Pecans	Reclamation
Potatoes	Miscellaneous Vegetables	Reclamation
Prunes	Pecans	Reclamation

Table 5A-1. Assignment of Reported Crops to Crop Groups

Crop Reported	Crop Group	Crop Reported by
Pumpkins	Miscellaneous Vegetables	Reclamation
Radish	Miscellaneous Vegetables	Reclamation
Rice	Corn, Sweet Corn, and Silage	Reclamation
Rye	Irrigated Pasture	Reclamation
Sesbania	Miscellaneous Vegetables	Reclamation
Silage or Ensilage	Corn, Sweet Corn, and Silage	Reclamation
Small Fruit	Miscellaneous Vegetables	Reclamation
Small Vegetables	Miscellaneous Vegetables	Reclamation
Soil Building	Miscellaneous Vegetables	Reclamation
Sorghums	Corn, Sweet Corn, and Silage	Reclamation
Soybeans	Corn, Sweet Corn, and Silage	Reclamation
Spearmint	Miscellaneous Vegetables	Reclamation
Spinach	Miscellaneous Vegetables	Reclamation
Squash	Miscellaneous Vegetables	Reclamation
Sudan	Irrigated Pasture	Reclamation
Sugar Beets	Corn, Sweet Corn, and Silage	Reclamation
Sugar Cane	Miscellaneous Vegetables	Reclamation
Sunflowers	Miscellaneous Vegetables	Reclamation
Sweet Corn	Corn, Sweet Corn, and Silage	Reclamation
Sweet Potatoes	Miscellaneous Vegetables	Reclamation
Timothy	Irrigated Pasture	Reclamation
Tomatoes	Miscellaneous Vegetables	Reclamation
Truck	Miscellaneous Vegetables	Reclamation
Turnips	Miscellaneous Vegetables	Reclamation
Vegetables	Miscellaneous Vegetables	Reclamation
Walnuts	Pecans	Reclamation
Wheat	Wheat and Small Grains	Reclamation
Wheat and Grains	Wheat and Small Grains	Reclamation
White Potatoes	Miscellaneous Vegetables	Reclamation

* Family Gardens and Orchards

Table 5A-2. Crop Assignments for Juarez Valley Irrigation District

Cultivo (Crop)	Crop Group
Alfalfa achicalada	Alfalfa Hay
Chile verde	Chile (Peppers)
Frijol	Corn, Sweet Corn, and Silage
Maíz forrajero en verde	Corn, Sweet Corn, and Silage
Maíz forrajero achicalado	Corn, Sweet Corn, and Silage
Sorgo grano	Corn, Sweet Corn, and Silage
Sorgo forrajero en verde	Corn, Sweet Corn, and Silage
Algodón hueso	Cotton
Melón	Miscellaneous Vegetables
Tomate verde	Miscellaneous Vegetables
Tomate rojo (jitomate)	Miscellaneous Vegetables
Hortalizas	Miscellaneous Vegetables
Sandía	Miscellaneous Vegetables
Calabacita	Miscellaneous Vegetables
Zacate	Irrigated pasture
Pastos y praderas en verde	Irrigated pasture
Ajo	Onions
Cebolla	Onions
Manzana	Pecans
Durazno	Pecans
Nuez	Pecans
Pistache	Pecans
Cebada grano	Wheat and Small Grains
Cebada forrajera en verde	Wheat and Small Grains
Cebada forrajera achicalada	Wheat and Small Grains
Avena forrajera en verde	Wheat and Small Grains
Avena forrajera achicalada	Wheat and Small Grains
Trigo grano	Wheat and Small Grains
Triticale forrajero en verde	Wheat and Small Grains

Appendix 5B. Irrigated Areas in Acres

Table 5B. Irrigated Areas in Acres Received from Intera

Year	Groundwater only in NM	District				Total US Districts	Total
		EBID - SW	EPCWID	Hudspeth	Juarez		
1938	0	78,237	59,117	11,033	57,991	148,387	206,378
1939	0	78,533	61,153	12,400	46,829	152,086	198,915
1940	0	80,379	62,450	13,347	48,457	156,176	204,633
1941	0	83,944	63,669	13,312	53,281	160,925	214,206
1942	0	86,482	64,816	13,710	51,171	165,008	216,179
1943	0	88,035	65,506	14,316	50,535	167,857	218,392
1944	0	88,116	65,699	14,187	50,548	168,002	218,550
1945	0	88,714	65,747	14,905	52,784	169,366	222,150
1946	0	90,099	66,477	15,917	54,052	172,493	226,545
1947	0	90,829	66,992	16,882	48,314	174,703	223,017
1948	258	89,162	66,554	17,060	43,326	172,776	216,360
1949	928	91,701	67,342	17,224	38,338	176,267	215,533
1950	1,168	91,521	67,183	17,318	33,350	176,022	210,540
1951	2,292	90,608	66,166	17,752	30,320	174,526	207,138
1952	3,389	92,109	66,356	17,318	33,110	175,783	212,282
1953	3,859	93,045	66,664	16,675	29,650	176,384	209,893
1954	3,930	85,834	56,594	12,127	24,700	154,555	183,185
1955	4,378	86,153	56,229	5,455	23,770	147,837	175,985
1956	3,192	82,110	50,245	5,180	23,670	137,535	164,397
1957	3,309	82,740	50,705	4,378	25,800	137,823	166,932
1958	3,425	83,923	56,879	6,844	34,620	147,646	185,691
1959	3,542	84,920	59,023	6,992	35,090	150,935	189,567
1960	3,535	85,162	58,228	8,907	34,400	152,297	190,232
1961	3,527	85,388	56,266	9,661	33,360	151,315	188,202
1962	3,520	86,191	59,457	11,429	35,570	157,077	196,167
1963	3,513	86,669	60,783	11,268	39,290	158,720	201,523
1964	3,505	84,881	57,118	8,421	26,930	150,420	180,855
1965	3,498	83,259	54,868	8,123	30,560	146,250	180,308
1966	3,490	80,402	53,753	7,815	32,370	141,970	177,830
1967	3,483	77,675	54,139	8,244	33,390	140,058	176,931
1968	3,476	82,959	55,904	8,649	35,080	147,512	186,068
1969	3,468	84,211	56,726	11,432	40,770	152,369	196,607
1970	3,461	84,948	56,291	14,177	41,370	155,416	200,247
1971	3,454	84,363	55,192	10,115	32,330	149,670	185,454
1972	3,446	80,598	54,636	6,546	31,270	141,780	176,496
1973	3,439	84,757	52,995	9,785	41,730	147,537	192,705
1974	3,432	85,380	51,896	12,446	39,470	149,722	192,623
1975	3,424	85,346	52,154	13,662	42,520	151,162	197,106
1976	3,417	78,721	44,617	11,268	31,887	134,606	169,910

Table 5B. Irrigated Areas in Acres Received from Intera

Year	Groundwater only in NM	District				Total US Districts	Total
		EBID - SW	EPCWID	Hudspeth	Juarez		
1977	3,611	84,682	51,590	10,740	33,154	147,012	183,777
1978	3,805	82,112	48,257	9,175	33,231	139,544	176,580
1979	3,999	78,877	51,995	11,768	35,159	142,640	181,799
1980	4,191	80,285	47,452	15,237	38,392	142,974	185,558
1981	4,118	83,655	49,045	14,028	37,885	146,728	188,731
1982	4,045	80,489	48,311	15,030	38,277	143,830	186,152
1983	3,973	75,177	46,276	9,316	35,931	130,769	170,673
1984	4,017	77,047	47,194	14,546	37,594	138,787	180,398
1985	4,062	78,697	45,605	14,880	39,257	139,182	182,501
1986	4,107	79,017	45,606	15,379	40,920	140,002	185,029
1987	3,913	77,597	47,428	15,043	42,583	140,068	186,564
1988	3,718	76,536	45,492	15,640	44,246	137,667	185,631
1989	3,991	78,962	47,185	17,309	38,448	143,456	185,895
1990	4,264	76,997	43,624	12,599	32,650	133,220	170,135
1991	4,322	78,899	49,637	15,717	34,086	144,253	182,661
1992	4,380	77,522	53,048	15,296	35,522	145,866	185,768
1993	4,438	75,743	53,044	14,667	36,958	143,454	184,851
1994	4,496	76,909	53,187	14,978	38,394	145,074	187,965
1995	4,554	77,620	53,145	15,430	39,830	146,195	190,580
1996	4,612	79,246	45,246	15,734	41,267	140,227	186,106
1997	4,732	77,795	52,591	15,278	41,752	145,664	192,148
1998	4,852	77,550	52,987	15,385	42,237	145,922	193,011
1999	4,972	77,150	51,594	15,462	42,721	144,206	191,899
2000	5,091	77,933	48,638	14,192	43,205	140,763	189,060
2001	5,140	79,061	41,579	14,379	36,411	135,019	176,571
2002	5,350	77,782	41,024	15,189	36,298	133,996	175,643
2003	5,096	74,377	38,763	8,769	35,535	121,909	162,541
2004	5,153	76,665	37,860	8,740	39,968	123,265	168,386
2005	5,008	77,358	40,207	9,467	38,518	127,032	170,558
2006	4,941	76,019	40,542	10,517	37,170	127,077	169,188
2007	4,980	77,030	40,569	12,257	39,311	129,856	174,148
2008	4,574	76,486	40,911	13,623	35,459	131,021	171,054
2009	4,397	71,210	40,142	14,206	33,300	125,559	163,255
2010	4,794	74,875	40,306	14,700	35,220	129,881	169,895
2011	4,411	71,592	39,659	12,154	29,953	123,404	157,768
2012	4,415	68,110	27,307	6,419	30,719	101,836	136,970
2013	4,706	72,494	29,903	6,227	32,209	108,623	145,538
2014	4,646	72,124	30,822	5,868	29,917	108,814	143,377
2015	4,559	69,057	30,134	7,097	30,918	106,288	141,765
2016	4,853	70,031	36,308	5,919	31,677	112,259	148,789
2017	4,616	69,602	35,031	7,891	32,014	112,524	149,154

Table 5B. Irrigated Areas in Acres Received from Intera

Year	Groundwater only in NM	District				Total US Districts	Total
		EBID - SW	EPCWID	Hudspeth	Juarez		
2018	4,547	69,302	36,002	7,557	30,102	112,861	147,509
Min	0	68,110	27,307	4,378	23,670	101,836	136,970
Avg	3,472	80,713	51,257	12,100	37,412	144,070	184,954
Max	5,350	93,045	67,342	17,752	57,991	176,384	226,545

*Groundwater only (GO) irrigated area in New Mexico (part of EBID, but total area is not included in Total US Districts acreage).

Appendix 5C. Irrigated Crop Areas in Percent

Table 5C-1. EBID Surface Water Irrigated Crop Areas in Percent.

Year	Alfalfa Hay	Chile (Peppers)	Corn, Sweet Corn, and Silage	Cotton	Irrigated Pasture	Miscellaneous Vegetables	Onions	Pecans	Wheat and Small Grains	Total
1938	27.91%	0.00%	10.02%	46.91%	1.82%	11.94%	0.21%	0.38%	0.82%	100%
1939	35.66%	0.00%	11.75%	43.03%	1.41%	6.54%	0.24%	0.41%	0.96%	100%
1940	34.24%	0.00%	10.22%	45.36%	0.82%	5.27%	0.22%	3.01%	0.86%	100%
1941	22.89%	0.00%	6.14%	60.84%	1.93%	4.38%	0.23%	3.29%	0.30%	100%
1942	17.56%	0.00%	4.41%	62.49%	1.00%	10.73%	0.24%	3.24%	0.33%	100%
1943	21.49%	0.00%	5.41%	63.08%	1.82%	3.71%	0.23%	3.46%	0.79%	100%
1944	24.67%	0.00%	5.60%	59.30%	1.15%	3.70%	0.48%	4.44%	0.66%	100%
1945	23.15%	0.00%	2.95%	62.01%	1.33%	4.78%	0.49%	4.58%	0.71%	100%
1946	22.07%	1.06%	2.89%	62.97%	1.18%	3.32%	1.21%	4.56%	0.72%	100%
1947	18.39%	0.39%	1.85%	70.46%	0.81%	2.82%	0.62%	4.39%	0.26%	100%
1948	10.05%	0.23%	1.03%	80.48%	0.49%	1.92%	0.37%	4.67%	0.77%	100%
1949	10.08%	0.32%	0.87%	81.42%	0.58%	1.84%	0.42%	4.46%	0.03%	100%
1950	16.09%	0.33%	2.18%	71.95%	1.34%	2.83%	0.46%	4.31%	0.49%	100%
1951	6.93%	0.37%	0.41%	85.33%	1.26%	0.91%	0.31%	4.47%	0.01%	100%
1952	11.82%	0.42%	0.34%	78.26%	2.74%	1.30%	0.36%	4.34%	0.43%	100%
1953	12.60%	0.51%	0.50%	76.85%	2.42%	1.87%	0.37%	4.49%	0.39%	100%
1954	21.87%	0.86%	2.96%	59.51%	2.48%	3.71%	0.37%	4.66%	3.57%	100%
1955	27.00%	0.54%	2.56%	57.08%	1.17%	3.41%	0.43%	4.85%	2.96%	100%
1956	24.63%	1.04%	3.50%	57.47%	1.40%	3.61%	0.65%	5.09%	2.61%	100%
1957	18.60%	0.81%	2.47%	64.56%	0.95%	4.53%	1.02%	5.08%	1.99%	100%
1958	19.14%	0.76%	2.57%	59.75%	3.00%	5.96%	1.35%	4.99%	2.48%	100%
1959	16.13%	0.78%	2.98%	64.19%	0.83%	5.13%	1.87%	5.16%	2.94%	100%
1960	16.13%	0.75%	2.79%	61.45%	4.49%	4.53%	1.94%	4.88%	3.03%	100%
1961	17.70%	0.86%	2.12%	62.85%	1.32%	4.21%	1.66%	5.09%	4.18%	100%
1962	13.15%	0.73%	2.09%	69.64%	0.82%	3.20%	1.86%	5.08%	3.43%	100%

Table 5C-1. EBID Surface Water Irrigated Crop Areas in Percent.

Year	Alfalfa Hay	Chile (Peppers)	Corn, Sweet Corn, and Silage	Cotton	Irrigated Pasture	Miscellaneous Vegetables	Onions	Pecans	Wheat and Small Grains	Total
1963	9.40%	0.78%	1.64%	75.84%	0.56%	3.08%	1.52%	5.01%	2.17%	100%
1964	11.83%	0.88%	2.35%	70.90%	0.70%	3.69%	1.97%	4.98%	2.69%	100%
1965	15.49%	0.94%	3.51%	62.82%	0.85%	5.77%	2.50%	5.23%	2.88%	100%
1966	14.81%	1.97%	4.39%	51.81%	1.65%	13.92%	3.52%	5.58%	2.35%	100%
1967	14.81%	1.97%	4.39%	51.81%	1.65%	13.92%	3.52%	5.58%	2.35%	100%
1968	12.87%	1.63%	4.06%	54.66%	1.30%	13.66%	3.88%	5.94%	1.99%	100%
1969	13.94%	3.23%	5.18%	50.17%	1.55%	13.94%	3.56%	5.99%	2.44%	100%
1970	16.25%	3.29%	5.57%	50.32%	1.51%	9.25%	3.68%	6.46%	3.66%	100%
1971	16.76%	3.82%	5.87%	50.59%	1.78%	8.99%	3.11%	6.59%	2.49%	100%
1972	17.26%	4.97%	3.91%	52.21%	1.91%	5.35%	3.34%	7.52%	3.53%	100%
1973	17.64%	4.79%	5.32%	48.28%	2.44%	5.68%	3.85%	7.47%	4.53%	100%
1974	16.28%	6.34%	3.27%	53.64%	2.54%	4.09%	2.84%	7.61%	3.39%	100%
1975	17.68%	5.75%	8.69%	37.14%	1.54%	8.67%	3.23%	7.66%	9.64%	100%
1976	18.46%	8.09%	9.81%	24.09%	1.17%	8.39%	3.54%	8.18%	18.28%	100%
1977	18.56%	9.04%	3.69%	36.12%	0.95%	9.15%	4.43%	9.87%	8.18%	100%
1978	16.99%	9.47%	4.23%	37.41%	0.75%	11.79%	3.72%	11.03%	4.60%	100%
1979	16.06%	12.99%	3.84%	36.51%	0.90%	9.27%	3.85%	12.05%	4.54%	100%
1980	18.14%	13.35%	4.92%	29.75%	1.14%	7.99%	3.86%	12.60%	8.24%	100%
1981	19.20%	11.19%	5.59%	27.44%	1.21%	7.54%	3.22%	12.80%	11.82%	100%
1982	21.39%	11.37%	5.07%	24.40%	1.15%	9.93%	4.46%	13.29%	8.94%	100%
1983	22.69%	12.72%	4.67%	22.25%	1.48%	11.28%	4.31%	14.96%	5.66%	100%
1984	22.85%	11.19%	6.54%	22.27%	1.48%	9.18%	3.92%	15.93%	6.63%	100%
1985	24.26%	14.68%	9.02%	17.09%	1.36%	9.44%	4.12%	15.35%	4.67%	100%
1986	21.85%	12.75%	6.99%	21.03%	1.70%	9.48%	3.95%	17.21%	5.05%	100%
1987	18.26%	12.90%	0.87%	26.45%	5.19%	10.47%	3.96%	17.83%	4.09%	100%
1988	16.24%	12.03%	5.44%	30.07%	1.22%	9.13%	4.30%	17.88%	3.69%	100%
1989	15.35%	9.97%	6.13%	35.82%	0.93%	6.05%	4.20%	18.42%	3.12%	100%

Table 5C-1. EBID Surface Water Irrigated Crop Areas in Percent.

Year	Alfalfa Hay	Chile (Peppers)	Corn, Sweet Corn, and Silage	Cotton	Irrigated Pasture	Miscellaneous Vegetables	Onions	Pecans	Wheat and Small Grains	Total
1990	16.74%	11.65%	6.77%	29.52%	1.10%	6.72%	5.14%	19.02%	3.35%	100%
1991	18.44%	10.10%	7.79%	30.13%	1.14%	6.52%	4.26%	19.26%	2.35%	100%
1992	19.17%	12.86%	8.52%	23.60%	0.99%	6.11%	5.54%	20.47%	2.74%	100%
1993	18.00%	11.19%	8.73%	23.03%	0.94%	7.22%	6.84%	21.44%	2.62%	100%
1994	20.80%	8.40%	10.76%	22.32%	1.15%	5.34%	5.52%	21.44%	4.27%	100%
1995	24.32%	7.29%	5.98%	25.21%	0.81%	4.21%	5.51%	22.37%	4.29%	100%
1996	22.43%	6.17%	10.10%	19.92%	0.66%	5.08%	5.40%	24.34%	5.90%	100%
1997	21.28%	6.69%	9.65%	21.98%	0.67%	6.65%	5.28%	22.35%	5.45%	100%
1998	21.75%	6.36%	10.67%	18.40%	0.60%	7.02%	5.52%	23.94%	5.75%	100%
1999	22.04%	6.95%	12.91%	17.03%	0.67%	5.23%	5.88%	25.65%	3.65%	100%
2000	21.88%	6.31%	10.62%	18.83%	0.76%	6.16%	6.55%	25.31%	3.59%	100%
2001	21.53%	5.57%	11.73%	18.56%	0.76%	6.70%	5.48%	26.79%	2.88%	100%
2002	22.75%	5.12%	11.82%	16.72%	0.82%	6.96%	6.30%	26.86%	2.64%	100%
2003	22.29%	3.76%	7.02%	17.78%	0.94%	17.02%	4.48%	26.37%	0.34%	100%
2004	18.76%	3.72%	5.68%	21.41%	0.66%	17.79%	3.99%	27.06%	0.92%	100%
2005	17.58%	4.00%	9.04%	18.37%	1.23%	16.08%	6.54%	25.27%	1.89%	100%
2006	18.74%	3.18%	7.71%	19.72%	1.06%	15.27%	5.08%	27.70%	1.54%	100%
2007	19.86%	3.55%	9.40%	16.56%	1.15%	14.35%	4.84%	27.74%	2.55%	100%
2008	21.28%	4.54%	9.17%	13.45%	1.18%	13.02%	4.62%	29.98%	2.76%	100%
2009	21.73%	4.08%	9.40%	9.47%	1.40%	15.21%	4.26%	31.05%	3.41%	100%
2010	20.28%	3.41%	8.25%	12.69%	0.77%	16.56%	4.43%	30.85%	2.76%	100%
2011	27.61%	0.54%	6.20%	25.43%	0.14%	0.48%	1.80%	33.94%	3.86%	100%
2012	22.21%	3.35%	11.23%	14.66%	2.30%	0.75%	6.40%	33.15%	5.95%	100%
2013	23.12%	4.56%	10.66%	13.18%	2.10%	0.80%	6.47%	34.48%	4.65%	100%
2014	23.47%	1.78%	11.77%	17.16%	0.77%	0.40%	4.96%	36.07%	3.62%	100%
2015	21.56%	2.20%	11.34%	14.74%	0.64%	0.87%	5.45%	39.08%	4.11%	100%
2016	20.42%	2.37%	9.72%	17.81%	0.18%	0.30%	4.61%	41.09%	3.49%	100%

Table 5C-1. EBID Surface Water Irrigated Crop Areas in Percent.

Year	Alfalfa Hay	Chile (Peppers)	Corn, Sweet Corn, and Silage	Cotton	Irrigated Pasture	Miscellaneous Vegetables	Onions	Pecans	Wheat and Small Grains	Total
2017	19.40%	2.82%	8.31%	15.84%	0.35%	0.63%	5.59%	42.63%	4.44%	100%
2018	18.97%	3.24%	8.87%	17.70%	1.03%	0.41%	4.38%	41.73%	3.67%	100%

Table 5C-2. EBID Groundwater Only Irrigated Crop Areas in Percent.

Year	Alfalfa Hay	Chile (Peppers)	Corn, Sweet Corn, and Silage	Cotton	Irrigated Pasture	Miscellaneous Vegetables	Onions	Pecans	Wheat and Small Grains	Total
1938	48.38%	5.11%	11.71%	5.14%	25.92%	1.23%	1.14%	0.00%	1.37%	100%
1939	48.38%	5.11%	11.71%	5.14%	25.92%	1.23%	1.14%	0.00%	1.37%	100%
1940	48.38%	5.11%	11.71%	5.14%	25.92%	1.23%	1.14%	0.00%	1.37%	100%
1941	48.38%	5.11%	11.71%	5.14%	25.92%	1.23%	1.14%	0.00%	1.37%	100%
1942	48.38%	5.11%	11.71%	5.14%	25.92%	1.23%	1.14%	0.00%	1.37%	100%
1943	48.38%	5.11%	11.71%	5.14%	25.92%	1.23%	1.14%	0.00%	1.37%	100%
1944	48.38%	5.11%	11.71%	5.14%	25.92%	1.23%	1.14%	0.00%	1.37%	100%
1945	48.38%	5.11%	11.71%	5.14%	25.92%	1.23%	1.14%	0.00%	1.37%	100%
1946	48.38%	5.11%	11.71%	5.14%	25.92%	1.23%	1.14%	0.00%	1.37%	100%
1947	48.38%	5.11%	11.71%	5.14%	25.92%	1.23%	1.14%	0.00%	1.37%	100%
1948	48.38%	5.11%	11.71%	5.14%	25.92%	1.23%	1.14%	0.00%	1.37%	100%
1949	48.38%	5.11%	11.71%	5.14%	25.92%	1.23%	1.14%	0.00%	1.37%	100%
1950	48.38%	5.11%	11.71%	5.14%	25.92%	1.23%	1.14%	0.00%	1.37%	100%
1951	48.38%	5.11%	11.71%	5.14%	25.92%	1.23%	1.14%	0.00%	1.37%	100%
1952	48.38%	5.11%	11.71%	5.14%	25.92%	1.23%	1.14%	0.00%	1.37%	100%
1953	48.38%	5.11%	11.71%	5.14%	25.92%	1.23%	1.14%	0.00%	1.37%	100%
1954	48.38%	5.11%	11.71%	5.14%	25.92%	1.23%	1.14%	0.00%	1.37%	100%
1955	48.38%	5.11%	11.71%	5.14%	25.92%	1.23%	1.14%	0.00%	1.37%	100%
1956	48.38%	5.11%	11.71%	5.14%	25.92%	1.23%	1.14%	0.00%	1.37%	100%
1957	48.38%	5.11%	11.71%	5.14%	25.92%	1.23%	1.14%	0.00%	1.37%	100%
1958	48.38%	5.11%	11.71%	5.14%	25.92%	1.23%	1.14%	0.00%	1.37%	100%
1959	48.38%	5.11%	11.71%	5.14%	25.92%	1.23%	1.14%	0.00%	1.37%	100%
1960	48.06%	5.07%	11.63%	5.11%	25.74%	1.22%	1.13%	0.67%	1.36%	100%
1961	47.74%	5.04%	11.55%	5.07%	25.58%	1.21%	1.13%	1.32%	1.35%	100%
1962	47.45%	5.01%	11.48%	5.04%	25.42%	1.21%	1.12%	1.93%	1.35%	100%
1963	47.16%	4.98%	11.41%	5.01%	25.26%	1.20%	1.11%	2.52%	1.34%	100%

Table 5C-2. EBID Groundwater Only Irrigated Crop Areas in Percent.

Year	Alfalfa Hay	Chile (Peppers)	Corn, Sweet Corn, and Silage	Cotton	Irrigated Pasture	Miscellaneous Vegetables	Onions	Pecans	Wheat and Small Grains	Total
1964	46.89%	4.95%	11.34%	4.98%	25.12%	1.19%	1.11%	3.09%	1.33%	100%
1965	46.62%	4.92%	11.28%	4.95%	24.98%	1.19%	1.10%	3.63%	1.32%	100%
1966	46.37%	4.90%	11.22%	4.93%	24.84%	1.18%	1.09%	4.15%	1.32%	100%
1967	46.13%	4.87%	11.16%	4.90%	24.71%	1.17%	1.09%	4.65%	1.31%	100%
1968	45.90%	4.85%	11.10%	4.88%	24.59%	1.17%	1.08%	5.13%	1.30%	100%
1969	45.67%	4.82%	11.05%	4.85%	24.47%	1.16%	1.08%	5.60%	1.30%	100%
1970	45.46%	4.80%	11.00%	4.83%	24.35%	1.16%	1.07%	6.05%	1.29%	100%
1971	45.25%	4.78%	10.95%	4.81%	24.24%	1.15%	1.07%	6.48%	1.28%	100%
1972	45.05%	4.76%	10.90%	4.79%	24.13%	1.15%	1.06%	6.89%	1.28%	100%
1973	44.85%	4.74%	10.85%	4.77%	24.03%	1.14%	1.06%	7.29%	1.27%	100%
1974	44.67%	4.72%	10.81%	4.75%	23.93%	1.14%	1.05%	7.68%	1.27%	100%
1975	44.49%	4.70%	10.76%	4.73%	23.83%	1.13%	1.05%	8.05%	1.26%	100%
1976	44.31%	4.68%	10.72%	4.71%	23.74%	1.13%	1.05%	8.41%	1.26%	100%
1977	43.87%	4.63%	10.61%	4.66%	23.50%	1.12%	1.04%	9.33%	1.24%	100%
1978	43.41%	4.58%	10.50%	4.61%	23.26%	1.10%	1.03%	10.27%	1.23%	100%
1979	42.95%	4.53%	10.39%	4.56%	23.01%	1.09%	1.01%	11.22%	1.22%	100%
1980	43.73%	4.62%	10.58%	4.65%	23.43%	1.11%	1.03%	9.61%	1.24%	100%
1981	43.02%	4.54%	10.41%	4.57%	23.05%	1.09%	1.02%	11.07%	1.22%	100%
1982	42.20%	4.46%	10.21%	4.48%	22.61%	1.07%	1.00%	12.78%	1.20%	100%
1983	41.22%	4.35%	9.97%	4.38%	22.08%	1.05%	0.97%	14.79%	1.17%	100%
1984	41.71%	4.40%	10.09%	4.43%	22.34%	1.06%	0.98%	13.79%	1.18%	100%
1985	42.09%	4.44%	10.18%	4.47%	22.55%	1.07%	0.99%	13.00%	1.19%	100%
1986	42.40%	4.48%	10.26%	4.51%	22.72%	1.08%	1.00%	12.36%	1.20%	100%
1987	40.91%	4.32%	9.90%	4.35%	21.92%	1.04%	0.97%	15.44%	1.16%	100%
1988	38.72%	4.09%	9.37%	4.11%	20.74%	0.99%	0.91%	19.97%	1.10%	100%
1989	38.61%	4.08%	9.34%	4.10%	20.69%	0.98%	0.91%	20.19%	1.10%	100%

Table 5C-2. EBID Groundwater Only Irrigated Crop Areas in Percent.

Year	Alfalfa Hay	Chile (Peppers)	Corn, Sweet Corn, and Silage	Cotton	Irrigated Pasture	Miscellaneous Vegetables	Onions	Pecans	Wheat and Small Grains	Total
1990	38.52%	4.07%	9.32%	4.09%	20.63%	0.98%	0.91%	20.39%	1.09%	100%
1991	38.30%	4.04%	9.27%	4.07%	20.52%	0.97%	0.90%	20.83%	1.09%	100%
1992	38.10%	4.02%	9.22%	4.05%	20.41%	0.97%	0.90%	21.26%	1.08%	100%
1993	37.90%	4.00%	9.17%	4.03%	20.30%	0.96%	0.89%	21.67%	1.08%	100%
1994	37.71%	3.98%	9.12%	4.01%	20.20%	0.96%	0.89%	22.06%	1.07%	100%
1995	37.52%	3.96%	9.08%	3.99%	20.10%	0.95%	0.89%	22.44%	1.06%	100%
1996	37.34%	3.94%	9.03%	3.97%	20.01%	0.95%	0.88%	22.81%	1.06%	100%
1997	37.38%	3.95%	9.04%	3.97%	20.02%	0.95%	0.88%	22.74%	1.06%	100%
1998	37.41%	3.95%	9.05%	3.98%	20.04%	0.95%	0.88%	22.67%	1.06%	100%
1999	37.44%	3.95%	9.06%	3.98%	20.06%	0.95%	0.88%	22.61%	1.06%	100%
2000	37.47%	3.96%	9.07%	3.98%	20.07%	0.95%	0.88%	22.55%	1.06%	100%
2001	36.21%	3.82%	8.76%	3.85%	19.40%	0.92%	0.86%	25.15%	1.03%	100%
2002	36.50%	3.85%	8.83%	3.88%	19.55%	0.93%	0.86%	24.56%	1.04%	100%
2003	35.62%	3.76%	8.62%	3.78%	19.08%	0.91%	0.84%	26.38%	1.01%	100%
2004	35.37%	3.73%	8.56%	3.76%	18.95%	0.90%	0.84%	26.90%	1.00%	100%
2005	35.06%	3.70%	8.48%	3.73%	18.78%	0.89%	0.83%	27.54%	0.99%	100%
2006	34.95%	3.69%	8.46%	3.71%	18.72%	0.89%	0.83%	27.77%	0.99%	100%
2007	35.18%	3.71%	8.51%	3.74%	18.84%	0.90%	0.83%	27.29%	1.00%	100%
2008	35.75%	3.77%	8.65%	3.80%	19.15%	0.91%	0.84%	26.10%	1.01%	100%
2009	31.39%	3.31%	7.59%	3.34%	16.81%	0.80%	0.74%	35.12%	0.89%	100%
2010	32.51%	3.43%	7.87%	3.45%	17.42%	0.83%	0.77%	32.80%	0.92%	100%
2011	29.74%	3.14%	7.20%	3.16%	15.93%	0.76%	0.70%	38.53%	0.84%	100%
2012	29.39%	3.10%	7.11%	3.12%	15.75%	0.75%	0.69%	39.25%	0.83%	100%
2013	32.64%	3.45%	7.90%	3.47%	17.49%	0.83%	0.77%	32.53%	0.93%	100%
2014	37.32%	0.14%	11.12%	9.76%	1.11%	0.00%	3.53%	35.05%	1.97%	100%
2015	27.74%	4.32%	14.77%	5.53%	2.09%	1.06%	7.30%	33.92%	3.26%	100%

Table 5C-2. EBID Groundwater Only Irrigated Crop Areas in Percent.

Year	Alfalfa Hay	Chile (Peppers)	Corn, Sweet Corn, and Silage	Cotton	Irrigated Pasture	Miscellaneous Vegetables	Onions	Pecans	Wheat and Small Grains	Total
2016	30.19%	3.74%	11.18%	8.94%	2.13%	0.00%	5.36%	35.97%	2.47%	100%
2017	27.27%	4.21%	9.98%	3.41%	0.66%	1.11%	8.91%	37.21%	7.22%	100%
2018	29.85%	6.08%	6.56%	3.38%	6.08%	0.00%	7.00%	38.34%	2.70%	100%

Table 5C-3. EPCWID Irrigated Crop Areas in Percent.

Year	Alfalfa Hay	Chile (Peppers)	Corn, Sweet Corn, and Silage	Cotton	Irrigated Pasture	Miscellaneous Vegetables	Onions	Pecans	Wheat and Small Grains	Total
1938	34.23%	0.00%	3.55%	51.90%	0.48%	9.53%	0.03%	0.06%	0.22%	100%
1939	40.45%	0.00%	3.68%	50.14%	0.63%	4.28%	0.05%	0.64%	0.14%	100%
1940	39.58%	0.00%	2.32%	52.62%	0.29%	4.43%	0.06%	0.48%	0.21%	100%
1941	29.48%	0.00%	1.10%	65.84%	0.38%	2.74%	0.08%	0.31%	0.06%	100%
1942	22.48%	0.00%	0.99%	68.47%	0.48%	7.21%	0.08%	0.23%	0.06%	100%
1943	25.92%	0.00%	1.54%	68.18%	0.72%	3.13%	0.07%	0.23%	0.21%	100%
1944	26.39%	0.00%	1.79%	66.51%	0.67%	3.48%	0.24%	0.18%	0.74%	100%
1945	27.68%	0.00%	1.14%	66.93%	0.72%	3.13%	0.10%	0.27%	0.04%	100%
1946	28.12%	0.00%	1.00%	65.66%	0.57%	3.62%	0.18%	0.22%	0.64%	100%
1947	22.74%	0.00%	0.36%	73.98%	0.23%	2.26%	0.14%	0.27%	0.01%	100%
1948	15.51%	0.00%	0.69%	80.79%	0.35%	2.27%	0.16%	0.24%	0.00%	100%
1949	14.07%	0.00%	0.25%	82.69%	0.58%	1.92%	0.27%	0.17%	0.05%	100%
1950	17.81%	0.00%	0.51%	77.28%	1.12%	2.60%	0.22%	0.17%	0.29%	100%
1951	13.34%	0.00%	0.17%	85.05%	0.19%	0.97%	0.14%	0.08%	0.06%	100%
1952	14.29%	0.01%	0.22%	82.54%	0.42%	1.98%	0.08%	0.17%	0.29%	100%
1953	16.56%	0.01%	0.29%	80.18%	0.35%	2.08%	0.09%	0.19%	0.25%	100%
1954	30.60%	0.08%	1.47%	62.87%	0.34%	2.88%	0.18%	0.14%	1.43%	100%
1955	27.32%	0.12%	2.75%	61.57%	0.23%	5.14%	0.27%	0.19%	2.40%	100%
1956	18.15%	0.23%	4.36%	70.16%	1.93%	1.44%	0.60%	0.66%	2.46%	100%
1957	10.70%	0.07%	0.99%	80.41%	0.88%	5.76%	0.32%	0.37%	0.49%	100%
1958	12.44%	0.10%	2.62%	72.57%	0.51%	8.65%	0.21%	1.05%	1.85%	100%
1959	17.56%	0.11%	3.05%	67.70%	1.69%	4.89%	0.37%	2.16%	2.47%	100%
1960	17.38%	0.12%	2.63%	70.69%	1.19%	4.79%	0.35%	1.86%	0.98%	100%
1961	17.49%	0.21%	2.58%	71.75%	1.86%	3.18%	0.37%	1.57%	0.99%	100%
1962	10.91%	0.11%	2.79%	80.71%	1.57%	2.05%	0.14%	1.38%	0.35%	100%
1963	5.67%	0.04%	1.12%	86.55%	0.81%	4.45%	0.01%	1.27%	0.09%	100%
1964	7.99%	0.24%	1.91%	85.37%	1.02%	2.29%	0.01%	1.12%	0.06%	100%
1965	14.15%	0.17%	5.00%	69.67%	1.44%	7.07%	0.16%	1.01%	1.32%	100%
1966	18.50%	0.27%	1.21%	72.34%	0.00%	0.29%	0.37%	0.49%	6.53%	100%

Table 5C-3. EPCWID Irrigated Crop Areas in Percent.

Year	Alfalfa Hay	Chile (Peppers)	Corn, Sweet Corn, and Silage	Cotton	Irrigated Pasture	Miscellaneous Vegetables	Onions	Pecans	Wheat and Small Grains	Total
1967	13.61%	0.32%	7.22%	63.31%	1.37%	10.57%	0.52%	0.71%	2.36%	100%
1968	12.94%	0.18%	8.36%	65.76%	1.53%	5.77%	0.40%	1.34%	3.71%	100%
1969	13.61%	0.31%	11.90%	63.65%	0.93%	4.42%	0.55%	0.00%	4.63%	100%
1970	15.65%	0.33%	12.63%	55.01%	1.37%	3.93%	0.56%	1.41%	9.11%	100%
1971	20.38%	0.33%	0.48%	49.17%	0.00%	0.35%	0.68%	1.75%	26.84%	100%
1972	21.18%	0.33%	0.53%	41.57%	0.00%	0.39%	0.78%	2.28%	32.95%	100%
1973	21.96%	0.32%	0.57%	34.15%	0.00%	0.43%	0.88%	2.79%	38.90%	100%
1974	22.71%	0.32%	0.61%	26.92%	0.00%	0.47%	0.97%	3.29%	44.71%	100%
1975	22.56%	0.38%	10.91%	36.00%	1.82%	3.71%	0.83%	2.89%	20.89%	100%
1976	19.69%	0.31%	17.74%	19.57%	1.21%	2.52%	1.07%	3.73%	34.16%	100%
1977	24.31%	0.77%	2.98%	52.36%	2.20%	3.45%	0.62%	4.50%	8.81%	100%
1978	20.77%	1.13%	4.29%	58.20%	2.37%	3.39%	0.79%	6.28%	2.77%	100%
1979	18.44%	1.45%	4.91%	62.29%	1.79%	0.74%	0.65%	7.39%	2.33%	100%
1980	19.25%	2.95%	1.73%	48.04%	2.05%	1.22%	1.08%	7.07%	16.60%	100%
1981	17.66%	1.96%	8.16%	44.66%	1.95%	1.28%	0.88%	6.89%	16.55%	100%
1982	15.25%	1.81%	11.23%	38.26%	1.87%	2.48%	1.45%	9.02%	18.62%	100%
1983	15.49%	2.45%	8.59%	43.59%	4.01%	3.31%	1.93%	9.44%	11.18%	100%
1984	16.92%	1.83%	9.25%	44.63%	2.45%	1.34%	1.76%	9.72%	12.10%	100%
1985	20.01%	2.31%	7.20%	44.21%	3.80%	3.44%	1.51%	10.28%	7.26%	100%
1986	17.17%	1.35%	5.63%	46.18%	5.10%	3.42%	1.35%	10.43%	9.39%	100%
1987	16.45%	0.68%	3.35%	55.64%	3.48%	4.95%	1.26%	11.63%	2.56%	100%
1988	14.16%	0.16%	3.60%	58.51%	4.92%	5.14%	1.01%	11.81%	0.69%	100%
1989	12.56%	0.35%	4.71%	62.77%	2.02%	4.69%	0.99%	11.41%	0.50%	100%
1990	10.91%	2.50%	6.05%	59.52%	2.29%	3.09%	1.86%	11.69%	2.09%	100%
1991	10.52%	2.44%	8.48%	58.54%	1.64%	2.07%	1.60%	11.96%	2.74%	100%
1992	12.21%	4.98%	9.15%	45.39%	6.89%	5.18%	1.48%	11.83%	2.90%	100%
1993	15.63%	4.99%	8.42%	39.07%	8.09%	5.75%	2.36%	12.77%	2.93%	100%
1994	12.85%	5.24%	4.90%	43.59%	8.00%	5.70%	3.24%	13.16%	3.33%	100%
1995	12.51%	1.84%	7.62%	49.18%	2.40%	6.06%	1.83%	13.38%	5.16%	100%

Table 5C-3. EPCWID Irrigated Crop Areas in Percent.

Year	Alfalfa Hay	Chile (Peppers)	Corn, Sweet Corn, and Silage	Cotton	Irrigated Pasture	Miscellaneous Vegetables	Onions	Pecans	Wheat and Small Grains	Total
1996	10.69%	2.40%	7.25%	49.19%	1.94%	6.10%	2.27%	14.47%	5.70%	100%
1997	12.33%	2.47%	6.26%	48.64%	1.24%	6.22%	2.34%	14.80%	5.69%	100%
1998	10.97%	2.34%	5.78%	50.22%	1.22%	6.37%	1.64%	15.30%	6.17%	100%
1999	12.20%	1.53%	7.55%	48.95%	4.61%	6.57%	1.83%	16.64%	0.12%	100%
2000	10.41%	1.63%	8.36%	42.94%	7.97%	6.60%	1.58%	20.50%	0.00%	100%
2001	10.18%	0.65%	9.85%	49.20%	4.88%	0.13%	1.83%	23.27%	0.00%	100%
2002	13.94%	1.36%	10.97%	44.71%	4.33%	0.61%	1.71%	22.38%	0.00%	100%
2003	11.07%	1.00%	0.52%	51.59%	3.62%	0.72%	1.62%	29.87%	0.00%	100%
2004	10.92%	0.40%	0.82%	55.24%	0.90%	0.72%	2.42%	28.42%	0.17%	100%
2005	8.92%	0.39%	1.32%	56.81%	1.97%	0.71%	2.38%	25.88%	1.64%	100%
2006	9.00%	0.92%	1.97%	54.88%	1.72%	0.80%	1.69%	28.74%	0.28%	100%
2007	12.12%	0.41%	0.20%	50.34%	1.10%	0.96%	1.42%	29.70%	3.76%	100%
2008	13.05%	0.10%	2.97%	41.70%	2.61%	1.25%	1.80%	33.16%	3.35%	100%
2009	9.72%	0.00%	2.50%	47.77%	0.22%	0.49%	0.00%	33.03%	6.28%	100%
2010	13.76%	0.89%	2.65%	44.13%	1.14%	0.10%	0.24%	29.38%	7.72%	100%
2011	6.68%	0.00%	1.60%	57.56%	0.07%	0.00%	0.12%	33.19%	0.78%	100%
2012	11.81%	0.00%	0.13%	43.04%	0.05%	0.00%	0.19%	44.73%	0.06%	100%
2013	16.10%	0.00%	0.43%	42.74%	0.00%	0.00%	0.50%	40.14%	0.09%	100%
2014	9.69%	0.00%	2.59%	40.52%	0.01%	0.00%	0.81%	46.37%	0.02%	100%
2015	4.37%	0.00%	0.25%	47.73%	0.00%	0.00%	0.31%	47.34%	0.00%	100%
2016	6.89%	0.00%	0.37%	50.22%	0.00%	0.00%	0.59%	41.78%	0.15%	100%
2017	6.92%	0.14%	0.00%	51.70%	0.08%	0.00%	0.00%	41.14%	0.02%	100%
2018	5.03%	0.00%	0.17%	54.47%	0.06%	0.00%	0.42%	39.82%	0.02%	100%

Table 5C-4. Hudspeth Irrigated Crop Areas in Percent.

Year	Alfalfa Hay	Chile (Peppers)	Corn, Sweet Corn, and Silage	Cotton	Irrigated Pasture	Miscellaneous Vegetables	Onions	Pecans	Wheat and Small Grains	Total
1938	21.64%	0.00%	0.00%	64.66%	0.00%	13.70%	0.00%	0.00%	0.00%	100%
1939	28.27%	0.00%	0.00%	71.73%	0.00%	0.00%	0.00%	0.00%	0.00%	100%
1940	28.69%	0.00%	15.88%	55.43%	0.00%	0.00%	0.00%	0.00%	0.00%	100%
1941	23.81%	0.00%	0.75%	66.24%	0.00%	9.20%	0.00%	0.00%	0.00%	100%
1942	19.82%	0.00%	0.50%	76.82%	0.00%	0.20%	0.00%	2.66%	0.00%	100%
1943	22.39%	0.00%	1.81%	65.71%	0.00%	10.09%	0.00%	0.00%	0.00%	100%
1944	26.84%	0.00%	1.04%	66.90%	0.00%	0.00%	0.00%	0.00%	5.22%	100%
1945	31.21%	0.00%	1.84%	63.89%	0.00%	0.00%	0.00%	0.00%	3.06%	100%
1946	26.28%	0.00%	0.35%	69.72%	0.00%	0.26%	0.00%	3.39%	0.00%	100%
1947	21.67%	0.00%	0.24%	76.21%	0.00%	0.12%	0.00%	1.75%	0.00%	100%
1948	18.47%	0.00%	0.00%	79.44%	0.00%	0.00%	0.00%	2.09%	0.00%	100%
1949	14.01%	0.00%	0.00%	84.30%	0.00%	0.00%	0.00%	1.68%	0.00%	100%
1950	22.83%	0.00%	0.09%	72.76%	0.00%	0.03%	0.00%	4.30%	0.00%	100%
1951	14.64%	0.00%	0.00%	82.54%	2.82%	0.00%	0.00%	0.00%	0.00%	100%
1952	19.42%	0.00%	0.00%	80.56%	0.00%	0.00%	0.00%	0.00%	0.02%	100%
1953	20.65%	0.00%	0.00%	74.89%	4.46%	0.00%	0.00%	0.00%	0.00%	100%
1954	35.70%	0.00%	0.21%	52.02%	0.00%	0.00%	0.00%	12.08%	0.00%	100%
1955	21.32%	0.00%	2.86%	59.65%	4.09%	0.40%	0.00%	6.58%	5.10%	100%
1956	10.68%	0.00%	9.65%	56.70%	19.32%	0.00%	0.00%	0.00%	3.65%	100%
1957	17.77%	0.00%	1.37%	66.06%	2.97%	0.30%	0.00%	0.00%	11.53%	100%
1958	29.69%	0.00%	0.45%	56.60%	0.00%	1.65%	0.00%	0.00%	11.60%	100%
1959	31.26%	0.00%	0.00%	61.87%	6.51%	0.00%	0.00%	0.00%	0.36%	100%
1960	30.92%	0.00%	4.57%	53.49%	9.86%	0.00%	0.00%	0.00%	1.17%	100%
1961	27.94%	0.00%	5.93%	58.66%	6.39%	0.00%	0.00%	0.00%	1.09%	100%
1962	24.95%	0.00%	4.06%	59.88%	9.01%	0.22%	0.00%	0.00%	1.87%	100%
1963	6.83%	0.00%	11.20%	77.58%	0.00%	0.00%	0.00%	0.00%	4.38%	100%
1964	10.56%	0.00%	0.00%	82.54%	5.99%	0.00%	0.00%	0.00%	0.91%	100%
1965	19.84%	0.00%	2.65%	63.51%	11.38%	0.00%	0.00%	0.00%	2.62%	100%
1966	20.74%	0.00%	16.79%	48.46%	12.13%	0.00%	0.00%	0.00%	1.88%	100%
1967	13.05%	0.00%	15.24%	53.30%	12.36%	0.00%	0.00%	0.00%	6.05%	100%

Table 5C-4. Hudspeth Irrigated Crop Areas in Percent.

Year	Alfalfa Hay	Chile (Peppers)	Corn, Sweet Corn, and Silage	Cotton	Irrigated Pasture	Miscellaneous Vegetables	Onions	Pecans	Wheat and Small Grains	Total
1968	11.15%	0.00%	13.73%	54.58%	14.60%	0.00%	0.00%	0.00%	5.94%	100%
1969	13.93%	0.00%	21.19%	37.80%	17.15%	0.00%	0.00%	0.00%	9.93%	100%
1970	9.47%	0.00%	30.30%	33.09%	14.50%	0.00%	0.00%	0.09%	12.56%	100%
1971	9.58%	0.00%	14.66%	34.22%	26.40%	0.00%	0.00%	0.00%	15.15%	100%
1972	18.38%	0.00%	12.22%	36.08%	14.45%	0.00%	0.00%	0.00%	18.87%	100%
1973	15.08%	0.00%	10.89%	32.40%	33.02%	0.00%	0.00%	0.00%	8.61%	100%
1974	17.28%	0.00%	5.29%	38.26%	30.85%	0.00%	0.00%	0.00%	8.32%	100%
1975	23.86%	0.00%	8.10%	25.29%	30.20%	0.00%	0.00%	0.00%	12.55%	100%
1976	33.03%	0.00%	0.00%	24.69%	30.04%	0.00%	0.00%	0.00%	12.25%	100%
1977	13.54%	0.00%	0.00%	71.87%	13.63%	0.00%	0.00%	0.00%	0.96%	100%
1978	7.07%	0.00%	0.00%	75.23%	17.70%	0.00%	0.00%	0.00%	0.00%	100%
1979	7.16%	0.00%	4.43%	59.15%	28.37%	0.00%	0.00%	0.00%	0.89%	100%
1980	8.98%	0.00%	2.40%	60.45%	22.31%	0.00%	0.00%	0.00%	5.86%	100%
1981	8.21%	0.00%	6.11%	63.60%	18.08%	0.46%	0.00%	0.00%	3.54%	100%
1982	6.29%	0.00%	3.93%	56.82%	26.25%	0.57%	0.00%	0.00%	6.15%	100%
1983	8.24%	0.00%	2.12%	47.67%	35.15%	6.44%	0.00%	0.00%	0.39%	100%
1984	15.36%	0.00%	2.02%	54.27%	24.20%	0.38%	0.00%	0.00%	3.77%	100%
1985	10.85%	0.00%	3.85%	72.72%	5.54%	0.37%	0.00%	0.00%	6.67%	100%
1986	4.88%	0.00%	1.52%	81.87%	8.68%	0.36%	0.00%	0.00%	2.69%	100%
1987	4.53%	0.00%	0.05%	91.68%	2.33%	0.00%	0.00%	0.37%	1.04%	100%
1988	3.71%	0.00%	1.15%	89.77%	3.63%	0.32%	0.00%	0.00%	1.42%	100%
1989	2.60%	0.00%	1.12%	94.62%	0.94%	0.72%	0.00%	0.00%	0.00%	100%
1990	4.55%	1.84%	0.00%	89.62%	1.03%	1.65%	0.00%	0.00%	1.32%	100%
1991	4.83%	6.87%	0.00%	85.12%	1.67%	0.88%	0.64%	0.00%	0.00%	100%
1992	3.92%	15.95%	1.52%	65.93%	0.50%	11.08%	1.10%	0.00%	0.00%	100%
1993	3.55%	16.19%	1.94%	70.67%	0.52%	5.10%	1.49%	0.00%	0.55%	100%
1994	3.20%	12.24%	2.62%	72.60%	1.32%	6.42%	0.97%	0.00%	0.63%	100%
1995	4.50%	10.38%	1.35%	79.92%	2.61%	0.06%	0.87%	0.30%	0.00%	100%
1996	9.22%	11.22%	4.41%	72.87%	1.03%	0.21%	0.73%	0.32%	0.00%	100%
1997	7.07%	10.80%	3.93%	77.58%	0.33%	0.00%	0.00%	0.30%	0.00%	100%

Table 5C-4. Hudspeth Irrigated Crop Areas in Percent.

Year	Alfalfa Hay	Chile (Peppers)	Corn, Sweet Corn, and Silage	Cotton	Irrigated Pasture	Miscellaneous Vegetables	Onions	Pecans	Wheat and Small Grains	Total
1998	10.64%	9.75%	4.22%	75.09%	0.00%	0.00%	0.00%	0.30%	0.00%	100%
1999	9.06%	4.37%	3.88%	82.40%	0.00%	0.00%	0.00%	0.30%	0.00%	100%
2000	10.74%	5.02%	8.37%	75.53%	0.00%	0.00%	0.00%	0.34%	0.00%	100%
2001	9.57%	4.48%	14.65%	70.97%	0.00%	0.00%	0.00%	0.32%	0.00%	100%
2002	9.83%	4.41%	3.97%	81.48%	0.00%	0.00%	0.00%	0.31%	0.00%	100%
2003	13.34%	2.90%	2.90%	72.74%	3.77%	3.70%	0.00%	0.67%	0.00%	100%
2004	13.98%	2.73%	0.00%	74.23%	0.00%	8.40%	0.00%	0.66%	0.00%	100%
2005	12.24%	0.00%	0.00%	77.64%	0.00%	9.61%	0.00%	0.51%	0.00%	100%
2006	10.94%	0.00%	0.00%	82.93%	0.00%	5.65%	0.00%	0.48%	0.00%	100%
2007	19.54%	0.00%	0.00%	75.40%	2.26%	2.34%	0.00%	0.46%	0.00%	100%
2008	13.88%	1.39%	12.91%	66.70%	0.00%	4.74%	0.00%	0.40%	0.00%	100%
2009	13.53%	0.00%	2.44%	72.64%	0.00%	8.87%	0.00%	0.00%	2.53%	100%
2010	16.18%	3.16%	0.21%	73.36%	0.00%	3.51%	0.00%	0.34%	3.24%	100%
2011	6.48%	0.00%	1.74%	91.16%	0.00%	0.00%	0.00%	0.61%	0.00%	100%
2012	12.86%	0.00%	0.00%	85.56%	0.00%	0.00%	0.00%	0.85%	0.73%	100%
2013	11.76%	0.00%	0.00%	85.27%	0.83%	0.00%	0.00%	2.14%	0.00%	100%
2014	20.72%	0.65%	0.00%	76.58%	0.00%	0.00%	0.00%	2.05%	0.00%	100%
2015	14.18%	0.00%	0.00%	82.49%	0.00%	0.00%	0.00%	0.53%	2.80%	100%
2016	20.16%	0.00%	0.00%	70.78%	0.00%	0.00%	0.00%	0.90%	8.16%	100%
2017	19.62%	1.29%	0.27%	72.80%	0.00%	0.00%	0.00%	1.73%	4.29%	100%
2018	19.77%	0.00%	0.59%	72.39%	0.00%	0.00%	0.00%	1.78%	5.47%	100%

Table 5C-5. Juarez Irrigated Crop Areas in Percent.										
Year	Alfalfa Hay	Chile (Peppers)	Corn, Sweet Corn, and Silage	Cotton	Irrigated Pasture	Miscellaneous Vegetables	Onions	Pecans	Wheat and Small Grains	Total
1938	1.47%	0.00%	0.00%	98.53%	0.00%	0.00%	0.00%	0.00%	0.00%	100%
1939	1.47%	0.00%	0.00%	98.53%	0.00%	0.00%	0.00%	0.00%	0.00%	100%
1940	1.47%	0.00%	0.00%	98.53%	0.00%	0.00%	0.00%	0.00%	0.00%	100%
1941	1.47%	0.00%	0.00%	98.53%	0.00%	0.00%	0.00%	0.00%	0.00%	100%
1942	1.47%	0.00%	0.00%	98.53%	0.00%	0.00%	0.00%	0.00%	0.00%	100%
1943	1.47%	0.00%	0.00%	98.53%	0.00%	0.00%	0.00%	0.00%	0.00%	100%
1944	1.47%	0.00%	0.00%	98.53%	0.00%	0.00%	0.00%	0.00%	0.00%	100%
1945	1.47%	0.00%	0.00%	98.53%	0.00%	0.00%	0.00%	0.00%	0.00%	100%
1946	1.47%	0.00%	0.00%	98.53%	0.00%	0.00%	0.00%	0.00%	0.00%	100%
1947	1.47%	0.00%	0.00%	98.53%	0.00%	0.00%	0.00%	0.00%	0.00%	100%
1948	1.47%	0.00%	0.00%	98.53%	0.00%	0.00%	0.00%	0.00%	0.00%	100%
1949	1.47%	0.00%	0.00%	98.53%	0.00%	0.00%	0.00%	0.00%	0.00%	100%
1950	1.47%	0.00%	0.00%	98.53%	0.00%	0.00%	0.00%	0.00%	0.00%	100%
1951	1.47%	0.00%	0.00%	98.53%	0.00%	0.00%	0.00%	0.00%	0.00%	100%
1952	1.47%	0.00%	0.00%	98.53%	0.00%	0.00%	0.00%	0.00%	0.00%	100%
1953	1.47%	0.00%	0.00%	98.53%	0.00%	0.00%	0.00%	0.00%	0.00%	100%
1954	1.47%	0.00%	0.00%	98.53%	0.00%	0.00%	0.00%	0.00%	0.00%	100%
1955	1.47%	0.00%	0.00%	98.53%	0.00%	0.00%	0.00%	0.00%	0.00%	100%
1956	1.47%	0.00%	0.00%	98.53%	0.00%	0.00%	0.00%	0.00%	0.00%	100%
1957	1.47%	0.00%	0.00%	98.53%	0.00%	0.00%	0.00%	0.00%	0.00%	100%
1958	1.47%	0.00%	0.00%	98.53%	0.00%	0.00%	0.00%	0.00%	0.00%	100%
1959	1.47%	0.00%	0.00%	98.53%	0.00%	0.00%	0.00%	0.00%	0.00%	100%
1960	1.47%	0.00%	0.00%	98.53%	0.00%	0.00%	0.00%	0.00%	0.00%	100%
1961	1.47%	0.00%	0.00%	98.53%	0.00%	0.00%	0.00%	0.00%	0.00%	100%
1962	2.08%	0.00%	0.00%	94.80%	0.00%	0.00%	0.00%	0.00%	3.12%	100%
1963	2.98%	0.00%	0.00%	94.81%	0.00%	0.00%	0.00%	0.00%	2.21%	100%
1964	6.42%	0.00%	0.00%	91.76%	0.00%	0.00%	0.00%	0.00%	1.82%	100%
1965	9.72%	0.00%	1.60%	87.47%	0.00%	0.00%	0.00%	0.00%	1.21%	100%
1966	8.40%	0.00%	0.00%	91.60%	0.00%	0.00%	0.00%	0.00%	0.00%	100%
1967	8.95%	0.00%	1.11%	77.72%	0.00%	0.00%	0.00%	0.00%	12.22%	100%

Table 5C-5. Juarez Irrigated Crop Areas in Percent.										
Year	Alfalfa Hay	Chile (Peppers)	Corn, Sweet Corn, and Silage	Cotton	Irrigated Pasture	Miscellaneous Vegetables	Onions	Pecans	Wheat and Small Grains	Total
1968	9.72%	0.00%	3.48%	76.45%	0.00%	0.00%	0.00%	0.00%	10.35%	100%
1969	9.81%	0.00%	2.62%	75.55%	0.00%	0.00%	0.00%	0.74%	11.28%	100%
1970	10.39%	0.00%	2.59%	74.69%	0.00%	0.00%	0.00%	0.73%	11.60%	100%
1971	12.37%	0.00%	1.64%	74.23%	0.00%	0.00%	0.00%	0.93%	10.83%	100%
1972	17.68%	0.00%	1.60%	70.13%	0.00%	0.00%	0.00%	0.99%	9.59%	100%
1973	16.56%	0.00%	9.18%	61.59%	0.00%	0.26%	0.00%	0.91%	11.50%	100%
1974	17.73%	0.00%	4.23%	62.33%	0.00%	0.25%	0.00%	1.01%	14.44%	100%
1975	20.34%	0.00%	5.22%	61.01%	0.00%	0.47%	0.00%	1.18%	11.78%	100%
1976	19.41%	0.00%	2.85%	51.18%	0.00%	0.80%	0.00%	1.44%	24.33%	100%
1977	18.79%	0.00%	9.47%	46.87%	0.00%	0.93%	0.00%	1.44%	22.51%	100%
1978	29.58%	0.00%	0.00%	55.19%	0.00%	0.90%	0.00%	1.34%	12.99%	100%
1979	30.27%	0.00%	0.00%	59.06%	0.00%	0.31%	0.00%	1.32%	9.04%	100%
1980	27.47%	0.00%	0.00%	62.63%	0.00%	0.30%	0.00%	1.78%	7.81%	100%
1981	27.47%	0.00%	0.00%	62.63%	0.00%	0.30%	0.00%	1.78%	7.81%	100%
1982	26.74%	0.00%	0.00%	56.82%	0.00%	12.54%	0.00%	1.09%	2.81%	100%
1983	26.74%	0.00%	0.00%	56.82%	0.00%	12.54%	0.00%	1.09%	2.81%	100%
1984	28.91%	0.00%	0.00%	58.28%	0.00%	10.53%	0.00%	1.28%	1.01%	100%
1985	28.44%	0.01%	0.53%	57.90%	0.13%	9.91%	0.01%	1.28%	1.78%	100%
1986	27.97%	0.01%	1.06%	57.52%	0.26%	9.29%	0.02%	1.29%	2.57%	100%
1987	27.49%	0.02%	1.60%	57.14%	0.39%	8.66%	0.03%	1.30%	3.36%	100%
1988	27.00%	0.02%	2.15%	56.75%	0.53%	8.02%	0.05%	1.31%	4.17%	100%
1989	26.51%	0.03%	2.70%	56.36%	0.67%	7.38%	0.06%	1.32%	4.98%	100%
1990	26.01%	0.03%	3.26%	55.96%	0.80%	6.72%	0.07%	1.33%	5.81%	100%
1991	25.50%	0.04%	3.83%	55.56%	0.94%	6.06%	0.08%	1.34%	6.64%	100%
1992	24.99%	0.05%	4.41%	55.15%	1.09%	5.39%	0.09%	1.35%	7.49%	100%
1993	24.47%	0.05%	4.99%	54.74%	1.23%	4.71%	0.11%	1.36%	8.35%	100%
1994	23.94%	0.06%	5.58%	54.32%	1.38%	4.02%	0.12%	1.37%	9.22%	100%
1995	23.41%	0.07%	6.18%	53.89%	1.52%	3.32%	0.13%	1.37%	10.10%	100%
1996	22.87%	0.07%	6.79%	53.46%	1.67%	2.62%	0.14%	1.38%	10.99%	100%
1997	22.32%	0.08%	7.40%	53.03%	1.82%	1.90%	0.16%	1.39%	11.89%	100%

Table 5C-5. Juarez Irrigated Crop Areas in Percent.										
Year	Alfalfa Hay	Chile (Peppers)	Corn, Sweet Corn, and Silage	Cotton	Irrigated Pasture	Miscellaneous Vegetables	Onions	Pecans	Wheat and Small Grains	Total
1998	21.77%	0.08%	8.02%	52.58%	1.98%	1.17%	0.17%	1.40%	12.81%	100%
1999	21.21%	0.09%	8.66%	52.14%	2.13%	0.44%	0.18%	1.41%	13.74%	100%
2000	20.40%	0.23%	10.60%	42.79%	2.64%	0.42%	0.11%	1.30%	21.51%	100%
2001	20.82%	0.03%	12.55%	42.47%	2.46%	0.47%	0.29%	1.74%	19.17%	100%
2002	23.79%	0.13%	10.58%	36.00%	5.93%	0.58%	0.23%	2.31%	20.45%	100%
2003	25.65%	0.07%	10.50%	42.21%	4.56%	0.35%	0.00%	3.22%	13.45%	100%
2004	20.16%	0.00%	8.99%	49.58%	5.92%	0.00%	0.00%	3.71%	11.64%	100%
2005	18.21%	0.04%	11.64%	41.14%	7.64%	1.18%	0.20%	3.00%	16.94%	100%
2006	19.97%	0.04%	8.99%	41.34%	6.86%	1.09%	0.19%	6.27%	15.25%	100%
2007	16.42%	0.19%	10.20%	42.59%	5.21%	1.84%	0.09%	6.58%	16.87%	100%
2008	16.09%	0.15%	4.31%	40.93%	5.23%	0.94%	0.00%	6.37%	25.98%	100%
2009	14.31%	0.00%	16.25%	33.59%	4.58%	0.88%	0.00%	5.67%	24.71%	100%
2010	11.86%	0.00%	11.76%	40.54%	5.01%	0.93%	0.00%	6.26%	23.63%	100%
2011	12.56%	0.00%	1.92%	52.56%	4.33%	1.25%	0.00%	6.62%	20.76%	100%
2012	15.05%	0.00%	1.85%	54.23%	4.67%	4.66%	0.00%	7.14%	12.41%	100%
2013	18.40%	0.26%	9.63%	42.75%	5.70%	3.71%	0.00%	5.98%	13.57%	100%
2014	19.06%	0.23%	8.88%	49.26%	4.51%	1.20%	0.00%	6.34%	10.51%	100%
2015	18.30%	0.32%	6.70%	46.09%	4.37%	1.84%	0.00%	9.13%	13.25%	100%
2016	17.50%	0.21%	6.62%	46.42%	4.27%	1.41%	0.16%	9.44%	13.97%	100%
2017	20.43%	0.23%	6.77%	48.91%	1.92%	1.49%	0.00%	9.35%	10.90%	100%
2018	20.43%	0.23%	6.77%	48.91%	1.92%	1.49%	0.00%	9.35%	10.90%	100%

Appendix 5D. Irrigated Crop Areas in Acres

Table 5D-1. EBID Surface Water Irrigated Crop Areas in Acres

Year	Alfalfa Hay	Chile (Peppers)	Corn, Sweet Corn, and Silage	Cotton	Irrigated Pasture	Miscellaneous Vegetables	Onions	Pecans	Wheat and Small Grains	Total
1938	21,834	1	7,836	36,702	1,421	9,338	167	298	641	78,237
1939	28,009	0	9,225	33,789	1,105	5,138	192	323	753	78,533
1940	27,524	0	8,211	36,464	660	4,238	177	2,417	688	80,379
1941	19,214	0	5,156	51,074	1,620	3,675	194	2,763	248	83,944
1942	15,185	0	3,810	54,045	866	9,279	210	2,802	284	86,482
1943	18,920	0	4,764	55,535	1,604	3,269	205	3,042	697	88,035
1944	21,739	2	4,933	52,251	1,012	3,258	419	3,917	585	88,116
1945	20,540	0	2,616	55,008	1,181	4,239	435	4,062	632	88,714
1946	19,885	958	2,604	56,740	1,066	2,995	1,091	4,110	650	90,099
1947	16,703	356	1,680	64,002	739	2,562	568	3,988	232	90,829
1948	8,956	209	916	71,754	440	1,708	328	4,165	685	89,162
1949	9,240	289	795	74,660	531	1,686	387	4,090	24	91,701
1950	14,725	305	1,999	65,852	1,231	2,594	425	3,944	447	91,521
1951	6,277	339	371	77,316	1,143	823	283	4,052	5	90,608
1952	10,884	384	317	72,083	2,523	1,193	329	3,999	396	92,109
1953	11,722	475	465	71,505	2,253	1,743	348	4,175	359	93,045
1954	18,769	742	2,545	51,077	2,131	3,184	320	3,999	3,067	85,834
1955	23,265	464	2,204	49,179	1,008	2,941	368	4,175	2,549	86,153
1956	20,224	856	2,871	47,191	1,149	2,962	534	4,181	2,141	82,110
1957	15,386	666	2,042	53,418	784	3,750	843	4,207	1,644	82,740
1958	16,062	636	2,161	50,145	2,515	5,003	1,130	4,188	2,084	83,923
1959	13,695	662	2,531	54,514	703	4,352	1,585	4,380	2,499	84,920
1960	13,733	640	2,373	52,332	3,826	3,859	1,654	4,160	2,584	85,162
1961	15,116	731	1,808	53,669	1,129	3,596	1,417	4,350	3,572	85,388
1962	11,335	633	1,806	60,023	703	2,758	1,603	4,375	2,955	86,191
1963	8,148	677	1,419	65,734	485	2,669	1,314	4,345	1,878	86,669
1964	10,041	750	1,997	60,181	596	3,136	1,674	4,226	2,279	84,881
1965	12,900	786	2,922	52,306	707	4,807	2,078	4,353	2,400	83,259
1966	11,908	1,584	3,533	41,655	1,324	11,191	2,830	4,490	1,887	80,402

Table 5D-1. EBID Surface Water Irrigated Crop Areas in Acres

Year	Alfalfa Hay	Chile (Peppers)	Corn, Sweet Corn, and Silage	Cotton	Irrigated Pasture	Miscellaneous Vegetables	Onions	Pecans	Wheat and Small Grains	Total
1967	11,504	1,530	3,413	40,242	1,279	10,812	2,734	4,338	1,823	77,675
1968	10,678	1,353	3,371	45,348	1,077	11,334	3,218	4,928	1,653	82,959
1969	11,741	2,717	4,363	42,245	1,305	11,739	3,001	5,047	2,054	84,211
1970	13,805	2,792	4,731	42,746	1,285	7,860	3,126	5,491	3,112	84,948
1971	14,136	3,224	4,955	42,680	1,499	7,587	2,625	5,556	2,101	84,363
1972	13,912	4,004	3,153	42,080	1,538	4,313	2,690	6,060	2,846	80,598
1973	14,951	4,058	4,506	40,922	2,071	4,814	3,261	6,334	3,840	84,757
1974	13,904	5,414	2,792	45,798	2,167	3,494	2,426	6,495	2,891	85,380
1975	15,091	4,906	7,420	31,697	1,313	7,402	2,754	6,535	8,228	85,346
1976	14,533	6,369	7,723	18,962	922	6,602	2,786	6,436	14,389	78,721
1977	15,721	7,657	3,121	30,591	808	7,751	3,752	8,358	6,923	84,682
1978	13,950	7,776	3,477	30,716	617	9,679	3,058	9,059	3,781	82,112
1979	12,667	10,244	3,031	28,794	707	7,312	3,035	9,507	3,579	78,877
1980	14,568	10,721	3,949	23,883	912	6,418	3,096	10,120	6,619	80,285
1981	16,059	9,360	4,673	22,953	1,008	6,311	2,695	10,705	9,891	83,655
1982	17,220	9,155	4,081	19,637	929	7,990	3,588	10,694	7,196	80,489
1983	17,054	9,563	3,508	16,727	1,114	8,476	3,238	11,243	4,252	75,177
1984	17,605	8,625	5,037	17,159	1,143	7,076	3,017	12,275	5,110	77,047
1985	19,096	11,554	7,101	13,447	1,071	7,430	3,241	12,079	3,679	78,697
1986	17,268	10,072	5,521	16,614	1,345	7,491	3,121	13,595	3,990	79,017
1987	14,167	10,008	671	20,522	4,026	8,126	3,070	13,832	3,174	77,597
1988	12,431	9,209	4,164	23,011	931	6,991	3,292	13,683	2,825	76,536
1989	12,123	7,875	4,837	28,286	732	4,780	3,317	14,548	2,464	78,962
1990	12,886	8,969	5,214	22,726	848	5,172	3,956	14,647	2,579	76,997
1991	14,549	7,971	6,143	23,776	902	5,148	3,361	15,192	1,858	78,899
1992	14,857	9,972	6,608	18,298	765	4,734	4,296	15,869	2,123	77,522
1993	13,637	8,474	6,611	17,445	708	5,466	5,184	16,237	1,982	75,743
1994	15,995	6,460	8,274	17,169	887	4,110	4,242	16,488	3,283	76,909
1995	18,877	5,662	4,639	19,571	625	3,270	4,276	17,367	3,333	77,620
1996	17,775	4,890	8,001	15,784	524	4,024	4,283	19,292	4,673	79,246

Table 5D-1. EBID Surface Water Irrigated Crop Areas in Acres

Year	Alfalfa Hay	Chile (Peppers)	Corn, Sweet Corn, and Silage	Cotton	Irrigated Pasture	Miscellaneous Vegetables	Onions	Pecans	Wheat and Small Grains	Total
1997	16,558	5,204	7,509	17,097	519	5,173	4,109	17,388	4,238	77,795
1998	16,866	4,929	8,271	14,267	467	5,445	4,280	18,563	4,462	77,550
1999	17,002	5,364	9,959	13,138	517	4,031	4,536	19,786	2,817	77,150
2000	17,050	4,915	8,278	14,674	595	4,798	5,102	19,722	2,799	77,933
2001	17,020	4,404	9,272	14,675	604	5,294	4,331	21,182	2,279	79,061
2002	17,694	3,986	9,193	13,005	638	5,415	4,898	20,896	2,056	77,782
2003	16,582	2,796	5,219	13,221	701	12,659	3,332	19,613	254	74,377
2004	14,382	2,856	4,357	16,413	505	13,640	3,061	20,744	708	76,665
2005	13,598	3,096	6,994	14,211	950	12,439	5,059	19,546	1,465	77,358
2006	14,246	2,415	5,857	14,993	807	11,610	3,863	21,054	1,174	76,019
2007	15,295	2,732	7,244	12,758	887	11,052	3,726	21,369	1,968	77,030
2008	16,276	3,473	7,011	10,291	906	9,956	3,534	22,933	2,108	76,486
2009	15,472	2,905	6,691	6,743	996	10,831	3,036	22,109	2,427	71,210
2010	15,188	2,550	6,179	9,504	573	12,397	3,319	23,097	2,068	74,875
2011	19,768	385	4,440	18,203	103	342	1,290	24,295	2,765	71,592
2012	15,130	2,283	7,650	9,982	1,565	511	4,357	22,579	4,053	68,110
2013	16,763	3,303	7,725	9,556	1,522	577	4,687	24,993	3,368	72,494
2014	16,929	1,286	8,488	12,380	553	291	3,575	26,013	2,609	72,124
2015	14,890	1,520	7,833	10,176	442	603	3,765	26,991	2,838	69,057
2016	14,300	1,662	6,807	12,475	127	209	3,226	28,779	2,446	70,031
2017	13,501	1,966	5,781	11,024	241	437	3,890	29,673	3,090	69,602
2018	13,144	2,243	6,144	12,268	717	281	3,038	28,920	2,546	69,302

Table 5D-2. EBID Groundwater Only Irrigated Crop Areas in Acres

Year	Alfalfa Hay	Chile (Peppers)	Corn, Sweet Corn, and Silage	Cotton	Irrigated Pasture	Miscellaneous Vegetables	Onions	Pecans	Wheat and Small Grains	Total
1938	0	0	0	0	0	0	0	0	0	0
1939	0	0	0	0	0	0	0	0	0	0
1940	0	0	0	0	0	0	0	0	0	0
1941	0	0	0	0	0	0	0	0	0	0
1942	0	0	0	0	0	0	0	0	0	0
1943	0	0	0	0	0	0	0	0	0	0
1944	0	0	0	0	0	0	0	0	0	0
1945	0	0	0	0	0	0	0	0	0	0
1946	0	0	0	0	0	0	0	0	0	0
1947	0	0	0	0	0	0	0	0	0	0
1948	125	13	30	13	67	3	3	0	4	258
1949	449	47	109	48	241	11	11	0	13	928
1950	565	60	137	60	303	14	13	0	16	1,168
1951	1,109	117	268	118	594	28	26	0	31	2,292
1952	1,640	173	397	174	878	42	39	0	47	3,389
1953	1,867	197	452	198	1,000	48	44	0	53	3,859
1954	1,901	201	460	202	1,019	48	45	0	54	3,930
1955	2,118	224	512	225	1,135	54	50	0	60	4,378
1956	1,544	163	374	164	827	39	36	0	44	3,192
1957	1,601	169	387	170	858	41	38	0	45	3,309
1958	1,657	175	401	176	888	42	39	0	47	3,425
1959	1,714	181	415	182	918	44	40	0	49	3,542
1960	1,699	179	411	180	910	43	40	24	48	3,535
1961	1,684	178	407	179	902	43	40	46	48	3,527
1962	1,670	176	404	177	895	42	39	68	47	3,520
1963	1,657	175	401	176	887	42	39	89	47	3,513
1964	1,643	174	398	175	880	42	39	108	47	3,505
1965	1,631	172	395	173	874	41	39	127	46	3,498
1966	1,619	171	392	172	867	41	38	145	46	3,490
1967	1,607	170	389	171	861	41	38	162	46	3,483

Table 5D-2. EBID Groundwater Only Irrigated Crop Areas in Acres

Year	Alfalfa Hay	Chile (Peppers)	Corn, Sweet Corn, and Silage	Cotton	Irrigated Pasture	Miscellaneous Vegetables	Onions	Pecans	Wheat and Small Grains	Total
1968	1,595	168	386	170	855	41	38	178	45	3,476
1969	1,584	167	383	168	849	40	37	194	45	3,468
1970	1,573	166	381	167	843	40	37	209	45	3,461
1971	1,563	165	378	166	837	40	37	224	44	3,454
1972	1,552	164	376	165	832	40	37	237	44	3,446
1973	1,542	163	373	164	826	39	36	251	44	3,439
1974	1,533	162	371	163	821	39	36	263	43	3,432
1975	1,523	161	369	162	816	39	36	276	43	3,424
1976	1,514	160	366	161	811	39	36	287	43	3,417
1977	1,584	167	383	168	849	40	37	337	45	3,611
1978	1,652	174	400	176	885	42	39	391	47	3,805
1979	1,718	181	416	183	920	44	41	449	49	3,999
1980	1,833	193	443	195	982	47	43	403	52	4,191
1981	1,772	187	429	188	949	45	42	456	50	4,118
1982	1,707	180	413	181	915	43	40	517	48	4,045
1983	1,638	173	396	174	877	42	39	588	46	3,973
1984	1,676	177	405	178	898	43	40	554	48	4,017
1985	1,710	181	414	182	916	44	40	528	49	4,062
1986	1,741	184	421	185	933	44	41	508	49	4,107
1987	1,601	169	387	170	858	41	38	604	45	3,913
1988	1,440	152	348	153	771	37	34	742	41	3,718
1989	1,541	163	373	164	826	39	36	806	44	3,991
1990	1,642	173	397	175	880	42	39	870	47	4,264
1991	1,656	175	401	176	887	42	39	901	47	4,322
1992	1,669	176	404	177	894	42	39	931	47	4,380
1993	1,682	178	407	179	901	43	40	962	48	4,438
1994	1,695	179	410	180	908	43	40	992	48	4,496
1995	1,709	180	413	182	916	43	40	1,022	48	4,554
1996	1,722	182	417	183	923	44	41	1,052	49	4,612
1997	1,769	187	428	188	948	45	42	1,076	50	4,732

Table 5D-2. EBID Groundwater Only Irrigated Crop Areas in Acres

Year	Alfalfa Hay	Chile (Peppers)	Corn, Sweet Corn, and Silage	Cotton	Irrigated Pasture	Miscellaneous Vegetables	Onions	Pecans	Wheat and Small Grains	Total
1998	1,815	192	439	193	972	46	43	1,100	52	4,852
1999	1,861	197	450	198	997	47	44	1,124	53	4,972
2000	1,908	201	462	203	1,022	49	45	1,148	54	5,091
2001	1,862	197	450	198	997	47	44	1,293	53	5,140
2002	1,953	206	472	207	1,046	50	46	1,314	55	5,350
2003	1,815	192	439	193	972	46	43	1,345	52	5,096
2004	1,822	192	441	194	976	46	43	1,386	52	5,153
2005	1,756	185	425	187	941	45	41	1,379	50	5,008
2006	1,727	182	418	183	925	44	41	1,372	49	4,941
2007	1,752	185	424	186	938	45	41	1,359	50	4,980
2008	1,635	173	396	174	876	42	39	1,194	46	4,574
2009	1,380	146	334	147	739	35	33	1,544	39	4,397
2010	1,558	165	377	166	835	40	37	1,573	44	4,794
2011	1,312	138	317	139	703	33	31	1,699	37	4,411
2012	1,298	137	314	138	695	33	31	1,733	37	4,415
2013	1,536	162	372	163	823	39	36	1,531	44	4,706
2014	1,734	7	517	453	52	0	164	1,629	92	4,646
2015	1,264	197	673	252	95	48	333	1,547	149	4,559
2016	1,465	182	543	434	103	0	260	1,746	120	4,853
2017	1,259	195	461	157	31	51	411	1,718	333	4,616
2018	1,357	276	298	154	277	0	318	1,743	123	4,547

Table 5D-3. EPCWID Irrigated Crop Areas in Acres.

Year	Alfalfa Hay	Chile (Peppers)	Corn, Sweet Corn, and Silage	Cotton	Irrigated Pasture	Miscellaneous Vegetables	Onions	Pecans	Wheat and Small Grains	Total
1938	20,237	0	2,100	30,683	286	5,632	18	33	129	59,117
1939	24,737	0	2,248	30,660	383	2,616	34	392	83	61,153
1940	24,718	0	1,452	32,859	181	2,768	38	302	131	62,450
1941	18,770	0	698	41,921	244	1,745	51	199	40	63,669
1942	14,573	0	639	44,377	312	4,675	50	150	41	64,816
1943	16,979	0	1,009	44,663	470	2,049	48	150	139	65,506
1944	17,339	0	1,178	43,697	438	2,288	156	116	487	65,699
1945	18,197	0	748	44,003	475	2,058	67	176	24	65,747
1946	18,691	1	662	43,649	377	2,408	119	147	424	66,477
1947	15,231	0	243	49,563	157	1,514	95	179	10	66,992
1948	10,319	0	461	53,768	230	1,510	104	163	0	66,554
1949	9,475	0	165	55,682	391	1,293	184	116	36	67,342
1950	11,965	0	345	51,921	750	1,748	148	113	194	67,183
1951	8,826	0	109	56,273	127	641	95	51	43	66,166
1952	9,480	8	147	54,772	278	1,313	54	110	194	66,356
1953	11,039	8	194	53,449	233	1,386	59	127	169	66,664
1954	17,317	45	834	35,578	194	1,632	102	80	812	56,594
1955	15,364	69	1,545	34,620	130	2,890	153	108	1,350	56,229
1956	9,119	117	2,192	35,254	970	724	302	332	1,235	50,245
1957	5,427	35	503	40,773	447	2,921	164	188	246	50,705
1958	7,073	57	1,493	41,276	288	4,923	119	596	1,054	56,879
1959	10,364	66	1,801	39,960	999	2,884	216	1,278	1,455	59,023
1960	10,118	73	1,533	41,159	691	2,790	207	1,085	573	58,228
1961	9,842	118	1,449	40,369	1,047	1,789	210	884	558	56,266
1962	6,484	64	1,661	47,986	934	1,221	81	818	208	59,457
1963	3,447	22	678	52,608	493	2,705	5	769	57	60,783
1964	4,561	135	1,088	48,760	583	1,307	5	642	37	57,118
1965	7,765	95	2,743	38,227	792	3,878	90	555	722	54,868
1966	9,943	146	650	38,886	0	154	199	262	3,513	53,753
1967	7,370	176	3,909	34,278	743	5,725	279	385	1,275	54,139

Table 5D-3. EPCWID Irrigated Crop Areas in Acres.

Year	Alfalfa Hay	Chile (Peppers)	Corn, Sweet Corn, and Silage	Cotton	Irrigated Pasture	Miscellaneous Vegetables	Onions	Pecans	Wheat and Small Grains	Total
1968	7,234	99	4,675	36,765	853	3,228	226	750	2,074	55,904
1969	7,720	178	6,752	36,107	527	2,508	311	0	2,625	56,726
1970	8,812	183	7,110	30,968	770	2,213	317	793	5,126	56,291
1971	11,249	184	267	27,141	0	193	378	968	14,813	55,192
1972	11,571	179	287	22,711	0	213	428	1,246	18,001	54,636
1973	11,635	172	300	18,098	0	228	466	1,480	20,616	52,995
1974	11,787	166	314	13,970	0	242	505	1,710	23,203	51,896
1975	11,767	196	5,692	18,777	951	1,936	431	1,508	10,896	52,154
1976	8,786	139	7,913	8,733	540	1,124	476	1,663	15,242	44,617
1977	12,542	395	1,538	27,014	1,134	1,779	319	2,324	4,547	51,590
1978	10,024	547	2,072	28,087	1,145	1,635	382	3,029	1,336	48,257
1979	9,589	752	2,553	32,390	932	385	337	3,844	1,214	51,995
1980	9,133	1,398	823	22,797	975	580	514	3,357	7,875	47,452
1981	8,663	961	4,002	21,905	956	630	432	3,379	8,117	49,045
1982	7,369	873	5,424	18,484	906	1,199	703	4,360	8,994	48,311
1983	7,168	1,134	3,973	20,174	1,856	1,533	893	4,369	5,176	46,276
1984	7,987	864	4,365	21,062	1,158	634	829	4,586	5,710	47,194
1985	9,124	1,052	3,281	20,161	1,733	1,567	690	4,687	3,310	45,605
1986	7,831	615	2,565	21,061	2,327	1,558	614	4,755	4,281	45,606
1987	7,802	321	1,590	26,390	1,649	2,347	598	5,516	1,216	47,428
1988	6,441	73	1,637	26,617	2,239	2,337	458	5,374	316	45,492
1989	5,925	166	2,225	29,616	952	2,215	466	5,385	237	47,185
1990	4,758	1,092	2,638	25,965	998	1,349	813	5,101	911	43,624
1991	5,222	1,213	4,211	29,059	815	1,026	796	5,936	1,358	49,637
1992	6,475	2,642	4,851	24,079	3,654	2,747	786	6,274	1,539	53,048
1993	8,289	2,647	4,468	20,725	4,289	3,049	1,253	6,773	1,552	53,044
1994	6,835	2,785	2,609	23,186	4,253	3,030	1,722	6,999	1,769	53,187
1995	6,651	980	4,051	26,137	1,275	3,223	974	7,112	2,742	53,145
1996	4,835	1,088	3,283	22,256	876	2,758	1,026	6,546	2,577	45,246
1997	6,485	1,300	3,290	25,582	653	3,272	1,231	7,785	2,994	52,591

Table 5D-3. EPCWID Irrigated Crop Areas in Acres.

Year	Alfalfa Hay	Chile (Peppers)	Corn, Sweet Corn, and Silage	Cotton	Irrigated Pasture	Miscellaneous Vegetables	Onions	Pecans	Wheat and Small Grains	Total
1998	5,813	1,238	3,065	26,609	647	3,376	867	8,105	3,268	52,987
1999	6,294	791	3,896	25,257	2,379	3,387	943	8,583	64	51,594
2000	5,063	795	4,067	20,887	3,876	3,210	768	9,971	0	48,638
2001	4,235	270	4,097	20,455	2,030	53	763	9,676	0	41,579
2002	5,720	557	4,499	18,341	1,776	249	702	9,181	0	41,024
2003	4,291	387	200	19,997	1,403	278	629	11,579	0	38,763
2004	4,134	150	310	20,913	342	272	916	10,760	63	37,860
2005	3,585	157	531	22,842	791	284	956	10,405	657	40,207
2006	3,650	371	799	22,248	698	325	686	11,650	114	40,542
2007	4,916	165	81	20,421	448	391	575	12,047	1,525	40,569
2008	5,340	42	1,214	17,060	1,069	513	737	13,566	1,370	40,911
2009	3,900	0	1,004	19,175	87	198	0	13,258	2,521	40,142
2010	5,547	358	1,069	17,787	458	40	95	11,840	3,111	40,306
2011	2,649	0	633	22,830	27	0	49	13,164	308	39,659
2012	3,226	0	34	11,752	13	0	52	12,214	16	27,307
2013	4,815	0	128	12,781	0	0	149	12,002	28	29,903
2014	2,986	0	797	12,489	2	0	249	14,293	5	30,822
2015	1,316	0	74	14,383	0	0	94	14,266	0	30,134
2016	2,501	1	134	18,235	0	0	214	15,168	54	36,308
2017	2,424	48	1	18,111	30	0	0	14,412	5	35,031
2018	1,810	1	61	19,612	22	0	152	14,336	8	36,002

Table 5D-4. Hudspeth Irrigated Crop Areas in Acres

Year	Alfalfa Hay	Chile (Peppers)	Corn, Sweet Corn, and Silage	Cotton	Irrigated Pasture	Miscellaneous Vegetables	Onions	Pecans	Wheat and Small Grains	Total
1938	2,387	0	0	7,134	0	1,512	0	0	0	11,033
1939	3,505	0	0	8,895	0	0	0	0	0	12,400
1940	3,829	0	2,120	7,398	0	0	0	0	0	13,347
1941	3,170	0	100	8,817	0	1,225	0	0	0	13,312
1942	2,718	0	68	10,532	0	27	0	365	0	13,710
1943	3,206	0	259	9,407	0	1,444	0	0	0	14,316
1944	3,808	0	148	9,491	0	0	0	0	740	14,187
1945	4,652	0	274	9,523	0	0	0	0	456	14,905
1946	4,183	0	56	11,098	0	41	0	539	0	15,917
1947	3,659	0	41	12,866	0	21	0	295	0	16,882
1948	3,151	0	0	13,553	0	0	0	356	0	17,060
1949	2,414	0	0	14,520	0	0	0	290	0	17,224
1950	3,953	0	15	12,601	0	5	0	744	0	17,318
1951	2,599	0	0	14,653	500	0	0	0	0	17,752
1952	3,364	0	0	13,951	0	0	0	0	3	17,318
1953	3,443	0	0	12,488	744	0	0	0	0	16,675
1954	4,329	0	25	6,308	0	0	0	1,465	0	12,127
1955	1,163	0	156	3,254	223	22	0	359	278	5,455
1956	553	0	500	2,937	1,001	0	0	0	189	5,180
1957	778	0	60	2,892	130	13	0	0	505	4,378
1958	2,032	0	31	3,874	0	113	0	0	794	6,844
1959	2,186	0	0	4,326	455	0	0	0	25	6,992
1960	2,754	0	407	4,764	878	0	0	0	104	8,907
1961	2,699	0	573	5,667	617	0	0	0	105	9,661
1962	2,852	0	464	6,844	1,030	25	0	0	214	11,429
1963	770	0	1,262	8,742	0	0	0	0	494	11,268
1964	889	0	0	6,951	504	0	0	0	77	8,421
1965	1,612	0	215	5,159	924	0	0	0	213	8,123
1966	1,621	0	1,312	3,787	948	0	0	0	147	7,815

Table 5D-4. Hudspeth Irrigated Crop Areas in Acres

Year	Alfalfa Hay	Chile (Peppers)	Corn, Sweet Corn, and Silage	Cotton	Irrigated Pasture	Miscellaneous Vegetables	Onions	Pecans	Wheat and Small Grains	Total
1967	1,076	0	1,256	4,394	1,019	0	0	0	499	8,244
1968	964	0	1,188	4,721	1,262	0	0	0	514	8,649
1969	1,592	0	2,423	4,321	1,961	0	0	0	1,135	11,432
1970	1,342	0	4,296	4,691	2,055	0	0	13	1,780	14,177
1971	969	0	1,483	3,461	2,670	0	0	0	1,532	10,115
1972	1,203	0	800	2,362	946	0	0	0	1,235	6,546
1973	1,476	0	1,066	3,170	3,231	0	0	0	842	9,785
1974	2,151	0	659	4,762	3,839	0	0	0	1,035	12,446
1975	3,260	0	1,107	3,455	4,126	0	0	0	1,714	13,662
1976	3,721	0	0	2,782	3,384	0	0	0	1,380	11,268
1977	1,454	0	0	7,719	1,464	0	0	0	103	10,740
1978	649	0	0	6,902	1,624	0	0	0	0	9,175
1979	843	0	521	6,961	3,338	0	0	0	105	11,768
1980	1,368	0	365	9,211	3,400	0	0	0	893	15,237
1981	1,152	0	857	8,922	2,536	65	0	0	496	14,028
1982	946	0	590	8,540	3,945	85	0	0	924	15,030
1983	768	0	197	4,441	3,274	600	0	0	36	9,316
1984	2,234	0	294	7,894	3,520	55	0	0	549	14,546
1985	1,615	0	573	10,820	824	55	0	0	993	14,880
1986	751	0	233	12,591	1,335	55	0	0	414	15,379
1987	682	0	8	13,791	350	0	0	55	157	15,043
1988	580	0	180	14,040	568	50	0	0	222	15,640
1989	450	0	194	16,377	163	125	0	0	0	17,309
1990	574	231	0	11,291	130	208	0	0	166	12,599
1991	759	1,080	0	13,378	262	138	100	0	0	15,717
1992	599	2,440	232	10,084	77	1,695	169	0	0	15,296
1993	521	2,374	285	10,365	76	748	218	0	80	14,667
1994	479	1,834	393	10,874	198	961	145	0	94	14,978
1995	695	1,602	209	12,331	403	10	134	46	0	15,430

Table 5D-4. Hudspeth Irrigated Crop Areas in Acres

Year	Alfalfa Hay	Chile (Peppers)	Corn, Sweet Corn, and Silage	Cotton	Irrigated Pasture	Miscellaneous Vegetables	Onions	Pecans	Wheat and Small Grains	Total
1996	1,451	1,765	695	11,465	162	33	115	50	0	15,734
1997	1,080	1,650	600	11,852	50	0	0	46	0	15,278
1998	1,637	1,500	650	11,552	0	0	0	46	0	15,385
1999	1,400	675	600	12,741	0	0	0	46	0	15,462
2000	1,524	712	1,188	10,719	0	0	0	49	0	14,192
2001	1,377	644	2,106	10,205	0	0	0	46	0	14,379
2002	1,493	669	603	12,377	0	0	0	47	0	15,189
2003	1,169	254	254	6,378	330	324	0	58	0	8,769
2004	1,222	239	0	6,488	0	735	0	58	0	8,740
2005	1,159	0	0	7,350	0	910	0	48	0	9,467
2006	1,151	0	0	8,721	0	594	0	50	0	10,517
2007	2,395	0	0	9,242	277	287	0	57	0	12,257
2008	1,890	189	1,758	9,086	0	645	0	54	0	13,623
2009	1,922	0	347	10,319	0	1,260	0	0	359	14,206
2010	2,379	465	30	10,784	0	517	0	50	476	14,700
2011	788	0	212	11,079	0	0	0	74	0	12,154
2012	825	0	0	5,492	0	0	0	54	47	6,419
2013	733	0	0	5,310	52	0	0	133	0	6,227
2014	1,216	38	0	4,494	0	0	0	120	0	5,868
2015	1,007	0	0	5,854	0	0	0	38	199	7,097
2016	1,193	0	0	4,190	0	0	0	53	483	5,919
2017	1,548	102	22	5,744	0	0	0	137	338	7,891
2018	1,494	0	45	5,470	0	0	0	134	414	7,557

Table 5D-5. Juarez Irrigated Crop Areas in Acres

Year	Alfalfa Hay	Chile (Peppers)	Corn, Sweet Corn, and Silage	Cotton	Irrigated Pasture	Miscellaneous Vegetables	Onions	Pecans	Wheat and Small Grains	Total
1938	852	0	0	57,139	0	0	0	0	0	57,991
1939	688	0	0	46,141	0	0	0	0	0	46,829
1940	712	0	0	47,746	0	0	0	0	0	48,457
1941	783	0	0	52,498	0	0	0	0	0	53,281
1942	752	0	0	50,419	0	0	0	0	0	51,171
1943	742	0	0	49,793	0	0	0	0	0	50,535
1944	742	0	0	49,805	0	0	0	0	0	50,548
1945	775	0	0	52,009	0	0	0	0	0	52,784
1946	794	0	0	53,258	0	0	0	0	0	54,052
1947	710	0	0	47,604	0	0	0	0	0	48,314
1948	636	0	0	42,690	0	0	0	0	0	43,326
1949	563	0	0	37,775	0	0	0	0	0	38,338
1950	490	0	0	32,860	0	0	0	0	0	33,350
1951	445	0	0	29,875	0	0	0	0	0	30,320
1952	486	0	0	32,624	0	0	0	0	0	33,110
1953	436	0	0	29,214	0	0	0	0	0	29,650
1954	363	0	0	24,337	0	0	0	0	0	24,700
1955	349	0	0	23,421	0	0	0	0	0	23,770
1956	348	0	0	23,322	0	0	0	0	0	23,670
1957	379	0	0	25,421	0	0	0	0	0	25,800
1958	509	0	0	34,111	0	0	0	0	0	34,620
1959	515	0	0	34,575	0	0	0	0	0	35,090
1960	505	0	0	33,895	0	0	0	0	0	34,400
1961	490	0	0	32,870	0	0	0	0	0	33,360
1962	740	0	0	33,720	0	0	0	0	1,110	35,570
1963	1,170	0	0	37,250	0	0	0	0	870	39,290
1964	1,730	0	0	24,710	0	0	0	0	490	26,930
1965	2,970	0	490	26,730	0	0	0	0	370	30,560
1966	2,720	0	0	29,650	0	0	0	0	0	32,370

Table 5D-5. Juarez Irrigated Crop Areas in Acres

Year	Alfalfa Hay	Chile (Peppers)	Corn, Sweet Corn, and Silage	Cotton	Irrigated Pasture	Miscellaneous Vegetables	Onions	Pecans	Wheat and Small Grains	Total
1967	2,990	0	370	25,950	0	0	0	0	4,080	33,390
1968	3,410	0	1,220	26,820	0	0	0	0	3,630	35,080
1969	4,000	0	1,070	30,800	0	0	0	300	4,600	40,770
1970	4,300	0	1,070	30,900	0	0	0	300	4,800	41,370
1971	4,000	0	530	24,000	0	0	0	300	3,500	32,330
1972	5,530	0	500	21,930	0	0	0	310	3,000	31,270
1973	6,910	0	3,830	25,700	0	110	0	380	4,800	41,730
1974	7,000	0	1,670	24,600	0	100	0	400	5,700	39,470
1975	8,650	0	2,220	25,940	0	200	0	500	5,010	42,520
1976	6,190	0	908	16,319	0	255	0	458	7,758	31,887
1977	6,231	0	3,138	15,538	0	308	0	477	7,462	33,154
1978	9,831	0	0	18,338	0	300	0	446	4,315	33,231
1979	10,642	0	0	20,764	0	110	0	464	3,180	35,159
1980	10,546	0	0	24,046	0	115	0	685	3,000	38,392
1981	10,407	0	0	23,728	0	114	0	676	2,960	37,885
1982	10,235	0	0	21,750	0	4,800	0	416	1,076	38,277
1983	9,608	0	0	20,417	0	4,506	0	390	1,010	35,931
1984	10,870	0	0	21,908	0	3,957	0	480	379	37,594
1985	11,166	2	207	22,730	51	3,891	4	504	700	39,257
1986	11,445	5	434	23,538	107	3,801	9	529	1,051	40,920
1987	11,705	7	682	24,332	168	3,688	14	554	1,432	42,583
1988	11,947	10	951	25,110	234	3,550	20	580	1,844	44,246
1989	10,192	11	1,039	21,669	256	2,836	22	507	1,916	38,448
1990	8,492	11	1,066	18,271	263	2,195	23	434	1,896	32,650
1991	8,693	14	1,306	18,937	322	2,066	28	456	2,265	34,086
1992	8,877	17	1,566	19,590	386	1,914	33	478	2,661	35,522
1993	9,044	19	1,845	20,229	455	1,741	39	501	3,086	36,958
1994	9,193	23	2,143	20,855	528	1,544	45	524	3,539	38,394
1995	9,325	26	2,462	21,466	607	1,324	52	548	4,022	39,830

Table 5D-5. Juarez Irrigated Crop Areas in Acres

Year	Alfalfa Hay	Chile (Peppers)	Corn, Sweet Corn, and Silage	Cotton	Irrigated Pasture	Miscellaneous Vegetables	Onions	Pecans	Wheat and Small Grains	Total
1996	9,438	30	2,801	22,062	690	1,080	59	571	4,536	41,267
1997	9,321	33	3,090	22,139	762	794	65	582	4,966	41,752
1998	9,195	36	3,389	22,210	835	496	72	593	5,411	42,237
1999	9,060	39	3,698	22,273	911	187	78	604	5,870	42,721
2000	8,812	99	4,581	18,486	1,139	180	49	563	9,295	43,205
2001	7,581	10	4,569	15,465	895	172	105	635	6,979	36,411
2002	8,634	47	3,841	13,068	2,151	212	83	840	7,422	36,298
2003	9,115	25	3,730	14,998	1,619	125	0	1,146	4,779	35,535
2004	8,056	0	3,595	19,816	2,367	0	0	1,483	4,652	39,968
2005	7,014	14	4,482	15,847	2,943	456	79	1,157	6,527	38,518
2006	7,424	14	3,340	15,367	2,550	404	72	2,330	5,670	37,170
2007	6,455	76	4,009	16,743	2,050	722	35	2,588	6,632	39,311
2008	5,705	55	1,527	14,515	1,854	332	0	2,260	9,212	35,459
2009	4,765	0	5,412	11,187	1,526	292	0	1,887	8,230	33,300
2010	4,179	0	4,141	14,278	1,766	329	0	2,203	8,323	35,220
2011	3,763	0	575	15,744	1,297	374	0	1,982	6,218	29,953
2012	4,622	0	567	16,658	1,436	1,430	0	2,195	3,811	30,719
2013	5,925	84	3,102	13,768	1,837	1,196	0	1,926	4,370	32,209
2014	5,703	69	2,657	14,737	1,349	360	0	1,898	3,144	29,917
2015	5,659	100	2,070	14,250	1,352	567	0	2,823	4,098	30,918
2016	5,543	67	2,096	14,706	1,352	448	50	2,990	4,426	31,677
2017	6,541	73	2,166	15,657	616	477	0	2,994	3,491	32,014
2018	6,150	68	2,037	14,721	579	449	0	2,815	3,282	30,102

Appendix 5E. Line Graphs of Annual Irrigated Areas in Acres

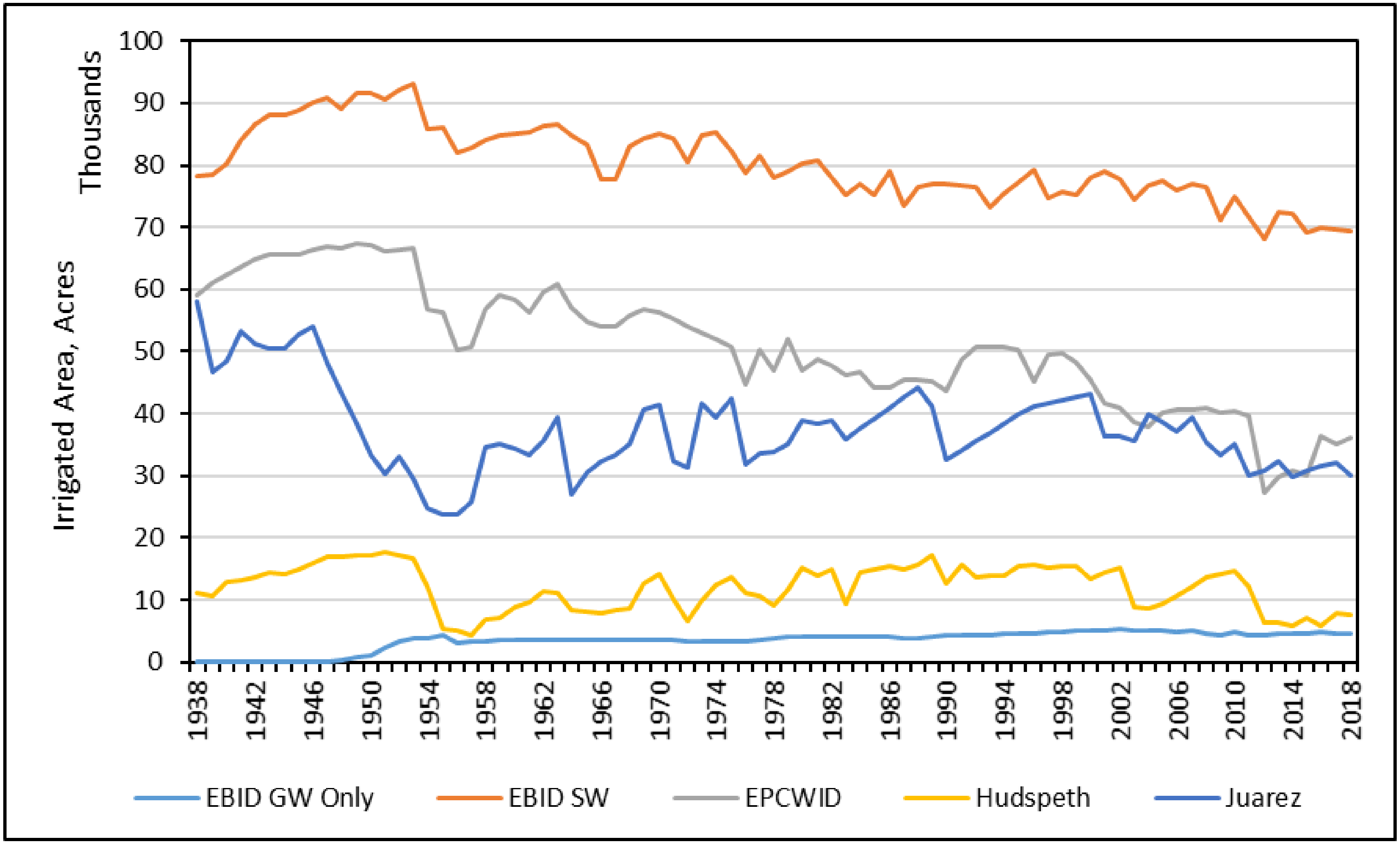


Figure 5E-1. Annual Irrigated Areas for All Areas.

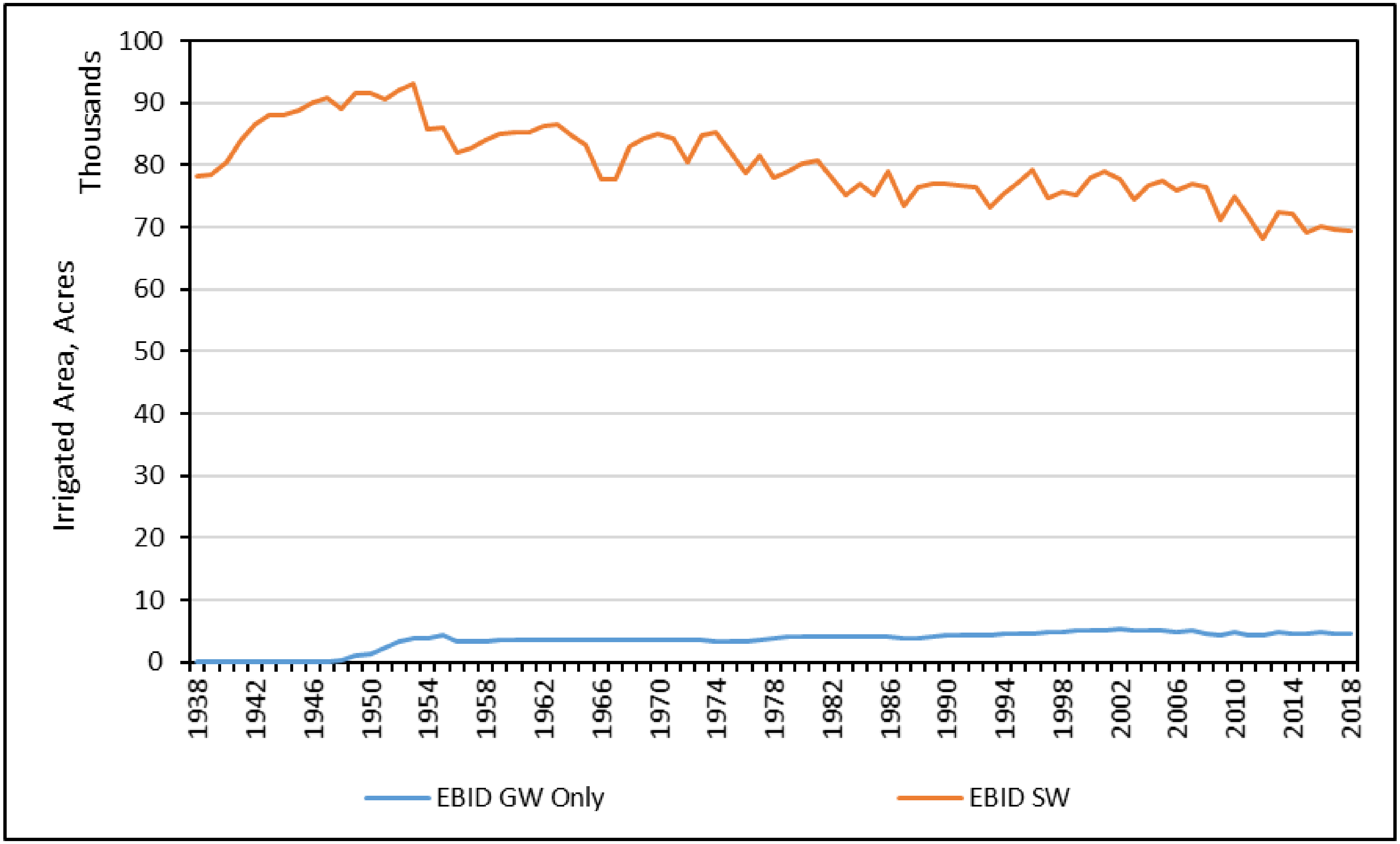


Figure 5E-2. Annual Irrigated Areas for EBID Irrigated Lands with Access to Both Surface Water and Groundwater.

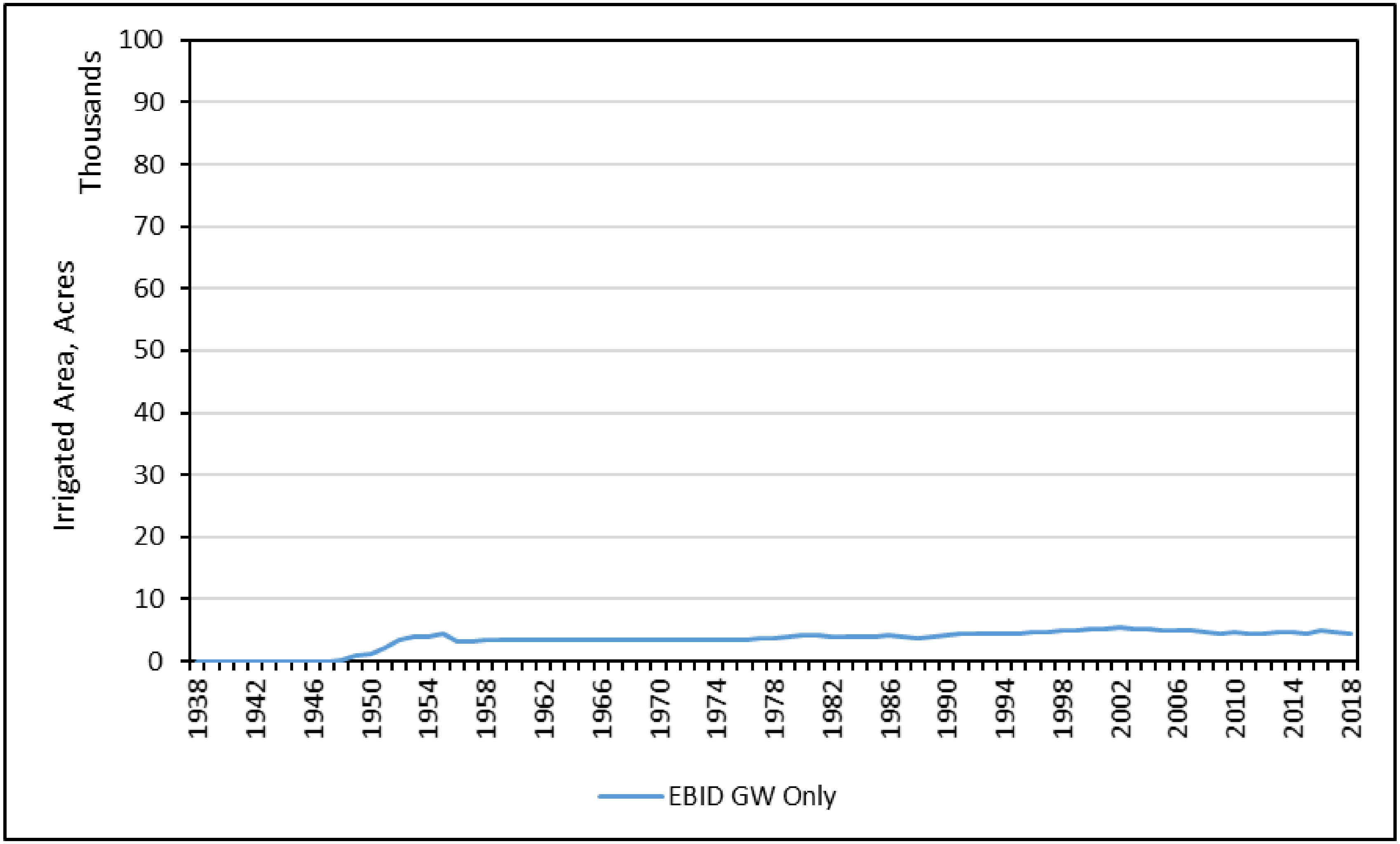


Figure 5E-3. Annual Irrigated Areas for EBID Irrigated Lands with Access to Groundwater Only.

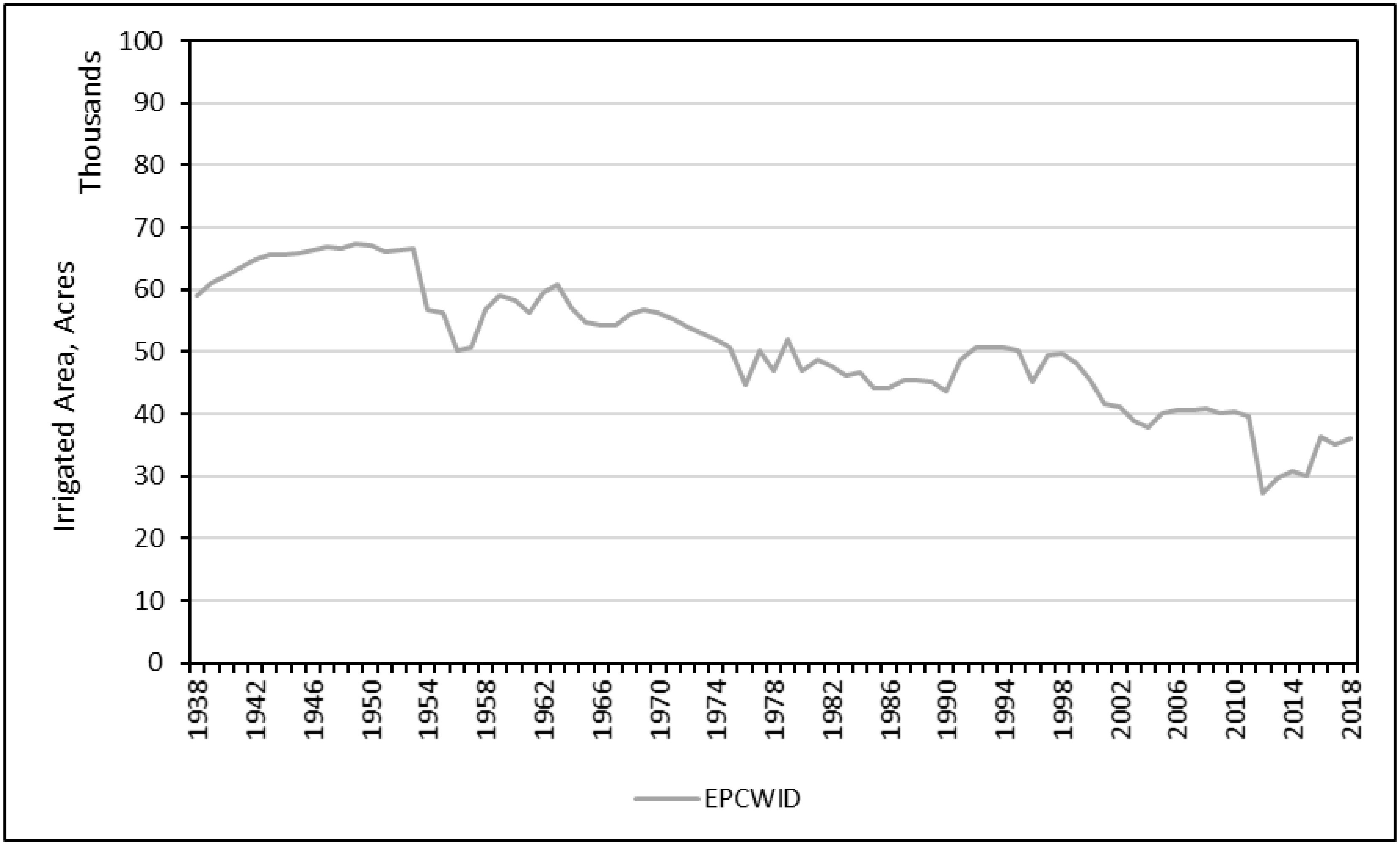


Figure 5E-4. Annual Irrigated Areas for EPCWID Irrigated Lands.

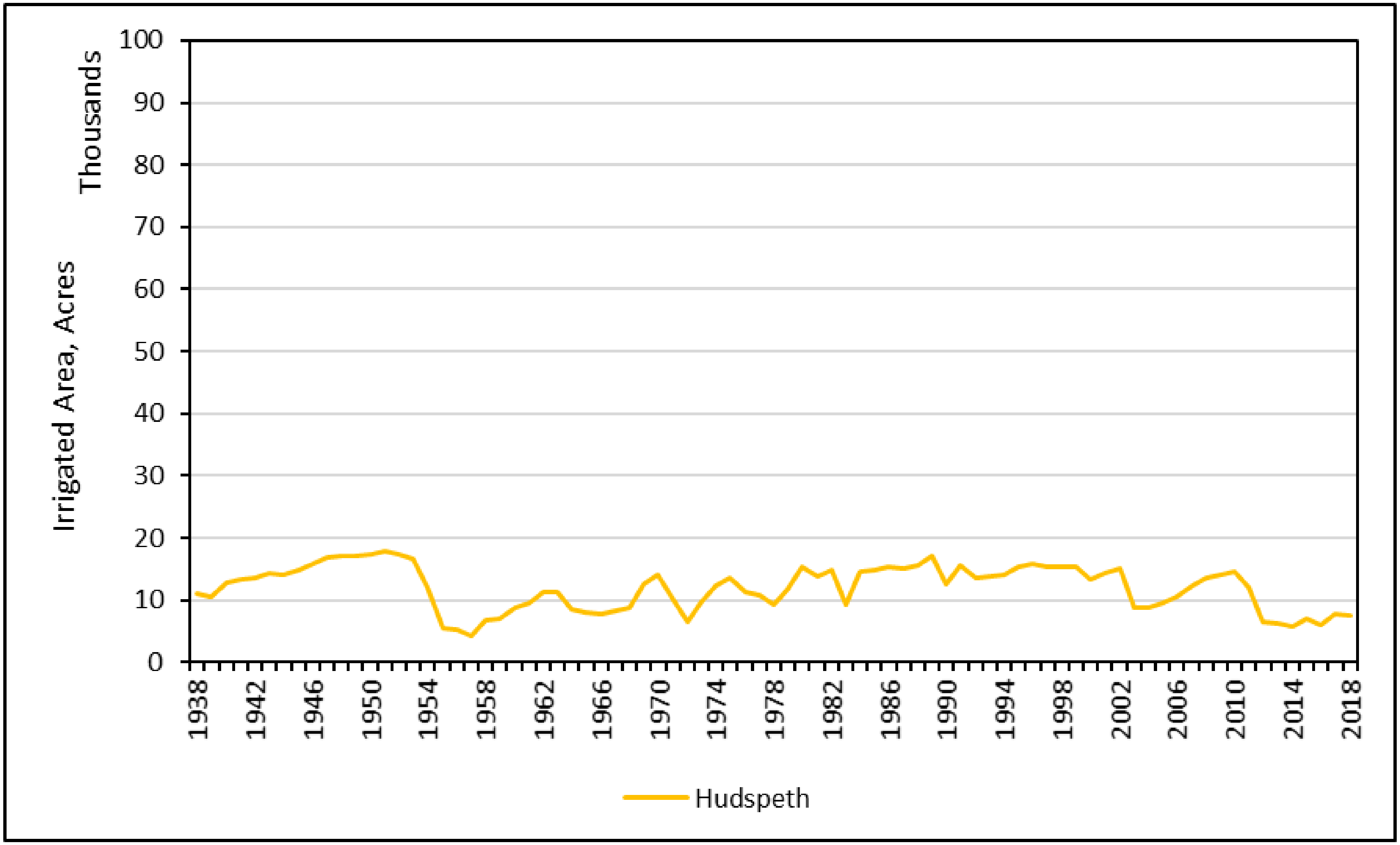


Figure 5E-5. Annual Irrigated Areas for Hudspeth Irrigated Lands.

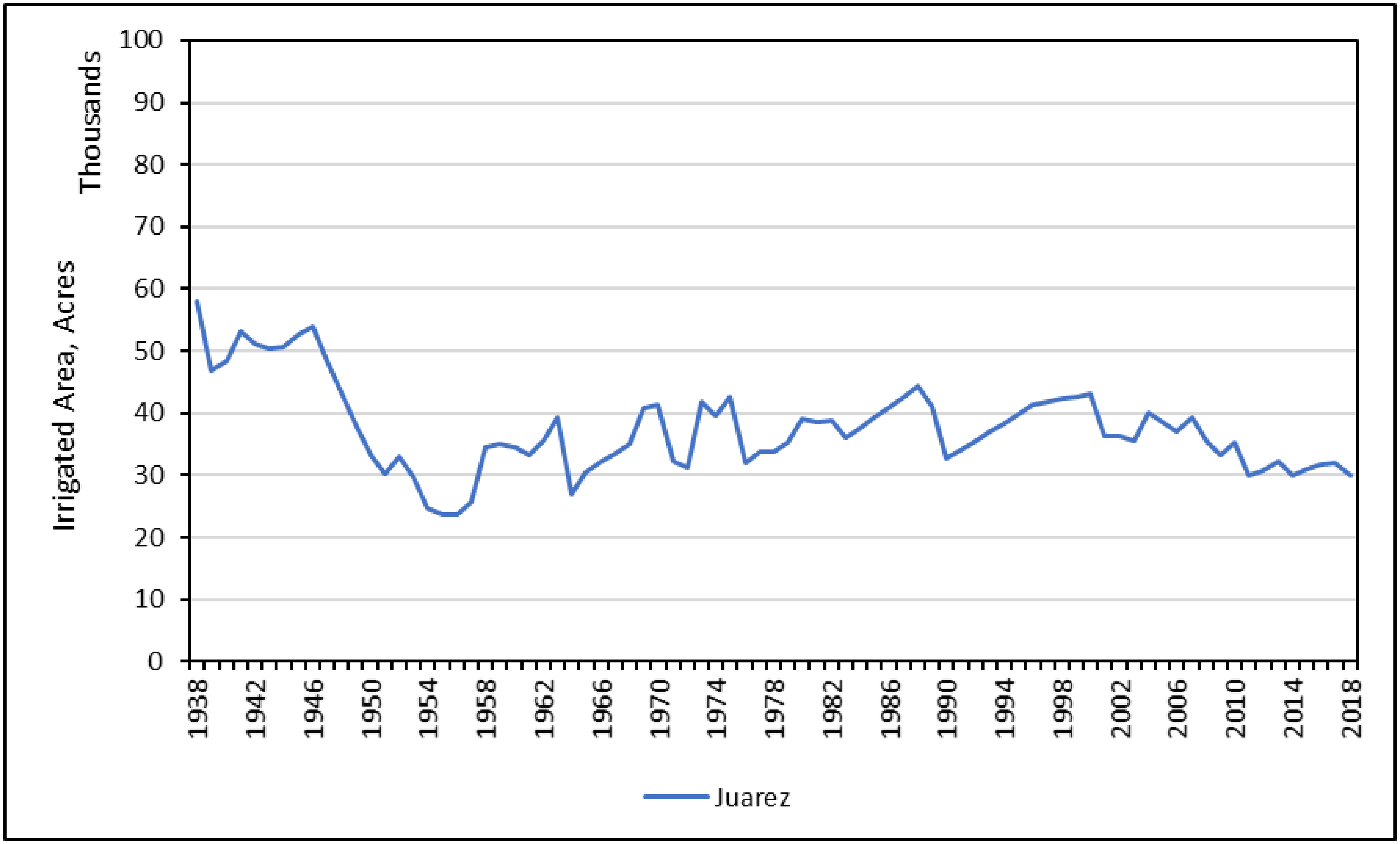


Figure 5E-6. Annual Irrigated Areas for Juarez Irrigated Lands.

Appendix 6A. Crop Coefficient Database Development

Developing the crop coefficient database consisted of two steps: 1.) assigning a crop type to each field; and 2.) extracting data pertaining to grass-based crop coefficients and normalized difference vegetation indices (NDVI) by field. The crop coefficient database is used for the Crop Data Layer (CDL) accuracy analysis and for developing crop coefficients. The CDL accuracy analysis was completed prior to developing crop coefficients, as developing crop coefficients relied on the results from the accuracy analysis. Steps required for the accuracy analysis (i.e. field crop information) were also required for developing crop coefficients. Additional steps were needed to extract field crop coefficient and NDVI data to develop crop coefficients for each crop category.

Data Sources

New Mexico field polygons were received on May 7, 2014 by download from the link titled, "DraftPrivilegedandConfidentialPreparedinAnticipationofLigitgation_CropSurveyPolys.mdb." The shapefile is titled "LRGCropSurveyDRAFT021810."

The Texas field polygons were received on May 7, 2014 in a shapefile titled, "EP1Huds10_EBID08_FieldBoundaries." The original Texas shapefile contains both Texas and New Mexico fields. New Mexico field boundaries found in this shapefile were deleted and New Mexico fields from the shapefile, "LRGCropSurveyDRAFT021810" were added to a new shape file. Texas field boundaries found in this shapefile were not used for the CDL accuracy evaluation because ground-based field survey data was not available for the Texas fields. However, CDL crops were assigned to the Texas fields using the procedure described to develop and analyze crop coefficients.

The CDL for 2008 was downloaded from USDA NASS <http://nassgeodata.gmu.edu/CropScape/> on May 28, 2014. Available data covers both the Texas and New Mexico areas within and nearby Elephant Butte Irrigation District (EBID) in New Mexico and the El Paso County Water Improvement District #1 (EPCWID) and the Hudspeth County Conservation & Reclamation District #1 (Hudspeth) in Texas.

Assigning Crop Type to Each Field

Crop types were assigned to each field based on two data sources: the USDA NASS CDL for Texas and New Mexico field survey for New Mexico. The section below outlines steps used to assign a crop to each field using both data sources:

Crop Data Layer

An analysis was completed using spatial crop data and field polygons using the ArcMap GIS software to assign crops to each field. Because each field contains multiple pixels[16], the possibility exists that pixels of more than one crop type may be found with the boundaries of one field. In a few instances, this may be due to the splitting of a field into two crops. But more often a few pixels within a field boundary have a second crop type due to classification error. The crop assignment procedure assigns one crop type to each field based on the number of pixels of each crop type as a percent of the total number of pixels within the field polygon. The purpose of this procedure is to assign a single crop type from the CDL to each field for comparison to the New Mexico ground-based crop survey and to develop $\mathbf{K_{cm}}$ values for crops in areas of the Study Area where ground-based crop survey data are not available.

[16] A single raster element in a computer image that has a constant value across its domain. In Landsat images, a pixel has dimensions of 30 m x 30 m.

Each crop type identified on each field is assigned a "field rank" according to the number of pixels identified as the crop type. The crop with the greatest number of pixels is given a field rank of one, the second highest is given a rank of two, and so on. In the case of multiple crop types occupying the same percent of the field polygon, the crop most commonly grown throughout all districts (EBID, EPCWID, and Hudspeth) based on the CDL data is assigned the higher rank. For example, the CDL identifies two crops on a field and both occupy 50% of a field: cotton and alfalfa. In this hypothetical example, assuming cotton covers the greatest area throughout EBID, EPCWID and Hudspeth, it would receive a rank of 1 and the field would be assigned cotton as the crop. Each field was assigned the crop type with a rank of 1.

Additional steps were completed during the ArcMap procedure to ensure that field identification numbers used later in the CDL analysis could be traced back to the "OBJECTID" found in the original Texas and New Mexico shapefiles. ArcMap re-assigns field identification numbers during geoprocessing steps that produce new spatial data layers. Adding separate, fixed field IDs to each polygon (or field boundary) ensures that the field identification number will not change during geoprocessing.

The steps followed to assign a single crop type to each field from the CDL are outlined below:

1. The 2008 crop data layer from USDA NASS covering both Texas and New Mexico fields was downloaded from http://nassgeodata.gmu.edu/CropScape/. Each 56-meter pixel from the CDL has an integer value representing a crop. The integer value refers to a specific crop type (i.e. cotton, pecans, alfalfa, etc).
2. In the original Texas shapefile ("EP1Huds10_EBID08_FieldBoundaries"), a new field identification number was created in the attribute table named "TX_id." The "TX_id" field is equal to the "OBJECTID" in the original shapefile "EP1Huds10_EBID08_FieldBoundaries."
3. The New Mexico field polygons, identified as those found within the boundaries of EBID (according to the attribute table) were deleted from the Texas shapefile ("EP1Huds10_EBID08_FieldBoundaries").
4. In the original New Mexico field shapefile ("LRGCropSurveyDRAFT021810") a new field identification number was assigned in the original New Mexico field attribute table, titled "NM_id." This id is used to relate extracted data back to the original field polygon layer, "LRGCropSurveyDRAFT021810."
5. The Texas shapefile, "EP1Huds10_EBID08_FieldBoundaries" was merged with the New Mexico field shapefile "LRGCropSurveyDRAFT021810."
6. A new field identification number was created called "FID_New" in the attribute table with the shapefile "TX_NM_Fields." "FID_New" corresponds to either "TX_id" or "NM_id." Fields in Texas have an "NM_id" equal to 0; likewise, fields in New Mexico have a "TX_id" equal to 0. There is a unique "FID_New" value for every "TX_id" and "NM_id."
7. A new shapefile "TX_NM_Fields_buf45" was created by buffering in 45 meters from the field boundaries. Buffering improves the assignment of field crop type by eliminating pixels that may have area in two or more fields, which may be different crop types.
8. The buffering process eliminated nearly all fields less than 1 hectare of actual area in shapefile, "TX_NM_Fields_buf45".
9. The polygon shapefile "TX_NM_Fields_buf45" was converted to a raster image where each pixel value corresponds to a field identification number (or "FID_New"). Pixel size and alignment matches the CDL layer.
10. Used ArcMap's spatial analyst extraction tool "Sample" to relate a CDL pixel value to each polygon pixel value ("FID_New").

11. The data was imported to a personal geodatabase, “Developing_Crop_Coefficient_Database.”
12. The query “001_CDL_Count_by_Field” creates a table that summarizes the data from ArcMap (step 10). The table summarizes the number of pixels within each field with the same CDL pixel value.
13. The query, “002_Number_of_Pixel_by_Field,” calculates the total number of CDL pixels within each field.
14. The query, “003_Percent_of_Pixel_by_Field” lists the percent of each crop type by field. Queries “001_CDL_Count_by_Field” and “002_Number_of_Pixel_by_Field” were used to create this query.
15. The “Make Table” query, “004_CDL_mk_query,” assigns a crop type to each CDL pixel value and creates a table titled “004_CDL_mk.”
16. The “Update” query, “004a_CDL_cropped_area_updt,” fills the column “Cropped_Area_ac” in the table “004_CDL_mk.” Cropped area is equal to field area (from table “Attributes_TX_NM”) times percent of crop type (from table “004_CDL_mk”).
17. The updated (with completed cropped_area_ac column) table “004_CDL_mk” was exported to the Excel file “CDL_Table.”
18. A column, titled “Crop_Order,” was added to table “004_CDL_mk.” A crop order was assigned to each crop type. Crop order ranges from 1 to 32 with one being the crop covering the greatest area and thirty-two being the crop covering the least area.
19. A column, “Field_Rank” was created in table “004_CDL_mk.” Field rank is useful for fields with more than one crop type identified by the CDL. Each crop identified by the CDL is ranked within the field by acreage.
20. The updated table, “CDL_final_mk,” is imported to the database titled “Developing_Crop_Coefficient_Database.”
21. The crop types were organized into ten crop categories by adding a column titled “Assigned_Crop_Group” to table “CDL_final_mk.” **Table 6A-1** shows the crop types based on the CDL and the groupings used for this analysis:

Table “CDL_final_mk” contains CDL data (by field) used in the crop coefficient analysis. The table contains the following columns:

a. FID_New – field identification number (same FID_New may appear multiple times in table depending on the number of crops identified in each field)
b. N_of_Pixels – total number of pixels that fall within field boundaries
c. CDL_Code – pixel value from CDL (pixel value represents crop type)
d. No_of_Pixels – number of pixels within each field with the same CDL pixel value
e. Percent_of_Crop_Type – “No_of_Pixels” divided by “N_of_Pixels”
f. Crop_Type – crop type (or landuse) the pixel value represents
g. Assigned_Crop_Group – re-assigned crop group based on **Table 6A-1**
h. Cropped_Area_ac – total area in acres of specific crop in field (based on “Percent_of_Crop_Type”)
i. Crop_Order – rank of crop throughout EBID, EPCWID, and Hudspeth according to area covered. The crop most covering the greatest area is given “Crop_Order” value of 1 and so on.
j. Field_Rank – rank of number of acres grown of specific crop by field.

Table 6A-1. Assignment of CDL crop categories to the crop groups for the actual ET analysis.

CDL Land Use Category	Assigned Group
Alfalfa	Alfalfa Hay
Peppers	Chile (Peppers)
Corn	Corn, Sweet Corn, and Silage
Sweet Corn	Corn, Sweet Corn, and Silage
Dbl Crop Barley/Corn	Corn, Sweet Corn, and Silage
Cotton	Cotton
Misc Vegs & Fruits	Miscellaneous Vegetables
Watermelons	Miscellaneous Vegetables
Onions	Onions
Other Hay/Non Alfalfa	Alfalfa Hay
Triticale	Wheat and Small Grains
Grass/Pasture	Irrigated Pasture
Other Tree Crops	Pecans
Pistachios	Pecans
Pecans	Pecans
Winter Wheat	Wheat and Small Grains
Oats	Wheat and Small Grains
Spring Wheat	Wheat and Small Grains
Sorghum	Corn, Sweet Corn, and Silage
Durum Wheat	Wheat and Small Grains
Shrubland	Not Irrigated and Water
Fallow/Idle Cropland	Not Irrigated and Water
Developed/Open Space	Not Irrigated and Water
Developed/Low Intensity	Not Irrigated and Water
Open Water	Not Irrigated and Water
Evergreen Forest	Not Irrigated and Water
Woody Wetlands	Not Irrigated and Water
Developed/Medium Intensity	Not Irrigated and Water
Barren	Not Irrigated and Water
Developed/High Intensity	Not Irrigated and Water
Herbaceous Wetlands	Not Irrigated and Water
Deciduous Forest	Not Irrigated and Water

New Mexico Field Survey

Below is a detailed list of the steps used to assign a New Mexico field survey crop to each field:

1. The “make table” query “001_NM_CropSurvey” related “OBJECTID” to “FID_New” and assigned the summer 2008 crop type to each “FID_New.” The new table created was titled “NM_Field_Survey_Crops.”

2. The column titled "Assigned_Crop" was added to table "NM_Field_Survey_Crops" to assign crop types to the eleven land-use categories to be used in the actual ET analysis (**Table 6A-2**).

Additional Steps for Developing Crop Coefficients

Steps required to develop crop coefficients include: extracting data using ArcMap, compiling data into a single table, and developing crop coefficient curves. The following sections give a more detailed description of each step.

Crop Coefficient ArcMap Analysis Procedure

1. Utilized ArcMap's "Model Builder" to run "Zonal Statistics as Table" tool to extract ET_oF and NDVI data for each image date. To obtain necessary data from the original ET_oF and NDVI raster images, the images had to be converted to integer grids. The following steps were completed in ArcMap's Model Builder to turn original images into integer grids and to extract data:
    a. Multiply by 10,000 to carry adequate number of significant figures (i.e. 1.252446 turns into 12524.46)
    b. Convert pixel values into integers (i.e. 12524.46 turns into 12524)
    c. Extract NDVI and ET_oF data by field using "Zonal Statistics as Table"

   These additional steps were necessary because ArcMap only calculates the "median" on integer grids. ArcMap was unable to perform zonal statistics on integer grids created using the model for path 33 ET_oF data. Consequently, integer grids were created using ERDAS Imagine and then the zonal statistics was completed in ArcMap (only for path 33 ET_oF data)
2. Exported raw ET_oF and NDVI data into the common personal geodatabase titled "Developing_Crop_Coefficient_Database."

Crop Coefficient Database

After completing the 45-meter buffering and ArcMap's crop coefficient procedure, a table titled "CropCoefficientDev" (in database "Developing_Crop_Coefficient_Database") was compiled with the following columns.

a. FID_New – field identification number
b. Flag_P32 – value equal to 1 means field boundary overlays Landsat image (path 32) outside region of usable data. Value of 0 means data is usable.
c. Flag_P33 – value equal to 1 means field boundary overlays Landsat image (path 33) outside region of usable data. Value of 0 means data is usable.
d. Image_Date – Landsat image date
e. Path – Landsat path number (i.e. path 32 or 33)
f. District – district field falls within (i.e. EBID, EPCWID, or Hudspeth)
g. Field_Size_ac – area of field in acres
h. No_of_Pixels – number of pixels within each field after buffering (pixel size: 15m by 15m – not the same as Landsat pixel size of 30m by 30m)
i. Mean_NDVI – average NDVI pixel value within each field after buffering
j. Median_NDVI – median NDVI pixel value within each field after buffering
k. Mean_ET_oF – average grass based crop coefficient pixel value within each after buffering
l. Median_ET_oF – median grass based crop coefficient pixel value within each after buffering
m. STD_NDVI – standard deviation of NDVI pixel values within each field after buffering
n. STD_ET_oF – standard deviation of grass based crop coefficient within field boundaries after buffering
o. Days_Since_Last_Rain – number of days since last rain event
p. Total_Rainfall_in_Last_15_Days – cumulative rainfall in last 15 days from image date

Table 6A-2. Assignment of New Mexico Field Survey Crop Categories to the Actual ET Analysis Crop Groups.

Summer08Crop	Assigned Group
Alfalfa	Alfalfa Hay
Chile	Chile (Peppers)
Corn	Corn, Sweet Corn, and Silage
Cotton	Cotton
Misc. Vegetables/Garden	Miscellaneous Vegetables
Melons/Summer Squash	Miscellaneous Vegetables
Cabbage	Miscellaneous Vegetables
Misc. Field Crops	Corn, Sweet Corn, and Silage
Vineyard	Pecans
Onions	Onions
Irrigated Pasture	Irrigated Pasture
Sudan Grass	Irrigated Pasture
Unknown Crop	Irrigated Pasture
Hay	Alfalfa Hay
Turfgrass/Lawn	Irrigated Pasture
Residential-Irrigated	Irrigated Pasture
Fruit Orchard	Pecans
Pistachio Orchards	Pecans
Christmas Trees	Pecans
Pecan Orchards	Pecans
Residential-Pecans	Pecans
Nursery Stock	Pecans
Sorghum	Corn, Sweet Corn, and Silage
Small Grain	Wheat and Small Grains
Plowed	Not Irrigated and Water
Non-Irrigated	Not Irrigated and Water
Fallow	Not Irrigated and Water
Residential-Non-Irrigated	Not Irrigated and Water
Water	Not Irrigated and Water
Residential	Not Irrigated and Water

Developing Crop Coefficient Curves

The following procedures were completed for each crop coefficient curve:

1. Created a query in database, “Developing_Crop_Coefficient_Database,” to export relevant data to Microsoft Excel. Filters were used to only select fields of interest (i.e. fields of specific crop, district, Landsat path number, etc.). The following constraints were used to only extract data

that overlaid pixel values that corresponded to crop coefficients. These constraints were included in all queries:

   a. Mean ET_oF greater than zero to crop coefficients
   b. Mean ET_oF less than two
   c. "Flag_P32" equal to zero

2. Calculated mean, median, percentile, and frequency distribution for the sample of fields obtained from the query
3. Developed plot that shows mean and median ET_oF values derived from the calendar year 2008 METRIC analysis, along with relative frequency values for the distribution of crop coefficients.

Appendix 6B. 2008 METRIC - Derived Crop Coefficients (ET_c/ET_o)

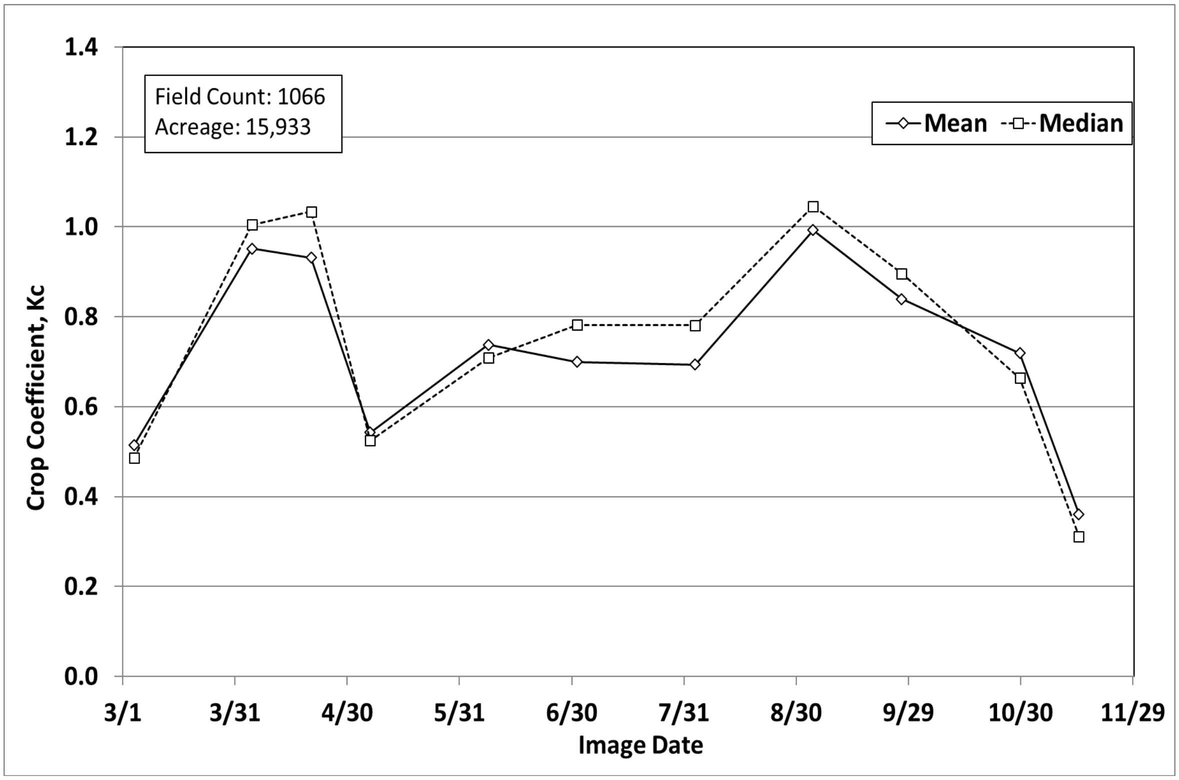


Figure 6B-1. 2008 METRIC - Derived Crop Coefficients (ET_c/ET_o) for Fields Identified to have Alfalfa Hay by NM Field Survey

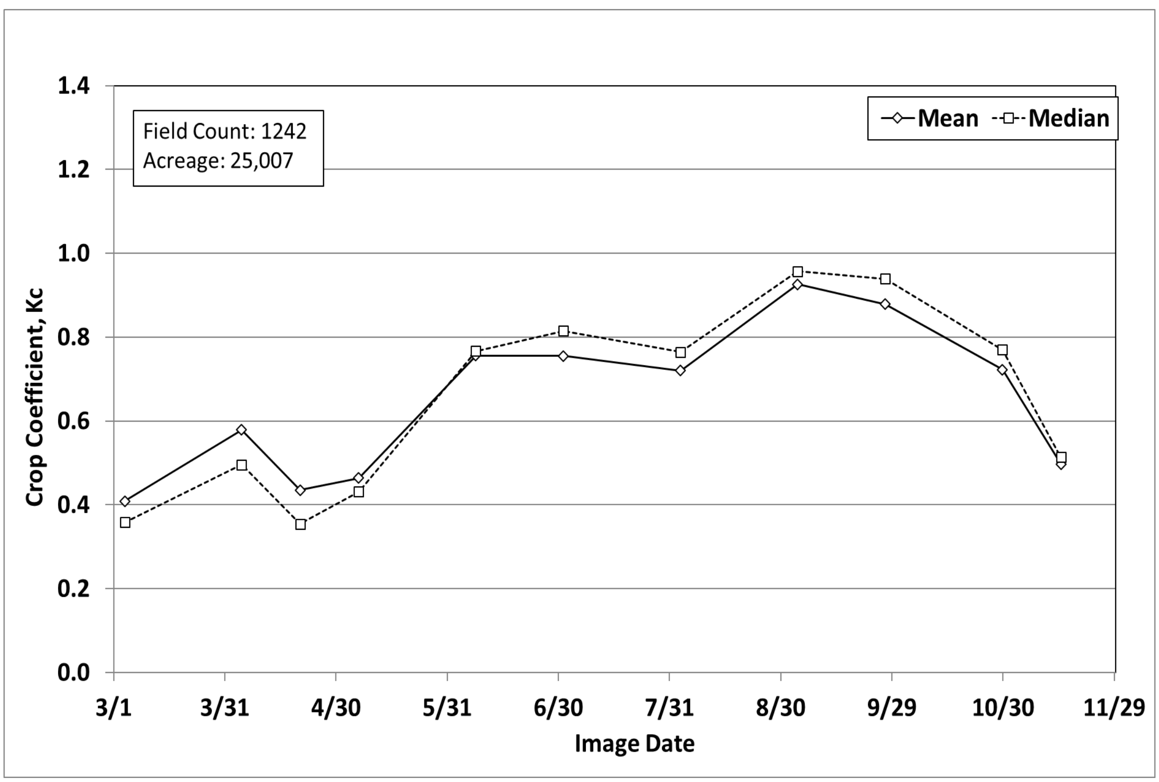


Figure 6B-2. 2008 METRIC - Derived Crop Coefficients (ET_c/ET_o) for Fields Identified to have Pecans by NM Field Survey

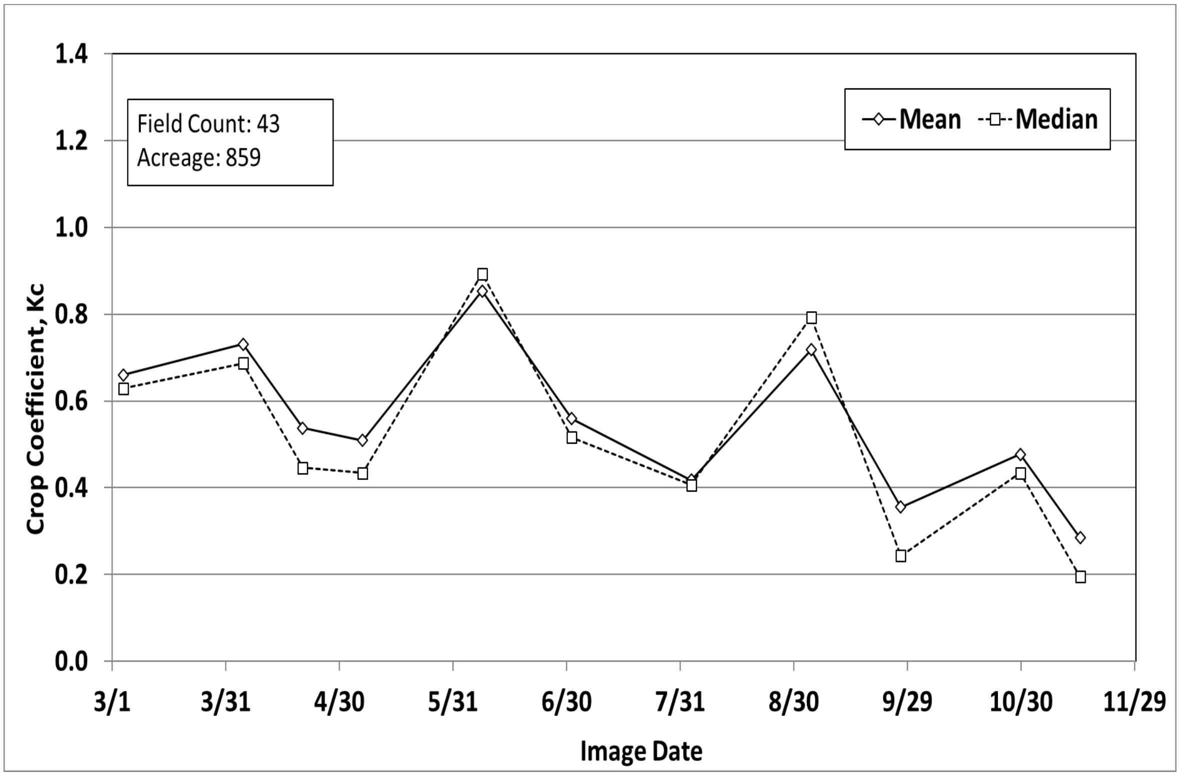


Figure 6B-3. 2008 METRIC - Derived Crop Coefficients (ET_c/ET_o) for Fields Identified to have Onions by NM Field Survey

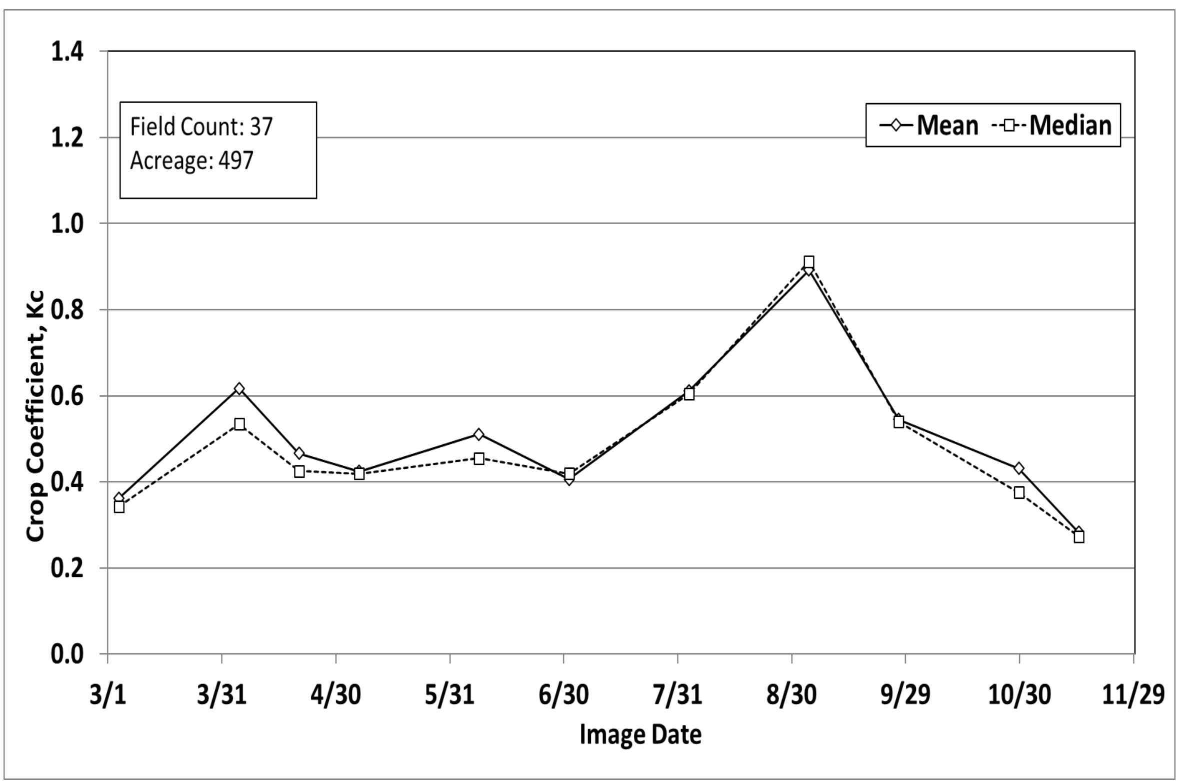


Figure 6B-4. 2008 METRIC - Derived Crop Coefficients (ET_c/ET_o) for Fields Identified to have Miscellaneous Vegetables by NM Field Survey

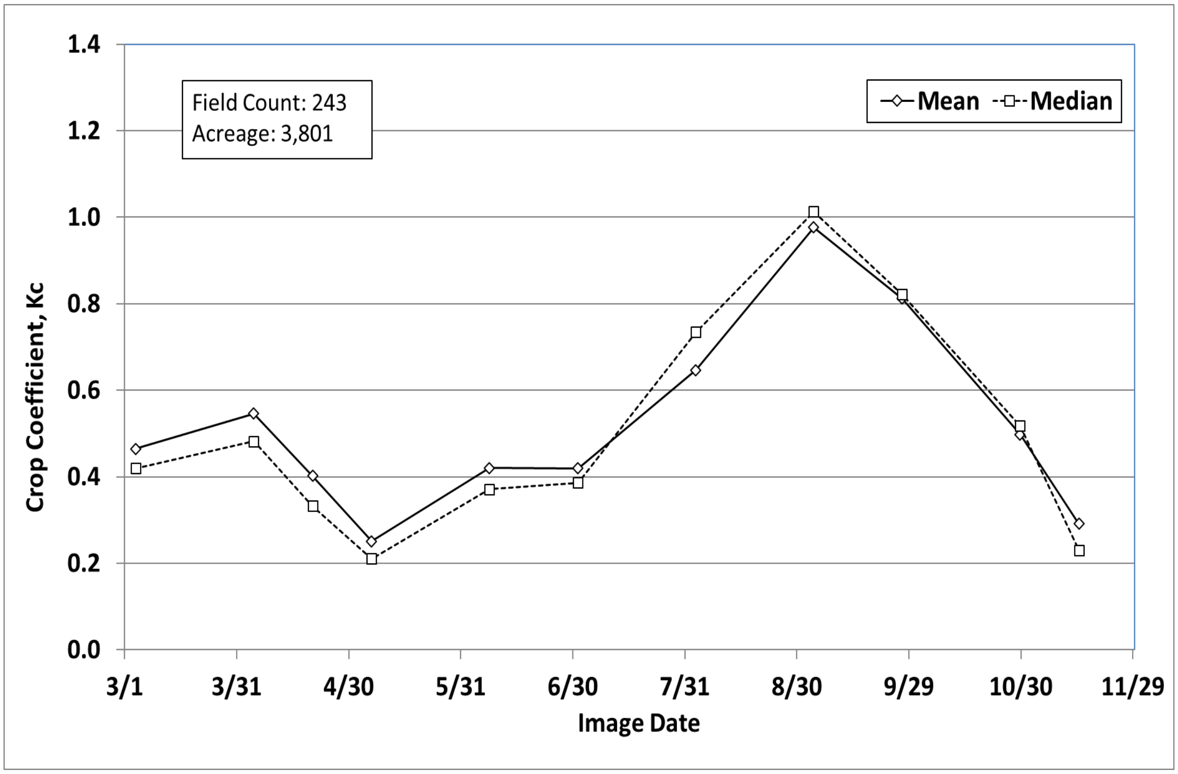


Figure 6B-5. 2008 METRIC - Derived Crop Coefficients (ET_c/ET_o) for Fields Identified to have Chile (Peppers) by NM Field Survey

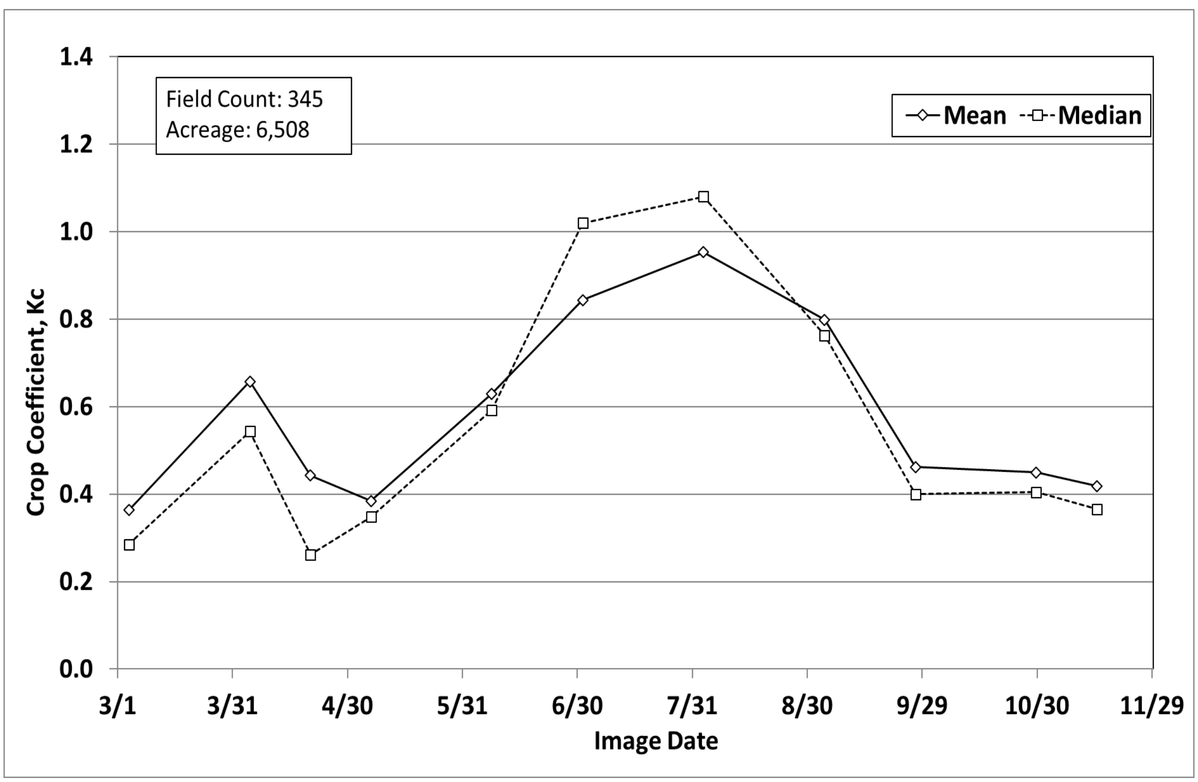


Figure 6B-6. 2008 METRIC - Derived Crop Coefficients (ET_c/ET_o) for Fields Identified to have Corn, Sweet Corn and Silage by NM Field Survey

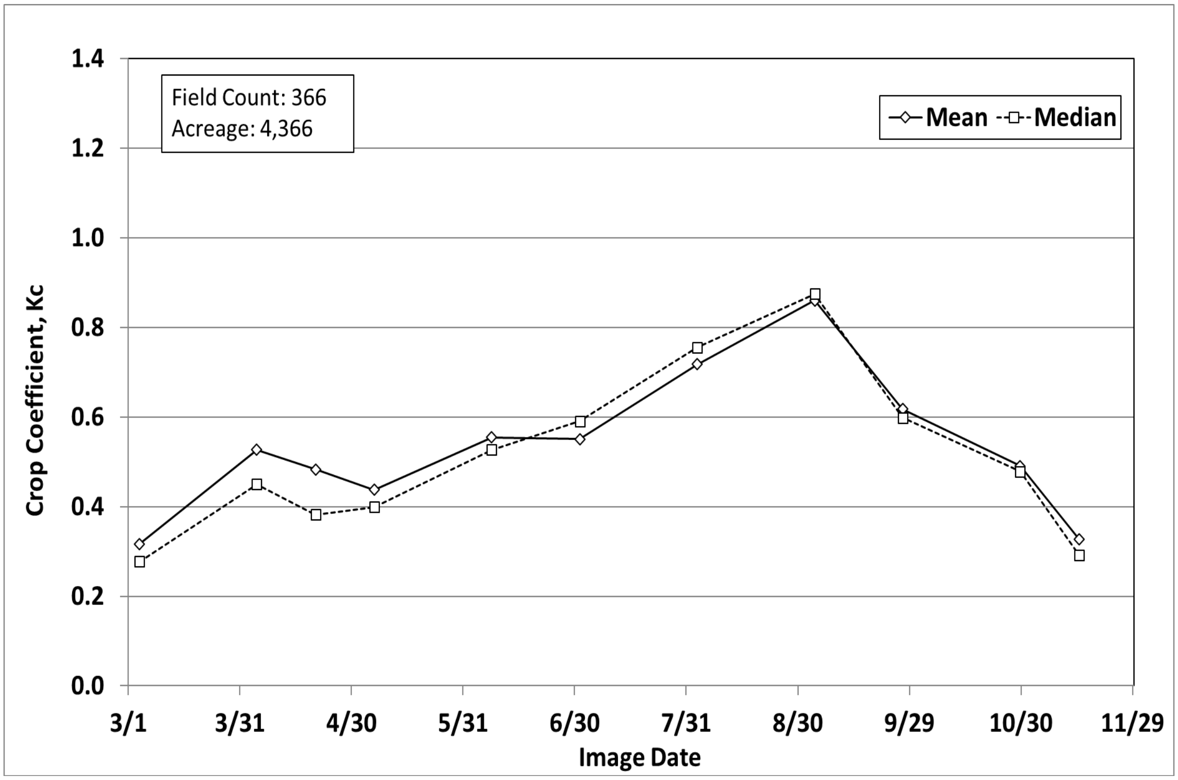


Figure 6B-7. 2008 METRIC - Derived Crop Coefficients (ET_c/ET_o) for Fields Identified to have Irrigated Pasture by NM Field Survey

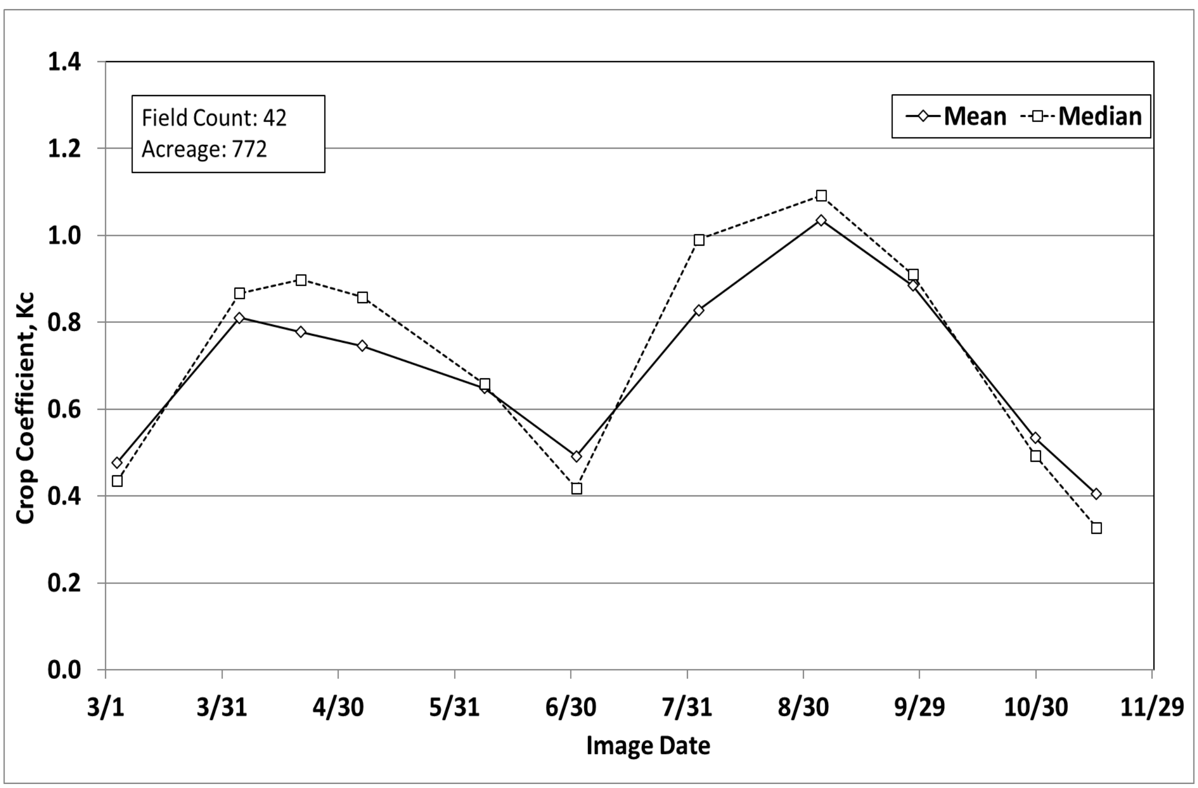


Figure 6B-8. 2008 METRIC - Derived Crop Coefficients (ET_c/ET_o) for Fields Identified to have Wheat and Small Grains by NM Field Survey

Appendix 6C. NDVI and ET_oF for EBID Fields

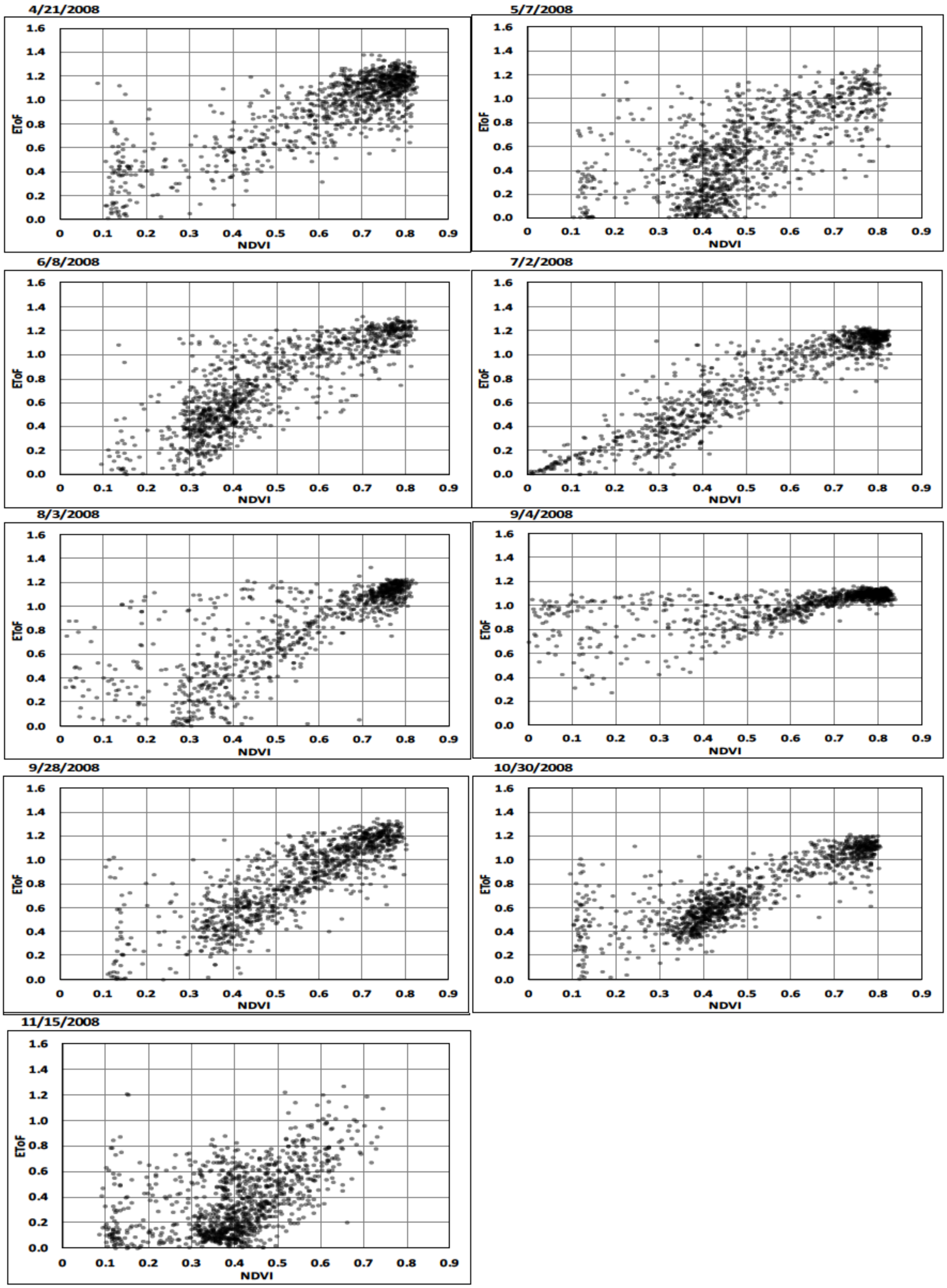


Figure 6C-1. NDVI and ET_oF for EBID Alfalfa Hay Fields, April 21 to November 15, 2008

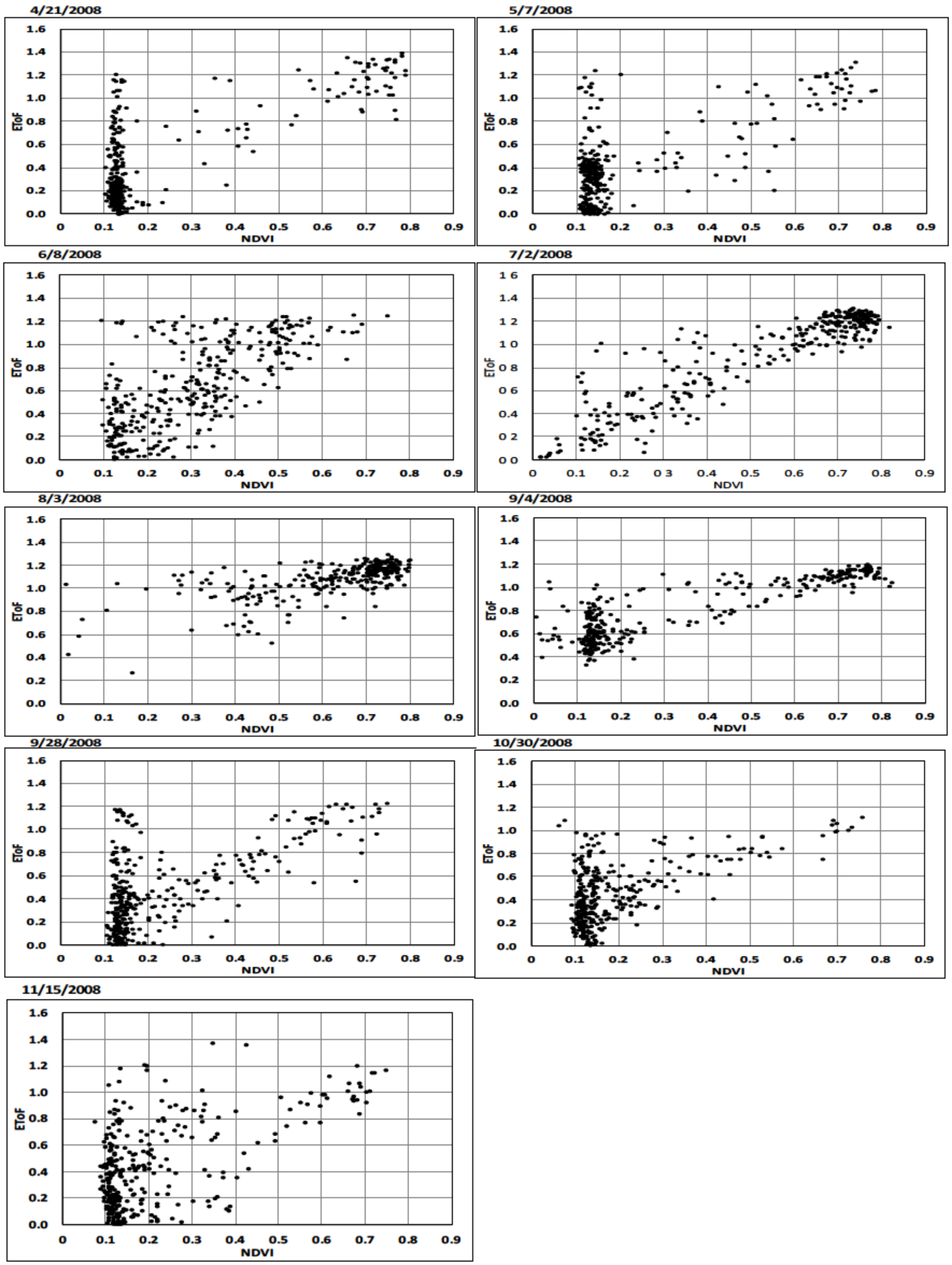


Figure 6C-2. NDVI and ET_oF for EBID Corn, Sweet Corn and Silage Fields, April 21 to November 15, 2008

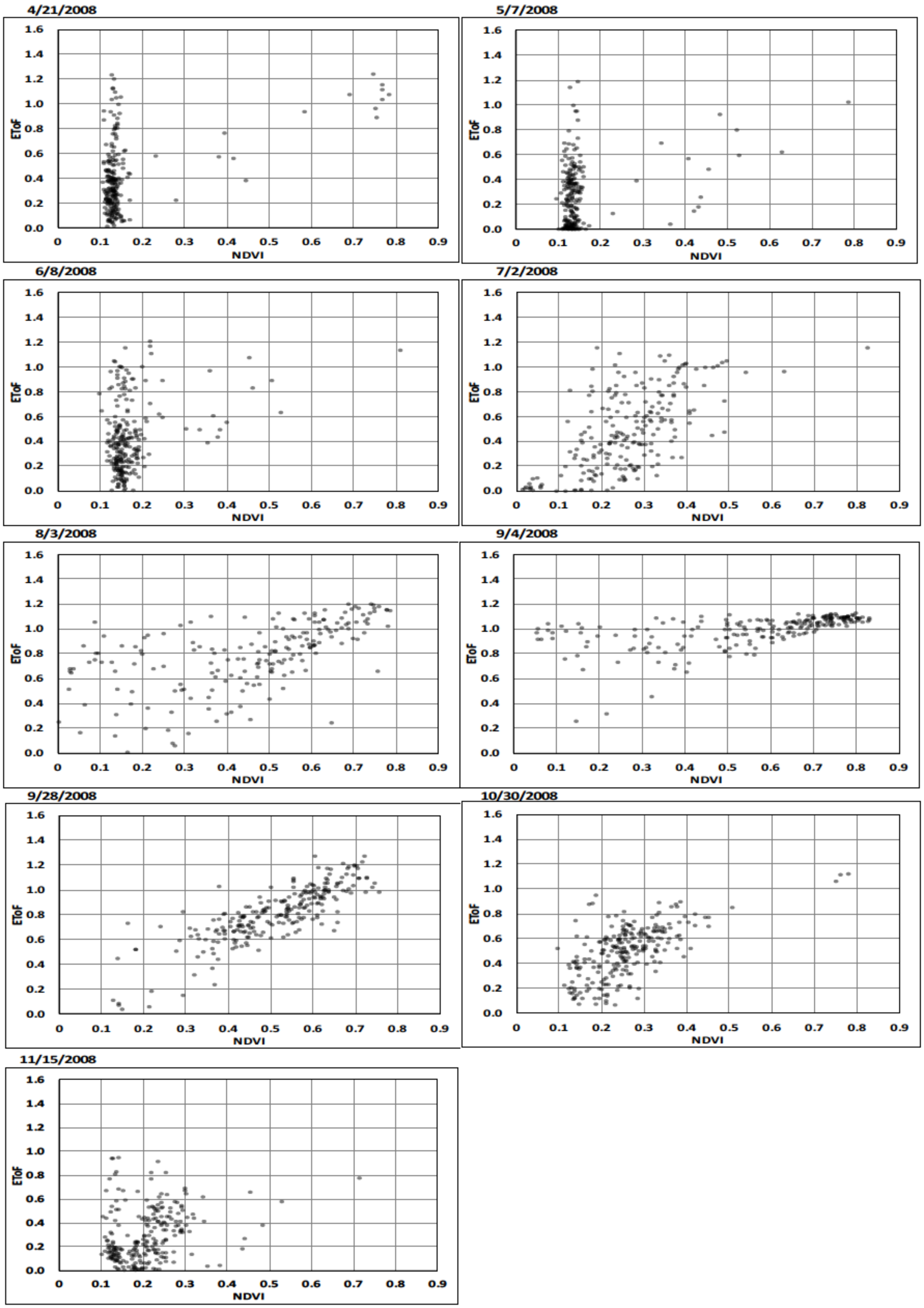


Figure 6C-3. NDVI and ET_oF for EBID Chile (Peppers), April 21 to November 15, 2008

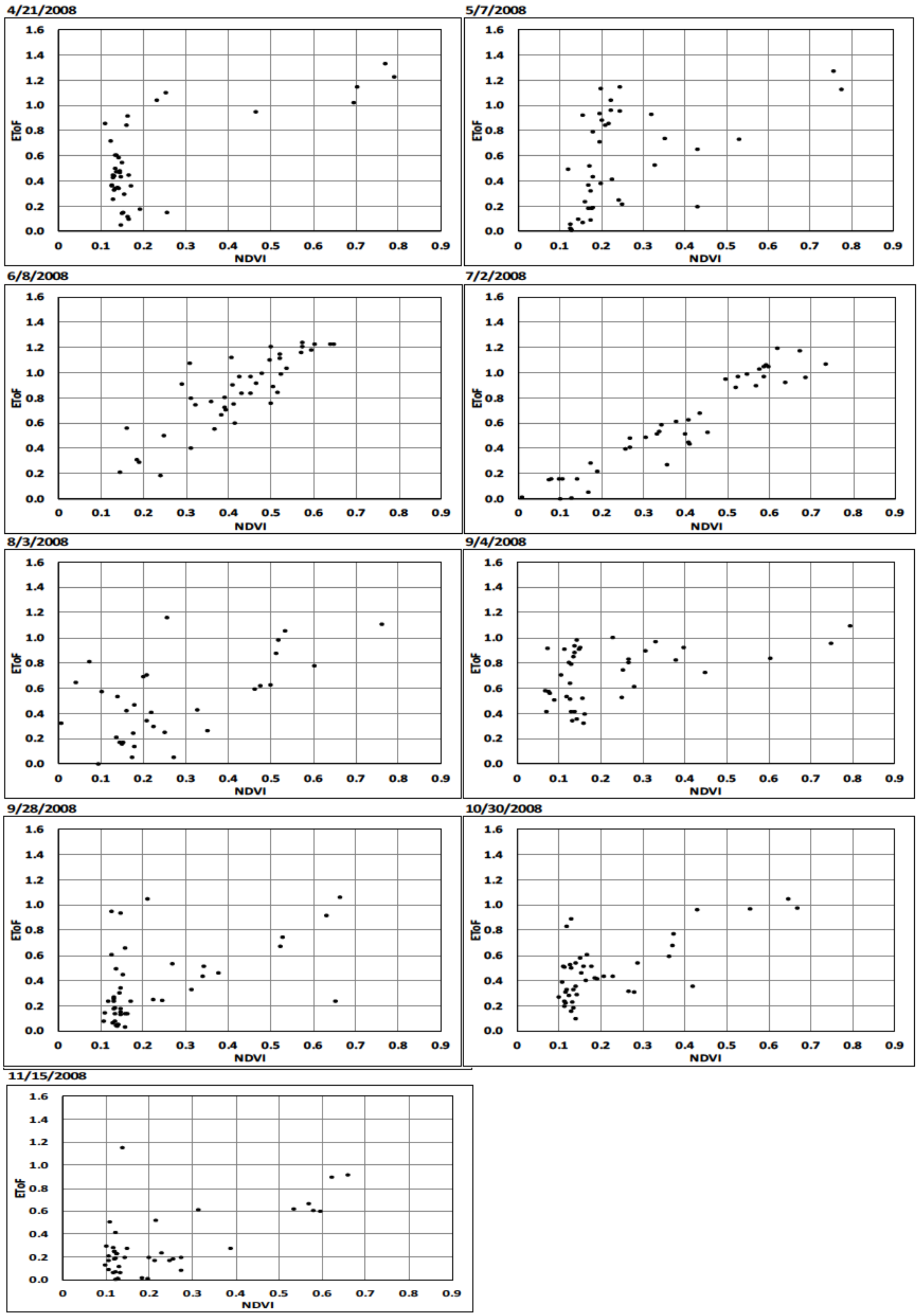


Figure 6C-4. NDVI and ET$_o$F for EBID Onion Fields, April 21 to December 1, 2008

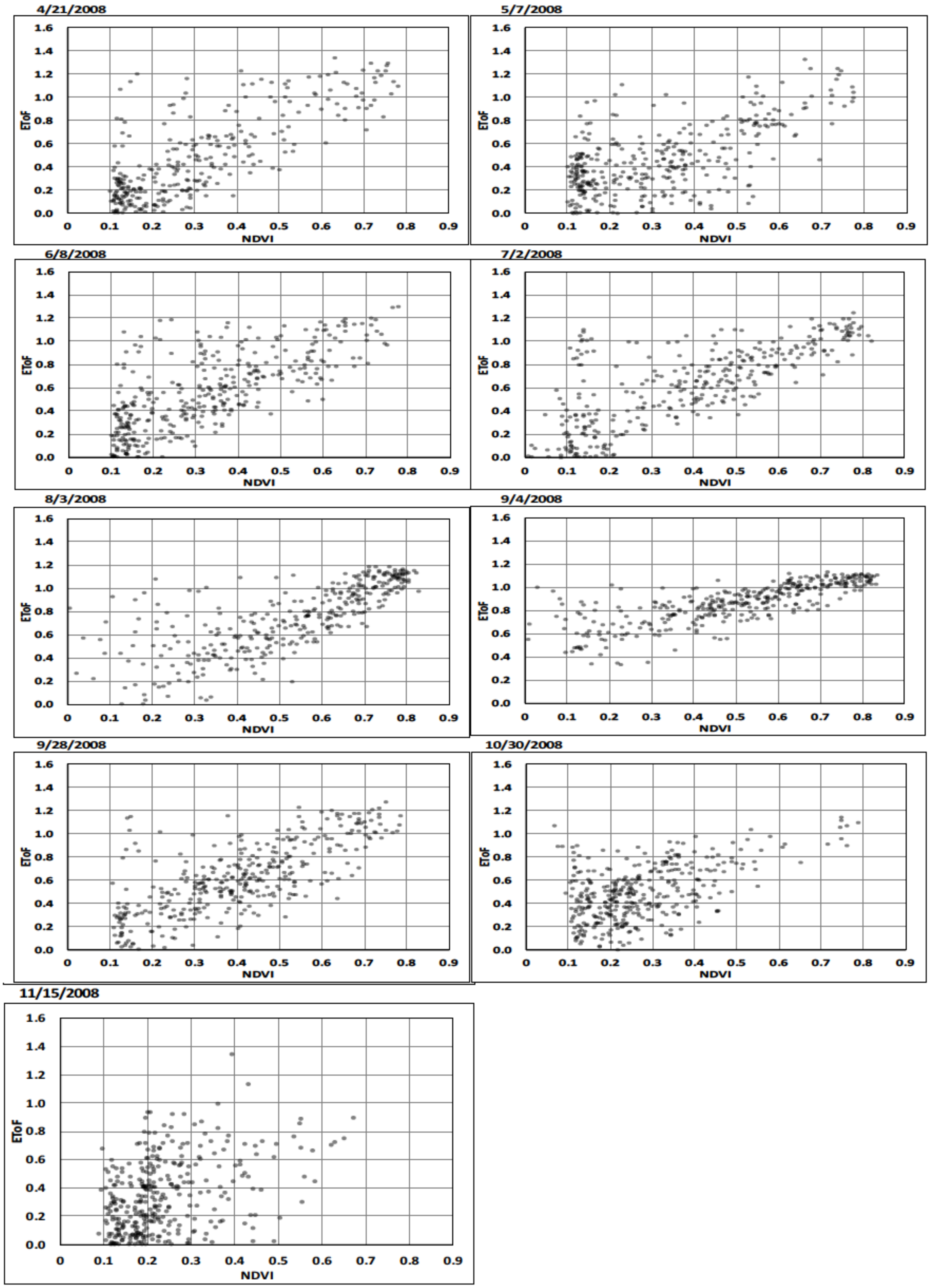


Figure 6C-5. NDVI and ET$_o$F for EBID Irrigated Pasture, April 21 to November 15, 2008

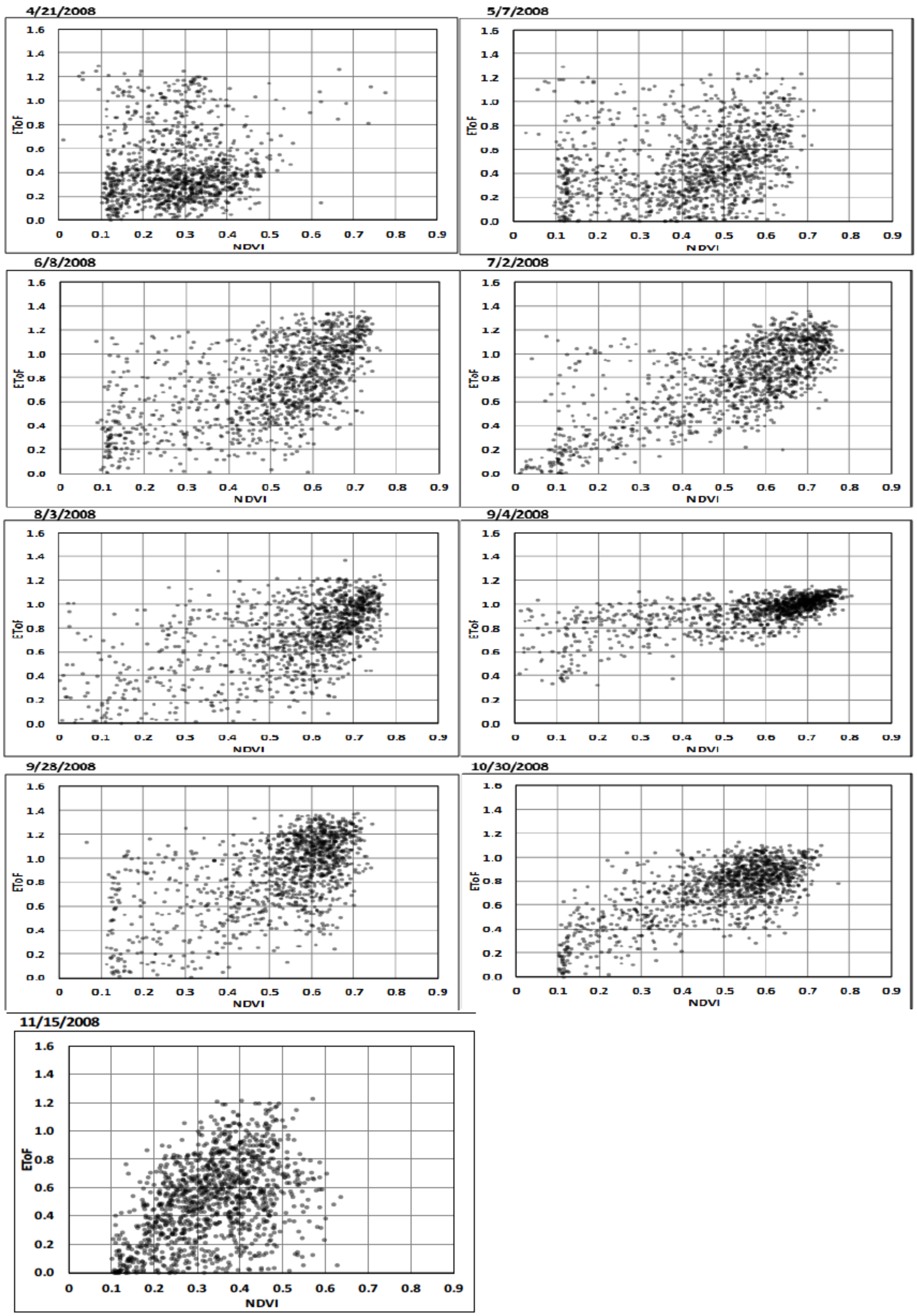


Figure 6C-6. NDVI and ET_oF for EBID Pecans, April 21 to November 15, 2008

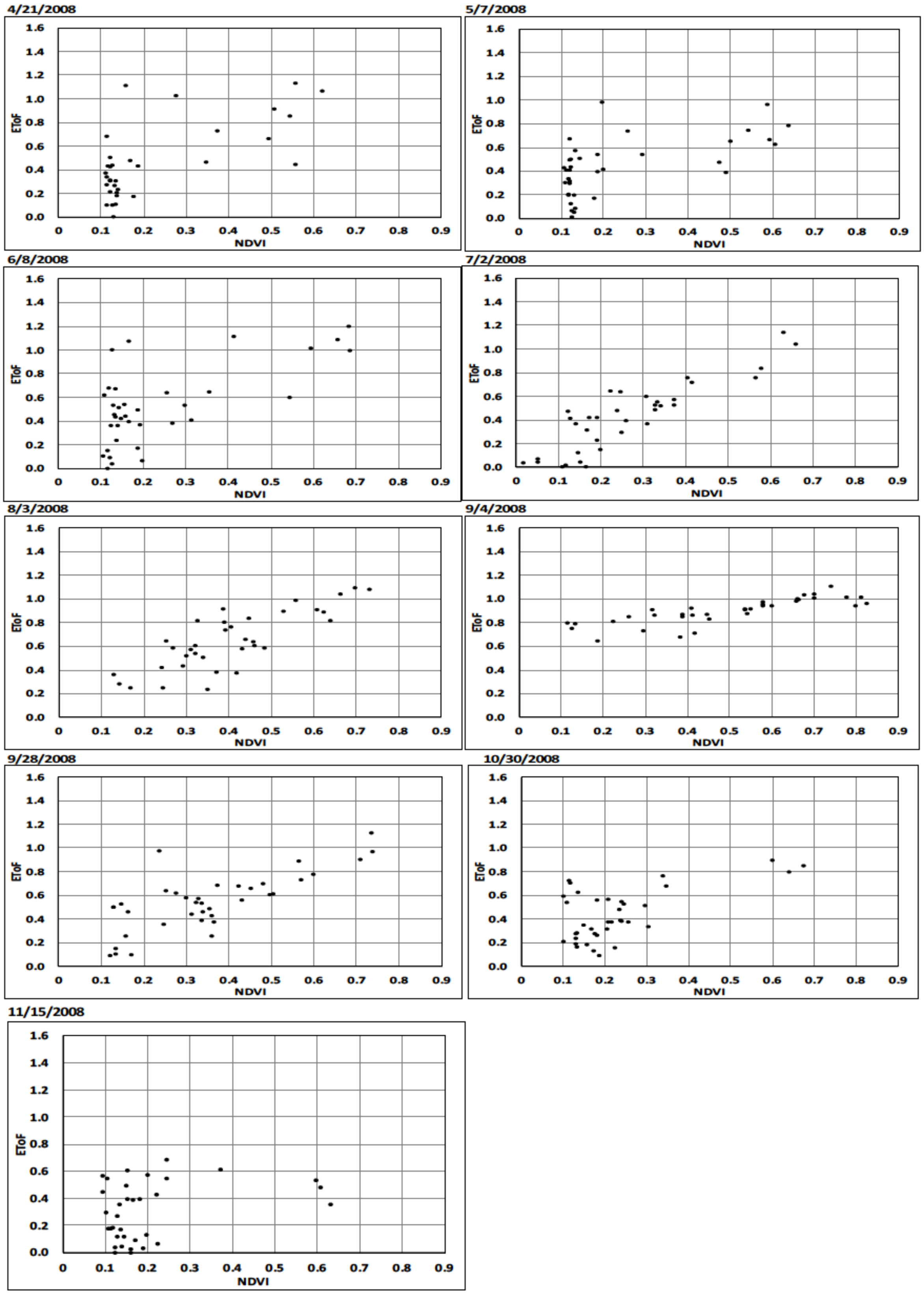


Figure 6C-7. NDVI and ET_oF for EBID Miscellaneous Vegetable Fields, April 21 to November 15, 2008

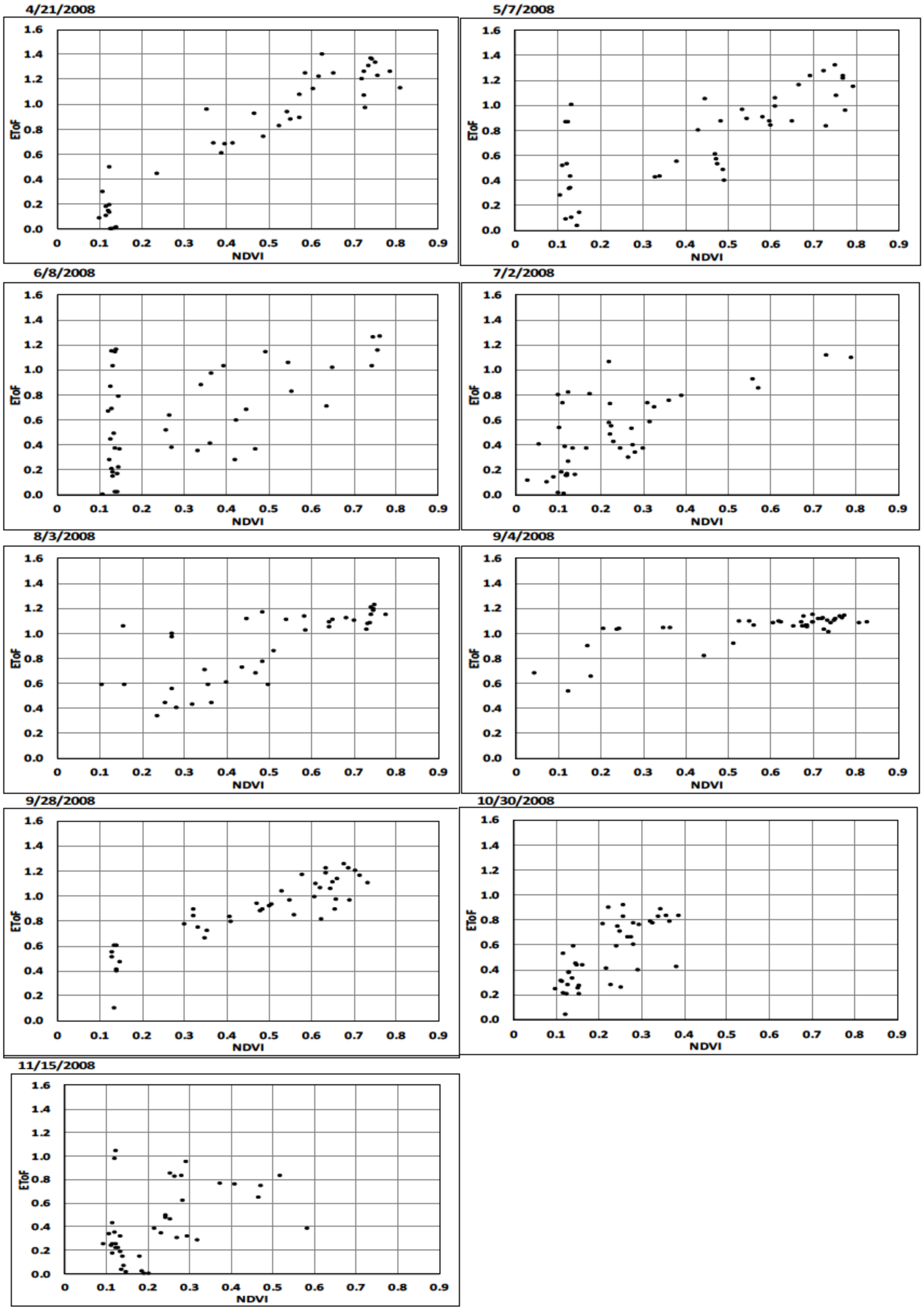


Figure 6C-8. NDVI and ET_oF for EBID Wheat and Small Grains Fields, April 21 to November 15, 2008

Appendix 6D. NDVI, ET_oF, and Estimated Relationships of K_{cb} to NDVI by Field for EBID Crops, June 4 to September 28, 2008

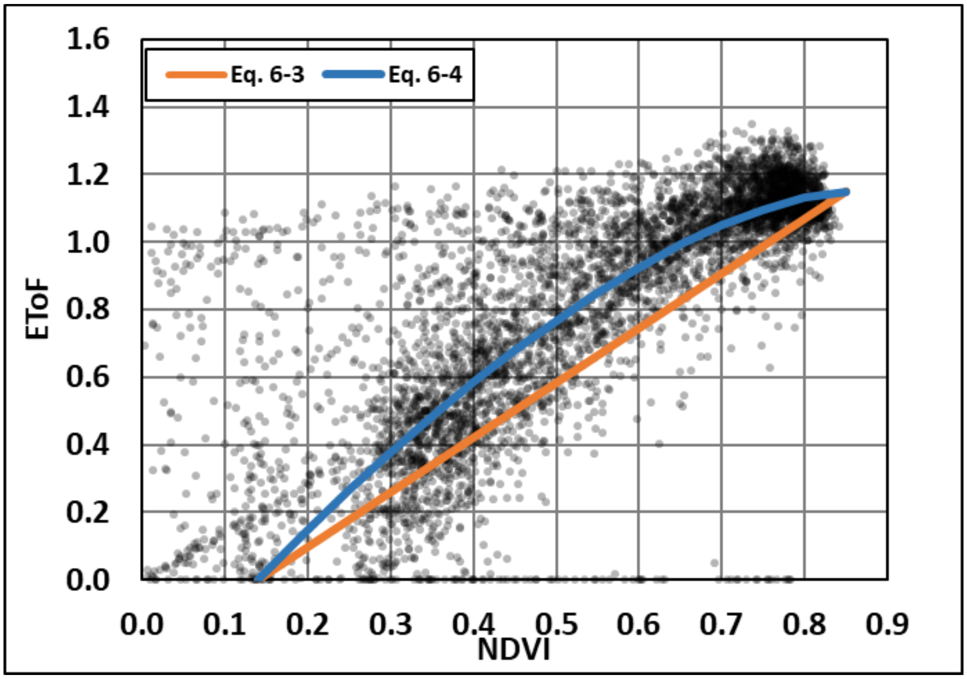


Figure 6D-1. NDVI, ET_oF, and Estimated Relationships of K_{cb} to NDVI for EBID Alfalfa Fields, June 4 to September 28, 2008.

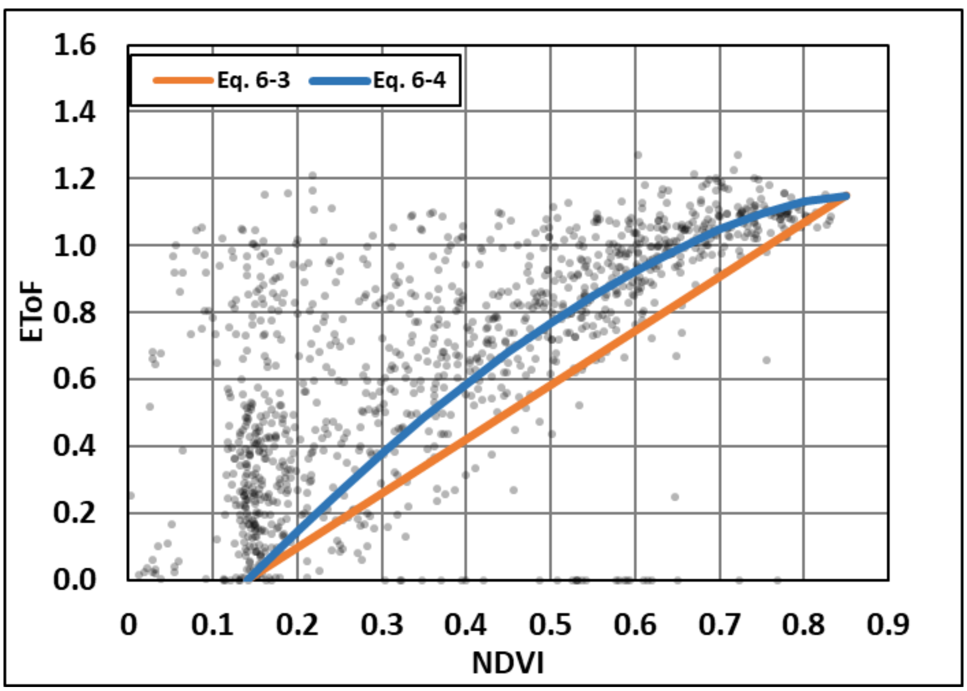


Figure 6D-2. NDVI, ET_oF, and Estimated Relationships of K_{cb} to NDVI for EBID Chile Fields, June 4 to September 28, 2008.

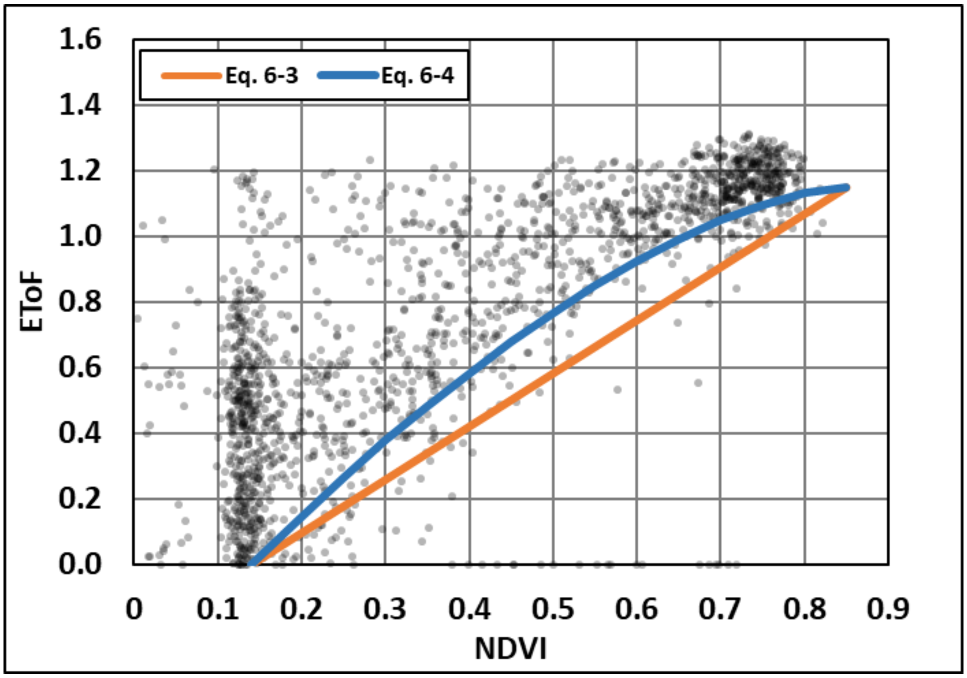


Figure 6D-3. NDVI, ET_oF, and Estimated Relationships of K_{cb} to NDVI for EBID Corn, Sweet Corn and Silage Fields, June 4 to September 28, 2008.

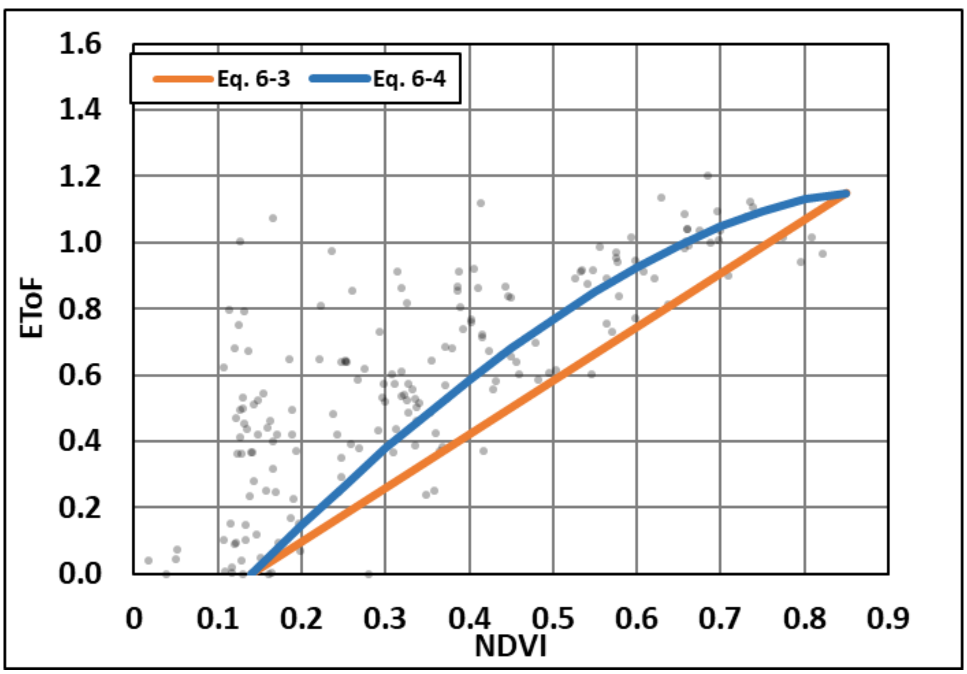


Figure 6D-4. NDVI, ET_oF, and Estimated Relationships of K_{cb} to NDVI for EBID Miscellaneous Vegetables Fields,
June 4 to September 28, 2008.

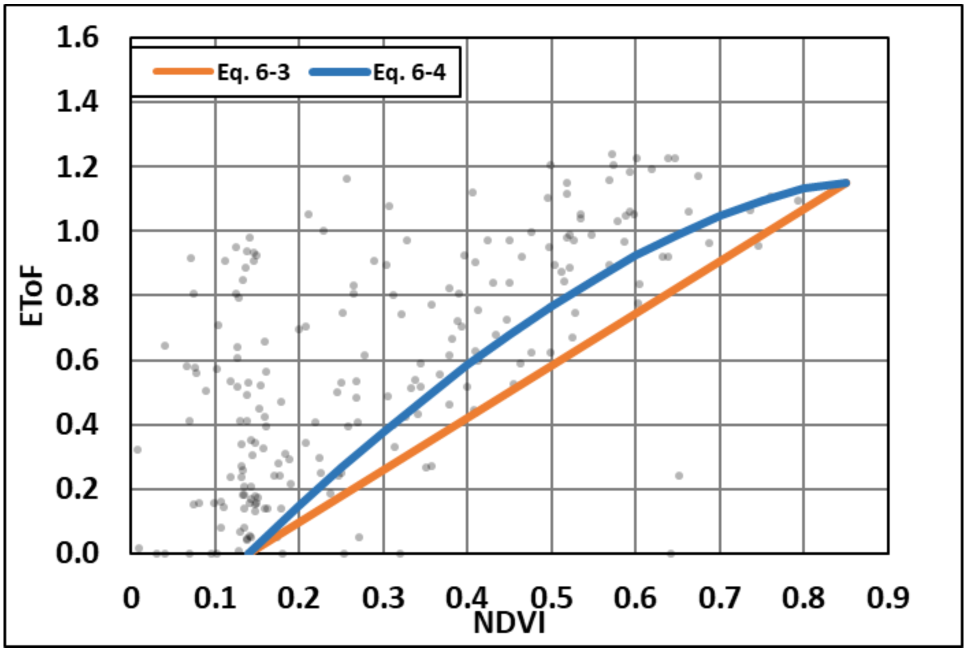


Figure 6D-5. NDVI, ET_oF, and Estimated Relationships of K_{cb} to NDVI for EBID Onion Fields, June 4 to September 28, 2008.

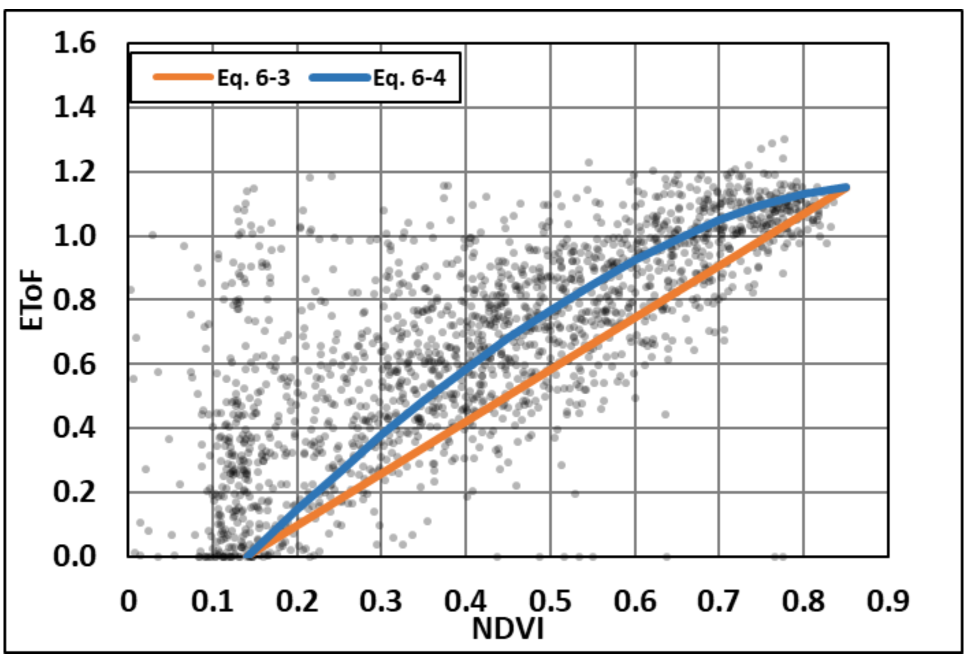


Figure 6D-6. NDVI, ET_oF, and Estimated Relationships of K_{cb} to NDVI for EBID Irrigated Pasture Fields, June 4 to September 28, 2008.

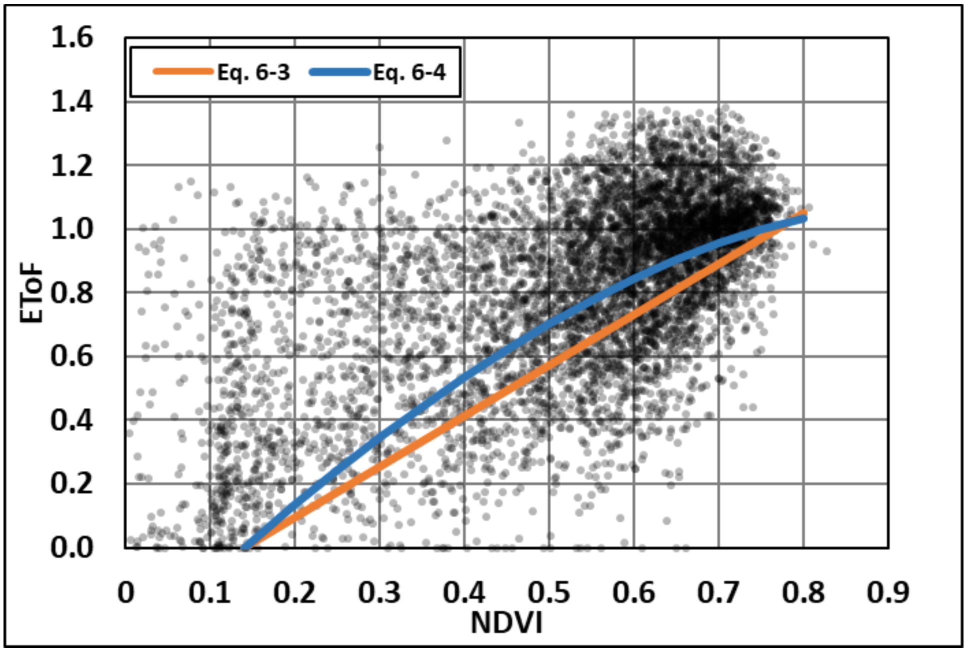


Figure 6D-7. NDVI, ET_oF, and Estimated Relationships of K_{cb} to NDVI for EBID Irrigated Pecan Fields, June 4 to September 28, 2008.

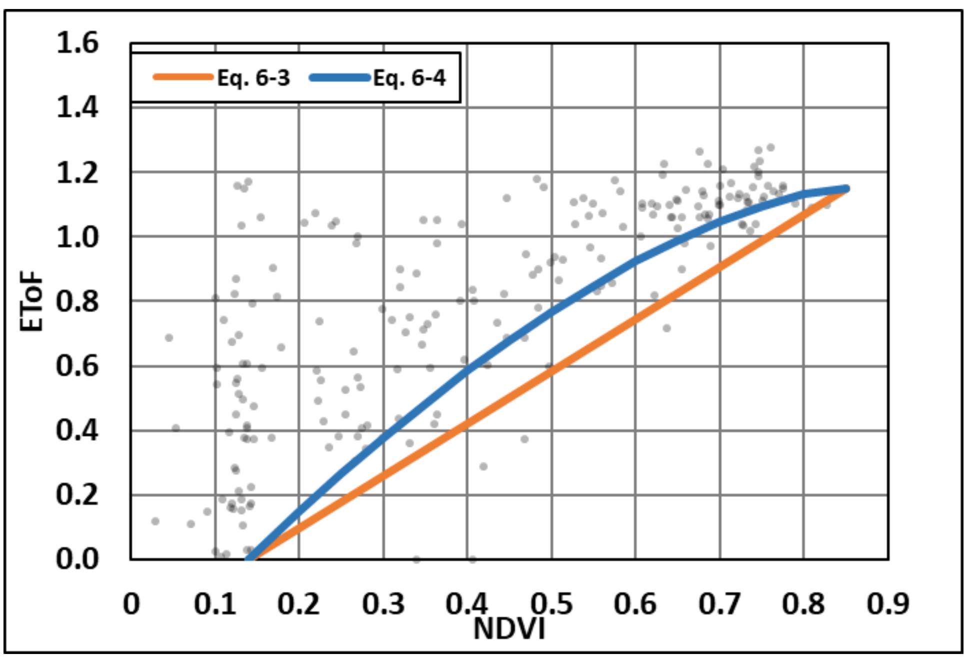


Figure 6D-8. NDVI, ET_oF, and Estimated Relationships of K_{cb} to NDVI for EBID Irrigated Wheat and Small Grain Fields, June 4 to September 28, 2008.

Appendix 7A. ET Demands Calibration Results by Crop Group

This appendix presents the ET Demands calibration results by crop group for 2008 and 2013, the years when information on the crop in each field is available. This information is primarily from the NASS CDL, except for 2008 in New Mexico when the NMOSE ground survey data is available. The following sections discuss results for EBID in 2008, the 2008 results for EPCWID, Hudspeth and Juarez and the 2013 results for EBID, EPCWID, Hudspeth and Juarez.

ET Demands Calibration Results for Elephant Butte Irrigation District, 2008

Monthly and seasonal estimates of ET Demands model ET_c for each crop in EBID in 2008, were compared to METRIC ET_c results for each crop (**Figure 7A-1**). The NMOSE 2008 ground-based crop survey identified the crop in each field for the METRIC results. The results presented are for the calibrated ET Demands model.

March through October 2008 METRIC and ET Demands ET_c estimates for each crop in EBID for irrigated lands with access to both surface water (SW) and groundwater (GW) are provided in **Table 7A-1a** and **Figure 7A-2a**. METRIC ET estimates range from 31.5 inches for chile to 44.9 inches for alfalfa with total ET_c estimated as 39.0 inches for the 2008 March to October period. Similarly, ET Demands ET_c estimates range from 32.5 inches for cotton to 46.4 inches for alfalfa with total ET_c estimated as 40.4 inches. ET Demands estimates of ET_c for wheat and other small grains are 1.7 inches less than the METRIC ET_c estimates. For alfalfa hay, ET Demands ET_c estimates are 1.5 inches higher than the METRIC ET_c results for alfalfa hay. On a percentage basis, ET Demands estimates of ET differ from METRIC estimates by -3.9 percent for wheat and small grains to 3.4 percent for alfalfa hay with total ET_c differing by 3.7 percent.

March through October METRIC and ET Demands results by crop for 2008 for irrigated lands in New Mexico with access to only groundwater are provided in **Table 7A-1b** and **Figure 7A-2b**. METRIC ET_c estimates range from 21.2 inches for miscellaneous vegetables to 39.6 inches for alfalfa with total ET_c equal to 30.3 inches for the 2008 March to October period. Similarly, ET Demands ET_c estimates range from 32.5 inches for cotton to 46.4 inches for alfalfa with total ET_c equal to 39.7 inches. ET Demands estimates of ET_c differ from METRIC ET_c estimates by -2.2 inches for onions to 11.6 inches for miscellaneous vegetables with total ET_c differing by 9.4 inches. On a percentage basis, ET Demands estimates of ET_c differ from METRIC estimates by -5.8 percent for onions to 54.5 percent for miscellaneous vegetables with total ET_c differing by 30.9 percent.

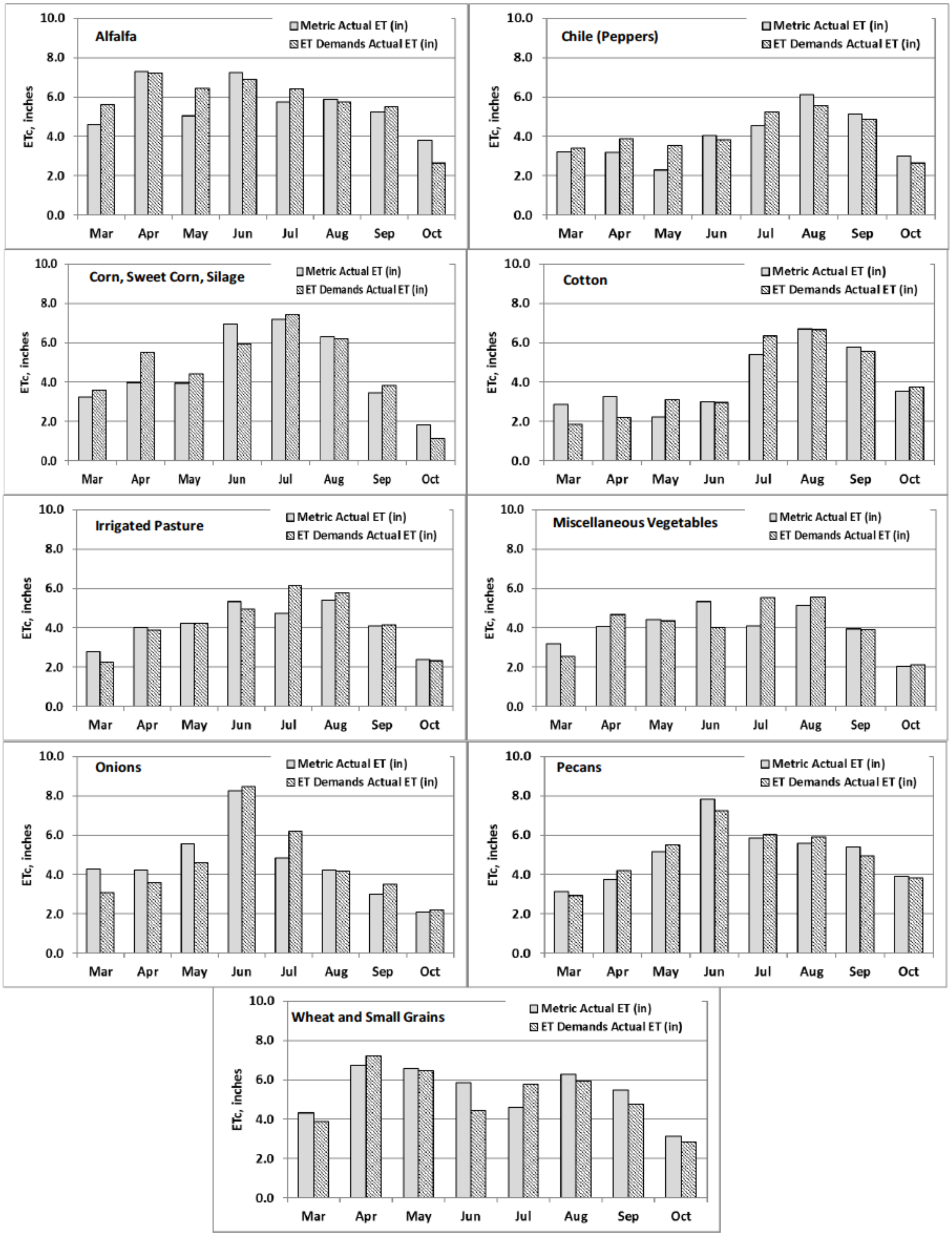


Figure 7A-1. METRIC and ET Demands 2008 Monthly Actual ET Estimates for EBID by Crop.

Table 7A-1a. Summary of METRIC and ET Demands 2008 Seasonal (March – October) ET_c Estimates by Crop for EBID Irrigated Lands with Access to Surface Water and Groundwater.

Crop	Acres	METRIC ET_c (in)	ET Demands ET_c (in)	Difference (in)	Difference (%)
Pecans	26,485	40.7	40.6	-0.1	-0.2%
Alfalfa Hay	18,042	44.9	46.4	1.5	3.4%
Cotton	11,885	32.8	32.5	-0.3	-1.0%
Corn, Sweet Corn, and Silage	8,097	36.9	38.1	1.2	3.2%
Onions	4,081	36.5	35.9	-0.6	-1.7%
Chile (Peppers)	4,011	31.5	33.0	1.5	4.8%
Wheat and Small Grains	2,434	43.0	41.3	-1.7	-3.9%
Irrigated Pasture	1,800	32.9	33.7	0.8	2.4%
Miscellaneous Vegetables	732	32.2	32.8	0.6	1.7%
Totals	77,567	39.0	40.4	1.4	3.7%

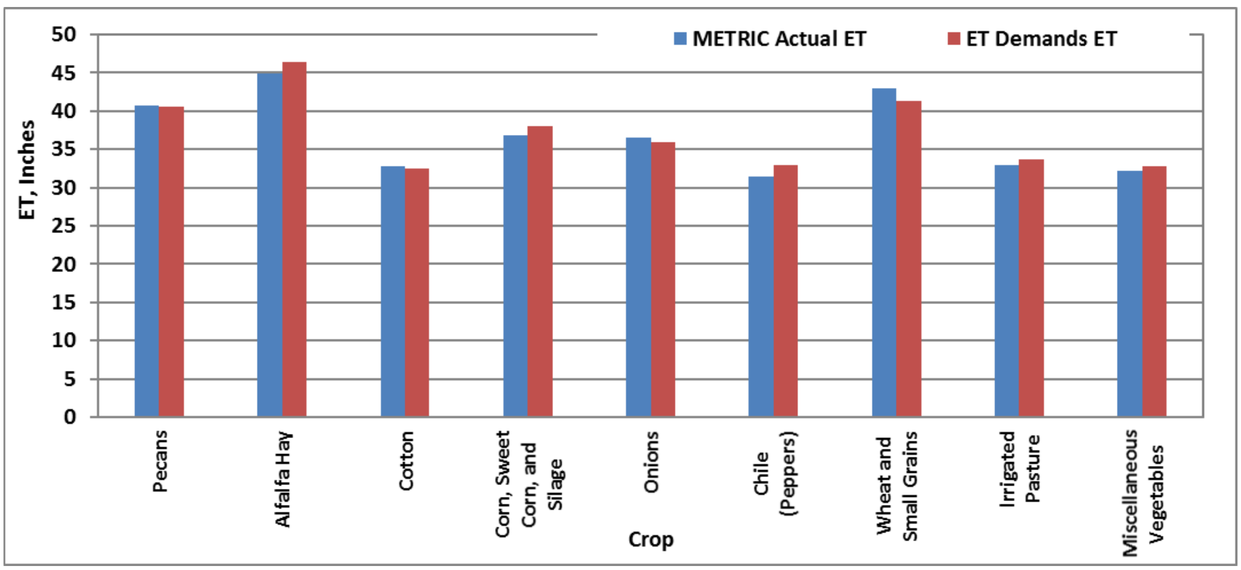


Figure 7A-2a. METRIC and ET Demands 2008 Seasonal (March – October) ET_c Estimates by Crop for EBID Irrigated Lands with Access to Surface Water and Groundwater.

Table 7A-1b. Summary of METRIC and ET Demands 2008 Seasonal (March – October) by Crop ET_c Estimates for Irrigated Lands in New Mexico with Access to Only Groundwater.

Crop	Acres	METRIC ET_c (in)	ET Demands ET_c (in)	Difference (in)	Difference (%)
Alfalfa Hay	1,751	39.6	46.4	6.8	17.2%
Pecans	1,278	29.4	40.6	11.2	38.1%
Irrigated Pasture	938	32.0	33.7	1.7	5.3%
Corn, Sweet Corn, and Silage	424	28.6	38.1	9.5	33.1%
Cotton	186	30.4	32.5	2.1	6.8%
Chile (Peppers)	185	21.8	33.0	11.2	51.4%
Wheat and Small Grains	50	30.3	41.3	11.0	36.3%
Miscellaneous Vegetables	45	21.2	32.8	11.6	54.5%
Onions	41	38.1	35.9	-2.2	-5.8%
Totals	4,898	30.3	39.7	9.4	30.9%

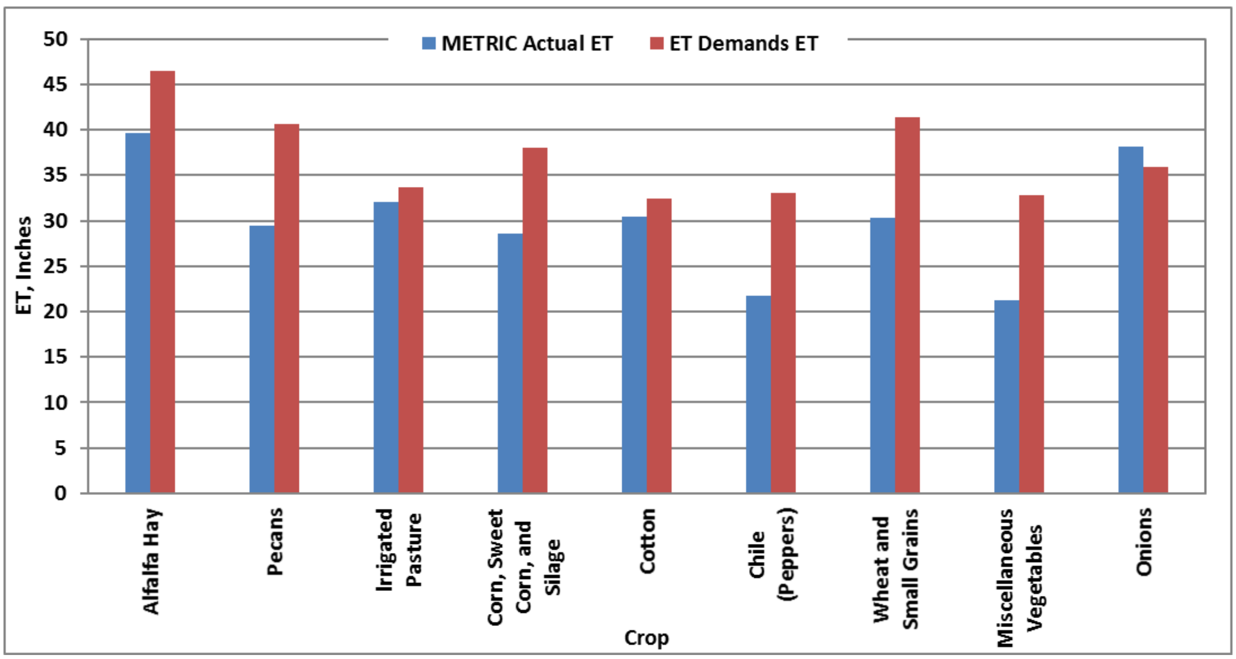


Figure 7A-2b. METRIC and ET Demands 2008 Seasonal (March – October) ET_c Estimates by Crop for Irrigated Lands in New Mexico with Access to Only Groundwater.

Relatively good agreement between METRIC and ET Demands results for EBID in 2008 is a direct result of the calibration process described previously, in which basal crop coefficients (k_{cb}) and model parameters ($k_{c,maxo}$) were iteratively adjusted to match the METRIC seasonal results within ten percent. This calibration also resulted in relatively good agreement for each month when ET_c from all crops is combined into a single monthly total (**Figure 7A-3**). With the exception of May and October, ET Demands monthly ET_c estimates were within plus or minus 14 percent of the monthly METRIC ET estimate (**Table 7A-2**).

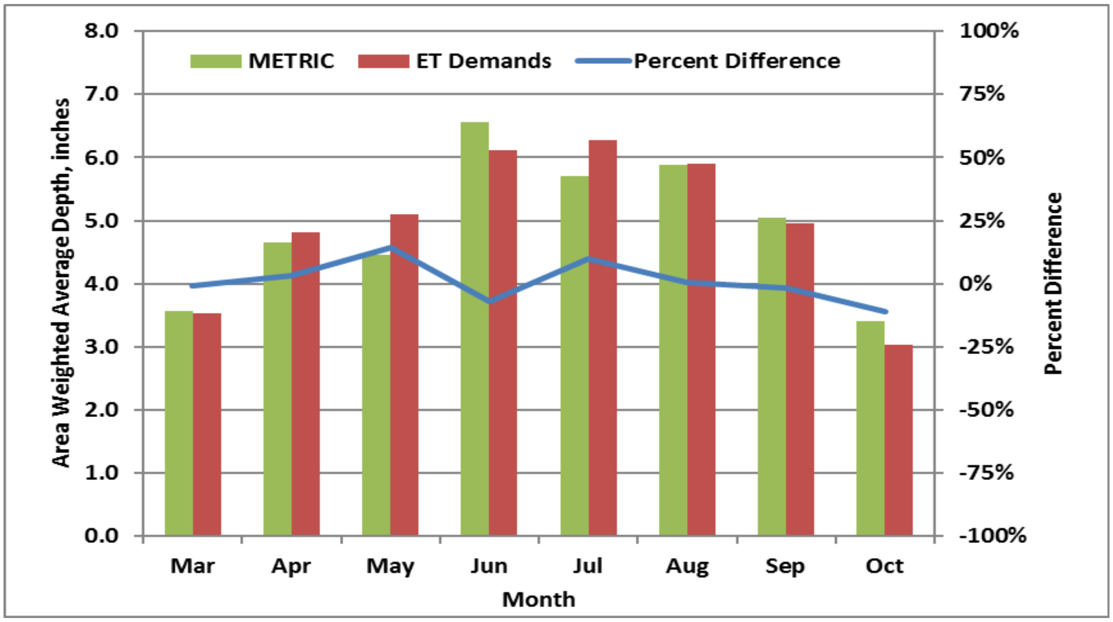


Figure 7A-3. METRIC and ET Demands 2008 Seasonal (March – October) ET_c Estimates for EBID by Month.

Table 7A-2. Summary of METRIC and ET Demands 2008 Seasonal (March – October) ET_c Estimates for EBID (Access to Surface Water) by Month.

Month	Metric ET_c (in)	ET Demands ET_c (in)	Difference (in)	Difference (%)
Mar	3.6	3.5	0.0	-1%
Apr	4.7	4.8	0.1	3%
May	4.5	5.1	0.6	14%
Jun	6.6	6.1	-0.5	-7%
Jul	5.7	6.3	0.6	10%
Aug	5.9	5.9	0.0	0%
Sep	5.0	5.0	-0.1	-2%
Oct	3.4	3.0	-0.4	-11%
Totals	39.3	39.7	0.4	1%

2008 Comparisons

The crop coefficients that were calibrated to the 2008 METRIC ET_c data in EBID were used in the ET Demands model to compute the ET_c in the service areas of the EPCWID, Hudspeth County, and the Juarez Irrigation District. These ET Demands ET_c estimates were compared to the 2008 METRIC ET_c estimates for each district, and the results of this comparison are described below.

El Paso County Water Improvement District

EPCWID delivers water to about 6,000 acres in the Mesilla Valley and about 40,000 acres in the El Paso Valley. Seasonal METRIC and ET Demands results by crop for 2008 in the EPCWID areas in the Mesilla and El Paso Valleys are provided in **Tables 7A-3a and 7A-3b** and **Figures 7A-4a and 7A-4b**, respectively. In the Mesilla Valley area of EPCWID, totaling about 11 percent of the EPCWID irrigated area in 2008, METRIC ET_c estimates range from 29.1 inches for cotton to 41.2 inches for alfalfa with total ET_c equal to 33.9 inches for the 2008 March to October period. Only crops identified in the CDL can be compared to the METRIC ET_c results, so only those crops and crops with more than 450 acres are discussed. ET Demands ET estimates range from 32.7 inches for cotton to 47.1 inches for alfalfa. ET Demands estimates of ET_c differ from METRIC estimates by 0.4 inches for pecans to 5.9 inches for alfalfa with total ET_c differing by 4.0 inches. ET Demands ET_c estimates for irrigated pasture are nearly twice the METRIC estimates for ET_c of irrigated pasture. This large difference is likely an indication that some of the about 150 acres in pasture identified by the 2008 CDL may have been irrigated for only part of the irrigation season. On a percentage basis, ET Demands estimates of ET_c differ from METRIC estimates by 1.0 percent for pecans to 14.4 percent for alfalfa with total ET_c differing by 11.8 percent.

Table 7A-3a. Summary of METRIC and ET Demands 2008 Seasonal (March – October) ET_c Estimates for the Mesilla Valley Area of EPCWID by Crop.

Crop	Acres	METRIC ET_c (in)	ET Demands ET_c (in)	Difference (in)	Difference (%)
Cotton	1,661	29.1	32.7	3.6	12.4%
Pecans	1,321	40.5	40.9	0.4	1.0%
Alfalfa Hay	480	41.2	47.1	5.9	14.4%
Irrigated Pasture	143	17.5	34.1	16.6	94.7%
Wheat and Small Grains	133	34.9	41.6	6.7	19.1%
Other	201	24.1	39.4	15.3	63.7%
Totals	3,940	33.9	37.9	4.0	11.8%

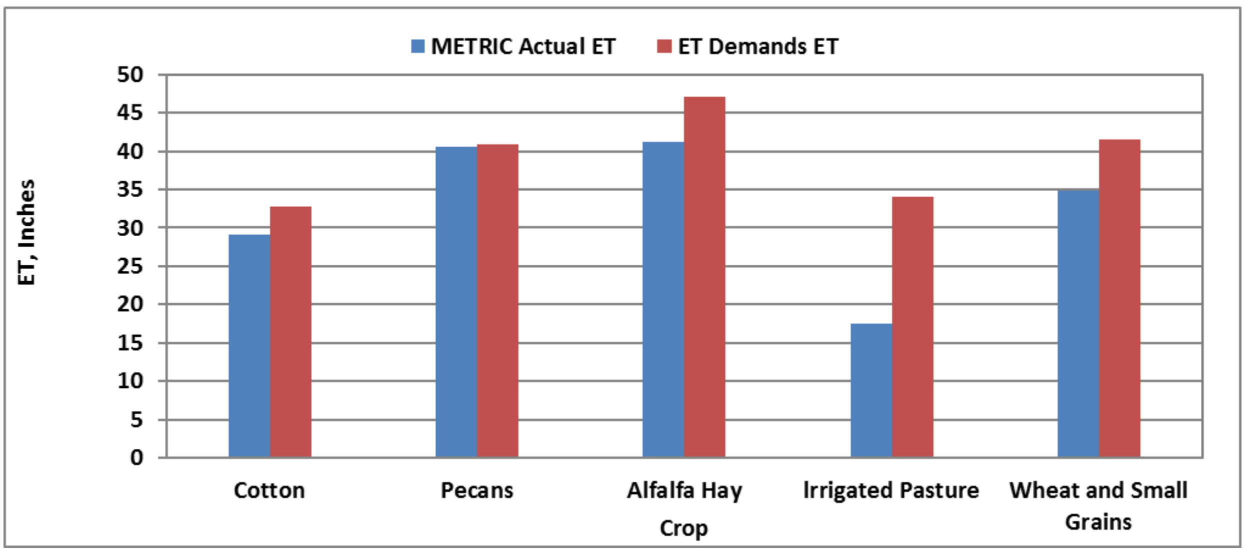


Figure 7A-4a. METRIC and ET Demands 2008 Seasonal (March – October) ET_c Estimates for the Mesilla Valley Area of EPCWID by Crop.

Table 7A-3b. Summary of METRIC and ET Demands 2008 Seasonal (March – October) ET_c Estimates for the El Paso Valley Area of EPCWID by Crop.

Crop	Acres	METRIC ET_c (in)	ET Demands ET_c (in)	Difference (in)	Difference (%)
Cotton	15,583	36.1	33.1	-3.0	-8.4%
Pecans	12,392	41.7	37.4	-4.3	-10.2%
Alfalfa Hay	4,508	46.9	47.5	0.6	1.2%
Wheat and Small Grains	1,251	47.1	42.5	-4.6	-9.7%
Other	3,233	18.9	37.1	18.2	95.9%
Totals	36,968	38.2	37.0	-1.2	-3.2%

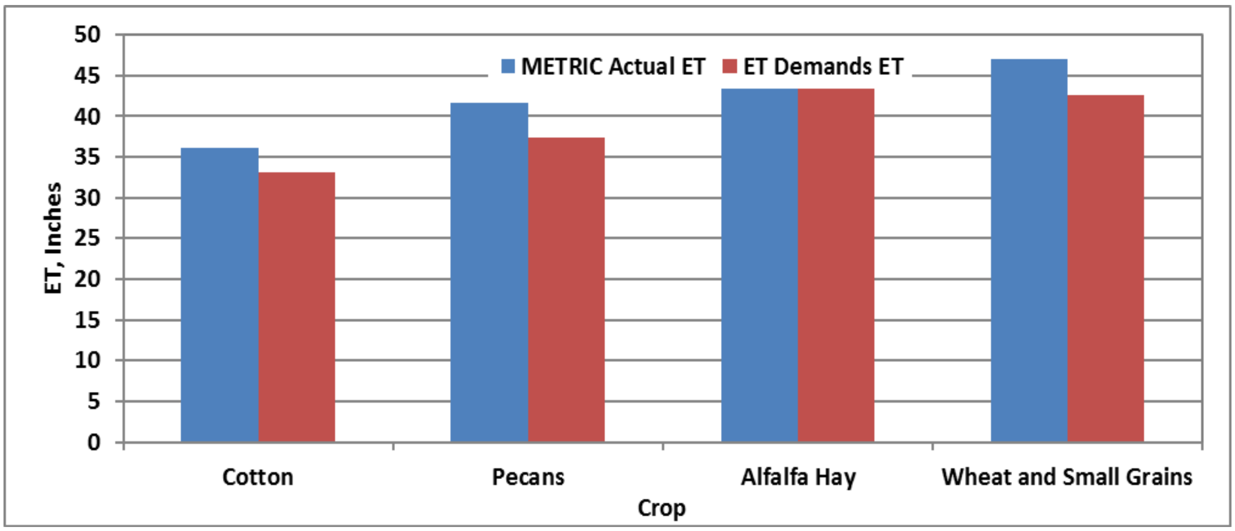


Figure 7A-4b. METRIC and ET Demands 2008 Seasonal (March – October) ET_c Estimates for the El Paso Valley area of EPCWID South by Crop.

In the El Paso Valley area of EPCWID, METRIC ET_c estimates range from 36.1 inches for corn to 47.1 inches for wheat and small grains with total ET_c of 38.2 inches for the 2008 March to October period. Only crops identified in the CDL can be compared to the METRIC ET results, so only those crops are discussed. ET Demands ET_c estimates range from 33.1 inches for cotton to 47.5 inches for alfalfa. ET Demands estimates of ET_c differ from METRIC estimates by -4.3 inches for pecans to 0.6 inches for alfalfa hay with total ET_c differing by -1.2 inches. On a percentage basis, ET Demands estimates of ET_c differ from METRIC estimates by -10.2 percent for cotton to 1.2 percent for alfalfa hay with the total ET_c differing by -3.2 percent.

ET Demands results for the area of EPCWID in the Mesilla Valley agree with METRIC results relatively well, but not as well as for EBID. The generally larger differences likely result from a combination of factors. One factor may be the different methods used to identify crops. Crops were identified in 2008 in EBID via ground-based surveys, whereas crops were identified in EPCWID and Hudspeth based on the Cropland Data Layer (CDL), a satellite based land use classification method (USDA, 2016). CDL results are considered more uncertain than ground-based surveys and could result in biases in the identification of certain crops. As a result, the METRIC ET_c estimates by crop within EPCWID may be influenced to a greater degree by misclassification than the METRIC ET_c results for EBID.

Hudspeth

Seasonal METRIC and ET Demands ET_c results by crop for 2008 in Hudspeth are provided in **Table 7A-4** and **Figure 7A-5**. As indicated, METRIC ET_c estimates range from 17.7 inches for chile to 39.8 inches for alfalfa with total ET_c equal to 28.3 inches for the March to October period. In contrast, ET Demands ET_c estimates range from 33.5 inches for cotton to 47.4 inches for alfalfa. ET Demands modeled ET_c estimates differ from METRIC ET_c estimates by 6.9 inches for cotton to 11.4 inches for corn with total ET_c differing by 7.7 inches. On a percentage basis, ET Demands estimates of ET_c differ from METRIC estimates by 25.8 percent for cotton to 44.9 percent for corn with total ET_c differing by 27.3 percent. In contrast to differences for EPCWID, ET Demands ET_c results for Hudspeth are substantially greater than METRIC ET_c results.

Table 7A-4. Summary of METRIC and ET Demands 2008 Seasonal (March – October) ET_c Estimates for Hudspeth by Crop.

Crop	Acres	METRIC ET_c (in)	ET Demands ET_c (in)	Difference (in)	Difference (%)
Cotton	9,544	26.6	33.5	6.9	25.8%
Alfalfa Hay	1,986	39.8	47.4	7.6	19.2%
Corn, Sweet Corn, and Silage	1,847	25.5	36.9	11.4	44.9%
Chile (Peppers)	198	17.7	32.9	15.2	85.6%
Pecans	57	28.6	37.5	8.9	31.2%
Totals	13,632	28.3	36.0	7.7	27.3%

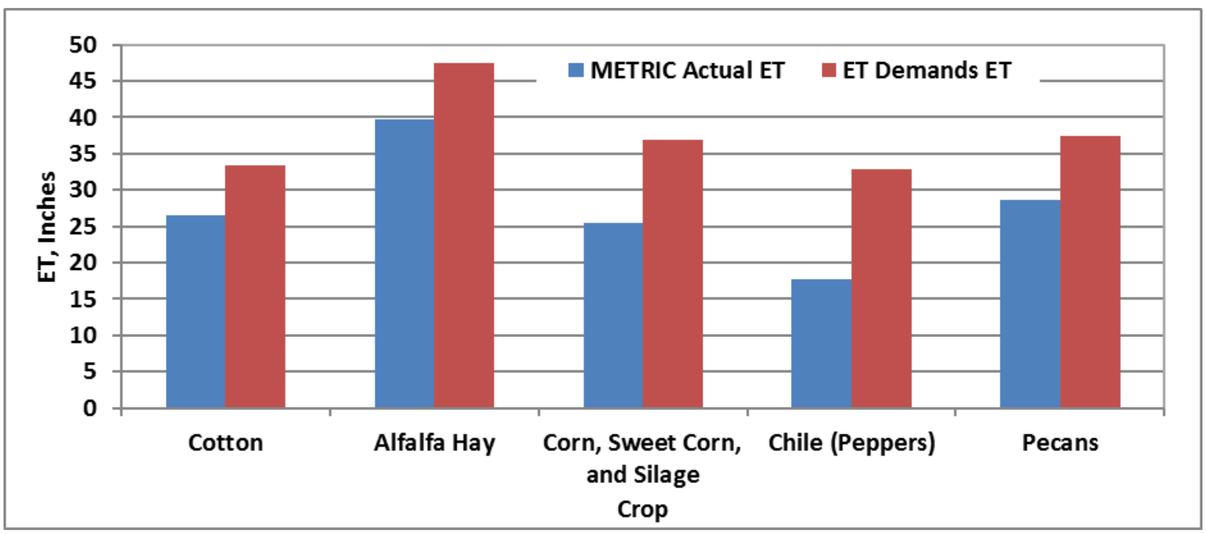


Figure 7A-5. METRIC and ET Demands 2008 Seasonal (March – October) ET_c Estimates for Hudspeth by Crop.

Juarez Valley Irrigation District, Mexico

Spatial crop distributions for the irrigated fields in Juarez were only available for pecans, so results for pecans and for all crops combined are reported. Intera developed pecan coverages for 1976, 1996, 2004 and 2010. Fields identified as pecans in both the 2004 and 2010 coverages were used to calculate ET_c for 2008. According to the fields identified as pecans by Intera, the pecan area in Juarez remained the same from 2004 to 2010. March through October 2008 METRIC ET_c totals for the Juarez Valley Irrigation District irrigated field polygons are 36.9 inches compared to 37.5 inches estimated by ET

Demands for 2008. ET Demands modeled ET_c estimates are 0.6 inches (or 1.5%) more than the METRIC ET_c estimates (**Table 7A-5** and **Figure 7A-6**). Thus, assuming that 2008 was a full supply year for Juarez, the ET Demands modeled ET_c is a reasonable upper limit on ET and will lead to reasonable upper limit for ET_{aw}.

Table 7A-5. Summary of METRIC and ET Demands 2008 Seasonal (March – October) Actual ET Estimates for Juarez by Crop.

Crop	Acres	METRIC ET_c (in)	ET Demands ET_c (in)	Difference (in)	Difference (%)
Pecans	921	36.9	37.5	0.6	1.5%
Other	34,542	36.9	38.4	1.5	4.1%
Totals	35,463	36.9	38.4	1.5	4.0%

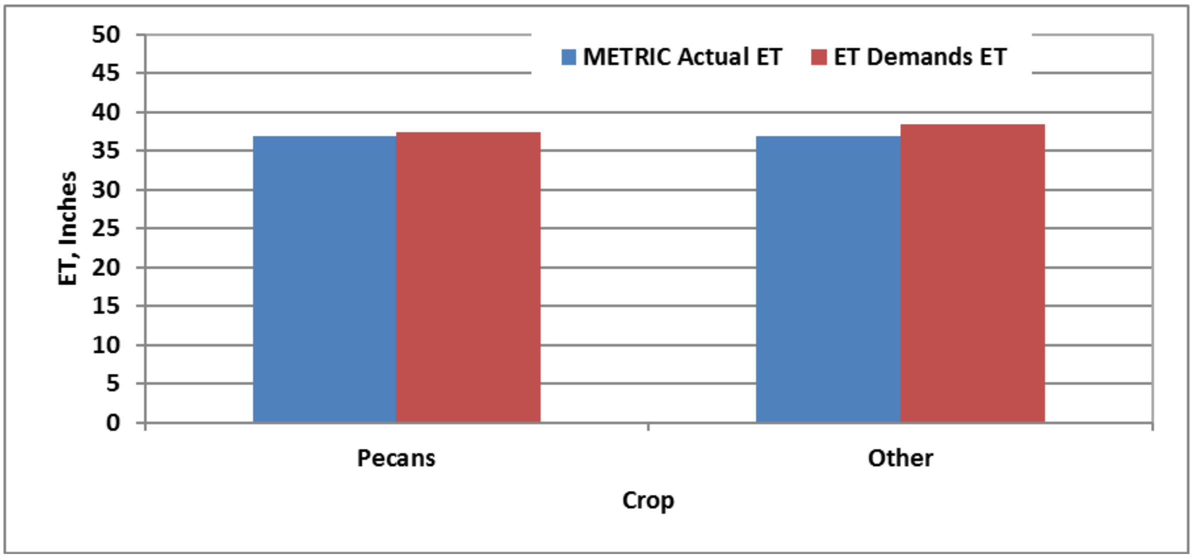


Figure 7A-6. METRIC and ET Demands 2008 Seasonal (March – October) ET_c Estimates for Juarez by Crop.

2013 Comparisons

EBID Elephant Butte Irrigation District

ET Demands results for 2013 were developed using the K_c parameterizations and related ET Demands settings for 2008. Seasonal METRIC and ET Demands results by crop for 2013 in EBID areas with access to both surface water and groundwater are provided in **Table 7A-6a** and **Figure 7A-7a**. As indicated, METRIC ET_c results range from 27.6 inches for miscellaneous vegetables to 48.6 inches for alfalfa with an area-weighted average of 37.4 inches for the March to October period. ET Demands ET_c results range from 30.8 inches for miscellaneous vegetables to 45.1 inches for alfalfa. ET Demands results for ET_c range from 9.0 inches less than METRIC ET_c results for irrigated pasture to 3.2 inches greater for miscellaneous vegetables with total ET_c 1.9 inches greater than the METRIC ET_c results. On a percentage basis, ET Demands results for ET_c range from 21.5 percent less than METRIC for irrigated pasture to 11.6 percent more for miscellaneous vegetables with total ET_c differing by 5.0 percent more.

Table 7A-6a. Summary of METRIC and ET Demands 2013 Seasonal (March – October) ET_c Estimates for EBID areas with SW and GW access by Crop.

Crop	Acres	METRIC ET_c (in)	ET Demands ET_c (in)	Difference (in)	Difference (%)
Pecans	25,347	38.4	39.8	1.4	3.6%
Alfalfa Hay	17,000	48.6	45.1	-3.5	-7.3%
Cotton	9,692	29.6	32.5	2.9	9.9%
Corn, Sweet Corn, and Silage	7,835	33.8	35.3	1.5	4.4%
Onions	4,753	33.5	34.8	1.3	3.8%
Wheat and Small Grains	3,415	38.3	39.9	1.6	4.3%
Chile (Peppers)	3,349	35.2	29.9	-5.3	-15.0%
Irrigated Pasture	1,544	42.0	33.0	-9.0	-21.5%
Miscellaneous Vegetables	585	27.6	30.8	3.2	11.6%
Totals	73,520	37.4	39.3	1.9	5.0%

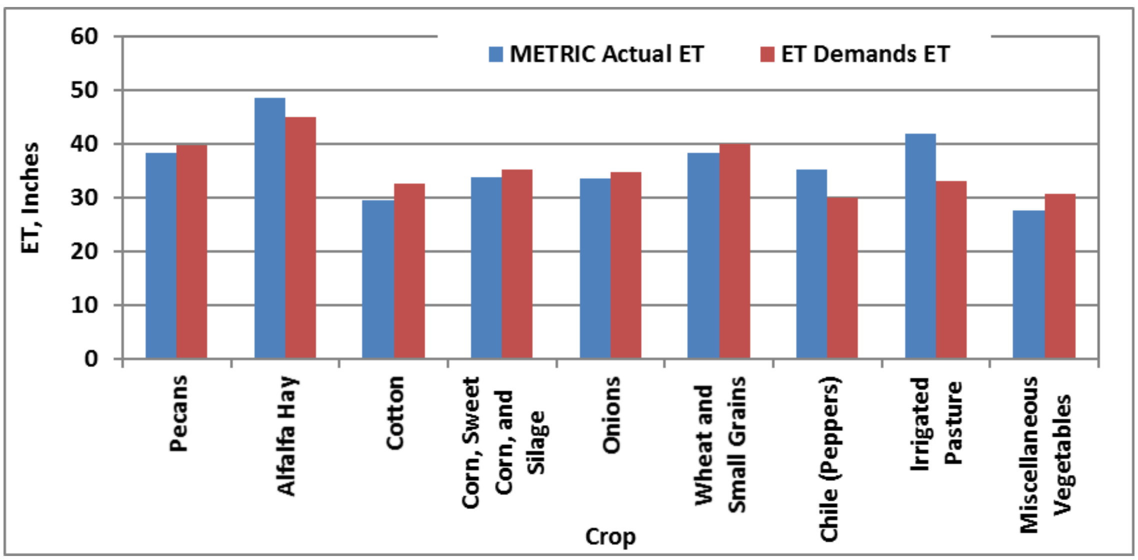


Figure 7A-7a. METRIC and ET Demands 2013 Seasonal (March – October) ET_c Estimates for EBID SW and GW access by Crop.

March through October METRIC and ET Demands results by crop for 2013 for irrigated lands in New Mexico with access to only groundwater are provided in **Table 7A-6b** and **Figure 7A-7b**. METRIC ET_c estimates range from 21.9 inches for cotton to 40.8 inches for alfalfa hay with total ET_c equaling 27.8 inches for the 2013 March to October period. Similarly, ET Demands ET_c estimates range from 29.9 inches for chile to 45.1 inches for alfalfa hay with total ET_c equal to 38.6 inches. ET Demands estimates of ET_c differ from METRIC estimates by 5.5 inches less for miscellaneous vegetables to 10.6 inches more for cotton and pecans with total ET_c differing by 10.7 inches. On a percentage basis, ET Demands estimates of ET_c differ from METRIC estimates by 15.2 percent less for miscellaneous vegetables to 48.5 percent more for cotton with total ET_c differing by 38.6 percent.

Table 7A-6b. Summary of METRIC and ET Demands 2013 Seasonal (March – October) ET_c Estimates for EBID GW only by Crop.

Crop	Acres	METRIC ET_c (in)	ET Demands ET_c (in)	Difference (in)	Difference (%)
Alfalfa Hay	1,654	40.8	45.1	4.3	10.4%
Pecans	1,648	29.2	39.8	10.6	36.3%
Irrigated Pasture	886	36.7	33.0	-3.7	-10.1%
Corn, Sweet Corn, and Silage	400	29.0	35.3	6.3	21.7%
Cotton	176	21.9	32.5	10.6	48.5%
Chile (Peppers)	175	28.0	29.9	1.9	6.8%
Wheat and Small Grains	47	32.3	39.9	7.6	23.7%
Miscellaneous Vegetables	42	36.3	30.8	-5.5	-15.2%
Onions	39	27.7	34.8	7.1	25.5%
Totals	5,066	27.8	38.6	10.7	38.6%

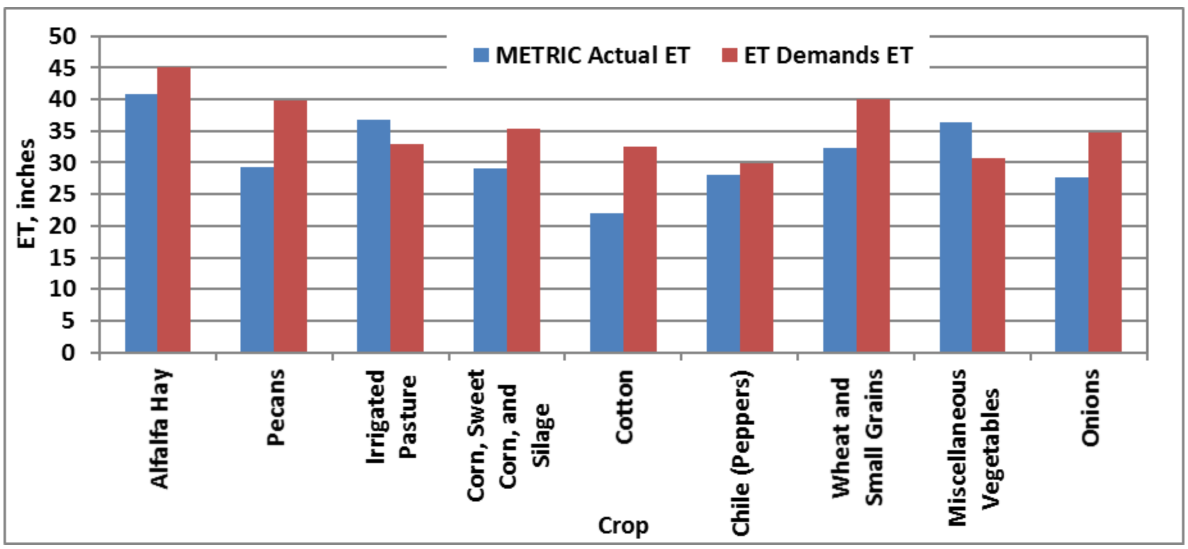


Figure 7A-7b. METRIC and ET Demands 2013 Seasonal (March – October) ET_c Estimates for EBID GW only by Crop.

ET Demands results for EBID agree with METRIC results relatively well, but not as well as for 2008. The generally larger differences likely result from a combination of factors. One potential factor is the method of identifying crops. Crops were identified in 2008 in EBID via ground-based surveys, whereas crops were identified in 2013 in EBID based on CDL. As a result, the METRIC ET_c results by crop in 2013 may be influenced to a greater degree by misclassification than the 2008 METRIC ET_c results. Modeled ET Demands ET_c greater than the METRIC ET_c is consistent with the objective of developing ET_{aw} data intended to represent a reasonable upper limit on ET_{aw} that would occur under "full supply" conditions.

El Paso County Water Improvement District

Seasonal METRIC and ET Demands ET_c results by crop for 2013 in the EPCWID areas in the Mesilla and El Paso Valleys are provided in **Tables 7A-7a and 7A-7b** and **Figures 7A-8a and 7A-8b**, respectively. In the Mesilla Valley area of EPCWID, METRIC ET_c estimates range from 30.4 inches for cotton to 41.9 inches for pecans with total ET_c equal to 36.9 inches for the 2013 March to October period. Crops not identified by the CDL do not have METRIC results. ET Demands ET_c estimates range from 32.4 inches for cotton to 45.1 inches for alfalfa. ET Demands estimates of ET_c differ from METRIC ET_c results by 2.3 inches less for pecans to 3.8 inches for alfalfa hay with total ET_c differing by 4.5 inches. On a percentage basis, ET Demands results for ET_c differ from METRIC ET_c estimates by 5.5 percent less for pecans to 9.1 percent more for alfalfa hay with total ET_c differing by 13.6 percent.

Table 7A-7a. Summary of METRIC and ET Demands 2013 Seasonal (March – October) ET_c Estimates for the Mesilla Valley Area of EPCWID by Crop.

Crop	Acres	METRIC ET_c (in)	ET Demands ET_c (in)	Difference (in)	Difference (%)
Cotton	1,511	30.4	32.4	2.0	6.6%
Pecans	1,419	41.9	39.6	-2.3	-5.5%
Alfalfa Hay	569	41.3	45.1	3.8	9.1%
Other	36	NA*	35.3	NA*	NA*
Totals	3,536	32.9	37.4	4.5	13.6%

*METRIC ET_c was not available crops other than cotton, pecans and alfalfa hay due to the small area of the other crops.

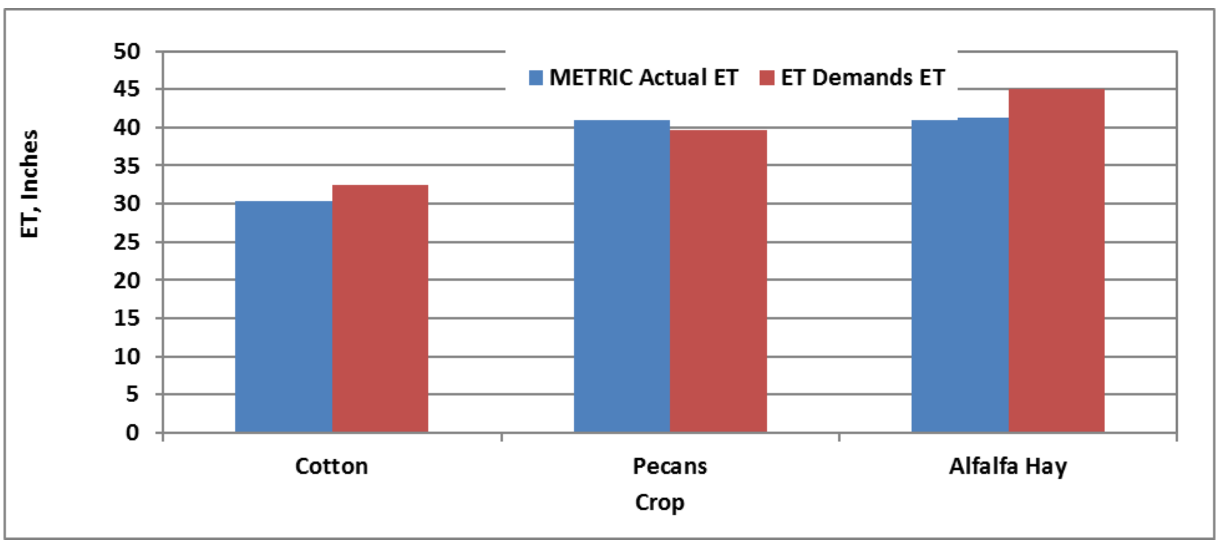


Figure 7A-8a. METRIC and ET Demands 2013 Seasonal (March – October) ET_c Results for the Mesilla Valley Area of EPCWID by Crop.

Table 7A-7b. Summary of METRIC and ET Demands 2013 Seasonal (March – October) ET_c Estimates for the El Paso Valley Area of EPCWID by Crop.

Crop	Acres	METRIC ET_c (in)	ET Demands ET_c (in)	Difference (in)	Difference (%)
Cotton	11,306	33.2	32.9	-0.3	-1.0%
Pecans	10,617	36.5	39.8	3.3	9.2%
Alfalfa Hay	4,259	40.1	45.1	5.0	12.5%
Other	270	NA*	36.4	NA*	NA*
Totals	26,451	34.1	37.7	3.6	10.6%

*METRIC ET_c was not available crops other than cotton, pecans and alfalfa hay due to the small area of the other crops.

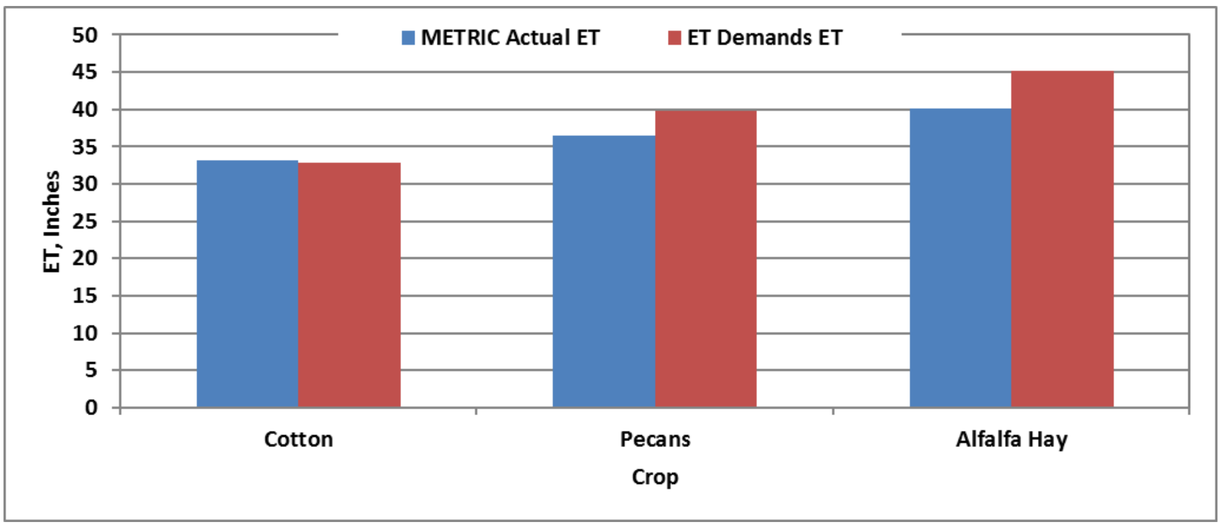


Figure 7A-8b. METRIC and ET Demands 2013 Seasonal (March – October) ET_c Results for the El Paso Valley Area of EPCWID by Crop.

In the El Paso Valley area of EPCWID, METRIC ET_c results range from 33.2 inches for cotton to 40.1 inches for alfalfa hay with total ET_c equal to 34.1 inches for the 2013 March to October period. Crops not identified in the CDL do not have METRIC results and are not discussed. ET Demands ET_c results range from 32.9 inches for cotton to 45.1 inches for alfalfa hay. ET Demands results for ET_c differ from METRIC results by 0.3 inches less for cotton to 5.0 inches more for alfalfa hay with total ET_c differing by 3.6 inches. On a percentage basis, ET Demands results for ET_c differ from METRIC results by 1.0 percent less for cotton to 12.5 percent more for alfalfa hay with total ET_c differing by 10.6 percent. The METRIC ET_c results for pecans could be higher than the ET Demands ET_c results because the "average" level of stress due to water shortage and other factors in EPCWID in 2013 is less than the "average" level of stress in the calibration data from EBID in 2008.

ET Demands ET_c results for EPCWID in the Mesilla and El Paso Valleys agree with METRIC ET_c results relatively well, but not as well as for EBID. The generally larger differences likely result from a combination of factors. The METRIC ET_c results are likely lower than the ET Demands ET_c results because the "average" level of stress due to water shortage and other factors in EPCWID in 2013 is more than the "average" level of stress in the calibration data from EBID in 2008.

Hudspeth

Seasonal METRIC and ET Demands ET_c results by crop for 2013 in Hudspeth are provided in **Table 7A-8** and **Figure 7A-9**. As indicated, METRIC ET_c results range from 24.8 inches for cotton to 31.8 inches for alfalfa hay with total ET_c equal to 26.5 inches for the March to October period. ET Demands ET_c results range from 33.0 inches for cotton to 45.8 inches for alfalfa hay. ET Demands results for ET_c differ from METRIC results by 8.2 inches for cotton to 14.0 inches for alfalfa hay with total ET_c differing by 8.2 inches. On a percentage basis, ET Demands results for ET_c differ from METRIC ET_c results by 33.1 percent for cotton to 44.0 percent for alfalfa with total ET_c differing by 30.9 percent.

Table 7A-8. Summary of METRIC and ET Demands 2013 Seasonal (March – October) ET_c Results for Hudspeth by Crop.

Crop	Acres	METRIC ET_c (in)	ET Demands ET_c (in)	Difference (in)	Difference (%)
Cotton	5,253	24.8	33.0	8.2	33.1%
Alfalfa Hay	725	31.8	45.8	14.0	44.0%
Other	183	NA*	38.2	NA*	NA*
Totals	6,160	26.5	34.7	8.2	30.9%

*METRIC ET_c was not available crops other than cotton, pecans and alfalfa hay due to the small area of the other crops.

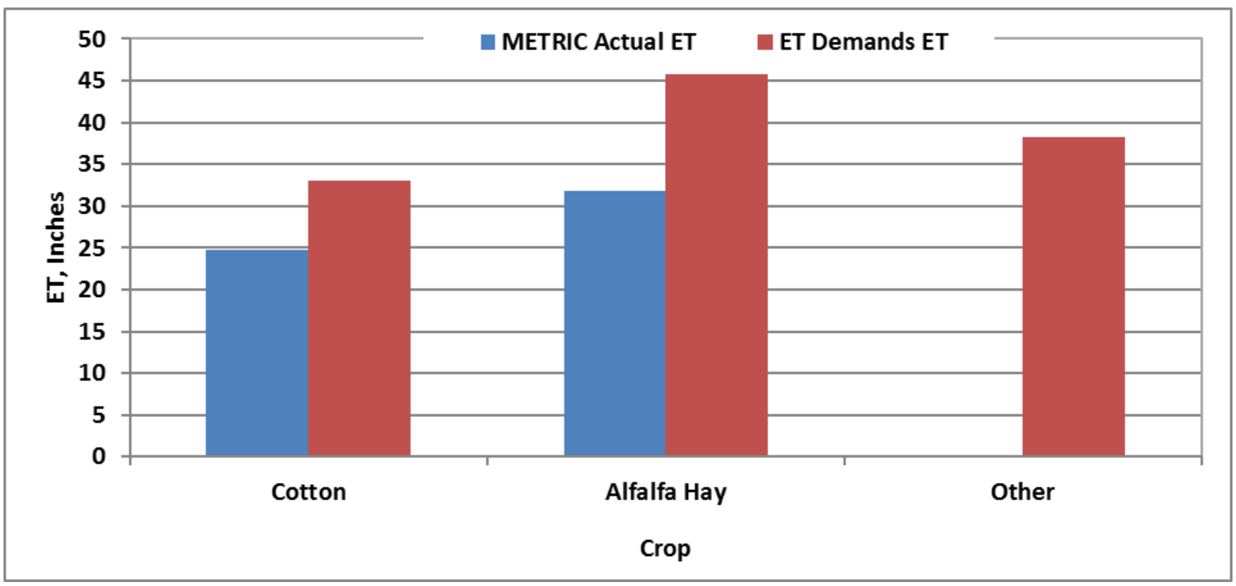


Figure 7A-9. METRIC and ET Demands 2013 Seasonal (March – October) ET_c Results for Hudspeth by Crop.

ET Demands ET_c results for Hudspeth are 33.1, and 44.0 percent higher than the METRIC ET_c results for the two major crops of cotton and alfalfa grown in 2013. Possible reasons for lower METRIC ET_c compared to ET Demands ET_c results include water shortages and poor water quality, perhaps due to increased salinity. Modeled ET Demands ET_c greater than the METRIC ET_c is consistent with the objective of developing ET_{aw} data intended to represent a reasonable upper limit on ET_{aw} that would occur under "full supply" conditions.

Juarez Valley Irrigation District, Mexico

Spatial crop distributions across the irrigated fields in Juarez were only available for pecans, so results for pecans and for all other crops combined are reported. Pecan fields identified by Intera in the 2010 coverage were assumed to still be pecans in 2013 and used to calculate ET_c for 2013. March through October 2013 METRIC ET_c totals for the Juarez Valley Irrigation District irrigated field polygons are 35.6 inches compared to ET Demands ET_c results of 37.0 inches. ET Demands modeled ET_c results are 1.4 inches (3.9 percent) greater than the METRIC ET_c results. Possible reasons for lower METRIC ET_c compared to ET Demands ET_c results include water shortages and poor water quality, perhaps due to salinity. Thus, the ET Demands modeled ET_c is a reasonable upper limit on ET and will lead to reasonable upper limit for ET_{aw}. **Table 7A-9** and **Figure 7A-10** summarize the results for Juarez.

Table 7A-9. Summary of METRIC and ET Demands 2013 Seasonal (March – October) ET_c Estimates for Juarez by Crop.

Crop	Acres	METRIC ET_c (in)	ET Demands ET_c (in)	Difference (in)	Difference (%)
Pecans	921	37.5	39.9	2.4	6.3%
Other	31,314	35.5	37.0	1.4	3.9%
Totals	32,235	35.6	37.0	1.4	4.0%

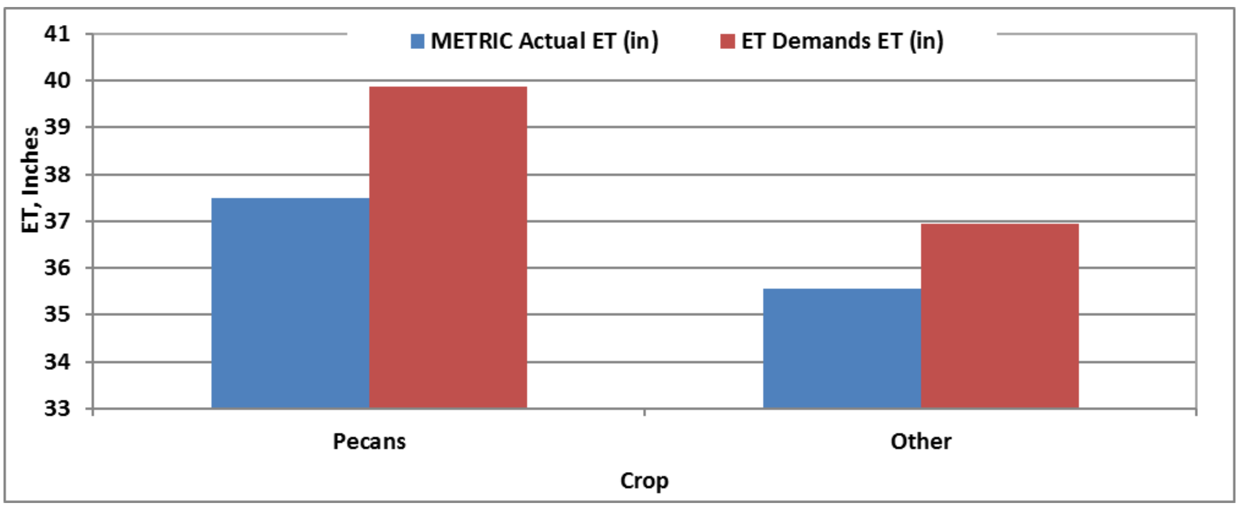


Figure 7A-10. METRIC and ET Demands 2013 Seasonal (March – October) ET_c Results for Juarez by Crop.

Appendix 8A. Selected Historical Cotton Photos

Cotton Bulletin 141-1924

Overpeck, J. C. and W. T. Conway. 1924. Cotton. New Mexico College of Agriculture and Mechanic Arts, Agricultural Experiment Station, Bulletin No. 141 January 1924. (Photos 8A.1 and 8A.2)

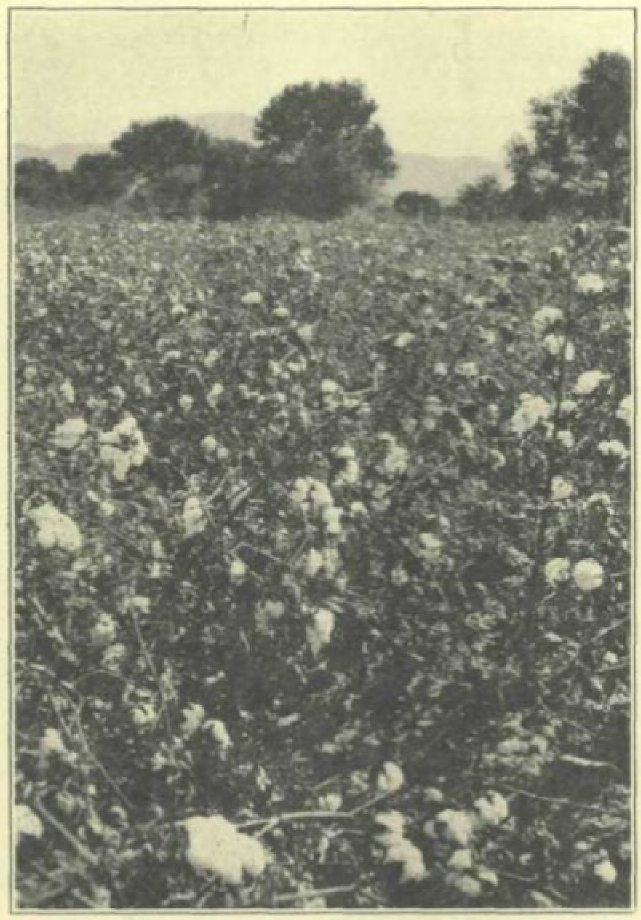
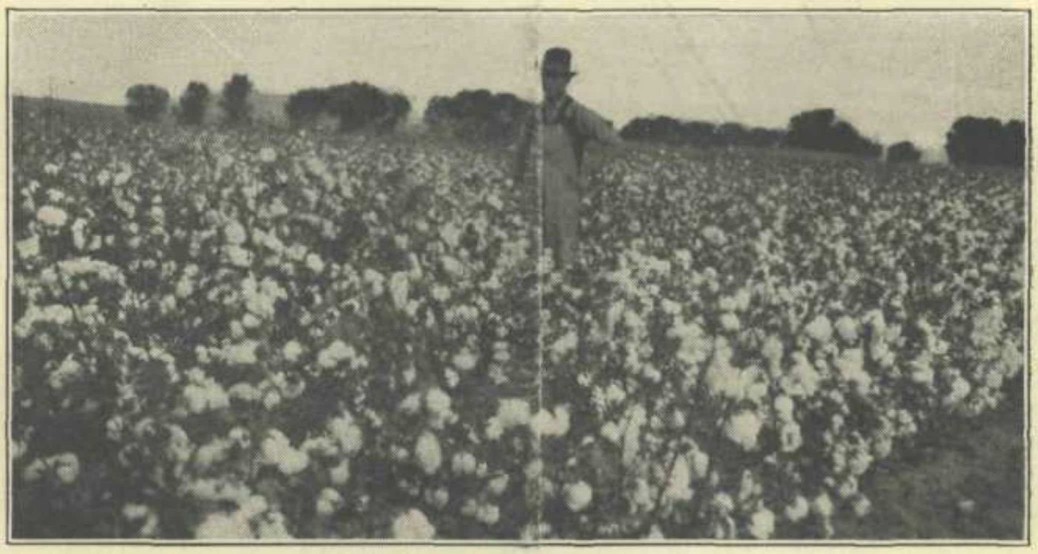


Fig. 1.—An Acala cotton field in southern New Mexico after a bale to the acre had been picked. Grown under irrigation in 1923.

Photo 8A-1



Acala cotton grown under irrigation in New Mexico in 1923.

Photo 8A-2

Cotton Growing Bulletin 120-1919

Stewart, R. L. 1919. Cotton Growing. New Mexico College of Agriculture and Mechanic Arts Agricultural Experiment Station, Bulletin No. 120 December 1919. (Photo 8A.3)

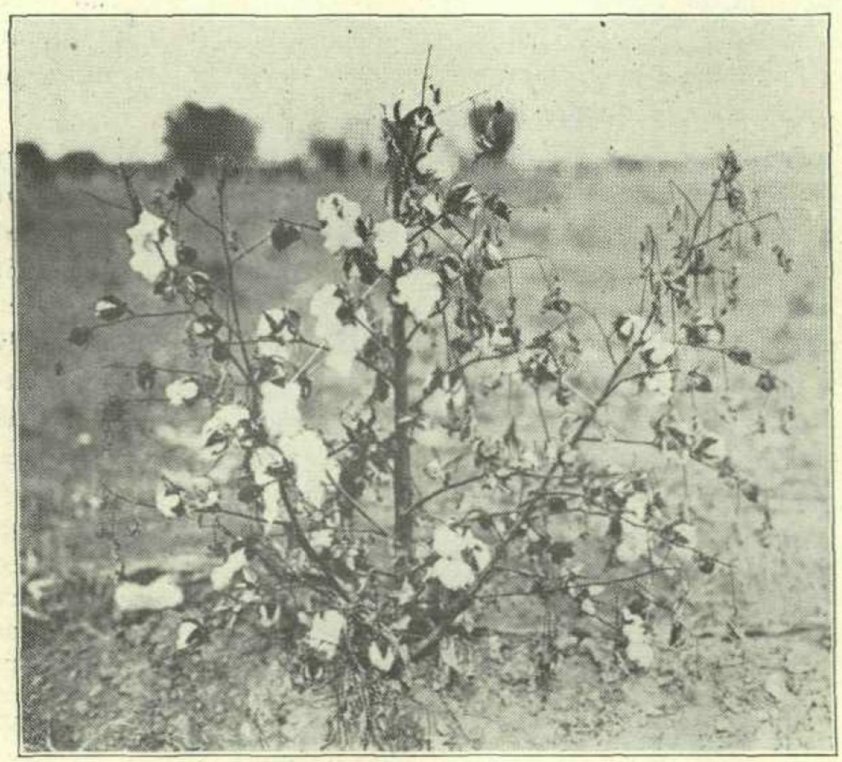


Fig. 1.—A plant of Durango cotton after first picking of 40 bolls.

Photo 8A-3

Cotton Bulletin 1001-1963

Longenecker, D. E., E. L. Thaxton, Jr. and P. J. Lyerly. 1963. Cotton Production in Farm West Texas with Emphasis on Irrigation and Fertilization. Texas A&M University Texas Agricultural Experiment Station, Bulletin 1001. (Photos 8A.4-8A.6)

Figure 4. Deep-plowing operation on alluvial soils in the El Paso Valley.

Photo 8A-4

Figure 14. Skip-row planted cotton in the El Paso Valley. On productive soils, this practice can greatly increase yields per planted acre without additional fertilizer or water.

Photo 8A-5

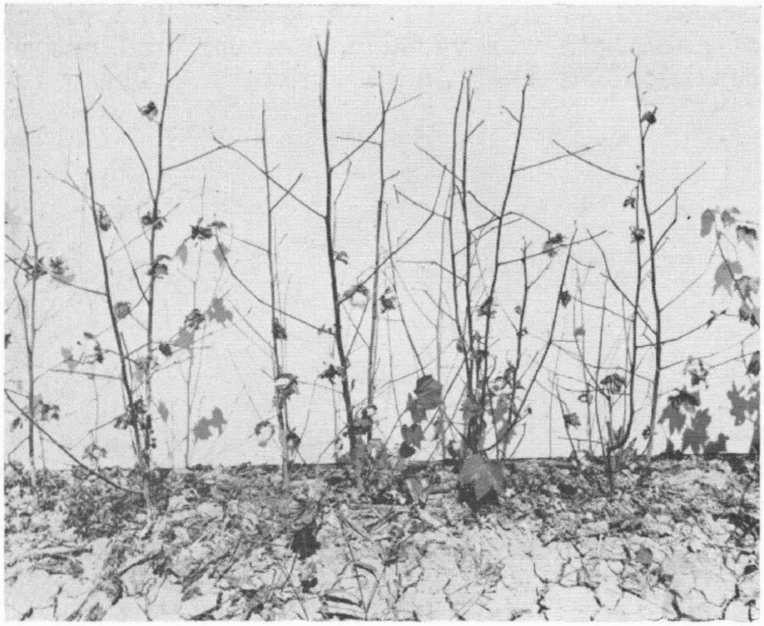


Figure 57. Upland cotton severely infected with verticillium wilt in the El Paso Valley. Both yields and fiber quality are adversely affected.

Photo 8A-6

Cotton Bulletin 220-1934

Curry, A. S. 1934. Results of Irrigation Treatments on Acala Cotton Grown in the Mesilla Valley, New Mexico. Agricultural Experiment Station of the New Mexico College of Agriculture and Mechanic Arts, Bulletin No. 220. (Photos 8A.7-8A.13)

Fig. 2.—Indicating variable productivity of Gila clay adobe. The plants in front of the measuring rod are about two feet in height and those three feet to the left are about three feet in height.

Photo 8A-7

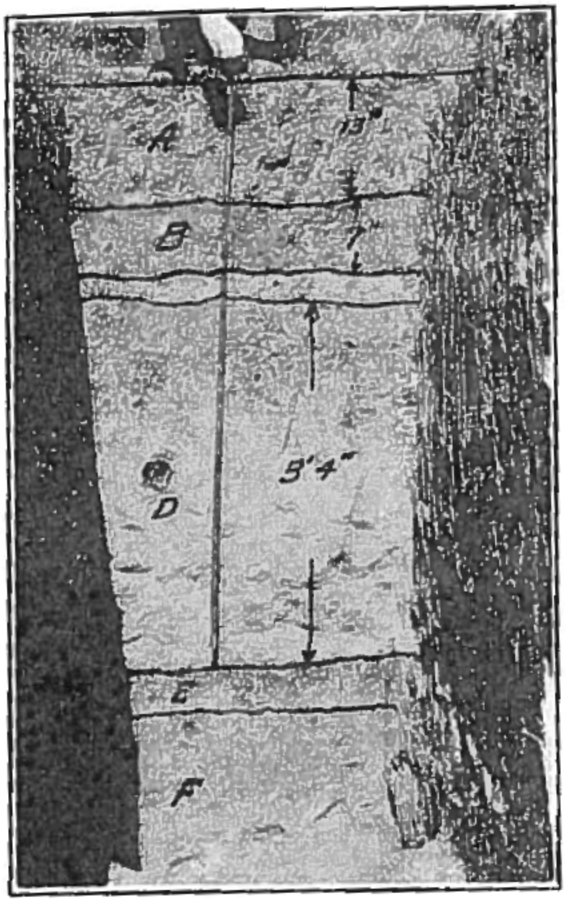


Fig. 3.—A trench showing different layers of soil. A, Gila clay adobe; B, sandy loam; C silt; D, sandy loam which gradually merges into a fine sand at the top of the layer; E, sand and clay admixture; F, sand gradually merging into coarse sand and gravel.

Photo 8A-8

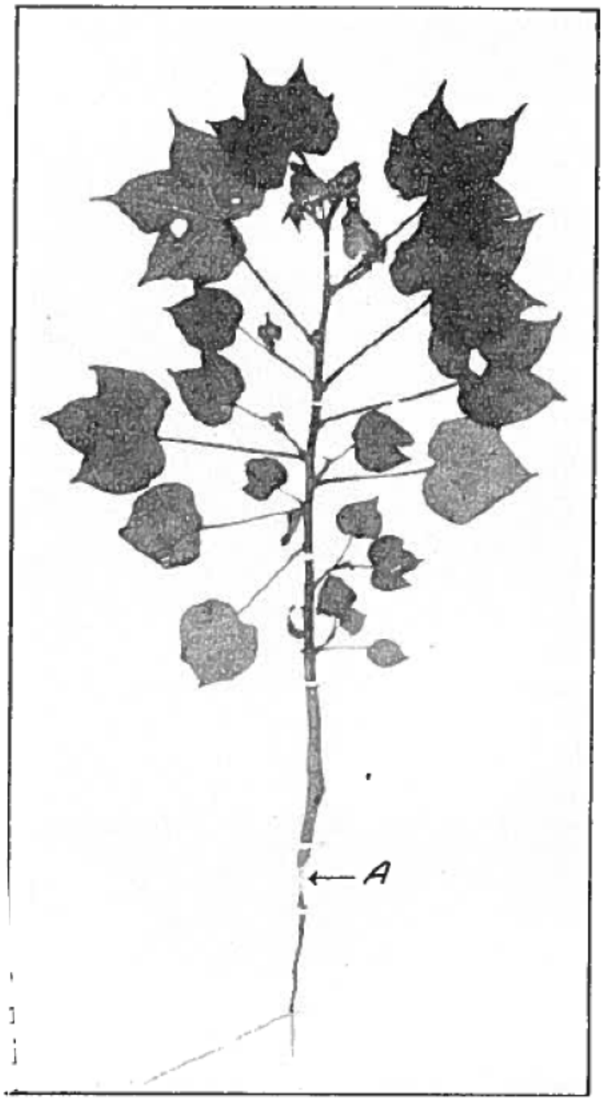


Fig. 4.—Root of cotton plant constricted at A, probably caused by expansion and contraction of the soil.

Photo 8A-9

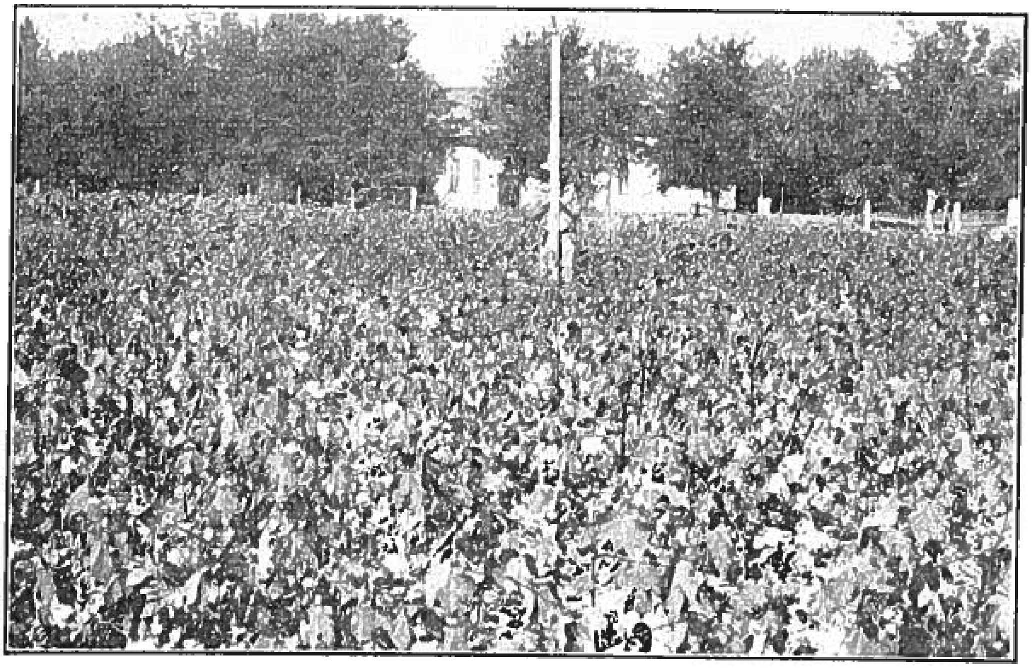


Fig. 7.—Effect of water stress on maturity. Group I, October 20, 1927. Compare with Fig. 8.

Photo 8A-10

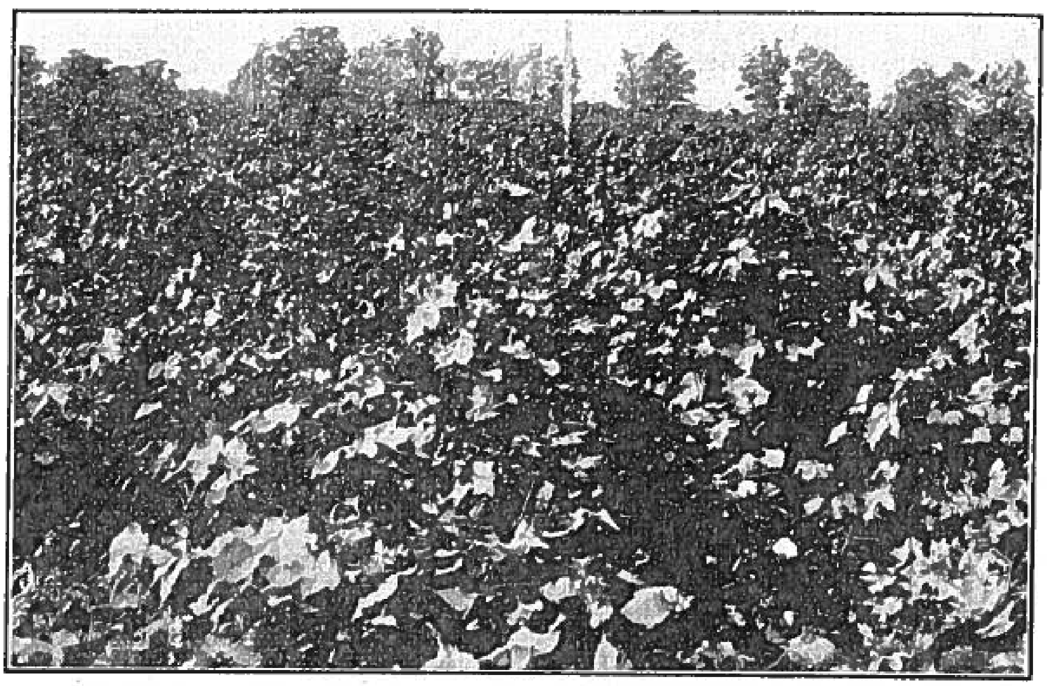


Fig. 8.—Effect of abundant and late moisture on maturity. Group III, October 20, 1927. Compare with Fig. 7.

Photo 8A-11

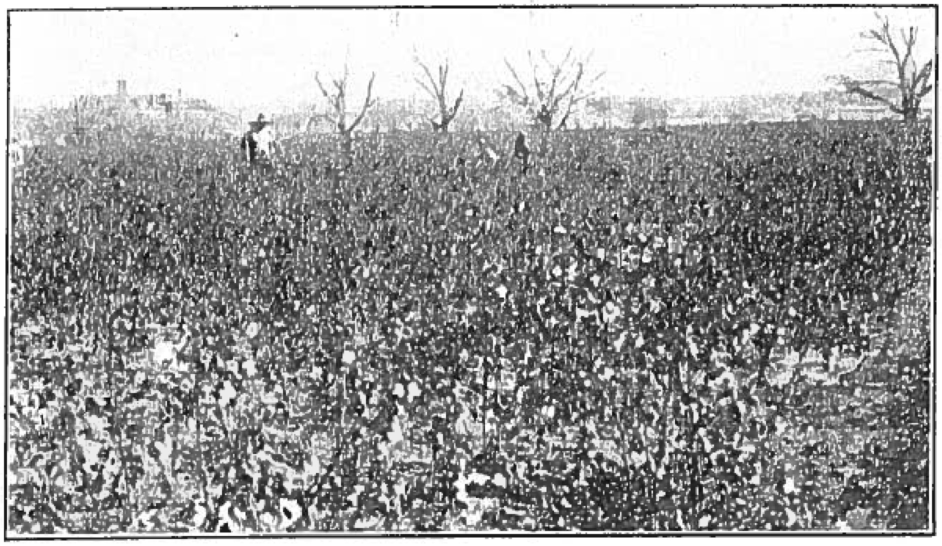


Fig. 9.—Illustrating the defoliated condition of Group I in 1928, due to water stress conditions and frost.

Photo 8A-12

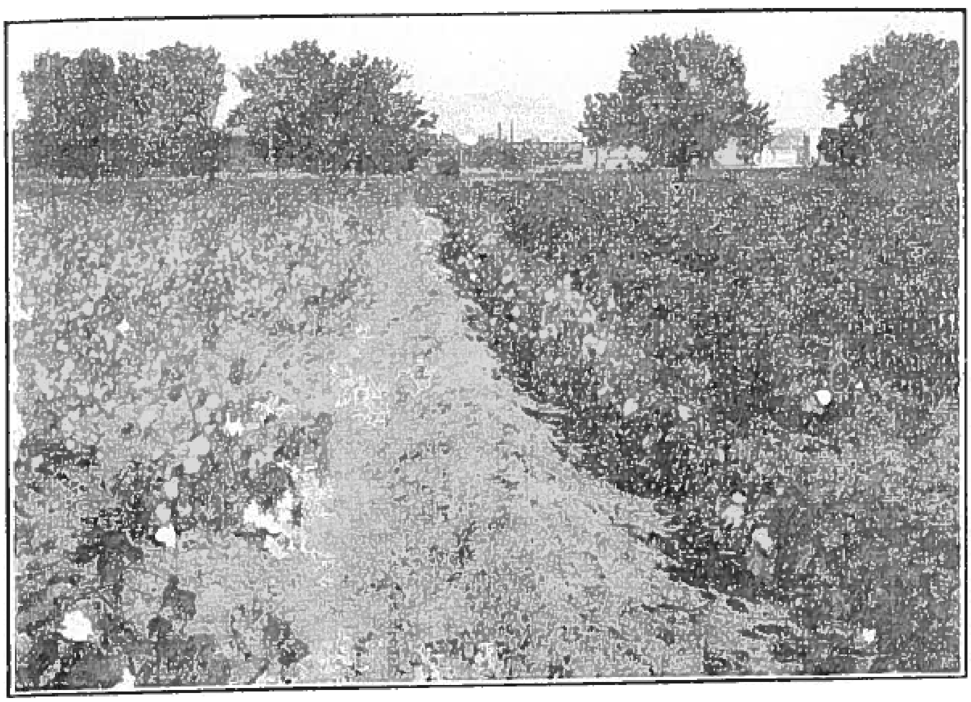


Fig. 10.—Illustrating increased maturity of Group I as compared with Group II, October 13, 1930.

Photo 8A-13

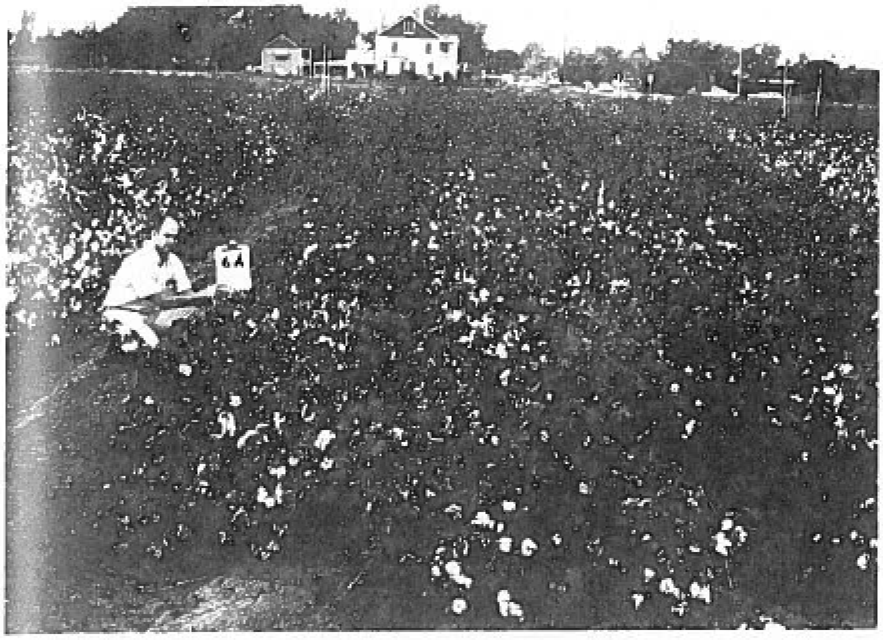
Cotton Bulletin 610

Williams, B. C. and E. G. Hanson. 1973. Subsurface Irrigation of Cotton: A System and Its Effects Upon Production, With and Without Fertilizer Application. New Mexico State University Agricultural Experiment Station, Bulletin 610 November 1973. (Photos 8A.14 and 8A.15)

Fig. 3. Stands of cotton under irrigation, 1968. Note full stand in surface irrigated plot 6A in photograph and skips in subsurface irrigated plot 6B in photograph.

Photo 8A-14

Fig. 7. **Open cotton for surface and subsurface plots approaching harvest in October. Note: plot 6A in photograph was surface irrigated and plot 6B in photograph was subsurfaced irrigated.**



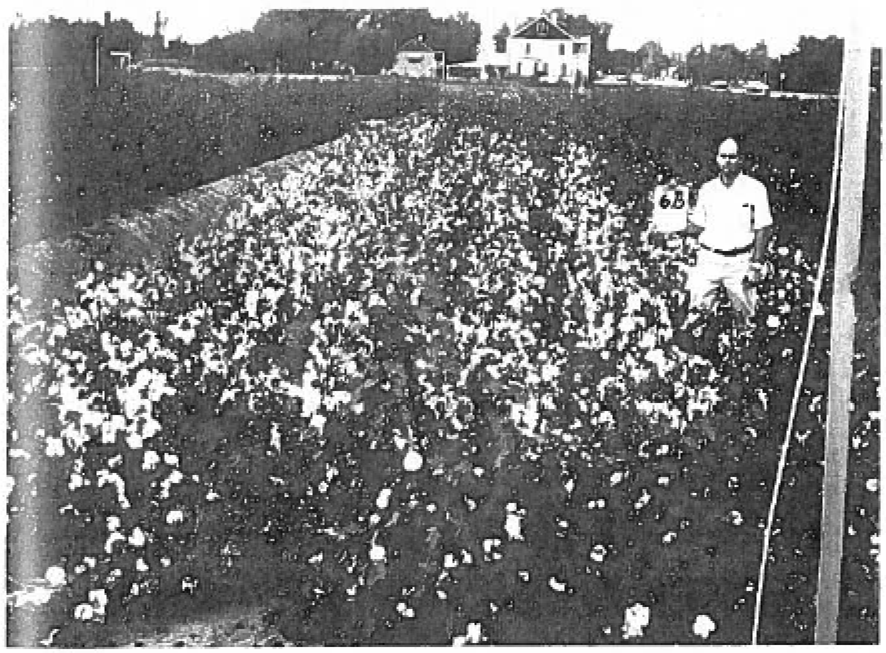


Photo 8A-15

Cotton Bulletin 149-1925

Bloodgood, D. W. and A. S. Curry. 1925. Net Requirements of Crops for Irrigation Water in the Mesilla Valley, New Mexico. Agricultural Experiment Station of the New Mexico College of Agriculture and Mechanic Arts, Bulletin No. 149. (Photos 8A.16 and 8A.17)

Fig. 11.—Irrigating young cotton in the Mesilla Valley, New Mexico.

Fig. 12.—Cotton grown by irrigation.

Photo 8A-16, 8A-17

Crop Production EBID Circular 97-1928

Hauter, L. H. 1928. Economics of Crop Production on The Elephant Butte Irrigation Project. New Mexico College of Agriculture and Mechanic Arts, Agricultural Extension Service, Extension Circular 97 September 1928. (Photo 8A.18)

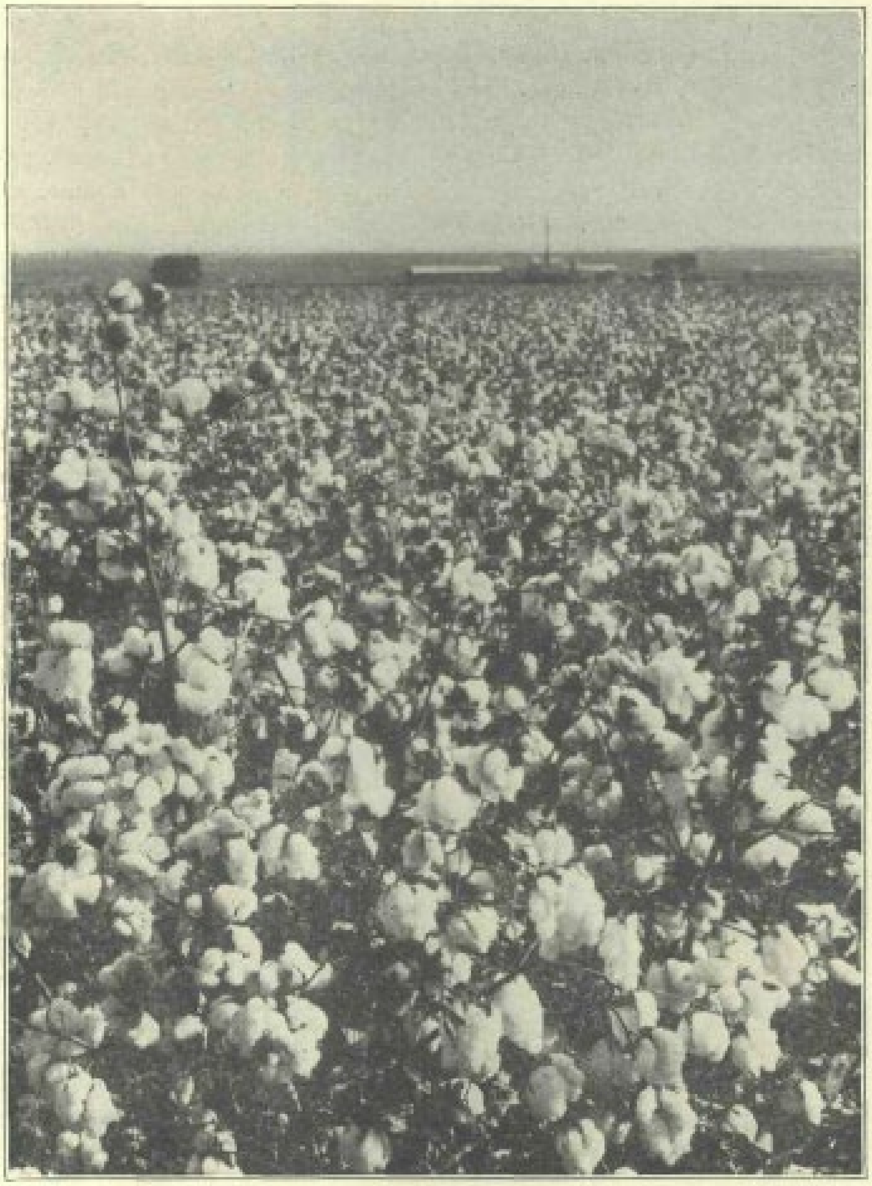


Fig. 18.—Cotton grows well on the Project and yields ranging from one to two bales are commonly secured on well developed farms. The large yields secured have made cotton an unusually profitable crop on the Project.

Photo 8A-18

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Appendix 8B. Selected Historical Alfalfa Photos

Alfalfa Bulletin 139-1923

Quesenberry, G. R. 1923. Alfalfa. Agricultural Experiment Station of the New Mexico College of Agriculture and Mechanic Arts, Bulletin No. 139. (Photos 8B.1 and 8B.2)

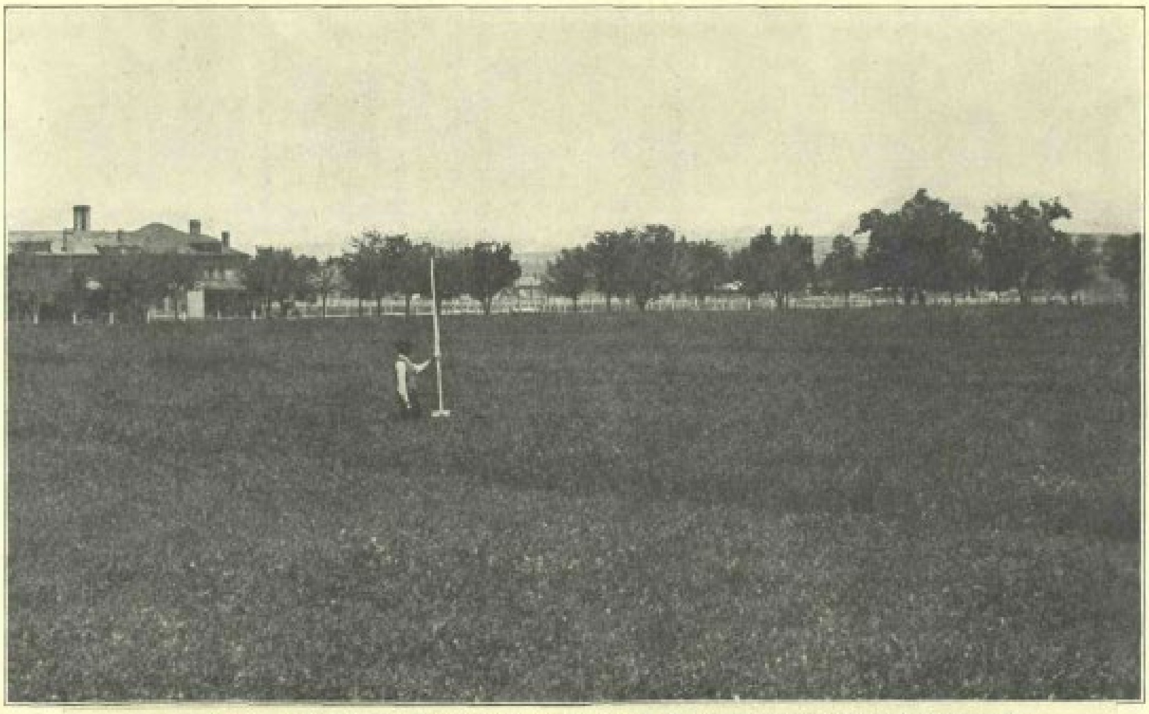

Fig. 2. Varietal experimental plats, State College, N. M. Hairy Peruvian shown in foreground.

ERRATA.

The next to the last sentence of the first paragraph, page 3, should read: "The first plantings were made by the Mexicans."

The second word of next to the last line of the first paragraph, page 9, should be "emerge."

The third word, line 8 of the second paragraph, page 18, should be "Mexicans," instead of "Spaniards."

Photo 8B-1

Fig. 4. Alfalfa treated with seven tons of manure per acre, four years after seeding had an average stand of fourteen plants per square foot.

Photo 8B-2

Alfalfa Bulletin 323-1945

Staten, G. and J. Carter, Jr. 1945. Alfalfa Production Investigations in New Mexico. Agricultural Experiment Station of the New Mexico College of Agriculture and Mechanic Arts, Bulletin 323. (Photo 8B.3)

Top: Uniform alfalfa nursery at State College, photographed March 8, 1941, showing the difference in early spring growth of different strains. Center row is New Mexico Common.

Bottom: The same nursery, photographed March 8, 1945, showing the decrease in stand and vigor due to alfalfa wilt.

Photo 8B-3

Cotton Bulletin 149-1925

Bloodgood, D. W. and A. S. Curry. 1925. Net Requirements of Crops for Irrigation Water in the Mesilla Valley, New Mexico. Agricultural Experiment Station of the New Mexico College of Agriculture and Mechanic Arts Bulletin, No. 149. (Photo 8B.4)

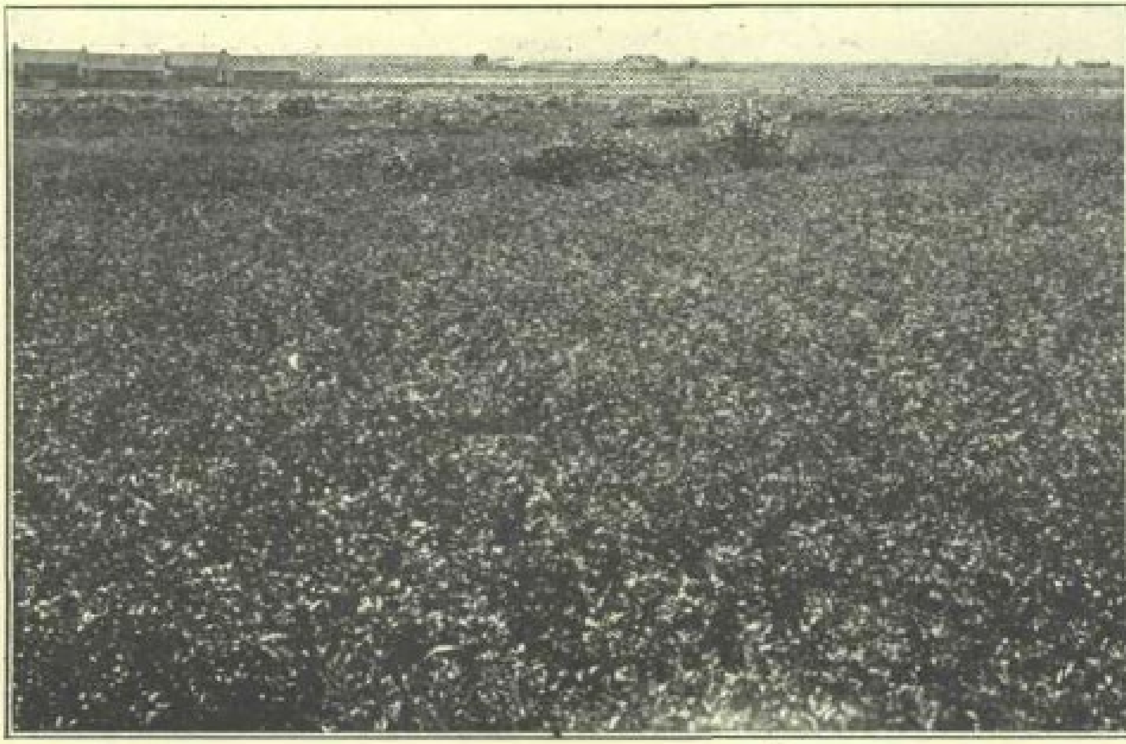

Fig. 7.—Alfalfa grown by irrigation in the Mesilla Valley, New Mexico.

Photo 8B-4

Crop Production EBID Circular 97-1928

Hauter, L. H. 1928. Economics of crop production on the Elephant Butte Irrigation Project. New Mexico College of Agriculture and Mechanic Arts Agricultural Extension Service, Extension Circular 97. (Photo 8B.5)

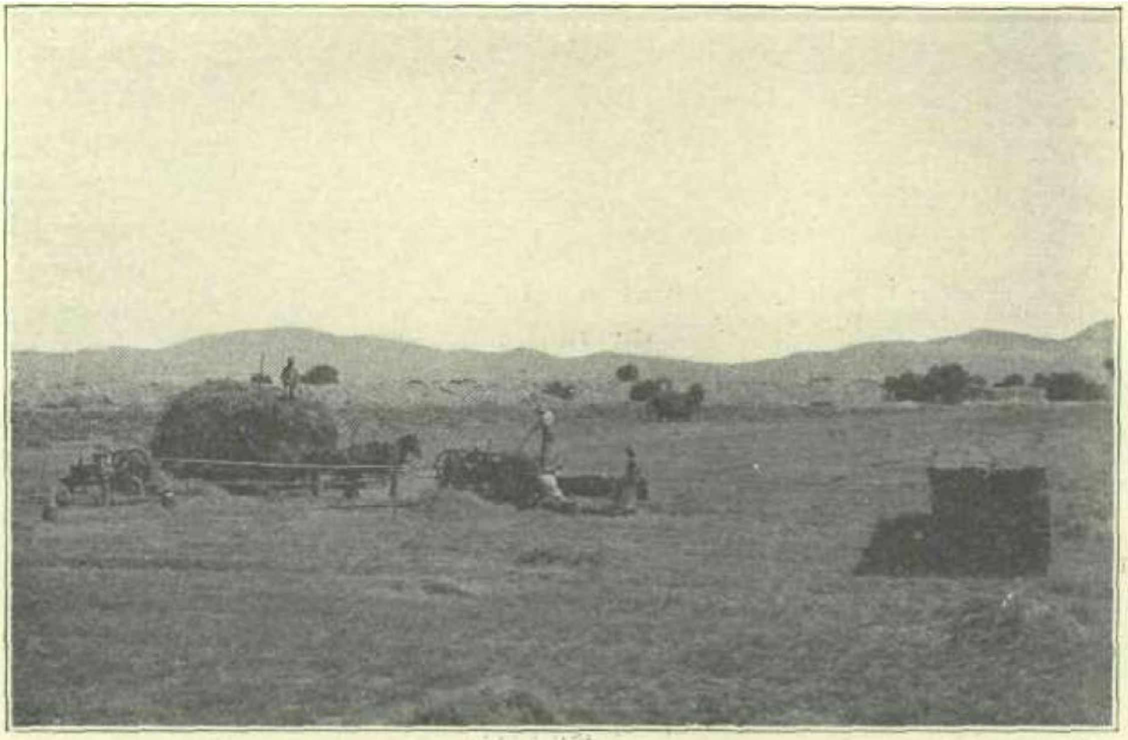

Fig. 16.—Alfalfa hay has always been an important crop on the Project, ranking as the most important crop until the introduction of cotton several years ago. The Project has had a good market for its alfalfa in southeastern Texas points.

Photo 8B-5

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Appendix 9A. Annual ICUC Values by Unit

Table 9A-1. Annual ICUC Values by Unit (%)

Year	Maximum On-Farm Efficiency (%)						
	EBID			EPCWID			
	Rincon	Leasburg	Mesilla, NM	Mesilla, TX	El Paso Valley	Hudspeth	Juarez
1938	66%	66%	66%	66%	66%	66%	66%
1939	66%	66%	66%	66%	66%	66%	66%
1940	66%	66%	66%	66%	66%	66%	66%
1941	66%	66%	66%	66%	66%	66%	66%
1942	66%	66%	66%	66%	66%	66%	66%
1943	66%	66%	66%	66%	66%	66%	66%
1944	66%	66%	66%	66%	66%	66%	66%
1945	66%	66%	66%	66%	66%	66%	66%
1946	66%	66%	66%	66%	66%	66%	66%
1947	66%	66%	66%	66%	66%	66%	66%
1948	66%	66%	66%	66%	66%	66%	66%
1949	66%	66%	66%	66%	66%	66%	66%
1950	66%	66%	66%	66%	66%	66%	66%
1951	67%	67%	67%	67%	67%	67%	67%
1952	68%	68%	68%	68%	68%	68%	68%
1953	69%	69%	69%	69%	69%	69%	69%
1954	70%	70%	70%	70%	70%	70%	70%
1955	71%	71%	71%	71%	71%	71%	71%
1956	71%	71%	71%	71%	71%	71%	71%
1957	71%	71%	71%	71%	71%	71%	71%
1958	71%	71%	71%	71%	71%	71%	71%
1959	71%	71%	71%	71%	71%	71%	71%
1960	71%	71%	71%	71%	71%	71%	71%

Table 9A-1. Annual ICUC Values by Unit (%)

Year	Maximum On-Farm Efficiency (%)						
	EBID			EPCWID			
	Rincon	Leasburg	Mesilla, NM	Mesilla, TX	El Paso Valley	Hudspeth	Juarez
1961	71%	71%	71%	71%	71%	71%	71%
1962	71%	71%	71%	71%	71%	71%	71%
1963	71%	71%	71%	71%	71%	71%	71%
1964	71%	71%	71%	71%	71%	71%	71%
1965	71%	71%	71%	71%	71%	71%	71%
1966	71%	71%	71%	71%	71%	71%	71%
1967	71%	71%	71%	71%	71%	71%	71%
1968	71%	71%	71%	71%	71%	71%	71%
1969	71%	71%	71%	71%	71%	71%	71%
1970	71%	71%	71%	71%	71%	71%	71%
1971	71%	71%	71%	71%	71%	71%	71%
1972	71%	71%	71%	71%	71%	71%	71%
1973	71%	71%	71%	71%	71%	71%	71%
1974	71%	71%	71%	71%	71%	71%	71%
1975	71%	71%	71%	71%	71%	71%	71%
1976	71%	71%	71%	71%	71%	71%	71%
1977	71%	71%	71%	71%	71%	71%	71%
1978	71%	71%	71%	71%	71%	71%	71%
1979	71%	71%	71%	71%	71%	71%	71%
1980	72%	72%	72%	72%	72%	72%	72%
1981	73%	73%	73%	73%	73%	73%	73%
1982	74%	74%	74%	74%	74%	74%	74%
1983	75%	75%	75%	75%	75%	75%	75%
1984	76%	76%	76%	76%	76%	76%	76%
1985	76%	76%	76%	76%	76%	76%	76%

Table 9A-1. Annual ICUC Values by Unit (%)

Year	Maximum On-Farm Efficiency (%)						
	EBID			EPCWID		Hudspeth	Juarez
	Rincon	Leasburg	Mesilla, NM	Mesilla, TX	El Paso Valley		
1986	76%	76%	76%	76%	76%	76%	76%
1987	76%	76%	76%	76%	76%	76%	76%
1988	76%	76%	76%	76%	76%	76%	76%
1989	76%	76%	76%	76%	76%	76%	76%
1990	76%	76%	76%	76%	76%	76%	76%
1991	76%	76%	76%	76%	76%	76%	76%
1992	76%	76%	76%	76%	76%	76%	76%
1993	76%	76%	76%	76%	76%	76%	76%
1994	76%	76%	76%	76%	76%	76%	76%
1995	76%	76%	76%	76%	76%	76%	76%
1996	76%	76%	76%	76%	76%	76%	76%
1997	76%	76%	76%	76%	76%	76%	76%
1998	76%	76%	76%	76%	76%	76%	76%
1999	76%	76%	76%	76%	76%	76%	76%
2000	76%	76%	76%	76%	76%	76%	76%
2001	76%	76%	76%	76%	76%	76%	76%
2002	76%	76%	76%	76%	76%	76%	76%
2003	76%	76%	76%	76%	76%	76%	76%
2004	76%	76%	76%	76%	76%	76%	76%
2005	76%	76%	76%	76%	76%	76%	76%
2006	76%	76%	76%	76%	76%	76%	76%
2007	76%	76%	76%	76%	76%	76%	76%
2008	76%	76%	76%	76%	76%	76%	76%
2009	76%	76%	76%	76%	76%	76%	76%
2010	76%	76%	76%	76%	76%	76%	76%

Table 9A-1. Annual ICUC Values by Unit (%)

Year	Maximum On-Farm Efficiency (%)						
	EBID			EPCWID			
	Rincon	Leasburg	Mesilla, NM	Mesilla, TX	El Paso Valley	Hudspeth	Juarez
2011	76%	76%	76%	76%	76%	76%	76%
2012	76%	76%	76%	76%	76%	76%	76%
2013	76%	76%	76%	76%	76%	76%	76%
2014	76%	76%	76%	76%	76%	76%	76%
2015	76%	76%	76%	76%	76%	76%	76%
2016	76%	76%	76%	76%	76%	76%	76%
2017	76%	76%	76%	76%	76%	76%	76%
2018	76%	76%	76%	76%	76%	76%	76%

Appendix 10A. Potential Bare Soil Evaporation from Groundwater Monthly Totals in Inches for the Mesilla/Rincon Groundwater Model for 1938-2018

Year	Month	Leyendecker ET_o, in	Potential Bare Ground Evaporation, in	Leyendecker Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
1938	1	2.5	3.0	0.6	0.6	2.4
1938	2	3.4	4.1	0.3	0.3	3.8
1938	3	5.4	6.4	0.1	0.1	6.3
1938	4	6.8	8.1	0.0	0.0	8.1
1938	5	8.0	9.6	0.0	0.0	9.6
1938	6	8.2	9.9	1.0	1.0	8.9
1938	7	7.7	9.2	3.7	2.3	6.9
1938	8	6.6	8.0	0.3	0.3	7.7
1938	9	5.1	6.2	2.5	1.6	4.6
1938	10	4.2	5.1	0.1	0.1	5.0
1938	11	2.9	3.5	0.1	0.1	3.4
1938	12	2.4	2.9	0.6	0.5	2.3
1939	1	2.5	3.0	0.7	0.7	2.3
1939	2	3.0	3.6	0.1	0.1	3.5
1939	3	5.5	6.6	0.1	0.1	6.4
1939	4	6.8	8.1	0.0	0.0	8.1
1939	5	8.2	9.8	0.0	0.0	9.8
1939	6	8.5	10.2	0.3	0.3	9.9
1939	7	7.6	9.1	0.7	0.7	8.3
1939	8	6.4	7.7	0.7	0.7	7.0
1939	9	5.4	6.5	1.3	0.9	5.6
1939	10	4.0	4.8	0.8	0.7	4.2
1939	11	2.6	3.1	0.7	0.6	2.5
1939	12	2.4	2.9	0.3	0.3	2.6
1940	1	2.4	2.9	0.1	0.1	2.7
1940	2	3.4	4.1	0.6	0.6	3.5
1940	3	5.6	6.7	0.0	0.0	6.7
1940	4	6.6	7.9	0.2	0.2	7.7
1940	5	7.9	9.5	0.6	0.6	8.8
1940	6	7.6	9.1	1.8	1.5	7.6
1940	7	7.6	9.2	1.5	1.4	7.7
1940	8	6.4	7.7	0.7	0.7	7.0
1940	9	5.2	6.2	1.7	1.5	4.7
1940	10	4.0	4.8	0.7	0.7	4.0
1940	11	2.6	3.1	0.6	0.6	2.4
1940	12	2.2	2.7	0.6	0.6	2.1

Year	Month	Leyendecker ET_o, in	Potential Bare Ground Evaporation, in	Leyendecker Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
1941	1	2.3	2.8	1.4	1.2	1.6
1941	2	3.1	3.8	0.4	0.4	3.4
1941	3	4.7	5.7	1.3	0.9	4.8
1941	4	6.0	7.3	1.0	0.8	6.4
1941	5	7.8	9.3	0.7	0.7	8.6
1941	6	7.7	9.2	0.9	0.8	8.4
1941	7	7.3	8.8	2.3	2.1	6.7
1941	8	6.3	7.6	2.3	1.7	5.9
1941	9	4.8	5.8	7.5	2.1	3.7
1941	10	3.7	4.4	1.0	1.0	3.5
1941	11	2.7	3.3	0.3	0.3	3.0
1941	12	2.2	2.6	0.5	0.5	2.1
1942	1	2.6	3.1	0.2	0.2	2.9
1942	2	3.0	3.7	0.5	0.5	3.2
1942	3	5.1	6.1	0.0	0.0	6.1
1942	4	6.4	7.7	0.8	0.8	6.8
1942	5	8.2	9.8	0.0	0.0	9.8
1942	6	8.7	10.4	0.5	0.5	9.9
1942	7	7.8	9.3	1.0	1.0	8.3
1942	8	6.1	7.3	3.0	2.3	5.0
1942	9	5.0	6.0	1.1	1.1	5.0
1942	10	3.8	4.5	1.6	1.4	3.1
1942	11	3.1	3.7	0.0	0.0	3.7
1942	12	2.3	2.7	1.1	1.0	1.8
1943	1	2.5	2.9	0.5	0.5	2.5
1943	2	3.7	4.4	0.0	0.0	4.4
1943	3	5.6	6.7	0.4	0.4	6.3
1943	4	7.5	9.0	0.0	0.0	8.9
1943	5	8.4	10.1	0.5	0.5	9.5
1943	6	8.2	9.8	1.0	1.0	8.8
1943	7	7.8	9.4	1.3	1.3	8.1
1943	8	7.1	8.5	0.9	0.9	7.6
1943	9	5.5	6.6	1.2	0.9	5.7
1943	10	4.3	5.2	0.0	0.0	5.2
1943	11	3.1	3.7	0.6	0.5	3.2
1943	12	2.1	2.5	1.1	0.8	1.7
1944	1	2.5	3.0	0.1	0.1	2.9
1944	2	3.3	3.9	0.9	0.9	3.0
1944	3	5.2	6.2	0.2	0.2	6.1

Year	Month	Leyendecker ET_o, in	Potential Bare Ground Evaporation, in	Leyendecker Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
1944	4	6.7	8.0	0.0	0.0	8.0
1944	5	7.9	9.5	0.4	0.4	9.1
1944	6	8.4	10.0	0.6	0.6	9.4
1944	7	8.0	9.6	1.2	1.1	8.4
1944	8	6.7	8.1	2.6	1.6	6.5
1944	9	5.3	6.4	0.6	0.6	5.7
1944	10	4.2	5.0	1.1	0.6	4.4
1944	11	2.5	3.0	1.0	0.8	2.2
1944	12	2.2	2.7	0.4	0.4	2.3
1945	1	2.6	3.1	0.3	0.3	2.9
1945	2	3.7	4.4	0.1	0.1	4.4
1945	3	5.4	6.4	0.2	0.2	6.3
1945	4	6.8	8.1	0.1	0.1	8.1
1945	5	8.4	10.1	0.0	0.0	10.1
1945	6	8.7	10.4	0.0	0.0	10.4
1945	7	7.9	9.5	1.5	1.5	8.0
1945	8	6.9	8.3	1.9	1.3	7.0
1945	9	6.0	7.2	0.3	0.3	6.9
1945	10	4.1	4.9	1.6	1.1	3.7
1945	11	3.4	4.1	0.0	0.0	4.1
1945	12	2.4	2.9	0.0	0.0	2.9
1946	1	2.3	2.7	0.8	0.8	1.9
1946	2	3.9	4.7	0.0	0.0	4.6
1946	3	5.8	6.9	0.0	0.0	6.9
1946	4	7.4	8.9	0.0	0.0	8.9
1946	5	8.2	9.8	0.4	0.4	9.5
1946	6	8.8	10.6	0.3	0.3	10.3
1946	7	8.1	9.7	0.1	0.1	9.6
1946	8	6.8	8.1	2.2	2.2	5.9
1946	9	5.5	6.6	2.4	2.1	4.5
1946	10	4.3	5.2	0.1	0.1	5.1
1946	11	2.9	3.5	0.1	0.1	3.3
1946	12	2.4	2.9	0.6	0.5	2.4
1947	1	2.3	2.8	1.1	1.1	1.7
1947	2	3.5	4.2	0.1	0.1	4.2
1947	3	4.6	5.6	0.5	0.5	5.1
1947	4	5.8	7.0	0.0	0.0	7.0
1947	5	7.4	8.9	0.2	0.2	8.7
1947	6	7.7	9.3	0.5	0.5	8.8

Year	Month	Leyendecker ET_o, in	Potential Bare Ground Evaporation, in	Leyendecker Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
1947	7	8.0	9.6	0.3	0.3	9.3
1947	8	6.6	7.9	2.4	1.9	5.9
1947	9	5.8	7.0	0.0	0.0	7.0
1947	10	4.1	4.9	0.0	0.0	4.9
1947	11	2.4	2.9	0.6	0.6	2.3
1947	12	1.9	2.3	0.5	0.5	1.8
1948	1	2.2	2.6	0.2	0.2	2.4
1948	2	2.7	3.3	1.4	1.0	2.3
1948	3	4.2	5.0	0.2	0.2	4.8
1948	4	6.5	7.8	0.1	0.1	7.8
1948	5	7.7	9.2	0.0	0.0	9.2
1948	6	8.0	9.6	0.9	0.9	8.7
1948	7	8.2	9.8	0.1	0.1	9.8
1948	8	7.1	8.5	0.5	0.5	8.0
1948	9	5.8	6.9	0.4	0.4	6.5
1948	10	3.8	4.6	0.4	0.4	4.2
1948	11	2.4	2.9	0.0	0.0	2.9
1948	12	1.9	2.3	1.1	0.6	1.7
1949	1	1.8	2.1	1.9	1.6	0.5
1949	2	2.7	3.2	0.5	0.4	2.8
1949	3	5.1	6.1	0.1	0.1	6.1
1949	4	6.0	7.2	0.1	0.1	7.1
1949	5	7.5	8.9	0.8	0.8	8.2
1949	6	7.9	9.5	0.1	0.1	9.3
1949	7	7.8	9.3	1.1	1.1	8.2
1949	8	6.9	8.3	0.7	0.7	7.6
1949	9	5.2	6.3	2.4	1.9	4.4
1949	10	4.0	4.8	0.9	0.7	4.1
1949	11	3.4	4.1	0.0	0.0	4.1
1949	12	2.1	2.6	0.5	0.5	2.1
1950	1	2.9	3.5	0.1	0.1	3.4
1950	2	3.7	4.5	0.5	0.5	4.0
1950	3	5.7	6.8	0.0	0.0	6.8
1950	4	7.1	8.5	0.0	0.0	8.5
1950	5	8.2	9.9	0.1	0.1	9.8
1950	6	8.7	10.4	0.3	0.3	10.2
1950	7	7.5	8.9	2.4	2.2	6.7
1950	8	7.2	8.6	0.5	0.5	8.1
1950	9	5.6	6.7	1.1	0.9	5.8

Year	Month	Leyendecker ET_o, in	Potential Bare Ground Evaporation, in	Leyendecker Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
1950	10	4.9	5.8	0.4	0.4	5.5
1950	11	3.4	4.1	0.0	0.0	4.1
1950	12	2.8	3.4	0.0	0.0	3.4
1951	1	2.8	3.4	0.3	0.3	3.1
1951	2	3.4	4.1	0.4	0.4	3.7
1951	3	5.2	6.3	0.2	0.2	6.1
1951	4	6.7	8.0	0.4	0.4	7.6
1951	5	8.4	10.1	0.0	0.0	10.1
1951	6	9.0	10.8	0.0	0.0	10.8
1951	7	8.4	10.1	1.5	1.5	8.6
1951	8	7.0	8.3	1.0	1.0	7.4
1951	9	6.2	7.4	0.0	0.0	7.4
1951	10	4.3	5.2	0.7	0.7	4.5
1951	11	2.5	3.0	0.1	0.1	2.9
1951	12	2.3	2.7	0.5	0.5	2.2
1952	1	2.9	3.4	0.0	0.0	3.4
1952	2	3.4	4.0	0.7	0.7	3.3
1952	3	4.8	5.8	0.7	0.7	5.1
1952	4	6.4	7.7	0.6	0.5	7.2
1952	5	8.0	9.6	0.2	0.2	9.5
1952	6	8.4	10.1	1.1	1.1	9.1
1952	7	7.8	9.4	1.1	1.1	8.3
1952	8	7.1	8.5	1.2	1.2	7.2
1952	9	5.8	6.9	0.4	0.4	6.5
1952	10	4.9	5.9	0.0	0.0	5.9
1952	11	2.8	3.3	0.2	0.2	3.1
1952	12	2.2	2.7	0.1	0.1	2.6
1953	1	3.2	3.8	0.0	0.0	3.8
1953	2	3.3	4.0	0.7	0.7	3.3
1953	3	5.5	6.6	0.4	0.4	6.2
1953	4	6.5	7.8	0.0	0.0	7.7
1953	5	7.8	9.3	0.0	0.0	9.3
1953	6	8.9	10.6	0.3	0.3	10.3
1953	7	8.2	9.8	1.3	1.3	8.5
1953	8	7.2	8.6	0.3	0.3	8.3
1953	9	6.3	7.6	0.0	0.0	7.6
1953	10	4.4	5.2	0.6	0.6	4.7
1953	11	3.0	3.6	0.0	0.0	3.6
1953	12	2.1	2.5	0.2	0.2	2.3

Year	Month	Leyendecker ET_o, in	Potential Bare Ground Evaporation, in	Leyendecker Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
1954	1	2.8	3.4	0.1	0.1	3.3
1954	2	3.8	4.6	0.3	0.3	4.3
1954	3	5.2	6.3	0.1	0.1	6.2
1954	4	7.3	8.7	0.0	0.0	8.7
1954	5	8.0	9.6	0.8	0.8	8.8
1954	6	8.4	10.0	0.3	0.3	9.8
1954	7	8.0	9.6	0.7	0.7	8.9
1954	8	6.5	7.8	1.3	1.3	6.5
1954	9	5.7	6.9	1.0	1.0	5.9
1954	10	4.3	5.2	1.3	0.7	4.5
1954	11	3.2	3.9	0.0	0.0	3.9
1954	12	2.5	3.0	0.0	0.0	3.0
1955	1	2.3	2.7	0.7	0.7	2.1
1955	2	3.2	3.9	0.0	0.0	3.9
1955	3	5.3	6.4	0.4	0.4	6.0
1955	4	6.8	8.2	0.0	0.0	8.2
1955	5	7.7	9.2	0.1	0.1	9.1
1955	6	8.2	9.8	0.1	0.1	9.7
1955	7	7.2	8.6	3.2	1.9	6.7
1955	8	6.6	7.9	0.6	0.6	7.3
1955	9	5.9	7.1	0.0	0.0	7.1
1955	10	4.3	5.2	2.1	1.1	4.1
1955	11	3.0	3.6	0.1	0.1	3.5
1955	12	2.6	3.1	0.0	0.0	3.1
1956	1	2.9	3.5	0.2	0.2	3.3
1956	2	3.3	4.0	1.0	0.7	3.3
1956	3	6.0	7.2	0.0	0.0	7.2
1956	4	6.8	8.1	0.0	0.0	8.1
1956	5	8.8	10.5	0.0	0.0	10.5
1956	6	8.6	10.3	0.5	0.5	9.8
1956	7	8.0	9.5	0.9	0.9	8.7
1956	8	6.9	8.2	1.4	1.4	6.9
1956	9	6.2	7.4	0.1	0.1	7.3
1956	10	4.5	5.4	0.3	0.3	5.1
1956	11	2.9	3.5	0.0	0.0	3.5
1956	12	2.3	2.8	0.4	0.4	2.3
1957	1	2.6	3.1	0.3	0.3	2.8
1957	2	3.7	4.5	1.5	0.8	3.7
1957	3	5.2	6.2	0.5	0.5	5.7

Year	Month	Leyendecker ET_o, in	Potential Bare Ground Evaporation, in	Leyendecker Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
1957	4	6.8	8.1	0.0	0.0	8.1
1957	5	7.5	9.0	0.3	0.3	8.6
1957	6	8.5	10.2	0.0	0.0	10.2
1957	7	8.1	9.7	0.8	0.8	8.9
1957	8	6.6	7.9	2.7	2.2	5.8
1957	9	5.8	6.9	0.5	0.4	6.5
1957	10	3.6	4.4	1.8	1.7	2.7
1957	11	2.5	3.0	0.8	0.8	2.2
1957	12	2.4	2.9	0.0	0.0	2.9
1958	1	2.4	2.9	0.9	0.9	2.0
1958	2	3.4	4.0	1.4	1.0	3.1
1958	3	4.4	5.3	1.8	1.3	4.0
1958	4	6.7	8.1	0.2	0.2	7.8
1958	5	8.2	9.8	0.3	0.3	9.5
1958	6	8.2	9.9	0.4	0.4	9.5
1958	7	8.3	9.9	0.9	0.9	9.0
1958	8	6.9	8.3	3.3	1.7	6.6
1958	9	5.0	6.0	3.4	2.2	3.8
1958	10	3.6	4.3	1.1	1.0	3.3
1958	11	2.9	3.5	0.4	0.4	3.1
1958	12	2.7	3.2	0.0	0.0	3.2
1959	1	2.9	3.5	0.1	0.1	3.4
1959	2	3.3	4.0	0.2	0.2	3.8
1959	3	5.7	6.8	0.0	0.0	6.8
1959	4	6.9	8.3	0.0	0.0	8.2
1959	5	8.1	9.8	0.7	0.5	9.3
1959	6	8.4	10.0	0.5	0.5	9.5
1959	7	7.8	9.4	0.6	0.6	8.8
1959	8	6.5	7.8	2.8	2.3	5.5
1959	9	6.0	7.2	0.0	0.0	7.2
1959	10	4.4	5.3	0.8	0.8	4.5
1959	11	2.9	3.4	0.1	0.1	3.4
1959	12	2.3	2.7	0.2	0.2	2.5
1960	1	2.4	2.9	0.7	0.6	2.2
1960	2	3.2	3.9	0.2	0.2	3.7
1960	3	5.9	7.1	0.2	0.2	7.0
1960	4	7.2	8.6	0.0	0.0	8.6
1960	5	8.2	9.9	0.0	0.0	9.9
1960	6	8.8	10.6	0.1	0.1	10.5

Year	Month	Leyendecker ET_o, in	Potential Bare Ground Evaporation, in	Leyendecker Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
1960	7	7.8	9.3	2.9	1.8	7.5
1960	8	6.7	8.1	1.0	0.9	7.1
1960	9	5.6	6.7	0.6	0.6	6.1
1960	10	4.1	4.9	0.8	0.7	4.3
1960	11	3.0	3.6	0.1	0.1	3.5
1960	12	1.9	2.2	1.3	1.1	1.2
1961	1	2.4	2.9	0.7	0.7	2.2
1961	2	3.6	4.3	0.0	0.0	4.2
1961	3	5.6	6.7	0.1	0.1	6.6
1961	4	7.1	8.5	0.0	0.0	8.5
1961	5	8.4	10.1	0.0	0.0	10.1
1961	6	8.3	10.0	2.3	0.9	9.1
1961	7	7.7	9.3	1.1	1.1	8.2
1961	8	6.7	8.1	1.8	1.8	6.3
1961	9	5.2	6.2	1.5	1.2	5.0
1961	10	4.3	5.1	0.0	0.0	5.1
1961	11	2.5	3.0	1.6	1.1	1.9
1961	12	2.1	2.5	0.8	0.8	1.7
1962	1	2.4	2.9	0.9	0.8	2.0
1962	2	3.6	4.3	0.5	0.5	3.8
1962	3	5.0	6.0	0.0	0.0	5.9
1962	4	7.1	8.5	0.1	0.1	8.4
1962	5	8.4	10.0	0.0	0.0	10.0
1962	6	8.4	10.0	0.3	0.3	9.8
1962	7	7.6	9.1	1.2	1.2	7.9
1962	8	7.3	8.8	0.5	0.5	8.2
1962	9	5.1	6.1	1.8	1.3	4.8
1962	10	4.2	5.0	0.6	0.6	4.4
1962	11	3.0	3.6	0.0	0.0	3.6
1962	12	2.2	2.7	0.5	0.5	2.2
1963	1	2.5	3.0	0.0	0.0	3.0
1963	2	3.5	4.2	0.9	0.6	3.7
1963	3	5.7	6.8	0.0	0.0	6.8
1963	4	7.1	8.5	0.0	0.0	8.5
1963	5	8.5	10.2	0.0	0.0	10.2
1963	6	8.4	10.1	0.1	0.1	10.0
1963	7	7.9	9.4	1.4	1.1	8.4
1963	8	6.3	7.5	2.2	1.9	5.7
1963	9	5.4	6.4	0.7	0.7	5.8

Year	Month	Leyendecker ET_o, in	Potential Bare Ground Evaporation, in	Leyendecker Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
1963	10	4.4	5.3	0.5	0.5	4.8
1963	11	2.9	3.5	0.3	0.3	3.2
1963	12	2.3	2.8	0.0	0.0	2.8
1964	1	2.5	3.0	0.0	0.0	2.9
1964	2	3.3	3.9	0.0	0.0	3.9
1964	3	5.2	6.3	0.6	0.6	5.7
1964	4	6.8	8.1	0.1	0.1	8.0
1964	5	8.3	10.0	0.1	0.1	9.9
1964	6	8.5	10.2	0.3	0.3	10.0
1964	7	8.1	9.7	0.5	0.5	9.1
1964	8	7.0	8.4	0.3	0.3	8.1
1964	9	5.3	6.4	1.2	0.8	5.6
1964	10	4.4	5.3	0.0	0.0	5.3
1964	11	3.0	3.6	0.0	0.0	3.6
1964	12	2.2	2.6	0.5	0.5	2.1
1965	1	2.7	3.2	0.3	0.3	3.0
1965	2	3.2	3.9	0.5	0.5	3.4
1965	3	5.1	6.1	0.2	0.2	5.9
1965	4	7.0	8.4	0.0	0.0	8.4
1965	5	8.2	9.8	0.3	0.3	9.5
1965	6	8.4	10.1	0.9	0.9	9.2
1965	7	8.1	9.7	0.8	0.8	8.9
1965	8	6.9	8.3	1.9	1.6	6.6
1965	9	5.3	6.4	1.7	1.4	5.0
1965	10	4.6	5.5	0.5	0.5	5.0
1965	11	3.2	3.8	0.2	0.2	3.6
1965	12	2.2	2.6	1.1	1.1	1.5
1966	1	2.4	2.9	0.2	0.2	2.6
1966	2	3.0	3.6	0.3	0.3	3.4
1966	3	5.8	7.0	0.4	0.4	6.6
1966	4	6.9	8.2	0.4	0.4	7.9
1966	5	8.1	9.8	0.0	0.0	9.7
1966	6	8.0	9.6	3.7	1.9	7.7
1966	7	8.1	9.7	0.8	0.8	8.9
1966	8	6.7	8.0	1.9	1.9	6.2
1966	9	5.4	6.5	1.2	1.2	5.3
1966	10	4.2	5.0	0.5	0.5	4.5
1966	11	3.0	3.7	0.4	0.4	3.3
1966	12	2.3	2.8	0.1	0.1	2.7

Year	Month	Leyendecker ET_o, in	Potential Bare Ground Evaporation, in	Leyendecker Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
1967	1	2.9	3.5	0.0	0.0	3.5
1967	2	3.5	4.2	0.1	0.1	4.1
1967	3	6.2	7.4	0.0	0.0	7.4
1967	4	7.1	8.6	0.0	0.0	8.6
1967	5	8.1	9.7	0.3	0.3	9.4
1967	6	8.0	9.6	1.4	1.4	8.2
1967	7	7.9	9.4	1.8	1.7	7.7
1967	8	6.6	7.9	2.2	2.1	5.7
1967	9	5.4	6.4	1.4	1.0	5.4
1967	10	4.5	5.4	0.0	0.0	5.4
1967	11	2.9	3.4	0.6	0.6	2.9
1967	12	1.9	2.3	0.7	0.6	1.7
1968	1	2.4	2.9	0.5	0.5	2.4
1968	2	3.4	4.1	0.8	0.8	3.3
1968	3	5.0	6.0	1.1	1.1	4.9
1968	4	6.5	7.8	0.3	0.3	7.5
1968	5	8.3	10.0	0.0	0.0	9.9
1968	6	8.7	10.4	0.1	0.1	10.2
1968	7	7.5	9.0	2.5	1.6	7.4
1968	8	6.4	7.6	3.9	2.8	4.8
1968	9	5.6	6.7	1.3	1.3	5.4
1968	10	4.6	5.5	0.4	0.4	5.1
1968	11	2.7	3.3	1.7	1.1	2.2
1968	12	2.3	2.7	0.4	0.4	2.3
1969	1	2.8	3.3	0.5	0.5	2.8
1969	2	3.3	4.0	0.2	0.2	3.8
1969	3	5.1	6.2	0.1	0.1	6.1
1969	4	7.1	8.5	0.0	0.0	8.5
1969	5	8.2	9.9	0.4	0.4	9.5
1969	6	8.4	10.0	0.9	0.9	9.1
1969	7	7.7	9.2	4.0	2.2	7.0
1969	8	7.0	8.4	1.6	1.1	7.3
1969	9	5.4	6.4	1.3	1.2	5.2
1969	10	4.1	4.9	1.3	1.0	3.9
1969	11	2.8	3.3	0.1	0.1	3.2
1969	12	2.3	2.8	1.4	1.1	1.7
1970	1	2.7	3.3	0.0	0.0	3.3
1970	2	3.4	4.0	0.4	0.4	3.6
1970	3	5.2	6.2	0.5	0.5	5.7

Year	Month	Leyendecker ET_o, in	Potential Bare Ground Evaporation, in	Leyendecker Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
1970	4	6.9	8.3	0.0	0.0	8.3
1970	5	8.4	10.1	0.1	0.1	10.0
1970	6	8.3	10.0	0.3	0.3	9.7
1970	7	7.9	9.5	0.8	0.8	8.7
1970	8	7.0	8.4	0.7	0.7	7.7
1970	9	5.6	6.7	0.4	0.4	6.3
1970	10	4.1	4.9	0.1	0.1	4.8
1970	11	3.2	3.8	0.0	0.0	3.8
1970	12	2.5	3.0	0.2	0.2	2.8
1971	1	2.9	3.5	0.1	0.1	3.4
1971	2	3.6	4.3	0.0	0.0	4.3
1971	3	6.1	7.4	0.0	0.0	7.4
1971	4	6.8	8.1	0.2	0.2	7.9
1971	5	8.1	9.8	0.0	0.0	9.8
1971	6	8.5	10.2	0.0	0.0	10.2
1971	7	8.0	9.7	1.8	1.4	8.3
1971	8	6.5	7.8	0.8	0.8	7.0
1971	9	5.7	6.9	0.6	0.6	6.3
1971	10	3.9	4.6	1.3	1.1	3.6
1971	11	2.8	3.4	0.4	0.4	3.0
1971	12	2.1	2.5	0.6	0.6	1.9
1972	1	2.8	3.4	0.3	0.3	3.1
1972	2	3.9	4.7	0.0	0.0	4.7
1972	3	6.3	7.6	0.0	0.0	7.6
1972	4	7.6	9.2	0.0	0.0	9.2
1972	5	8.1	9.8	0.1	0.1	9.6
1972	6	8.0	9.6	1.8	1.8	7.8
1972	7	8.0	9.6	1.3	1.3	8.4
1972	8	6.4	7.7	3.2	2.6	5.1
1972	9	5.1	6.1	1.4	1.1	5.0
1972	10	4.0	4.8	3.1	1.5	3.3
1972	11	2.6	3.1	0.3	0.3	2.9
1972	12	2.2	2.7	0.7	0.7	2.0
1973	1	2.3	2.8	0.9	0.9	1.8
1973	2	2.9	3.5	1.3	1.0	2.5
1973	3	5.0	6.0	0.3	0.3	5.7
1973	4	6.4	7.7	0.0	0.0	7.7
1973	5	7.8	9.3	0.4	0.4	8.9
1973	6	8.1	9.8	1.2	0.5	9.3

Year	Month	Leyendecker ET_o, in	Potential Bare Ground Evaporation, in	Leyendecker Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
1973	7	7.4	8.9	4.1	2.6	6.3
1973	8	6.9	8.3	0.7	0.7	7.5
1973	9	5.7	6.9	0.1	0.1	6.7
1973	10	4.5	5.4	0.0	0.0	5.4
1973	11	3.3	3.9	0.0	0.0	3.9
1973	12	2.4	2.9	0.0	0.0	2.9
1974	1	2.7	3.2	0.6	0.6	2.6
1974	2	3.4	4.1	0.0	0.0	4.1
1974	3	6.0	7.2	0.4	0.4	6.8
1974	4	6.9	8.3	0.0	0.0	8.3
1974	5	8.2	9.9	0.0	0.0	9.9
1974	6	8.5	10.2	0.1	0.1	10.1
1974	7	7.4	8.9	3.2	2.9	6.0
1974	8	6.3	7.6	3.4	2.9	4.7
1974	9	5.1	6.1	3.1	1.9	4.2
1974	10	3.8	4.5	1.9	1.2	3.3
1974	11	2.7	3.2	0.3	0.3	2.9
1974	12	2.1	2.5	0.7	0.7	1.8
1975	1	2.4	2.9	0.5	0.5	2.4
1975	2	3.2	3.8	0.4	0.4	3.5
1975	3	5.2	6.3	0.2	0.2	6.0
1975	4	6.3	7.5	0.0	0.0	7.5
1975	5	7.7	9.2	0.5	0.5	8.7
1975	6	8.5	10.2	0.0	0.0	10.2
1975	7	7.5	9.1	0.8	0.8	8.2
1975	8	7.0	8.3	2.6	2.1	6.3
1975	9	5.5	6.6	1.9	1.8	4.8
1975	10	4.5	5.4	0.6	0.6	4.8
1975	11	3.1	3.7	0.2	0.2	3.5
1975	12	2.3	2.8	0.4	0.4	2.4
1976	1	2.6	3.1	0.3	0.3	2.8
1976	2	3.8	4.6	0.4	0.4	4.2
1976	3	5.5	6.6	0.0	0.0	6.6
1976	4	6.6	7.9	0.6	0.6	7.4
1976	5	7.7	9.2	0.2	0.2	8.9
1976	6	8.3	9.9	0.9	0.5	9.4
1976	7	7.6	9.1	1.8	1.7	7.4
1976	8	7.1	8.5	0.3	0.3	8.2
1976	9	5.2	6.3	1.5	1.3	5.0

Year	Month	Leyendecker ET_o, in	Potential Bare Ground Evaporation, in	Leyendecker Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
1976	10	3.9	4.6	0.9	0.9	3.8
1976	11	2.6	3.2	0.9	0.9	2.3
1976	12	2.1	2.6	0.0	0.0	2.5
1977	1	2.4	2.9	0.4	0.4	2.5
1977	2	3.6	4.3	0.0	0.0	4.3
1977	3	5.0	6.0	0.3	0.3	5.7
1977	4	6.7	8.0	0.2	0.2	7.8
1977	5	7.9	9.5	0.1	0.1	9.3
1977	6	8.4	10.0	0.2	0.2	9.9
1977	7	8.1	9.7	1.4	1.4	8.3
1977	8	7.2	8.7	2.5	1.5	7.1
1977	9	5.7	6.8	2.1	1.8	5.1
1977	10	4.1	4.9	1.2	1.2	3.6
1977	11	3.2	3.8	0.1	0.1	3.7
1977	12	2.5	3.0	0.2	0.2	2.8
1978	1	2.5	3.0	0.6	0.6	2.4
1978	2	3.1	3.7	0.4	0.4	3.4
1978	3	5.5	6.6	0.1	0.1	6.5
1978	4	7.1	8.6	0.0	0.0	8.6
1978	5	8.0	9.6	1.0	0.8	8.8
1978	6	8.8	10.5	1.0	0.8	9.7
1978	7	8.3	10.0	0.9	0.7	9.3
1978	8	6.8	8.2	2.6	1.4	6.8
1978	9	5.0	6.0	3.0	1.7	4.3
1978	10	4.1	4.9	1.9	1.0	3.9
1978	11	2.6	3.1	2.6	1.8	1.3
1978	12	2.0	2.4	0.8	0.8	1.7
1979	1	2.2	2.7	0.8	0.8	1.9
1979	2	3.2	3.9	0.2	0.2	3.7
1979	3	5.3	6.4	0.0	0.0	6.4
1979	4	6.8	8.2	0.4	0.4	7.8
1979	5	7.5	9.0	0.2	0.2	8.8
1979	6	8.2	9.8	0.3	0.3	9.5
1979	7	8.2	9.8	0.8	0.8	9.0
1979	8	6.7	8.0	5.0	1.9	6.1
1979	9	5.5	6.7	0.5	0.5	6.2
1979	10	4.9	5.8	0.0	0.0	5.8
1979	11	2.8	3.3	0.0	0.0	3.3
1979	12	2.3	2.8	1.2	1.0	1.8

Year	Month	Leyendecker ET_o, in	Potential Bare Ground Evaporation, in	Leyendecker Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
1980	1	2.6	3.2	0.7	0.7	2.4
1980	2	3.4	4.1	1.0	1.0	3.1
1980	3	5.1	6.2	0.3	0.3	5.9
1980	4	6.5	7.7	0.6	0.6	7.1
1980	5	7.5	9.1	0.8	0.6	8.4
1980	6	9.0	10.8	0.0	0.0	10.8
1980	7	8.5	10.1	0.2	0.2	10.0
1980	8	6.7	8.1	1.6	1.5	6.6
1980	9	5.1	6.2	2.1	2.1	4.1
1980	10	3.9	4.7	0.5	0.5	4.2
1980	11	2.9	3.4	0.4	0.4	3.1
1980	12	2.6	3.1	0.0	0.0	3.1
1981	1	2.4	2.9	0.6	0.6	2.3
1981	2	3.6	4.3	0.0	0.0	4.3
1981	3	5.0	5.9	0.4	0.4	5.5
1981	4	6.8	8.1	0.9	0.9	7.3
1981	5	7.6	9.1	0.7	0.7	8.4
1981	6	8.5	10.2	0.8	0.8	9.4
1981	7	7.9	9.5	0.9	0.9	8.6
1981	8	6.5	7.8	2.7	2.6	5.2
1981	9	5.3	6.4	1.2	1.1	5.3
1981	10	4.1	4.9	0.8	0.8	4.1
1981	11	3.2	3.9	0.6	0.6	3.2
1981	12	2.5	3.0	0.0	0.0	3.0
1982	1	2.6	3.2	0.9	0.9	2.3
1982	2	3.3	4.0	0.1	0.1	3.8
1982	3	5.5	6.6	0.0	0.0	6.6
1982	4	6.6	8.0	0.0	0.0	8.0
1982	5	7.8	9.3	0.2	0.2	9.1
1982	6	8.5	10.2	0.0	0.0	10.2
1982	7	8.0	9.6	0.6	0.6	9.0
1982	8	6.7	8.0	2.1	1.9	6.1
1982	9	5.4	6.5	1.2	1.2	5.3
1982	10	4.1	5.0	0.7	0.6	4.3
1982	11	2.6	3.1	0.5	0.5	2.7
1982	12	2.0	2.4	1.5	1.2	1.2
1983	1	2.3	2.8	0.8	0.8	2.0
1983	2	3.2	3.9	0.7	0.7	3.1
1983	3	5.1	6.1	0.2	0.2	5.9

Year	Month	Leyendecker ET_o, in	Potential Bare Ground Evaporation, in	Leyendecker Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
1983	4	5.9	7.1	0.7	0.7	6.4
1983	5	7.9	9.4	0.5	0.5	9.0
1983	6	8.5	10.2	0.2	0.2	10.0
1983	7	8.1	9.8	0.3	0.3	9.5
1983	8	6.7	8.1	0.9	0.9	7.2
1983	9	5.7	6.8	0.1	0.1	6.7
1983	10	3.9	4.7	1.3	1.3	3.4
1983	11	2.8	3.3	1.5	0.7	2.6
1983	12	2.2	2.6	0.2	0.2	2.5
1984	1	2.5	3.0	0.5	0.5	2.5
1984	2	3.6	4.3	0.0	0.0	4.3
1984	3	5.7	6.8	0.1	0.1	6.7
1984	4	6.6	8.0	0.0	0.0	8.0
1984	5	8.3	10.0	1.1	0.6	9.4
1984	6	7.8	9.4	1.1	1.1	8.3
1984	7	7.9	9.4	0.4	0.4	9.0
1984	8	6.3	7.5	4.8	3.9	3.6
1984	9	5.4	6.5	0.3	0.3	6.3
1984	10	3.5	4.2	2.7	1.6	2.6
1984	11	2.7	3.3	0.4	0.4	2.9
1984	12	2.0	2.4	2.4	1.2	1.2
1985	1	2.0	2.4	1.3	1.0	1.4
1985	2	3.3	4.0	0.9	0.7	3.3
1985	3	5.2	6.2	0.1	0.1	6.1
1985	4	6.5	7.8	0.6	0.5	7.2
1985	5	7.6	9.2	0.0	0.0	9.1
1985	6	8.2	9.9	0.1	0.1	9.7
1985	7	7.8	9.4	1.5	1.5	7.9
1985	8	6.8	8.2	2.0	1.5	6.7
1985	9	5.0	6.0	2.7	2.2	3.8
1985	10	3.5	4.2	3.2	1.6	2.6
1985	11	2.6	3.1	0.1	0.1	3.0
1985	12	2.2	2.7	0.1	0.1	2.5
1986	1	2.7	3.3	0.0	0.0	3.3
1986	2	3.5	4.2	0.2	0.2	4.1
1986	3	5.4	6.5	0.2	0.2	6.3
1986	4	6.0	7.2	0.0	0.0	7.1
1986	5	7.6	9.1	0.9	0.6	8.5
1986	6	7.2	8.7	1.8	1.1	7.5

Year	Month	Leyendecker ET_o, in	Potential Bare Ground Evaporation, in	Leyendecker Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
1986	7	7.0	8.4	1.9	1.6	6.8
1986	8	6.0	7.2	2.0	2.0	5.3
1986	9	5.1	6.1	1.8	1.4	4.7
1986	10	3.5	4.3	0.6	0.6	3.7
1986	11	2.0	2.4	1.6	0.7	1.7
1986	12	1.4	1.7	2.1	1.0	0.7
1987	1	2.4	2.9	0.2	0.2	2.7
1987	2	2.9	3.4	0.2	0.2	3.2
1987	3	4.9	5.9	0.0	0.0	5.8
1987	4	6.3	7.6	0.1	0.1	7.5
1987	5	7.8	9.4	0.0	0.0	9.4
1987	6	7.9	9.5	1.3	1.2	8.3
1987	7	8.2	9.8	0.2	0.2	9.6
1987	8	6.6	7.9	4.8	2.2	5.7
1987	9	4.6	5.5	0.6	0.6	4.9
1987	10	3.7	4.4	0.3	0.3	4.1
1987	11	2.5	3.0	0.3	0.3	2.7
1987	12	2.0	2.4	1.2	1.1	1.3
1988	1	2.2	2.7	0.2	0.2	2.5
1988	2	3.1	3.7	0.8	0.7	3.0
1988	3	5.4	6.5	0.1	0.1	6.4
1988	4	6.4	7.7	0.3	0.3	7.4
1988	5	8.4	10.1	0.1	0.1	10.0
1988	6	8.0	9.6	0.3	0.3	9.4
1988	7	7.7	9.2	1.7	1.6	7.6
1988	8	5.6	6.7	3.7	2.6	4.1
1988	9	4.8	5.7	2.1	1.6	4.1
1988	10	3.5	4.2	1.1	1.0	3.2
1988	11	3.0	3.6	0.1	0.1	3.5
1988	12	2.0	2.4	1.0	0.8	1.7
1989	1	2.6	3.1	0.3	0.3	2.8
1989	2	3.2	3.8	0.8	0.6	3.2
1989	3	5.4	6.5	0.7	0.6	5.9
1989	4	6.9	8.2	0.0	0.0	8.2
1989	5	8.0	9.6	0.6	0.6	9.1
1989	6	8.1	9.7	0.0	0.0	9.7
1989	7	7.8	9.4	1.1	1.1	8.3
1989	8	6.1	7.3	3.4	3.2	4.0
1989	9	5.2	6.2	0.8	0.8	5.4

Year	Month	Leyendecker ET_o, in	Potential Bare Ground Evaporation, in	Leyendecker Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
1989	10	3.7	4.4	0.3	0.3	4.1
1989	11	3.0	3.6	0.0	0.0	3.5
1989	12	2.1	2.5	1.0	0.6	1.9
1990	1	2.1	2.5	0.5	0.5	2.0
1990	2	2.9	3.5	0.0	0.0	3.5
1990	3	4.9	5.8	0.2	0.2	5.6
1990	4	6.7	8.1	0.9	0.9	7.2
1990	5	7.4	8.9	0.3	0.3	8.6
1990	6	8.1	9.8	0.0	0.0	9.8
1990	7	7.2	8.7	1.9	1.9	6.8
1990	8	5.9	7.0	2.2	1.5	5.5
1990	9	4.6	5.5	2.3	1.9	3.6
1990	10	3.6	4.3	0.1	0.1	4.2
1990	11	2.4	2.9	0.6	0.6	2.2
1990	12	2.2	2.6	0.4	0.4	2.2
1991	1	2.3	2.8	0.4	0.4	2.3
1991	2	3.2	3.9	0.4	0.4	3.5
1991	3	4.9	5.9	0.7	0.7	5.2
1991	4	6.7	8.0	0.0	0.0	8.0
1991	5	8.1	9.8	0.3	0.3	9.4
1991	6	8.3	9.9	0.1	0.1	9.8
1991	7	7.1	8.5	1.7	1.5	7.0
1991	8	6.2	7.5	5.2	3.4	4.1
1991	9	4.8	5.8	2.2	1.7	4.1
1991	10	4.4	5.2	0.4	0.4	4.8
1991	11	2.6	3.1	0.3	0.3	2.8
1991	12	1.9	2.3	2.9	1.5	0.8
1992	1	2.1	2.5	1.5	1.1	1.4
1992	2	3.2	3.9	0.0	0.0	3.8
1992	3	5.2	6.2	0.4	0.4	5.9
1992	4	6.9	8.2	0.4	0.4	7.8
1992	5	7.3	8.8	2.0	1.9	6.8
1992	6	8.4	10.0	0.1	0.1	9.9
1992	7	8.0	9.6	0.6	0.6	9.1
1992	8	6.5	7.8	3.2	2.5	5.3
1992	9	5.8	6.9	0.8	0.6	6.3
1992	10	4.3	5.2	0.6	0.6	4.6
1992	11	2.6	3.1	0.1	0.1	3.1
1992	12	1.9	2.3	1.3	0.6	1.7

Year	Month	Leyendecker ET_o, in	Potential Bare Ground Evaporation, in	Leyendecker Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
1993	1	1.3	1.5	1.5	1.0	0.5
1993	2	3.0	3.6	0.4	0.4	3.2
1993	3	5.1	6.1	0.0	0.0	6.1
1993	4	5.8	7.0	0.0	0.0	7.0
1993	5	7.5	9.0	0.0	0.0	9.0
1993	6	8.8	10.5	0.4	0.4	10.1
1993	7	8.1	9.8	2.4	1.9	7.9
1993	8	7.1	8.5	2.5	2.1	6.4
1993	9	5.8	7.0	0.3	0.3	6.7
1993	10	3.9	4.7	0.7	0.7	4.0
1993	11	2.8	3.3	0.3	0.3	3.0
1993	12	2.4	2.8	0.8	0.8	2.1
1994	1	2.9	3.4	0.1	0.1	3.3
1994	2	3.4	4.0	0.2	0.2	3.9
1994	3	5.3	6.4	0.1	0.1	6.3
1994	4	7.3	8.7	0.4	0.4	8.4
1994	5	7.6	9.1	0.6	0.6	8.6
1994	6	9.0	10.8	0.1	0.1	10.7
1994	7	9.0	10.8	3.4	1.2	9.6
1994	8	7.6	9.1	0.6	0.6	8.5
1994	9	5.6	6.7	0.8	0.8	5.9
1994	10	4.2	5.0	0.3	0.3	4.7
1994	11	2.9	3.5	0.7	0.6	2.9
1994	12	1.5	1.8	1.1	1.0	0.8
1995	1	1.9	2.3	0.7	0.7	1.6
1995	2	3.1	3.8	0.6	0.6	3.2
1995	3	5.6	6.7	0.1	0.1	6.6
1995	4	6.7	8.1	0.0	0.0	8.1
1995	5	8.2	9.9	0.1	0.1	9.8
1995	6	9.0	10.8	0.7	0.7	10.1
1995	7	8.9	10.7	1.6	1.5	9.2
1995	8	7.6	9.2	0.5	0.5	8.7
1995	9	5.4	6.5	2.8	2.0	4.5
1995	10	4.6	5.5	0.0	0.0	5.5
1995	11	2.9	3.5	0.2	0.2	3.3
1995	12	2.3	2.7	0.4	0.4	2.3
1996	1	3.1	3.7	0.2	0.2	3.5
1996	2	3.9	4.7	0.0	0.0	4.6
1996	3	5.6	6.7	0.0	0.0	6.7

Year	Month	Leyendecker ET_o, in	Potential Bare Ground Evaporation, in	Leyendecker Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
1996	4	7.0	8.4	0.5	0.5	8.0
1996	5	8.8	10.5	0.0	0.0	10.5
1996	6	8.4	10.0	1.0	0.9	9.2
1996	7	7.8	9.4	1.5	1.5	7.9
1996	8	6.7	8.0	0.9	0.9	7.1
1996	9	5.3	6.4	1.7	1.0	5.4
1996	10	4.2	5.1	0.3	0.3	4.8
1996	11	2.8	3.4	0.1	0.1	3.3
1996	12	2.2	2.7	0.0	0.0	2.7
1997	1	2.3	2.8	0.6	0.6	2.2
1997	2	3.1	3.7	0.8	0.8	2.8
1997	3	5.2	6.3	0.1	0.1	6.1
1997	4	6.1	7.3	0.2	0.2	7.1
1997	5	7.4	8.9	0.1	0.1	8.8
1997	6	7.6	9.1	1.3	1.3	7.8
1997	7	7.5	9.0	1.4	1.4	7.6
1997	8	6.5	7.8	2.8	2.2	5.6
1997	9	5.5	6.6	1.1	1.1	5.5
1997	10	4.3	5.2	0.5	0.5	4.7
1997	11	2.4	2.9	0.1	0.1	2.8
1997	12	1.6	1.9	1.5	1.2	0.7
1998	1	2.1	2.5	0.2	0.2	2.3
1998	2	2.9	3.4	0.3	0.3	3.1
1998	3	4.8	5.8	0.5	0.5	5.4
1998	4	6.3	7.5	0.0	0.0	7.5
1998	5	7.5	9.0	0.0	0.0	9.0
1998	6	8.1	9.7	0.3	0.3	9.4
1998	7	7.3	8.7	1.2	1.0	7.7
1998	8	6.7	8.0	0.8	0.8	7.2
1998	9	5.4	6.5	0.0	0.0	6.5
1998	10	3.7	4.5	3.2	1.4	3.1
1998	11	2.3	2.8	0.4	0.4	2.4
1998	12	2.0	2.4	0.1	0.1	2.2
1999	1	2.4	2.9	0.1	0.1	2.8
1999	2	3.4	4.1	0.0	0.0	4.1
1999	3	5.4	6.4	0.1	0.1	6.3
1999	4	6.6	7.9	0.0	0.0	7.8
1999	5	8.1	9.8	0.4	0.4	9.4
1999	6	7.5	8.9	1.2	1.1	7.9

Year	Month	Leyendecker ET_o, in	Potential Bare Ground Evaporation, in	Leyendecker Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
1999	7	7.3	8.8	2.3	1.9	6.9
1999	8	7.0	8.3	1.7	1.7	6.7
1999	9	5.3	6.4	1.7	1.6	4.8
1999	10	3.4	4.0	0.9	0.6	3.5
1999	11	2.0	2.4	0.0	0.0	2.4
1999	12	1.3	1.6	0.7	0.5	1.1
2000	1	2.5	3.0	0.0	0.0	3.0
2000	2	3.7	4.4	0.0	0.0	4.4
2000	3	5.2	6.3	0.2	0.2	6.1
2000	4	6.6	7.9	0.0	0.0	7.9
2000	5	7.7	9.2	0.0	0.0	9.2
2000	6	7.6	9.2	4.9	2.8	6.4
2000	7	7.8	9.4	1.6	1.6	7.8
2000	8	6.9	8.3	0.6	0.6	7.7
2000	9	5.7	6.9	0.1	0.1	6.7
2000	10	3.4	4.0	1.4	1.3	2.8
2000	11	2.2	2.6	1.0	0.7	1.9
2000	12	2.0	2.4	0.1	0.1	2.2
2001	1	2.1	2.6	0.3	0.3	2.3
2001	2	2.9	3.5	0.2	0.2	3.4
2001	3	4.9	5.9	0.4	0.4	5.6
2001	4	6.4	7.7	0.0	0.0	7.7
2001	5	7.4	8.8	0.7	0.5	8.3
2001	6	7.9	9.5	0.4	0.4	9.2
2001	7	7.6	9.1	1.2	1.2	7.9
2001	8	6.6	7.9	1.2	1.2	6.6
2001	9	5.4	6.5	0.6	0.6	5.9
2001	10	4.1	4.9	0.0	0.0	4.9
2001	11	2.6	3.2	0.2	0.2	2.9
2001	12	2.2	2.6	0.0	0.0	2.6
2002	1	2.4	2.9	0.4	0.4	2.5
2002	2	3.0	3.6	0.9	0.5	3.2
2002	3	5.6	6.7	0.0	0.0	6.7
2002	4	6.5	7.8	0.0	0.0	7.8
2002	5	7.9	9.5	0.1	0.1	9.4
2002	6	8.3	10.0	0.0	0.0	10.0
2002	7	7.4	8.9	1.9	1.9	7.0
2002	8	6.5	7.8	1.5	1.5	6.3
2002	9	5.3	6.4	0.2	0.2	6.1

Year	Month	Leyendecker ET_o, in	Potential Bare Ground Evaporation, in	Leyendecker Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
2002	10	3.4	4.1	1.1	1.1	3.0
2002	11	2.5	3.0	0.0	0.0	3.0
2002	12	1.6	1.9	1.6	1.0	0.9
2003	1	2.3	2.8	0.0	0.0	2.8
2003	2	2.7	3.3	1.7	1.0	2.3
2003	3	4.6	5.6	0.1	0.1	5.5
2003	4	6.5	7.8	0.0	0.0	7.8
2003	5	7.4	8.9	0.0	0.0	8.9
2003	6	8.3	10.0	1.1	0.9	9.1
2003	7	8.2	9.8	1.0	1.0	8.8
2003	8	6.9	8.3	0.5	0.5	7.8
2003	9	5.4	6.5	0.2	0.2	6.3
2003	10	4.0	4.7	0.2	0.2	4.5
2003	11	2.7	3.2	0.7	0.6	2.6
2003	12	2.0	2.4	0.0	0.0	2.4
2004	1	2.4	2.8	0.3	0.3	2.5
2004	2	3.1	3.7	0.0	0.0	3.7
2004	3	5.1	6.1	1.2	1.1	5.0
2004	4	6.0	7.1	1.9	1.7	5.4
2004	5	7.9	9.5	0.1	0.1	9.4
2004	6	8.3	10.0	1.5	1.1	8.9
2004	7	7.8	9.4	0.5	0.5	8.9
2004	8	6.6	7.9	3.1	1.4	6.5
2004	9	5.1	6.1	1.7	1.4	4.6
2004	10	3.7	4.4	1.2	1.1	3.3
2004	11	2.2	2.7	1.4	0.8	1.9
2004	12	1.8	2.1	0.4	0.4	1.7
2005	1	2.2	2.6	0.9	0.8	1.8
2005	2	2.2	2.7	2.6	1.7	1.0
2005	3	4.4	5.3	0.2	0.2	5.2
2005	4	6.0	7.2	0.2	0.2	7.0
2005	5	6.7	8.0	0.5	0.5	7.5
2005	6	8.2	9.8	0.0	0.0	9.8
2005	7	8.4	10.1	0.4	0.4	9.7
2005	8	6.6	7.9	1.4	1.2	6.7
2005	9	5.7	6.8	3.1	0.8	6.0
2005	10	3.7	4.5	1.6	1.6	2.9
2005	11	3.4	4.1	0.0	0.0	4.1
2005	12	2.8	3.3	0.0	0.0	3.3

Year	Month	Leyendecker ET_o, in	Potential Bare Ground Evaporation, in	Leyendecker Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
2006	1	3.1	3.7	0.0	0.0	3.6
2006	2	3.4	4.1	0.2	0.2	3.9
2006	3	5.2	6.2	0.0	0.0	6.2
2006	4	7.3	8.7	0.0	0.0	8.7
2006	5	8.3	10.0	0.4	0.4	9.6
2006	6	8.3	9.9	0.2	0.2	9.7
2006	7	7.4	8.9	1.7	1.7	7.2
2006	8	6.0	7.2	4.6	3.3	3.9
2006	9	4.7	5.6	4.4	1.4	4.2
2006	10	3.7	4.4	2.4	2.2	2.3
2006	11	2.9	3.4	0.2	0.2	3.3
2006	12	2.2	2.6	0.1	0.1	2.5
2007	1	1.8	2.2	1.4	1.1	1.1
2007	2	2.7	3.3	0.1	0.1	3.2
2007	3	5.0	6.0	0.1	0.1	6.0
2007	4	6.4	7.6	1.4	0.7	6.9
2007	5	7.2	8.7	1.9	1.8	6.9
2007	6	7.7	9.2	0.2	0.2	9.0
2007	7	7.4	8.9	1.9	1.9	7.0
2007	8	6.6	7.9	1.6	1.4	6.4
2007	9	4.9	5.9	0.7	0.7	5.3
2007	10	4.3	5.1	0.1	0.1	5.0
2007	11	2.4	2.8	0.6	0.6	2.3
2007	12	1.9	2.3	0.3	0.3	2.0
2008	1	2.7	3.3	0.0	0.0	3.3
2008	2	3.9	4.6	0.2	0.2	4.5
2008	3	5.8	7.0	0.0	0.0	7.0
2008	4	7.0	8.3	0.0	0.0	8.3
2008	5	8.0	9.6	0.0	0.0	9.6
2008	6	8.5	10.2	0.1	0.1	10.1
2008	7	7.0	8.4	5.0	2.1	6.4
2008	8	6.3	7.5	2.5	2.1	5.4
2008	9	5.0	6.1	0.8	0.8	5.3
2008	10	3.9	4.7	0.3	0.3	4.4
2008	11	2.7	3.3	0.4	0.4	2.9
2008	12	2.3	2.8	0.1	0.1	2.7
2009	1	2.9	3.5	0.0	0.0	3.5
2009	2	3.8	4.6	0.0	0.0	4.6
2009	3	5.6	6.7	0.0	0.0	6.7

Year	Month	Leyendecker ET_o, in	Potential Bare Ground Evaporation, in	Leyendecker Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
2009	4	7.1	8.5	0.0	0.0	8.5
2009	5	8.0	9.6	0.6	0.6	9.0
2009	6	7.5	9.0	0.2	0.2	8.8
2009	7	7.9	9.5	1.8	1.6	8.0
2009	8	7.0	8.4	1.0	1.0	7.4
2009	9	5.4	6.4	1.9	1.8	4.7
2009	10	4.1	5.0	0.7	0.7	4.3
2009	11	2.7	3.3	2.0	0.6	2.7
2009	12	2.0	2.4	0.6	0.6	1.8
2010	1	2.2	2.6	1.0	0.9	1.7
2010	2	3.0	3.6	0.5	0.5	3.1
2010	3	5.2	6.2	0.0	0.0	6.2
2010	4	6.6	8.0	0.1	0.1	7.9
2010	5	8.6	10.3	0.0	0.0	10.3
2010	6	8.3	10.0	0.6	0.6	9.4
2010	7	7.5	9.0	4.0	1.3	7.7
2010	8	7.0	8.4	1.5	1.5	6.9
2010	9	5.6	6.7	1.2	1.2	5.5
2010	10	4.4	5.3	0.4	0.4	4.9
2010	11	3.2	3.8	0.0	0.0	3.8
2010	12	2.7	3.2	0.0	0.0	3.2
2011	1	2.9	3.5	0.0	0.0	3.5
2011	2	3.4	4.1	0.1	0.1	4.0
2011	3	6.4	7.7	0.0	0.0	7.7
2011	4	8.2	9.8	0.0	0.0	9.8
2011	5	8.9	10.6	0.0	0.0	10.6
2011	6	9.2	11.0	0.4	0.4	10.6
2011	7	8.5	10.2	2.0	1.4	8.8
2011	8	7.4	8.9	1.4	1.4	7.5
2011	9	6.0	7.2	1.1	0.7	6.5
2011	10	4.5	5.4	0.1	0.1	5.3
2011	11	2.9	3.4	0.4	0.4	3.0
2011	12	1.7	2.0	1.5	1.4	0.6
2012	1	2.7	3.2	0.8	0.6	2.6
2012	2	3.7	4.5	0.1	0.1	4.4
2012	3	5.8	7.0	0.0	0.0	7.0
2012	4	7.3	8.8	0.0	0.0	8.8
2012	5	8.4	10.1	0.6	0.6	9.5
2012	6	8.8	10.5	0.0	0.0	10.5

Year	Month	Leyendecker ET_o, in	Potential Bare Ground Evaporation, in	Leyendecker Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
2012	7	7.6	9.1	1.1	1.1	7.9
2012	8	7.4	8.9	0.7	0.7	8.2
2012	9	5.0	6.1	2.1	1.3	4.8
2012	10	4.4	5.3	0.0	0.0	5.3
2012	11	3.0	3.5	0.0	0.0	3.5
2012	12	2.4	2.9	0.1	0.1	2.8
2013	1	2.3	2.7	0.1	0.1	2.6
2013	2	3.2	3.8	0.1	0.1	3.8
2013	3	5.5	6.6	0.0	0.0	6.6
2013	4	6.9	8.3	0.0	0.0	8.3
2013	5	8.0	9.6	0.1	0.1	9.5
2013	6	8.3	9.9	0.2	0.2	9.7
2013	7	6.9	8.3	1.4	1.4	6.9
2013	8	6.3	7.6	1.1	1.1	6.6
2013	9	5.1	6.1	3.1	1.1	5.0
2013	10	4.0	4.9	0.0	0.0	4.9
2013	11	2.4	2.9	0.3	0.3	2.6
2013	12	1.9	2.3	0.2	0.2	2.2
2014	1	2.9	3.4	0.0	0.0	3.4
2014	2	3.8	4.6	0.0	0.0	4.6
2014	3	5.6	6.7	0.3	0.3	6.3
2014	4	7.1	8.5	0.0	0.0	8.5
2014	5	7.9	9.5	0.0	0.0	9.5
2014	6	8.3	10.0	0.0	0.0	9.9
2014	7	8.1	9.8	1.1	1.1	8.7
2014	8	6.3	7.5	2.1	1.8	5.7
2014	9	4.9	5.8	3.2	1.7	4.1
2014	10	4.4	5.3	0.8	0.6	4.7
2014	11	2.8	3.3	0.4	0.4	2.9
2014	12	2.2	2.7	0.3	0.3	2.4
2015	1	2.0	2.4	1.3	1.2	1.2
2015	2	3.3	4.0	0.1	0.1	3.9
2015	3	4.8	5.8	0.2	0.2	5.5
2015	4	6.6	7.9	0.4	0.4	7.4
2015	5	7.9	9.5	0.5	0.5	9.0
2015	6	8.1	9.7	0.3	0.3	9.4
2015	7	7.6	9.1	3.2	2.6	6.5
2015	8	7.5	9.0	1.0	1.0	7.9
2015	9	5.2	6.3	0.3	0.3	6.0

Year	Month	Leyendecker ET_o, in	Potential Bare Ground Evaporation, in	Leyendecker Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
2015	10	3.8	4.5	3.3	1.8	2.7
2015	11	2.6	3.2	0.9	0.6	2.6
2015	12	2.1	2.6	1.0	0.5	2.0
2016	1	2.6	3.1	0.3	0.3	2.8
2016	2	3.8	4.6	0.0	0.0	4.6
2016	3	6.1	7.3	0.0	0.0	7.3
2016	4	6.6	8.0	0.5	0.5	7.5
2016	5	8.0	9.6	1.3	0.7	8.9
2016	6	8.5	10.1	0.9	0.7	9.5
2016	7	8.8	10.5	0.8	0.8	9.8
2016	8	7.0	8.4	1.6	1.6	6.8
2016	9	5.2	6.2	2.0	1.6	4.6
2016	10	4.2	5.1	0.0	0.0	5.1
2016	11	3.2	3.8	0.4	0.4	3.4
2016	12	2.4	2.8	0.7	0.6	2.2
2017	1	2.6	3.1	1.6	1.0	2.1
2017	2	3.5	4.2	0.5	0.5	3.7
2017	3	5.8	7.0	0.0	0.0	7.0
2017	4	7.2	8.6	0.1	0.1	8.6
2017	5	8.6	10.3	0.8	0.5	9.9
2017	6	8.7	10.4	0.2	0.2	10.2
2017	7	7.7	9.2	3.3	2.0	7.2
2017	8	6.8	8.1	3.2	2.3	5.8
2017	9	5.6	6.7	0.2	0.2	6.5
2017	10	4.6	5.5	1.3	1.0	4.5
2017	11	3.2	3.9	0.4	0.4	3.5
2017	12	2.3	2.8	0.2	0.2	2.6
2018	1	2.9	3.5	0.0	0.0	3.5
2018	2	3.5	4.2	0.7	0.5	3.6
2018	3	5.7	6.8	0.1	0.1	6.8
2018	4	7.6	9.1	0.0	0.0	9.1
2018	5	8.6	10.3	0.0	0.0	10.3
2018	6	8.7	10.5	0.7	0.6	9.9
2018	7	7.6	9.1	1.9	1.6	7.5
2018	8	7.0	8.4	0.9	0.9	7.5
2018	9	5.3	6.3	1.5	1.2	5.1
2018	10	3.2	3.9	2.3	1.5	2.3

Year	Month	Leyendecker ET_o, in	Potential Bare Ground Evaporation, in	Leyendecker Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
2018	11	3.0	3.6	0.1	0.1	3.5
2018	12	2.1	2.5	1.1	0.9	1.6

Appendix 10B. Potential Bare Soil Evaporation from Groundwater Monthly Totals in Inches for the Hueco Groundwater Model for 1938-2018.

Year	Month	Art Ivey ET_o, in	Potential Bare Ground Evaporation, in	Art Ivey Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
1938	1	2.5	3.0	1.2	0.8	2.1
1938	2	3.4	4.1	0.2	0.2	3.9
1938	3	5.3	6.4	0.5	0.5	5.9
1938	4	6.7	8.0	0.0	0.0	8.0
1938	5	8.0	9.5	0.0	0.0	9.5
1938	6	8.2	9.8	2.9	1.9	7.9
1938	7	7.7	9.2	0.6	0.6	8.6
1938	8	6.6	7.9	1.5	0.9	7.1
1938	9	5.1	6.1	1.0	0.9	5.2
1938	10	4.2	5.0	0.2	0.2	4.8
1938	11	2.9	3.5	0.0	0.0	3.5
1938	12	2.4	2.9	0.3	0.3	2.6
1939	1	2.5	2.9	0.6	0.6	2.3
1939	2	3.4	4.1	0.0	0.0	4.1
1939	3	5.8	6.9	0.3	0.3	6.6
1939	4	7.0	8.5	0.1	0.1	8.4
1939	5	8.3	10.0	0.1	0.1	9.9
1939	6	8.4	10.0	0.0	0.0	10.0
1939	7	7.9	9.4	0.5	0.5	9.0
1939	8	7.0	8.4	1.3	0.8	7.5
1939	9	5.6	6.7	1.0	0.8	5.9
1939	10	3.8	4.6	1.1	0.9	3.7
1939	11	2.2	2.7	0.9	0.7	2.0
1939	12	2.3	2.7	0.1	0.1	2.6
1940	1	2.2	2.7	0.7	0.6	2.0
1940	2	3.5	4.2	0.4	0.4	3.8
1940	3	5.6	6.7	0.1	0.1	6.7
1940	4	6.9	8.3	0.0	0.0	8.3
1940	5	8.0	9.6	1.0	0.8	8.8
1940	6	7.7	9.2	0.7	0.7	8.5
1940	7	8.0	9.6	0.5	0.5	9.1
1940	8	6.8	8.2	0.3	0.3	8.0
1940	9	5.5	6.6	0.1	0.1	6.5
1940	10	3.9	4.7	0.5	0.5	4.2
1940	11	2.3	2.8	0.9	0.9	1.9
1940	12	2.2	2.6	0.4	0.4	2.2

Year	Month	Art Ivey ET_o, in	Potential Bare Ground Evaporation, in	Art Ivey Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
1941	1	2.2	2.7	0.4	0.4	2.3
1941	2	3.3	4.0	0.4	0.4	3.6
1941	3	4.9	5.9	1.6	0.6	5.2
1941	4	6.4	7.7	0.9	0.9	6.9
1941	5	7.7	9.3	1.6	1.6	7.7
1941	6	7.8	9.3	0.3	0.3	9.1
1941	7	7.4	8.9	1.3	1.3	7.7
1941	8	6.7	8.0	1.9	1.9	6.1
1941	9	4.8	5.7	3.9	1.8	3.9
1941	10	3.5	4.2	1.2	0.8	3.3
1941	11	2.4	2.8	0.4	0.4	2.4
1941	12	2.0	2.4	0.4	0.4	2.1
1942	1	2.5	3.0	0.1	0.1	2.9
1942	2	3.2	3.8	0.4	0.4	3.4
1942	3	5.1	6.1	0.0	0.0	6.1
1942	4	6.7	8.1	0.6	0.6	7.4
1942	5	8.1	9.7	0.0	0.0	9.7
1942	6	8.3	10.0	0.2	0.2	9.8
1942	7	8.0	9.5	0.9	0.9	8.6
1942	8	6.3	7.6	4.3	3.2	4.5
1942	9	5.1	6.1	0.9	0.9	5.2
1942	10	3.6	4.3	1.0	1.0	3.3
1942	11	2.8	3.4	0.0	0.0	3.4
1942	12	2.2	2.6	1.3	0.8	1.8
1943	1	2.4	2.8	0.0	0.0	2.8
1943	2	3.8	4.5	0.0	0.0	4.5
1943	3	5.6	6.7	0.0	0.0	6.7
1943	4	7.5	9.0	0.0	0.0	9.0
1943	5	7.8	9.3	0.0	0.0	9.3
1943	6	8.0	9.6	1.9	1.8	7.7
1943	7	7.7	9.3	0.9	0.9	8.4
1943	8	7.3	8.7	0.1	0.1	8.6
1943	9	5.1	6.1	1.7	0.7	5.4
1943	10	3.7	4.5	0.0	0.0	4.5
1943	11	2.6	3.1	0.9	0.5	2.6
1943	12	1.8	2.2	0.6	0.6	1.6
1944	1	2.3	2.8	0.4	0.4	2.4
1944	2	3.3	4.0	0.4	0.4	3.7
1944	3	5.2	6.2	0.1	0.1	6.1
1944	4	6.8	8.1	0.0	0.0	8.1

Year	Month	Art Ivey ET_o, in	Potential Bare Ground Evaporation, in	Art Ivey Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
1944	5	7.6	9.1	0.6	0.5	8.7
1944	6	8.0	9.6	0.5	0.5	9.1
1944	7	7.9	9.5	1.5	1.3	8.3
1944	8	6.8	8.2	1.3	1.3	6.9
1944	9	5.0	6.0	1.3	0.8	5.2
1944	10	3.8	4.6	1.1	0.6	4.0
1944	11	2.3	2.8	0.6	0.6	2.2
1944	12	2.2	2.6	0.6	0.5	2.1
1945	1	2.5	3.0	0.1	0.1	2.9
1945	2	3.7	4.5	0.0	0.0	4.5
1945	3	5.4	6.4	0.8	0.8	5.7
1945	4	6.8	8.1	0.0	0.0	8.1
1945	5	8.1	9.7	0.0	0.0	9.7
1945	6	8.0	9.7	0.1	0.1	9.5
1945	7	7.7	9.3	0.3	0.3	9.0
1945	8	7.1	8.5	0.3	0.3	8.3
1945	9	5.6	6.8	0.1	0.1	6.7
1945	10	3.5	4.2	3.5	1.1	3.0
1945	11	2.8	3.4	0.0	0.0	3.4
1945	12	2.1	2.6	0.0	0.0	2.6
1946	1	2.2	2.7	0.5	0.5	2.2
1946	2	3.7	4.4	0.0	0.0	4.4
1946	3	5.6	6.7	0.0	0.0	6.6
1946	4	7.4	8.9	0.4	0.4	8.5
1946	5	7.8	9.3	0.6	0.6	8.8
1946	6	8.4	10.0	0.2	0.2	9.9
1946	7	7.9	9.4	0.4	0.4	9.0
1946	8	7.0	8.4	0.4	0.4	8.0
1946	9	5.3	6.4	1.2	1.2	5.2
1946	10	3.8	4.5	0.4	0.4	4.1
1946	11	2.5	3.0	0.1	0.1	2.9
1946	12	2.1	2.6	1.1	0.7	1.8
1947	1	2.2	2.7	0.8	0.8	1.9
1947	2	3.6	4.4	0.0	0.0	4.4
1947	3	5.4	6.5	0.3	0.3	6.3
1947	4	7.1	8.5	0.0	0.0	8.5
1947	5	8.2	9.8	0.5	0.5	9.3
1947	6	8.1	9.7	0.7	0.5	9.3
1947	7	8.3	9.9	0.1	0.1	9.8
1947	8	6.7	8.0	1.7	1.6	6.5

Year	Month	Art Ivey ET_o, in	Potential Bare Ground Evaporation, in	Art Ivey Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
1947	9	5.7	6.8	0.0	0.0	6.8
1947	10	4.2	5.1	0.4	0.4	4.7
1947	11	2.4	2.8	0.4	0.4	2.5
1947	12	2.0	2.4	0.4	0.4	1.9
1948	1	2.4	2.9	0.2	0.2	2.7
1948	2	3.5	4.2	0.6	0.6	3.6
1948	3	5.1	6.1	0.0	0.0	6.1
1948	4	7.5	9.1	0.0	0.0	9.1
1948	5	8.2	9.9	0.0	0.0	9.9
1948	6	8.2	9.8	0.7	0.7	9.1
1948	7	8.2	9.8	1.2	1.2	8.7
1948	8	7.2	8.6	0.7	0.5	8.1
1948	9	5.5	6.6	0.0	0.0	6.6
1948	10	3.6	4.3	0.5	0.5	3.8
1948	11	2.6	3.2	0.0	0.0	3.2
1948	12	2.1	2.5	0.6	0.6	1.9
1949	1	1.7	2.0	2.2	1.4	0.6
1949	2	3.2	3.9	0.1	0.1	3.7
1949	3	5.7	6.8	0.0	0.0	6.8
1949	4	6.9	8.2	0.1	0.1	8.1
1949	5	8.1	9.7	0.8	0.8	8.9
1949	6	8.2	9.8	0.5	0.5	9.3
1949	7	7.8	9.4	1.1	1.1	8.3
1949	8	7.0	8.4	0.4	0.4	8.1
1949	9	5.2	6.3	1.1	1.1	5.2
1949	10	3.6	4.3	1.4	0.7	3.6
1949	11	2.9	3.5	0.0	0.0	3.5
1949	12	2.0	2.4	0.7	0.6	1.7
1950	1	2.6	3.1	0.9	0.8	2.3
1950	2	3.7	4.5	0.3	0.3	4.2
1950	3	5.6	6.7	0.0	0.0	6.7
1950	4	7.3	8.7	0.0	0.0	8.7
1950	5	8.0	9.5	0.0	0.0	9.5
1950	6	8.4	10.1	0.0	0.0	10.1
1950	7	7.4	8.9	2.7	1.6	7.3
1950	8	7.2	8.6	0.0	0.0	8.6
1950	9	5.2	6.2	1.9	1.7	4.5
1950	10	4.4	5.3	0.4	0.4	4.9
1950	11	2.9	3.5	0.0	0.0	3.5
1950	12	2.5	3.0	0.0	0.0	3.0

Year	Month	Art Ivey ET_o, in	Potential Bare Ground Evaporation, in	Art Ivey Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
1951	1	2.6	3.1	0.3	0.3	2.9
1951	2	3.4	4.1	0.8	0.8	3.3
1951	3	5.3	6.3	0.4	0.4	5.9
1951	4	6.7	8.1	0.0	0.0	8.1
1951	5	8.1	9.7	0.1	0.1	9.6
1951	6	8.4	10.1	0.0	0.0	10.1
1951	7	8.4	10.0	1.0	0.8	9.2
1951	8	7.1	8.5	1.8	1.3	7.3
1951	9	5.8	7.0	0.0	0.0	7.0
1951	10	4.0	4.8	0.5	0.5	4.4
1951	11	2.4	2.9	0.0	0.0	2.9
1951	12	2.0	2.3	0.7	0.7	1.6
1952	1	2.8	3.3	0.0	0.0	3.3
1952	2	3.4	4.1	0.8	0.8	3.3
1952	3	5.0	6.0	0.0	0.0	6.0
1952	4	6.7	8.0	1.1	0.9	7.1
1952	5	8.0	9.6	0.5	0.5	9.0
1952	6	8.2	9.9	0.8	0.8	9.0
1952	7	7.9	9.5	1.7	0.9	8.6
1952	8	7.3	8.7	1.3	0.9	7.9
1952	9	5.6	6.7	0.0	0.0	6.7
1952	10	4.3	5.1	0.0	0.0	5.1
1952	11	2.4	2.8	0.0	0.0	2.8
1952	12	2.2	2.6	0.4	0.4	2.2
1953	1	2.9	3.5	0.0	0.0	3.5
1953	2	3.3	4.0	0.3	0.3	3.7
1953	3	5.6	6.7	0.2	0.2	6.5
1953	4	6.7	8.1	0.7	0.5	7.6
1953	5	7.7	9.2	0.3	0.3	8.9
1953	6	8.6	10.3	0.3	0.3	9.9
1953	7	7.8	9.4	1.4	1.2	8.2
1953	8	7.2	8.7	0.1	0.1	8.6
1953	9	5.9	7.1	0.0	0.0	7.1
1953	10	4.1	4.9	0.5	0.5	4.4
1953	11	2.7	3.2	0.0	0.0	3.2
1953	12	1.9	2.3	0.1	0.1	2.2
1954	1	2.8	3.4	0.1	0.1	3.4
1954	2	3.8	4.6	0.0	0.0	4.6
1954	3	5.3	6.4	0.1	0.1	6.3
1954	4	7.6	9.1	0.0	0.0	9.1

Year	Month	Art Ivey ET_o, in	Potential Bare Ground Evaporation, in	Art Ivey Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
1954	5	8.1	9.7	0.5	0.5	9.2
1954	6	8.0	9.6	0.2	0.2	9.4
1954	7	8.2	9.9	0.7	0.7	9.1
1954	8	6.8	8.1	2.7	1.8	6.3
1954	9	5.7	6.8	0.8	0.8	6.0
1954	10	4.0	4.8	0.0	0.0	4.8
1954	11	2.8	3.4	0.0	0.0	3.4
1954	12	2.3	2.8	0.0	0.0	2.8
1955	1	2.2	2.6	0.4	0.4	2.2
1955	2	3.4	4.0	0.0	0.0	4.0
1955	3	5.5	6.6	0.1	0.1	6.5
1955	4	7.0	8.4	0.0	0.0	8.4
1955	5	7.7	9.2	0.1	0.1	9.1
1955	6	8.1	9.7	0.1	0.1	9.6
1955	7	7.6	9.1	2.3	2.3	6.8
1955	8	7.0	8.4	2.0	1.4	7.0
1955	9	5.8	6.9	0.1	0.1	6.8
1955	10	3.9	4.7	0.8	0.7	4.0
1955	11	2.7	3.2	0.1	0.1	3.0
1955	12	2.4	2.9	0.0	0.0	2.9
1956	1	2.7	3.2	0.4	0.4	2.8
1956	2	3.4	4.1	0.5	0.5	3.5
1956	3	5.8	6.9	0.0	0.0	6.9
1956	4	6.7	8.1	0.0	0.0	8.1
1956	5	8.6	10.3	0.0	0.0	10.3
1956	6	8.6	10.3	1.1	1.1	9.2
1956	7	8.1	9.7	0.5	0.5	9.2
1956	8	7.0	8.4	0.7	0.7	7.7
1956	9	5.9	7.1	0.1	0.1	7.0
1956	10	4.3	5.2	0.0	0.0	5.2
1956	11	2.5	3.0	0.0	0.0	3.0
1956	12	2.1	2.5	0.2	0.2	2.3
1957	1	2.6	3.1	0.1	0.1	2.9
1957	2	3.8	4.6	0.6	0.6	4.0
1957	3	5.2	6.2	0.1	0.1	6.2
1957	4	6.8	8.1	0.1	0.1	8.1
1957	5	7.4	8.9	0.1	0.1	8.9
1957	6	8.2	9.9	0.0	0.0	9.9
1957	7	8.3	9.9	1.2	1.2	8.7
1957	8	6.9	8.3	2.2	1.9	6.3

Year	Month	Art Ivey ET_o, in	Potential Bare Ground Evaporation, in	Art Ivey Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
1957	9	5.5	6.6	0.0	0.0	6.6
1957	10	3.3	3.9	2.3	1.7	2.3
1957	11	2.1	2.6	0.4	0.4	2.2
1957	12	2.2	2.6	0.0	0.0	2.6
1958	1	2.2	2.6	0.9	0.9	1.7
1958	2	3.4	4.1	1.1	0.8	3.3
1958	3	4.4	5.3	2.1	1.9	3.3
1958	4	6.8	8.2	0.2	0.2	8.0
1958	5	8.1	9.7	0.6	0.6	9.1
1958	6	8.4	10.0	1.4	1.0	9.0
1958	7	8.2	9.9	0.9	0.8	9.1
1958	8	7.3	8.8	1.4	1.4	7.4
1958	9	5.0	6.1	5.1	2.3	3.8
1958	10	3.2	3.8	1.8	1.2	2.6
1958	11	2.5	3.0	0.2	0.2	2.8
1958	12	2.4	2.8	0.0	0.0	2.8
1959	1	2.7	3.3	0.1	0.1	3.2
1959	2	3.3	4.0	0.0	0.0	4.0
1959	3	5.3	6.4	0.1	0.1	6.4
1959	4	7.0	8.4	0.0	0.0	8.3
1959	5	8.1	9.7	0.1	0.1	9.7
1959	6	8.3	10.0	0.4	0.4	9.6
1959	7	8.0	9.6	0.5	0.5	9.1
1959	8	7.0	8.4	1.5	1.4	7.0
1959	9	5.8	7.0	0.0	0.0	6.9
1959	10	4.0	4.8	0.6	0.6	4.2
1959	11	2.3	2.8	0.1	0.1	2.6
1959	12	2.0	2.4	0.4	0.4	2.0
1960	1	2.2	2.6	0.8	0.7	2.0
1960	2	3.2	3.8	0.4	0.4	3.4
1960	3	5.7	6.9	0.1	0.1	6.8
1960	4	7.2	8.7	0.0	0.0	8.7
1960	5	7.9	9.5	0.0	0.0	9.5
1960	6	8.6	10.3	0.6	0.5	9.8
1960	7	7.5	9.0	2.9	1.6	7.4
1960	8	7.1	8.5	0.7	0.7	7.8
1960	9	5.6	6.7	0.2	0.2	6.5
1960	10	3.9	4.7	0.9	0.7	4.0
1960	11	2.7	3.2	0.0	0.0	3.2
1960	12	1.7	2.0	1.4	1.0	0.9

Year	Month	Art Ivey ET_o, in	Potential Bare Ground Evaporation, in	Art Ivey Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
1961	1	2.2	2.6	0.7	0.6	2.0
1961	2	3.5	4.2	0.0	0.0	4.2
1961	3	5.4	6.5	0.2	0.2	6.3
1961	4	7.1	8.5	0.0	0.0	8.5
1961	5	8.3	9.9	0.0	0.0	9.9
1961	6	8.3	9.9	0.0	0.0	9.9
1961	7	8.1	9.7	1.1	1.1	8.6
1961	8	6.9	8.2	1.4	1.3	6.9
1961	9	5.2	6.2	0.9	0.9	5.3
1961	10	4.0	4.8	0.1	0.1	4.7
1961	11	2.0	2.4	0.9	0.7	1.7
1961	12	2.1	2.5	0.4	0.4	2.1
1962	1	2.2	2.7	0.8	0.8	1.9
1962	2	3.7	4.5	0.6	0.5	3.9
1962	3	4.8	5.8	0.1	0.1	5.7
1962	4	7.2	8.6	0.0	0.0	8.6
1962	5	8.1	9.7	0.0	0.0	9.7
1962	6	8.2	9.8	0.0	0.0	9.8
1962	7	7.4	8.9	2.4	2.4	6.5
1962	8	7.3	8.8	0.1	0.1	8.7
1962	9	4.8	5.8	4.2	1.8	4.0
1962	10	3.8	4.6	0.8	0.8	3.7
1962	11	2.6	3.1	0.3	0.3	2.8
1962	12	1.9	2.3	0.1	0.1	2.2
1963	1	2.3	2.8	0.2	0.2	2.6
1963	2	3.5	4.2	0.5	0.5	3.8
1963	3	5.5	6.6	0.0	0.0	6.6
1963	4	7.1	8.6	0.0	0.0	8.6
1963	5	8.3	9.9	0.0	0.0	9.9
1963	6	8.1	9.7	0.1	0.1	9.7
1963	7	8.0	9.6	0.4	0.4	9.2
1963	8	6.6	7.9	1.2	1.2	6.7
1963	9	5.2	6.3	1.4	0.9	5.4
1963	10	4.0	4.7	0.7	0.7	4.1
1963	11	2.5	3.0	0.6	0.6	2.4
1963	12	2.1	2.5	0.1	0.1	2.4
1964	1	2.4	2.9	0.0	0.0	2.8
1964	2	3.2	3.8	0.0	0.0	3.8
1964	3	5.0	6.0	0.8	0.7	5.2
1964	4	6.8	8.2	0.1	0.1	8.2

Year	Month	Art Ivey ET_o, in	Potential Bare Ground Evaporation, in	Art Ivey Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
1964	5	8.1	9.7	0.0	0.0	9.7
1964	6	8.1	9.7	0.0	0.0	9.7
1964	7	8.0	9.6	1.5	1.4	8.2
1964	8	7.1	8.5	1.1	1.1	7.5
1964	9	5.3	6.3	0.3	0.3	6.0
1964	10	4.0	4.8	0.4	0.4	4.4
1964	11	2.6	3.2	0.0	0.0	3.2
1964	12	1.9	2.2	0.4	0.4	1.8
1965	1	2.4	2.9	0.1	0.1	2.8
1965	2	3.2	3.8	0.6	0.6	3.2
1965	3	5.0	5.9	0.1	0.1	5.9
1965	4	7.2	8.6	0.0	0.0	8.6
1965	5	7.9	9.5	0.0	0.0	9.4
1965	6	8.0	9.6	0.6	0.6	9.0
1965	7	8.2	9.8	0.2	0.2	9.6
1965	8	6.9	8.3	1.9	1.5	6.8
1965	9	5.2	6.2	2.7	1.1	5.1
1965	10	4.0	4.8	0.2	0.2	4.6
1965	11	2.8	3.4	0.0	0.0	3.4
1965	12	1.9	2.3	0.8	0.8	1.5
1966	1	2.2	2.7	0.3	0.3	2.4
1966	2	2.9	3.5	0.2	0.2	3.3
1966	3	5.5	6.6	0.1	0.1	6.5
1966	4	6.8	8.2	1.6	0.8	7.4
1966	5	7.9	9.4	0.5	0.5	8.9
1966	6	7.8	9.4	3.9	2.2	7.2
1966	7	8.2	9.8	0.7	0.7	9.1
1966	8	6.5	7.8	2.6	2.0	5.8
1966	9	5.3	6.3	1.5	1.3	5.0
1966	10	3.8	4.6	0.0	0.0	4.6
1966	11	2.8	3.4	0.1	0.1	3.3
1966	12	2.2	2.7	0.1	0.1	2.6
1967	1	2.8	3.3	0.0	0.0	3.3
1967	2	3.6	4.3	0.1	0.1	4.2
1967	3	6.1	7.3	0.1	0.1	7.2
1967	4	7.4	8.8	0.0	0.0	8.8
1967	5	7.9	9.4	0.2	0.2	9.2
1967	6	7.9	9.5	1.3	1.3	8.1
1967	7	7.8	9.4	1.7	1.6	7.8
1967	8	6.8	8.1	0.4	0.4	7.8

Year	Month	Art Ivey ET_o, in	Potential Bare Ground Evaporation, in	Art Ivey Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
1967	9	5.0	6.0	0.3	0.3	5.7
1967	10	4.2	5.0	0.0	0.0	5.0
1967	11	2.5	3.0	0.2	0.2	2.7
1967	12	1.8	2.1	0.9	0.8	1.4
1968	1	2.2	2.6	0.5	0.4	2.2
1968	2	3.4	4.1	1.5	1.3	2.7
1968	3	4.9	5.9	1.1	1.1	4.7
1968	4	6.7	8.1	0.1	0.1	8.0
1968	5	8.1	9.8	0.0	0.0	9.7
1968	6	8.5	10.2	0.0	0.0	10.2
1968	7	7.8	9.3	7.1	2.5	6.8
1968	8	6.7	8.0	1.2	1.2	6.9
1968	9	5.5	6.6	0.3	0.3	6.3
1968	10	4.2	5.1	0.1	0.1	5.0
1968	11	2.4	2.9	1.9	1.1	1.7
1968	12	2.0	2.4	0.3	0.3	2.1
1969	1	2.7	3.2	0.1	0.1	3.1
1969	2	3.5	4.2	0.2	0.2	4.0
1969	3	5.0	6.0	0.2	0.2	5.8
1969	4	7.5	9.0	0.0	0.0	9.0
1969	5	8.3	9.9	0.4	0.4	9.5
1969	6	8.4	10.0	0.0	0.0	10.0
1969	7	8.3	9.9	1.1	1.0	8.9
1969	8	7.5	9.0	0.8	0.6	8.5
1969	9	5.6	6.7	0.5	0.5	6.2
1969	10	3.9	4.6	0.3	0.3	4.3
1969	11	2.3	2.8	0.9	0.6	2.2
1969	12	2.0	2.4	0.6	0.4	2.0
1970	1	2.5	3.0	0.0	0.0	3.0
1970	2	3.3	4.0	0.7	0.7	3.3
1970	3	4.9	5.9	0.5	0.5	5.4
1970	4	6.9	8.3	0.0	0.0	8.3
1970	5	8.1	9.7	0.1	0.1	9.6
1970	6	8.1	9.7	0.6	0.6	9.2
1970	7	8.1	9.7	1.1	1.1	8.6
1970	8	7.1	8.5	1.6	1.5	7.1
1970	9	5.4	6.4	0.7	0.7	5.7
1970	10	3.5	4.2	0.6	0.6	3.6
1970	11	2.7	3.2	0.0	0.0	3.2
1970	12	2.4	2.9	0.0	0.0	2.8

Year	Month	Art Ivey ET_o, in	Potential Bare Ground Evaporation, in	Art Ivey Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
1971	1	2.7	3.3	0.2	0.2	3.1
1971	2	3.5	4.2	0.0	0.0	4.2
1971	3	5.7	6.8	0.0	0.0	6.8
1971	4	7.0	8.4	0.4	0.4	8.0
1971	5	7.9	9.4	0.4	0.4	9.1
1971	6	8.3	9.9	0.3	0.3	9.6
1971	7	8.2	9.9	2.0	1.8	8.1
1971	8	6.8	8.2	0.8	0.8	7.4
1971	9	5.7	6.8	0.5	0.5	6.3
1971	10	3.6	4.3	1.1	1.1	3.3
1971	11	2.6	3.1	0.4	0.4	2.7
1971	12	2.0	2.4	0.4	0.4	1.9
1972	1	2.6	3.1	0.2	0.2	2.9
1972	2	3.9	4.6	0.0	0.0	4.6
1972	3	6.2	7.5	0.0	0.0	7.5
1972	4	7.5	9.0	0.0	0.0	9.0
1972	5	8.0	9.6	0.0	0.0	9.6
1972	6	7.7	9.3	2.5	1.9	7.4
1972	7	8.2	9.8	1.0	1.0	8.8
1972	8	6.7	8.0	3.6	1.7	6.3
1972	9	5.1	6.1	3.4	2.5	3.5
1972	10	3.9	4.7	1.6	1.3	3.4
1972	11	2.5	3.0	0.6	0.6	2.4
1972	12	2.2	2.6	0.2	0.2	2.4
1973	1	2.2	2.6	1.1	1.0	1.6
1973	2	2.9	3.5	2.3	1.6	1.8
1973	3	5.0	5.9	0.2	0.2	5.7
1973	4	6.4	7.7	0.0	0.0	7.7
1973	5	7.8	9.3	0.6	0.6	8.8
1973	6	8.3	9.9	0.2	0.2	9.8
1973	7	7.8	9.4	2.1	1.5	7.9
1973	8	7.2	8.7	0.0	0.0	8.6
1973	9	5.9	7.1	0.0	0.0	7.1
1973	10	4.3	5.2	0.0	0.0	5.2
1973	11	3.0	3.6	0.0	0.0	3.5
1973	12	2.3	2.8	0.0	0.0	2.8
1974	1	2.5	3.0	0.2	0.2	2.7
1974	2	3.6	4.3	0.0	0.0	4.3
1974	3	6.0	7.1	0.0	0.0	7.1
1974	4	7.3	8.8	0.3	0.3	8.5

Year	Month	Art Ivey ET_o, in	Potential Bare Ground Evaporation, in	Art Ivey Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
1974	5	8.4	10.0	0.0	0.0	10.0
1974	6	8.6	10.3	0.1	0.1	10.2
1974	7	7.9	9.5	2.1	2.1	7.4
1974	8	6.7	8.0	0.9	0.9	7.1
1974	9	4.8	5.8	9.5	1.8	3.9
1974	10	3.6	4.4	2.3	2.0	2.4
1974	11	2.3	2.8	0.5	0.5	2.3
1974	12	1.9	2.3	0.9	0.6	1.7
1975	1	2.3	2.7	0.8	0.8	2.0
1975	2	3.2	3.8	0.8	0.4	3.4
1975	3	5.5	6.6	0.2	0.2	6.4
1975	4	6.9	8.2	0.0	0.0	8.2
1975	5	8.0	9.6	0.0	0.0	9.6
1975	6	8.4	10.1	0.0	0.0	10.1
1975	7	7.6	9.2	1.3	1.3	7.9
1975	8	7.2	8.6	0.5	0.5	8.1
1975	9	5.2	6.2	2.1	0.9	5.3
1975	10	4.1	4.9	0.1	0.1	4.8
1975	11	2.9	3.4	0.0	0.0	3.4
1975	12	2.2	2.6	0.8	0.6	2.0
1976	1	2.4	2.9	0.4	0.4	2.5
1976	2	3.8	4.6	0.5	0.5	4.1
1976	3	5.5	6.6	0.0	0.0	6.6
1976	4	7.1	8.5	0.3	0.3	8.2
1976	5	7.5	9.0	0.8	0.7	8.4
1976	6	8.2	9.9	0.9	0.9	9.0
1976	7	7.5	9.0	1.9	1.9	7.1
1976	8	7.2	8.6	0.9	0.9	7.7
1976	9	4.9	5.9	1.5	1.5	4.4
1976	10	3.4	4.1	1.2	1.2	2.9
1976	11	2.4	2.9	0.9	0.9	1.9
1976	12	1.9	2.3	0.6	0.6	1.6
1977	1	2.3	2.7	0.7	0.7	2.1
1977	2	3.6	4.3	0.0	0.0	4.3
1977	3	5.0	6.0	0.4	0.4	5.5
1977	4	7.0	8.4	0.2	0.2	8.1
1977	5	7.9	9.5	0.1	0.1	9.4
1977	6	8.4	10.1	0.3	0.3	9.8
1977	7	8.1	9.7	1.5	1.3	8.4
1977	8	7.5	9.0	1.8	1.8	7.3

Year	Month	Art Ivey ET_o, in	Potential Bare Ground Evaporation, in	Art Ivey Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
1977	9	5.9	7.1	1.3	1.2	5.9
1977	10	3.6	4.3	2.6	1.6	2.7
1977	11	2.7	3.2	0.0	0.0	3.2
1977	12	2.3	2.7	0.2	0.2	2.5
1978	1	2.3	2.8	0.4	0.4	2.5
1978	2	3.1	3.8	0.5	0.5	3.2
1978	3	5.5	6.6	0.0	0.0	6.6
1978	4	7.3	8.8	0.0	0.0	8.8
1978	5	8.0	9.6	0.8	0.8	8.8
1978	6	8.7	10.5	0.8	0.6	9.9
1978	7	8.5	10.2	0.4	0.4	9.8
1978	8	6.9	8.3	1.5	0.8	7.5
1978	9	4.7	5.6	3.1	1.3	4.2
1978	10	3.8	4.5	2.5	1.3	3.2
1978	11	2.2	2.7	0.5	0.5	2.2
1978	12	1.9	2.3	0.3	0.3	2.0
1979	1	2.0	2.4	0.8	0.8	1.6
1979	2	3.3	3.9	0.7	0.7	3.2
1979	3	5.4	6.4	0.0	0.0	6.4
1979	4	7.1	8.5	0.2	0.2	8.3
1979	5	7.8	9.3	0.6	0.6	8.7
1979	6	8.1	9.7	0.3	0.3	9.4
1979	7	8.5	10.1	2.3	2.1	8.0
1979	8	6.9	8.3	2.5	2.0	6.3
1979	9	5.6	6.7	0.6	0.6	6.1
1979	10	4.5	5.3	0.0	0.0	5.3
1979	11	2.8	3.3	0.0	0.0	3.3
1979	12	2.4	2.9	0.2	0.2	2.7
1980	1	2.8	3.3	0.5	0.5	2.8
1980	2	3.7	4.4	0.7	0.7	3.7
1980	3	5.5	6.6	0.1	0.1	6.5
1980	4	7.1	8.5	0.5	0.5	7.9
1980	5	8.0	9.6	0.1	0.1	9.5
1980	6	9.1	11.0	0.0	0.0	11.0
1980	7	8.8	10.5	0.8	0.8	9.7
1980	8	7.1	8.6	1.8	1.6	6.9
1980	9	5.1	6.2	2.8	2.0	4.2
1980	10	3.8	4.5	0.8	0.8	3.8
1980	11	2.6	3.1	0.3	0.3	2.8
1980	12	2.7	3.2	0.1	0.1	3.1

Year	Month	Art Ivey ET_o, in	Potential Bare Ground Evaporation, in	Art Ivey Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
1981	1	2.4	2.9	1.3	1.2	1.7
1981	2	3.9	4.7	0.3	0.3	4.3
1981	3	5.5	6.6	0.3	0.3	6.3
1981	4	7.5	9.0	0.8	0.8	8.1
1981	5	8.2	9.9	0.8	0.8	9.1
1981	6	8.8	10.6	0.5	0.5	10.1
1981	7	8.0	9.6	0.9	0.9	8.6
1981	8	6.6	7.9	3.0	2.0	5.8
1981	9	5.2	6.3	0.7	0.7	5.5
1981	10	3.7	4.4	1.2	1.0	3.4
1981	11	3.1	3.8	0.1	0.1	3.6
1981	12	2.9	3.4	0.0	0.0	3.4
1982	1	2.7	3.3	0.5	0.5	2.8
1982	2	3.5	4.2	0.4	0.4	3.9
1982	3	5.8	6.9	0.0	0.0	6.9
1982	4	7.0	8.4	0.1	0.1	8.3
1982	5	7.9	9.5	0.5	0.5	9.0
1982	6	8.5	10.2	0.3	0.3	10.0
1982	7	8.4	10.0	0.7	0.7	9.3
1982	8	7.2	8.6	0.4	0.4	8.2
1982	9	5.7	6.8	3.3	1.6	5.2
1982	10	4.0	4.8	0.0	0.0	4.8
1982	11	2.4	2.8	0.5	0.5	2.4
1982	12	1.7	2.0	3.4	1.7	0.3
1983	1	2.2	2.6	0.5	0.5	2.2
1983	2	3.4	4.1	0.6	0.6	3.5
1983	3	5.1	6.1	0.3	0.3	5.8
1983	4	6.2	7.5	1.6	1.0	6.5
1983	5	8.1	9.7	0.4	0.4	9.4
1983	6	8.4	10.1	0.5	0.5	9.6
1983	7	8.4	10.1	0.2	0.2	9.9
1983	8	7.3	8.8	1.1	1.1	7.7
1983	9	5.8	7.0	0.8	0.8	6.1
1983	10	3.8	4.5	2.2	1.6	2.9
1983	11	2.5	3.1	0.5	0.5	2.5
1983	12	2.1	2.6	0.1	0.1	2.5
1984	1	2.3	2.8	0.5	0.5	2.2
1984	2	3.8	4.6	0.0	0.0	4.6
1984	3	5.8	6.9	0.5	0.5	6.4
1984	4	7.2	8.6	0.0	0.0	8.6

Year	Month	Art Ivey ET_o, in	Potential Bare Ground Evaporation, in	Art Ivey Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
1984	5	8.4	10.1	0.1	0.1	10.0
1984	6	8.0	9.6	2.2	2.2	7.4
1984	7	8.0	9.6	0.5	0.5	9.1
1984	8	7.0	8.3	4.0	2.9	5.5
1984	9	5.6	6.7	0.7	0.6	6.1
1984	10	3.4	4.1	4.1	0.9	3.1
1984	11	2.6	3.1	0.5	0.5	2.6
1984	12	1.8	2.2	1.3	1.1	1.1
1985	1	2.2	2.6	0.9	0.9	1.7
1985	2	3.4	4.1	0.1	0.1	4.0
1985	3	5.4	6.5	0.4	0.4	6.1
1985	4	7.3	8.8	0.1	0.1	8.7
1985	5	8.2	9.8	0.0	0.0	9.8
1985	6	8.2	9.8	0.4	0.4	9.4
1985	7	8.0	9.6	2.1	0.9	8.6
1985	8	7.0	8.4	0.9	0.9	7.4
1985	9	5.0	6.0	2.6	2.0	3.9
1985	10	3.5	4.2	1.3	0.9	3.3
1985	11	2.6	3.2	0.2	0.2	3.0
1985	12	2.4	2.8	0.0	0.0	2.8
1986	1	2.9	3.4	0.1	0.1	3.4
1986	2	3.6	4.3	0.3	0.3	4.1
1986	3	5.6	6.8	0.5	0.5	6.3
1986	4	7.4	8.8	0.0	0.0	8.8
1986	5	7.7	9.3	1.4	1.2	8.0
1986	6	7.5	9.0	2.4	1.6	7.4
1986	7	7.4	8.9	2.7	2.2	6.7
1986	8	6.6	7.9	2.4	2.3	5.7
1986	9	5.3	6.4	0.5	0.5	5.8
1986	10	3.6	4.3	0.8	0.8	3.5
1986	11	2.3	2.7	1.2	0.8	2.0
1986	12	1.6	2.0	1.7	1.3	0.7
1987	1	2.6	3.1	0.0	0.0	3.1
1987	2	3.3	4.0	0.1	0.1	3.8
1987	3	5.3	6.3	0.3	0.3	6.0
1987	4	6.6	8.0	0.4	0.4	7.6
1987	5	7.5	9.0	0.1	0.1	9.0
1987	6	7.8	9.4	2.8	1.5	7.9
1987	7	7.8	9.4	0.6	0.6	8.7
1987	8	6.6	8.0	1.7	1.5	6.4

Year	Month	Art Ivey ET_o, in	Potential Bare Ground Evaporation, in	Art Ivey Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
1987	9	5.0	6.0	1.4	1.4	4.6
1987	10	4.0	4.8	0.9	0.8	4.1
1987	11	2.6	3.1	0.1	0.1	3.0
1987	12	2.1	2.5	1.6	1.2	1.3
1988	1	2.4	2.9	0.1	0.1	2.8
1988	2	3.7	4.5	0.5	0.5	3.9
1988	3	5.6	6.7	0.1	0.1	6.7
1988	4	7.1	8.5	0.2	0.2	8.3
1988	5	8.1	9.7	0.0	0.0	9.7
1988	6	7.9	9.5	0.6	0.6	8.9
1988	7	7.5	9.0	2.6	2.4	6.6
1988	8	6.3	7.6	2.8	2.4	5.2
1988	9	5.3	6.4	1.3	1.3	5.1
1988	10	3.9	4.7	0.3	0.3	4.4
1988	11	2.8	3.3	0.2	0.2	3.1
1988	12	2.1	2.5	0.4	0.4	2.1
1989	1	2.5	3.0	0.3	0.3	2.7
1989	2	3.4	4.1	0.8	0.5	3.6
1989	3	5.9	7.1	0.6	0.6	6.5
1989	4	7.9	9.5	0.0	0.0	9.5
1989	5	8.4	10.1	1.2	1.0	9.1
1989	6	8.3	10.0	0.0	0.0	10.0
1989	7	7.5	9.0	1.4	1.4	7.6
1989	8	6.4	7.7	1.9	1.5	6.2
1989	9	5.3	6.3	0.6	0.6	5.8
1989	10	4.0	4.8	0.6	0.6	4.1
1989	11	2.6	3.2	0.0	0.0	3.2
1989	12	2.0	2.3	0.2	0.2	2.2
1990	1	2.6	3.2	0.4	0.4	2.7
1990	2	3.5	4.2	0.1	0.1	4.1
1990	3	5.4	6.5	1.0	1.0	5.5
1990	4	7.2	8.6	0.9	0.9	7.8
1990	5	7.8	9.4	0.3	0.3	9.1
1990	6	8.4	10.1	0.0	0.0	10.1
1990	7	7.1	8.5	2.2	1.9	6.7
1990	8	6.3	7.5	2.6	2.2	5.3
1990	9	4.8	5.7	4.8	2.6	3.2
1990	10	3.7	4.4	0.0	0.0	4.4
1990	11	2.5	2.9	1.2	1.1	1.8
1990	12	2.1	2.5	0.4	0.4	2.1

Year	Month	Art Ivey ET_o, in	Potential Bare Ground Evaporation, in	Art Ivey Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
1991	1	2.1	2.5	0.6	0.6	2.0
1991	2	3.4	4.1	0.7	0.7	3.4
1991	3	5.2	6.2	0.0	0.0	6.2
1991	4	7.2	8.6	0.1	0.1	8.6
1991	5	8.3	9.9	0.2	0.2	9.7
1991	6	8.1	9.7	0.3	0.3	9.4
1991	7	7.0	8.4	1.9	1.9	6.5
1991	8	6.5	7.8	3.8	3.0	4.8
1991	9	4.5	5.4	2.0	1.7	3.7
1991	10	4.1	4.9	0.2	0.2	4.7
1991	11	2.4	2.8	0.8	0.8	2.0
1991	12	1.7	2.1	3.3	1.3	0.8
1992	1	1.8	2.2	2.2	1.6	0.6
1992	2	3.3	3.9	0.2	0.2	3.8
1992	3	5.3	6.3	0.8	0.8	5.5
1992	4	7.3	8.8	0.5	0.5	8.3
1992	5	7.1	8.6	2.5	2.5	6.1
1992	6	8.2	9.9	0.0	0.0	9.8
1992	7	7.9	9.4	0.0	0.0	9.4
1992	8	6.7	8.0	1.8	1.5	6.6
1992	9	5.5	6.6	1.1	0.9	5.8
1992	10	4.0	4.8	0.6	0.6	4.1
1992	11	2.3	2.8	0.4	0.4	2.4
1992	12	1.7	2.1	1.8	0.8	1.2
1993	1	2.1	2.6	1.4	1.3	1.3
1993	2	3.3	4.0	0.2	0.2	3.7
1993	3	5.5	6.6	0.0	0.0	6.6
1993	4	7.2	8.7	0.1	0.1	8.6
1993	5	8.0	9.6	0.0	0.0	9.6
1993	6	8.1	9.7	0.9	0.7	9.1
1993	7	7.5	9.0	1.2	1.2	7.8
1993	8	6.7	8.1	1.9	1.9	6.2
1993	9	5.3	6.3	0.5	0.5	5.9
1993	10	3.7	4.5	0.4	0.4	4.1
1993	11	2.5	3.0	0.5	0.5	2.4
1993	12	2.1	2.5	0.8	0.5	2.0
1994	1	2.6	3.1	0.0	0.0	3.1
1994	2	3.6	4.3	0.6	0.6	3.6
1994	3	5.4	6.5	0.5	0.5	6.0
1994	4	7.3	8.7	0.1	0.1	8.6

Year	Month	Art Ivey ET_o, in	Potential Bare Ground Evaporation, in	Art Ivey Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
1994	5	8.1	9.7	2.2	1.8	7.9
1994	6	8.6	10.3	0.2	0.2	10.1
1994	7	8.0	9.7	1.1	1.1	8.5
1994	8	7.2	8.6	0.2	0.2	8.4
1994	9	5.3	6.4	0.6	0.6	5.8
1994	10	3.8	4.6	0.7	0.7	3.9
1994	11	2.5	3.1	0.6	0.6	2.5
1994	12	2.1	2.5	1.8	1.3	1.2
1995	1	2.4	2.9	0.3	0.3	2.6
1995	2	3.6	4.3	1.0	0.9	3.4
1995	3	5.6	6.7	0.4	0.4	6.3
1995	4	7.0	8.4	0.1	0.1	8.4
1995	5	8.0	9.6	0.2	0.2	9.5
1995	6	8.1	9.7	0.7	0.7	9.0
1995	7	8.1	9.7	0.7	0.7	9.0
1995	8	6.9	8.3	0.7	0.7	7.6
1995	9	5.0	6.0	3.4	2.2	3.8
1995	10	4.2	5.1	0.0	0.0	5.1
1995	11	2.7	3.2	0.4	0.4	2.8
1995	12	2.3	2.8	0.3	0.3	2.5
1996	1	2.8	3.4	0.2	0.2	3.2
1996	2	4.2	5.0	0.1	0.1	4.9
1996	3	5.7	6.8	0.0	0.0	6.8
1996	4	7.3	8.8	0.7	0.7	8.0
1996	5	8.7	10.5	0.0	0.0	10.5
1996	6	8.3	10.0	1.3	1.3	8.7
1996	7	7.6	9.2	1.8	1.4	7.8
1996	8	6.4	7.7	3.8	2.8	4.9
1996	9	5.2	6.3	2.0	1.0	5.2
1996	10	4.1	4.9	0.0	0.0	4.9
1996	11	2.7	3.2	0.3	0.3	2.9
1996	12	2.3	2.8	0.0	0.0	2.8
1997	1	2.3	2.8	0.3	0.3	2.5
1997	2	3.3	3.9	0.6	0.6	3.3
1997	3	5.7	6.9	0.5	0.5	6.4
1997	4	6.7	8.0	0.6	0.6	7.4
1997	5	8.0	9.6	0.8	0.8	8.8
1997	6	8.0	9.6	1.2	1.1	8.6
1997	7	7.7	9.2	0.7	0.7	8.5
1997	8	6.8	8.2	3.3	2.0	6.2

Year	Month	Art Ivey ET_o, in	Potential Bare Ground Evaporation, in	Art Ivey Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
1997	9	5.5	6.6	3.4	1.7	4.9
1997	10	4.0	4.8	0.2	0.2	4.5
1997	11	2.4	2.9	1.2	0.9	2.0
1997	12	1.7	2.0	1.1	1.0	1.0
1998	1	2.7	3.2	1.0	0.6	2.7
1998	2	3.2	3.8	0.1	0.1	3.7
1998	3	5.4	6.4	0.3	0.3	6.2
1998	4	6.9	8.2	0.0	0.0	8.2
1998	5	8.3	10.0	0.1	0.1	10.0
1998	6	8.4	10.1	0.4	0.4	9.7
1998	7	7.8	9.4	2.0	2.0	7.4
1998	8	6.9	8.3	1.1	0.9	7.4
1998	9	5.6	6.7	0.6	0.6	6.1
1998	10	3.7	4.4	2.0	1.5	3.0
1998	11	2.7	3.3	0.3	0.3	3.0
1998	12	2.2	2.6	0.2	0.2	2.4
1999	1	2.8	3.4	0.1	0.1	3.3
1999	2	4.1	4.9	0.0	0.0	4.9
1999	3	5.8	7.0	0.1	0.1	6.9
1999	4	7.1	8.6	0.0	0.0	8.6
1999	5	8.0	9.6	0.1	0.1	9.5
1999	6	7.9	9.5	1.1	1.1	8.3
1999	7	7.3	8.7	1.6	1.6	7.1
1999	8	6.8	8.2	0.6	0.6	7.6
1999	9	5.3	6.4	0.9	0.9	5.4
1999	10	4.1	4.9	0.6	0.6	4.3
1999	11	3.0	3.6	0.0	0.0	3.6
1999	12	2.0	2.4	0.6	0.5	1.9
2000	1	2.9	3.5	0.0	0.0	3.5
2000	2	4.2	5.1	0.0	0.0	5.1
2000	3	5.8	7.0	0.1	0.1	6.9
2000	4	7.7	9.2	0.2	0.2	9.0
2000	5	8.5	10.2	0.0	0.0	10.2
2000	6	7.5	9.0	3.1	1.7	7.4
2000	7	8.0	9.6	0.8	0.8	8.8
2000	8	6.9	8.3	0.2	0.2	8.0
2000	9	5.8	7.0	0.0	0.0	7.0
2000	10	3.6	4.3	1.1	1.0	3.3
2000	11	2.1	2.6	1.1	0.8	1.8
2000	12	2.0	2.4	0.0	0.0	2.4

Year	Month	Art Ivey ET_o, in	Potential Bare Ground Evaporation, in	Art Ivey Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
2001	1	2.3	2.7	0.1	0.1	2.7
2001	2	3.6	4.4	0.5	0.5	3.8
2001	3	5.4	6.5	0.0	0.0	6.5
2001	4	7.2	8.7	0.0	0.0	8.7
2001	5	8.2	9.9	0.0	0.0	9.8
2001	6	8.2	9.8	0.3	0.3	9.5
2001	7	7.8	9.3	0.4	0.4	9.0
2001	8	6.7	8.0	0.9	0.9	7.1
2001	9	5.4	6.4	0.8	0.8	5.7
2001	10	4.1	4.9	0.0	0.0	4.9
2001	11	2.5	2.9	0.6	0.6	2.3
2001	12	2.2	2.6	0.1	0.1	2.6
2002	1	2.7	3.2	0.1	0.1	3.1
2002	2	3.2	3.9	1.5	0.7	3.2
2002	3	5.7	6.8	0.0	0.0	6.8
2002	4	7.8	9.3	0.0	0.0	9.3
2002	5	8.4	10.0	0.0	0.0	10.0
2002	6	8.3	10.0	0.3	0.3	9.7
2002	7	7.6	9.1	3.3	3.2	5.9
2002	8	7.1	8.5	1.2	1.2	7.4
2002	9	5.5	6.6	0.1	0.1	6.5
2002	10	3.6	4.3	1.6	1.4	2.9
2002	11	2.5	3.0	0.0	0.0	3.0
2002	12	1.8	2.2	2.0	1.4	0.8
2003	1	2.8	3.4	0.3	0.3	3.1
2003	2	3.2	3.8	2.9	1.3	2.5
2003	3	5.3	6.4	0.3	0.3	6.1
2003	4	7.2	8.6	0.0	0.0	8.6
2003	5	8.4	10.1	0.0	0.0	10.1
2003	6	8.2	9.8	0.7	0.7	9.1
2003	7	8.1	9.7	0.3	0.3	9.4
2003	8	7.1	8.5	0.2	0.2	8.3
2003	9	5.4	6.5	0.2	0.2	6.3
2003	10	3.8	4.6	0.4	0.4	4.2
2003	11	2.7	3.2	0.6	0.6	2.6
2003	12	2.3	2.7	0.0	0.0	2.7
2004	1	2.5	3.0	0.4	0.4	2.6
2004	2	3.2	3.8	0.0	0.0	3.8
2004	3	5.5	6.6	1.4	0.8	5.8
2004	4	6.8	8.2	1.2	1.2	7.0

Year	Month	Art Ivey ET_o, in	Potential Bare Ground Evaporation, in	Art Ivey Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
2004	5	9.4	11.3	0.4	0.4	10.9
2004	6	9.4	11.3	1.2	1.2	10.1
2004	7	8.8	10.6	2.6	1.2	9.4
2004	8	7.5	9.0	2.0	1.6	7.4
2004	9	5.8	7.0	1.9	1.7	5.3
2004	10	4.5	5.4	0.5	0.5	5.0
2004	11	2.4	2.9	3.1	0.8	2.1
2004	12	2.0	2.4	0.2	0.2	2.2
2005	1	2.5	3.0	0.6	0.6	2.3
2005	2	2.9	3.5	1.9	1.5	2.0
2005	3	5.1	6.2	0.1	0.1	6.1
2005	4	7.1	8.5	0.1	0.1	8.4
2005	5	7.8	9.4	1.0	1.0	8.4
2005	6	8.3	9.9	0.0	0.0	9.9
2005	7	8.0	9.6	0.5	0.5	9.2
2005	8	6.5	7.8	4.4	2.5	5.3
2005	9	5.5	6.6	2.7	1.1	5.5
2005	10	3.5	4.2	1.4	1.2	3.1
2005	11	2.8	3.4	0.0	0.0	3.4
2005	12	2.3	2.8	0.0	0.0	2.8
2006	1	3.2	3.9	0.0	0.0	3.9
2006	2	3.6	4.3	0.1	0.1	4.2
2006	3	5.5	6.6	0.0	0.0	6.6
2006	4	8.2	9.9	0.0	0.0	9.9
2006	5	9.2	11.1	0.3	0.3	10.8
2006	6	8.6	10.4	0.2	0.2	10.2
2006	7	7.6	9.2	4.6	2.8	6.4
2006	8	6.1	7.3	2.6	1.3	6.0
2006	9	5.4	6.5	4.1	2.0	4.5
2006	10	4.4	5.2	1.0	1.0	4.3
2006	11	3.1	3.7	0.0	0.0	3.7
2006	12	2.1	2.5	0.1	0.1	2.5
2007	1	2.0	2.4	1.5	1.2	1.1
2007	2	3.6	4.3	0.1	0.1	4.2
2007	3	5.8	6.9	0.0	0.0	6.9
2007	4	6.8	8.2	0.3	0.3	7.9
2007	5	7.6	9.1	2.0	1.4	7.7
2007	6	8.0	9.6	0.8	0.8	8.7
2007	7	6.9	8.3	2.2	2.2	6.1
2007	8	7.0	8.4	0.6	0.6	7.8

Year	Month	Art Ivey ET_o, in	Potential Bare Ground Evaporation, in	Art Ivey Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
2007	9	5.0	6.0	2.1	1.5	4.5
2007	10	4.6	5.6	0.0	0.0	5.6
2007	11	2.7	3.2	1.2	0.9	2.3
2007	12	2.3	2.8	0.4	0.3	2.5
2008	1	2.5	3.0	0.0	0.0	3.0
2008	2	4.2	5.0	0.1	0.1	4.9
2008	3	6.3	7.6	0.0	0.0	7.6
2008	4	7.5	9.0	0.0	0.0	9.0
2008	5	7.8	9.3	0.1	0.1	9.3
2008	6	8.3	9.9	0.0	0.0	9.9
2008	7	6.6	8.0	8.6	4.7	3.3
2008	8	5.9	7.0	2.6	2.6	4.4
2008	9	4.9	5.9	1.9	1.8	4.0
2008	10	4.0	4.8	0.5	0.5	4.3
2008	11	3.0	3.6	0.2	0.2	3.5
2008	12	2.4	2.9	0.2	0.2	2.7
2009	1	2.9	3.5	0.0	0.0	3.5
2009	2	4.0	4.8	0.0	0.0	4.8
2009	3	5.9	7.0	0.1	0.1	6.9
2009	4	7.0	8.4	0.0	0.0	8.4
2009	5	7.6	9.1	0.5	0.5	8.6
2009	6	7.3	8.8	2.5	1.5	7.3
2009	7	7.6	9.1	1.0	1.0	8.1
2009	8	6.7	8.0	0.6	0.6	7.4
2009	9	5.1	6.1	3.0	2.2	3.9
2009	10	3.8	4.5	0.2	0.2	4.3
2009	11	2.8	3.3	1.3	0.6	2.7
2009	12	1.9	2.2	0.5	0.5	1.7
2010	1	2.2	2.7	0.7	0.7	2.0
2010	2	2.9	3.5	1.4	1.2	2.3
2010	3	5.2	6.3	0.0	0.0	6.2
2010	4	6.2	7.4	0.1	0.1	7.3
2010	5	8.0	9.6	0.0	0.0	9.6
2010	6	8.3	9.9	1.1	0.9	9.0
2010	7	6.9	8.3	1.1	1.1	7.2
2010	8	6.9	8.3	0.3	0.3	8.0
2010	9	5.4	6.4	1.6	1.0	5.4
2010	10	4.4	5.3	0.2	0.2	5.1
2010	11	3.4	4.0	0.0	0.0	4.0
2010	12	2.9	3.5	0.2	0.2	3.3

Year	Month	Art Ivey ET_o, in	Potential Bare Ground Evaporation, in	Art Ivey Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
2011	1	2.9	3.5	0.1	0.1	3.4
2011	2	3.5	4.1	0.1	0.1	4.1
2011	3	6.5	7.8	0.0	0.0	7.8
2011	4	8.5	10.2	0.0	0.0	10.2
2011	5	8.6	10.4	0.0	0.0	10.4
2011	6	8.3	10.0	0.1	0.1	9.9
2011	7	8.3	10.0	2.6	2.0	8.0
2011	8	7.3	8.8	1.1	1.1	7.7
2011	9	5.9	7.1	0.4	0.4	6.7
2011	10	4.8	5.7	0.0	0.0	5.7
2011	11	3.0	3.6	0.2	0.2	3.4
2011	12	2.0	2.3	0.7	0.7	1.6
2012	1	2.9	3.5	0.7	0.6	2.9
2012	2	4.0	4.7	0.0	0.0	4.7
2012	3	5.5	6.7	0.1	0.1	6.6
2012	4	7.4	8.9	0.1	0.1	8.8
2012	5	7.6	9.1	0.5	0.5	8.6
2012	6	7.8	9.3	0.0	0.0	9.3
2012	7	7.2	8.6	2.4	2.2	6.4
2012	8	7.5	9.0	0.6	0.6	8.3
2012	9	5.4	6.4	1.4	1.2	5.2
2012	10	4.3	5.2	0.1	0.1	5.1
2012	11	2.7	3.3	0.0	0.0	3.3
2012	12	2.4	2.8	0.1	0.1	2.7
2013	1	2.3	2.7	0.3	0.3	2.4
2013	2	3.2	3.8	0.4	0.4	3.4
2013	3	5.5	6.6	0.0	0.0	6.6
2013	4	6.9	8.3	0.0	0.0	8.3
2013	5	8.0	9.6	0.2	0.2	9.4
2013	6	8.3	9.9	0.2	0.2	9.7
2013	7	6.9	8.3	3.1	2.1	6.2
2013	8	6.3	7.6	1.1	1.0	6.6
2013	9	5.1	6.1	3.9	1.4	4.7
2013	10	4.0	4.9	0.0	0.0	4.9
2013	11	2.4	2.9	0.1	0.1	2.8
2013	12	1.9	2.3	0.3	0.3	2.1
2014	1	2.9	3.4	0.0	0.0	3.4
2014	2	3.8	4.6	0.0	0.0	4.6
2014	3	5.6	6.7	0.2	0.2	6.5
2014	4	7.1	8.5	0.4	0.4	8.0

Year	Month	Art Ivey ET_o, in	Potential Bare Ground Evaporation, in	Art Ivey Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
2014	5	7.9	9.5	0.0	0.0	9.5
2014	6	8.3	10.0	0.0	0.0	9.9
2014	7	8.1	9.8	0.7	0.7	9.1
2014	8	6.3	7.5	1.8	1.7	5.8
2014	9	4.9	5.8	4.2	2.0	3.9
2014	10	4.4	5.3	1.0	0.6	4.7
2014	11	2.8	3.3	0.1	0.1	3.2
2014	12	2.2	2.7	0.1	0.1	2.6
2015	1	2.0	2.4	0.9	0.8	1.6
2015	2	3.3	4.0	0.0	0.0	3.9
2015	3	4.8	5.8	0.6	0.6	5.1
2015	4	6.6	7.9	0.2	0.2	7.6
2015	5	7.9	9.5	0.8	0.8	8.7
2015	6	8.1	9.7	0.2	0.2	9.5
2015	7	7.6	9.1	2.9	2.8	6.4
2015	8	7.5	9.0	1.5	1.5	7.4
2015	9	5.2	6.3	0.3	0.3	5.9
2015	10	3.8	4.5	3.2	2.0	2.5
2015	11	2.6	3.2	0.3	0.3	2.9
2015	12	2.1	2.6	1.1	0.6	1.9
2016	1	2.6	3.1	0.5	0.4	2.7
2016	2	3.8	4.6	0.1	0.1	4.5
2016	3	6.1	7.3	0.0	0.0	7.3
2016	4	6.6	8.0	0.0	0.0	7.9
2016	5	8.0	9.6	0.1	0.1	9.6
2016	6	8.5	10.1	0.3	0.3	9.8
2016	7	8.8	10.5	0.2	0.2	10.3
2016	8	7.0	8.4	4.8	3.5	4.9
2016	9	5.2	6.2	2.1	1.6	4.6
2016	10	4.2	5.1	0.0	0.0	5.1
2016	11	3.2	3.8	0.4	0.4	3.4
2016	12	2.4	2.8	0.9	0.9	2.0
2017	1	2.6	3.1	1.1	1.0	2.1
2017	2	3.5	4.2	0.2	0.2	4.1
2017	3	5.8	7.0	0.0	0.0	7.0
2017	4	7.2	8.6	0.1	0.1	8.5
2017	5	8.6	10.3	0.0	0.0	10.3
2017	6	8.7	10.4	1.2	1.1	9.4
2017	7	7.7	9.2	3.4	2.0	7.2
2017	8	6.8	8.1	2.0	1.5	6.6

Year	Month	Art Ivey ET_o, in	Potential Bare Ground Evaporation, in	Art Ivey Precipitation, in	Bare Ground Evaporation from Precipitation, in	Potential Bare Ground Evaporation from Groundwater, in
2017	9	5.6	6.7	1.2	0.7	6.0
2017	10	4.6	5.5	0.1	0.1	5.4
2017	11	3.2	3.9	0.3	0.3	3.6
2017	12	2.3	2.8	0.7	0.7	2.1
2018	1	2.9	3.5	0.1	0.1	3.4
2018	2	3.5	4.2	0.7	0.5	3.7
2018	3	5.7	6.8	0.2	0.2	6.6
2018	4	7.6	9.1	0.0	0.0	9.1
2018	5	8.6	10.3	0.4	0.4	9.9
2018	6	8.7	10.5	0.4	0.4	10.1
2018	7	7.6	9.1	1.4	1.0	8.1
2018	8	7.0	8.4	1.2	0.9	7.5
2018	9	5.3	6.3	1.2	0.9	5.4
2018	10	3.2	3.9	2.4	1.5	2.4
2018	11	3.0	3.6	0.0	0.0	3.6
2018	12	2.1	2.5	0.4	0.4	2.1

Appendix 11. Resume for Bryan P. Thoreson PhD, PE

Bryan P. Thoreson, Ph.D., P. E.

Education

Ph.D., Agricultural Engineering, University of Arizona, Tucson

M.S., Agricultural Engineering, South Dakota State University, Brookings

B.S., Agricultural Engineering, South Dakota State University, Brookings

Registration

Civil Engineer, CA
No. C56194

Civil Engineer, WA
No. 36249

Years of Experience:

25 Years

Distinguishing Qualifications

- Crop consumptive water use
- Complex water balance development

Summary

Dr. Thoreson has 25 years of professional experience in water resources and irrigation engineering both in the western United States and overseas. Dr. Thoreson specializes in crop consumptive water use and water balances of agricultural areas including database development for water balances, water flow measurement and uncertainty analysis water right analysis, land use analysis, and reservoir operations. Dr. Thoreson has worked extensively using Access and Oracle databases to store time series data for assembling and computing water balances. Dr. Thoreson has played a major role in developing water balances and quantifying water conserved by various conservation practices for irrigation and water districts in the Sacramento, San Joaquin and Imperial Valleys of California and elsewhere. These water balances have ranged from the field to basin scale and included analysis and formulation of conjunctive management strategies. Dr. Thoreson has authored more than 50 papers focusing on analysis of crop ET developed from remote sensing (SEBAL®) techniques and on data management for irrigation water resources planning and management.

Relevant Experience

Project Manager and Lead Engineer, Crop Consumptive Water Use and Agricultural Water Budget Projects. Dr. Thoreson has served as project manager and lead engineer developing agricultural water budgets for numerous irrigation and water districts in the Sacramento and San Joaquin Valleys. Technical aspects of Dr. Thoreson's work in these projects involved estimating agricultural applied water use and using a root zone water budget to estimate evapotranspiration (ET) of applied water and precipitation. In each of these projects, Dr. Thoreson worked closely with local staff to develop the water use estimates and water budgets. Remotely sensed ET estimates are typically used to develop crop coefficients for these projects. Customized semi-automatic water budget tools to assemble data from supplier spreadsheets and databases and develop the water budget were developed for the first three entities on the following partial list of the entities and time periods for which Dr. Thoreson has led or substantially contributed to development of agricultural water budgets.

1. Imperial Irrigation District (2006 – 2009 completed by Dr. Thoreson, 2010 – 2016 District completed with tool)
2. Turlock Irrigation District (1950 – 2010 completed by Dr. Thoreson, 2011 – 2016 District completed with tool)
3. Sonoma County Water Agency (2002-2014 completed by Dr. Thoreson)
4. Yuba County Water Agency (2001-2015)
5. Oakdale Irrigation District (2005-2016)
6. South San Joaquin Irrigation District (1994-2015)
7. Merced Irrigation District (1970-2009)
8. Stony Creek Fan Area includes Orland Unit Water Users' Association, Orland-Artois Water District, Glen Colusa Irrigation District and surrounding groundwater pumpers (1970-1999)
9. Chowchilla Water District (1991-2015)
10. Glenn-Colusa Irrigation District (1970-2012)
11. Orland Unit Water Users Association (1970-2016)
12. RD108 Water District (1986-2010)
13. Dunnigan Water District (1961-2004)
14. Solano Irrigation District (1991-2014)
15. Benton Irrigation District in Washington
16. Madera Irrigation District (1991-2015)
17. Root Creek Water District (1991-2015)
18. Gravelly Ford Water District (1991-2015)
19. New Stone Water District (1991-2015)
20. Triangle T Water District (1991-2015)
21. Sierra Vista Mutual Water Company (1991-2015)
22. Madera County Groundwater Sustainability Agency (1991-2015)

Project Manager, GSP Development and SGMA Data Collection and Analysis Projects, Madera County, Madera, CA. Dr. Thoreson served as the project manager for the SGMA Data Collection and Analysis projects for the critically overdrafted Chowchilla and Madera subbasins in Madera County completed in the spring of 2018. He more recently served as project manager for the GSP Development for both subbasins, with draft GSPs released in August 2019. The objective in both subbasins for the data collection and analysis project was to identify significant data gaps that must be addressed during GSP preparation. The technical approach inventoried all data needed to prepare a compliant GSP based on California Department of Water Resources' (DWR's) GSP regulations and anticipated measures to achieve sustainability. Immediately after the conclusion of the data collection and analysis project, the GSP development project began. In addition to coordinating overall development of the GSPs, which included extensive stakeholder outreach and coordination with technical experts representing various GSAs in each subbasin, Dr. Thoreson oversaw development of basin boundary and GSA water budgets and managed the development of projects and management actions. Dr. Thoreson was an active participant in the development of minimum thresholds and measurable objectives for the sustainability management criteria in each subbasin. The work has included numerous technical meetings with GSA representatives and public meetings, including coordination with neighboring subbasins to ensure consistency in understanding of interbasin flows.

Lead Engineer, IWFM Demand Calculator Parameter Development, Yolo County, CA. Dr. Thoreson served as lead engineer on this project to review and calibrate the soil and irrigation management input parameters used in the Integrated Water Flow Model (IWFM) Demand Calculator (IDC) for the Yolo County IWFM (YCIWFM) application. The IDC was used to develop estimates of agriculture water use and partition the use between applied water (surface water or groundwater) and precipitation. Dr. Thoreson completed a comprehensive literature review of soil drainage characteristics to serve as the basis for IDC calibration.

Confidential Client. Assist a confidential client develop crop water use requirements for cotton and various other crops and achievable on-farm application efficiencies in an arid climate in the U.S. Southwest.

California Department of Water Resources. Spatial Mapping of ET in the Sacramento-San Joaquin River Delta using SEBAL. Dr. Thoreson led a project to estimate ET_a for crops and native vegetation for the 2007 crop growing season in the Sacramento-San Joaquin River Delta. The California Department of Water Resources (DWR) uses several models to estimate water demand and consumptive use in the Delta. Improving estimates of water demand and consumptive use for crops and native vegetation in the Delta is important in planning for future water conveyance options through the Delta. DWR completed a detailed land use survey for the area in 2007 to support the computation of daily evapotranspiration of applied water (ET_{aw}) using three, existing models and comparison to the SEBAL results. Nine Landsat multispectral satellite images acquired between March and September 2007 were analyzed using the Surface energy Balance Algorithm for Land (SEBAL®). DWR developed actual crop coefficients for use in estimating applied water within the Delta. To determine if these crop coefficients accurately estimated actual ET, and the corresponding applied water, of the various crops grown in the Delta, an additional SEBAL ET analysis was completed for 2009. DWR found that model estimates of water demand and applied water in 2009 using the actual crop coefficients developed from the 2007 SEBAL results were in good agreement with the 2009 SEBAL results.

Data Management and Water Resources Planning. Imperial Irrigation District. Led the SEBAL application and data management effort for water resources planning and management in support of the Quantification Settlement Agreement (QSA) Definite Plan for the Imperial Irrigation District. This included providing data management support and assisting with database and analysis design in support of the project GIS, developing computer programs and databases in support of crop water use and land use analysis, and surface water operational models. These databases and models also track the surface water hydrology of rainfall and runoff.

Time Series Evapotranspiration and Applied Water Estimates from Remote Sensing. Kaweah Delta Water Conservation District. Dr. Thoreson provided senior review of the development of SEBAL actual ET (ET_a) estimates and the development and review of a daily root zone water balance model to leverage available SEBAL results for three years over a 14-year period. Actual ET estimates for the additional years were developed using crop coefficients estimated based on the normalized difference vegetation index (NDVI). Combining these estimates with a daily rootzone water balance model avoided the relatively high cost of estimating spatially distributed ET_a on an annual basis using SEBAL. NDVI imagery was acquired at monthly or more frequent intervals and used to develop a daily time series of the basal crop coefficient, which describes crop transpiration, for each field within the District.

The daily root zone water balance model was developed based on the procedures described in FAO Irrigation and Drainage Paper No. 56 for the dual crop coefficient approach. This model was implemented in a database environment and used to estimate inflows to and outflows from each field from applied irrigation water and precipitation. Model results for an independent set of fields were used to validate the approach, and it was found that total ET estimated based the combination of NDVI imagery and the daily root zone water balance model agree with SEBAL results within 1% for each of the three years for which SEBAL results were available.

This approach to quantifying ET_a and applied water demand at highly discrete spatial and temporal scales over a multi-year time period has resulted in increased reliability in estimates of total pumpage and changes in groundwater storage by reducing reliance on cropping data, inherently accounting for changes in crop timing and intensity from year to year, and inherently accounting for differences between actual growing conditions and the idealized conditions upon which many published crop coefficients were developed. Because of the relatively low cost of running the NDVI-based model, the District is able to incorporate annual updates into its analysis and reporting processes.

Lead Engineer, Water Data Analysis Support and Water Information System Development, Imperial Irrigation District, Imperial, CA. Dr. Thoreson has led the effort to develop IID's Water Information System (WIS), an integrated data management system that supports water accounting and IID's on-farm and canal distribution system conservation programs. The data management system calculates ET of applied water and precipitation for thousands of fields in IID every month. The results are compiled into crop season water budgets for each field. The WIS also performs ongoing accounting of on-farm and system level water conservation. Dr. Thoreson developed a semi-automated water balance application including accounting centers for the water distribution system, irrigated lands, and drainage system. This semi-automated water balance, programmed in IID's WIS, compiles flow records, computes estimates for all flow paths, and assembles monthly and annual water balances for each accounting center. Models run daily and monthly, tracking water use and conservation.

Lead Engineer, Water Management Planning, Turlock Irrigation District, Turlock, CA. In 1998, Dr. Thoreson developed a database to complete a 25-year monthly water budget for Turlock Irrigation District in support of the District's Agricultural Water Management Plan (AWMP). This AWMP was developed under the guidelines of the Agricultural Water Management Council created by the Agricultural Water Suppliers Efficient Water Management Practices Act and approved in 2001. Dr. Thoreson served as the project manager and lead engineer for updating the water balance through 2008 and to update the initial AWMP. An assessment of accuracy and computation of confidence intervals (uncertainty) for each flow path in the water balance was also completed. In 2011, Dr. Thoreson led the development of a semi-automated TID water balance application to be utilized by TID staff. The application was programmed in an MS Access database. With this application, TID is able to complete each year's water balance analysis soon after the calendar year ends. Again in 2012 and in 2015, TID called on Dr. Thoreson to serve as the project manager for the preparation of the District's AWMP. Dr. Thoreson is also supporting TID's efforts to improve delivery measurement accuracy to directly measure agricultural water demands.

Solano Irrigation District. System Optimization Review. Dr. Thoreson is serving as the project manager for a water balance supporting a System Optimization Review for the Solano Irrigation District (SID). Agricultural water demands were quantified using a daily root zone water balance model to estimate the portion of total crop evapotranspiration resulting from applied irrigation water (ET_{aw}) over time (1991 to 2010) on the basis of cropping, soil characteristics, and weather (evaporative demand and precipitation). These demands were then incorporated into a full water balance analysis to identify water conservation opportunities. Dr. Thoreson led the quantification of demands and the water balance analysis. The water balance results will focus the development of cost effective programs and projects to optimize management of SID's water resources.

Project Manager, Water Management Planning and Feasibility Assessment of Pressurized Water Delivery, South San Joaquin Irrigation District, Manteca, CA. Dr. Thoreson served as the project manager for the preparation of the South San Joaquin Irrigation District (SSJID) Agricultural Water Management Plan (AWMP) in 2012 and 2015. Dr. Thoreson also assisted the District with a feasibility assessment of pressurized water delivery service. Technical aspects of Dr. Thoreson's work included developing projections of future cropping, associated water demands, and associated water supply requirements. These projections are based on historical cropping, grower interviews, and a District water budget analysis including a root zone water budget to partition evapotranspiration between applied water and precipitation. Dr. Thoreson worked closely with SSJID staff to interview growers and develop the water budget. The feasibility assessment evaluated different pressurization options ranging from pressurization of the entire distribution system to pressurization in selected areas with high concentrations of permanent crops irrigated with pressurized on farm irrigation systems.

Imperial Irrigation District. Efficiency Conservation Definite Plan and Efficiency Conservation Program. Dr. Thoreson managed the data component of the Efficiency Conservation Definite Plan (ECDP). Since the completion of the ECDP in 2007, Dr. Thoreson has continued to support Imperial Irrigation District's (IID) Efficiency Conservation Program implementing the ECDP. As part of this work, Dr. Thoreson has led the effort to develop IID's Water Information System (WIS), an integrated data management system that supports water accounting and on-farm and distribution system conservation programs. The data management system calculates ET of applied water and precipitation for thousands of fields in IID every month based on IID delivery data. The results are then compiled into crop season water balance for each field. For the on-farm conservation program, the WIS supports enrollment of growers in the program and management of grower contracts. The WIS also performs on ongoing accounting of on-farm and system level water conservation, thereby documenting IID's compliance with the terms of the Colorado River Quantification Settlement Agreement (QSA). Dr. Thoreson developed a semi-automated water balance including the water distribution system, irrigated lands and drainage system tracking surface water imports and rainfall. This semi-automated water balance, programmed in IID's WIS, assembles flow records and computes estimates for other flow paths into monthly and annual system water balances. Models run daily and monthly tracking water use and conservation.

Project Manager, 2012 and 2015 SBx7-7 Agricultural Water Management Plans, Yuba County Water Agency and Oakdale Irrigation District, Marysville and Oakdale, CA. Dr. Thoreson served as project manager for the Oakdale Irrigation District agricultural water management plan (AWMPs) completed in 2012 and is assisting with the 2015 AWMP. Dr. Thoreson served as the water budget task leader for the development of the Yuba County Water Agency's 2012 AWMP and assisted with the development of the 2015 AWMP. For both AWMPs, Dr. Thoreson supported various aspects of the technical analyses, which included the preparation of detailed, multi-year water budgets for irrigation distribution (canal) systems, farmed lands, and drainage systems. Additionally, Dr. Thoreson assisted with the evaluation of each district's Efficient Water Management Practice (EWMPs) implementation status.

Data Management Task Leader, Water Conservation Verification, Imperial Irrigation District, Imperial, CA. Dr. Thoreson led the data management for the water conservation verification for the Imperial Irrigation District under its Water Conservation and Transfer Program with Metropolitan Water District of Southern California (MWD). He conducted data analyses supporting determination of the water conserved by a suite of 18 projects encompassing on-farm and system conservation. Dr. Thoreson implemented the final verification algorithm for each project in a data management system supporting automatic annual computation of water savings based on information collected, quality-controlled and stored in IID's Water Information System (WIS).

Water Balance Task Leader, Merced Irrigation District Water Management Plan, Merced Irrigation District, Merced, CA. Dr. Thoreson developed a database used to complete a multi-year water balance for Merced Irrigation District in support of the District's Water Management Plan (WMP). In this water balance, separate water balances were completed for various regions of the district. This WMP was developed under the guidelines of the Agricultural Water Management Council created by the Agricultural Water Suppliers Efficient Water Management Practices Act, referred to as AB 3616. Dr. Thoreson led the water balance task, developing a water balance structure, quantifying monthly flow path volumes, assembling the balance and presenting the results.

Expert Witness Testimony

No experience as an expert witness at trial or by deposition.

Professional Publications

Book Chapters

Johnson, L., R. Nemani, J. Hornbuckle, W. Bastiaanssen, **B. Thoreson**, B. Tisseyre, and L. Pierce, 2012. Remote sensing for vineyard research and production. Chapter 12 in The Geography of Wine: Regions, Terroir, and Techniques (P. Dougherty, Ed.), Springer Science, The Netherlands (ISBN: 978-94-007-0463-3).

Proceedings Edited

Macaulay, S. **B. Thoreson** and S. Anderson. 2014. *Groundwater Issues and Water Management — Strategies Addressing the Challenges of Sustainability.* Proceedings from a USCID Water Management Conference, Sacramento, CA.

B. Thoreson and S. Anderson. 2010. *Upgrading Technology and Infrastructure in a Finance-Challenged Economy.* Proceedings from a USCID Water Management Conference, Sacramento, CA.

Refereed Journal Articles and Proceedings Papers

Hopkins, J.M., P. Fuchslin, K.L. King, and **B.P. Thoreson**. 2016. Evolving Capital Improvement Program to Meet Future Water Demands. In *Water Shortages and Drought: From Challenges to Solutions.* Proceedings from a USCID Water Management Conference, San Diego, CA.

Steele, D.D., **B.P. Thoreson**, D.G. Hopkins, B.A. Clark, S.R. Tuscherer, and R. Gautam. 2015. Spatial mapping of evapotranspiration over Devils Lake basin with SEBAL: Application to flood mitigation via irrigation of agricultural crops. Irrig. Sci. 33(1):15-29. Accepted 09 Sept 2014; published online 30 Sept 2014. DOI: 10.1007/s00271-014-0445-1. The final publication is available at link.springer.com. See also http://dx.doi.org/ 10.1007/s00271-014-0445-1

Clark, B., G. Davids, D. Lal, **B. Thoreson** and S. Macaulay. 2014. Indicators of Changes in Sacramento Valley Consumptive Use and Potential Water Management Implications. In *Groundwater Issues and Water Management — Strategies Addressing the Challenges of Sustainability.* Proceedings from a USCID Water Management Conference, Sacramento, CA.

Liebersbach, D.B., **B.P. Thoreson** and B. Clark. 2014. Conjunctive Management of Surface Water and Groundwater in the Turlock Irrigation District. In *Groundwater Issues and Water Management — Strategies Addressing the Challenges of Sustainability.* Proceedings from a USCID Water Management Conference, Sacramento, CA.

Welch, D., P. Leffler, **B. Thoreson** and N Ruud. 2014. Conjunctive Management of Groundwater and Surface Water in Chowchilla Water District. In *Groundwater Issues and Water Management — Strategies Addressing the Challenges of Sustainability.* Proceedings from a USCID Water Management Conference, Sacramento, CA.

Mendez-Costabel M., N. Dokoozlian, A. Morgan, **B. Thoreson** and B. Clark. 2013. Remote Sensing of Irrigation Requirements in Wine Grapes. In *Urban Water Interface – Conflicts and Opportunities.* Proceedings from a USCID Water Management Conference, Denver, CO.

Thoreson, **B.,** D. Lal, and B. Clark. 2013. Drip Irrigation Impacts on Evapotranspiration Rates in California's San Joaquin Valley. In *Using 21st Century Technology to Better Manage Irrigation Water Supplies.* Proceedings from a USCID Water Management Conference, Phoenix, AZ.

Thoreson, **B.,** R. Massa, and T. Ostrowski. 2013. Regulating Reservoir and Lateral Improvements Result in Spillage Reduction. In *Using 21st Century Technology to Better Manage Irrigation Water Supplies.* Proceedings from a USCID Water Management Conference, Phoenix, AZ.

Clark, B., D. Lal, K. Lynn-Patterson, B. Sanden, and **B. Thoreson**. 2013. Development and Distribution of Crop Coefficients via Remote Sensing in California's San Joaquin Valley. In *Using 21st Century Technology to Better Manage Irrigation Water Supplies.* Proceedings from a USCID Water Management Conference, Phoenix, AZ.

Lal, D., B. Clark, T Bettner, **B. Thoreson**, and R Snyder. 2012. Rice Evapotranspiration Estimates and Crop Coefficients in Glenn-Colusa Irrigation District, Sacramento Valley, California. In *Irrigated Agriculture Responds to Water Use Challenges – Strategies for Success.* Proceedings from a USCID Water Management Conference, Austin, TX.

Roberson, M.J., **B. Thoreson**, D Lal, and M. Garcia. 2011. Use of Remote Sensing to Identify Urban Landscape Water Use in Sacramento, California. In Irrigation Association Conference Proceedings, San Diego.

Thoreson, B.P., A.A. Keller, M. Kidwell, and J.R. Eckhardt. 2011. Main Canal Decision Support System for Scheduling Flow Changes on Main Canals Imperial Irrigation District Efficiency Conservation Program. In *The Struggle for Efficiency – Actions and Consequences.* Proceedings from a USCID Water Management Conference, San Diego, CA. pp. 339-350.

D. MacEwan, B. Clark, **B. Thoreson**, R. Howitt, J. Medellin-Azuara and G Davids. 2010. Assessment of Economic and Hydrologic Impacts of Reduced Surface Water Supply for Irrigation Via Remote Sensing. In *Meeting Irrigation Demands in a Water-Challenged Environment SCADA and Technology: Tools to Improve Production.* Proceedings from a USCID Water Management Conference, Fort Collins, CO.

Lal, D., B. Clark, **B. Thoreson**, G Davids and W Bastiaanssen. 2010. Monitoring Near-Real Time Evapotranspiration Using SEBAL®: An Operation Tool for Water Agencies/Growers. In *Upgrading Technology and Infrastructure in a Finance-Challenged Economy.* Proceedings from a USCID Water Management Conference, Sacramento, CA.

Thoreson, B., D. Lal, B. Clark, and G. Davids. 2009. Energy Balance Evapotranspiration Estimates Over Time for the Southern San Joaquin Valley. Proceedings of the U.S. Committee on Irrigation and Drainage Fifth International Conference on Irrigation and Drainage. Salt Lake City, Utah. November 4-7, 2009.

Thoreson, B.P. and R Massa. 2009. Orland Unit Water Users Association Regulating Reservoir, An Example of Verification-Based Modernization Planning. In *Irrigation District Sustainability—Strategies to Meet the Challenges.* In Irrigation District Sustainability – Strategies to Meet the Challenge. Proceedings from a USCID Water Management Conference, Reno, NV. pp. 399-352.

Thoreson, B., B. Clark, R. Soppe, A. Keller, W Bastiaanssen, and J Eckhardt. 2009. Comparison of Evapotranspiration Estimates from Remote Sensing (SEBAL), Water Balance, and Crop Coefficient Approaches. In **Great** Rivers. Proceedings from an EWRI Congress, Kansas City, MO.

Lal, D., B. Clark, **B. Thoreson**, and J.R. Eckhardt. 2008. Application of The Surface Energy Balance Using Landsat Thermal Imagery To Improve On-Farm Water Management In The Imperial Irrigation District. In the 17TH PECORA Remote Sensing Symposium – An ASPRS Fall 2008 Conference Proceedings. November 16-20, 2008, Denver, Colorado.

Bastiaanssen, W.B., R.G. Allen, H. Pelgrum, A.H. de C. Texeira, R.W.O. Soppe and **B.P. Thoreson** 2008. Thermal-Infrared Technology for Local and Regional Scale Irrigation Analyses in Horticultural Systems. In Proc. Vth IS on Irrigation of Hort. Crops. Eds. I Goodwin and M.G. O'Connell. *Acta Horticulture.* 792, ISHS 2008.

Lal, D., Clark, B., J. Hetrick, **B. Thoreson**, D. Roberts and G Davids. 2008. Consumptive Use in the Phoenix Area—Remote Sensing to Evaluate Changes in Evapotranspiration from Urbanization. In *Urbanization of Irrigated Lands and Water Transfers.* Proceedings from a USCID Water Management Conference, Phoenix, AZ. pp. 331-345.

Thoreson, B.P., J.R. Eckhardt, G.G. Davids, A.A. Keller and B Clark. 2008. Imperial Irrigation District Efficiency Conservation Definite Plan - Delivery/On-Farm System Conservation Program Interrelationships. In *Urbanization of Irrigated Lands and Water Transfers.* Proceedings from a USCID Water Management Conference, Phoenix, AZ. pp. 281-292.

Keller, A.A., **B.P. Thoreson**, E. Triana and J.R. Eckhardt. 2008. Imperial Irrigation District Efficiency Conservation Definite Plan – Decision Support System for Evaluating Alternatives. In *Urbanization of Irrigated Lands and Water Transfers.* Proceedings from a USCID Water Management Conference, Phoenix, AZ. pp. 293-306.

Clark, B., R. Soppe, D Lal, **B. Thoreson**, W. Bastiaanssen and G Davids. 2007. Variability of Crop Coefficients in Space and Time-Examples from California. In *The Role of Irrigation and Drainage in a Sustainable Future.* Proceedings from the USCID Fourth International Conference on Irrigation and Drainage, Sacramento, CA. pp. 481-500.

Thoreson, B., L. Mullins, G. Davids and A. Divine. 2005. Ten Years of SCADA Data Quality Control and Utilization for System Management and Planning Modernization. In *SCADA and Related Technologies for Irrigation District Modernization.* Proceedings from a USCID Water Management Conference, Vancouver, WA. pp. 123-132.

Young, G., **B. Thoreson**, A Baro and C. Villalón. 2005. Development of a Water Management System to Improve Management and Scheduling of Water Orders in Imperial Irrigation District. In *Water District Management and Governance.* Proceedings from the USCID Third International Conference on Irrigation and Drainage, San Diego, CA. pp. 253-261.

Bastiaanssen, W.B., E.J.M. Noordman, H. Pelgrum, G. Davids, **B.P. Thoreson** and R.G. Allen. 2005. SEBAL Model with Remotely Sensed Data to Improve Water Resources Management under Actual Field Conditions. *Journal of Irrigation and Drainage Engineering* (Vol. 131, No. 1, pp. 85-93), New York, NY.

Thoreson, B.P.; S. Zwart, W. Bastiaanssen and G.G. Davids. 2004. Estimating Actual Evapotranspiration Without Land Use Classification. In *Water Rights and Related Water Supply Issues*. Proceedings from the USCID 2004 Water Management, Salt Lake City UT. pp. 355-364.

Thoreson, B.P.; C. Villalón, M. Kidwell and K. Dimmitt. 2003. Initial Development of a Decision Support System for Operating a Lateral Interceptor Reservoir System. In *Water for a Sustainable World – Limited Supplies and Expanding Demand.* Proceedings from the USCID Second International Conference on Irrigation and Drainage, Phoenix, AZ. pp. 313-322.

Thoreson, B.P.; P. Kosciusko, J. Burns, G. Davids, K. Dimmitt, J. Keller and M. King. 2003. Water Conservation: Savings Determination in Near Real-Time. In *Water for a Sustainable World – Limited Supplies and Expanding Demand.* Proceedings from the USCID Second International Conference on Irrigation and Drainage, Phoenix, AZ. pp. 747-756.

Eckhardt, J.; A. Keller and **B.P Thoreson**. 2002. Modeling Changes in Flow Using the Imperial Irrigation Decision Support System. In *Helping Irrigated Agriculture Adjust to TMDLs*. Proceedings from the USCID Water Management Seminar, Denver, CO. pp. 265-277.

Prasad; K.C., **B. P. Thoreson** and D.J. Molden. 2000. Tracing The History Of The Development And Management Of Two Irrigation Systems In The Terai Of Nepal. *Challenges Facing Irrigation and Drainage in the New Millennium*. Proceedings from the USCID Water Management Seminar, Denver, CO. pp. 357-371

Thoreson, B. P.; J. Eckhardt and A.J. Divine. 2000. Correlation Between Sampling Interval and Daily Volume Calculations. In *Benchmarking Irrigation System Performance Using Water Measurement and Water Balances*, Proceedings from the USCID Water Management Seminar, Denver, CO.pp. 121-134.

Archer, M. C.; **B. P. Thoreson** and A.J. Divine. 2000. Correction For Daily Flow Records Computed By Averaging 24 Hourly Head Values. *Benchmarking Irrigation System Performance Using Water Measurement and Water Balances*, Proceedings from the USCID Water Management Seminar, Denver, CO. p.109-120.

Thoreson, B. P.; A.J. Divine and M.C. Archer. 1999. IID Water Information System – Irrigation Database Principles and Management. In *Contemporary Challenges for Irrigation and Drainage*, Proceedings from the USCID Water Management Seminar, Denver, CO. pp. 41-54.

M.C. Archer; A.J. Divine and **B.P. Thoreson**. 1999. Irrigation Flow Data Collection, Quality Control, Flow Computation and Site Monitoring. ICID 17th Congress, Granada, Spain. Volume 1A, p.289-299.

Appendix 12. Resume for Richard Glen Allen

RICHARD GLEN ALLEN, Ph.D., P.E.

Water Resources Engineering Professor

Dept. Soil and Water Systems

UNIVERSITY of IDAHO

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September 2019

SPECIALIZATIONS:

Hydrology and Water Resources – Surface and Subsurface Systems, Modeling, Wetlands
Evapotranspiration – Remote Sensing, Calculation, Energy Balance, Wetlands, Crop Water Requirements, Climate Change Impacts, Measurement: Eddy Covariance, Bowen Ratio, Lysimeters, Scintillometers, Standardization, Quality Assessment and Quality Control
Irrigation – Water Management, Demands, System Design, Soil Water – Flow Processes
Electronic Instrumentation

DEGREES:

B.S. Agricultural Engineering, Iowa State University, November 1974
M.S. Agricultural Engineering, University of Idaho, June 1977
Ph.D. Civil Engineering, University Idaho, May 1984

PROFESSIONAL REGISTRATION:

Civil Engineer, State of Idaho, #4351, July 1981 (U.S. Citizen)

PROFESSIONAL POSITIONS:

Professor of Soil and Water Systems, December 2015 to Present. University of Idaho.
Professor of Civil Engineering and Biological and Agricultural Engineering, December 1998 to 2015. University of Idaho.
Member, Landsat Science Team, National Aeronautics and Space Administration and U.S. Geological Survey, 2006-2017.
Owner/Proprietor of Evapotranspiration, Plus, LLC (ET+) 2010 to Present.
Professor of Biological and Irrigation Engineering, May 1998 to December 1998. Utah State University.
Assistant/Associate Professor of Biological and Irrigation Engineering, January 1986 to April 1998. Utah State University.
Assistant Professor of Civil Engineering, January 1984 to December 1985. Iowa State University.
Research Associate, May 1977 to December 1983. University of Idaho.
Owner and Principal, Allen Engineering, 631 Saratoga Drive, No. 201, Twin Falls, Idaho 83301 – 2005 to present.

SIGNIFICANT PUBLICATIONS:

162 Papers in **Refereed Journals and Chapters** - primary author on 46
H-Index from the Web of Science (Jan 2018) is 40

PROFESSIONAL ORGANIZATIONS:

American Society of Civil Engineers:
Environmental and Water Resources Institute –Past Chair, Technical Committee on Evapotranspiration in Irrigation and Hydrology, Vice-Chair, Task Committee on Crop Coefficients
International Commission on Irrigation and Drainage

U.S. Representative to the Working Group on Sustainable Crops and Water Use

U.S. Committee on Irrigation and Drainage

Ex-officio Member of the National Board of Directors

American Geophysical Union
Irrigation Association - *Water Management Committee – former member*
Honoraries: Tau Beta Pi, Phi Kappa Phi, Alpha Epsilon, Chi Epsilon, Sigma Xi, Gamma Sigma Delta

PROFESSIONAL CONSULTING:

Irrigation system design, water requirements, water rights, remote sensing of evapotranspiration, hydrologic systems, hydropower, evapotranspiration, lysimeter measurement of evapotranspiration, software development, water balances, impacts of climate change on irrigation water requirements, electronic weather stations, expert witness.

INTERNATIONAL EXPERT PANELS:

Member of the **Landsat Science Team**, 2006 – 2017.
Expert Meeting on Water Security, Land and Water Development Division, United Nations Food and Agriculture Service, **Rome**, Italy, Oct. 2012.
Advisory Board, PLEIADeS Remote Sensing for Irrigation Water Management, European Union, Albacete, **Spain**, 2006 – 2009.
Advisory Board, DEMETER Remote Sensing Study for Irrigation Water Management, European Union, Albacete, **Spain**, 2002 – 2005.
Expert Meeting on Evaporation and Evapotranspiration Standardization, (U.S. Rep.), Meteorological Organization, Vozokany, **Slovakia**, May, 1995.
Intl. Expert Panel on Irrig. Res. Needs in Middle East. UN-FAO, **Cairo**, Egypt, Nov. 1994.
World Expert Consultation on Procedures for Revision of FAO Guidelines for Prediction of Crop Water Requirements. Land and Water Development Division, United Nations Food and Agriculture Service, **Rome**, Italy, May, 1990.

EXPERT WITNESS TESTIMONY AND WORK IN THE LAST SIX YEARS:

Year	Court	Client	Case	Type of Expert Work	Court appearance
2013	US Supreme Court	State of Montana	Montana v. Wyoming, N.Dakota – Tongue River	ET mapping by Satellite	Yes

OTHER INTERNATIONAL EXPERIENCE:

July 2018. **Indian National Agricultural Research Institute**, New Delhi. National training course on Satellite-based production of Evapotranspiration (METRIC and EEFlux)

Sept. 2015, Dec. 2016, Nov. 2018. **Chinese Academy of Science – Center for Agricultural Resources Research**, Shijiazhuang. Satellite-based ET mapping.

Jan. 2014. **Univ. Talca, Chile.** Advisory on application of METRIC processing to vine and tree crops.

July 2012. **Federal Univ. Bahia, Brazil.** Advisory on studies for evaporation from open water and application of METRIC to tropical vegetation.

June 2011. **King Saud Univ., Riyadh, Saudi Arabia.** Advisory on application of METRIC to the Arabian Pennisula and advisory on irrigation water management research.

Oct. 2009. **Univ. Natal, Pretoria, South Africa.** Collaboration on satellite-based sensing of evapotranspiration.

July 2005. **Cordoba, Spain**. One month visiting scientist, Centro Alameda del Obispo, Instituto de Investigación y Formación Agraria y Pesquera (IFAPA) – CICE

February 2001. **Amman, Jordan**. Irrigation specialist and advisor to Jordan Ministry of Water and Irrigation on National Water Development Plan. (US-AID)

2001, 2000, 1999, 1998, 1997. Four day guest lecturer at Institute for Infrastructure, Hydraulics, and Environment, **Delft, Netherlands**.

1995 - 2001. Various consultancy meetings with UN-FAO in Rome, Belgium, Lisbon.

October 1994. **Spain**. National Research Program Reviewer, National Irrigation Water Management Program of Spain (Zaragoza, Valencia, Badajoz, Tenerife).

April 1998, April 1999. Intercomparison Workshop on Evapotranspiration from Remote Sensing. Sponsored by Int. Water Man. Inst., **Menemen, Turkey** and **Wageningen, Netherlands**.

April-May 1998. Three week lecturer at Katholic University of Leuven**, Leuven, Belgium**.

November 1994. **Cairo, Egypt**. Int. Expert Panel on Irrigation Research. (UN-FAO)

September 1993. **Rabat, Morocco**. Review of irrigation research program of Inst. Agronomique et Veterinaire Hassan II. (USAID).

April - May 1992. **Sana'a, Yemen**. Senior Irrigation Specialist for simulation of groundwater recharge and extraction. (UNDP).

March - April 1991. Central Soil Salinity Research Institute, **Karnal, India**. Designed and installed two precision, electronic weighing lysimeter systems (2m x 2m x 2m) for evapotranspiration research and installed associated weather and data acquisition equipment. (FAO/UNDP).

May - June 1990. Participation in 12-Member Panel of International Expert Consultants on Crop Water Requirements, UN-FAO, **Rome, Italy**, revision of FAO publication ID-24.

May 1990 & Aug 1991. **Amman, Jordan**. Irrigation specialist and advisor to Jordan Ministry of Water and Irrigation on National Water Development Plan. (UNDP)

Nov. - Dec. 1989. **Peshawar, Pakistan**. Conducted a 4 week training course on irrigation principles and design (USAID).

July - Sept. 1988. **Lahore, Pakistan**. Conducted 3 week training course in Irrigation Scheduling Research. (US-AID ISM/R, Univ. Idaho)

Nov. - Dec. 1988. Central Soil Salinity Research Institute, **Karnal, India**. Instructed training course in Water Management Research. (FAO/UNDP)

NATIONAL PROGRAM REVIEWS:

2013, 2010, 2004, 2002, 2000, 1999, 1998. **Centro de Estudos de Engenharia rural (CEER) (Center for Agricultural Engineering Research)**. Instituto Superior de Agronomia, Universidade Téchica de Lisboa. Research Program Review, Lisbon, Portugal.

2008. National Programme on Remote Sensing of Evapotranspiration, **South Africa**.

February, 1999. **National Science Foundation**. Review and Site Visit, Center for Excellence in Hydrology of Arid Lands, Univ. Arizona Dept. Hydrology. Tucson, AZ.

October, 1994. **National Irrigation Water Management Program of Spain**. National Research Program Review and Site Visits (Zaragoza, Valencia, Badajoz, Tenerife).

PROFESSIONAL TASK COMMITTEES:

ASCE Task Committee on Remote Sensing of Evapotranspiration. 2012-2019.

ASCE Task Committee on Standardization of Calibration and Usage of Neutron Moisture Profile Gauges. Chair, and Vice-Chair. 1992 – 1998.

ASCE Task Committee on Standardization of Calculations for Reference Evapotranspiration. Vice-Chairman. 1999 - 2004.

ASCE Task Committee on Crop Coefficients. Vice-Chairman. 2004 - 2011.

FORMAL UNIVERSITY COURSES TAUGHT:

Engineering Hydrology (Iowa State University)
Water Resources Planning (Iowa State University)
Water Management (Utah State University)
Irrigation Engineering Principles (Utah State University)
Sprinkle and Trickle Design (Utah State University)
Physical Properties of Biological Materials (Utah State University)
Modeling Biological Systems (Utah State University)
Freshman Biological Engineering Seminar (Utah State University)

TOP FIVE SOFTWARE DEVELOPMENTS:

Allen, R.G. 1999, 2000, 2011, 2017. REF-ET Standard Reference Evapotranspiration computer model, Windows Version: User's Manual. University of Idaho, Research and Extension Center, Kimberly, ID 83341, 70 p.

Allen, R.G., M. Tasumi, R. Trezza, J. Kjaersgaard. 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2013, 2016. METRIC Evapotranspiration from Satellite – User's Manual.

Allen, R.G. and C.W. Robison. 2007-2017. ETIdaho Crop Evapotranspiration Calculation for the State of Idaho. Visual Basic code for calculating daily ET for approximately 120 weather stations in Idaho for periods of record. Univ. Idaho, Kimberly, Idaho.

Allen, R.G. and J. Huntington. 2009-2013. ETNevada Crop Evapotranspiration Calculation for the State of Nevada. Visual Basic code for calculating daily ET for approximately 100 weather stations in Nevada for periods of record. Univ. Idaho, Kimberly, Idaho and Desert Research Institute/Nevada Office of the State Engineer.

Allen, R.G. 2011-2014. ET Calculation code for the USBR Penman-Monteith (PM) Model (also referred to as the ET-Demands model). Visual Basic code for calculating daily ET for extended time periods over large regions using weather station data. The ET calculation code has been incorporated with a graphical interface by the US Bureau of Reclamation, Denver Technical Center.

PROFESSIONAL AWARDS:

(in reverse chronological order)

The **2016 Irrigation Association Person of the Year Award** for "*Outstanding contributions toward the acceptance of sound irrigation practices*"

The U.S. Dept. Interior / NASA ***William T. Pecora Award.*** **Nov. 2014** *to the* ***Landsat Science Team*** *for their contributions to study of Earth's land surface and coastal regions, and meeting the challenge of continuing and advancing the Landsat legacy of observations. Mission performance has exceeded expectations, providing more imagery, higher quality measurements, and new capabilities over previous missions.*

Outstanding Faculty Award, College of Engineering, University of Idaho. **May 2010. University of Idaho. *"For his exemplary contributions to research"***

***Innovations in American Government Award*, 2009, Ash Center for Democratic Governance and Innovation of the Harvard Kennedy School of Government, Harvard University.** *Mapping Evapotranspiration*. Award shared by the University of Idaho and Idaho Department of Water Resources. http://ash.harvard.edu/Home/News-Events/Press-Releases/Innovations/Mapping-Evapotranspiration-Wins-Innovations-Award

Best Paper Award, Am. Society Civil Engineers, Journal of Irrigation and Drainage Engineering. 2009. *(Satellite-based energy balance for mapping evapotranspiration with internalized calibration (METRIC) –I. Model, II. Applications*, R.G. Allen and others, 2007, 133(4):380-406*).* *http://www.kimberly.uidaho.edu/water/papers/remote/ASCE_JIDE_Allen_et_al_METRIC_model_2007_QIR000380.pdf*

ASCE 2005 Arid Lands Hydraulic Engineering Award, *"For his research on conjunctive management of groundwater and surface water, evapotranspiration and irrigation systems operation and design in arid lands"* May 18, 2005.

Founding Diplomate, American Academy of Water Resources Engineers, EWRI 2005

ASCE Task Committee Excellence Award: Task Committee on Standardization of Reference evapotranspiration. *"For excellence and diligence in producing a national standardization for the calculation of reference evapotranspiration that will advance engineering practice and water resources management."* May 18, 2005.

Distinguished Service Award, College of Engineering, Utah State University, 2004

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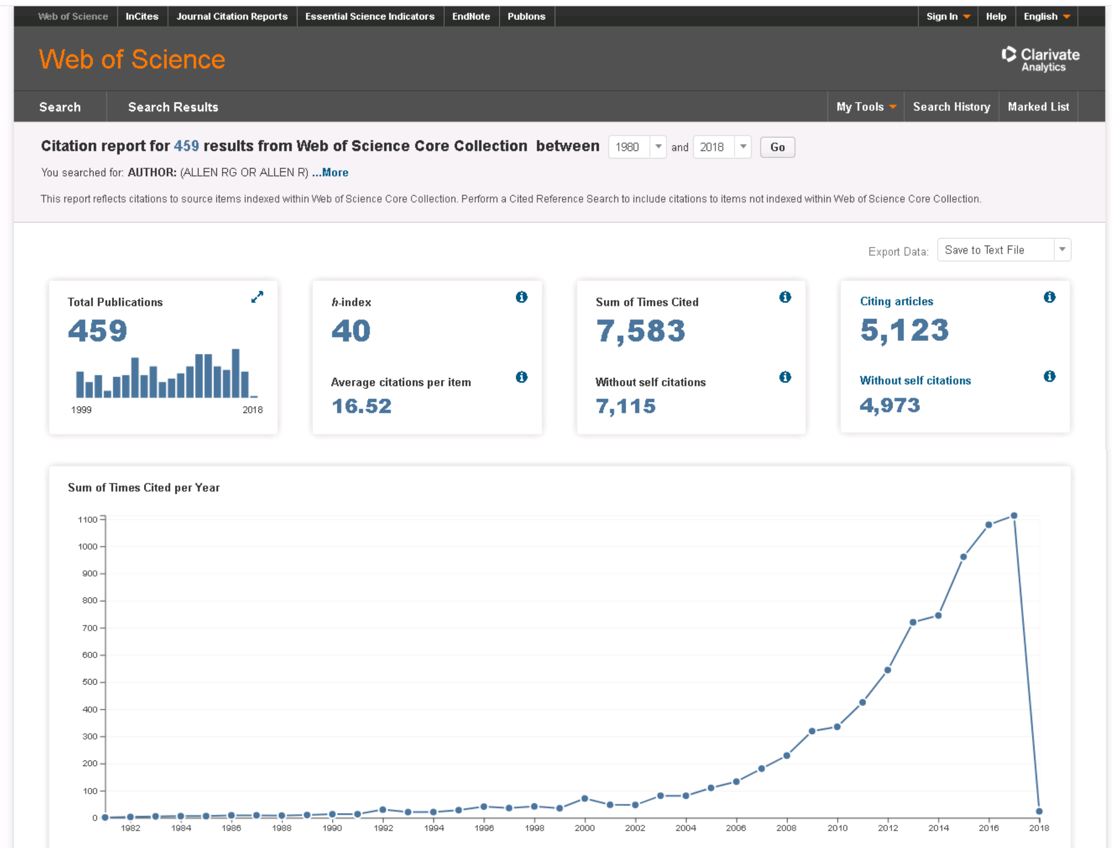
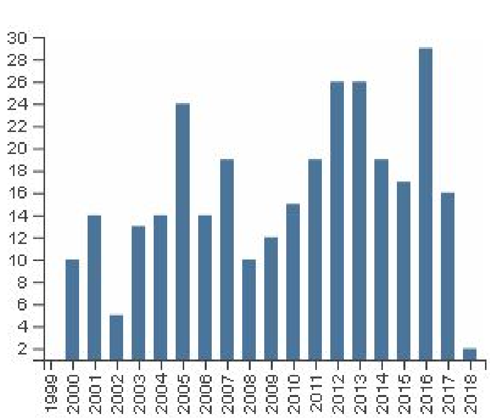
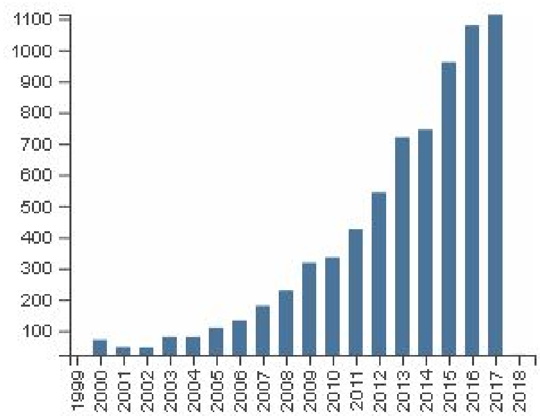
Publication H-Index:

H-Index = 40 for cited publications by R. Allen on Web of Science, Jan. 2018, meaning 40 publications have been cited 40 or more times each. 80 publications have been cited more than 10 times each, with a total of 6280 citations. When the 2998 FAO-56 publication is included, with 9680 citations, the total number of citations is 15,960.







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1. Satellite-based energy balance for mapping evapotranspiration with internalized calibration (METRIC) - Model By: Allen, Richard G.; Tasumi, Masahiro; Trezza, Ricardo JOURNAL OF IRRIGATION AND DRAINAGE ENGINEERING Volume: 133 Issue: 4 Pages: 380-394 Published: JUL-AUG 2007	58	72	58	68	1	509	42.42
2. OPERATIONAL ESTIMATES OF REFERENCE EVAPOTRANSPIRATION By: ALLEN, RG; JENSEN, ME; WRIGHT, JL; et al. AGRONOMY JOURNAL Volume: 81 Issue: 4 Pages: 650-662 Published: JUL-AUG 1989	17	21	12	17	1	370	12.33
3. Landsat-8: Science and product vision for terrestrial global change research By: Roy, D. P.; Wulder, M. A.; Loveland, T. R.; et al. REMOTE SENSING OF ENVIRONMENT Volume: 145 Pages: 154-172 Published: APR 5 2014	18	79	135	115	7	354	70.80
4. History and evaluation of Hargreaves evapotranspiration equation By: Hargreaves, GH; Allen, RG JOURNAL OF IRRIGATION AND DRAINAGE ENGINEERING Volume: 129 Issue: 1 Pages: 53-63 Published: JAN-FEB 2003	40	41	51	38	1	297	18.56
5. SEBAL model with remotely sensed data to improve water-resources management under actual field conditions By: Bastiaanssen, WGM; Noordman, EJM; Pelgrum, H; et al. JOURNAL OF IRRIGATION AND DRAINAGE ENGINEERING Volume: 131 Issue: 1 Pages: 85-93 Published: JAN-FEB 2005	29	29	25	31	0	287	20.50
6. Satellite-based energy balance for mapping evapotranspiration with internalized calibration (METRIC) - Applications By: Allen, Richard G.; Tasumi, Masahiro; Morse, Anthon; et al. JOURNAL OF IRRIGATION AND DRAINAGE ENGINEERING-ASCE Volume: 133 Issue: 4 Pages: 395-406 Published: JUL-AUG 2007	25	35	33	46	1	244	20.33
7. Evapotranspiration information reporting: I. Factors governing measurement accuracy By: Allen, Richard G.; Pereira, Luis S.; Howell, Terry A.; et al. AGRICULTURAL WATER MANAGEMENT Volume: 98 Issue: 6 Pages: 899-920 Published: APR 2011	31	54	35	54	1	230	28.75
8. A recommendation on standardized surface resistance for hourly calculation of reference ETO by the FAO56 Penman-Monteith method By: Allen, RG; Pruitt, WO; Wright, JL; et al. AGRICULTURAL WATER MANAGEMENT Volume: 81 Issue: 1-2 Pages: 1-22 Published: MAR 10 2006	17	27	23	33	0	196	15.08
9. Using the FAO-56 dual crop coefficient method over an irrigated region as part of an evapotranspiration intercomparison study By: Allen, RG JOURNAL OF HYDROLOGY Volume: 229 Issue: 1-2 Pages: 27-41 Published: MAR 27 2000	16	23	21	14	0	190	10.00
10. Assessing integrity of weather data for reference evapotranspiration estimation By: Allen, RG JOURNAL OF IRRIGATION AND DRAINAGE ENGINEERING-ASCE Volume: 122 Issue: 2 Pages: 97-106 Published: MAR-APR 1996	6	13	10	9	1	190	8.26

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12. Use of Landsat thermal imagery in monitoring evapotranspiration and managing water resources By: Anderson, Martha C.; Allen, Richard G.; Morse, Anthony; et al. REMOTE SENSING OF ENVIRONMENT Volume: 122 Special Issue: SI Pages: 50-65 Published: JUL 2012	25	30	32	41	0	146	20.86
13. Estimating crop coefficients from fraction of ground cover and height By: Allen, Richard G.; Pereira, Luis S. IRRIGATION SCIENCE Volume: 28 Issue: 1 Special Issue: SI Pages: 17-34 Published: NOV 2009	20	26	22	24	2	138	13.80
14. A PENMAN FOR ALL SEASONS By: ALLEN, RG JOURNAL OF IRRIGATION AND DRAINAGE ENGINEERING-ASCE Volume: 112 Issue: 4 Pages: 348-368 Published: NOV 1986	9	3	7	8	0	132	4.00
15. SELF-CALIBRATING METHOD FOR ESTIMATING SOLAR RADIATION FROM AIR TEMPERATURE By: Allen, Richard G. JOURNAL OF HYDROLOGIC ENGINEERING Volume: 2 Issue: 2 Pages: 56-67 Published: APR 1997	8	10	17	4	0	125	5.68
16. Comparison of reference evapotranspiration calculations as part of the ASCE standardization effort By: Itenfisu, D; Elliott, RL; Allen, RG; et al. JOURNAL OF IRRIGATION AND DRAINAGE ENGINEERING Volume: 129 Issue: 6 Pages: 440-448 Published: NOV-DEC 2003	16	10	9	6	0	107	6.69
17. Increasing productivity in irrigated agriculture: Agronomic constraints and hydrological realities By: Perry, Chris; Steduto, Pasquale; Allen, Richard. G.; et al. AGRICULTURAL WATER MANAGEMENT Volume: 96 Issue: 11 Pages: 1517-1524 Published: NOV 2009	22	14	11	14	0	102	10.20
18. Computation of ETo under nonideal conditions By: Jensen, DT; Hargreaves, GH; Temesgen, B; et al. JOURNAL OF IRRIGATION AND DRAINAGE ENGINEERING-ASCE Volume: 123 Issue: 5 Pages: 394-400 Published: SEP-OCT 1997	13	8	7	7	0	97	4.41
19. Dynamics of reference evapotranspiration in the Bolivian highlands (Altiplano) By: Garcia, M; Raes, D; Allen, R; et al. AGRICULTURAL AND FOREST METEOROLOGY Volume: 125 Issue: 1-2 Pages: 67-82 Published: SEP 20 2004	8	13	13	10	0	92	6.13
20. An intercomparison of three remote sensing-based surface energy balance algorithms over a corn and soybean production region (Iowa, US) during SMACEX By: Choi, Minha; Kustas, William P.; Anderson, Martha C.; et al. AGRICULTURAL AND FOREST METEOROLOGY Volume: 149 Issue: 12 Special Issue: SI Pages: 2082-2097 Published: DEC 4 2009	13	12	11	18	0	88	8.80

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22.	Evapotranspiration: Concepts and future trends By: Pereira, LS; Perrier, A; Allen, RG; et al. JOURNAL OF IRRIGATION AND DRAINAGE ENGINEERING Volume: 125 Issue: 2 Pages: 45-51 Published: MAR-APR 1999	10	6	8	9	0	85	4.25
23.	Satellite-based ET estimation in agriculture using SEBAL and METRIC By: Allen, Richard; Irmak, Ayse; Trezza, Ricardo; et al. HYDROLOGICAL PROCESSES Volume: 25 Issue: 26 Special Issue: SI Pages: 4011-4027 Published: DEC 30 2011	8	13	21	22	0	80	10.00
24.	Software for missing data error analysis of Penman-Monteith reference evapotranspiration By: Annandale, JG; Jovanovic, NZ; Benade, N; et al. IRRIGATION SCIENCE Volume: 21 Issue: 2 Pages: 57-67 Published: MAR 2002	14	9	12	5	0	79	4.65
25.	Daily grass and alfalfa-reference evapotranspiration estimates and alfalfa-to-grass evapotranspiration ratios in Florida By: Irmak, S; Allen, RG; Whitty, EB JOURNAL OF IRRIGATION AND DRAINAGE ENGINEERING Volume: 129 Issue: 5 Pages: 360-370 Published: SEP-OCT 2003	10	6	10	2	0	78	4.88
26.	Satellite-based energy balance to assess with in-population variance of crop coefficient curves By: Tasumi, M; Allen, RG; Trezza, R; et al. JOURNAL OF IRRIGATION AND DRAINAGE ENGINEERING Volume: 131 Issue: 1 Pages: 94-109 Published: JAN-FEB 2005	9	8	3	6	0	76	5.43
27.	Crop evapotranspiration estimation with FAO56: Past and future By: Pereira, Luis S.; Allen, Richard G.; Smith, Martin; et al. AGRICULTURAL WATER MANAGEMENT Volume: 147 Special Issue: SI Pages: 4-20 Published: JAN 1 2015	0	7	27	37	1	72	18.00
28.	Twenty-five years modeling irrigated and drained soils: State of the art By: Bastiaanssen, W. G. M.; Allen, R. G.; Droogers, P.; et al. AGRICULTURAL WATER MANAGEMENT Volume: 92 Issue: 3 Pages: 111-125 Published: SEP 16 2007	6	8	9	5	0	69	5.75
29.	At-surface reflectance and albedo from satellite for operational calculation of land surface energy balance By: Tasumi, Masahiro; Allen, Richard G.; Trezza, Ricardo JOURNAL OF HYDROLOGIC ENGINEERING Volume: 13 Issue: 2 Pages: 51-63 Published: FEB 2008	8	11	18	11	0	67	6.09
30.	Analytical integrated functions for daily solar radiation on slopes By: Allen, Richard G.; Trezza, Ricardo; Tasumi, Masahiro AGRICULTURAL AND FOREST METEOROLOGY Volume: 139 Issue: 1-2 Pages: 55-73 Published: SEP 21 2006	8	9	10	11	0	67	5.15

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32. FAO-24 REFERENCE EVAPOTRANSPIRATION FACTORS By: ALLEN, RG; PRUITT, WO JOURNAL OF IRRIGATION AND DRAINAGE ENGINEERING-ASCE Volume: 117 Issue: 5 Pages: 758-774 Published: SEP-OCT 1991	6	4	4	5	0	65	2.32
33. Adjusting temperature parameters to reflect well-watered conditions By: Temesgen, B; Allen, RG; Jensen, DT JOURNAL OF IRRIGATION AND DRAINAGE ENGINEERING-ASCE Volume: 125 Issue: 1 Pages: 26-33 Published: JAN-FEB 1999	8	4	4	4	1	60	3.00
34. Measuring versus estimating net radiation and soil heat flux: Impact on Penman-Monteith reference ET estimates in semiarid regions By: Gavilan, Pedro; Berengena, Joaquin; Allen, Richard G. AGRICULTURAL WATER MANAGEMENT Volume: 89 Issue: 3 Pages: 275-286 Published: MAY 10 2007	3	9	8	4	0	53	4.42
35. RATIONAL USE OF THE FAO BLANEY-CRIDDLE FORMULA By: ALLEN, RG; PRUITT, WO JOURNAL OF IRRIGATION AND DRAINAGE ENGINEERING-ASCE Volume: 112 Issue: 2 Pages: 139-155 Published: MAY 1986	5	3	6	4	0	53	1.61
36. Implementing the dual crop coefficient approach in interactive software. 1. Background and computational strategy By: Rosa, Ricardo D.; Paredes, Paula; Rodrigues, Goncalo C.; et al. AGRICULTURAL WATER MANAGEMENT Volume: 103 Pages: 8-24 Published: JAN 2012	8	12	8	10	1	48	6.86
37. Selection for drought resistance in dry bean landraces and cultivars By: Munoz-Perea, Carlos German; Teran, Henry; Allen, Richard G.; et al. CROP SCIENCE Volume: 46 Issue: 5 Pages: 2111-2120 Published: SEP-OCT 2006	2	6	3	5	0	48	3.69
38. Evaporation research: Review and interpretation By: Burt, CM; Mutziger, AJ; Allen, RG; et al. JOURNAL OF IRRIGATION AND DRAINAGE ENGINEERING Volume: 131 Issue: 1 Pages: 37-58 Published: JAN-FEB 2005	3	4	9	4	0	43	3.07
39. Predicting daily net radiation using minimum climatological data By: Irmak, S; Irmak, A; Jones, JW; et al. JOURNAL OF IRRIGATION AND DRAINAGE ENGINEERING-ASCE Volume: 129 Issue: 4 Pages: 256-269 Published: JUL-AUG 2003	5	4	4	2	0	41	2.56
40. HYDRAULICS OF IRRIGATION LATERALS - COMPARATIVE-ANALYSIS By: SCALOPPI, EJ; ALLEN, RG JOURNAL OF IRRIGATION AND DRAINAGE ENGINEERING-ASCE Volume: 119 Issue: 1 Pages: 91-115 Published: JAN-FEB 1993	4	1	0	2	0	41	1.58

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	745	961	1079	1113	24	7583	199.55
41. Satellite-based ET mapping to assess variation in ET with timing of crop development By: Tasumi, Masahiro; Allen, Richard G. AGRICULTURAL WATER MANAGEMENT Volume: 88 Issue: 1-3 Pages: 54-62 Published: MAR 16 2007	3	5	4	3	0	40	3.33
42. Integrating satellite-based evapotranspiration with simulation models for irrigation management at the scheme level By: Santos, C.; Lorite, I. J.; Tasumi, M.; et al. IRRIGATION SCIENCE Volume: 26 Issue: 3 Pages: 277-288 Published: MAR 2008	7	6	4	5	0	39	3.55
43. Implementing the dual crop coefficient approach in interactive software: 2. Model testing By: Rosa, Ricardo D.; Paredes, Paula; Rodrigues, Goncalo C.; et al. AGRICULTURAL WATER MANAGEMENT Volume: 103 Pages: 62-77 Published: JAN 2012	5	11	8	1	0	34	4.86
44. Estimating evaporation from bare soil and the crop coefficient for the initial period using common soils information By: Allen, RG; Pruitt, WO; Raes, D; et al. JOURNAL OF IRRIGATION AND DRAINAGE ENGINEERING Volume: 131 Issue: 1 Pages: 14-23 Published: JAN-FEB 2005	2	6	6	3	0	34	2.43
45. Standardized ASCE Penman-Monteith: Impact of sum-of-hourly vs. 24-hour timestep computations at reference weather station sites By: Irmak, S; Howell, TA; Allen, RG; et al. TRANSACTIONS OF THE ASAE Volume: 48 Issue: 3 Pages: 1063-1077 Published: MAY-JUN 2005	2	3	4	4	0	32	2.29
46. Assessment of reference evapotranspiration methods in semi-arid regions: Can weather forecast data be used as alternate of ground meteorological parameters? By: Er-Raki, S.; Chehbouni, A.; Khabba, S.; et al. JOURNAL OF ARID ENVIRONMENTS Volume: 74 Issue: 12 Pages: 1587-1596 Published: DEC 2010	5	6	7	5	0	31	3.44
47. EVAPOTRANSPIRATION FROM ISOLATED STANDS OF HYDROPHYTES - CATTAIL AND BULRUSH By: ALLEN, RG; PRUEGER, JH; HILL, RW TRANSACTIONS OF THE ASAE Volume: 35 Issue: 4 Pages: 1191-1198 Published: JUL-AUG 1992	5	0	1	0	0	31	1.15
48. LOW-COST ELECTRONIC WEIGHING LYSIMETERS By: ALLEN, RG; FISHER, DK TRANSACTIONS OF THE ASAE Volume: 33 Issue: 6 Pages: 1823-1833 Published: NOV-DEC 1990	4	0	1	2	0	31	1.07
49. Evapotranspiration information reporting: II. Recommended documentation By: Allen, Richard G.; Pereira, Luis S.; Howell, Terry A.; et al. AGRICULTURAL WATER MANAGEMENT Volume: 98 Issue: 6 Pages: 921-929 Published: APR 2011	3	8	6	8	0	30	3.75
50. Evaluation of multidecadal variability in CMIP5 surface solar radiation and inferred underestimation of aerosol direct effects over Europe, China, Japan, and India By: Allen, R. J.; Norris, J. R.; Wild, M. JOURNAL OF GEOPHYSICAL RESEARCH-ATMOSPHERES Volume: 118 Issue: 12 Pages: 6311-6336 Published: JUN 27 2013	6	9	8	6	0	29	4.83

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McCabe, J., J. Ossa, **R.G. Allen**, B. Carleton, B. Carruthers, C. Corcos, T. A. Howell, R. Marlow, B. Mecham, T. L. Spofford. 2003. Turf and Landscape Irrigation Best Management Practices. September 2003 edition. Irrigation Association – Water Management Committee. 48 pages. http://www.irrigation.org/PDF/IA_BMP_SEPT_2003_DRAFT.pdf

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Allen, R.G. AND C.W. Robison. 2004. Comparison of ET by METRIC™ with Canal System Diversions. Report submitted to the Twin Falls Canal Company, Twin Falls, Idaho. 15 p.

Allen, R.G., M. Tasumi and R. Trezza. 2005. METRIC: Mapping evapotranspiration at high resolution. Applications manual for Landsat satellite imagery. version 2.0. University of Idaho Kimberly Research and Extension Center, 130 p.

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Allen, **R.G.,** C.W. Robison, M. Tasumi, R. Trezza, I. Lorite Torres, and C.N. Kelly. 2006. The Change in Total Evaporation and Water Consumption from the American Falls Reservoir Reach following the Creation and Filling of the Reservoir. University of Idaho Research and Extension Ctr. Report submitted to the Idaho Department of Water Resources. 75 p.

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Trezza, Ricardo, **Richard Allen**, Jeremy Greth, and C.W. Robison. 2015. Report on the Calibration of Evapotranspiration Maps from Landsat Images for the Eastern Snake Plain Region, Paths 39 and 40, Idaho for Year 1992 using the METRIC Model. Report submitted to Idaho Department of Water Resources by the University of Idaho.

Kelly, Carlos, Jeremy Greth, Ricardo Trezza, **Richard Allen**, and C.W. Robison. 2015. Report on the Production of Evapotranspiration Maps from Landsat Images for the Eastern Snake Plain Region, Paths 39 and 40, Idaho for Year 2011 using the METRIC Model. Report submitted to Idaho Department of Water Resources by the University of Idaho

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Robison, C.W., R. Trezza, **R.G. Allen**, B. Urie and J. Stewart. 2018. Report on the Production of Near-Real-Time Evapotranspiration Maps using the METRIC Model for the Eastern Snake Plain Region, Idaho April -- October 2017 – Final report submitted to Idaho Department of Water Resources by University of Idaho, Kimberly, Idaho

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W. Zhao, **R.G. Allen**, C.W. Robison, Q. Huang and R. Trezza. 2018. Report on the Production of Evapotranspiration Maps using the METRIC^{tm} Model for the Treasure Valley Region, Idaho -- March -- October 2007. Report submitted to Idaho Department of Water Resources

RECENT PRESENTATIONS

Allen, R.G. June 2018. Status on METRIC applications with ECOSTRESS thermal data. ECOSTRESS annual meeting, Cape Canaveral, Florida.

Allen, R.G. and A. Kilic. Sept. 2018. Production of Spatial Water Consumption via the Web. New Mexico Water Law Conference, Santa Fe, NM.

Allen, R.G. Nov. 2018. Evapotranspiration tools – METRIC and EEFlux with applications in the USA. Invited speaker at Graduate Student Seminar, Guangxi Teachers Education University, Nanning, China.

Allen, R.G. Nov. 2018. Hydrological Impacts of Water Conservation in Irrigation. International Meeting on Precision in Agriculture and Remote Sensing. Chinese Academy of Science, Shijiazhuang, China.

Allen, R.G. Dec. 2018. Developing maps of Water Consumption in Idaho. Annual Meeting of the Idaho Farm Bureau, Boise, Idaho.

Allen, R.G. Dec. 2017. Evapotranspiration mapping for water management – METRIC and EEFlux applications in the USA. Invited keynote presentation at the 2017 Silk Road Innovation Forum on Surveying, Remote Sensing and Geographical Information Sciences (IFSRG), Xi'an, China.

Allen, R.G. Dec. 2017. The University of Idaho METRIC ET mapping process and Google EEFlux – model and applications. Seminar presented to the Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing, China.

Allen, R.G., A. Kilic and R. Trezza. Nov. 2017. The METRIC model for surface energy balance-derived ET from Landsat imagery and the importance of calibration and accuracy for water management in operational agricultural decision-making. Annual Meeting of the American Society of Agronomy, Tampa, FL. Invited Speaker, with abstract.

Allen, R.G. and A. Kilic. Oct. 2017. Google Earth Engine App for Residential Water Use and Preservation --- GEARUP ---. International Conference on Innovations in Irrigated Agriculture, Fortaleza, Brazil. Invited Speaker.

Kilic, A. and **R.G. Allen**. Oct. 2017. Google Earth Engine Evapotranspiration Flux --- EEFlux: - Application, Parameterization, Accuracy, Challenges and Successes. International Conference on Innovations in Irrigated Agriculture, Fortaleza, Brazil. Invited Speaker.

Allen, R.G. and W. Zhao. August 2017. METRIC results for the Treasure Valley Region. Presentation to the Treasure Valley Groundwater Modeling Committee. IDWR, Boise.

Allen, R.G. and A. Kilic. July 2017. Status Update on EEFlux Google Application. Presentation to the Landsat Science Team, Sioux Falls, SD.

Allen, R.G. and C.W. Robison. July 2017. Status on ETIdaho Update. Presentation to the Eastern Snake River Plain Hydrologic Modeling Committee. IDWR, Boise.

Allen, R.G., June 2017. METRIC, SEBAL and Google EEFlux Models for Spatial Evapotranspiration at the Field Scale. New Mexico Conference on Evapotranspiration, Las Cruces, NM. Invited Speaker. With Abstract.

Allen, R.G. and A. Kilic. May 2017. ECOSTRESS METRIC Evapotranspiration Algorithm. ECOSTRESS Science Team meeting, Davis, CA. Invited Speaker.

Allen, R.G., C. Robison, A. Kilic, and R. Trezza. 2016. A Technique to Retain Original Georegistration Accuracy of VIIRS Imagery for use at Landsat Scales. Presentation to the Landsat Science Team, January 12-14, 2016, Blacksburg, VA. (invited)

Allen, R.G., A. Kilic and J. Huntington. 2016. METRIC/EEFlux - Application, Parameterization, Accuracy, Challenges, Successes. Presentation at the Remote Sensing of Evapotranspiration Workshop, Davis, CA, February 10, 2016. (invited)

Allen, R.G., A. Kilic and J. Huntington. 2016. METRIC/EEFlux - Application, Parameterization, Accuracy, Challenges, Successes. Presentation at the Remote Sensing of Water Consumption Workshop for Philanthropic Organizations, Technology Companies, and Key Decision Makers. NASA Ames, Mountain View, CA, March 24-25, 2016. (invited)

Allen, R.G. and A. Kilic. 2016. Landsat-based (Field-Scale) Evapotranspiration Estimates - METRIC Overview and Applications. Seminar presented to the NASA Applied Remote Sensing Training Program (ARSET) -- SMAP and ET Applications Webinar series, September 22, 2016. (invited)

Allen, R.G. and M.E. Jensen. 2016. ASCE Manual on Evapotranspiration. USCID 9th International Conference on Irrigation and Drainage, October 11-14, 2016, Fort Collins, CO. (invited)

Allen, R.G. and A. Kilic. 2016. EEFlux: Google Earth Engine ET — ET Maps for the Public — Current Status. USCID 9th International Conference on Irrigation and Drainage, October 11-14, 2016, Fort Collins, CO. (invited)

Allen, R.G. Adapting Crop Coefficients for Local Conditions. USCID 9th International Conference on Irrigation and Drainage, October 11-14, 2016, Fort Collins, CO. (invited)

Allen, R.G. and A. Kilic, Applications of Remote Sensing for Evapotranspiration in the USA at Landsat Spatial Scales for Agricultural Water Management and to Support Climate Change Research Univ. Talca, Chile, Water Resources Seminar Series. Invited Speaker, Jan. 2014.

Allen, R.G. Remote Sensing for Evapotranspiration in Idaho at Field Spatial Scales for Agricultural Water Management. Idaho Agricultural Appraisers Meeting, Twin Falls, ID, Feb. 2014 Featured Speaker.

Allen, R.G. and R. Trezza. Determining Evapotranspiration Coefficients (Crop Coefficients) from Satellite-based Energy Balance, INOVAGRI International Innovations in Irrigation Conference, Fortaleza, Brazil. Invited Speaker. April 2014.

Kilic, A., **Allen, R.G.** and J. Huntington. Landsat Energy Balance in Managing Water Consumption. Landsat Science Team meeting. EROS Center, USGS, Sioux Falls. July 2014

Allen, R.G. ECOSTRESS METRIC Evapotranspiration Algorithm, HyspIRI TQ3 Science Support. HyspIRI Science Meeting, Jet Propulsion Lab, Pasadena, CA, Oct 2014.

Where the Water Goes: Retrieving Evapotranspiration from Landsat's Thermal Imager. GIS Day, Univ. Idaho, Moscow, ID. Invited Speaker, Nov. 2014.

Hendrickx, J.; Umstot T.; Stephens, D.; Wilson, J.; **Allen, R**.; Trezza, R. Remote sensing of soil water storage capacity using the LANDSAT and MODIS Images archive, 2014. AGU-Fall Meeting. San Francisco, 15-19 December 2014,

Geli, H; Neale, C.; Verdin, J.; Senay, G.; **Allen, R**.; Trezza, R.; Ershadi, A.; McCabe, M.; Elhaddad, A.; Yan, Y.; Anderson, M. Intercomparison of remote sensing models for estimating daily and seasonal evapotranspiration. 2014. AGU-Fall Meeting. San Francisco, 15-19 December 2014

Allen, R.G. and Trezza, R. The application of METRIC in the Palo Verde Irrigation District. USU/USGS Workshop on Estimating Crop Water Use with Remote Sensing. 2014. June 31th. USGS/USU Intercomparison of Remote Sensing of ET Workshop. Department of Civil and Environmental Engineering. Logan, Utah.

Allen, R.G. 2008. Evapotranspiration from Satellite. CSIR of South Africa. Pietermaritzberg and Stellenbosch. October 2008.

Allen, R.G. 2009. Water Science and Research Issues associated with the Future of Water for Food. Featured speaker in Water for Food: First Annual International Conference. Lincoln, Nebraska, May, 2009.

SOFTWARE DEVELOPMENT

Allen, R.G. 1988, 1991. IRRISKED irrigation scheduling computer model user's manual. Dept. Biol. and Irrig. Engrg, Utah State University, 189 p.

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Allen, R.G. 1989, 1991. REF-ET Standard Reference Evapotranspiration computer model user's manual. Dept. Biol. Irrig. Engrg, Utah State University, 40 p.

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Allen, R.G. 2011-2014. ET Calculation code for the USBR Penman-Monteith (PM) Model (also referred to as the ET-Demands model). Visual Basic code for calculating daily ET for extended time periods over large regions using weather station data. The ET calculation code has been incorporated with a graphical interface by the US Bureau of Reclamation, Denver Technical Center.

Ph.D. Students Supervised as Major Professor

Name	Date of Degree	Dissertation Title
Carlos Hernandez-Yanez	1990	A time-series-based planning model for management of grass and beef production
Paul Vanderkimpen	1991	Estimation of crop evapotranspiration by means of the Penman-Monteith equation
Majid Mirlatifi	1991	Quantification of aerodynamic and canopy resistance terms for estimating reference evapotranspiration
Wigdan Ahmad	1991	Evaporation and transpiration as related to subsurface flow
John Prueger	1992	Evapotranspiration from isolated stands of hydrophytes: cattail and bulrush
Camilo Andrade	1997	Pressure and discharge distribution simulation in pressurized irrigation systems
Daniel Itenfisu	1997	Direct application of resistance-based evapotranspiration methods to row crops
Ricardo Trezza	2002	Evapotranspiration using a satellite-based surface energy balance with standardized ground control
Masahiro Tasumi	2003	Progress in operational estimation of regional evapotranspiration using satellite imagery
Maria Gloria Romero	2003	Daily evapotranspiration estimation from instantaneous values by means of evaporative fraction and reference evapotranspiration fraction
Ramesh Dhungel	2014	Interpolation between satellite overpass dates using the Penman-Monteith method

M.S. Students Supervised as Major Professor

Name	Date of Degree	Thesis Title
Mohammed Al-Thamary	1987	Evaluating irrigation uniformity of a side roll sprinkler system under various catch can spacings
Shadab Shadzad	1988	Estimation of weather parameters required in evapotranspiration calculations
Hossein Moazami	1988	Infiltration rate and times of ponding under a rainfall sprinkler simulator and double ring infiltrometer
Daniel Segura	1989	Effect of the microenvironment on soil-moisture determination by a neutron moisture meter
Joao Costa	1989	The irrigation design toolbox computer application
Gerald Fernandez	1989	Development of a computer model for diagnostic analysis of sprinkler and pumping systems
Naglaa Eid	1990	Evaluation of the Shany method for estimating the hydraulic properties of soil
D. Ken Fisher	1990	Evaluating performance of electronic weighing lysimeters
Walkyria Gonzalez	1991	Runoff and uniformities under gridded sprinkler systems

Eugenia Molina	1991	Simulation model to predict operating pressures and flow rates for a sprinkler system in operation
Luis Olivarez	1991	Refinement of computer software for hydraulic analysis of sprinkle irrigation systems
Abdulhadi Alghori	1992	Development of insulative covers for surface mounted lysimeter load cells
Bekele Temesgen	1995	Temperature and humidity data correction for calculating reference evapotranspiration at nonreference weather stations
Shrikanth Vemulapali	1996	Wetland evapotranspiration (nonthesis opt.)
Yaseen Al-Mula	1997	Interactive software for design of laterals and tapered manifolds for trickle irrigation systems
Christopher Bright	2001	Evapotranspiration from wetland communities (did not complete)
Patrick Ferrell	2004	Impacts of reservoir level change on landslope stability in the Hagermann National Monument, Idaho
Brock Dillé	2004	Impacts of irrigation and ground-water on spring flows and landslope stability in the Hagermann National Monument, Idaho
Boyd Burnett	2007	Influence of evaporation from soil during estimation of evapotranspiration from vegetation indices
Bibha Dhungara	2012	A look at conditioning of arid weather data - nonthesis
John Stewart	2016	QAQC of energy balance fluxes from pine forest and grasslands and comparisons with satellite-based retrievals.

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Allen, R.G. 1977. Water Quality Management with Controlled Furrow Irrigation Flow Rates. M.S. Thesis, Dept. Ag. Engineering, Univ. Idaho, 150 pages.

Allen, R.G., J. R. Busch, D. W. Fitzsimmons and G. L. Lewis. 1977. Management of Irrigation Stream Size for Improved Water Quality. ASAE Paper 77-2570. Presented at the 1977 Winter Meeting ASAE, Chicago, IL, 10 pages.

Busch, J.R., **R. G. Allen**, and C. E. Brockway, October 1978. Irrigation Rehabilitation Plans in the Teton Flood Area. Paper presented at Annual Meeting, ASCE, Chicago, IL, 18 pages.

Brockway, C.E., **R.G. Allen**, and J. R. Busch. 1979. Optimal Irrigation System Subject to Available Resource Constraints. Paper presented at IX Congress of CIGR, Michigan State University, 11 pages.

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Allen, R.G. and C. E. Brockway. 1983. Estimating Consumptive Use on a Statewide Basis. Proceedings of the 1983 Specialty Conference, Irrigation and Drainage Division, American Society of Civil Engineers, Jackson Hole, WY p. 79-89.

Allen, R.G. and J. L. Wright. 1983. Variation Within the Measured and Estimated Consumptive Use Requirements. Proceedings of the 1983 Specialty Conference, Irrigation and Drainage Division, American Society of Civil Engineers, Jackson Hole, WY p. 1-12.

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Allen, R.G. and D. Segura. 1990. Access Tube Characteristics and Neutron Meter Calibration. Proceedings of the 1990 National Conference on Irrigation and Drainage Engineering, ASCE, S. Harris (ed) pp.21-31.

Wells, R.D. and **R.G. Allen**. 1990. Practical Approaches used in Neutron Moisture Monitoring. Proceedings of the 1990. National Conference on Irrigation and Drainage Engineering, ASCE, S. Harris (ed) pp. 218-225.

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May 31, 2019

EXPERT REPORT OF:
Scott A. Miltenberger, Ph.D.

In the matter of:

No. 141, Original
In the Supreme Court of the United States
State of Texas v. State of New Mexico and State of Colorado

Prepared for:

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Introduction

I, Scott A. Miltenberger, Ph.D., am a partner at JRP Historical Consulting, LLC (JRP), located at 2850 Spafford Street, Davis, California. This expert report was prepared by me for Somach Simmons & Dunn, attorneys representing the State of Texas before the Supreme Court of the United States in *State of Texas v. State of New Mexico and State of Colorado*, No. 141, Original. I have been asked to provide opinions on the following questions regarding the Rio Grande Compact of 1938 and its historical interpretation:

1. What was the purpose of the 1938 Rio Grande Compact?
2. Did the amount of water apportioned to Texas by the 1938 Rio Grande Compact include water to address water quality concerns on Rio Grande Project lands in Texas?
3. What comprised the water supply for the Rio Grande Project, circa 1938?
4. What did delivery of water by the State of New Mexico to San Marcial, under the terms of the 1938 Rio Grande Compact, constitute?
5. Did the 1938 Rio Grande Compact limit the uses to which water in the Upper Rio Grande Basin could be put?
6. Did the Special Master fairly describe the background history leading to the 1938 Rio Grande Compact on pages 31 through 187 and 203 through 209 of the *First Interim Report of the Special Master*, dated February 9, 2017?

In addressing these questions, I have relied upon my education and nearly 13 years of experience as a professional historian, primarily of western water and land use, as well as my review and analysis of archival documents, published sources, and academic monographs. Together with my former business partner (now retired) Mr. Stephen Wee and JRP staff under my direction (all of whom possess graduate degrees in history), I undertook research and collected historical material from a number of federal, state, and local repositories. These include: the National Archives in Washington, DC, at College Park, Maryland, at Denver, Colorado, and at Fort Worth, Texas; the Dolph Briscoe Center for American History at The University of Texas at Austin; the Texas State Archives in Austin; the C.L. Sonnichsen Special Collections Department of the University of Texas at El Paso; the El Paso Historical Society; the New Mexico State Archives in Santa Fe; the University of New Mexico Special Collections in Albuquerque; the New Mexico State University Archives and Special Collections in Las Cruces; History Colorado (formerly the Colorado Historical Society) in Denver; the Water Resource Archives at Colorado State University, Fort Collins; the American Heritage Center at the University of Wyoming in Laramie; the Water Resources Collections and Archives at the University of California, Riverside; and the Harvard Law School Library, Historical and Special Collections, in Cambridge, Massachusetts. I also examined documents produced by the states of Texas, Colorado, and New Mexico, and the United States in this action as well as the materials appended to the *First Interim Report of the Special Master*.

Initial review of these documents was a collaborative effort between Mr. Wee and myself, but I am the sole author of this expert report. My current (as of May 31, 2019) resume is included in the **Appendix** to this report.

My compensation for this matter is $154 per hour for time spent in research, analysis, and preparation of this expert report. My compensation for deposition and trial testimony is $308. A list of cases for which I have provided expert testimony at deposition or trial over the past four years is included in my resume, along with a list of my publications in the previous 10 years.

As indicated above, I have based my opinions on primary and secondary sources known to me, gathered by me or those under my direction, or produced in this action. Those sources are cited in the history profession's preferred footnote citation format as detailed in the *Chicago Manual of Style*. There are other documents that support my opinions which are not cited herein. In the interests of brevity and to avoid repetition, I have chosen to discuss the historical evidence that most directly informs my responses to the questions posed to me. If any other historical material is presented or made known to me, or if I review any additional documents, it may have some effect on the specific opinions offered herein.

Opinion I: The purpose of the 1938 Rio Grande Compact was to protect the water supply of the federal Rio Grande Project while making possible new water developments in Colorado and New Mexico above the project's Elephant Butte Reservoir by equitably apportioning the waters of the Upper Rio Grande Basin among the states of Colorado, New Mexico, and Texas.

Since the 1880s, the Rio Grande had been a source of international and interstate conflict with the US and Mexico, and Colorado, New Mexico, and Texas each making claims to the river's waters. The Rio Grande Project, authorized in 1905, offered a partial solution by delivering water via its Elephant Butte Reservoir to Mexico under the terms of a 1906 treaty, and to lands in southern New Mexico and western Texas that had been deprived by upstream diversions near the river's headwaters. The so-called Rio Grande "embargo," enacted to prevent further upstream diversions from inflaming international tensions until a settlement with Mexico could be negotiated, supported the project's development into the 1920s yet restricted further utilization of the Rio Grande above Elephant Butte. Revocation of the embargo in 1925 created momentum for the negotiation of a tristate compact, with Colorado seeking the opportunity to develop its own water resources projects comparable to the Rio Grande Project. Texas and New Mexico, while not entirely opposed to Colorado, nonetheless sought to safeguard not only the water necessary for the federal reclamation project but also for Texas, the water necessary for lands down to Fort Quitman. Texas and New Mexico's subsequent dispute over the Middle Rio Grande Conservancy District's proposed development above Elephant Butte created further urgency for a compact in the mid-1930s and precipitated the federal Rio Grande Joint Investigation. With data gathered by federal engineers, the engineering advisors for three states recognized that in the absence of additional water being imported into the Upper Rio Grande Basin the usable water supply was limited. They therefore devised two water delivery schedules that became the foundation for the compact – one for Lobatos, near the Colorado-New Mexico state line, and another for San Marcial, above Elephant Butte Reservoir. These schedules were intended to enable water resource development in Colorado and New Mexico above Elephant Butte Reservoir without compromising the Rio Grande Project and the supply of water to lands in Texas above Ft. Quitman.

The limited availability of usable water in the Upper Rio Grande Basin spawned the international and interstate problem of equitable distribution of the Rio Grande waters. The basin is an area of approximately 34,000 square miles that stretches from the headwaters of the Rio Grande in the San Juan Mountains in Colorado southward through the narrow Rio Grande Valley in New Mexico and then southeast to Fort Quitman, Texas. Historically, it has been divided into three smaller sections: the San Luis Valley in Colorado; the Middle Rio Grande Valley between the Colorado-New Mexico state line and San Marcial, New Mexico; and the Elephant Butte-Ft. Quitman section that encompasses the area between Elephant Butte Reservoir and Ft. Quitman (roughly 80 miles downstream from El Paso).

At nearly 2,000 miles long, draining approximately 175,000 square miles before debouching into the Gulf of Mexico, the Rio Grande is the principal river within the basin. Ft. Quitman has long been recognized as a natural dividing point on the river's course. Above Ft. Quitman, nearly all of the water supply for the Rio Grande originates in Colorado and New Mexico, and by the early 1930s the river in this stretch was devoted almost entirely to irrigated agriculture. Below Ft. Quitman, numerous arroyos and tributary streams originating in Mexico feed the river for the remainder of its course.[1]

Like most western rivers under natural conditions, the Rio Grande was irregular; sustained periods of minimal or no flow were punctuated by shorter periods of high flows and even flood. Lack of precipitation in the Upper Rio Grande Basin floor historically demanded the use of the river's waters for irrigation. Native Americans in the basin had irrigated from the Rio Grande, its lesser tributaries, and intermittent basin streams long before the Spanish encountered them in the mid-sixteenth century. They cultivated wheat, corn, fruit, and flowers, principally through the use of what the Spanish identified as "acequias," or community ditches. The most historically significant of these was the so-called "Acequia Madre" located in present-day Ciudad Juarez opposite El Paso, Texas. This large diversion, which could be more than four centuries old in origin, became the centerpiece of Spanish colonization in the area in the seventeenth century.[2]

Following the signing of the Treaty of Guadalupe Hidalgo in 1848 at the end of the Mexican-American War, American settlers in Colorado's San Luis Valley began irrigating from the river. It was not until the 1880s, however, that considerable development occurred on both sides of the international border established at the Rio Grande. Many of the canal systems that predated the federal Rio Grande Project were constructed during this decade. In the immediate vicinity of Juarez and El Paso, an estimated 550 cubic feet per second (cfs, or second feet) of water was diverted to support irrigated agriculture and burgeoning populations – some 15,000 acres and nearly 10,000 people on the American side, and 25,000 acres and 20,000 people on the Mexican

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[1] National Resources Committee, *Regional Planning Part VI – The Rio Grande Joint Investigation in the Upper Rio Grande Basin in Colorado, New Mexico, and Texas 1936-1937*, vol. 1 (GPO, 1938) [hereafter *JIR*], 7; and Douglas R. Littlefield, *Conflict on the Rio Grande: Water and the Law, 1879-1939* (Norman: University of Oklahoma Press, 200), 18-19, and 33-36.

[2] *International Dam in Rio Grande River, Near El Paso, Tex.*, 54th Cong., 1st sess., 1896, H. Doc. 125, 1; and Ottamar Hamele, Special Attorney Representing the Bureau of Reclamation before the Rio Grande Commission, "The Embargo on the Upper Rio Grande," November 11, 1924, 1. 8-3 Rio Grande Distribution of Waters (Loose File), Box 1638, 8-3, Rio Grande C-D, Central Classified File 1907-1936 [hereafter CCF 1907-36], Records of the Department of the Interior, Office of the Secretary, Record Group 48 [hereafter RG 48], National Archives at College Park, Maryland [hereafter NARA II]; and *JIR*, 7.

side. Demands on the river were reportedly still greater upstream. In the Territory of New Mexico nearly 183,000 acres used 5,600 cfs, and in Colorado, roughly 122,000 acres used 3,700 cfs.[3]

As upstream diversions increased, downstream American irrigators in the Mesilla and El Paso valleys and Mexican irrigators in the vicinity of Juarez began to complain of diminished river flows. They focused their ire on Colorado's San Luis Valley, near the Rio Grande's headwaters. The Mexican government took up their citizens' complaints, arguing to the US State Department that the diversions were an abrogation of the 1848 treaty. The dispute lingered over the next decade, and while Congress authorized the president in 1890 to negotiate a resolution with Mexico, the only achievement was the creation of the joint US and Mexican International Boundary Commission (predecessor to the present International Boundary and Water Commission) to address questions of the international boundaries formed by the Rio Grande and Colorado rivers.[4]

The Rio Grande Dam and Irrigation Company's proposed dam in New Mexico ultimately brought decisive action from the US. In early 1895, under the March 3, 1891 federal right-of-way act that granted ditch and canal companies and drainage and irrigation districts a right of way through federal (public domain) lands, the secretary of the interior authorized the company to develop a reservoir site near the mountain peak of Elephant Butte, more than 100 miles upstream from El Paso and Juarez. The company, financed largely by British capital, was led by Dr. Nathan Boyd. Boyd envisioned developing much of the narrow Rio Grande Valley running through New Mexico into small, irrigated farms. When the Mexican government learned of the proposed dam, it renewed its protest. The State Department was unwilling to embrace the view articulated by the attorney general that denied any US "duty or obligation" under the 1848 treaty or international law to see that Rio Grande water reached Mexican ditches. Together with the Mexican foreign minister, Secretary of State Richard Olney directed the boundary commission to investigate the problem further. The boundary commissioners endorsed construction of an "international dam" at El Paso to resolve the international dispute, and warned that Boyd's development imperiled this dam. US commissioner Anson Mills went further, recommending that further applications for rights-of-way to appropriate water on the public domain in the Upper Rio Grande Basin be denied. Olney relayed Mills' recommendation to the Interior Department, and on December 5, 1896, Secretary of the Interior D.R. Francis directed the commissioner of the General Land Office by letter "to suspend action on any and all applications for right of way through public lands for

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[3] Hamele, "The Embargo on the Upper Rio Grande," November 11, 1924, 3. 8-3 Rio Grande Distribution of Waters (Loose File), Box 1638, CCF 1907-36, RG 48, NARA II; and *JIR*, 8.

[4] Hamele, "The Embargo on the Upper Rio Grande," November 11, 1924, 3-5. 8-3 Rio Grande Distribution of Waters (Loose File), Box 1638, CCF 1907-36, RG 48, NARA II; and Littlefield, *Conflict on the Rio Grande*, 18-32.

the purpose of irrigation by using the waters of the Rio Grande River or any of its tributaries in the State of Colorado or in the Territory of New Mexico until further instructed…."[5]

This "embargo," as it came to be known, brought private irrigation development above Elephant Butte, particularly in Colorado, almost to a halt for three decades. The embargo was modified several times, prior to its revocation in 1925. These modifications permitted some rights of way that made possible the appropriation of nearly 115,000 af in Colorado by 1923. Nearly every modification, however, safeguarded the delivery of water to Mexico under the 1906 treaty and the Rio Grande reclamation project, authorized in 1905.[6]

Coloradoans chafed at the embargo's restrictions. San Luis Valley landowners were the most vocal in their condemnation. They insisted that their irrigation works did not impair downstream developments. Valley landowners and their state representatives argued that the embargo violated both the enabling act by which Colorado was admitted to the Union, and the 1891 right-of-way act.

Federal authorities into the 1920s rejected these arguments. They maintained that the enabling act reserved unto the federal government control of public lands within Colorado, and that the secretary of the interior enjoyed "discretion" under the 1891 act to approve or disapprove of right-of-way applications in the "public interest." Congressional authorization of the Rio Grande Project, they further argued, provided "that as a condition precedent to the approval of any application, it must appear clear that the Government project will not be injured thereby."[7]

As controversial as the embargo was within the Upper Rio Grande Basin, it nevertheless fostered settlement of the international dispute between the US and Mexico and development of the Rio Grande Project. In 1897, the federal government moved against Boyd and his company, seeking

[5] Edw. A. Bowers, Assistant Commissioner, Department of the Interior, General Land Office, to Register and Receiver, Las Cruces, N. Mex., February 11, 1895, "Correspondence Touching the Protest of Mexican Citizens Against the Construction of Dams by the Rio Grande Dam and Irrigation Company," in *Equitable Distribution of the Waters of the Rio Grande. Message from the President of the United States, transmitting, in response to resolution of the Senate of February 26, 1898, reports from the Secretary of State, the Secretary of War, the Secretary of the Interior, and the Attorney-General, with accompanying papers, relative to the equitable distribution of the waters of the Rio Grande River*, 55th Cong., 2d sess, 1898, S. Doc. 229, 2-3; Hamele, "The Embargo on the Upper Rio Grande," November 11, 1924, 6, 14-15, and Exhibit E, 49. 8-3 Rio Grande Distribution of Waters (Loose File), Box 1638, CCF 1907-36, RG 48, NARA II; and Littlefield, *Conflict on the Rio Grande*, 39-40, and 46-52.

[6] Hamele, "The Embargo on the Upper Rio Grande," November 11, 1924, 15-16, and 25-28. 8-3 Rio Grande Distribution of Waters (Loose File), Box 1638, CCF 1907-36, RG 48, NARA II.

[7] Hamele, "The Embargo on the Upper Rio Grande," November 11, 1924, 29-30. 8-3 Rio Grande Distribution of Waters (Loose File), Box 1638, CCF 1907-36, RG 48, NARA II; and Littlefield, *Conflict on the Rio Grande*, 170-171.

to nullify the right-of-way for the private Elephant Butte Dam. Over the next 12 years, federal attorneys and company lawyers argued over whether the river was a navigable waterway; if the Rio Grande was navigable, as US lawyers argued, then the secretary of the interior could not issue a right-of-way under the 1891 act. Twice the US Supreme Court reversed findings made in trial court and affirmed by the New Mexico Territorial Supreme Court that favored the Rio Grande Dam and Irrigation Company, remanding the case back to the lower court. The US changed tactics for the third and final trial. Federal attorneys argued that as five years' time had elapsed for the company to begin construction with no work being done, the right-of-way had expired. Persuaded, the trial court found for the US in May 1903. Both the Territorial Supreme Court and the US Supreme Court subsequently affirmed the decision, effectively bringing the private effort to develop an Elephant Butte reservoir to end in 1909.[8]

The federal government's victory over the Rio Grande Dam and Irrigation Company coincided with a policy shift that finally brought forth a settlement with Mexico. The embargo had eased Mexican concerns, leading the US's southern neighbor to propose a treaty, but the US's own efforts to provide a physical solution to the international problem had lagged. Ongoing litigation with the private company contributed to delays, as did opposition in New Mexico. Several bills were introduced in Congress in the late 1890s and early 1900s that provided for the construction of an international dam at El Paso, and a system of distribution between the US and Mexico. Interests in New Mexico, however, reportedly opposed the idea of this dam, fearing that it would flood much of the Mesilla Valley and impede agricultural development.[9]

This was a view that the principal federal engineer responsible for the Rio Grande Project, Benjamin M. Hall, shared.[10] Passage of the National Reclamation Act of 1902 – also known as the Newlands Reclamation Act, or the Newlands Act for its sponsor Representative Francis Newlands of Nevada – established a new federal program to furnish water to arid regions of the American West. The act created the United States Reclamation Service (Reclamation), forerunner to the present Bureau of Reclamation. Reclamation initially focused on developing those Western

[8] Hamele, "The Embargo on the Upper Rio Grande," November 11, 1924, 18-19, 11, and Exhibit G, 55-56. 8-3 Rio Grande Distribution of Waters (Loose File), Box 1638, CCF 1907-36, RG 48, NARA II. The complicated legal fight between the United States and Boyd's Rio Grande Dam and Irrigation Company is discussed at length in Littlefield, *Conflict on the Rio Grande*, 56-78.

[9] Hamele, "The Embargo on the Upper Rio Grande," November 11, 1924, 19-20. 8-3 Rio Grande Distribution of Waters (Loose File), Box 1638, CCF 1907-36, RG 48, NARA II.

[10] Benjamin M. Hall, or B.M. Hall, earned a degree in engineering from the University of Georgia in 1876. He was a mathematics instructor at what is now North George College and State University, before finding work as an engineer on water and mining projects. Hall consulted with the USGS in 1896, and joined Reclamation soon after it was established. Hall was the supervising engineer on a number of federal reclamation projects in New Mexico, and after leaving Reclamation worked in Puerto Rico. Littlefield, *Conflict on the Rio Grande*, 97.

reservoir sites that had been identified by the "Irrigation Survey" of the United States Geological Survey (USGS) between 1889 and 1890. The Elephant Butte site that Boyd had intended to develop was among these. A more detailed federal investigation began in March 1903, as the final trial with Rio Grande Dam and Irrigation Company neared its conclusion, and involved assessing the possible irrigable acreage that could be served by a reservoir at Elephant Butte. By February 1904, borings for a federal dam at the location were complete. In June, after Mexico once again entreated the US for a settlement, Secretary of State John Hay suggested to Secretary of the Interior Ethan Hitchcock that the National Reclamation Act might offer a path to a settlement with Mexico. Planning for a federal reclamation project centered at Elephant Butte embraced the idea.[11]

Before the assembled delegates to the National Irrigation Congress in November 1904, Hall declared that 180,000 acres of land in the United States could be served by a dam opposite Engle, New Mexico, a third of a mile below Elephant Butte, while delivering water to Mexico. Hall's presentation was based upon a much larger study that he had made prior to the congress, "A Discussion of Past and Present Plans for Irrigation of the Rio Grande Valley." Both in his presentation to the congress and in that study, Hall asserted that a Reclamation dam near Elephant Butte could offer more than the "International Dam" proposed for the El Paso area; it would furnish valuable flood control benefits and supply more US lands with water. Hall's proposed reservoir would have a storage capacity of 2 million af and would yield 600,000 acre-feet (af) to serve "110,000 acres in New Mexico," "20,000…[in] Texas above El Paso," and "50,000…[in] El Paso Valley below El Paso." In order to serve the valley lands sufficiently, given the area's aridity, seasonal flooding, and the high silt content of the Rio Grande, Hall insisted upon building a reservoir

> as large as possible, and as deep as possible; having capacity for carrying a supply of water over from year to year to equalize the yearly inequalities, a surplus capacity for mud accumulations, and a surface for evaporation that is as small as possible in comparison with the quantity of water in storage.

As he emphasized in his presentation and study, "[a]ll of the water that comes down the river is needed for irrigation. We can not [*sic*] afford to waste any of it."[12]

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[11] Hamele, "The Embargo on the Upper Rio Grande," November 11, 1924, 20-211. 8-3 Rio Grande Distribution of Waters (Loose File), Box 1638, CCF 1907-36, RG 48, NARA II; and Littlefield, *Conflict on the Rio Grande*, 94-97.

[12] Guy Elliott Mitchell, ed., *The Official Proceedings of the Twelfth National Irrigation Congress, Held at El Paso, Texas, Nov. 15-16-17-18, 1904* (Galveston, TX: Clarke & Courts, 1905), 215-216; B.M. Hall, Supervising Engineer, U.S. Reclamation Service, "A Discussion of Past and Present Plans for Irrigation of the Rio Grande Valley," November 1904, 7-8, and 57-58. ff. 46 Rio Grande Project. Penasco Rock Resv.

The delegates were pleased with Hall's proposal, calling it "an equitable distribution of the waters of the Rio Grande with due regard to the rights of New Mexico, Texas and Mexico," and Congress acted swiftly to make the project a reality. In 1905, it authorized the Rio Grande Project for New Mexico and Texas. Specifically, it extended the 1902 Newlands Act

> to the portion of the State of Texas bordering upon the Rio Grande which can be irrigated from a dam to be constructed near Engle, in the Territory of New Mexico, on the Rio Grande, to store the flood waters of that river, and if there shall be ascertained to be sufficient land in New Mexico and in Texas which can be supplied with the stored water at a cost which shall render the project feasible and return to the reclamation fund the cost of the enterprise, then the Secretary of the Interior may proceed with the work of constructing a dam on the Rio Grande as part of the general system of irrigation, should all other conditions as regards feasibility be found satisfactory.[13]

The following year, with the conclusion of successful negotiations with Mexico, the Senate ratified a treaty promising the US's southern neighbor 60,000 af of water a year from the Rio Grande.[14]

Federal reclamation authorities worked to develop the Rio Grande Project over the next several years. In 1906, Hall filed a notice of appropriation with the New Mexico territorial engineer for 730,000 af of water for the project. That same year, Reclamation entered into the first of several agreements with two water users associations, the Elephant Butte Water Users Association in New Mexico and the El Paso Valley Water Users Association in Texas, and their successors Elephant Butte Irrigation District (EBID) and El Paso County Water Improvement District No. 1 (EP #1), to furnish water from the project. Two years later, new project supervising engineer Louis C.

Site-Elephant Butte Resv. Site, 1904-1905, Box No. 792, Rio Grande 17-46, Entry 3, General Administrative and Project Records, 1902-1919 [hereafter Entry 3], Records of the Bureau of Reclamation, Record Group 115 [hereafter RG 115], National Archives at Denver [hereafter NARA Denver]; and Littlefield, *Conflict on the Rio Grande*, 100-102 and 108-109.

[13] Historian Douglas Littlefield argues that by extending the provisions of Newlands Act to the El Paso Valley in Texas – a non-"Reclamation" state – Congress "authorized the Reclamation Service to carry out the first true apportionment of any interstate stream." He goes on to connect this act to the later 1938 "interdistrict agreement" between Elephant Butte Irrigation District and El Paso County Water Improvement District No. 1, approved by the Interior Department to explain why no state-line delivery to Texas was established. See Littlefield, *Conflict on the Rio Grande*, 114-115, 203 and 207, and Opinion IV below.

[14] Mitchell, ed., *Official Proceedings*, 107; Hamele, "The Embargo on the Upper Rio Grande," November 11, 1924, 23-25. 8-3 Rio Grande Distribution of Waters (Loose File), Box 1638, CCF 1907-36, RG 48, NARA II; *An Act Relating to the construction of a dam and reservoir on the Rio Grande, in New Mexico, for the impounding of the flood waters of said river for purposes of irrigation*, February 25, 1905, chap. 798, 33 Stat. 814; and Littlefield, *Conflict on the Rio Grande*, 105-145.

Hill filed a supplemental notice for "[a]ll of the unappropriated water of the Rio Grande and its tributaries."[15]

Construction proceeded apace. Leasburg Diversion Dam and its canal, the first elements of the project system, were completed in 1908. Eight years later, Elephant Butte Dam was completed, and the remaining major irrigation works were constructed between 1914 and 1919. In the late 1910s, work began on a vast drainage system to manage rising groundwater levels and fulfill Hall's plan to utilize all of the waters of the Rio Grande, including return flow (see Opinion III). By the mid-1920s, while planning and construction of various elements would continue into the 1930s, the project was substantially completed.[16]

Although the embargo was intended to last until a resolution could be found to the diplomatic dispute with Mexico, federal officials eager to protect the water supply of the Rio Grande Project continued to supported it into the early 1920s. Successful conclusion of the Colorado River Compact, however, prompted Reclamation Director A.P. Davis to solicit the opinions of the Colorado attorney general and the general managers of EBID and EP #1 as to a modification of the embargo and possible negotiation of a compact in December 1922.[17]

In March 1923, citing recent criticism of the embargo by Coloradoans, Davis recommended to Secretary of the Interior Albert B. Fall that the embargo be modified such that Reclamation could "negotiate for the release of specific areas of public land for purposes of water storage under conditions that will best conserve and protect vested rights in all parts of the Rio Grande Basin."

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[15] B.M. Hall, Supervising Engineer to Mr. David L. White, Territorial Irrigation Engineer, Jan. 23, 1906. ff. 41 New Mexico, Water Appropriations- -General, Thru 1910, Box 6 38C- -41; Supervising Engineer [Louis C. Hill] to Mr. Vernon L. Sullivan, Territorial Engineer, Subject: Supplemental notice of the intention of the United States to use the waters of the Rio Grande for irrigation purposes on the Rio Grande Project, April 14, 1908. ff. 41-D New Mexico. Water Appropriations. RIO GRANDE PROJECT THRU 1910, Box 9 41B- -41D; Articles of Agreement between the United States of America, the Elephant Butte Water Users' Association, and the El Paso Valley Water Users' Association, June 27, 1906. ff. 330-B Rio Grande. Contracts with Elephant Butte Irri. Dist., Box 817 Rio Grande 330B- -348C, Entry 3, RG 115, NARA Denver.

[16] F.H. Newell, Director, *Seventh Annual Report of the Reclamation Service 1907-1908* (GPO, 1908), 150; Arthur P. Davis, Director and Chief Engineer, and Will R. King, Chief Counsel, *Seventeenth Annual Report of the Reclamation Service 1917-1918* (GPO, 1918), 250-251; and *Twenty-Fourth Annual Report of the Bureau of Reclamation, Transmitted to Congress in pursuance of the Act of June 17, 1902 (32 Stat. 388) for the Fiscal Year Ended June 30, 1925* (GPO, 1925), 25.

[17] A.P. Davis, Director, to Hon. V.E. Keynes, Attorney General of Colorado, Dec. 12, 1922; A.P. Davis, Director, to Mr. H.H. Brook, President, Elephant Butte Irrigation District, Dec. 12, 1922.; and A.P. Davis, Director, to Mr. Roland Harwell, President, El Paso County Water Improvement Dist. #1, Dec. 12, 1922. ff. 032.02, Rio Grande Basin Water Rights: Rio Grande River Basin Embargo, Thru 1925, Box No. 925 Rio Grande Basin 032.02-- Lower Rio Grande 090., Project Files, 1919-1929, General Administrative and Project Records, 1919-1945, Entry 7 [hereafter Entry 7], RG 115, NARA Denver; and Littlefield, *Conflict on the Rio Grande*, 170-171.

The director predicated this recommendation on an analysis proffered by federal reclamation engineer Harold Conkling nearly four years earlier. In a June 1919 memorandum, Conkling argued that water developments in the San Luis and the Middle Rio Grande valleys would have a negligible impact on the Rio Grande Project downstream. In fact, he believed that with the construction of drainage works these developments could augment the water supply below Elephant Butte. Davis echoed this belief, expressing confidence that with Reclamation granted new authority, upstream projects could move forward without compromising the Rio Grande Project's water supply. Fall concurred, authorizing the modification in March 1923.[18]

The embargo came to an end entirely two years later. In September 1924, Davis's successor Elwood Mead expressed his support for the long-contemplated Vega-Sylvestre Reservoir in San Luis Valley. In April 1925, the Interior Department approved the reservoir. A little over a month later, Secretary of the Interior Hubert Work rescinded the embargo, reasoning that it was no longer necessary.[19]

Colorado and New Mexico had already moved forward with negotiating a compact, prior to Work's decision. In 1923, both states appointed commissioners to meet with a federal representative, and they initially sought to negotiate an agreement solely between themselves with the secretary of the interior's support and encouragement.[20] Concern for the possible

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[18] Memorandum, From: Engineer Harold Conkling, To: Chief of Construction, Subject: Water Supply-Rio Grande River, June 18, 1919. ff. 302.31 New Mexico, Surveys & Investigations, Thru 1929, 2 of 2, Transfer Case, Box 262 302.28- -302.31 A NV-NM, Entry 7 General Files, 1919-1929; A.P. Davis, Director, to The Secretary of the Interior, March 2, 1923, Approved: Albert B. Fall, Secretary, 9-11. ff. 032.02 Rio Grande Basin Water Rights: Rio Grande Basin Embargo Thru 1929, Box No. 925 Rio Grande Basin 032.02--Lower Rio Grande 090., Entry 7, RG 115, NARA Denver; and Littlefield, *Conflict on the Rio Grande*, 183.

[19] Elwood Mead, Commissioner, Memorandum to the Secretary, September 6, 1924. ff. 032.02 Rio Grande Basin Water Rights: Rio Grande Basin Embargo Thru 1929, Box No. 925, Entry 7, RG 115, NARA Denver; and Hubert Work, Secretary, to The President, May 23, 1925. ff. Rio Grande Compact Commission Records, 1924-1941, Richard Burges Papers: Correspondence, 1924-1935, May-December 1925, Box 2F468, Rio Grande Compact Commission Records, 1924-1941, 1970 [hereafter RGCCR, 1924-1941, 1970], Briscoe Center for American History, University of Texas at Austin [hereafter UTA]; and Littlefield, *Conflict on the Rio Grande*, 184-187.

[20] According to Colorado Lieutenant Governor George Corlett's recollection, that encouragement came circa 1925, when at a conference with Work in Washington, D.C. The Secretary of the Interior urged Corlett to meet with New Mexico's commissioner Francis Wilson, who was also in D.C., and find "just one thing" upon which they agreed. Arrangements were made for the two men to meet at the Senate office building, and they ultimately sat down with Work and Reclamation representatives to discuss the possibility of an "outlet drain" for Colorado. Proceedings of the Rio Grande Compact Conference held at Santa Fe, New Mexico, December 10-11, 1934, 5-6. ff. Proceedings of the Rio Grande Compact Commission, Santa Fe, New Mexico. 1934-1935, Box 62, Series 7: Publications and reports, 1856-1992 and undated [hereafter Series 7], Subseries 7.1: Compacts and rivers, 1893-1986 and undated [hereafter Series 7.1], Papers of Delph E. Carpenter and Family [hereafter PDECF], Water Resources Archives

impact of water projects upstream from the Rio Grande Project, however, led Texas to push for inclusion. Following a preliminary "first" meeting of the Rio Grande Compact Commission in October 1924, in which El Paso attorney Major Richard F. Burges argued on Texas's behalf as an unofficial representative, the federal representative, Secretary of Commerce Herbert Hoover and the Colorado and New Mexico commissioners agreed to include Texas.[21] The parties further agreed that their negotiations should focus on the allocation of the waters of the Rio Grande above Fort Quitman, Texas as this was a natural dividing point in the river.[22]

Appointment of an official commissioner for Texas, New Mexico's withdrawal from compact negotiations following Work's rescission of the embargo, and the resignation of Hoover upon his election to the presidency delayed further talks among the three states until December 1928.

[hereafter WRA], Colorado State University, Fort Collins [hereafter CSU-FC], available online at http://hdl.handle.net/10217/41293, last accessed April 8, 2019.

[21] Richard Fenner Burges came from a prominent family of El Paso attorneys. After graduating from Texas Agricultural and Mechanical College (today Texas A&M University), he read law in Seguin, Texas. He joined the El Paso law practice of his oldest brother, William Henry Burges, Jr., in 1892. Burges was admitted to the bar two years later, and along with William and his middle brother Alfred Rust Burges (who joined Richard in his separate law practice in 1912) established the El Paso Bar Association in the early 1910s. Burges was the city attorney for El Paso between 1905 and 1907, where he drafted the City Charter and continued an anti-vice campaign began by William when he was city attorney. As a member of the Texas State Legislature between 1913 and 1915, Burges authored the Texas Forestry Act and the Texas Irrigation Code. He earned the military title of major for his service in France during World War I; Burges also earned a Croix de Guerre for his bravery on the battlefield. Returning to El Paso after the war, he was considered as a potential gubernatorial candidate but Burges declined. Instead he dedicated much of the rest of his life to representing El Paso, El Paso County, and adjacent Hudspeth County, particularly on matters related to the Rio Grande – as noted in the opinions offered here. From 1935 to 1940, Burges served as a special counsel to the Department of Justice on the Rio Grande Rectification Project (see footnote 169). See Laura Hollingsed, Biography, "Guide to MS 262 Burges-Perrenot Family Papers," C.L. Sonnichsen Special Collections Department, University of Texas at El Paso, available online at digitalcommons.utep.edu/cgi/viewcontent.cgi?article=1073&context=finding_aid, last accessed April 15, 2019.

[22] Pat M. Neff, Governor of Texas, to Honorable Herbert Hoover, Secretary of Commerce, Re: Commission to Divide Waters of the Rio Grande, September 20, 1924. Folder 3, Herbert Hoover, Sec. of Commerce (11.); First Meeting, Rio Grande River Compact Commission, Breadmoor Hotel, Colorado Springs, Colo., Sunday, October 26, 1924, 1-37. Folder 1. First Meeting Rio Grande Compact Commission. Oct. 26, 1924, Box 02-D.002, MS 0235 Elephant Butte Irrigation District Records, 1883-1981 [hereafter MS 0235], Rio Grande Historical Collections [hereafter RGHC], New Mexico State University Archives and Special Collections, Las Cruces [hereafter NMSU Spec. Coll]; and Littlefield, *Conflict on the Rio Grande*, 177-183.

As Burges put it, "It is a matter of fact, and it can be established to the satisfaction of any fair minded person, that the use of water of the Rio Grande above Fort Quitman does not at least materially affect the interests of the people below Del Rio, Texas, as there is no irrigation that is of any consequence, and I think no possible irrigation of any importance between Fort Quitman and Del Rio, Texas." First Meeting, Rio Grande River Compact Commission…October 26, 1924, 4.

Over the course of three meetings, from December 19 through December 21, New Mexico and Texas aligned in defending the Rio Grande Project against Colorado. New Mexico's commissioner Francis Wilson was adamant that a specific quantity of water for New Mexico be determined and delivered at the Colorado-New Mexico state line. Wilson also argued that the best development Colorado could make, and which would have little effect on projects downstream, would be to drain the so-called "Closed Basin" – lands in the San Luis Valley waterlogged by the river. Any dam or reservoir that would impound the existing surface flow of the stream, in his view, threatened the Rio Grande Project and its 1906 and 1908 water filings in New Mexico.[23]

Burges, speaking for Texas, argued that his state's claims to the waters of the Rio Grande derived largely from the Rio Grande Project filings and the allocation of water to lands in New Mexico and Texas within the project. He further pointed out that approximately 20,000 acres below the end of the project (roughly Fabens, Texas) down to Ft. Quitman was irrigated. These lands in Hudspeth County relied almost entirely upon return flow from the project, obtained under the provisions of a federal Warren Act contract (see Opinion III).[24]

Colorado sought the freedom to develop its San Luis Valley. Lieutenant Governor George M. Corlett was the principal voice for the state. He insisted downstream water users would not be harmed by the construction of upstream reservoirs and in fact, stood to benefit from return flows and reduced evaporation caused by the long transit time in stream flow to Elephant Butte. Corlett acknowledged the benefits of the drain suggested by Wilson, and although he did not abandon the idea of a San Luis reservoir he ultimately agreed to join with New Mexico and Texas to request federal support for a Closed Basin drainage project.[25]

Although Colorado marshaled data to convince New Mexico and Texas of its position, there was little else upon which the states agreed aside from the Closed Basin project. In February 1929, limited again by their states' respective schedules and needing more time to study the problem, Colorado, New Mexico, and Texas concluded a temporary compact. This agreement, in effect, was to maintain the status quo in the basin for a period of six years until June 1935. Neither Colorado (Article V) nor New Mexico (Article XII) was to "cause or suffer the water supply" of the

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[23] Proceedings of the Rio Grande Compact Conference, Held December 19-20-21, 1928, At Santa Fe, New Mexico, 3, and 10-11. ff. Rio Grande Compact Commission Records, 1924-1941, 1970, Richard F. Burges Papers, Proceedings of the Rio Grande Compact Conference Held Dec. 19-20-21 at Santa Fe, N.M. (Title page, 78 pp.) [hereafter ff. Proceedings of the Rio Grande Compact Conference Held Dec. 19-20-21], Box 2F471, RGCCR, 1924-1941, 1970, UTA; and Littlefield, *Conflict on the Rio Grande*, 187-189.

[24] Proceedings of the Rio Grande Compact Conference...1928, 13. ff. Proceedings of the Rio Grande Compact Conference Held Dec. 19-20-21, Box 2F471, RGCCR, 1924-1941, 1970, UTA.

[25] Proceedings of the Rio Grande Compact Conference...1928, 14-19. ff. ff. Proceedings of the Rio Grande Compact Conference Held Dec. 19-20-21, Box 2F471, RGCCR, 1924-1941, 1970, UTA; and Littlefield, *Conflict on the Rio Grande*, 190.

river "to be impaired by new or increased diversions or storage" – affording protection for the Rio Grande Project water supply – during this time. However, should the Closed Basin drain and State Line Reservoir be constructed prior to June 1935, "depletions" were permissible if "offset by increase of drainage return." The temporary compact further provided for the establishment of several stream-gaging stations to gather flow data (Article III), necessary to formulating a permanent compact and endorsed construction of the Closed Basin Drain and State Line Reservoir by the federal government (Article II).[26]

With the expiration of the temporary compact a mere six months away, Colorado commissioner M.C. Hinderlider, New Mexico commissioner Thomas McClure, Texas commissioner T.H. McGregor, and the new federal representative (and Reclamation assistant chief engineer) S.O. Harper re-opened talks on a permanent compact in December 1934. Little had changed for the three states; all remained committed to the positions they articulated back in 1928. Corlett once again insisted that Colorado have "parity" with New Mexico and Texas in the use of Rio Grande waters – which Harper understood to mean "equality as regards dependability of water supply with the lands under the Elephant Butte Reservoir in New Mexico and Texas." New Mexico and Texas representatives, however, demanded to know whether Colorado intended to accept federal monies then being offered by the President Franklin Roosevelt's New Deal administration for a Closed Basin drain study. Ralph Carr, legal advisor to Colorado, responded that certain obligations attached to this funding were objectionable, and he asked for New Mexico and Texas's support in addressing those objections. He also maintained that the commission's "problem" and "task" was "to make an equitable division of the waters of the Rio Grande." Colorado sought to "arrive at a permanent compact," and notwithstanding the issues surrounding the drain, Carr argued for the opportunity to "present the data which is needed to arrive at a solution…."[27]

Burges countered that until the drain was constructed it was impossible to estimate the quantity of additional water to be developed by storage for use in Colorado, and thus an equitable apportionment remained elusive. Texas, according to Burges, preferred to continue the present compact until the effective yield of the Closed Basin drain could be determined. Carr, however, believed that this was unnecessary, as the 1929 compact, in Harper's words, "concedes to

[26] Proceedings of the Rio Grande Compact Conference...1928, 22-78. ff. Proceedings of the Rio Grande Compact Conference Held Dec. 19-20-21, Box 2F471, RGCCR, 1924-1941, 1970, UTA; *JIR*, 8; and Littlefield, *Conflict on the Rio Grande*, 191-193.
[27] Proceedings of the Rio Grande Compact Conference…1934, 10-11, 19-23, and 27-29. ff. Proceedings of the Rio Grande Compact Commission, Santa Fe, New Mexico. 1934-1935, Box 62, Series 7, Subseries 7.1, PDECF, WRA, CSU-FC; S. O. Harper to Secretary of the Interior, December 14, 1934, 4-5. File No. 8-3 (Part 2), Rio Grande-Distribution of Waters-Compact, C-D, August 18, 1930-February 25, 1936, Box No. 1638, CCF 1907-36, RG 48, NARA II; and Littlefield, *Conflict on the Rio Grande*, 196-197.

Colorado an additional amount of water equivalent to that developed by the drain…." At an impasse, but with each of the states informed as to the others positions, the commissioners decided to adjourn, study the questions in more detail, and reconvene in January 1935.[28]

The January meeting picked up where the December meeting had left off, with Colorado continuing to insist on parity with Texas and New Mexico. Corlett argued that construction of "the Outlet Drain" (i.e., the Closed Basin Drain) together "with the savings of avoidable waste from the Elephant Butte Project" would ensure sufficient water for Colorado's intended developments. By "avoidable waste," he meant the water released below Rio Grande Project lands in Texas. Corlett insisted that this waste had been controlled following the adoption of the temporary compact but since that time it had "crept into the operations of these projects, so that the releases at the Elephant Butte have now come back to approximately what they were before." Construction of the Closed Basin drain, together with control of "avoidable waste" on the Rio Grande Project would enable, he argued, "an annual uniform supply of water to the lands of Colorado on a parity with the supply now furnished to lands in New Mexico and Texas."[29]

As before, negotiation of the compact for Colorado was not contingent upon construction of the drain. Corlett believed that "with all of the excellent accumulated engineering data and advice" available to the commissioners that a compact could be devised, and to that end, Colorado's engineering advisor Royce J. Tipton took the floor.[30] Tipton elaborated on the argument first

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[28] Proceedings of the Rio Grande Compact Conference…1934, 23-24, 29-30, and 34-38. ff. Proceedings of the Rio Grande Compact Commission, Santa Fe, New Mexico. 1934-1935, Box 62, Series 7, Subseries 7.1, PDECF, WRA, CSU-FC; Harper to Secretary of the Interior, December 14, 1934, 5-6. File No. 8-3 (Part 2), Box No. 1638, CCF 1907-36, RG 48, NARA II; and Littlefield, *Conflict on the Rio Grande*, 197-198.

[29] Proceedings of the Rio Grande Compact Commission, Santa Fe, January 28-30, 1935, 3-4. ff. Proceedings of the Rio Grande Compact Commission, Santa Fe, New Mexico. 1934-1935, Box 62, Series 7, Subseries 7.1, PDECF, WRA, CSU-FC.

[30] Born in Illinois in 1893, Royce Jay Tipton grew up in Colorado. After he graduated high school, he worked as an elementary school teacher before receiving practical training as an engineer with a mining company. Tipton entered the University of Colorado in 1915 to study civil engineering but before completing his degree he went overseas during World War I. Tipton never finished his academic studies, although in 1940 he was awarded "an Honorary Degree in Civil Engineering" by the university. Following his military service, Tipton worked as chief engineer for the San Luis Valley Land and Cattle Company, and in the early 1920s formed the first of several business partnerships and engineering consulting companies. In 1929, he became Colorado's engineering advisor in the Rio Grande Compact negotiations, and briefly assisted with Reclamation water supply studies for what became the Hoover Dam. His association with the Colorado State Engineer's office continued into the 1930s. Tipton's professional life took him abroad, and he partnered with Hill on a water supply projects in Pakistan and Egypt. Texas's engineering advisor recalled Tipton fondly in a 1968 deposition that Hill gave in an original action filed against Colorado by Texas and New Mexico, alleging violations of the 1938 Compact: "Mr. Royce Tipton was one of the outstanding engineer in this field… and I considered him of the of the ablest engineers in the field….I liked the man personally, I admired his ability…." "Memoir, Royce Jay Tipton, F. ASCE, Died December 23, 1967,"

advanced back in 1928 that the entire Rio Grande Basin stood to gain from the construction of reservoirs to serve the San Luis Valley. He presented technical data that he maintained demonstrated such works would assist in regulating the water supply and providing sufficient carryover storage from high to low water years in the valley, and by doing so return as much as 100,000 af to the stream to the benefit of downstream users in New Mexico and Texas.[31]

The rest of the commission, while intrigued by Tipton's presentation, felt that they had little time to consider it in detail. Extensive questioning by Burges (serving as Texas's acting commissioner at the request of the Governor James V. Allred), led to Colorado agreeing to make Tipton's work available to Texas and New Mexico for further review. In the meantime, the commissioners decided to recommend to their respective governors and legislatures a two-year extension of the temporary compact until June 1937.[32]

Before negotiations resumed, Texas filed suit against New Mexico and the Middle Rio Grande Conservancy District (MRGCD) in the US Supreme Court in October 1935. Texas alleged that by permitting diversions above Elephant Butte by MRGCD, diversions that diminished both the quantity and quality of water reaching Texas lands, New Mexico had abrogated the terms of the 1929 compact. Organized in August 1925 under the laws of New Mexico, the Middle Rio Grande Conservancy District aimed to reclaim and develop that portion of the basin above San Marcial, providing not only water but also flood protection to lands in the vicinity of Albuquerque. As the negotiations leading to the 1929 temporary compact were underway, MRGCD had formulated its plans and had contracted with Reclamation for additional technical support and study, leading to an assessment of "the water conditions of the Rio Grande." By the early 1930s, primarily with financial support from the federal Reconstruction Finance Corporation, the district had embarked on constructing El Vado, a proposed 190,000-af storage reservoir on the Rio Chama near the

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enclosed with Olin Kalmbach to Mr. William H. Wisely, Executive Secretary, ASCE, January 28, 1969. Folder 1 Biographical notes – Royce J. Tipton, 1967-1969, Box 1, Series 1: Tipton's biography and writings, 1915-1969 and undated, Papers of Royce J. Tipton, 1915-1969, WRA, CSU-FC, available online at https://mountainscholar.org/handle/10217/181886, last accessed May 20, 2019; and Deposition of Raymond A. Hill. Taken December 4, 1968. Denver, Colorado, *State of Texas and State of New Mexico, Plaintiffs, vs. State of Colorado, Defendant,* No. 29, Original, in the Supreme Court of the United States, October Term 1967, 9-11. ff. Texas & New Mex. v. Colo., w. 66-1061 Texas vs. Colorado, Box 1989 41-240, LF-TAG, TSA.

[31] Proceedings of the Rio Grande Compact Commission...January 28-30, 1935, 6, 7, and 8-17. ff. ff. Proceedings of the Rio Grande Compact Commission, Santa Fe, New Mexico. 1934-1935, Box 62, Series 7, Subseries 7.1, PDECF, WRA, CSU-FC.

[32] Proceedings of the Rio Grande Compact Commission...January 28-30, 1935, 43-45. ff. Proceedings, Box 62, Series 7, Subseries 7.1, PDECF, WRA, CSU-FC; and Littlefield, *Conflict on the Rio Grande*, 198.

Colorado-New Mexico state line, as well as half a dozen diversion dams on the Rio Grande, and several hundred miles of irrigation and drainage canals and levees.[33]

MRGCD's plans notwithstanding, New Mexico rejected Texas's allegations. The state asserted that diversions by Mexico in excess of that permitted under the 1906 treaty and inefficient operation of Elephant Butte Dam were to blame for the diminished water supply to lands in Texas. New Mexico further argued that the US's 1906 appropriation of water for the federal reservoir was not made in accordance with New Mexico law, in violation of the 1902 Newlands Act.[34]

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[33] State of New Mexico, County of Bernalillo, In the District Court, In the Matter of the Middle Rio Grande Conservancy District, No. 14157, First Report of the Board of Directors, G.E. Cook, President, Ramon Baca y Chavez, Director, Robert E. Dietz, Director, E.G. Watson, Secretary. Dated at Albuquerque, New Mexico, August 27th, 1926, 2-5, and 13. ff. 222. Rio Grande Basin Irrigation Districts Middle Rio Grande Transfer Case Thru 1929, Box 928 Rio Grande Basin-Lower Rio Grande 301.- -545., Middle Rio Grande 222.- -223., Entry 7, RG 115, NARA Denver; *Supreme Court of the United States, October Term 1936, No. 12 Original, State of Texas vs. State of New Mexico, et al., Ad Interim Report of the Special Master*, received Mar. 26, 1937, 4-5. ff. RG 267, Entry 26, TX v NM #10, Box 401 1939 to 1939 PI 139, Entry 26, Original Jurisdiction Case Files, 1792-2005 [hereafter Entry 26], Records of the Supreme Court of the United States, Record Group 267 [hereafter RG 267], National Archives Building, Washington, DC [hereafter NAB]; and Littlefield, *Conflict on the Rio Grande*, 198-199.

Discussions with Reclamation regarding development of the Middle Rio Grande extended back to late 1919, and resulted in the drafting of an initial study in December 1922 by Homer Gault. Ottamar Hamele, Acting Director, to The Secretary of the Interior, Dec.-1 1919. ff. 301. Rio Grande Basin-Middle Rio Grande Engineering Reports & Estimate Thru 1929, Box 929 Rio Grande Basin, Middle Rio Grande 301.- -400.05, Entry 7, RG 115, NARA Denver; and Homer J. Gault, Engineer, US Reclamation Service, Denver, Colorado, Department of the Interior, United States Reclamation Service, in cooperation with The State of New Mexico, Report on the Middle Rio Grande Reclamation Project, New Mexico (December 1922). ff. 21, Rio Grande Commission, 1921-1930, Box 15, MSS 90 BC Richard Charles Dillon Papers, 1918-1944, University of New Mexico Special Collections, Albuquerque.

[34] The State of Texas, By Wm. McCraw, Its Attorney General, H. Grady Chandler, Assistant Attorney General, Richard F. Burges, Walter S. Howe, Edwin Mechem, Of Counsel, Supreme Court of the United States, October Term, 1935, No. – Original, *State of Texas, Complainant, vs. State of New Mexico, et al.*, Motion for Leave to File Bill of Complaint and Bill of Complaint [October 29, 1935]; Supreme Court of the United States, October Term, 1935, No. 15, Original, *State of Texas, Complainant vs. State of New Mexico, et al.*, Answer of the Defendant State of New Mexico, and Answer of Defendants, Middle Rio Grande Conservancy District, Robert Dietz, M.R. Buchanan, T.J. Seneker, George Cook, and Constancio Hendren, Directors of Said District - Supreme Court of the United States [March 26, 1936]. w. Texas' Briefs, A.G. 51-238, State of Texas v. State of New Mexico, et al., Box 1993/127-1, Litigation Files, Texas Attorney General [hereafter LF-TAG], Texas State Archives, Austin [hereafter TSA]; Supreme Court of the United States, No. 15, Original, October Term, 1935, *The State of Texas, Complainant, v. The State of New Mexico, et al.*, Docket Entries, nd. ff. 4-1 Warren Charles, Correspondence re Texas v. New Mexico June 1936; and *State of Texas v. State of New Mexico*, No. 12 Original, 1936 Term. *Statement by Special Master*, March 5, 1937. ff. Warren Charles, Correspondence re Texas vs. New Mexico / March, 1937, Box 4 Correspondence,

The Supreme Court granted leave to Texas to proceed with its suit in November, and appointed a special master, attorney Charles Warren, to take testimony in May 1936. Between November 1936 when Warren opened hearings and March 1937 when hearings concluded, nearly 40 hearings were held in Albuquerque, New Mexico, and El Paso, Texas, and in excess of 3,000 pages of evidence – including more than 260 exhibits, maps, charts, graphs, and witness testimony – were produced. Warren further personally inspected several hundred miles of the Rio Grande and the various irrigation and drainage system that served lands in New Mexico and Texas.[35]

Despite all of this, when the hearings ended the special master could not see a clear resolution. In his *Ad Interim Report* to the Supreme Court in March 1937, Warren indicated that he was "of opinion that findings of fact by me based on the evidence in its present shape would be unsatisfactory and might not result in an equitable adjustment of the situation." Essential legal issues (such as the absence of the US and Colorado as parties to the litigation) aside, the special master cited incomplete records and partial analyses of flow depletion and salinity levels as constituting an insufficient basis for findings of fact. Aware that the federal government through the National Resources Committee (NRC) was "investigating the whole problem of water supply and distribution in the Upper Rio Grande region," and at the request by counsel representing Texas, New Mexico, and MRGCD, to hold "further proceedings…in abeyance until the first day of October 1937," Warren recommended postponement of the case until January 1938. The high court approved the recommendation in April.[36]

The National Resources Committee referenced by Warren was a special working group of government officials and consultants within the Roosevelt Administration that aimed to foster development of the nation's natural resources through planned regional public works programs. In September 1935, a month prior to Texas filing suit against New Mexico and MRGCD, "spurred by the need for prompt action to avoid uncoordinated development of water utilization projects" in the Upper Rio Grande Basin, the group appointed a Board of Review to study the various water use problems and proposed projects in the basin. The board readily identified the potential for

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Notes, Reports re: Texas vs. New Mexico [hereafter Box 4], Series 1: Materials re: cases, Charles Warren Papers 1885-1954 [hereafter CWP], Manuscripts Unit, Harvard Law School Library, Historical and Special Collections, Cambridge, Massachusetts [hereafter HLS HSC]; and *Ad Interim Report of the Special Master*, received Mar. 26, 1937, 4-6. ff. RG 267, Entry 26, TX v NM #10, Box 401, Entry 26, RG 267, NAB.

[35] *Ad Interim Report of the Special Master*, received Mar. 26, 1937, 1. ff. RG 267, Entry 26, TX v NM #10, Box 401, Entry 26, RG 267, NAB.

[36] Special Master to Richard F. Burges, Esquire, March 26, 1937. ff. Correspondence re: Texas vs. New Mexico/March, 1937, Box 4, CWP, HLS HSC; *Ad Interim Report of the Special Master*, received Mar. 26, 1937, 5-13; and *Supreme Court of the United States, October Term 1936, No. 10 Original, State of Texas vs. State of New Mexico, et al., Final Report of the Special Master*, filed Sep. 25, 1939, 4. ff. RG 267, Entry 26, TX v NM #10, Box 401, Entry 26, RG 267, NAB.

the MRGCD to jeopardize the 1906 treaty with Mexico and prior federal investment in the Rio Grande Project. Other proposed federal water projects, such as the Conejos and Vega-Sylvestre dams and the so-called "State Line Reservoir" in Colorado, also presented potential conflicts with not only the Rio Grande Project and the MRGCD but also with the tristate compact under negotiation. Furthermore, the river basin was considered to be fully appropriated. New drafts on existing water resources without enhancing supply, the board ultimately concluded, would damage vested rights in the basin.[37]

In the interests of efficient, full, and equitable utilization of the basin's waters, the board recommended that no action be taken "to approve any application for a project involving the use of Rio Grande waters without securing from the National Resources Committee a prompt opinion on it from all relevant points of view." President Franklin D. Roosevelt, at the urging of Secretary of the Interior Harold Ickes, issued an executive order in September 1935 prohibiting federal officials from authorizing any water projects for the Rio Grande Basin without obtaining the approval of the NRC – in effect, restoring the embargo.[38]

In early October 1935, the NRC contacted Harper about the possibility of having representatives from the group meet with the Rio Grande Compact Commission to discuss how they might facilitate conclusion of a permanent compact by providing "needed basic data" that would foster "agreement on facts by the three states…." With the approval of Harper and the other compact commissioners, the NRC sent Harlan H. Barrows, a University of Chicago historical geographer and a member of the Board of Review, and Frank Adams, an agricultural economist with the NRC's Water Resources Committee, to meet with the commission in December.[39] At that

[37] "Report of the Rio Grande Board of Review," September 13, 1935, 1-4. Folder 390-Rio Grande Joint Investigation Purpose and Organization, 1935-1937, Box 26, Frank Adams Collection [hereafter FAC], Water Resources Collections and Archives, University of California, Riverside [hereafter WRCA]; *JIR*, 10; and Littlefield, *Conflict on the Rio Grande*, 200-201. For more on the NRC, see Richard Lowitt, *The New Deal and the West* (Norman: University of Oklahoma Press, 1993).

[38] "Report of the Rio Grande Board of Review," September 13, 1935, 6-11. Folder 390, Box 26, FAC, WRCA; and Franklin D. Roosevelt, To Federal agencies concerned with projects or allotments for water use in the Upper Rio Grande Valley above El Paso, September 23, 1935. File No. 8-3 (Pt. 7). Reclamation Bureau - Rio Grande Project - Rio Grande River - Distribution of Waters – General, February 6, 1933 to December 12, 1956, Box 1642, 8-3, Rio Grande, R, CCF 1907-1936, RG 48, NARA II.

[39] Harlan H. Barrows came to the University of Chicago as an undergraduate in 1903, earned a BA in geology, and later joined the university's Department of Geography – the first such academic department for the discipline in the United States. He went on to become a foundational figure in the study of historical geography, and garnered recognition and acclaim for his lectures. Barrows entered public service during World War I, as a member of the United States War Trade Board. In the early 1930s, he consulted on a number of US Department of the Interior-led, or -based initiatives, such as the Water Resources Committee of the National Resources Committee. See Biographical Note, "Guide to the Harlan H. Barrows Papers, circa 1880-1939,", University of Chicago Library, available online at

meeting, Barrows and Adams proposed a joint federal-state investigation of the water resources, uses, and needs throughout the Upper Rio Grande Basin, and the commissioners agreed. The investigation, it was determined, would include: 1) the water resources of the Rio Grande Basin "above Fort Quitman;" 2) the "past, present and prospective uses and consumption of water" in the basin within the United States; and 3) opportunities for conserving and enlarging the water supply to assist the commission "in reaching a satisfactory basis for the equitable apportionment of the waters of the Rio Grande Basin in the United States above Fort Quitman, as contemplated by such Rio Grande Compact."[40]

The commissioners embraced the offer of assistance, but were wary of the investigation coming to conclusions or making recommendations. Texas's new commissioner, attorney Frank B. Clayton (who also represented Texas in its suit against New Mexico and MGRCD) explicitly raised this concern, and the other state commissioners concurred.[41] In the final resolution authorizing the NRC to move forward, the Rio Grande Compact Commission pledged to assist in the joint

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https://www.lib.uchicago.edu/e/scrc/findingaids/view.php?eadid=ICU.SPCL.BARROWSH, last accessed April 8, 2019.

Much like Barrows, Frank Adams was a pioneer in his field. He earned degrees in economics from Stanford and the University of Nebraska in the early 1900s, and worked for the US Office of Experiment Stations, based in the Department of Agriculture, between his degrees. After a brief interlude working with his brother on a commercial venture, Adams re-joined with the Office of Experiment Stations in 1910 and was later appointed to lead the Division of Irrigation Investigations and Practices at the University of California's College of Agriculture. In the 1920s and through the 1940s, he consulted with Reclamation and was a key member of the National Resources Committee. See Biography, "Inventory of the Frank Adams papers, 1889-1962," Water Resources Collections and Archives, University of California, Riverside, available online at https://oac.cdlib.org/findaid/ark:/13030/tf9489p11x/entire_text/, last accessed April 8, 2019.

[40] Proceedings of the Rio Grande Compact, held in Santa Fe, New Mexico, December 2-3, 1935, 2-3 and 5-7. ff. 032.1 (2/3), Box 1326 Owyhee Proj. 222., Rio Grande Basin 032.1, Entry 7, RG 115, NARA Denver; and "Resolution Passed by Rio Grande Compact Commission at Santa Fe, New Mexico," December 3, 1935, 1-2. Folder 401-Rio Grande Compact Commission Resolutions, 1935-1937, Box 26, FAC, WRCA.

[41] A native of El Paso, born in 1902, Frank Britton Clayton attended Texas Western College (now the University of Texas at El Paso) and later enrolled at the University of Texas (at Austin) where he earned his law degree in 1925. He held fellowships at Yale and Harvard in 1927 and 1928, and taught at the University of Texas law school until 1930 when he entered private practice. Between 1933 and 1935, Clayton served as special counsel to the City of El Paso before becoming Texas's Rio Grande Compact Commissioner. As noted above, he represented the State of Texas in the original action against the State of New Mexico and the Middle Rio Grande Conservancy District; and as noted in Opinion IV, Clayton was counsel to Hudspeth County Conservation and Reclamation District No. 1. Following the ratification of the 1938 compact, he resigned his position as compact commission to become the city attorney for El Paso. In 1941, Clayton became counsel to the International Boundary and Water Commission. See Frank B. Clayton to Governor W. Lee O'Daniel, April 18, 1939. ff. Rio Grande Compact, Commissioner Appointments, 1938-9, 2001/138-143, W. Lee O'Daniel Governor's Papers, TSA; and "F.B. Clayton, Prominent Lawyer, Dies," *The El Paso Times*, December 2, 1951.

investigation, to secure matching state funds and services, and to share costs of the studies with the federal government. They also expressed their understanding that the cooperative investigation "shall be limited to the collection, correlation and presentation of factual data."[42]

After nearly two years of work, with the USGS, Reclamation, and the US Department of Agriculture's Bureau of Agricultural Engineering and Bureau of Plant Industry all contributing, an initial draft of the Rio Grande Joint Investigation report, or *JIR*, was available in August 1937.[43] Barrows, in presenting that draft to the commissioners when negotiations resumed in late September, expressed his belief that the report provided "a factual basis for an allocation of the waters of the river above Ft. Quitman that would be fair and just to each of the three states and to its citizens dependent upon the river."[44]

Although Texas's engineering advisors expressed reservations over the *JIR* (discussed in Opinion II), later accounts of the meetings between the engineering advisors for all three states and the US indicate that the report was an essential compilation of information for them. As Tipton reported to Hinderlider, "all the basic data pertaining to the problem were assembled and analyzed" in *JIR*. This data included "detailed studies" by the individual states as well as the federal investigation itself. From this, Tipton and his fellow engineers were able to ascertain "the discharge of the river at various points under present development in the basin," and "schedules of water delivery which would insure each section of the basin against injury by acts of water

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[42] Richard F. Burges to Governor James V. Allred, telegram, March 9, 1935. [2nd unlabeled file folder], Box 2F470, RGCCR, 1924-1941, 1970, UTA; Richard F. Burges, to Hon. S.O. Harper, Chairman, Rio Grande Compact Commission, Hon. M.C. Hinderlider, State Engineer, Hon. Thomas M. McClure, March 9, 1935. NM_00120235; James V. Allred, Governor of Texas, to His Excellency, the Governor of New Mexico, telegram, April 27, 1935. ff. 301 Gov. Clyde K. Tingley, Rio Grande Compact, 1935-1938, Box 9, Serial No. 13103, 09-19 special reports, conservation, new deal. Dates: 1935-1938, Governor Clyde Tingley Papers, New Mexico State Records Center & Archives, Santa Fe [hereafter NMSA]; Proceedings of the Rio Grande Compact...December 2-3, 1935, 19, and 42-43. ff. 032.1 (2/3), Box 1326, Entry 7, RG 115, NARA Denver; and "Resolution Passed by Rio Grande Compact Commission at Santa Fe, New Mexico," December 3, 1935, 1-2. Folder 401, Box 26, FAC, WRCA.

[43] The final draft was released in February 1938 as National Resources Committee, *Regional Planning Part VI – The Rio Grande Joint Investigation in the Upper Rio Grande Basin in Colorado, New Mexico, and Texas 1936-1937* (GPO, 1938).

[44] Frank Adams and Harlan H. Barrows, consulting board Rio Grande Joint Investigation, to Abel Wolman, chairman Water Resources Committee, Letter of Transmittal, August 10, 1937. Folder 397-Rio Grande Joint Investigation Outlines and Drafts, 1936-1937, Box 26, FAC, WRCA; and Proceedings of the Meeting of the Rio Grande Compact Commission Held in Santa Fe, New Mexico, September 27, to October 1, 1937, 1, 3 and 5. Unnamed folder 5, Box 2F463, Rio Grande Compact Comm'n. Frank B. Clayton Papers [hereafter RGCC-FBCP], UTA; and Littlefield, *Conflict on the Rio Grande*, 201.

uses in another section and yet would permit of the construction and operation of additional reservoirs above Elephant Butte Reservoir."[45]

Three decades after the permanent compact was signed, the recollections of Texas's engineering advisor Raymond A. Hill were similar.[46] Hill acknowledged that in the course of the federal investigation requests for "clarification" were made, "questions were raised as to the accuracy of some of the data," and "exceptions were taken to some of the findings." The *JIR* nevertheless assembled "all essential data as to the sources and quantities of water available for use in the several States, the needs for water in these States, and means for development and use of those supplies." Where it specifically came to development of delivery schedules that were at the heart of the compact, Hill stressed that the report brought together "all pertinent data." With this data provided to the commission, the engineering advisors crafted the technical basis for the compact.[47]

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[45] R.J. Tipton, *Analysis of Report of Committee of Engineers to Rio Grande Compact Commissioner, Dated December 27, 1937* (February, 1938), 1-4. ff. 70, Box 44-70, MSS 312 Michael Creed Hinderlider Collection, 1897-1987 [hereafter MCHC 1897-1987], History Colorado, Denver [hereafter HC].

[46] Raymond A. Hill was a consulting engineer and partner with the Los Angeles-based engineering firm of Quinton, Code and Hill-Leeds and Bernard (after 1940, Leeds, Hill, Bernard and Jewett). The son of Louis C. Hill, the second supervising engineer for the Rio Grande Project, Raymond Hill graduated from the University of Michigan in 1914 with a Bachelor of Civil Engineering. He worked for Reclamation while in college on Strawberry Valley Project in Utah, the Green River Project in Colorado, and the Yuma Project in Arizona. Hill first became familiar with the Upper Rio Grande Basin when assisted in the investigation of the proposed high-line canal between Elephant Butte Reservoir and El Paso led by his father in the late 1910s. After a stint in the US Army Corps of Engineers during World War I, he returned to the University of Michigan and obtained, in his words, "the degree of Civil Engineer" in 1922. Hill and his firm were hired by EBID and EP#1 to investigate possible hydroelectric power development at the federal reservoir. In 1934, he studied possible canalization of the Rio Grande from Elephant Butte through El Paso, a study that became the basis for the Rio Grande Rectification Project (see discussion in footnote 169). In addition to serving as Texas's engineering advisor (which he did for nearly 40 years), Hill advised the International Boundary and Water Commission and served as consulting water engineer to the cities of Santa Barbara and San Diego. He also worked internationally on projects in Mexico and the Middle East. *State of Texas vs. State of New Mexico, et al*, *Plaintiff's Case in Chief*, Volumes III & IV [hereafter *Plaintiff's Case in Chief*, Vols.], 599a-603. CB-F-171A thru CB-F-1716: Transcripts of TX v. NM, Vol. 1-16, Box 4X219, Raymond A. Hill Papers [hereafter RAHP], UTA. See also Littlefield, *Conflict on the Rio Grande*, 161.

Hill's recollections were prompted by a suit filed in US Supreme Court by Texas and New Mexico against Colorado for breach of the compact in the mid-1960s. For more, see Opinion V below.

[47] Raymond A. Hill, Consulting Civil Engineer, "Development of the Rio Grande Compact of 1938," 14 and 21. In re: Rio Grande Project AG No. 011504362, Copies from the Center for American History, Raymond A. Hill Papers & The Rio Grande Compact Commission Collection. See also same cited pages in Raymond Hill, Consulting Engineer, "Development of the Rio Grande Compact of 1938." ff. 49 Development of Rio Grande Compact of 1938, good history on water conflict, Texas, New Mexico, Colorado, prepared in context of 1966 Supreme Court Case, Box 4, MS 555 Joseph F. Friedkin Papers, C.L. Sonnichsen Special

When the Rio Grande Compact Commission re-opened negotiations in September 1937 few of the attendees had had an opportunity to examine the report in advance, so the engineer-in-charge of the investigation, Harlowe M. Stafford, presented the *JIR*'s findings.[48] Calling attention to the report's immense size (1,700 mimeographed pages), he conceded that it was not easily summarized. At Harper's prodding, Stafford focused on those issues most critical to the commissioners. He emphasized that the investigation aimed to offer "factual data on the water supply, water utilization and water requirements, with the possibilities of augmenting supplies to the basin by transmountain diversion or conservation by storage." The quantity and quality of water, the federal engineer assured the commissioners, were central concerns. He described the efforts made by the various federal agencies involved to measure the water supply and assess water quality, and identified in which volumes specific information developed by these agencies could be found. Findings as to runoff, return flow, groundwater, irrigation development and irrigated acreage, and water uses and requirements within the Upper Rio Grande Basin were summarized in Volume I and, according to Stafford, assisted in the determination of the "diversion requirements of major units of the basin" – namely the San Luis Valley in Colorado, the Middle Rio Grande in New Mexico, and the lands between Elephant Butte Reservoir in New Mexico and Fort Quitman, Texas.[49]

Asked by Harper to identify the amount of irrigable acreage and current water uses in these areas for the benefit of those who had not yet seen the report, Stafford went to the tables in Volume I. The study had determined that 3 million af of water was produced in the basin – almost all of which came from sources in Colorado and New Mexico. Irrigated and "water consuming" acreage in the basin amounted to nearly 2 million acres, but less than 1 million was "actually irrigated with the balance taken up by areas temporarily out of crop and areas occupied by cities and towns and bare lands." The engineer noted that the "Total for the basin [was] 924,000" – "600,000 in the San Luis section; 153,000 in the Middle Rio Grande section, which includes acreage in tributary areas; and 171,000 in the Elephant Butte-Fort Quitman sections." Basin-wide stream flow depletion was 2.7 million af, which according to Stafford suggested there was "about 200,000" acre-feet of surplus flow on average during the 46-year study period (1890-1935)

Collections Department, University of Texas at El Paso [hereafter UTEP Spec Coll]. Additionally, this narrative was published posthumously in the *Natural Resources Journal* in 1974. See Raymond A. Hill, "Development of the Rio Grande Compact of 1938," *Natural Resources Journal* 14:2 (April 1974): 64-200.

[48] The NRC selected Stafford, then serving as Water Commissioner for the Sacramento and San Joaquin Valleys of California to lead the federal effort in January 1936. Barrows and Adams were to serve as "a Consulting Board," "an advisory group," to work with Stafford and liaise with the Rio Grande Compact Commission. Rio Grande Joint Investigation, January 10, 1936, Approved: January 11, 1936, by Frederic A. Delano, Vice Chairman, National Resources Committee, 4-5. Folder 390, Box 26, FAC, WRCA.

[49] Proceedings of the Meeting of the Rio Grande Compact Commission...September 27, to October 1, 1937, 6-8. Untitled folder 5, Box 2F463, RGCC-FBCP, UTA.

chosen by the investigation. This same 200,000 af was, he also noted, "about what now flows at Fort Quitman." Of this 2.7 million af, the San Luis Valley, "exclusive of the consumption in the closed basin," took 1,047,000 af; the Middle Rio Grande, 768,000 af; and the Elephant Butte-Ft. Quitman lands, 885,000 af. As to the diversion requirements for the various areas within the basin, Stafford presented the investigation's findings concisely:

> 650,000 acre-feet would be the diversion demand at Del Norte; in the Conejos area 230,000; Middle Rio Grande area 580,000 at Otowi Bridge; between Middle Rio Grande and San Marcial about 80,000, and Elephant Butte-Fort Quitman section 953,000 at San Marcial; or taking out the estimate of seepage and evaporation, 773,000 acre-feet demand on the reservoir. Those figures are set up on the basis of the irrigated acreage as follows: In the San Luis section 353,000 acres; Conejos, 80,000; Middle Rio Grande, 100,000; Elephant Butte-Fort Quitman section, 145,000 acres. That would not be total irrigated acreage, but the maximum for any one year.

Almost immediately following presentation of these figures, the commission adjourned at Clayton's suggestion. Texas's commissioner, citing an earlier proposal by former Colorado Governor A.T. Hannett, recommended that the individual commissioners withdraw to meet with their advisors and draft "written statements" outlining "the minimum conditions under which we would be willing to negotiate."[50]

When the commission reconvened the afternoon of September 28, Colorado commissioner M.C. Hinderlider explicitly used information contained in tables and charts presented in Volume I to support his state's longstanding view that there was sufficient water in the basin for the development of lands in Colorado "comparable to that which now exists in the Middle and Elephant Butte-Fort Quitman sections" without harming established developments in New Mexico and Texas. "As a matter of fact," he asserted, "the usable water supply for the Middle section would be improved by the construction and operation of the reservoirs required in the San Luis section."[51]

For their part, both New Mexico and Texas signaled their willingness to negotiate with each other and with Colorado. New Mexico was open to discussing "increased storage" in the basin for Colorado provided that "proper safeguards" for New Mexico's water users were instituted and a transmountain diversion to bring additional water into the basin was "made an accomplished fact coincident with the construction of such storage in Colorado." With regard to Texas, New Mexico indicated it was receptive to talks focusing on "the right to the use of water claimed by

[50] Proceedings of the Meeting of the Rio Grande Compact Commission...September 27, to October 1, 1937, 9. Untitled folder 5, Box 2F463, RGCC-FBCP, UTA.
[51] Proceedings of the Meeting of the Rio Grande Compact Commission...September 27, to October 1, 1937, 2-3 and 11. Untitled folder 5, Box 2F463, RGCC-FBCP, UTA.

citizens of Texas under the Elephant Butte Project on the basis of fixing a definite amount of water to which said project is entitled." It insisted that Mexican diversions had to "be strictly limited to treaty provision of 60,000 acre-feet per annum." Development of the Middle Rio Grande Conservancy District to its approximately 123,000 acres, moreover, had to be respected as did "[a]ll existing rights to the use of water in the Rio Grande Basin in New Mexico."[52]

Texas's negotiation position was the most succinct and direct of the three:

> Although the State of Texas feels that it should share in the benefits from new works for the augmentation of the water supply of the Rio Grande, it will not insist thereon, provided that the States of Colorado and New Mexico will release and deliver at San Marcial a supply of water sufficient to assure the release annually from Elephant Butte Reservoir of 800,000 acre-feet of the same average quality as during the past ten years, or the equivalent of this quantity if the quality of the supply is altered by any developments upstream.

The proceedings then adjourned for an "informal discussion" between the commissioners and their advisors regarding how the meeting might move forward. The commissioners decided to meet in executive session the following day with each commissioner limited to two advisors who could participate in discussions. Additional representatives from each state and the NRC attended, but only as observers. No record was made of this executive session.[53]

Substantive talks resumed on the third day, and quickly became technical in nature with the engineering advisors debating the relative merits of flow schedules and the quantity as well as the quality of water the downstream states (Texas, in particular) could expect should Colorado develop its own reservoirs upstream. For its part, Colorado offered a schedule of deliveries that would provide 750,000 af per year for the "mean required releases from Rio Grande Project storage." After considerable discussion, principally among the engineering advisors, the commissioners elected to adjourn to provide their advisors an opportunity to meet as a group, sift through the data, develop the "technical basis" for a compact, and report back to the full commission.[54]

The engineering advisors met twice following the October adjournment – the first time in Santa Fe from November 22 to 24, and the second in Los Angeles from December 15 to 27. On both

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[52] Proceedings of the Meeting of the Rio Grande Compact Commission...September 27, to October 1, 1937, 12-13. Untitled folder 5, Box 2F463, RGCC-FBCP, UTA.
[53] Proceedings of the Meeting of the Rio Grande Compact Commission...September 27, to October 1, 1937, 13. Untitled folder 5, Box 2F463, RGCC-FBCP, UTA.
[54] Proceedings of the Meeting of the Rio Grande Compact Commission...September 27, to October 1, 1937, 16-42, 53, and Exhibit No. 4, 61 (the schedule is also given on p. 32 of the proceedings themselves). Untitled folder 5, Box 2F463, RGCC-FBCP, UTA; and Littlefield, *Conflict on the Rio Grande*, 201.

occasions the attendees were the same: Reclamation engineer E.B. Debler for the US, Tipton for Colorado, John Bliss for New Mexico, and Hill for Texas.[55] The Santa Fe meeting was dedicated to discussions about the factors influencing discharge of Rio Grande water at the Colorado-New Mexico state line and delivery of water to Elephant Butte Reservoir. The Los Angeles meetings dealt with these same issues in greater detail, developing explicit delivery schedules at certain control stations on the Rio Grande and its tributaries.

In Santa Fe in November, the engineers clung to their state's positions and were quite apart from each other. Tipton, as he had with the full commission meetings, opened the discussion. According to a memorandum prepared for Clayton by Hill following the meeting, in addition to insisting that Colorado receive credits for water prevented from being illegally diverted by Mexican interests, Colorado's engineering advisor stressed:

> a. Colorado can not [*sic*] consider anything less than present requirements, which means that depletion in the future will be at least as great as during the past few years.[56]
>
> b. The people in the San Luis valley are strongly opposed to any state line schedule that will restrict their use of water prior to the time that storage is provided.
>
> c. Even after storage is provided, they do not want any schedule that will give more water in dry years than actually did pass the state line.

Hill took all of this to mean that Colorado would not accept any restrictions on its use of water. He nevertheless believed that Colorado desired a compact and was willing to work toward "some reasonable schedule." Tipton, in fact, had developed such a schedule for a state-line delivery, "which could have been satisfied under natural conditions during the past eight or nine years." Colorado's engineering advisor was going to try to persuade San Luis Valley interests to accept

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[55] A graduate of the Colorado Agricultural College (today Colorado State University) in 1925, John Bliss first worked to the Colorado State Engineer's office in land surveying. In 1926, he joined the New Mexico State Engineer's office and eventually rose to become the state engineer in 1946. He worked on several hydrographic investigations on streams in New Mexico, which included work in the Upper Rio Grande Basin, in Colorado's San Luis Valley, the Middle Rio Grande (above Elephant Butte), and as discussed in greater detail in Opinion III below, between Elephant Butte and El Paso. In addition to serving as engineering advisor to McClure, the New Mexico State Engineer, Bliss had substantial involvement in New Mexico's contributions to the federal Rio Grande Joint Investigation. *Defendant's Case in Chief*, Vols. X & XI, 2011. CB-F-171A thru CB-F-1716: Transcripts of TX V. NM, Box 4X219, RAHP, UTA; and "Past New Mexico State Engineers," New Mexico Office of the State Engineer / Interstate Stream Commission, available online at http://www.ose.state.nm.us/ProgramSupport/sepastEngineers.php, last accessed May 11, 2019.

[56] In his notes, Hill did not elaborate on what Tipton meant by "depletion."

this schedule. The other advisors, for their part, did not accept it outright but rather indicated that it "might be acceptable."[57]

Bliss, according to Hill, was apparently willing to accept deliveries to Elephant Butte based upon water actually stored in the reservoir in prior years. Yet, New Mexico's engineering advisor was apparently "very fearful of any fixed schedule, on account of uncertainty of physical conditions, particularly as to the amount of tributary inflow between Ottiwi [*sic*] and San Marcial." Hill thought that an agreeable schedule on the basis of prior years' inflow could be found "[i]f some formula can be developed that will protect them against under-deliveries through causes beyond their control."

As discussed in Opinion II, Hill addressed the issue of water quality with Bliss independently of the discussions with Debler and Tipton. Texas's engineering advisor believed that Bliss was sympathetic but unsure of how to proceed. Hill remained hopeful that he could convince Bliss "that some allowance be made for change in quality of water."[58]

For his part, Hill continued to advocate for 800,000 af for Texas via Elephant Butte. In the fact of skepticism from Tipton, Bliss, and Debler, Texas's engineering advisor argued that this quantity of water was necessary to assure downstream lands in Texas with a sufficient quality of water – what he called "equivalent service." Hill privately acknowledged to Clayton that the 800,000 af was open to dispute given recent releases from Elephant Butte and careful operation of the project:

> Unfortunately the project, with 1,500,000 acre feet in storage and more acres in crop than in any other year, or in several years, the release from Elephant Butte has been only about 730,000 acre feet, and will be less than 730,000 acre for the entire year 1937. This desire to save water in one year, when there was every reason for using larger amounts, has made and will make it very difficult to substantiate the 800,000 acre feet requirement, especially as we can look to some reduction in diversion, particularly on that to Mexico.
>
> The economy in use this year may cost the project 50,000 acre feet annually hereafter.[59]

Transmountain diversions were also discussed at the engineers' meeting. Debler was of the mind that new water from outside the basin was needed to provide a "permanent solution." Hill grudgingly accepted that if new water was brought into the basin for the benefit of existing lands, "the situation will be corrected automatically." In Hill's view, if a state paid for a water-

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[57] Raymond A. Hill, Memo to Mr. Clayton: In re Meeting of Committee of Engineers, at Santa Fe, November 22 to 24, 1937, November 26, 1937, 1-2. [1937], Box 2F467, RGCC-FBCP, UTA.
[58] Hill, Memo to Mr. Clayton, November 26, 1937, 2. [1937], Box 2F467, RGCC-FBCP, UTA.
[59] Hill, Memo to Mr. Clayton, November 26, 1937, 2-3. [1937], Box 2F467, RGCC-FBCP, UTA. Notably, 730,000 af was the quantity of water first appropriated by Reclamation for the Rio Grande Project in 1906.

importation project, it should receive sole benefit of the water. If the federal government brought new water to the Rio Grande, however, each of the three states should receive equal amounts of that water. Tipton was strongly opposed to Texas receiving any new water, but he conceded "the equity of the provision" suggested by Hill.[60]

Despite the limited progress Hill described in his account of the November meetings, the engineering advisors arrived at what they believed was the technical basis for a compact by the end of the December meetings. Critically for Texas, Hill secured the concession of 800,000 af from the engineering advisors from Colorado and New Mexico. At that meeting, Bliss offered his own calculations of the project requirements for Elephant Butte. Allowing for delivery of water not only within the project and to Mexico but also to downstream lands in Hudspeth County, "unavoidable" project wastes and losses, "undivertable winter flow," and water necessary to achieve a "salt balance" down to Ft. Quitman, the engineer projected 750,000 af from Elephant Butte. This was the same figure developed by Tipton and offered by Colorado at the September-October compact proceedings.[61]

Yet, both Tipton and Bliss ultimately accepted 800,000 af. Tipton was persuaded, as he later explained to Hinderlider, that this "amount [was] not far different from the proposal made by Colorado [at the compact proceedings], and not far different from the conclusions of the engineers for the N.R.C. [i.e., the Rio Grande Joint Investigation]." "These engineers," he pointed out,

> arrived at two demands on Elephant Butte by two methods of analysis, one demand being 773,000 acre-feet and one being 736,000 acre-feet. The 773,000 acre-foot demand was recommended. Both were based on a delivery of 60,000 acre-feet to Mexico. It was estimated by N.R.C. engineers that the diversions to Mexico in 1930-1936 inclusive above the Tornillo Canal heading averaged 130,000 acre-feet per year. Therefore, if these diversions were reduced to 60,000 acre-feet there would result a saving of 70,000 acre-feet, and the normal release from Elephant Butte Reservoir would become 800,000 acre-feet, minus two-thirds of 70,000, or about 753,000 acre-feet. This is almost exactly the average between the two demands worked out by the engineers of the N.R.C. and practically the same as the 750,000 acre-feet suggested by Colorado in October, 1937, which was based upon a diversion to Mexico of 60,000.

This reasoning appears to have held true for Bliss as well. On December 22, as the engineering advisors prepared to draft their recommendations, he informed McClure by letter that all had

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[60] Hill, Memo to Mr. Clayton, November 26, 1937, 3. [1937], Box 2F467, RGCC-FBCP, UTA.

[61] [Raymond Hill], "TEXAS COMPACT: John Bliss Estimate of Project Requirements at Elephant Butte," 12/17/37. CB-F-137-34, Box 4X215, RAHP, UTA; and "John Bliss Estimate of Project Requirements at Elephant Butte," typescript, n.d. CB-F-137-34, Box 4X215, RAHP, UTA.

agreed that "the Elephant Butte Project [would]…be limited to annual releases of 800,000 acre feet reduced by two-thirds of the savings to be made by limiting Mexico."[62]

In the resulting "Report of Committee of Engineers to the Rio Grande Compact Commissioners," dated December 27, 1937, the engineering advisors noted that they had "avoided discussion of the relative rights of water users in the three States." Instead, they "were guided…by the general policy – expressed at the meeting of the Compact Commission in October – that present uses of water in each of the three States must be protected in the formulation the Compact," as "the usable water supply is no more than sufficient to satisfy such needs." The engineers further recognized that "precise determination of past conditions and close estimates of future changes" were "not possible," so they recommended "review of these matters" by the commission "after five years and for adjustments within the intent of the Compact."[63]

For the purposes of their discussion on how to distribute equitably the existing water among the three states, the engineers recognized the three natural divisions of the Upper Rio Grande Basin:

1. San Luis Valley – "the drainage area above the Lobatos gaging station on the Rio Grande near the Colorado-New Mexico State Line;"
2. "The Middle Rio Grande from Lobatos to Elephant Butte Reservoir…;"
3. "The balance of the Rio Grande Basin from Elephant Butte and Fort Quitman, including the Juarez Valley in Mexico."

The main issue with respect to Colorado was to adopt a state-line delivery schedule to New Mexico. The engineers noted that there was a "consistent relationship…between the combined inflow of the major streams flowing into San Luis Valley and the outflow of the Rio Grande at Lobatos." Construction of upstream storage reservoirs would disrupt this relationship so the engineers offered "separate schedules [of water delivery] for the Conejos and Rio Grande stream systems." These schedules would "automatically" compensate for "variations in discharge of contributing streams…particularly, if storage reservoirs are constructed." "The obligation of Colorado to deliver water in the Rio Grande at the Colorado-New Mexico State Line" the engineers observed, "would be the sum of the quantities set forth" in the schedules provided, subject to certain permissible departures. Use of these schedules would permit "appropriate

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[62] Tipton, *Analysis*, 11. ff. 70, Box 44-70, MCHC 1897-1987, HC; and John H. Bliss to Tom [Thomas M. McClure, State Engineer], December 22, 1937.Rio Grande Compact – July 7, 1937 to June 30, 1938, 26th Fiscal Year, NM_0015692 – NM_00156929.

[63] Hill, Memo to Mr. Clayton, November 26, 1937, 3. [1937], Box 2F467, RGCC-FBCP, UTA; "Report of Committee of Engineers to Rio Grande Compact Commissioners," December 27, 1937, in Proceedings of the Meeting of the Rio Grande Compact Commission, Held at Santa Fe, New Mexico, March 3rd to March 18th, inc., 1938, Appendix No. 1, 40. ff. 032.1, Box No. 936, Entry 7, RG 115, NARA Denver.

adjustments…[to] made for any trans-mountain diversions, for any change in location in gaging stations, and for any new or increased depletion of natural run-off at gaging stations above Lobatos."[64]

With regard to New Mexico's obligation to Texas, the engineers observed that "wide variations in the discharge of tributary streams" rendered the "amount of water in the Rio Grande above the principal agricultural areas of New Mexico and inflow into Elephant Butte Reservoir" inconsistent and unpredictable. After careful study, they agreed that a "reasonable relationship" existed "between the discharge of Rio Grande at Otowi Bridge and the inflow to Elephant Butte Reservoir," excluding the months of July, August, and September. Removing these three months from the calculations, the remaining data could be used to adopt a proper schedule of deliveries at Otowi Bridge to obtain the appropriate supply of water at Elephant Butte. The curve then required some adjustment "to compensate for increased salinity of the Elephant Butte supply." The New Mexico's obligation to deliver water into Elephant Butte Reservoir was subject to several factors: a system of accrued credits and debits on annual scheduled deliveries; "appropriate adjustments…for any change in points of measurement"; "any new and increased depletion in New Mexico of the natural runoff measured at Otowi Bridge"; and "any trans-mountain diversions between Lobatos and Elephant Butte."[65]

The engineers set an average of 800,000 af per year as the "normal release" from Elephant Butte Reservoir – the quantity for which Hill and Clayton had argued. This release was subject to "any gain and loss in usable water resulting from the operation of any reservoir below Elephant Butte." As both Tipton and Bliss indicated to their commissioners, it would also be "reduced or increased by two-thirds of any change in aggregate diversions and loss to Mexico between Courchesne gaging station and the lowest point of diversion to lands of the Rio Grande Project." The suggested index used to determine the amount of change was "the average annual diversion and loss to Mexico from 1928 to 1937." Should "normal release…[be] modified by any change in the amount of diversions and loss to Mexico," Colorado and New Mexico had to "share equally" with

[64] "Report of Committee of Engineers to Rio Grande Compact Commissioners," December 27, 1937, in Proceedings of the Meeting of the Rio Grande Compact Commission…March 3rd to March 18th, inc., 1938, Appendix No. 1, 40-42. ff. 032.1, Box No. 936, Entry 7, RG 115, NARA Denver.

[65] "Report of Committee of Engineers to Rio Grande Compact Commissioners," December 27, 1937, in Proceedings of the Meeting of the Rio Grande Compact Commission…March 3rd to March 18th, inc., 1938, Appendix No. 1, 42-44. ff. 032.1, Box No. 936, Entry 7, RG 115, NARA Denver.

their "accrued credits or debits…adjusted annually by an amount equal to one-third of such change in diversions and loss to Mexico."[66]

Although the engineers recognized that natural variations in discharge at their selected control stations and additional storage of flood waters in upstream reservoirs would require appropriate adjustments to delivery schedules, they established definite limitations on accrued debits and credits. Colorado's annual or accrued debit was capped at 100,000 acre-feet, except as caused by storage in reservoirs constructed above Lobatos after 1937. New Mexico's allowable accrued debit was capped at 200,000 acre-feet, except as caused by storage in reservoirs in New Mexico. However, in both states accrued debit caused by such storage could not exceed the amount of water held in storage in such reservoirs. If in any year the total accrued debits of Colorado and New Mexico exceeded "the difference between the total capacity of [Rio Grande] Project storage and the amount of usable water then in storage, such debit shall be reduced proportionally to an aggregate amount equal to the minimum unfilled capacity in that year." If there was unusable spill from Elephant Butte, all accrued debits of Colorado and New Mexico for that year would be cancelled, "excepting debits caused by storage in reservoirs prior to the time of spill."[67]

Accruals in excess of the limits established for Colorado and New Mexico, respectively, could be applied to offset debits caused by storage in reservoirs. In computing accrued credits or debits, annual credits in excess of 150,000 acre-feet were to be taken as equal to that amount. If unusable spill occurred at Elephant Butte Reservoir, the aggregate credits of Colorado and New Mexico would be reduced by the amount of such spill in proportion to each state's respective credits at the time of the spill. "[N]o credits…[would] be considered in a year of spill."[68]

The report also proposed specific protections for the Rio Grande Project water supply. "[W]henever there [was] less than 400,000 acre-feet of water in storage available for use in the Rio Grande Project," neither Colorado nor New Mexico would be allowed to increase storage in any reservoir built after 1929 in the Upper Rio Grande Basin. Furthermore, if the same minimum stage was reached on January 1 of any year, Colorado and New Mexico had to "release on

[66] "Report of Committee of Engineers to Rio Grande Compact Commissioners," December 27, 1937, in Proceedings of the Meeting of the Rio Grande Compact Commission…March 3rd to March 18th, inc., 1938, Appendix No. 1, 45 and 47. ff. 032.1, Box No. 936, Entry 7, RG 115, NARA Denver.

[67] "Report of Committee of Engineers to Rio Grande Compact Commissioners," December 27, 1937, in Proceedings of the Meeting of the Rio Grande Compact Commission…March 3rd to March 18th, inc., 1938, Appendix No. 1, 45-46. ff. 032.1, Box No. 936, Entry 7, RG 115, NARA Denver.

[68] "Report of Committee of Engineers to Rio Grande Compact Commissioners," December 27, 1937, in Proceedings of the Meeting of the Rio Grande Compact Commission…March 3rd to March 18th, inc., 1938, Appendix No. 1, 46. ff. 032.1, Box No. 936, Entry 7, RG 115, NARA Denver.

demand, at the greatest rate practicable, water from reservoirs in the amount equal to the total debit of each which was caused by storage of water in reservoirs."[69]

In addition to adjusting the curve for New Mexico's deliveries into Elephant Butte to compensate for increased salinity in the reservoir, the engineers also recommended a limitation on the salinity at the Colorado-New Mexico state line. It was still unclear whether or not Colorado's "Closed Basin Drain" would be constructed and what effect the drain would have on the salt content of the Rio Grande downstream. Therefore, the engineers suggested that if any works were constructed after 1937 to deliver water from the Closed Basin Drain into the Rio Grande, Colorado would only be credited for the water so delivered if "the proportion of sodium ions is less than 45% of the total positive ions in that water."[70]

Concluding their report, the engineers offered their recommendation for the basis of a compact. They noted that "no material expansion of the irrigated area in the Rio Grande Basin above Fort Quitman" was feasible without transfers of water from outside the basin. Acknowledging that "[g]ood use could be made of this [imported] water," they nevertheless determined that the "allocation of any supply so obtained constituted a matter of policy beyond our province." Therefore, "no recommendation [was] made" on this issue. Three other recommendations were:

1. "…that the normal release from Elephant Butte Reservoir be deemed to be 800,000 acre-feet per annum, adjusted for gains or loss of usable water resulting from the operation of any reservoir below Elephant Butte," and "that this normal release be reduced or increased by two-thirds of any change in aggregate diversions and loss to Mexico."
2. "…that deliveries by New Mexico into Elephant Butte Reservoir be made in accordance with the schedule based on the flow at Otowi Bridge and the usable supply at Elephant Butte, subject to proper limitations on departures" (as outlined in the table in the report, "Deliveries Into Elephant Butte Reservoir Exclusive of July, August, and September").
3. "…that deliveries by Colorado be the sum of the amounts set forth in the schedules for the Conejos stream system and for the Rio Grande system, exclusive of Conejos River, both subject to proper limitations on departures."

[69] "Report of Committee of Engineers to Rio Grande Compact Commissioners," December 27, 1937, in Proceedings of the Meeting of the Rio Grande Compact Commission…March 3rd to March 18th, inc., 1938, Appendix No. 1, 46-47. ff. 032.1, Box No. 936, Entry 7, RG 115, NARA Denver.
[70] For more on the water quality requirements at the Colorado-New Mexico state line, see footnote 120 below.

Inclusion of the delivery schedules and other provisions of the report, in the opinion of the engineering advisers, would result in both "the maximum practicable use of the waters of the Rio Grande, and would minimize unusable spill at Elephant Butte."[71]

Confident that progress was being made toward an interstate compact, Texas filed a motion in December for a continuance of the *Texas v. New Mexico* hearings, which Warren subsequently granted. A month later, Clayton forwarded a copy of the report of the committee of engineers to the special master. Texas's commissioner confessed that the report "means more to an engineer than to a lawyer," but after having Hill explain the approach and conclusions, he and the other attorneys for Texas had been convinced that it represented "a reasonably fair compromise of the views of the three States and provides a fairly workable basis for a permanent compact."[72]

Although all of the engineering advisors signed off on the December 1937 report and recommended its adoption by the compact commission, McClure objected to the report in late January 1938. Even before the report was completed, he had reservations. When the New Mexico state engineer and compact commissioner learned the general outlines of the report on December 22 from Bliss, McClure confidentially told his advisor that the 800,000 af release "will not be agreeable."[73]

The New Mexico commissioner's opposition hardened in the wake of a detailed analysis of the December 1937 report prepared by MRGCD consulting engineer H.C. Neuffer. After reviewing the engineering advisors' report in January, Neuffer forwarded a six-page memorandum to Bliss critical of the work. In his transmittal letter he suggested re-consideration "of the schedules of delivery at San Marcial or Elephant Butte," and recommended that "the figures upon which the curves" of the "usable supply at Elephant Butte" be obtained as he was having difficulty deriving those curves based upon the data he had on hand.[74]

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[71] "Report of Committee of Engineers to Rio Grande Compact Commissioners," December 27, 1937, in Proceedings of the Meeting of the Rio Grande Compact Commission…March 3rd to March 18th, inc., 1938, Appendix No. 1, 47. ff. 032.1, Box No. 936, Entry 7, RG 115, NARA Denver. Water quality is also discussed in Opinion II below.

[72] Charles Warren to Frank Clayton, December 21, 1937; and Frank B. Clayton to Charles Warren, January 27, 1938. [1938], Box 2F467, RGCC-FBCP, UTA.

[73] Bliss to [McClure], December 22, 1937; and T.M. McClure to John H. Bliss, telegram, 1937 Dec 24 AM 10 27. Rio Grande Compact – July 7, 1937 to June 30, 1938, 26th Fiscal Year, NM_0015692 – NM_00156929 and NM_00156927.

[74] Two weeks after this letter, and after receiving his own from Neuffer, McClure contacted Hill to obtain "the data used in corrected the Elephant Butte storage figures and thereby arriving at your [Hill's] Usable Supply table." Thomas M. McClure, Engineer, to Mr. Raymond A. Hill, January 14, 1938. Rio Grande Compact – July 7, 1937 to June 30, 1938, 26th Fiscal Year, NM_00156897.

Neuffer and the district's "chief objection," as Bliss privately informed Tipton, was the report's recommended "normal release" of 800,000 af from Elephant Butte. According to New Mexico's engineering advisor, "The Middle Valley people have set their mind upon a much smaller figure as ample Project release annually." Indeed, Neuffer argued that figure "need not be in excess of 700,000 acre feet per annum." The MRGCD consulting engineer pointed in his memorandum that over the past decade, 1927 to 1936, 781,000 af on average had been released from the reservoir – a figure inclusive "of excessive quantities of water delivered to Mexico, avoidable project wastes, and savings which can be made after the channel rectification is completed."[75] He calculated that as little as 686,000 af could satisfy "Project use above El Paso," "Mexican Treaty Requirements plus river loss to riverside drain in Mexico," "Unavoidable project wastes below Riverside heading," "Winter discharge of Project drains in New Mexico not redivertable," and "Net project diversions below El Paso." In Neuffer's mind, 700,000 af "would be liberal allowance" for Elephant Butte Reservoir. The engineer nonetheless conceded the necessity for negotiation, and expressed his openness to 750,000 af "as the very maximum figure without injury to New Mexico or the Middle Valley" – the same figure suggested by Tipton and Bliss prior to the December 1937 report.[76]

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[75] For more on this channel rectification program, see footnote 169 below.

[76] H.C. Neuffer, Consulting Engineer, to Mr. John H. Bliss, State Engineer's Office, Re: Report of Committee of Engineers to Rio Grande Compact Commissioners, December 27, 1937, January 7th, 1938. NM_00054005; H.C. Neuffer, Memorandum, Subject: Report of Committee of Engineers to Rio Grande Compact Commissioners, December 27, 1937, np [1-3, and 6]; JHB, Engineer, to Mr. R.J. Tipton, Consulting Engineer, January 14th, 1938. Rio Grande Compact – July 7, 1937 to June 30, 1938, 26th Fiscal Year, NM_00156900 – NM_00156902, NM_00156905, and NM_00156892 – NM_00156894.

The other objections included adjustments to be made for Caballo; accounting for losses to Mexico; the tally of 2,638,860 af for the "maximum storage for the Rio Grande Project"; language in the December 27, 1937 report concerning "unusable spill"; "the arbitrary figure of 400,000 acre feet storage in Project reservoirs, below which all storage debits of the upper basin states could be called for by the Project"; and the relation between Colorado-New Mexico state line deliveries and Otowi. Independently, Bliss expressed second thoughts as to the exclusion of the months of July, August, and September, in the Otowi-Elephant Butte index – although Neuffer had "no serious objection" to this. See Neuffer, Memorandum, December 27, 1937, np [1-6]; and JHB to Tipton, January 14th, 1938. Rio Grande Compact – July 7, 1937 to June 30, 1938, 26th Fiscal Year, NM_00156900 – NM_00156905, and NM_00156892 – NM_00156894.

On the issue of Elephant Butte releases, Tipton wrote back a few days later that he was "inclined to agree with" Bliss, and that it was "a matter which will have to be thoroughly discussed by the Compact Commissioner." Tipton himself was "going to give more thought to" the issue. Tipton also clarified some matters relating to the 400,000 af figure, and expressed interest in developing "a State Line-Otowi relationship." As to the exclusion of the three months from the Otowi-Elephant Butte index, the Colorado engineer admitted that he "did not follow in sufficient detail your [Bliss], and Mr. Hill's work in connection with setting up the Otowi-Elephant Butte relationship to express an opinion…." R.J. Tipton, to Mr. John H.

Two weeks after writing Bliss, Neufer urged McClure to reject the engineering advisors' report. The MRGCD consulting engineer had thus far been unable to verify portions of the report because "of the availability of the data used by the Committee in working out the relationship of the flow of the Rio Grande at various stations." Moreover, he argued that "[t]here are…certain other items which we feel, if agreed upon, would result in permanent damage to the Middle Rio Grande Conservancy District and other water users in New Mexico above the Elephant Butte Dam." Neuffer did not specify what those are items were in his letter, but they were likely the same as he raised in the memorandum forwarded to Bliss. The MRGCD consulting engineer further offered the services of the district to the engineering advisors.[77]

McClure formally objected to the "Report of the Committee of Engineers" in a January 25, 1938 letter to Harper. The New Mexico state engineer indicated that he had given the report "additional consideration," and was now "in thorough accord with the position taken by Mr. Neuffer." McClure had also discussed the work "with others in authority representing the State of New Mexico," and all were of the same mind to reject it. He dismissed the report as "too vague and indefinite in some respects," lacking a sufficiency of data to support "the relationship of flow at various stations." The "basis for the water supply to the State of Texas," furthermore, was in McClure's "judgment and in the judgment of others in authority in New Mexico…so far out of reason that it could not be considered as a basis for negotiations." Most damningly, the New Mexico state engineer asserted that "the engineers in their recommendation plainly exceeded their authority." Rather than "reporting accurate basic data," which McClure understood to be their charge, they offered "a compromise of basic data." Echoing Neuffer, he called "for the engineers to reassemble at the earliest possible moment and give this matter further study."[78]

New Mexico's view of the December 1937 report was in stark contrast to Texas's and Colorado's. Two days after McClure's letter to Harper, which was circulated to the other commissioners, Clayton praised the work of the engineers to the Rio Grande Compact Commission chair. He thought their report offered "a fairly workable basis for the equitable apportionment of the waters of the Rio Grande, without permitting further encroachments upon Texas' already inadequate supply." Texas's commissioner neither accepted McClure's characterization of the

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Bliss, January 18, 1938. Rio Grande Compact – July 7, 1937 to June 30, 1938, 26th Fiscal Year, NM_00156881 – NM_00156882.

[77] [H.C. Neuffer] to Mr. Thomas M. McClure, State Engineer, January 13, 1938; and Thomas M. McClure, State Engineer, to Mr. S.O. Harper, Chairman, Rio Grande Compact Commission, January 25th, 1938. ff. 032.1 Rio Grande Basin Corres. re Compact between States of Colorado; New Mexico & Texas re Rio Grande Basin Water Rights, Jan. 1938 thru May 1939, Box No. 936 Rio Grande Basin 023._246., Entry 7, RG 115, NARA Denver.

[78] McClure to Harper, January 25th, 1938. ff. 032.1, Box No. 936, Entry 7, RG 115, NARA Denver.

work nor believed that the engineers had exceeded their authority. As to the assertion that "the basis for water supply to the State of Texas" was unreasonable, Clayton countered

> It seems to me and to those interested with me in the protection of Texas' water supply that the report contains no recommendations for the benefit of Texas than what she is plainly entitled to. In fact, it makes concessions to the upper States about which we are somewhat dubious. But in the interests of an amicable settlement of our common problems, we are willing to accept the report as a basis for further negotiation…. [T]he engineering representatives of all three States and of the United States, as well, apparently reached the conclusion, after considerable research and negotiation, that the basis suggested in the report will do no more than preserve the status quo as far as the water supply is concerned, while, at the same time, permitting New Mexico and Colorado to proceed with certain desired developments.

He further pointed out

> in passing that the commissioner for New Mexico seems to lose sight of the fact that there is a very extensive section of his own State lying below the Elephant Butte dam, and that its large vested interests are likewise entitled to representation and protection, along with the Middle Rio Grande Conservancy District.

Texas was "unwilling to recede from…the minimum requirements for the protection of Texas' water supply in the report," but was ready "to proceed with negotiations towards a permanent compact, based upon the report of the committee of engineers."[79]

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[79] Frank B. Clayton, Rio Grande Compact Commissioner for Texas, to Mr. S.O. Harper, Chairman, Rio Grande Compact Commission, January 27, 1938. ff. 032.1, Box No. 936, Entry 7, RG 115, NARA Denver.

Hill also took exception to McClure's objections in two separate letters to Clayton in early February. In the first, he admitted he was "somewhat amused by McClure's position," in that the New Mexico's compact commissioner "relies more upon the judgment of Neuffer than that of his own deputy." He supported Clayton's position that another meeting of the engineers was unnecessary and the compact commission was the best venue for further deliberation. Raymond A. Hill to Mr. Frank B. Clayton, February 3, 1938. Box 2F466, RGCC-FBCP, UTA.

The tone of Hill's second letter, sent less than a week after the first, was angrier. Noting that Clayton had admonished McClure for failing to recognize the interests of New Mexican lands within the Rio Grande Project (Elephant Butte Irrigation District), Texas's engineering advisor insisted "that the time has come when the State of Texas should cease being the direct representative of an irrigation district situated in New Mexico." He argued that as long as Texas advocated for the water rights of all lands under the Rio Grande Project, New Mexico officials would identify more strongly with the interests of the Middle Rio Grande Conservancy District. Hill suggested that "pressure" be brought to bear on McClure to defend all of New Mexico's interests, and that Texas demand a schedule of deliveries measured at Courchesne for its lands only. Such a schedule would provide roughly 500,000 af for Texas:

(a) for all water diverted or lost to Mexico;

(b) for all consumptive requirements below El Paso;

Hinderlider was similarly critical of McClure. Writing to Harper in early February, he insisted that "Mr. McClure should not unqualifiedly accept the views of Mr. Neuffer," and he strongly opposed including the MRGCD engineers in the discussions. The Colorado commissioner objected further to what he saw as local interests influencing state authorities, insisting "that it will be impossible to reach an interstate agreement so long as every individual group of water users is permitted to inject and insist upon individual points of view." Colorado sought "parity with the two lower states, in the development of her water resources in the San Luis Valley," and Hinderlider believed that the engineers' report "could be accepted in principle as a basis of further discussions and negotiations by the Compact Commission." He suggested that McClure "specifically and definitely point out the items in said report to which he takes exception, and indicate the particular points upon which he desires further information." On this basis, the commission as a whole could determine if the engineers needed to meet again prior to the commissioners.[80]

Because of McClure's letter and the subsequent correspondence from Clayton and Hinderlider, Harper suggested the commission meet on March 3 in Santa Fe. When proceedings re-opened both Clayton and Hinderlider expressed their support of the engineering advisors' report even as McClure rose to repudiate it. Altogether New Mexico's commissioner proposed nine separate specific changes to the report. Before the commission, however, McClure stressed that the two most important issues were: 1) the indexing between Otowi and Elephant Butte "usable [supply]," and 2) use of 800,000 af as the "basis of releases from the Elephant Butte Reservoir." He argued that the engineers offered no "actual factual data" to support the Otowi-Elephant Butte indexing relationship and the release schedules for the reservoir. The 800,000 af was, moreover, "far in excess of past and present average releases and [was] far in excess of their project needs." As evidence of the report's deficiencies, McClure asserted that his office had

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(c) for drainage outflow in sufficient amount to give a salt balance and provide equivalent service;

(d) for operating waste; and

(e) for water undivertible in the winter and in excess of irrigation demands during the irrigation season.

Hill recognized that this idea had been discussed and rejected previously, but he was of the opinion "that the situation is sufficiently changed to warrant such a demand from Texas." Raymond A. Hill to Mr. Frank B. Clayton, February 8, 1938. Box 2F466, RGCC-FBCP, UTA. As discussed in Opinion IV, such an arrangement was untenable owing to the nature of the Rio Grande Project. No historical evidence, moreover, has come to light that Hill's suggestion was seriously entertained by Clayton or discussed at the subsequent (and last) compact commission meetings in March 1938. See also Littlefield, *Conflict on the Rio Grande*, 202-203.

[80] M.C. Hinderlider, Commissioner for Colorado, to S.O. Harper, Chairman, Rio Grande Compact Commission, February 4, 1938. ff. 032.1, Box No. 936, Entry 7, RG 115, NARA Denver.

analyzed the indexing stations used in the report and found the Otowi-Elephant Butte indexing in the report inaccurate.[81]

Clayton preferred the commissioners to work out these issues, calling upon the engineering advisors or NRC representatives for clarification as necessary. Harper, Hinderlider, and the engineers themselves, however, were persuaded that the engineers should formally assess the merits of New Mexico's objections. In a presentation the following day (March 4), the engineers indicated their willingness to re-consider their report on the basis of nearly all the issues raised by McClure.[82] With regard to the two key objections – use of an Otowi-Elephant Butte index and the 800,000 af to be released from the reservoir – they agreed "to give further consideration" to New Mexico's proposal for an Otowi-San Marcial index, and to examine "any data in support" of New Mexico's claim that "800,000 acre-feet of water exceeds both past uses and requirements below Elephant Butte," data hitherto unavailable to them. The commissioners concluded that the engineering advisors should meet again to revise their report, with Clayton insisting that New Mexico "furnish the data and other figures on which they predicate their demands" and the commission proceed with negotiations while awaiting a revised report.[83]

That revision took a week to complete. The engineers worked in isolation, joined only by Neuffer who acted as a "witness."[84] A "Memo of Suggested Changes to be Made in the Engineering

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[81] S. O. Harper, Chairman, Rio Grande Compact Commission, to Mr. M.C. Hinderlider, Rio Grande Compact Commissioner for Colorado, Mr. Thomas M. McClure, Rio Grande Compact Commissioner for New Mexico, and Mr. Frank B. Clayton, Rio Grande Compact Commissioner for Texas, February 12, 1938. ff. 032.1, Box No. 936, Entry 7, RG 115, NARA Denver; and Proceedings of the Meeting of the Rio Grande Compact Commission…March 3rd to March 18th, inc., 1938, 1, 3, 5 and 9. ff. 032.1, Box No. 936, Entry 7, RG 115, NARA Denver.

[82] On two issues the engineering advisors were unwilling to concede to further review. Collectively, they concluded that New Mexico's request "to be relieved of responsibility for Indian or other operations beyond its control" was "a matter…of policy for determination by the Compact Commission." The group further dismissed New Mexico's assertion that their December 1937 report had engaged in a "judicial interpretation" of the Mexican treaty. They were nevertheless open to examining data that New Mexico might have with regard to fixing the figure of present-day use by New Mexico. Proceedings of the Meeting of the Rio Grande Compact Commission...March 3rd to March 18th, inc., 1938, 11-15. ff. 032.1, Box No. 936, Entry 7, RG 115, NARA Denver.

[83] Proceedings of the Meeting of the Rio Grande Compact Commission...March 3rd to March 18th, inc., 1938, 7-15, and Appendix No. 6, 56-57. ff. 032.1, Box No. 936, Entry 7, RG 115, NARA Denver.

[84] Neuffer's attendance was prompted by a suggestion by one of McClure's legal advisors, former New Mexico governor Arthur T. Hannett in a stated bid to "save a lot of time." Edwin Mechem, EBID's counsel and a legal advisor to Clayton, immediately objected to what he saw as MRGCD engineering consultant being "substituted for the State's [New Mexico's] expert." Mechem asserted that EBID's interests were greater and that "Mr. Neuffer doesn't represent us." Hannett countered that his suggestion was not to replace Bliss, but simply to include Neuffer. It was a "practical matter," because MRGCD's support for the compact was essential to the compact's ratification by New Mexico's legislature. "For that reason the

Advisors' Report," prepared by Bliss coming out of the March 3 meeting, indicates that altogether 11 revisions were to be made or considered. The most notable of these were the substitution of "an "Otowi-San Marcial relation" for the engineers' recommended "Otowi-Elephant Butte Supply relation," and the reduction in the proposed 800,000 af average "Normal Release from Elephant Butte" per year to 775,000 af. This was close to the figure that the federal Rio Grande Joint Investigation had determined as the demand on the reservoir for the Elephant Butte-Ft. Quitman section of the basin, and 25,000 af more than Tipton and Bliss had calculated ahead and during the engineering advisors' meetings.[85]

Dated March 9 but presented the following day, the revised engineers' report reflected the two key changes sought by New Mexico. An Otowi-San Marcial index (excluding the months of July, August, and September) replaced the original Otowi-Elephant Butte index, and the recommended figure for "normal release from Elephant Butte" was reduced. However, that reduction was not from 800,000 af annually to 775,000 af as suggested by Bliss's "Memo." Instead the normal release was proposed to be "an average of 790,000 acre-feet per annum, adjusted for any gain or loss of usable water resulting from the operation of any reservoir below Elephant Butte."[86]

As discussed above, Hill had been adamant that 800,000 af was critical to serving lands in Texas with a sufficient quantity and quality of water, and it was a position that Clayton strongly supported before the rest of the commission. Nonetheless, the revised report recommended a lesser figure under pressure from interest in New Mexico. The reason for Texas's concession may very well lie in the problem Hill had identified back in November 1937: the fact that in recent years the Rio Grande Project had utilized closer to 730,000 af. Thirty years after the compact had been signed, Hill gave sworn testimony in a deposition for the *Texas and New Mexico v. Colorado*

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engineering expert of that district," he asserted, "has got at least to have the opportunity to check our figures before we bind ourselves, and that's all we ask." At Hinderlider's suggestion, Neuffer was therefore designated a "witness" rather than a direct participant in the engineering discussions with the commissioners agreeing that his contributions would be at the discretion of the engineers. Proceedings of the Meeting of the Rio Grande Compact Commission...March 3rd to March 18th, inc., 1938, 18-20. ff. 032.1, Box No. 936, Entry 7, RG 115, NARA Denver.

[85] J.H. Bliss, Memo of Suggested Changes to be Made in Engineering Advisors' Report, March 3, 1937. . Rio Grande Compact – July 7, 1937 to June 30, 1938, 26th Fiscal Year, NM_00156842-NM_00156843. The date, "March 3, 1937," on the face of this document is likely a typographic error. The memo's content makes clear that it was drafted either just before or just after the March 3, 1938 compact meeting, in light of McClure's objections to the December 27, 1937 engineering advisors' report. Additionally, this particular copy of the memo (NM_00156842) appears in sequence of chronologically organized documents between other documents from 1938.

[86] Proceedings of the Meeting of the Rio Grande Compact Commission...March 3rd to March 18th, inc., 1938, 61, 62, and 65. ff. 032.1, Box No. 936, Entry 7, RG 115, NARA Denver.

suit before the US Supreme Court in 1968 that succinctly explained the 790,000 af figure adopted by the commission and later ratified in the 1938 Compact:

> The 790,000 acre-feet that was arrived at as the normal release, so defined in the Compact, included the water which was obligated to be delivered to Mexico under the Treaty of 1906, the 60,000 acre-feet in the Acequia Madre. So that the allotment on the downstream side of Elephant Butte was really seven hundred thirty for uses in the United States and sixty for uses in Mexico, and the provision that was incorporated that if they used more than sixty in Mexico, it came out of the seven hundred thirty….[87]

Following Debler's presentation and submittal of the written report, the commission recessed until March 11 to give the compact commissioners an opportunity to review the proposed changes to the December 1937 engineering advisors' report. When the commission reconvened, it almost immediately went into a closed session to permit an "informal discussion, off the record" so the commissioners could "speak freely" on points in the report that required "further clarification or change." The precise substance of this discussion is unknown; it went unrecorded by the commission secretary. The recorded proceedings merely indicate that the commission as whole sought "additional information" about the report.

A formal written clarification report was submitted by the engineers on March 11, and before the commission Debler and Hill addressed two specific issues: "the stage of project storage when the upstream reservoirs ceased storing," and the meaning of "average" with regard to the proposed 790,000 af releases from Elephant Butte annually. For the first, Debler explained that the group had settled on 400,000 af as the minimum level of project storage to serve lands below Elephant Butte. As the clarification report went on to detail, if there was less than 400,000 af of usable storage in the reservoir then neither of the upper states could continue storing water in any reservoirs built after 1929. The "intent" (in Debler's words) or "principle" (in Hill's), was that the states would share proportionately in diminished stored water.[88]

As for the second issue, according to Debler, use of the term "average" reflected the engineers' understanding that releases could be greater or lesser from year to year. McClure was concerned about the potential impact of years of releases greater than 790,000 af. Debler assured McClure that the system of debits and credits would protect the upper states from significant depletion. He also made plain that so long as the United States operated the reservoir, it would "bear down

[87] Deposition of Raymond A. Hill. Taken December 4, 1968, 18. ff. Texas & New Mex. v. Colo., w. 66-1061 Texas vs. Colorado, Box 1989 41-240, LF-TAG, TSA.
[88] Proceedings of the Meeting of the Rio Grande Compact Commission...March 3rd to March 18th, inc., 1938, 25-27, and Appendix No. 8, 66. ff. 032.1, Box No. 936, Entry 7, RG 115, NARA Denver.

awfully hard so those boys down there [i.e., the waterusers] don't short themselves in low periods as they have in the past."[89]

Following this presentation, the commissioners' focus shifted to the drafting of the compact. They accepted these revisions and appointed a "Drafting Committee" to put the final document together. The legal advisors to the commissioners comprised this committee: Corlett and Carr for Colorado; former New Mexico governor Arthur Hannett and Fred E. Wilson for New Mexico; and Burges and EBID attorney Edwin Mechem for Texas. No federal representative was available to attend, so the attorneys for the state commissioners worked out a draft. The full commission recessed for nearly a week, from March 11 to March 17, as the legal committee deliberated. "Several closed and informal meetings of the Commission," according to the recorded commission proceedings, "were held." At these meetings "controversial questions were discussed with the Drafting Committee and the engineering advisors and differences were resolved" confidentially with "[n]o record of these meetings…kept."[90]

The engineers reviewed at least one draft of the compact dated March 16. A memorandum signed by all of the engineering advisors and Neuffer and dated that same day suggested some changes. They recommended, for instance, the inclusion of a paragraph compelling the Commission to undertake "special studies" of the flow at San Acacia, San Marcial, and below Elephant Butte should "the necessity arise" for "an equivalent schedule." The engineers also suggested "[a]mplifying" paragraph 15 of the draft compact like so:

> During the month of January of any year the Commissioner for Texas may demand of Colorado and New Mexico, and the Commissioner for New Mexico may demand of Colorado, the release of water from storage reservoirs constructed after 1929 to the amount of the accrued debits of Colorado and New Mexico, respectively, and such release . . .

"In the next to the last line" of this paragraph, they further called for the addition of the phrase "of 790,000 acre-feet" to modify the term "release."[91]

On March 17, 1938, the Drafting Committee submitted their final compact draft to the commissioners who accepted it unanimously the following day. Although no provision was made in the final document for the "special studies" suggested by the engineers, Article IV required that "[c]oncurrent records…be kept of the flow of the Rio Grande at San Marcial, near San Acacia,

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[89] Proceedings of the Meeting of the Rio Grande Compact Commission...March 3rd to March 18th, inc., 1938, 29. ff. 032.1, Box No. 936, Entry 7, RG 115, NARA Denver.
[90] Proceedings of the Meeting of the Rio Grande Compact Commission...March 3rd to March 18th, inc., 1938, 31-33. ff. 032.1, Box No. 936, Entry 7, RG 115, NARA Denver.
[91] Proceedings of the Meeting of the Rio Grande Compact Commission...March 3rd to March 18th, inc., 1938, Appendix No. 9, 68-70. ff. 032.1, Box No. 936, Entry 7, RG 115, NARA Denver.

and of the release from Elephant Butte Reservoir, to the end that the records at these stations may be correlated." The final draft also incorporated the language suggested by the engineers for paragraph 15 as Article VIII.[92]

The state compact commissioners, Clayton, Hinderlider, and McClure, soon after forwarded the document to their respective governors, and in the case of Harper, to the secretary of the interior. In his November 1938 transmittal letter to Governor W. Lee O'Daniel, Clayton expressed his opinion that the "compact represents a fair and equitable settlement of the controversies that have raged almost continuously for over forty years between the three States." "As far as Texas is concerned," the commissioner wrote, "it in effect prevents further encroachments on the waters of the Rio Grande by the upper basin States.""[93]

Letters by Hinderlider, McClure, and Harper all evoked the same optimism, even as each touted the individual benefits of the compact of their respective states or for the United States. Hinderlider "believed" that the "interstate River Compact or Agreement…equitably allocates the waters of the Rio Grande Basin originating above Fort Quitman, Texas, between the States of Colorado, New Mexico, and Texas." For Colorado specifically, he informed Governor Teller Ammons a few days after Clayton wrote O'Daniel, the "permanent compact…fully protects present and future uses of waters in the San Luis Valley, and the San Juan Basin in Colorado against exportations of water out of that basin for use in the Rio Grande Basin in New Mexico, except upon the conditions stated in the Compact." That protection further extended, according to Hinderlider, to "the rights of the water users under federal reclamation projects in New Mexico and Texas," as well as to "Indian tribes, and to the Republic of Mexico under existing treaty obligations."[94]

McClure used almost identical language to Hinderlider in his letter to New Mexico Governor John E. Miles in January 1939. "The Compact," he wrote, "fully protects present and future uses of the waters of the Rio Grande stream system in New Mexico." He envisioned an end to the controversies over the use of the Rio Grande waters with the compact, "particularly the suit

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[92] Proceedings of the Meeting of the Rio Grande Compact Commission...March 3rd to March 18th, inc., 1938, 33-37, and Appendix No. 11, 78 and 80. ff. 032.1, Box No. 936, Entry 7, RG 115, NARA Denver.
[93] Frank B. Clayton to Hon. W. Lee O'Daniel, November 16, 1938, 1-4. [1938], Box 2F467, RGCC-FBCP, UTA.
[94] M.C. Hinderlider, Commissioner for Colorado, to His Excellency, Governor Teller Ammons, State Capitol, Denver, Colorado, November 15, 1938, in *Rio Grande Basin Compact* [and Analysis Thereof by M.C. Hinderlider in Address to Colorado Legislature and to Gov. Teller Ammons on Nov. 15-1938], 5-9. ff. 58 Rio Grande Basin Compact, Box 44-70, MSS 312, MCHC 1897-1987, HC.

between the States of New Mexico and Texas now pending in the Supreme Court of the United States."[95]

Likewise, writing to Secretary of the Interior Harold Ickes, days following the conclusion of the compact negotiations in March 1938, Harper was unequivocal: "The Compact, if ratified, will end over forty years of controversy and dispute among the States, and it is the unanimous opinion of the Commissioners and their advisors that it provides an eminently fair and equitable solution of this troublesome problem." Harper believed that U.S. "interests" were "fully safeguarded" in the compact, in part as a result of the "inclusion, in the State allocations, of all water to which Federal irrigation projects are entitled."[96]

Although some Texans below Ft. Quitman expressed concerns for the compact (discussed in Opinion IV), all three states and the United States ratified the agreement in 1939.[97] As the statements of the compact commissioners indicate, all those representatives believed that the compact equitably apportioned the waters of the Rio Grande above Ft. Quitman after several decades of controversy. That apportionment protected the Rio Grande Project in New Mexico and Texas, which also served lands down to Ft. Quitman, and gave Colorado and New Mexico above Elephant Butte the freedom to pursue new water projects. The water delivery schedules devised by the engineering advisors for the three states were the basis for that apportionment, and reflected the understanding among the engineers that in the absence of a transfer of additional water into the Upper Rio Grande Basin the Rio Grande was fully appropriated.

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[95] Thomas M. McClure, Commissioner for New Mexico, to His Excellency, Governor John E. Miles, Santa Fe, New Mexico, January 9, 1939. ff. RG 267, Entry 26, TX v NM #9, Box 460 1957 (TX v. MN #9) to 1957, Entry 26, RG 267, NAB

[96] S.O. Harper, Chairman, Rio Grande Compact Commission, to The Honorable, The Secretary of the Interior, Washington, D.C., Re: Rio Grande Compact, March 26, 1938, 2. ff. 032.1 Box No. 936, Entry 7, RG 115, NARA Denver.

[97] M.C. Hinderlider, Rio Grande Compact Commissioner for Colorado to Mr. Frank B. Clayton, Rio Grande Compact Commission for Texas and Mr. Thos. M. McClure, Rio Grande Compact Commissioner for New Mexico, February 21, 1939. [1939], RGCC-FBCP, UTA; Governor of New Mexico [John E. Miles] to Hon. W. Lee O'Daniel, Governor of Texas, March 2, 1939; and W. Lee O'Daniel, Governor of Texas to Honorable John E. Miles, March 9, 1939. ff. 277 Gov. John E. Miles, Conservation – Ratification of the Rio Grande Compact, 1939, Box 9, Serial No. 13225, Governor John E. Miles, special issues, Dates: 1939-1942, Governor John E. Miles Papers, NMSA; and United States of America, *Congressional Record: Proceedings and Debates of the 76th Congress, First Session*, Volume 84-Part 6, May 19, 1939, to June 9, 1939 (pages 5771 to 6948) (GPO, 1939), 6589.

Opinion II: The quantity of water apportioned to Texas by the 1938 Rio Grande Compact included flows to address water quality concerns for Rio Grande project lands in Texas.

As noted in Opinion I, the quantity of water to be apportioned to Texas by the 1938 Rio Grande Compact was inextricably linked to the quality of water. The loudest voice for water quality belonged to Texas's engineering advisor Raymond A. Hill. Hill was vociferous in his advocacy of flows to mitigate the salinity of irrigation water reaching downstream lands in Texas. In the *Texas v. New Mexico* original action, in the compact proceedings, and before his fellow engineering advisors, he was adamant that an 800,000 af release from Elephant Butte was essential to achieving a "salt balance." Broadly speaking, Hill argued that Texas required more water than it could use consumptively to ensure that little or no additional alkali salts were deposited as a result of irrigation on downstream lands to the detriment of those lands. The 800,000 af figure reflected his calculations of what was necessary to achieve what he called, "equivalent service." Neither of Hill's counterparts in Colorado and New Mexico, Royce Tipton and John Bliss, readily agreed that such a large release from Elephant Butte was justified. The federal Rio Grande Joint Investigation, which aimed to provide the requisite technical data to craft a compact, similarly did not assess a sufficient quantity of water to achieve Hill's equivalent service. With the completion of the federal investigation and the resumption of negotiations in late 1937, Texas's engineering advisor redoubled his efforts to convince his fellow advisors that 800,000 af was the appropriate amount – and he succeeded. The December 1937 engineering advisors' report recommended 800,000 af as the "normal release" from Elephant Butte. Although this figure was reduced to 790,000 af after New Mexico's compact commissioner Thomas McClure objected (reflecting the concerns of upstream interests in New Mexico), Texas's acceptance of this reduction and the compact indicates that 790,000 af was inclusive of the flows necessary to achieve Hill's "equivalent service."

Salinity was a known issue within the stretch of the Rio Grande between Elephant Butte Reservoir and Ft. Quitman. Beginning in the 1920s, the Bureau of Reclamation (Reclamation), the US Department of Agriculture (USDA), and the International Boundary Commission (predecessor to today's International Boundary and Water Commission), responsible for overseeing the provisions of the 1906 treaty with Mexico, had made various measurements and analyses of water quality and salt concentration in the river and at riverside drains. In 1929-1930 and in 1933-1934, Rio Grande Project drainage waters were the subject of close study. According to project superintendent L.R. Fiock, in 1933 alone water from the reservoir carried 600,000 tons of dissolved salts. As noted below and discussed in Opinion IV, Reclamation purposefully released additional water from Elephant Butte to compensate for increased salinity at the lowest end of the project, which further benefitted lands downstream to Ft. Quitman.[98]

The issue of water quality with regard to the quantity of Rio Grande water to be apportioned to Texas by a compact, however, was not clearly articulated until Texas filed suit against New Mexico and the Middle Rio Grande Conservancy District (MRGCD) in the US Supreme Court in October 1935. Texas alleged that New Mexico "violated the [1929] Compact by impairing the water supply in the Elephant Butte Reservoir through excessive diversions and through injurious increase of the salt contents of the water," and "that such excessive diversions and increase of salt contents were in violation of the rights of Texas waters users." As discussed in Opinion I, New Mexico denied this claim and instead asserted that illegal Mexican diversions and inefficient operation of Elephant Butte were to blame.[99]

Quantity and quality of water reaching lands in Texas went hand-in-hand, as Frank Clayton, attorney for Texas and the state's Rio Grande Compact commissioner, explained to Special Master Charles Warren near the outset of the hearings in November 1936. Clayton, citing Article XII of the 1929 compact that the water supply for Elephant Butte "shall not…be impaired by new or increased diversions or storage on the upper Rio Grande," argued that "the increased diversion in the Middle Rio Grande District has impaired both as to quality and quantity." Compensation for the diminished quality, the attorney insisted, "required an increased quantity in order to give equivalent service."[100]

Although Fiock testified that Reclamation released water "for the purpose of washing out salts," characterizing this practice as "both beneficial and necessary," much of the testimony and evidence for Texas's argument was offered by Hill and his associate (later partner) J.Q. Jewett.[101]

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[98] *Plaintiff's Case in Chief*, Vols. III, IV, 805-836; *Defendant's Case in Chief*, Vols. X, XI, 1862-1864, 1871, and 1874. CB-F-171A thru CB-F-1716: Transcripts of TX V. NM, Box 4X219; C.S. Scofield, Principal Agriculturalist in Charge, Messrs. Quinton, Code and Hill-Leeds and Barnard, Attention Mr. J.Q. Jewett, August 9, 1935. ff. Elephant Butte-El Paso Dists. General Correspondence G352 1935, Box 4X190, RAHP, UTA; Charles Warren, Attorney, Mills Building, Wash. DC, large leather black binder, unpaginated [65-66]. ff. Large black binder, Box 4, CWP, HLS HSC; and "Water From Dam Enriches Lands," *El Paso Herald-Post*, June 30, 1933. ff. 023. Rio Grande – Clippings 1930 thru 1937, Box 908 Rio Grande Pro. 010.-023, Entry 7, RG 115, NARA Denver.

[99] *Ad Interim Report of the Special Master*, received Mar. 26, 1937, 4-6. ff. RG 267, Entry 26, TX v NM #10, Box 401, Entry 26, RG 267, NAB.

[100] *Plaintiff's Case in Chief*, Vol. III, IV, 498-499. CB-F-171A thru CB-F-1716: Transcripts of TX v. NM, Vol. 1-16, 4X219, RAHP, UTA.

[101] John Q. Jewett earned his Bachelor of Science in Civil Engineering from the University of Colorado in 1920, and like Hill, later received "the degree of Civil Engineer." He was an instructor at the university during the 1922 and 1923 academic years. After the University of Colorado, Jewett joined the Yaqui Valley Irrigation Project in Mexico as an "office engineer," rising the position of "assistant to the Chief Engineer."

Using a demonstrative exhibit, Hill endeavored to explain to Warren the dynamic between irrigation, drainage, and increased salt concentration in the waters of the Rio Grande as it moved downstream. The illustration from which the engineer spoke compared a typical cross-section of the Rio Grande Valley as it would appear in “a state of nature” to that same cross-section “after irrigation and drainage.” Hill noted that part of the water from the irrigation canal passed out to the land, carrying with it salts in solution. Some of that water was lost into the atmosphere as vapor, and carried no salts. Part of the water consumed by crops, the excess over the consumptive use, passed into the ground and found its way to the drainage system. Only part of this water reached the drain, but in a well-designed irrigation system, no salts can be allowed to accumulate, Hill pointed out. If it did, the land would become unfit for cultivation over time. In a successful drainage system, the engineer emphasized, there had to be a continuous movement of salt from the canal to the drain – i.e., as much salt must reach the drain as left the canal. Therefore, water in the drain would necessarily have a higher salt concentration than the water in the delivery canal. These drains necessarily connected and discharged back into the river, with the result of increased salinity as in the Rio Grande as the river flowed downstream.[102]

Jewett pointed out in his testimony that this was in fact the case for land in Texas. Water quality analyses, he argued, indicated that there had been an accumulation of salts between Courchesne, Texas (immediately upstream from El Paso) and Ft. Quitman in every year from 1930-1935, inclusive, a period of consistent record. The accumulation varied from 141,000 tons in 1931-1932 to 345,000 tons in 1934. The total salt accumulation during the entire six-year period, 1930-1935, was nearly 1.3 million tons. The purpose of Jewett’s testimony, Clayton told the special master, was “to show whether we are increasing the concentration of [salt in] the soil through too sparing use of the water.” Or, put in another way, “how much water is necessary to be used to maintain a balance.” Jewett indicated that the evidence pointed to a substantial salt balance between Elephant Butte and Courchesne, lands largely in New Mexico, but a salt balance between Courchesne and Ft. Quitman, lands in Texas, was “not being maintained by a very wide margin.” If the same area was to be irrigated under the same conditions and the same amount

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In 1926, Jewett joined Quinton, Code & Hill, Leeds & Barnard. He assisted in the water supply-hydroelectric power study the firm made of Elephant Butte Dam in the 1920s, and in the 1930s, oversaw the company’s work on water supply studies of the federal Salt River Project in Arizona. *Plaintiff’s Case in Chief*, Vols. I, II, 215-216. CB-F-171A thru CB-F-1716: Transcripts of TX v. NM, Vol. 1-16, Box 4X219, RAHP, UTA

[102] *Plaintiff’s Case in Chief*, Vo. I, II, 409-416; and Vol. III, IV, 603-615. CB-F-171A thru CB-F-1716: Transcripts of TX v. NM, Vol. 1-16, 4X219, RAHP, UTA.

of water consumed, the only way to produce a more favorable salt balance, the engineer testified, would be to "increase the supply at the head of the valley."[103]

To accomplish this, Hill testified that 800,000 af was the necessary release of water for lands below Elephant Butte. This was the "maximum amount which can be properly withdrawn" from the reservoir, according to the engineer, based upon recorded releases from the reservoir over the past decade. Hill calculated that gross consumptive use between the reservoir and Ft. Quitman over the previous decade (1925-1935) had amounted to 675,000 af: 300,000 af from Elephant Butte to Courchesne, and 375,000 af from Courchesne to Ft. Quitman (including land in Mexico). The engineer further estimated that the "average total consumption" between Elephant Butte and Ft. Quitman "under present conditions of distribution of crops" at 3 af per acre (af/a), and in his judgment, 50,000 af of unavoidable operating waste was a "reasonable allowance" for the Rio Grande Project. Beyond these figures, Hill argued that an additional 145,000 af was necessary to maintain a "salt balance" for the lands between Courchesne and Ft. Quitman. Cumulatively, these figures were in excess of 800,000 af by 70,000 af. This led to additional testimony by Hill ascribing the additional water use to Mexican diversions above the 60,000 af prescribed by the 1906 treaty.[104]

An undated memorandum, "Equivalent Service Under Present Conditions (Hill)," located in Clayton's papers at the Dolph Briscoe Center University for American History at The University of Texas at Austin sheds additional light on the salt balance Hill believed necessary. According to this memorandum – which may be Clayton's summary of a larger analysis prepared by Hill or which may have been prepared for Clayton by Hill – "[t]he "average concentration of water available for diversion to the El Paso Valley [as] 50% greater than the concentration of water available for diversion to the valleys above El Paso at the present time." To achieve equivalent service in the valley, therefore, "the farm duty should be about 1.5 greater than for the other valleys [above El Paso, i.e., Palomas, Rincon, and Mesilla]." "However," the memorandum acknowledged, "this excess is evidently not available even under present conditions."[105]

New Mexico challenged this analysis. John Bliss, New Mexico's engineering advisor and an expert witness called by the state, in particular offered an alternative view. He acknowledged that the further downstream water travelled from Elephant Butte, the higher the concentration of salts. However, Bliss argued that project "officials dilute the entire flow of the river to produce a

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[103] *Plaintiff's Case in Chief,* Vols. III, IV, 838-851. CB-F-171A thru CB-F-1716: Transcripts of TX v. NM, Vol. 1-16, Box 4X219, RAHP, UTA.
[104] *Plaintiff's Case in Chief*, Vols. V, VI & VII, 1202-1206, 1210, 1220-1221, and 1235-1238. CB-F-171A thru CB-F-1716: Transcripts of TX v. NM, Vol. 1-16, Box 4X219, RAHP, UTA.
[105] "Equivalent Service Under Present Conditions (Hill)," undated. ff. Rio Grande Commission (Memorandum), Box 2F465, RGCC-FBCP, UTA.

satisfactory quality" at the lowest end of the project – the "Tornillo unit." As much as 50,000 af, New Mexico's engineer calculated, was passed out of the project to achieve this balance at Tornillo. In fact, passing this much water, Bliss further observed, resulted in lands outside the project, in Hudspeth County above Ft. Quitman receiving as much 38,000 af of reservoir water.[106]

As discussed in Opinion I, after nearly five months of testimony and argument, Warren was unable to arrive at suitable findings of fact for the Supreme Court. The amount of data presented and analyzed in testimony was considerable. The special master nevertheless found the evidence regarding the salt content of Rio Grande water "limited" and "unsatisfactory." At the urging of counsel for Texas, New Mexico, and MRGCD, he recommended in March 1937 that the case be stayed, in part until the federal Rio Grande Joint Investigation completed its studies of the water resources of the Upper Rio Grande Basin.[107]

Water quality was a critical concern for Texas in the federal investigation, but Colorado and New Mexico were initially hesitant to examine the issue of salinity. The Middle Rio Grande Conservancy District was especially opposed. Federal engineers, however, concurred with Texas as to the necessity of the work, as did representatives from Colorado following an organizational meeting of the Rio Grande Joint Investigation held in Santa Fe in late April and early May 1936. The USDA Bureau of Plant Industry and its principal agriculturalist, C.S. Scofield, were charged with the study of water quality in the basin as part of the federal investigation. Although Texas did not contribute to that investigation as Colorado and New Mexico did, Hill endeavored to relay what he believed was the appropriate consideration of "equivalent service" to the federal investigators.[108] In particular, he provided Scofield with the mathematical formula for "service

[106] *Defendant's Case in Chief*, Vols. X & XI, 2011. CB-F-171A thru CB-F-1716: Transcripts of TX V. NM, Box 4X219, RAHP, UTA.
[107] *Ad Interim Report of the Special Master*, received Mar. 26, 1937, 7-13. ff. RG 267, Entry 26, TX v NM #10, Box 401, Entry 26, RG 267, NAB.
[108] At a series of meetings in Santa Fe in early February 1936, Barrows, Adams, the state engineering advisors, and compact commissioners worked out the plans for the joint investigation – including the work to be done and the various costs of work. Meeting with C. C. Hezmalhalch, deputy state engineer for Colorado, McClure, Clayton, and W.A. Laflin (an engineer working with Clayton's engineering advisor Raymond Hill), Barrows and Adams asked the states to collectively contribute upwards of $55,000 either "in cash or acceptable services." Hezmalhalch indicated that Colorado was willing to provide a third of this amount, "how much, if any…in services to be worked out later." McClure likewise pledged a third for New Mexico "in money or services," but indicated that it "would take a good deal of scratching about to do this." Clayton agreed that an equal division of the cost among the three states was "entirely fair and equitable," but he was unable even after speaking with Gov. Allred to commit Texas to any amount of money. He pledged to "'do his damnedest'" to convince the Texas legislature to "make an emergency appropriation for the purposes of the Rio Grande Compact Commission for the balance of the fiscal year ending Aug. 31, 1937," but subsequent events suggest that he was unable to secure a financial contribution from Texas. Only the Colorado State Engineering Department and the Office of the New

equivalence" that was used in the Bureau of Plant Industry's study for which the federal engineer expressed his indebtedness.[109]

Hill's contribution notwithstanding, the draft *JIR* distributed in mid-August 1937 failed, in his mind and Jewett's, to recommend the necessary for equivalent service. Writing to Texas's compact commissioner Frank Clayton not long after securing a copy of the report, Hill remarked that he was "becoming discouraged at the progress possible." He observed that much of the "discussion of water supply [was] limited to records taken prior to the instigation of the Rio Grande Joint Investigation," and reflected "the opinions" of federal engineers.[110]

In September, in advance of the next round of compact proceedings, Jewett elaborated on the concerns Hill alluded to in his letter to Clayton. The engineer prepared a thorough critique of the draft summary report of *JIR* (which he called Volume I, and which is identified in the final released copy as Part I). Jewett, in particular, took the study to task for failing to appreciate the scope of

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Mexico State Engineer are credited in the final report as "Cooperating Agencies" from the three states. Acknowledgments are also given to "the contributions and assistance" of the MRGCD, the San Luis Valley-based Rio Grande Water Users Association, the "Rio Grande Reclamation Project," but to no Texas state agency or local organization. Hill, in his 1968 report on the development of the compact did note that "the engineering advisor to each of the Rio Grande Compact commissioners worked closely with those carrying out the Joint Investigation" – and that certainly seems to be the case where it came to the salinity issue, as discussed below. See Typed notes, Conference in U.S.G.S. office, Santa Fe, 2-4-36, 2-5-36, and 2-6-36. Folder 393-Rio Grande Joint Investigation Financial Statements, 1935-1937; Handwritten notes, Conference with members Rio Grande Compact Com., 2-3-36, Santa Fe. Folder 394-Rio Grande Joint Investigation Minutes and Memoranda of Meetings, 1936-1937; National Resources Committee, Rio Grande Joint Investigation, Progress Report – September 1, 1936, 5. Folder 391-Rio Grande Joint Investigation Progress Reports, 1936-1937; and Rio Grande Joint Investigation, Progress Reports – February 1, 1937. Folder 390, Box 26, FAC, WRCA; *JIR*, 6 and 10; and Hill, "Development of the Rio Grande Compact of 1938," 14.

[109] Even before the federal investigation, on the eve of the hearings before Special Master Warren, Hill was in communication with Scofield. During the spring and summer of 1936, he solicited the federal investigator for information and shared his views on the problem. See, for example, Raymond A. Hill to Mr. C.S. Scofield, Division of Western Irrigation, Bureau of Plant Industry, U.S. Department of Agriculture, April 16, 1936; Raymond A. Hill to Mr. C.S. Scofield, Bureau of Plant Industry, U.S. Department of Agriculture, May 12, 1936; C.S. Scofield, Principal Agriculturalist in Charge to Mr. Raymond A. Hill, June 3, 1936. ff. Elephant Butte-El Paso Dists. General Correspondence G352 1935, Box 4X190, RAHP, UTA; and *JIR*, 464.

Hill also explained how he developed this equation for equivalent service in a letter to the investigation's engineer-in-charge, Harlowe M. Stafford, in May 1937. Raymond A. Hill to Mr. Harlowe Stafford, Engineer in Charge, Rio Grande Joint Investigation, May 18, 1937. [1937], Box 2F467, RGCC-FBCP, UTA.

[110] Proceedings of the Meeting of the Rio Grande Compact Commission…September 27, to October 1, 1937, 1. Unnamed folder 5, Box 2F463; and Raymond A. Hill to Mr. Frank B. Clayton, August 20, 1937. ff. Correspondence Business and Legal, 1935-1938, Pamphlets, 1935-1938, Box 2F464, RGCC-FBCP, UTA.

water quality issues confronting downstream lands in Texas. These lands included not only those project lands at the furthest end of the Rio Grande Project, "the Tornillo unit," but also beyond, down to Ft. Quitman, "in the Hudspeth District." Jewett acknowledged that the report observed that "more abundant applications [of irrigation water] are needed to prevent the accumulation of salt in the soil and resultant deleterious effect upon plant growth" in these areas of the basin. Yet, the engineer pointed out, the report failed to recognize "that the concentration of salts in irrigation water may affect the production of crops regardless of whether or not there be an accumulation of salts in the soil." No "consideration," moreover, "[is] given to the possibility that any other portions of the Rio Grande Valley below Elephant Butte [i.e., other than Tornillo or Hudspeth] may be affected either by concentrations of the irrigation water or by accumulation of salts within the area."[111]

Jewett maintained that the draft summary report gave short shrift to "equivalent service" despite Scofield's own use of Hill's formula. In his assessment of the work of the federal investigators, he stressed that "nowhere in Volume I or studies of water supply by R.G.J.I. is any consideration given to the outflow of Rio Grande which should be maintained either from Rio Grande Project or from the basin at Fort Quitman to preserve the irrigated areas in a productive condition by removal of salts." The engineer further remarked, "[n]o consideration is given to the question as to whether there has been a sufficient outflow from the El Paso District above Fabens to preserve a salt balance in that district in the past three years." "[L]iberal allowance for water to the Tornillo District" – on the order of 19,000 af – appeared to the engineer as "an excuse for not giving further consideration to salinity control."[112]

Bringing his appraisal to a conclusion, Jewett expressed the view that Texas and its needs hardly seem to matter to the federal investigators. The "general implication," he wrote,

> is that proposed storage development on Rio Grande in Colorado and New Mexico will benefit developed lands, and probably new lands in Colorado, and will improve the water supply to lands in New Mexico above Elephant Butte. The further general implication is that the lands below Elephant Butte would suffer shortages during drouth [sic] period anyway, and that probably the shortages would not be much worse if conditions in Colorado and New Mexico were to be improved.
>
> It seems to the writer that the answer to the voluminous report of R.G.J.I. can be stated very simply. The purpose of the proposed development on the Upper Rio Grande, principally construction of storage reservoirs, is to regulate the water supply in Colorado and New Mexico to meet as closely as possible the irrigation demands in those areas, and secondarily to conserve the water supply for the purpose of avoiding shortages in

[111] J.Q. Jewett, "Notes and Comments on Volume I of Report of Rio Grande Joint Investigation," September 1937, 41. CB-F-137-11, Box 4X215, RAHP, UTA.
[112] Jewett, "Notes and Comments," 42, 44-45, 55, and 56. CB-F-137-11, Box 4X215, RAHP, UTA.

> developed areas, or for the purpose of irrigating new lands. Such being the purpose of the proposed development, it follows directly that the effect upon the lands below Elephant Butte will be an impairment of their water supply in either quantity or quality, or both. This inevitable action of cause and effect cannot be stopped by estimates and opinions, by fortuitous 46-year averages [the years 1890-1935 were used as the basis for calculating water supply], or by an unsound grouping of statistics.[113]

It was within this context, this critical assessment by Texas's engineers that the water quality needs of lands in Texas above Ft. Quitman were not adequately addressed by the federal investigation, that Clayton offered Texas's sole demand when the Rio Grande Compact Commission reconvened in September 1937:

> …that the State of Colorado and New Mexico will release and deliver at San Marcial a supply of water sufficient to assure the release annually from Elephant Butte Reservoir of 800,000 acre-feet of the same average quality as during the past ten years, or the equivalent of this quantity if the quality of the supply is altered by any developments upstream.[114]

Texas's concerns for water quality were thus not limited to developments immediately above Elephant Butte in New Mexico; those concerns extended to the water supply that Colorado proposed to develop from draining the so-called "Closed Basin" in San Luis Valley. When the subject was raised during the September-October 1937 meeting, "[s]peaking for the people at the lower end of the [El Paso] valley," Hill observed that this water was "of a highly undesirable quality [87 percent sodium content]…." Consequently, if it were "added to the Rio Grande it would be necessary for dilution at the lower end to offset it, and we much prefer that it not be dumped into the river."[115]

Federal investigators, Jewett's criticism of the *JIR* notwithstanding, were sympathetic to Texas's desire for an improved quality of water. NRC representative Harlan Barrows echoed Hill's position when called upon by commission chair S.O. Harper to offer his views at that same meeting. After praising the group for tackling the problem of the equitable distribution of the waters of the Rio Grande, Barrows surveyed various possibilities for development of each of the sections of the Upper Rio Grande Basin. The lower end, he believed, unquestionably required a higher-quality water:

> Going to the lower valley, - shall I say for the sake of brevity the El Paso District, meaning the whole lower end, - what does it need if it is to realize, so far as conditions of water

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113 Jewett, "Notes and Comments," 63-64. CB-F-137-11, Box 4X215, RAHP, UTA.
114 Proceedings of the Meeting of the Rio Grande Compact Commission...September 27, to October 1, 1937, 13. Untitled folder 5, Box 2F463, RGCC-FBCP, UTA.
115 Proceedings of the Rio Grande Compact…September 27 to October 1, 1937, 24. Unnamed folder 5, Box 2F463, RGCC-FBCP, UTA. See also footnote 120.

> and land are concerned, its potentialities? Of course, it needs an adequate supply of water, a reliable supply and a supply of good quality…. Hudspeth has poor water and it ought to have good water.[116]

When the development of the technical basis for the compact moved to the respective states' engineering advisors, as discussed in Opinion I above, Hill continued to insist that 800,000 af was the necessary release from Elephant Butte to meet the needs of the project in New Mexico and Texas down to Ft. Quitman. He expressly urged his fellow engineering advisors, Royce Tipton of Colorado, Bliss and E.B. Debler for the United States, to adopt "the 800,000-acre-feet requirements" for the benefit of Texas during their November 1937 meetings. Tipton and Bliss, Hill noted in a memorandum to Clayton, expressly opposed this quantity. "I showed them," the engineer explained

> …by different methods of calculation that this amount [800,000 af] would be needed for equivalent service to lands below El Paso, in the Rio Grande project, or to maintain a salt balance in the El Paso area. In fact, it worked out about the same either way. If the salt balance is maintained, then equivalent service is given, and vice versa.[117]

According to Hill, New Mexico in particular did "not want to accept responsibility of furnishing Texas any additional water for salinity control in case the quality of water should change adversely." A letter to Texas's engineering advisor prepared by Bliss for McClure less than a week before the November meetings summed up the upstream state's position:

> New Mexico believes that the quality of water available to Texas under present conditions is influenced by so many factors in Colorado, New Mexico and Texas, many of which are uncontrollable and for many of which New Mexico can in no way be responsible, that she is not justified in assuming the responsibility of furnishing Texas additional water for salinity control in case that quality should change adversely.[118]

Hill was not dissuaded. Away from Debler and Tipton at the November meeting, he discussed with Bliss increased water deliveries to address rising salinity levels in the Rio Grande below Elephant Butte. As noted in Opinion I above, Hill believed that New Mexico engineer sympathized with Texas's position on this issue "but does not know how to measure the effect upon the water supply produced by an irrigation development above Elephant Butte." Texas's engineering

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[116] Proceedings of the Rio Grande Compact…September 27 to October 1, 1937, 46. Unnamed folder 5, Box 2F463, RGCC-FBCP, UTA.

[117] Raymond A. Hill, Memo to Mr. Clayton: In re Meeting of Committee of Engineers, at Santa Fe, November 22 to 24, 1937:-, November 26, 1937, 3. [1937], Box 2F467, RGCC-FBC, UTA.

[118] Raymond A. Hill to Mr. Frank B. Clayton, November 17, 1937. [1937], Box 2F467, RGCC-FBC, UTA; and Thomas M. McClure, State Engineer, By _____ Engineer to Mr. Raymond A. Hill, JAH:EM, cc: Mr. Royce J. Tipton, November 16, 1937, 3. Rio Grande Compact – July 7, 1937 to June 30, 1938, 26th Fiscal Year, NM_00156944.

advisor remained hopeful that he could convince Bliss "that some allowance be made for change in quality of water."[119]

As discussed in Opinion I, Hill succeeded by the end of the December meetings. When the group reconvened in Los Angeles, Bliss had prepared his own estimate of the demand on Elephant Butte Reservoir. Out of a total of 750,000 af, the New Mexico engineering advisor had made an allowance of 19,000 af for "Salt Balance & Service Equivalents" – the same amount that the *JIR* made, as Jewett had noted. At the end of the meetings, Bliss and Tipton had both conceded the 800,000 af figure to Hill.[120] The December 1937 "Report of the Committee of Engineers" subsequently adopted the figure as an average for the "Normal Release from Elephant Butte."[121]

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[119] Hill, Memo to Mr. Clayton, November 26, 1937, 2. [1937], Box 2F467, RGCC-FBCP, UTA.

[120] Hill also sought a water-quality guarantee from Colorado for deliveries made at the Colorado-New Mexico state line, and here he was less successful. Hill's own notes of the engineering advisors' meetings do not disclose much information on this issue, but Tipton discussed the matter in his February 1938 *Analysis of Report of Committee of Engineers to Rio Grande Compact Commissioner, Dated December 27, 1937*. According to the Colorado engineer,

> Due to the fears of Texas with respect to the quality of water below Courchesne, this item was a very controversial one during the meetings of the engineering committee. The Texas representative [Hill] insisted that so far as Colorado was concerned, credits at the stateline should be reduced by one acre-foot for each three ton increase in salt at the stateline over 80,000 tons per annum. Such a provision would have prevented further development in the [San Luis] Valley since Colorado cannot put into effect the proposed plan of reservoir operation without increasing the salt content at the stateline. The proposed provision by the Texas member of the Committee, therefore, was not made a part of the agreement. It was provided, however, that no credit should be claimed by Colorado for water imported from the "Dead Area" which had sodium ions in excess of 45% of the total positive ions. This would prevent the receiving by Colorado of credit for water brought to the river from the sump area proper, but would not prevent its receiving credit for water developed west of the sump, or from water developed from such creeks as Saguache, San Luis, Sand, and east side creeks.

This provision, as noted in Opinion I above, was recommended in the report, and it was ultimately incorporated into the 1938 Compact as part of Article III. Tipton, *Analysis*, 10-1. ff. 70, Box 44-70, MCHC 1897-1987, HC; and "Rio Grande Compact," in Proceedings of the Meeting of the Rio Grande Compact Commission…March 3rd to March 18th, inc., 1938, Appendix No. 11, 77. ff. 032.1, Box No. 936, Entry 7, RG 115, NARA Denver.

[121] [Raymond Hill], "TEXAS COMPACT: John Bliss Estimate of Project Requirements at Elephant Butte," 12/17/37. CB-F-137-34, Box 4X215, RAHP, UTA; "John Bliss Estimate of Project Requirements at Elephant Butte," typescript, n.d. CB-F-137-34, Box 4X215, RAHP, UTA; Tipton, *Analysis*, 11. ff. 70, Box 44-70, MCHC 1897-1987, HC; Bliss to Tom, December 22, 1937. Rio Grande Compact – July 7, 1937 to June 30, 1938, 26th Fiscal Year, NM_0015692 – NM_00156929; and "Report of Committee of Engineers to Rio Grande Compact Commissioners," December 27, 1937, in Proceedings of the Meeting of the Rio Grande Compact Commission…March 3rd to March 18th, inc., 1938, Appendix No. 1, 45 and 47. ff. 032.1, Box No. 936, Entry 7, RG 115, NARA Denver.

Although the 800,000 af figure was later reduced to 790,000 af following objections raised by New Mexico (as discussed in Opinion I above), historical evidence exists that this slightly smaller figure nevertheless encompassed the flows that Hill argued was necessary for "equivalent service." Article XI of the 1938 Compact, for example, states in pertinent part, "New Mexico and Texas agree that upon the effective date of this Compact all controversies between said States relative to the quantity or quality of the water of the Rio Grande are composed and settled…."[122] Such a statement, given Texas's position on the quality of Rio Grande water during the compact negotiations of the late 1930s, is indicative that the 790,000 af figure was sufficient.

Clayton joining with McClure and Hinderlider in signing the compact in March 1938, and later advocating for ratification is further evidence. In a pamphlet "To Water Users Under The Rio Grande Compact" that included a copy of the compact, released soon after the negotiations, Texas's commissioner stressed that the compact "seeks primarily to protect vested uses of water above Fort Quitman, and guard them against future impairment, both as to quantity and quality." Clayton delivered a similar message to water users outside the geographical confines of the compact in May 1938 (addressed in Opinion IV). At a meeting of the Lower Rio Grande Water Users Association, he expressed his conviction that Texas had obtained "every drop of water originating in Colorado and New Mexico that she was entitled to" above Ft. Quitman – a declaration that given his earlier statement would appear to be inclusive of the flows to ensure a sufficient quality of water. To Texas Governor W. Lee O'Daniel in November 1938, Clayton indicated the "engineers, attorneys, and other technical experts" for Texas were similarly convinced. In their collective "judgment," the commissioner confidently predicted to the governor, the compact would "restore a feeling of security to the water users in Texas above Fort Quitman…."[123] Indeed, as noted above (and discussed in Opinion IV below), water users between the end of the Rio Grande Project and Ft. Quitman relied upon unused waters released through the project. These waters possessed a higher quality owing to Rio Grande Project operations intended to ensure a sufficient quality of water throughout the project.

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[122] "Rio Grande Compact," in Proceedings of the Meeting of the Rio Grande Compact Commission, Held at Santa Fe, New Mexico, March 3rd to March 18th, inc., 1938, Appendix No. 11, 80. ff. 032.1, Box No. 936, Entry 7, RG 115, NARA Denver.

[123] Frank B. Clayton, "To Water Users Under The Rio Grande Project," El Paso, Texas, March 25, 1938. Folder 1, Memos of Interior Department, 1913-1915, Box 14, Arthur Powell Davis Papers, 1896-1952, Accession Number 1366 [hereafter APDP 1896-1952, American Heritage Center, University of Wyoming, Laramie [hereafter AHC]; *Proceedings of Meeting Held on Friday, May 27, 1938 at El Paso, Texas, between Representative of Lower Rio Grande Water Users and Representatives of Irrigation Districts Under the Rio Grande Project of the Bureau of Reclamation*, 10. ff. Proceedings and Minutes 1935-1938, Box 2F463; Clayton to O'Daniel, November 16, 1938, 4. Box 2F467, RGCC-FBCP, UTA; and Littlefield*, Conflict on the Rio Grande*, 209-210.

That the quality of the water of the Rio Grande reaching its lands was a central concern for the State of Texas in the negotiations leading to the 1938 compact is clear. The state had singular demand by 1937: the annual release of 800,000 af from Elephant Butte Reservoir "of the same average quality as during the past ten years, or the equivalent of this quantity if the quality of the supply is altered by any developments upstream." Texas's engineering advisor Raymond Hill advocated for this figure, and sought to convince federal engineers and the engineering advisors for Colorado and New Mexico of the necessity of additional flows to Texas above what the state's present consumptive use suggested. The other engineers agreed that lands downstream required an improved quality, but until late 1937 were unconvinced of Hill's projection. Hill managed to persuade them, and while Texas ultimately agreed to a slightly lesser figure of 790,000 af, the state's commitment to the final compact strongly indicates that this quantity of water was inclusive of the flows to ensure water of sufficient quality for downstream lands.

Opinion III: The Rio Grande Project water supply, circa 1938, included not only the surface flow of the Rio Grande captured in Elephant Butte Reservoir, but also all water tributary to the project including groundwater as well as return flows.

At the outset of the federal reclamation program established by the 1902 Newlands Act, federal lawyers and engineers embraced a broad conception of what constituted the water supply for federal projects primarily out of concerns for adequacy. The United States Reclamation Service's principal legal officer Morris Bien argued that while the Newlands Act obligated the United States to recognize state and territorial water laws concerning the appropriation of water, the federal government held dominion over public lands and unappropriated waters. The scale of proposed reclamation projects, moreover, demanded that the US have unique freedom as an appropriator, that the water supply for projects be protected from adverse claims. This latter idea found expression in New Mexico territorial water laws in 1905 and 1907 that drew upon a draft water code prepared by Bien. Legal arguments aside, Rio Grande Project supervising engineer Benjamin M. Hall envisioned the project in 1904 as utilizing all of the waters of the Rio Grande – the surface flow within the river's channel, tributary flows to the river, and groundwater – so as to serve lands in New Mexico and Texas adequately. At the recommendation of Reclamation attorneys, Hall's 1906 filing for 730,000 af was supplemented in 1908 with a filling for "[a]ll the unappropriated water of the Rio Grande and its tributaries." By the early 1910s, federal reclamation authorities were claiming "waste, seepage, spring, and percolating water arising within the project" as well as "return flows," water released from the Elephant Butte Reservoir that was diverted, used on project lands, and returned to the river channel for further use downstream. As Rio Grande Compact negotiations moved forward in the 1920s and 1930s, federal and state engineers alike recognized that surface flows, water tributary to the project including groundwater, and return flows constituted the water supply for the Rio Grande Project.

The 1902 Newlands Act, or National Reclamation Act, that created the Reclamation Service (or Reclamation, predecessor to the present Bureau of Reclamation) was not the first attempt by the US to provide for the irrigation of arid western lands. The act replaced the 1894 Federal Desert Lands Act, better known as the Carey Act after its sponsor Senator Joseph M. Carey of Wyoming. The Carey Act sought to foster private-state irrigation projects. It authorized the General Land Office, working in concert with individual western state governments, to award upwards of 1 million acres of the public domain to each semi-arid western state. The states were to administer the sale of this land, see that it was irrigated and developed into no larger than 160-acre farms sold to actual settlers only, with irrigation systems being built and operated either by individual states or by private enterprises that sold water to irrigators owning farms within the project. Project plans were to be submitted to the secretary of the interior. Although the Interior Department set aside nearly 4 million acres of the public domain for use by the states, outside of Idaho and Wyoming, the program had few demonstrably successful projects. Most western states did not possess the necessary administrative and financial resources to fulfill the Carey Act's promise and speculative investors often had insufficient capital to carry their irrigation projects to completion. By 1902 nearly 90% of the private irrigation companies developing Carey Act projects were nearing bankruptcy, and arid land development continued to lag further behind the number of acres set aside under the Carey Act. With the failure of the Carey Act, western proponents of irrigation, led by Senator Francis Warren of Wyoming, turned to the federal government, recommending federal construction of dams and reservoirs, leaving to the states the building of water distribution systems with allocation of water in accordance with state water right laws. When Congress failed to approve Warren's bill, Representative Francis Newlands of Nevada introduced a bill in 1901 providing for the federal government itself to construct irrigation projects in western states and territories.[124]

Some western representatives were hesitant of Newland's proposed legislation, fearing centralized authority and concerned that railroad and other more highly capitalized interests would benefit. Following extensive legislative negotiations involving President Theodore Roosevelt and debates over competing bills that proposed more modest programs and measures, Congress enacted the National Reclamation Act, or Newlands Act in June 1902. The act provided for the federal government, through the secretary of the interior, to withdraw un-entered and unoccupied public lands in 16 western states and territories: Arizona, California, Colorado, Idaho, Kansas, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oklahoma, Oregon, South Dakota, Utah, Washington, and Wyoming. Upon these lands, Reclamation was to build dams, canals, and other irrigation works for the benefit of small family farmers settling on irrigable land within the designated reclamation project area.[125]

Appropriation of water was central to the newly-created federal reclamation program. To varying degrees, state and territorial law by the early 1900s required that claims to the use of water were to be recorded by filing notices of appropriation that would be perfected by applying the water

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[124] *An Act Making appropriations for sundry civil expenses of the Government for the fiscal year ending June thirtieth, eighteen hundred and ninety-five, and for other purposes*, August 18, 1894, ch. 301, section 4, 28 Stat. 422; Paul W. Gates, *History of Public Land Law Development* (Washington D.C.: U. S. Government Printing Office, 1968), 647-652; and Robert G. Dunbar, *Forging New Rights in Western Waters* (Lincoln: University of Nebraska Press, 1983), 36-45; and Donald J. Pisani, *To Reclaim a Divided West: Water, Law, and Public Policy, 1848-1902* (Albuquerque: University of New Mexico Press, 1992), 252-303.

[125] *An Act Appropriating the receipts from the sale and disposal of public lands in certain States and Territories to the construction of irrigation works for the reclamation of arid lands*, June 17, 1902, chap. 1093, Public, No. 161, 32 Stat. 388; Gates, *Public Land Law Development*, 652-659; Dunbar, *Forging New Rights*, 51; Pisani, *To Reclaim a Divided West*, 298-325; and William D. Rowley, *The Bureau of Reclamation: Origins and Growth to 1945*, Bureau of Reclamation, United States Department of the Interior, vol. 1 (GPO, 2006), 100-101.

so claimed to beneficial use. Such law also provided for adjudication of existing rights and prescribed methods for the determination, regulation, and control of the rights to water in the future. Some states, such as California, looked to the judiciary to settle claims of appropriators, while others like Wyoming relied upon a state board or a state engineer to adjudicate claims before the courts became involved.[126]

Reclamation supervising engineer and principal legal officer Morris Bien saw the US as having a unique status relative to all other appropriators, especially with regard to its reclamation projects.[127] At the first conference of Reclamation engineers and officials in Ogden, Utah, in September 1903, he articulated a position that shaped not only Reclamation's early approach to its projects, but also state and territorial water law in the early 20th century. Bien asserted that "[t]he control of the Federal Government over the public lands and the nonnavigable waters is that of a proprietor…." Put another way, as he did in a February 1904 memorandum prepared "in connection with the motion of U.S. to intervene in the case of Kansas v. Colorado" – an interstate dispute over the waters of the Arkansas River – the federal government was the "sole proprietor" of the public domain and was consequently "in sole control of the waters on such lands." Prior acts of Congress, specifically the 1891 right-of-way act and the 1897 organic act (which provided for the establishment of federal forest reserves), as well as the Newlands Act, "merely…recognize the system of state control, regulation, and recording" of water appropriation.

Bien found support in recent case law, most notably the US Supreme Court's ruling in favor of the federal government against the Rio Grande Dam and Irrigation Company. In the Rio Grande

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[126] Morris Bien, "Relation of Federal and State Laws to Irrigation," in *Proceedings of First Conference of Engineers of the Reclamation Service with Accompanying Papers*, F.H. Newell, Chief Engineer, comp., Department of the Interior, United States Geological Survey, Water Supply and Irrigation Paper No. 93 (Washington: GPO, 1904), 233; Morris Bien, "Proposed State Code of Water Laws," in *Proceedings of Second Conference of Engineers of the Reclamation Service with Accompanying Papers*, F.H. Newell, Chief Engineer, comp., Department of the Interior, United States Geological Survey Water Supply and Irrigation Paper No. 146. (Washington: GPO, 1905), 29-30, and Morris Bien, Supervising Engineer, U.S. Reclamation Service, to Mr. Samuel C. Wiel, November 1, 1905, in Samuel C. Wiel, *Water Rights in the Western States* (San Francisco: Bancroft-Whitney Company, 1905), vi-ix. This development is also traced in Dunbar, *Forging New Rights*, 73-132.

[127] Morris Bien was a University of California, Berkeley-trained engineer who later earned a law degree from Columbian University (predecessor to George Washington University in Washington, DC). In 1903, at the request of Reclamation Chief Engineer F.H. Newell, he came to the Reclamation Service from the General Land Office in 1903. Over the next 20 years, he led Reclamation's Land and Legal Division. His "expansive view of the authority and prerogatives of the Reclamation Service," laid out here with specific reference to the Rio Grande Project, is discussed more broadly in William Rowley's official history of the Bureau of Reclamation. See Rowley, *Bureau of Reclamation*, 147-151.

Dam and Irrigation Company case, the high court identified "'two limitations'" to state control of waters "'within its dominion.'" The Reclamation official highlighted the first:

> in the absence of specific authority from Congress a state cannot by its legislation destroy the right of the United States, as the owner of lands bordering on a stream, to the continued flow of its waters; so far at least as may be necessary for the beneficial uses of the government property.

This sentence, Bien maintained,

> indicates clearly that the United States has the right to the continued flow of the waters that have not already been appropriated, for there has been no specific authority granted to the States to infringe upon this right, Congress having merely authorized the acquirement of rights by prior appropriation, and the States having undertaken to regulate this right of appropriation.

A "similar view was expressed" in *Gutierrez v. the Albuquerque Land and Irrigation Company* (188 U.S. 545) concerning "the utilization of water for irrigation purposes in the Territory of New Mexico." Whether a state or territory was concerned, Bien saw "no reason why the same view should not be held…." He also pointed out that in *Howell v. Johnson* (89 Fed. Rep. 556), a dispute over the waters of Sage Creek, an interstate stream flowing from Montana to Wyoming, the US Circuit Court of Appeals "held in a similar way as to the rights of the Federal government over the unappropriated waters on the public domain."[128]

In 1904, following meetings with commissioners from Oregon and Washington seeking a "code of irrigation law," Bien was asked to "prepare a draft" of his own. Bien's draft reflected his views of federal dominion over public lands and waters, and made special provision for developing federal reclamation projects. As he explained to the second Reclamation conference in November 1904,

> In order that the State may obtain the full benefit of this work and prevent serious interference with and perhaps the entire abandonment of the projects to be investigated, it is provided that the water supply for such projects shall be reserved from general appropriation until the investigations of the Reclamation Service shall determine the precise amount required for the project, the remainder being then released from such reservation.

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[128] Bien, "Relation of Federal and State Laws to Irrigation," 233-234; and Morris Bien, "Memorandum Concerning the Origin of the Right of Appropriation of the Public Domain," February 6, 1904, 1-5. ff. 762. Legal Discussions -General. Thru December 31, 1907., Box 223 760F- -762, Entry 3, RG 115, NARA Denver. Bien also discussed the Rio Grande Dam and Irrigation Company case and *Howell v. Johnson* in "Relation of Federal and State Laws to Irrigation," 234-236.

The "theory" behind this was

> that the State regulates the appropriation of water, exercising this power and holding the land in trust for the public, and that when the interest of the public are so directly involved as in these large irrigation projects, and when further, there is no element of individual speculation and profit in the construction the works, which are for the purpose of establishing the maximum number of homes on the land, it is the duty of every State to which the reclamation act is applicable to assist with every resource under its control.[129]

Bien insisted that the water supply for federal projects be protected against adverse claims by other appropriators. When Idaho Commissioner of Reclamation D.W. Ross "object[ed] to the proposition providing for the withholding of water for appropriation after the filing of the claim for it by the Reclamation Service," the supervising engineer argued in January 1904 letter to F.H. Newell, Reclamation's chief engineer, that Ross "fails to perceive…that a project might be completed and fail because of interference with water rights." Reclamation, Bien believed, would in "nearly every project…develop the whole water resources of the stream." It would "build better and must do more preliminary work on that account," and thus could not "compete with private parties as to time of completion…." Instead, with this "safety against speculative water filings," the federal government would "act in good faith and promptly release any claim to water which it does not propose to use."[130]

Elements of Bien's draft water code were ultimately reflected in the New Mexico territorial water laws under which Reclamation made its filings for the Rio Grande Project in 1906 and 1908. In 1905, the states of Colorado, Idaho, Montana, Nebraska, Nevada, North Dakota, Oregon, South Dakota, Utah, Washington, and Wyoming and the territories of Oklahoma and New Mexico all adopted new water codes. Each state and territory, as Bien noted to his colleagues at the second Reclamation conference in El Paso, made provision "for cooperation with the work of the United States in the construction of reclamation projects." In some instances, this cooperation extended to the "Necessary water supply" along the lines that he had proposed in his draft code.[131]

This was certainly true for New Mexico. Section 22 of its new water code stated:

> Whenever the proper officers of the United States authorized by law to construct irrigation works, shall notify the territorial irrigation engineer that the United States intends to utilize certain specified waters, the waters so described, and unappropriated at the date of such notice, shall not be subject to further appropriations under the laws of New Mexico, and no adverse claims to the use of such waters, initiated subsequent to the date of such notice, shall be recognized under the laws of the territory, except as to

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[129] Bien, "Proposed State Code of Water Laws," 32-33.
[130] Morris Bien, engineer, to Mr. F.H. Newell, Chief Engineer, January 5, 1904. ff. 110-E Legislation. Corres. Re Irrigation Laws; Water Codes; Etc., Box 91 110E- -110E-6, Entry 3, RG 115, NARA Denver.
[131] Bien, "Proposed State Code of Water Laws," 34; and Rowley, *Bureau of Reclamation*, 149.

> such amount of the water described in such notice as may be formally released in writing by an officer of the United States thereunto duly authorized.

Section 22, as Reclamation "assistant examiner," or attorney B.E. Stoutemyer later observed, did "not affirmatively provide that the U.S. shall acquire any rights by filing the notice described [in this section] but provides that after this notice is given, no other person shall acquire any right," which presumably may have been adverse to the federal government's.[132]

As noted in Opinion I, on January 23, 1906, pursuant to the 1905 code, B.M. Hall, the engineer supervising Reclamation's proposed reclamation projects in New Mexico, formally notified New Mexico Territorial Engineer David L. White through Reclamation's chief engineer of Reclamation's intent to construct the Rio Grande Project. The proposed project would "utilize…a volume of water equivalent to 730,000 acre feet per year requiring a maximum diversion or storage of 2,000,000 miner's inches. This water would "be diverted or stored from the Rio Grande River," in a 2 million acre-foot storage reservoir at Elephant Butte, "and diversion dams below at Palomas, Rincon, Mesilla and El Paso Valleys in New Mexico and Texas." Hall "requested" that these "waters…be withheld from further appropriation and that rights and interests of the United States" as contemplated in the 1905 territorial statute "be otherwise protected."[133]

Hall found this filing "unsatisfactory.". It was prepared on the basis of a form provided by the chief engineer, and was used not only for the Rio Grande Project but also for filings for four other proposed storage projects in New Mexico. In forwarding these for approval, Hall lamented that he "would have greatly preferred filing on <u>the entire unappropriated flow</u> [original emphasis] in each case."[134]

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[132] Chapter 102, "An Act Creating the Office of Territorial Irrigation Engineer, to Promote Irrigation Development and Conserve the Waters of New Mexico for the Irrigation of Lands and for Other Purposes," A.H.B. No. 98; Approved March 16, 1905, Section 22, *1905 Acts of the Legislative Assembly of the Territory of New Mexico, Thirty-Sixth Session* (Santa Fe: The New Mexican Printing Company, 1905), 277; and B.E. Stoutemyer, Assistant Examiner, to Mr. W. M. Reed, District Engineer, U.S.R.S., re Appropriation Notices in New Mexico, Nov. 8, 1907. ff. 41, Box 6, Entry 3, RG 115, NARA Denver. For more on the 1905 law, see Ira G. Clark, *Water in New Mexico: A History of Its Management and Use* (Albuquerque: University of New Mexico Press, 1987), 117-118.

[133] Hall to White, Jan. 23, 1906; B.M. Hall, Supervising Engineer, to Chief Engineer, U.S. Reclamation Service, re Appropriations, Jan. 23, 1906; and David M. White, New Mexico Territorial Engineer, to B. M. Hall, Supervising Engineer, U.S. Reclamation Service, February 16, 1906. ff. 41, Box 6, Entry 3, RG 115, NARA Denver.

[134] B.M. Hall to Chief Engineer, Jan. 23, 1906; and Acting Chief Engineer to B. M. Hall, January 29, 1906. ff. 41, Box 6, Entry 3, RG 115, NARA Denver. The other projects were Hondo, Urton Lake, Carlsbad, and Las Vegas

Hall's preference was in keeping with the conception of the project's water supply that he articulated at the same Reclamation conference at which Bien discussed his water code. "The 180,000 acres of land to be irrigated" by the project, Hall informed his colleagues, "are in a long, narrow valley, and the return water from the irrigation of the upper valley can be rediverted on lands lower down the valley." The "Engle Dam," as the engineer called it,

> will hold back all of the floods and distribute them over the irrigation period of ten months. The water will be let out as needed and there will be no more disastrous floods below the dam. The river bed will never be dry at any time of year, as the return water from such a large irrigated area will form constant springs along the whole course of the river. Lastly, the supply of ground water for pumping will be greater and more constant than it now is, as the water entering the ground from the irrigated lands will form a constant supply.[135]

As noted above, Hall emphasized in both his study and in his presentation to the National Irrigation Congress that "[a]ll of the water that comes down the river is needed for irrigation. We can not [*sic*] afford to waste any of it."[136]

Responding to a question from a delegate regarding his proposal at the congress, Hall suggested that the water coming down the Rio Grande channel was a mix of surface and subsurface flows, and that Elephant Butte Dam would aggregate and control these waters for the beneficial use of downstream lands:

> Question – As I understand it, you propose to bring that water [from the dam] down the river channel, is that true, Mr. Hall?
>
> Mr. Hall – The water that you get now in the river, that is underneath the river bed and in the valley lands comes from the rains on the high lands and from floods down the river, and from the water that is flowing in the river at certain periods. The under gravel gets saturated. We estimate that when we get in that storage dam, that instead of injuring that condition we will better it. You will still get all of the rainfall that comes down below the dam; of course you will have the floods originated below the dam – they will not be disastrous floods – but you will at all times have a wet river bed, and considerable water flowing in it, while at present you have a river bed that is dry for five months – and longer this year – and I suppose the conditions ought to be better because of the percolation from the river bed more or less and there is always a flow from the rain-fall on the mesa.[137]

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135 B.M. Hall, "Rio Grande Project," in *Proceedings of Second Conference of Engineers of the Reclamation Service*, 77.

136 Mitchell, ed., *Official Proceedings*, 215-216; and Hall, "A Discussion of Past and Present Plans for Irrigation of the Rio Grande Valley," November 1904, 7-8. ff. 46, Box No. 792, Entry 3, RG 115, NARA Denver.

137 Mitchell, ed., *Official Proceedings*, 219.

The work of Charles Slichter, a hydrologist consulting with USGS, informed Hall's response. Interested in learning more about the potential water supply to be derived from groundwater sources, particularly in the Mesilla Valley, the Reclamation engineer had contacted Slichter in July 1904, before the National Irrigation Congress meeting. Hall observed in a letter to the hydrologist that valley irrigators who pumped groundwater had found a "plentiful quantity of water at a short distance from the surface." Pumps with a capacity of 1,000 gallons per minute could operate "continuously for weeks without lowering the water plane." The water table might be drawn down as much as seven feet, observed Hall, but returned to its former level "within a few minutes after the pump stops." He therefore sought to know:

> 1st:- How much water per square mile can be pumped continuously from the ground at lowest season, without lowering the water table?
>
> 2nd:- What were the sources of supply of this underground water? Does the water all come down the river bed, or is there a large quantity coming from beneath the mesa country on each side?
>
> 3rd:- If there is a continuous under-flow along the river bed, what is its volume in cubic feet per second, during the time that the river is dry, so far as surface flow is concerned?
>
> 4th:- The river bed of the Rio Grande consists of coarse sand to a depth of 70 to 100 feet and more. Just above El Paso the bed rock is limestone and there is a narrow pass where the bluffs are only 400 feet apart at the river level, and the bed rock is at a depth of about 100 feet. If a submerged concrete dam or weir were constructed here with its crest at the level of the river bed surface, how much underflow would be brought to the surface by such a structure?

These were not idle questions for Hall. As he stressed to Slichter,

> In order to irrigate the rich lands of the Rio Grande Valley in the Territory of New Mexico alone it will probably be necessary to use all of the floods and all of the underground water than can possibly be made available, and no time is to be lost in determining this vital question of underflow.[138]

The hydrologist began his work the following month, and by October, a month before the National Irrigation Congress, he had completed his pumping plant tests. Slichter found a direct connection between the river and the ground water in the Mesilla Valley, as he told the assembled delegates following Hall's presentation:

> I will not take up your time with any further matters except one point I observed in the Mesilla Valley, near Mesilla Park and Las Cruces, where we succeeded in measuring the amount of water lost by the river and contributed to the gravels. I think we have

[138] B. M. Hall, supervising engineer, to Charles E. Slichter, July 9, 1904. Folder 432 Rio Grande – Power Development – Slichters Reports as to Water Supply, Box 819 Rio Grande 430A – 458A, Entry 3, RG 115, NARA Denver.

> established that the source of the water that is used by the pumping plants is the river itself; that the origin of the ground waters or the supply of ground waters which are used by the pumping plant, is the water contributed to the river itself or lost by the river.[139]

Slichter made this same point when he published his work as USGS Water-Supply and Irrigation Paper No. 141, *Observations on the Ground Water of Rio Grande Valley* in 1905. According to his "observations of the test wells" in the Mesilla Valley,

> the ground waters in the Mesilla Valley originate in the flood waters of the river. During times of low water the river bed is so thoroughly covered with mud that probably only a small amount of water escapes in the sand and gravels of the valley. During the period of flood, when the scour is deep, the contributions of the river to the underflow reach a maximum, as at that time the greatest amount of water is available for this purpose.[140]

Federal reclamation plans for the Rio Grande Project thus from the outset anticipated utilizing all of the waters hydrologically connected to the river for the benefit of lands in New Mexico and Texas.

New Mexico's adoption of a more comprehensive irrigation code in 1907 opened an opportunity to expand federal claims to Rio Grande waters as Hall had wished. Stoutemyer had a direct role in shaping this new water code, especially with respect to "the work of the Reclamation Service," as he later informed Hall.[141] The new code further drew upon aspects of Bien's draft code. Section 40 of the 1907 act was virtually identical to Section 22 of the prior 1905 act, and the new law greatly expanded the authority of the territorial engineer. That office was soon filled by the appointment of Vernon L. Sullivan, who Stoutemyer noted to Bien in April was "well known to the Reclamation Service." Under Sullivan, the office placed greater emphasis on the public interest, ascertaining the validity of old claims to water rights, determining the quantity of

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[139] Charles S. Slichter to F. H. Newell, USGS Chief Engineer, October 25, 1904. Folder 432, Box 819, Entry 3, RG 115, NARA Denver; Mitchell, *Official Proceedings*, 218; and Charles S. Slichter, *Observations on the Ground Water of Rio Grande Valley*, Department of the Interior, United States Geological Survey Water-Supply and Irrigation Paper No. 141 (GPO, 1905), 1.

[140] Slichter, *Observations*, 27. Slichter further noted "that a small portion of the underflow reaches the river valley from the mesa and foothills to the north and east of Las Cruces."

[141] Stoutemyer had met with the New Mexico territorial governor and attorney general to "outline a plan" for the "proposed Irrigation Code" in 1907. He later met with various members of the territorial assembly and local attorneys to discuss "some features of the bill, particularly as to the territorial engineer and his work…." Stoutemyer believed that the new law would "be satisfactory to the Reclamation Service," and that it was "a great improvement over the present [1905] law." See B.E. Stoutemyer, Assistant Examiner, to Mr. B.M. Hall, Supervising Engineer, El Paso, Texas, Proposed Irrigation Code in New Mexico, March 4, 1907. ff. 110-E9, Legislation, Irrigation Laws; Water Codes; Etc., New Mexico, Transfer Case, Box 92 110E-7- -110E-12, Entry 3, RG 115, NARA Denver. See also Clark, *Water in New Mexico*, 118-122.

unappropriated water in the public streams of the territory, setting reasonable timetables for completion of large projects initiated prior to the adoption of the new water code.[142]

In early November 1907, Stoutemyer wrote to Reclamation district engineer W.M. Reed, recommending a "supplemental" filing for the Rio Grande Project under the revised territorial water code. After reviewing copies of the various notices of water appropriations made for projects in the Office of the Territorial Engineer, the assistant examiner believed re-filing Reclamation's notice of water right appropriation for Elephant Butte Reservoir and the Rio Grande Project was prudent. Stoutemyer was concerned about the highly variable flow of the Rio Grande from year to year, a flow that could be as small as 200,000 af to upwards of 2 million af per year. Hall's 1906 filing for 730,000 af could thus become a significant limitation on project operations. If Reclamation desired "all the flow of the river," then Stoutemyer favored amending the notice of appropriation to read "all the unappropriated water of the Rio Grande and its tributaries," or if a definite number of acre-feet was required to "make it large enough to cover the entire flow of the largest year." He cautioned that the filing must be made in a manner that did not forfeit any of the government's existing rights under the 1906 notice, and recommended the inclusion of language that "clearly expressed" Reclamation's "intention to preserve our rights under the former notice…." Stoutemyer noted there were a number of water right applications in the Rio Grande drainage pending in the territorial engineer's office and undoubtedly more would be filed before the federal dam was completed.[143] Filing for all the unappropriated waters

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[142] Chapter 49, "An Act to Conserve and Regulate the Use and Distribution of the Waters of New Mexico; to Create the Office of Territorial Engineer; to Create a Board of Water Commissioners, and for Other Purposes," H.B. No. 120; Approved March 19, 1907, *1907 Acts of the Legislative Assembly of the Territory of New Mexico, Thirty-Seventh Session* (Santa Fe: New Mexican Printing Company, 1907), 71-95; B. F. Stoutemeyer to Morris Bien, April 2, 1907. ff. 110-E9, Box 92, Entry 3, RG 115, NARA Denver; and Clark, *Water in New Mexico*, 118-123.

[143] B.E. Stoutemyer, Assistant Examiner, to Mr. W. M. Reed, District Engineer, U.S.R.S., re Appropriation Notices in New Mexico, Nov. 8, 1907. ff. 41, Box 6, Entry 3, RG 115, NARA Denver.

Several applications for water rights on the Rio Grande and its tributaries that had the potential to adversely affect the Rio Grande Project were filed in late 1907. Stoutemyer responded with formal protests against each application. One application was for a partially constructed irrigation project with two failed dams on the Rio Puerco that flowed into the Rio Grande near Albuquerque. Some $80,000 had been invested in the project, but no water had been applied to irrigate the land within the project. A second project was designed to divert water from the Rio Grande into the old La Union Community Acequia. This was a small project but its location was bothersome as it was located between Elephant Butte Reservoir and the Texas state line. The third, and largest, project was an application by the Red River Land & Water Company in Taos, New Mexico for development of a large irrigation project involving the La Plata River. Reclamation filed formal protests with the territorial engineer against the three applications, but later withdrew its protest against the Red River Land & Water Company as Reclamation's La Plata River project had been abandoned. B.E. Stoutemyer, assistant examiner, to W. M. Reed, district engineer, U.S. Reclamation Service, December 20, 1907; Morris Bien, Acting Director, to B. E. Stoutemyer, of the Rio Grande could check adverse competition by taking advantage of Section 28 of the 1907 law which declared that "If in the opinion of the territorial engineer there is no unappropriated water available, he shall reject the application."[144]

Reed forwarded Stoutemyer's recommendation to the Reclamation director and Bien, serving as acting director, responded in late November. He agreed that the 1906 filing for "a volume of water equivalent to 730,000 acre feet per year" under the 1905 act was an insufficient quantity of water and should be expanded to include a supplemental filing for "all unappropriated water of the Rio Grande and its tributaries" under the 1907 act while "reserving all rights under notice of January 23, 1906." The director's office was nonetheless of the opinion that Reclamation's 1906 filing was legally sufficient without further action. Bien specifically cited Section 22 of the 1905 act as constituting

> a waiver by the Territory or a release to the Federal Government of all territorial rights over unappropriated waters upon the completion of certain acts by agents of the United States. By Section 22 of Chapter 102 of 1905, and the notice filed in pursuance thereof, the Territorial Legislature has relinquished claim to the waters of the Rio Grande in favor of the Federal Government, and there remains to be done only the filing of amendment of the notice as suggested.[145]

As noted in Opinion I above, on April 14, 1908, Louis C. Hill, Hall's successor as supervising engineer of the Rio Grande Project, filed a "supplemental notice" with Sullivan, pursuant to Section 40 of Chapter 49 of the laws of the 37th New Mexico territorial assembly enacted in 1907. The filing declared that the United States intended to utilize "[a]ll the unappropriated water of the Rio Grande and its tributaries" to be diverted or stored at a storage dam located 9 miles west of Engle, New Mexico, with a capacity of 2 million af and at diversion dams below in Palomas, Mesilla and El Paso valleys in New Mexico and Texas. Hill requested that these waters be withheld from further appropriation and that the rights of the United States be protected.[146]

By the 1910s, however, Sullivan had embraced the idea that a large proportion of water diverted upstream would return to the Rio Grande – the "'return water theory,'" in the words of one Reclamation official – and thereby cause no material damage to the federal project. It was a stance that inclined the territorial engineer toward approval of most other filings for water on

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February 18, 1908. ff. 41-D New Mexico. Water Appropriations. Rio Grande Project. THRU 1910, Box 9 41B-41D, Entry 3, RG 115, NARA Denver.

[144] Expressly reserving all of the unappropriated water in excess of 730,000 af per year would also tie the hands of an unfriendly territorial engineer who might favor private enterprises, Stoutemyer noted. Stoutemyer to Reed, Nov. 8, 1907. ff. 41, Box 6, Entry 3, RG 115, NARA Denver.

[145] W.M. Reed, District Engineer, to The Director, U.S. Reclamation Service, November 15, 1907; Acting Director [Morris Bien] to Reed, November 29, 1907. ff. 41, Box 6, Entry 3, RG 115, NARA Denver.

[146] Supervising Engineer to Sullivan, April 14, 1908. ff. 41-D, Box 9, Entry 3, RG 115, NARA Denver.

the Rio Grande and its tributaries. After carefully examining the issue, Reclamation and the Interior Department came out against such applications. Federal authorities believed that these filings would have an adverse effect on the water supply for Elephant Butte Reservoir. They asserted that approval would set a "precedent for the general allowance of such claims and the ultimate destruction of the Rio Grande Project," abrogating treaty obligations to Mexico and contracts with water users dependent on the project water supply. These arguments, coupled with the Rio Grande "embargo" and the temporary 1929 compact, were sufficient to preclude significant developments upstream from Elephant Butte until the advent of the Middle Rio Grande Conservancy District's proposed project.[147]

Around this same time, Reclamation began asserting the right to "waste, seepage, spring, percolating water," as well as "return flows" from project operations. As noted above, in proposing the Rio Grande Project in 1904, Hall had suggested that the project would make use of "return water." Bien's 1905 draft water code had also provided for the appropriation "of seepage water…in the same manner as other waters…provided that the seepage can be traced to such works beyond reasonable doubt." The 1905 New Mexico territorial water law did not adopt such a provision, but Section 53 of the 1907 law did. There is no indication from the historical record reviewed that a formal filing for "seepage water" from the Rio Grande Project was made by either Reclamation or another party, pursuant to Section 53.[148]

Federal authorities nevertheless saw such waters as an essential element of the overall supply for the Rio Grande Project as it developed into the 1930s. In 1912, four years prior to the completion of Elephant Butte Reservoir, a board of US Army engineers reporting on the progress of the project to Congress recognized that "losses in the distribution system," estimated at 20

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[147] P.W. Dent, Assistant Examiner, to Director, U.S. Reclamation Service, April 26, 1910. ff. 41, Box 6; William Reed, district engineer, to Director, U.S. Reclamation Service, April 28, 1910; F. H. Newell, Director, to Secretary of the Interior, May 11, 1910; and Secretary of the Interior to Vernon L. Sullivan, Territorial Engineer, May 12, 1910. ff. 41-D, Box 9, Entry 3, RG 115, NARA Denver. For more on the Rio Grande "embargo" and the 1929 temporary compact, see Opinion I.

[148] Bien, "Proposed State Code of Water Laws," 33; and Chapter 49, Section 53, *1907 Acts of the Legislative Assembly of the Territory of New Mexico*, 89. Section 53 stated:

> In the case of the seepage of water from any constructed works, the owner of such works shall have the first right to use thereof upon filing an application with the territorial engineer as in the case of an original appropriation, but if such owner shall not file said application within one year after the completion of such works, or the appearance upon the surface of such seepage water, any party desiring to use the same shall make application to the territorial engineer, as in the case of unappropriated water, and such party shall pay to the owner of such works reasonable charge for the storage or carriage of such water in such works; Provided, That the appearance of such seepage water can be traced beyond reasonable doubt to the storage or carriage of water in such works.

percent, would occur as a result of "transit between the reservoir and the diversion dams." However, such "losses in transit," these engineers maintained would "be partly offset by the return seepage in upper parts of the valley, which will be available for diversion lower down."[149]

The following year, in April 1913, Reclamation chief engineer A.P. Davis prepared for the new secretary of the interior a report on the Rio Grande Project and its water supply, "Water Supply of Rio Grande, from Official Records, 1912," that again emphasized the importance of return flows:

> In the irrigation development of a large river system, such as the Rio Grande, it is undoubtedly wise to use a considerable proportion of the water in the upper valleys soon after it leaves the mountains and before it has had much opportunity to evaporate. As more tributaries reach the river, the additional water supply justifies other diversions lower down, which can also utilize return seepage from the upper valleys.[150]

The *Twelfth Annual Report of the Reclamation Service for 1912-1913*, released in 1914, offered this explicit statement with regard to the Rio Grande Project: "The United States claims all waste, seepage, spring, and percolating water arising within the project, and proposes to use such water in connection therewith." Such claims for other Reclamation projects were asserted in the *Twelfth Annual Report* as well.[151]

Subsequent Reclamation annual reports repeated this claim within the context of the project's "Irrigation Plan." The 1914-1915 report, for instance, described the Rio Grande Project as 19.7 percent complete exclusive of storage and 50 per cent complete including the storage works at Elephant Butte Dam. The project at that time served 47,160 acres. No stored water was yet available to project lands in 1914, only direct diversions, but the following year stored water was. The report indicated that the project would increasingly rely on water now being stored at Elephant Butte Reservoir. Its "Irrigation Plan" nonetheless included a claim to "all waste, seepage, spring, and percolating water arising within the project and proposes to use such water

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[149] United States Congress, House of Representatives, *Fund for Reclamation of Arid Lands: Message from the President of the United States, Transmitting a Report of the Board of Army Engineers in Relation to the Reclamation Fund*, H. Doc. No. 1262, 61st Cong. 3d sess. (1911-12), 106.

[150] A.P. Davis, Chief Engineer, Memorandum for Secretary Lane, April 17, 1913, and "Water Supply of Rio Grande, from Official Records, 1912," 4-5. File 8-3 (Part 4) Reclamation Service, Rio Grande Project, New Mexico, Rio Grande River, Distribution of Waters, Nov. 21, 1912 – Apr. 17, 1914, Box No. 1639 8-3, Rio Grande D-E, CCF 1907-1936, RG 48, NARA II.

[151] *Twelfth Annual Report of the Reclamation Service, 1912-1913* (GPO, 1914), 176. The plan for Colorado's "Uncompahgre Valley project," for instance, included "utilization of all the waste, seepage, spring, percolating, and return water arising within the project in the irrigation of lands in the Uncompahgre Valley." The irrigation plan for the Minidoka Project in Idaho used the exact same language as used for the Rio Grande Project. Newell, *Twelfth Annual Report*, 78 and 95.

in connection therewith." Three years later, in its 1917-1918 annual report, Reclamation again described its "Irrigation Plan," which was estimated as 40 per cent complete excluding Elephant Butte Dam and 66.4 per cent including the dam. The project at that time was serving about 90,000 acres. As in the 1914-1915 report, Reclamation asserted "claims [to] all waste, seepage, spring, and percolating water arising within the project…."[152]

In June 1919, Reclamation engineers Harold Conkling and Erdman Debler produced the first comprehensive assessment of the operations of the Rio Grande Project since the completion of Elephant Butte Dam, an assessment that emphasized the importance of "return flows." Conkling and Debler noted that given the long irrigation season in the basin (from February to November) "conditions are favorable for a reuse of almost the entire return flow." This return flow, according to the engineers, "consist[ed] of the transportation loss from canals and deep percolation from irrigated areas." Such waters were often captured in project drains, and brought back to the river channel. The engineers maintained that unlike with most projects, such return flow did not pose much of a problem "because of immediate rediversion by canal headings below," and in fact the lowest units of the project – San Elizario Island and the Tornillo District – could "probably use the entire return from the El Paso Valley." Although the amount of return flow from drains was then "uncertain," Conkling and Debler estimated 1.5 af/a per year. They further anticipated that other than the return flow from the Tornillo unit (which would be lost to the project because Tornillo was the lowest unit) and return flow during the winter (which would be lost because of lack of use) return flow would be fully utilized on project lands.[153]

Conkling prepared a separate memorandum report on the water supply for the San Luis Valley in Colorado, the Middle Rio Grande Valley in New Mexico, and the Rio Grande Project in New Mexico and Texas later that same month. He once again stressed that "on each…project conditions are favorable for re-use of return flow by the acreage on the lower end." With specific reference to the Rio Grande Project, the engineer reiterated the analysis he and Debler offered in their larger report. Conkling assumed 4.32 af/a for the diversion duty for the project, and

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[152] U.S. Department of the Interior, *14th Annual Report of the Reclamation Service, 1914-1915* (Washington: Government Printing Office, 1915), 214-217; and U.S. Department of the Interior, *17th Annual Report of the Reclamation Service, 1917-1918* (Washington: Government Printing Office, 1918), 250-251, and 254-256.

[153] Harold Conkling, Engineer, and Erdman Debler, Asst. Engr., Water Supply for and Possible Developments on Irrigation and Drainage Projects on the Rio Grande River Above El Paso, Texas, June-1919, 105, 111-112. ff. 302.31, New Mexico. Report dated June 1919 by Conkling and Debler on Water Supply for and Possible Developments on Irrigation and Drainage Projects on the Rio Grande River Above El Paso, Texas, transmitted by letter July 15, 1919, Box 262 302.28--302.31 A. NV-NM, Entry 7, RG 115, NARA Denver.

believed that given the basin's 10-month irrigation season, "almost all of the return flow may be utilized on the project if this duty can be obtained."[154]

The engineer took further note of the potential impact of non-federal groundwater development on project lands. He observed that the project was then assumed to serve 155,000 acres ("as estimated by the project office") but could be extended "privately [i.e., not by federal authorities] by pumping from ground water under assumed unirrigable acreage of 29,000 acres." "An additional draft of 70,000 acre feet annually," Conkling pointed out, would significantly worsen two prior years of shortages "without adverse effect in other years." Whether such expansion was advisable, he left to the "attitude of the government toward the question of allowing such possible shortages."[155]

Conkling's observations highlight the interrelationship of surface, subsurface, and return flows upon which the Rio Grande Project and many other federal projects had come to rely. The claim to waters other than surface flow was, as Assistant Attorney General William D. Riter wrote to John F. Truesdell, Special Assistant to the Attorney General, in July 1921, a "matter of policy…for the Secretary of the Interior to decide." In Riter's view, as evidenced by the assertions made over the years in "annual reports and otherwise," the Interior Department had "announced the intention of reclaiming seepage and waste waters of government projects for further use thereon." At the time of Riter's writing, Truesdell was apparently uncertain of the efficacy of this position. While acknowledging that the question was not entirely settled from a legal perspective, Riter noted that both the Justice Department's Public Land Division and US Solicitor General Alexander Campbell King gave "careful consideration" to the issue. Both believed that the federal government was on firm ground, provided that it took the position

> that when the Government makes an appropriation of water for a reclamation project, it is for the project as a whole, and not for particular farms comprising parts of the project; and the fact that a portion of the water, after serving to irrigate one farm escapes by seepage and finds its way to a piece of private land which happens to be inclosed [*sic*] by the project lands, is no evidence of an intent on the part of the Government to abandon that water, and does not in law amount to an abandonment; but the Government may recapture it and apply it to other parts of the same project.

[154] Memorandum, From: Engineer Harold Conkling, To: Chief of Construction, Subject: Water Supply – Rio Grande River, June 18, 1919 [hereafter Conkling Memorandum…June 18, 1919, 2 and 17. ff. 302.31, New Mexico. Surveys and Investigations. THRU 1929, Box 262, Entry 7 RG 115, NARA Denver. This report led to the modification of the Rio Grande "embargo" in 1923, as discussed in Opinion I.

[155] Conkling Memorandum, June 18, 1919, 17-19. ff. 302.31, New Mexico. Surveys and Investigations. THRU 1929, Box 262, Entry 7, RG 115, NARA Denver.

Riter later informed Reclamation chief counsel Ottamar Hamele, who steadfastly insisted upon the federal government's claim to these waters, "that the two Departments [Justice and Interior] are in accord."[156]

The federal government's assertions of ownership over waters returning to or arising on project lands further won judicial approval in federal and state courts in the early 1920s. In the case of *United States v. Ramshorn Ditch Co.*, which concerned waters initially diverted for the North Platte River Project in Nebraska, the federal Circuit Court of Appeals in November 1920 reportedly "sustained the right of the Government to reclaim seepage waters from a part of the reclamation project and use them again upon other lands of the same project." The federal district court in Idaho likewise sustained "the right of the Government to recapture and again use seepage waters" for lands in the Boise Project in Idaho in *New York Canal Co. (Ltd.) v. Bond and Weinkauf*. US attorneys made similar arguments in 1921 for the recapture and reuse of water previously diverted to serve lands in the Shoshone Project in Wyoming in *United States v. Ide et al.*, and *The Lincoln Land Co. et al. v. Weymouth et al.*[157]

Within the Rio Grande Project itself, Elephant Butte Irrigation District recognized the importance of what its president H.H. Brook termed "Drainage return flow." Brook, writing project superintendent L.R. Fiock to express concerns about the proposed inclusion of downstream lands in Hudspeth County into the project (discussed in Opinion IV below), observed that the "water supply of these arises from two sources":

> (1) The formally acquired unappropriated natural flow, flood and torrential waters of the Rio Grande including the ancient natural flow rights of the landowners of the present project and stored in the Elephant Butte Dam…
>
> (2) Drainage return flow artificially created by the expenditure of large sums by the United States under contract with the landowners giving a first lien on their land to secure repayment and which artificially created water supply, according to the law of the West, belongs to the landowners creating it to be used or disposed of by the United States as trustee for the benefit of the said land and water right owners.

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[156] Assistant Attorney General [William D. Riter], For the Attorney General, to John F. Truesdell, Esq., Special Assistant to the Attorney General, July 21, 1921; Ottamar Hamele, Chief Counsel, to Hon. William D. Ritter, Assistant Attorney General, July 26, 1921; and W.D. Riter, Assistant Attorney General, For the Attorney General, to Ottamar Hamele, Esq., Chief Counsel, US Reclamation Service, July 27, 1921. ff. 030.1 General Correspondence re Return flow, Waste & Seepage Water Thru 1929, Box 33 023.6- -032, Entry 7, RG 115, NARA Denver.

[157] *Annual Report of the Attorney General for the United States, For the Fiscal Year 1921* (GPO, 1921), 86.

Brook further asserted in his letter that "the right to drainage and seep water was reserved in the water right filings" for the project.[158]

Persistent interest in the issue of return flow into the late 1920s prompted Reclamation Commissioner Elwood Mead to suggest that an article be drafted for the agency's *New Reclamation Era* publication, whose readership included farmers and water users on federal reclamation projects. This article would discuss "the utilization of the return flow of water in connection with various irrigation projects." E.B. Debler, who had co-authored with Harold Conkling the 1919 study that identified the central importance of return flows to the Rio Grande Project, drafted the piece for the August 1927 issue.[159]

In "Return Flow and Its Problems on Reclamation Projects," Debler emphasized both the necessity of return flow while acknowledging the somewhat legally ambiguous status of such water. By way of introduction, he offered a detailed and inclusive definition of "return flow," that seemed to embrace not only previously diverted surface flow that made its way back to the stream within the project but also water underlying project lands:

> When water is applied to the earth's surface naturally through rains and snow or artificially by irrigation it is disposed of in a number of ways. A part passes away immediately or very soon as surface run-off or evaporation from the surface of the snow, ground, or from the exposed surfaces of plants which catch the moisture. Another part enters the ground is in part returned to the surface by capillary action to replace water evaporated from the surface. Some is taken up through the roots of plants and evaporated in the growth processes of the plant or stored in the plant structure and hauled away as a plant product. The remainder passes beyond the limit of capillary action and joins the mass of water existing under the ground surface, there generally to form part of a moving stream seeking a lower level, and reappearing in the form of seepage, springs, or artesian flow, the particular name popularly applied being dependent on the concentration of flow and the pressure with which it reaches the surface. The reappearance of these waters may be but a few hundred feet from the source thereof, or it may be several hundred miles, depending entirely on the ground structure and topography.

Return flow in "arid regions" was thus

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[158] Elephant Butte Irrigation District, (Signed) H.H. Brook, President & Manager to Mr. L.R. Fiock, Acting Project Manager, US Bureau of Reclamation, August 8, 1923, 1 and 3. Folder 222. Rio Grande Project. Corres. re Organization of Irrigation Districts and Execution of Contracts Guaranteeing Repayment of Construction Costs, Thru 1929.Transfer Case, Box 902, Rio Grande 212.—222, Entry 7, RG 115, NARA Denver.

[159] Memorandum, From: Commissioner [Elwood Mead], To: Chief Engineer, Denver, Colorado, Subject: Article for the New Reclamation Era on Return Flow, February 4, 1927. ff. 030.1, Box 33, Entry 7, RG 115, NARA Denver.

> the increase therein due to the application of irrigation water. This includes waters lost by seepage from canals and reservoirs, as well as waters applied by the irrigator to his land. Such return flow is in these places particularly prominent, as the return flow from precipitation prior to irrigation development is usually so small that the stream in its passage through the region actually loses a part of the water it brings from its mountain sources, at times drying up completely. With irrigation development such conditions are materially changed and living stream often result therefrom.[160]

Return flow was "heavily concentrated in the irrigation season," with "large irrigation areas underlain to great depths with permeable deposits" experiencing nearly continuous return flow. Debler estimated that 60 percent of the water diverted for irrigating crops became return flow "and reenters streams for further use unless intercepted." In some areas with diversions of up to 15 af /a return flow could be as much as 90 percent, and in other areas, concrete-lined canals and "favorable soils" could reduce return flow to 25 percent of the water diverted.[161]

Regardless of the amount, the engineer stressed the importance of return flow to federal reclamation projects. He argued that

> return flow augments the irrigation water available in the late summer after the stream flow, due to melting snows, has declined to less than the irrigation requirements of lands dependent thereon, and in that way serves a similar purpose as do storage reservoirs, but with the advantage that there is no loss from evaporation. In practice the effect has been to materially improve water rights on the lower portions of stream systems due to irrigation development on the upper reaches. In some cases the irrigation systems that have produced such return flow have been able to benefit in that less water is thereafter necessary to be passed down the stream to care for prior rights.

Debler pointed out that return flow was vital to the water supply for both federal projects and beyond.[162] For Texas specifically, he noted Hudspeth County water users (discussed in Opinion IV) who were not part of the Rio Grande Project were nonetheless "entirely dependent on return flow and waste water from project lands" upstream in the El Paso Valley. The El Paso Valley,

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[160] E.B. Debler, Engineer, Bureau of Reclamation, "Return Flow and Its Problems on Reclamation Projects," *New Reclamation Era* (August, 1927), 124. ff. 030.1, Box 33, Entry 7, RG 115, NARA Denver.
[161] Debler, "Return Flow and Its Problems on Reclamation Projects," *New Reclamation Era* (August, 1927), 124. ff. 030.1, Box 33, General Files, 1919-1929, Entry 7, RG 115, NARA Denver.
[162] According to Debler, both the Notus Division of the Boise Project in Idaho and the "west extension division" of the Umatilla Project relied upon return flows from upstream project diversions. On the North Platte Project in Wyoming and Nebraska, utilization of return flow likewise enabled more efficient use of stored water.

which was within the project, "in turn uses return flow from Mesilla Valley in New Mexico and Texas."[163]

The importance of return flows to established reclamation projects aside, Debler observed that state law was neither entirely decided nor altogether antagonistic to the issue. Early water codes in western states were "generally…framed before return flow became a recognized factor in irrigation supply" and consequently were "in a rather unsatisfactory shape" with "decisions…in conflict." "The general tendency, however," according to the engineer, "is to regard return flow in all of its forms recoverable by the agent producing it until it enters a stream which in its natural condition supplied irrigation diversions, when it becomes a part of such stream and subject to appropriation therefrom as are other waters of the same stream."[164]

As the states of Colorado, New Mexico, and Texas moved forward with negotiations for a compact, federal and state engineers alike recognized that the Rio Grande project water supply encompassed a range of surface and return flows, both of which influenced and were influenced by waters lying beneath the surface of project lands. As early as 1924, Reclamation measured the groundwater in the Mesilla Valley, in the later words of the Rio Grande Joint Investigation report, or *JIR*, "chiefly to derive the annual increment or decrement of ground water as a necessary factor in computing the annual consumptive use of water in the valley by the inflow-outflow method."[165]

In an internal Reclamation report on silt issues prepared by Rio Grande Project Superintendent L. R. Fiock for Reclamation's Chief Engineer in July 1931 (at the latter's request), the superintendent yet again emphasized the importance of return flows in his discussion of project operations. Fiock observed that the reservoir retained the "entire flow or discharge of the Rio Grande reaching [it]," and fully controlled and regulated releases "to meet irrigation demand requirements." According to the project superintendent,

> The water as released is drawn from the river at the various diversion throughout the project. Part of the amount diverted at each respective diversion point is compensated for by waste return and drainage recovered flow which mingling with the remaining released reservoir water as it passes through each succeeding project division is available for rediversion at the diversion points on farther down.[166]

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[163] Debler, "Return Flow and Its Problems on Reclamation Projects," *New Reclamation Era* (August, 1927), 124-125. ff. 030.1, Box 33, General Files, 1919-1929, Entry 7, RG 115, NARA Denver.
[164] Debler, "Return Flow and Its Problems on Reclamation Projects," *New Reclamation Era* (August, 1927), 125. ff. 030.1, Box 33, General Files, 1919-1929, Entry 7, RG 115, NARA Denver.
[165] *JIR*, 62.
[166] L.R. Fiock, "Effect of the Operation of Elephant Butte Reservoir on the River through Rio Grande," 1-2, enclosed with Memorandum, From Superintendent [signed L.R. Fiock], To Chief Engineer, Denver,

This was especially true for lands below El Paso in Texas (as Debler had previously suggested):

> The flow required at El Paso to meet the normal irrigation requirements from April 1st to September 1st is from 800 to 1,000 second feet, this has required from 300 to 500 second feet in the river below Mesilla Dam, the difference being made up of waste return and drain recovery in the valley above between Mesilla Dam and El Paso….[167]

The surface flow of the Rio Grande captured by Elephant Butte and the return flow from diversions – i.e., "waste return and drain recovery" – also fed and relied upon the groundwater underlying the project, as New Mexico engineer John Bliss found in the mid-1930s. Conkling's observations about the potential impact of private groundwater pumping within the project notwithstanding, there were few investigations of groundwater below Elephant Butte prior to Bliss's study in 1935-1936. Slichter's study of the Mesilla Valley in 1904 had indicated a hydrological connection between the river and the valley's groundwater, but it was made prior to the construction of the Rio Grande Project. Reclamation had made "[m]easurements" in 1917 and 1918, however, as Bliss pointed out, "the data were obtained prior to drainage construction and are not applicable to present day conditions." In 1928, E.L. Barrows, working for the New Mexico State Engineer's Office, made "a preliminary seepage determination" for the stretch between Elephant Butte Reservoir and the Leasburg Diversion Dam, yet a planned follow-up study ultimately was not undertaken. Later that same year, a study of river hydrographs by Middle Rio Grande Conservancy District Designing Engineer R.G. Hosea found no "evidence of an invisible underground flow tributary to the river." He instead noted instead that "it is apparent that when the reservoir is not releasing water during the winter months, the Ft. Quitman flow is just about equal to the total drainage water from the project."[168]

Bliss's investigation, by contrast, identified "a direct relation of seepage to ground water and irrigation": at certain critical points between Elephant Butte and El Paso, underflow fed the groundwater table, providing basin lands with additional water that was recovered by project

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Colorado, Subject: Effect of clear water on bed of Rio Grande below Elephant Butte Reservoir – Rio Grande Project, July 25, 1931. ff. 301.1 Rio Grande Project-Dams-Elephant Butte Dam 1930 thru, Box 928 Rio Grande Pro. 301.-301.12, Entry 7, RG 115, NARA Denver.

[167] Fiock, "Effect of the Operation of Elephant Butte Reservoir on the River through Rio Grande," 2-3. ff. 301.1, Box 928, Entry 7, RG 115, NARA Denver.

[168] R.G. Hosea, Report on Irrigation in the Rio Grande Valley, State of New Mexico, The Rio Grande Valley Survey Commission, Albuquerque, New Mexico, December, 1928, 169. Folder 3 Report on Irrigation in the Rio Grande Valley-R.G. Hosea-December 1928 [EBID Item #20], December 1928, Box 02-D.003, MS 0235, RGHC, NMSU; and John H. Bliss, "Report on Investigation of Invisible Gains and Losses in the Channel of the Rio Grande from Elephant Butte to El Paso." Feb. 1936, 1. Folder 1435, Bliss, Report on Investigation of Invisible Gains and Losses in the Channel of the Rio Grande from Elephant Butte to El Paso, February 1936, Box 55, State Engineer Reports: Rio Grande, Exps. 161-163, Nos. 1417-1437 [hereafter Box 55], NMSA.

drains and returned to the river channel for use on lands downstream. Bliss's study, presented to New Mexico State Engineer and Rio Grande Compact Commissioner Thomas McClure in February 1936 as "Report on Investigation of Invisible Gains and Losses in the Channel of the Rio Grande from Elephant Butte to El Paso" grew out of a suggestion for such an investigation made by Fiock in fall 1935. "[D]etermination of invisible gains and losses in the bed of the Rio Grande," as Bliss noted in his report, were "an important item in the study of the use and distribution of the waters of the river" yet "few such data are available below Elephant Butte Reservoir." Fiock had proposed that such an investigation be made prior to the construction of Caballo Dam; Caballo was a critical feature of international efforts to rectify the river's channel downstream from Elephant Butte, and pursuing a study before the dam was built would permit "work in the canyon above Percha Dam."[169] With the cooperation and assistance of USGS, Reclamation, and

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[169] Caballo Dam, which today regulates the flow of the Rio Grande for flood control purposes, compensates for the loss of storage space in Elephant Butte due to silting, and generates hydroelectric power, came about as a result of international efforts to rectify the channel of the Rio Grande. The treaty of Guadalupe Hidalgo had established the river as the boundary between the two nations. Periodic high flow events since the treaty's ratification, however, altered the river's course, damaging land and property on both sides of the river and confusing the precise location of the border. Completion of Elephant Butte Dam in May 1916 brought greater control over the river, but the Rio Grande continued to meander into the 1920s. See Department of the Interior, *Fifteenth Annual Report of the Reclamation Service 1915-1916* (GPO, 1916), 324; and History and Development of the International Boundary and Water Commission, United States and Mexico, El Paso, Texas, April 1952, Revised April 1954, 45-49. Item 41, Box 1, MS042 International Boundary & Water Commission Records [MS042], UTEP Spec Coll.

A major flood in 1925 prompted the US and Mexico to enact a treaty eight years later that committed to the nations to stabilizing the river channel through the Rio Grande Rectification Project. A chief feature of this project was "the construction of [a] flood retention dam at Caballo, New Mexico" to enhance river regulation and prevent further meanders. Between 1934 and 1936, under pressure from local interests that had long sought a hydroelectric power facility at Elephant Butte as well as additional water for Rio Grande Project lands, the USBR in conjunction with the International Boundary Commission committed to building an 85-foot high and 4,250-foot long dam at Caballo. The proposed dam, according to the Interior Department:

> will, through flood control, become a highly important feature of the International Boundary Commission's plan for rectification of the Rio Grande in El Paso and Hudspeth counties, Texas, and it will provide an afterbay for the Elephant Butte Dam of the Bureau of Reclamation. Elephant Butte Dam stores water for the Rio Grande Federal Reclamation project in New Mexico and Texas. Provision of an afterbay will provide additional storage for project lands and will make it possible to install hydroelectric generation equipment at Elephant Butt Dam in the future.

Caballo was substantially completed in September 1938. History and Development of the International Boundary and Water Commission, United States and Mexico, El Paso, Texas, April 1952, Revised April 1954, 45-49. Item 41, Box 1, MS042, UTEP Spec Coll; Chronology – Caballo Dam Construction, February 1, 1933-November 30, 1935, December 16, 1935. ff. B-8.2.4.2, Conservation, Power, Diversion & Drainage Projects, Caballo Dam, 5 of 6. August 1935 thru March 1937, Box 5, Accession Number 076-69A-0928, Records of the International Boundary and Water Commission, Record Group 76 [hereafter RG 76], National Archives and Records Administration at Fort Worth, Texas [hereafter NARA Ft. Worth]; and the International Boundary Commission, Bliss embarked on the study in early January 1936 so as "to allow ground water and bank storage to reach a minimum" before water was released for the 1936 irrigation season."[170]

Bliss initially intended to examine that stretch of the Upper Rio Grande Basin between Elephant Butte and Ft. Quitman. Field work was to consist of two parties each making "complete series of measurements," guided by Reclamation engineers. Reclamation also installed temporary recording gages at Percha and Leasburg diversion dams, and brought into service the "operation station at Mesilla Dam…during the investigation." The methodology was like so:

> River stations were selected at frequent intervals to localize channel gains and losses in order to determine their probable sources or causes. No diversions were being made in any of the canals during the period of the investigation. To speed the work, all drain flows were measured but once, which was felt to be sufficient as these discharges vary but slightly.

Conditions during the investigation, however, forced alterations. The ongoing channelization program limited Bliss's work to the area between Elephant Butte and Courchesne, and unexpected rains soon after surveys began forced a "remeasurement of the entire river" – a "third series" of measurements starting February 1. High winds further affected this third series, "caus[ing] considerable variation in the discharge" as well as "preclude[ing] any reliable additional measurements." Despite these issues, survey work was completed by February 7, and the three sets of measurements were tabulated and averaged. Discharges were ascertained "by comparison of the three series, those apparently in error being discarded," and a "few measurements were corrected for change in river stage due to rain." Other corrections were made for the rising river stage below Elephant Butte and evaporation.[171]

Whatever the limitations of the study, Bliss felt confident enough in the work to make several significant observations about the complicated dynamics of underflow, groundwater, irrigation, and gains and losses in the Rio Grande that affected the project. He noted, for instance, that there was a "consistent increase in the canyon from the [Elephant Butte] Dam to the Dona Ana-

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Department of the Interior, Memorandum for the Press, Immediate Release, May 2, 1936. ff. 023.6 Rio Grande-Caballo Dam-Press Releases, Box 939, Rio Grande-Caballo Dam 011.-301.1, Entry 7, RG 115, NARA Denver; *Project History, Rio Grande Project, Calendar Year 1938*, 42-43. United States Bureau of Reclamation, Washington, DC, Project Histories of the Rio Grande Project, 1912-1988. Microfilmed by the Government Publications Department, General Library, University of New Mexico, Eulalie W. Brown, In cooperation with the United States Bureau of Reclamation, Rio Grande Project, El Paso, Texas, Dan N. Page, Project Superintendent, December, 1992, Southwest Micropublishing, Inc. [hereafter USBR PHRGP 1912-1988 (mf)]; and Robert Autobee, "Rio Grande Project," (Bureau of Reclamation, 1994), 17.

[170] Bliss, "Report on Investigation of Invisible Gains and Losses," 1-2 and 12. Folder 1435, Box 55, NMSA.

[171] Bliss, "Report on Investigation of Invisible Gains and Losses," 3-4, 7, and 14. Folder 1435 Box 55, NMSA.

Sierra Country line," which Bliss ascribed "chiefly to underflow from the large intermittent streams entering [the Rio Grande channel] from the west."[172]

In the Rincon and Mesilla valleys, there were further fluctuations. "[W]ater lost in the Rincon Valley," the engineer asserted, "feeds the ground water of the surrounding lands and is recovered largely by the [project] drains." In the valley's Selden Canyon, Bliss identified a "small increase" attributable to "several short arroyos and from seeps in the vicinity of Radium Springs." In the Mesilla Valley, losses were greater "particularly in the section between Picacaho Flume and Mesquite, through which the large Del Rio Drain parallels the river at a short distance." Yet, "above Vinton bridge where the rivers enters a canalized section," he found an "increase." Bliss hypothesized that this was caused either by "underflow in the old river channels on the west side of the valley entering the present channel above the bridge," or "that the cut, which traverses an apparently undisturbed deposit of caliche and heavy clay, is effective in bringing a considerable underflow to the surface in this section."[173]

For the Mesilla Valley losses, Bliss made a further analysis of the data gathered. Taking a closer look at the drain measurements, the engineer noted that "much" of the Del Rio Drain flow was "drawn directly from the river channel through underflow." This was less true of the Montoya Drain and the "the Chamberine which drains the old river channels on the west side of the valley below Las Cruces."[174]

Attempting to develop curves for his study in comparison to others previously made, Bliss acknowledged that the data sets all differed from each other and those differences were not fully explainable. "It is impossible to account for the eccentricities of the curves prior to the present one, as little is known of the conditions of flow, irrigation, etc., at the time the measurements were made," he wrote. Bliss nevertheless argued that the curves demonstrated "a direct relation of seepage to ground water and irrigation." He proposed further study of "seepage during the non-irrigation period" so as to compare "against gains and losses found during the summer at a period when river and canal flows can be kept in a stable condition."[175]

This "direct relation of seepage to ground water and irrigation" was not addressed in the testimony given in the original action between Texas and New Mexico in the mid-1930s. However, Bliss, Fiock, and Texas engineers Raymond Hill and J.Q. Jewett all gave testimony acknowledging that the Rio Grande Project relied upon return flows. These were the flows that Bliss's study suggested intercepted groundwater, found their way to drains that fed the river

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[172] Bliss, "Report on Investigation of Invisible Gains and Losses," 9. Folder 1435, Box 55, NMSA.
[173] Bliss, "Report on Investigation of Invisible Gains and Losses," 9-10. Folder 1435, Box 55, NMSA.
[174] Bliss, "Report on Investigation of Invisible Gains and Losses," 10. Folder 1435, Box 55, NMSA.
[175] Bliss, "Report on Investigation of Invisible Gains and Losses,"12. Folder 1435, Box 55, NMSA.

channel below Elephant Butte, and would have served, either wholly or in part, downstream lands in Texas.

Fiock was among the first to affirm the importance of all the waters arising on the Rio Grande Project before Special Master Charles Warren. Confirming Warren's understanding that "nearly double" the amount of water released from Elephant Butte Dam was needed to satisfy irrigation demands on the project, for instance, the project superintendent stated, "That is nearly, approximately the proportion, although we [federal Rio Grande Project officials and staff] do recover and redistribute water over and over down through the project."[176]

Fiock reiterated this point later when asked by Texas's attorney Frank Clayton, "Now, in the upper reaches of the river, the sand traps, or sluice ways, go back into the river and the water is rediverted below, is that correct?":

> With successive operating diversion points, and operating divisions down the river, as the Rio Grande Project has, that water is available and is counted on as part of the supply for the succeeding diversion below.[177]

The project superintendent not only testified that water released from Elephant Butte was used multiple times – such water variously identified by Fiock as "return flow from drainage," "drain water," "drain flow," or "drain runoff" – but also reported the same officially, outside of the courtroom. From one project operations report, dated November 7, 1934, New Mexico's attorney George Hannett read:

> …the demand for water was high due to continued dry warm weather. There was eight thousand five hundred twenty-eight acre feet delivered with a release of nineteen hundred acre feet from storage. In 1933 all water used for satisfying irrigation demands was return flow from drainage, which was rediverted into various canals as demands required.

When asked if he could recall making this report, the federal Reclamation official replied: "I don't recall the exact words, but that is the nature of our reports." [178]

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[176] *Plaintiff's Case in Chief*, Vols I & II, 312. CB-F-171A thru CB-F-1716: Transcripts of TX v. NM, Vol. 1-16, Box 4X219, RAHP, UTA.
[177] *Plaintiff's Case in Chief*, Vols I &II, 327. CB-F-171A thru CB-F-1716: Transcripts of TX V. NM, Box 4X219, RAHP, UTA.
[178] *Plaintiff's Case in Chief*, Vols. I & II, 343. CB-F-171A thru CB-F-1716: Transcripts of TX V. NM, Box 4X219, RAHP, UTA.

Later still, under cross examination, when asked "How do you deliver water down from the dam, the Elephant Butte Dam, to serve the Tornillo canal for mixing for this Tornillo area?" Fiock responded:

> After being released from Elephant Butte reservoir, which is a hundred fifty miles above the heading of the Tornillo canal, it passes down the Rio Grande, which is utilized as a main carrier canal. In passing through the main Rio Grande Project, water is diverted at the successive diversion dams, and the drain discharge from the successive operating divisions of the Project discharges at the other end, lower end respectively of each division; and, each time one of the operating divisions is passed, then there is that much higher percent of drain water, so that when the water has arrived at Fabens, it has, some of it, been diverted and used, and is returned through the drains, as much as four times. A certain percent of it, of course, flows right on through, directly through the channel of the river.[179]

Under further questioning from Warren about the measurement of drain flow within the project, Fiock explained

> The drain flow over the Rio Grande Project constitutes a very important element in the irrigation supply, and must be taken account of in computing the release of water for irrigation from the reservoir, so we [Rio Grande Project staff] measure those drains frequently, that is once a week we meter the drains.[180]

The project superintendent stressed again the importance of such water to the overall project water supply when the special master asked him about the reported 1934 reservoir release, which was substantially larger than in prior years. Fiock noted that project staff had estimated the delivery at farms in the project to be 1.5 af/a and thus twice that amount had been released to ensure this delivery. "There are other things," he cautioned "to take into consideration" in making releases. One of these was the "drain runoff," which was "to make up part of the irrigation supply."[181]

Fiock was not alone in his conception of what constituted the water supply for the Rio Grande Project. Two other expert witnesses for the State of Texas similarly asserted the critical value of re-diverted water (to paraphrase Fiock). J.Q. Jewett testified that in his calculations "reservoir water" was "all the water reaching Courchesne station except the estimated tributary flow" – in other words, "a mixture of drain water and water released from Elephant Butte reservoir." When

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[179] *Plaintiff's Case in Chief*, Vols. I & II, 399-400. CB-F-171A thru CB-F-1716: Transcripts of TX V. NM, Box 4X219, RAHP, UTA.
[180] *Plaintiff's Case in Chief*, Vols. V, VI, VII, 1029. CB-F-171A thru CB-F-1716: Transcripts of TX V. NM, Box 4X219, RAHP, UTA.
[181] *Plaintiff's Case in Chief*, Vols. V, VI, VII, 1034. CB-F-171A thru CB-F-1716: Transcripts of TX V. NM, Box 4X219, RAHP, UTA.

asked a clarifying question as to whether this "reservoir water" was in fact the "reservoir release no matter how many times it has been used in the meanwhile," Jewett replied in the affirmative.[182]

Texas's engineering advisor Raymond Hill likewise acknowledged the project's reliance upon what Clayton called "drain waters," and expressed concerns for the practice owing the diminishing quality of the water as it moved downstream (see Opinion II above):

> [Clayton]: "The testimony adduced in the trial of this case has shown that drain waters in the valleys below Elephant Butte dam to Fort Quitman has been used and re-used progressively as you proceed down the stream. What is your conclusion, Mr. Hill, as to whether that is a proper use of those waters?"
>
> [Hill]: "As a general principal [*sic*], the use of drainage waters at the successive points of diversion from Elephant Butte down through the valleys is proper; however it is my judgment that the process has been carried to an extreme in the case of the Rio Grande Project, or in other words there has been too great a use of the drainage waters and that additional dilution of these waters would have been better, and taken over a longer period of time some greater dilution of those waters will be necessary in order to insure continued production of a profitable nature."[183]

New Mexico's own experts did not offer direct testimony on the issue of return flow. Bliss nevertheless acknowledged under cross-examination from Clayton that "drain water" was utilized on the lands below Elephant Butte:

> [Clayton]: "You mean to say that drain water that enters the river in the Rincon and Mesilla Valleys is not used?"
>
> [Bliss]: "It is altered – Yes."
>
> [Clayton]: "It is rediverted down below?"
>
> [Bliss]: "Yes"
>
> [Clayton]: "And used for irrigation?"
>
> [Bliss]: "Yes"[184]

The subsequent federal Rio Grande Joint Investigation likewise took note of the importance of return flows to the Rio Grande Project and lands beyond, as discussed in Opinion IV. With regard to groundwater, the *JIR* focused largely on the San Luis and Middle Rio Grande valleys.

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[182] *Plaintiff's Case in Chief*, Vols. III & IV, 781. CB-F-171A thru CB-F-1716: Transcripts of TX V. NM, Box 4X219, RAHP, UTA.
[183] *Plaintiff's Case in Chief*, Vols. V, VI, VII, 1307-1308. CB-F-171A thru CB-F-1716: Transcripts of TX V. NM, Box 4X219, RAHP, UTA.
[184] *Defendant's Case in Chief*, Vols. X, XI, 2058. CB-F-171A thru CB-F-1716: Transcripts of TX V. NM, Box 4X219, RAHP, UTA.

Nonetheless, observations made in the report suggest federal engineers were aware of the relationship between surface and subsurface flows and groundwater in the basin. For the Middle Rio Grande, for instance, "Ground water in the Middle Valley" was identified as having several sources," including "seepage from canals" and "seepage from irrigated lands." For the basin overall, the *JIR* made three critical observations that underscore the complicated relationship between surface water and groundwater:

1) "extensive development of ground water for irrigation would add no new water to the Upper Rio Grande Basin…",
2) "recharge of the ground-water basins would necessarily involve a draft on surface supplies which are now utilized otherwise"; and
3) "The chief element to be considered in such a development [of groundwater] would be the redistribution of the availability and use of present supplies and the resulting effect upon the water supply of lower major units [i.e., the Rio Grande Project and beyond to Ft. Quitman]"[185]

The compact negotiations of the 1930s neither engaged with the issue of groundwater on Rio Grande Project lands nor the specific nature of the project water supply. However, as discussed above, both engineering advisors for New Mexico and Texas, Bliss and Hill, and the federal engineering advisor, Debler, were familiar with the project, its diverse water supply, and the hydrology of the Elephant Butte-Ft. Quitman section. The commissioners themselves believed the compact protected the project with the federal representative S.O. Harper insisting that the compact garnered "all water to which Federal irrigation projects are entitled." This was water that as a matter of longstanding Reclamation policy and practice included surface, subsurface, tributary, and return flows – waters arising on project lands.[186]

Reclamation's broad conception of the Rio Grande Project water supply arose from the impulse to assure sufficient water for the project. Reclamation authorities leveraged New Mexico territorial law, which recognized a unique standing for the United States with regard to reclamation projects, to protect and support the project's development. The project's aim from the outset was to utilize as much of the Rio Grande's flow, surface and subsurface, for the benefit of lands in New Mexico and Texas. In due course, Reclamation recognized that water released from Elephant Butte and diverted to project lands could be and necessarily must be reused. Such waters – characterized as "return flow," "seepage," "waste water," and "drain water" – were

[185] *JIR*, 56, 59, and 62.

[186] S.O. Harper, Chairman, Rio Grande Compact Commission, to The Honorable, The Secretary of the Interior, Washington, D.C., Re: Rio Grande Compact, March 26, 1938, 2. ff. 032.1, Box No. 936, Entry 7, RG 115, NARA Denver.

captured in project drains. These waters, as New Mexico's engineering advisor John Bliss later found and explained to New Mexico State Engineer and Rio Grande Compact Commissioner Thomas McClure, intercepted basin groundwaters, joined with tributary flows before re-entering the river's channel, and ultimately supplied lands downstream within the project and (as discussed in Opinion IV) below the project. The engineers most involved in developing the compact thus knew and understood that the Rio Grande Project's water supply included more than the surface flow stored in Elephant Butte. Waters arising on project lands, including groundwater, tributary flows, and return flows, however defined, were as essential as storage waters to the project.

Opinion IV: Delivery of water by New Mexico to San Marcial, under the terms of the 1938 Rio Grande Compact, constituted the delivery of water to serve lands in Texas within the Rio Grande Project as well as downstream to Fort Quitman.

As discussed in Opinion III above, water released from Elephant Butte Reservoir and water arising on the Rio Grande Project was used and re-used throughout the project. Reclamation and other federal, state, and local authorities considered such waters part and parcel of the project's water supply. By the 1920s, these waters had also become important to several thousand acres of Rio Grande bottomlands that stretched downstream from the end of the project through Hudspeth County to Fort Quitman, an area historically known as the "Fort Hancock district." Under a Warren Act contract, in exchange for relinquishing claims to Rio Grande flow, Hudspeth county landowners – organized as Hudspeth County Conservation and Reclamation District No. 1 in 1923 – obtained the use of waters captured by Elephant Butte, used on project lands, and ultimately passed out of the project. This extra-project water supply figured into the technical studies leading to the 1938 compact, and thus formed part of the 790,000 af "normal release" from the federally-controlled Elephant Butte Reservoir that was apportioned to Texas for lands above Ft. Quitman by the compact. In an acknowledgement of federal control over the Rio Grande between Elephant Butte and Ft. Quitman, encompassing lands both within and without the Rio Grande Project, the compact commissioners eschewed a state-line delivery by New Mexico for Texas and instead made the delivery point for the Rio Grande water apportioned to Texas at San Marcial, above the federal reservoir.

Reclamation plans for the Rio Grande Project initially did not consider land beyond the El Paso Valley. As discussed in Opinion I above, the project's first supervising engineer, B.M. Hall, conceived of a project to water arid lands in southern New Mexico and the El Paso Valley in Texas. Reclamation subsequently executed contracts for the delivery of water to two local water users' associations, and later their successors, Elephant Butte Irrigation District (EBID) in New Mexico and El Paso County Water Improvement District No. 1 (EP #1). Reclamation's *Twelfth Annual Report* for 1912-1913 also plainly described that the project was to serve lands in the Palomas, Rincon, and Mesilla valleys in New Mexico, and the El Paso Valley in Texas.[187]

Nevertheless, as construction of the federal project advanced in the late 1910s, individual Hudspeth County landowners began diverting water that flowed down the Rio Grande from the project. Reclamation, in response, executed annual rental contracts with these water users to deliver water into the Rio Grande "at the end of the project limits where four private and community ditches have their heads." This was done, as project superintendent L.R. Fiock later

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[187] *Twelfth Annual Report*, 176.

explained, "under the theory that it was project developed water" – that is, having originated out of the project's water supply, as surface flow, drainage water, or return flow.[188]

By the early 1920s, according to one Reclamation estimate, this surplus water irrigated more than 10,000 acres downstream of the project, and area landowners sought to obtain a still greater supply. In April 1923, they met with Reclamation director A.P. Davis during his visit to the El Paso Valley to discuss extension of the project's Tornillo Canal to serve their lands. The current Hudspeth-area diversion works were insufficient for taking water from the Rio Grande unless there was "a very large excess flow." Davis, although concerned that additional project releases would encourage Mexican diversions on the opposite side of the river that would diminish the project water supply, was sympathetic to the Hudspeth landowners. Observing that their irrigated lands were "mainly in large holdings" and there was "no organization…thru which to act," the director suggested the formation of a separate "irrigation district" and subdivision of agricultural holdings so as to conform with federal reclamation law. Davis also charged project officials to investigate the cost of extending Tornillo Canal, but he made no commitment to encumber government funds to do so. He further cautioned Acting Director F. E. Weymouth that any renewal of the surplus water contracts must contain "proper provision protecting the Government against adverse diversion, and against initiating a right to permanent water supply. However, as Rio Grande project manager L.M. Lawson recalled afterwards, Davis was of the opinion that "surplus waters recovered at the end of the project" would probably "take care of lands now under cultivation."[189]

Hudspeth-area landowners acted quickly following their meeting with Davis. In August, they organized their own water district, Hudspeth County Conservation and Reclamation District No. 1 (HCCRD #1). That same month, the district's new president W.T. Young addressed petitions to both the secretary of the interior and EP #1 seeking to join the project through consolidation with the El Paso district.[190]

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[188] Memorandum, From: Project Manager [L.M. Lawson], To: Chief Engineer, Denver, Colorado, Subject: Disposition of Surplus Water – Rio Grande Project, April 28, 1923. Folder 303. Rio Grande Project. Petitions for Construction, Fort Hancock. THRU 1929, Box 919, Rio Grande 301.4—303; L.R. Fiock, Superintendent to Commissioner, Subject: Protest of Hudspeth County Conservation and Reclamation District No. 1 – Rio Grande Project, May 22, 1939, 1-2. ff. 301 Rio Grande Project - Board and Engineering Report on Construction Features, Jan 1, 1937, Box 927 Rio Grande Pro. 246. - 301., Entry 7, RG 115, NARA Denver.

[189] A.P. Davis, Director, to F.E. Weymouth, Acting Director, Reclamation Service, April 21, 1923; and Memorandum, From: Project Manager, To: Chief Engineer, April 28, 1923. Folder 303, Box 919, Entry 7, RG 115, NARA Denver.

[190] W.T. Young, President, Hudspeth County Conservation and Reclamation District No. 1, To the Honorable, The Secretary of the Interior, August 16, 1923; and W.T. Young, President, Hudspeth County

EBID and EP #1 were wary about the addition of these downstream lands to the project. Their concerns were similar to those articulated by Davis, that the project water supply would prove insufficient to irrigate land down to Ft. Quitman. EP #1 manager Roland Harwell, although like Davis sympathetic to Hudspeth landowners, consequently declined to accept the district's petition citing the need for "the consent of the Secretary of the Interior."[191]

Lawson, however, believed that efforts could be made to improve the water available to lands downstream without incorporating those lands into the project. Having received a forwarded copy of Harwell's reply to Young, the Rio Grande project manager observed in his own letter to the EP #1 manager that "recovered water from the Juarez and El Paso valleys below the International Dam [which turned water released from Elephant Butte into Mexico] if properly collected, would probably supply irrigation demands for the area now in cultivation in the Fort Hancock district." Additionally, given that current "methods employed by the Fort Hancock area in obtaining their water supply are entirely inadequate and wasteful," Lawson favored those area landowners undertaking "such construction work as will place them in a position to receive the beneficial use of such water as is available in the Rio Grande at the upper end of the area." Such an effort would leverage "the recently constructed intake works near Fabens for the [Rio Grande Project's] Tornillo Main Canal, which intake has the advantage of full river control," and would provide "for the collection of the lower project's recovered water and the delivery of this supply undiminished by river losses and unauthorized diversion to the Fort Hancock area." The Rio Grande Project manager also favored continuation of the delivery of such water to Hudspeth-area landowners on an annual contract basis "with the particular understanding that the quantity furnished is on a surplus basis and subject to prior project demands."[192]

Lawson had made substantially the same suggestions in a memorandum to Reclamation Chief Engineer F.E. Weymouth back in August 1923, and in October, Weymouth furnished his endorsement. At the same time, the chief engineer noted the need for the approval of EBID and EP #1, and advised against a proposed plan for downstream landowners to pay for the canal

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Conservation and Reclamation District No. 1, To the President and Board of Directors of El Paso County Water Improvement District No. 1, August 18, 1923. Folder 303, Box 919, Entry 7, RG 115, NARA Denver.

[191] H.H. Brook, President & Manager, to Hon. D.W. Davis, US Bureau of Reclamation, August 23, 1923. Folder 303, Box 919; Brook to Fiock, Acting Project Manager, US Bureau of Reclamation, August 8, 1923; Roland Harwell, El Paso Co. Water Imp. Dist. No. 1, to Mr. L.M. Lawson, Project Manager, September 19, 1923. Folder 222, Box 902; El Paso Co. Water Imp. Dist. No. 1, By (SGD) Harwell, Manager to Mr. W.T. Young, President, Hudspeth Co. Conservation & Reclamation Dist No. 1, September 19, 1923. Folder 303, Box 919, Entry 7, RG 115, NARA Denver.

[192] L.M. Lawson, Project Manager to Mr. Roland Harwell, Manager, El Paso County Water Improvement District No. 1, Subject: Water Supply for Fort Hancock Lands – Rio Grande Project, September 21, 1923. Folder 303., Rio Grande Project. Petitions for Construction, Fort Hancock. THRU 1929, Box 919 Rio Grande 301.4--303, Entry 7, RG 115, NARA Denver.

extension itself and thereby obtain an ownership interest and a legal claim to its use. Weymouth expressly cautioned that "no water can be turn out of the Elephant Butte Storage for its [Hudspeth's] benefit."[193]

Reclamation Commissioner D.W. Davis approved of the plan in November, and after obtaining an assurance that it could enter into a temporary contract for "such waste water as would be available at the end of the Tornillo Canal," HCCRD #1 agreed to the proposal. Financed through a bond issue of $750,000, the district subsequently built a main canal with distribution laterals as well as a deep-well pump drainage system that was later replaced by an open drain system. In August 1924, Hudspeth executed a temporary contract which provided for the diversion of water from the river below the Rio Grande Project, as Fiock later reported, "through several private or community ditch headings which existed before the organization and development as a District."[194]

With the completion of the extension of Tornillo Canal, HCCRD #1 entered into a Warren Act contract with Reclamation in December 1924. Passed by Congress in 1911, the Warren Act authorized Reclamation to contract for impoundment, storage, or conveyance of non-project irrigation water in federal facilities, when excess waste was available. The Hudspeth district's Warren Act contract permitted the district to purchase waste or other excess water available at the end of the Tornillo Canal, the last major project irrigation structure, but it did not expressly guarantee any quantity of water to the district. According to Fiock, the canal was to supply those lands between Fabens and Ft. Quitman with "such waste, return flow and developed water as was considered might be available at the lower end of the project." It further defined the water delivered as "secondary and inferior to the right to use water for any purposed on the lands of the Rio Grande Federal Irrigation Project." In executing the contract, HCCRD #1 "relinquish[ed] any and all right, title, interest, and claim to any and all waters of the Rio Grande, except…as provided" by the contract. Both EBID and EP #1 acquiesced to the canal's construction, and paid for its construction. The two project districts viewed the arrangement with downstream

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193 Memorandum, From: Project Manager [L.M. Lawson], To: Chief Engineer, Denver, Colorado, Subject: Disposition of Surplus Water – Rio Grande Project, August 23, 1923; and Memorandum, From: Chief Engineer [F.E. Weymouth], To: Commissioner, Subject: Petition of the Hudspeth County Conservation and Reclamation District No. 1 – Rio Grande Project, October 29, 1923. Folder 303., Rio Grande Project. Petitions for Construction, Fort Hancock. THRU 1929, Box 919, Rio Grande 301.4--303, Entry 7, RG 115, NARA Denver.

194 Memorandum, From: Commissioner [D.W. Davis], To: Chief Engineer, Subject: Petition of the Hudspeth County Conservation and Reclamation District No. 1 – Rio Grande Project, November 6, 1923. Folder 303., Rio Grande Project. Petitions for Construction, Fort Hancock. THRU 1929, Box 919 Rio Grande 301.4—303; and Fiock to Commissioner, May 22, 1939, 1. ff. 301, Box 927, Entry 7, RG 115, NARA Denver.

landowners as not only defraying their own project expenses, but also ensuring "beneficial use of such water [i.e., available waste, return flow, and developed water] at the end of the project.[195]

Starting with the 1925 irrigation season, water was delivered to land in Hudspeth County through the Tornillo Canal. The water supplied, however, remained inadequate. Both the Tornillo Canal and the Hudspeth district's own main canal lacked the capacity to deliver all the water required for irrigable lands downstream of the project. Moreover, the amount of water within the Tornillo Canal available for diversion was limited to that which passed through unused by the Rio Grande Project above. HCCRD #1 had to supplement its supply by diverting directly from the Rio Grande below the end of the Tornillo Canal. This water, although not part of the supply to be delivered when available pursuant to the Warren Act contract, nonetheless consisted of project drainage water (from drains emptying below Tornillo Canal) and surplus water in the river that had not been diverted into the Tornillo Canal yet had passed through the project. The latter occurred typically when the water in the river exceeded the capacity of the Tornillo Canal at its heading.[196]

That any water was available to Hudspeth County lands through Tornillo Canal was the result of project operations intended to supply the Tornillo district of the Rio Grande Project with water of sufficient quality (as noted in Opinion II above). This district was the last unit of the project, the furthest downstream. According to Fiock, a "50-50 mixture of upper valley irrigation water and the drain water discharging immediately above Fabens" was necessary to dilute the alkali in the water reaching this area, so Reclamation endeavored "to carry enough of the reservoir released water on through to Fabens" so that it could be "mixed with the drain water discharging immediately above Fabens." This, consequently,

> produced a total discharge at Fabens about equal to the capacity of the Tornillo Canal, or more than twice the amount necessary for the irrigation requirements of the Tornillo area alone, thus making available water for delivery to the heading of the Hudspeth District Canal at the terminus of the Tornillo Canal.

Moreover, when the amount of water – "a mixture of drain and upper valley irrigation water" – reaching Fabens exceeded "the capacity or requirements of the Tornillo Canal…[it] has been allowed to go on down the river." This was particularly true during the fall, winter, and early spring irrigations, which required "as much of the upper valley irrigation water supply reaching Fabens in order to accomplish the dilution of drain water." "[A] large part of the mixed water"

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[195] C.M. Newman to Dr. Elwood Mead, April 19, 1924. Folder 303., Rio Grande Project. Petitions for Construction, Fort Hancock. THRU 1929, Box 919, Rio Grande 301.4—303, Project Files, 1919-1929, General Administrative and Project Records, 1919-1945; and Fiock to Commissioner, May 22, 1939, 2-3. ff. 301, Box 927, Entry 7, RG 115, NARA Denver.
[196] Fiock to Commissioner, May 22, 1939, 3. ff. 301, Box 927, Entry 7, RG 115, NARA Denver.

thus went "to waste" below the project and became available to lands downstream, between Fabens and Ft. Quitman.[197]

In the negotiations leading to the 1929 temporary compact, the water received by Hudspeth County lands was a focus of discussion. Various parties maintained that this water had to be considered in drafting a compact that would equitably apportion the waters of the Rio Grande above Ft Quitman. Major Richard Burges, an El Paso attorney who represented EP #1, HCCRD #1, and the City of El Paso, established the geographic boundaries for the commission's consideration at the first compact commission meeting in October 1924. Burges was deeply interested in a compact as lands in both El Paso and Hudspeth counties depended upon Rio Grande water. As no representative for Texas had yet been selected, he attended the meeting with Texas Governor Pat Neff's blessing. Burges stressed to the Colorado and New Mexico commissioners, Delph Carpenter and Julian O. Seth, respectively, that "the problem of the Rio Grande, as it affects the state of Texas," principally concerned "the El Paso Valley, which includes the irrigable lands in El Paso County and Hudspeth County." This was a point of view that Carpenter heartily accepted and Seth was willing to entertain once a Texas commissioner was formally appointed.[198]

Burges reiterated this stance in December 1928 after T.H. McGregor had been appointed the commissioner for Texas. Serving as special counsel, he delivered at McGregor's request Texas's opening statement, and in that statement, he made clear that Texas claimed not only "its rights under the federal Rio Grande Project" but also waters for some 20,000 acres between the project and Fort Quitman that was "under successful cultivation today by irrigation" – land in Hudspeth County.[199]

For Colorado, excess water beyond the project, the water for Hudspeth that Burges identified, was objectionable. Provided the state secured its own water project for San Luis Valley, however, that water could be tolerated. Corlett, for instance, complained that the "return water" received by Hudspeth lands "would some three or four times supply all of the water that was conceded to Mexico" yet was denied Colorado. Colorado's engineering advisor R.I. Meeker, supported Corlett's contention in his presentation to the commission, noting "that there are large wastes passing the lower end of the Rio Grande Project at Fort Quitman," and among the beneficiaries

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[197] Fiock to Commissioner, May 22, 1939, 4. ff. 301, Box 927, Entry 7, RG 115, NARA Denver.

[198] First Meeting, Rio Grande River Compact Commission, Breadmoor Hotel, Colorado Springs, Colo., Sunday, October 26, 1924, 3-4, 9-12, and 24-25. Folder 1, Box 02-D.003:1, MS 0235, RGHC, NMSU Spec. Coll.

[199] Proceedings of Rio Grande Compact Commission, Held December 19-20-21, 1928, At Santa Fe, New Mexico, 13. Folder Rio Grande Compact Commission Records, 1924-1941, 1970, Richard F. Burges Papers, Proceedings of Rio Grande Compact Conference Held Dec. 19-20-21, 1928 at Santa Fe, N.M., Box 2F471, RGCCR, 1924-1941, 1970, UTA.

of this water was land in Hudspeth County. Nevertheless, in calculating an equitable quantity for Texas that made possible development of Colorado's San Luis Valley, Meeker included the water received by land downstream of the project along with the water demands of lands within the Rio Grande Project and the obligations to Mexico under the 1906 treaty, even though the water diverted by Hudspeth landowners was "junior in every respect."[200]

Harwell likewise sought to condition the rights of landowners downstream of the project before the commission, although he did not dismiss the fact that those in Hudspeth obtained water via the project and would in the future. He explained that "the Hudspeth District is entitled to no more water than the surplus waters which may exist at the Tornillo canal." Put another way, "Hudspeth District was entitled to receive no more water from the project than this unavoidable waste which is bound to occur through this 150 miles of operation between the dam [Elephant Butte] and the point of lowest delivery." Any additional water that Hudspeth landowners could obtain, according to Harwell, would be "by their own pumping operations for drainage…putting to use water which would otherwise be put to use in the stream bed by them or anyone else interested." He believed that with increased efficiencies in water use by the project and its completion to serve the full irrigable acres within the project, future water use downstream of the project would be "limited to… [that] which can be called legitimately unavoidable waste."[201]

The temporary compact of 1929 did not specifically address the relative water needs of the three states, save to endorse federal construction of a "closed basin drain" and "State line reservoir" in Colorado. Nevertheless, as noted above, Article XII acknowledged the importance of Elephant Butte Reservoir to lands below, lands that as the federal project was operated included lands in Hudspeth, and attempted to safeguard the reservoir's water supply:

> New Mexico agrees with Texas with the understanding that prior vested rights above and below Elephant Butte Reservoir shall never be impaired hereby, that she will not cause or suffer the water supply of the Elephant Butte Reservoir to be impaired by new or increased diversions or storage within the limits of New Mexico unless and until such

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[200] Proceedings of Rio Grande Compact Commission…December 19-20-21, 17, 37-38, 40-41, and 43. Folder Rio Grande Compact Commission Records, 1924-1941, 1970, Richard F. Burges Papers, Proceedings of Rio Grande Compact Conference Held Dec. 19-20-21, 1928 at Santa Fe, N.M., Box 2F471, RGCCR, 1924-1941, 1970, UTA.

[201] Proceedings of Rio Grande Compact Commission…December 19-20-21, 1928, 52-58. Folder Rio Grande Compact Commission Records, 1924-1941, 1970, Richard F. Burges Papers, Proceedings of Rio Grande Compact Conference Held Dec. 19-20-21, 1928 at Santa Fe, N.M., Box 2F471, RGCCR, 1924-1941, 1970, UTA.

> depletion is offset by increase of drainage waters [i.e., through development of Colorado's Closed Basin].[202]

The water supply and needs of the lands between Fabens and Ft. Quitman were more specifically analyzed and considered in 1930s as Colorado, New Mexico, and Texas sought to arrive at a permanent compact.[203] As first discussed in Opinion I, critical to the development of the compact was the federal Rio Grande Joint Investigation of the National Resources Committee. This investigation provided much of the technical data for the drafting of the compact. Endeavoring to scope that work for the Rio Grande Compact Commission in December 1935, University of Chicago historical geographer Harlan H. Barrows and agricultural economist Frank Adams, both with NRC, suggested confining the study to "the water resources and irrigable and irrigated lands of the Rio Grande Basin above El Paso." Colorado, however, insisted that any investigation "should include the area between El Paso and Ft. Quitman" – an area inclusive of Hudspeth County – as the "duties of the Rio Grande Compact Commission relate to that area of the Rio

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[202] Francis C. Wilson, Rio Grande Compact Commissioner, *Rio Grande Compact: Report of Commissioner for New Mexico and Memorandum of Law on Interstate Compacts on Interstate Streams* 2/19/29, 9. ff. 032.1, Rio Grande Basin. Water Rights: Rio Grande Compact. THRU 1929., Box 924 Rio Grande Basin 023.--032.02, Entry 7, RG 115, NARA Denver.

[203] There is some historical evidence that water users downstream of the Rio Grande Project did not figure into the compact negotiations of the 1930s. In the early 1950s, EP#1 retained Raymond Hill as a technical expert in a lawsuit filed in US District Court for the Western District of Texas, El Paso Division, by HCCRD #1. HCCRD #1 sued several parties, including EP#1, over the availability of water in the Rio Grande for appropriation. The district insisted that the construction of Caballo Reservoir had increased the water supply in the basin. EP #1, however, argued that despite Caballo's construction there was no water to be appropriated from the river; the federal Rio Grande Project had already fully appropriated the stream. Hill, Texas's engineering advisor, was called upon to submit an affidavit supporting this position. According that document, signed and dated by Hill on January 20, 1953 (but stamped as received on January 19), he

> participated in the negotiation of the Rio Grande Compact and particularly in the negotiations conducted by the engineers representing the Federal Government and the several States. At no time in such negotiations were the needs of the Hudspeth County Conservation and Reclamation District No. 1 in Texas considered. On the contrary, the representatives of Colorado and New Mexico consistently and emphatically refused to consider any rights or uses of water in the Hudspeth District.

In the United States District Court, for the Western District of Texas, El Paso Division, *Hudspeth County Conservation and Reclamation District No. 1, et al., Plaintiffs v. Howard E. Robbins, et al, Defendants*, Civil Action No. 1342, Affidavit of Raymond A. Hill in Support of Defendants' Cross-motion for Summary Judgment, January 20, 1953. ff. El Paso County Water Impr. Dist. No. 1 a/c Hudspeth CCRD No. 1 G3330, Box 4X189, RAHP, UTA. This single statement stands in stark contrast to a larger body of evidence discussed in this opinion that indicates that downstream water users were a consideration in the negotiations.

Grande Valley above Ft. Quitman." After some deliberation, the commission adopted a resolution that identified the study area as "the Rio Grande Basin above Ft. Quitman."[204]

The reliance of downstream water users on Rio Grande project water was also noted and intended to be a focal point in Texas's suit against New Mexico and the Middle Rio Grande Conservancy District before the US Supreme Court. In testimony before Special Master Charles Warren in November 1936, Fiock explained that under current operations Hudspeth received the waste water from the project, below the Tornillo district. By December 1936, with the hearings continuing, Frank Clayton, who was not only Texas's attorney in its original action and the state's Rio Grande Compact Commissioner but also the attorney for HCCRD #1, sought to demonstrate "that millions of dollars were added to tax valuations in Hudspeth County as a result of irrigation development under this project, commencing about 1918 and reaching its culmination about 1928."[205]

This information was apparently not introduced before Warren (as noted in Opinion I above) placed the proceedings on hold to enable the Rio Grande Joint Investigation to complete its work. Delayed by several months, a copy of the investigation's report, the *JIR*, was distributed to the compact commission in September 1937. In presenting the *JIR*, Barrows expressed his belief "that the report provides a basis, a factual basis, for an allocation of the waters of the river above Ft. Quitman that would be fair and just to each of the three states and to its citizens [*sic*] dependent upon the river."[206]

The *JIR* recognized the dependence of lands downstream of the project on the water captured, stored, and released from the Rio Grande Project's Elephant Butte Reservoir. It specifically included HCCRD #1's current water needs in its assessment of the available diversions necessary from the reservoir to supply the stretch of the Rio Grande between the reservoir and Ft Quitman. The investigation was truly a series of studies of the Upper Rio Grande Basin, undertaken by federal agencies that included Reclamation as well as the USGS and the US Department of Agriculture's Bureau of Agricultural Engineering. The summary report produced by the investigation noted that the Hudspeth district was located within the Elephant Butte-Fort Quitman section of the basin, and "maintenance of an adequate water supply for irrigation" of its lands and "maintaining satisfactory control of salinity" were both major problems. The latter

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[204] Proceedings of the Rio Grande Compact…December 2-3, 1935, 24-43. ff. 032.1 (2/3), Box 1326, Entry 7, RG 115, NARA Denver.
[205] *Plaintiff's Case in Chief*, Vol. I, II, 399-406. CB-F-171A thru CB-F-1716: Transcripts of TX v. NM, Vol. 1-16, 4X219, RAHP; and Frank B. Clayton, Rio Grande Compact Commissioner for Texas, to Milam H. Wright, Tax Assessor and Collector, December 1, 1936. [1936], Box 2F467, RGCC-FBCP, UTA.
[206] Proceedings of the Rio Grande Compact, Held in Santa Fe, New Mexico, September 27 to October 1, 1937, 5. Unnamed folder 5, Box 2F463, RGCC-FBCP, UTA.

issue of salinity, in particular, was "an important consideration" in assessing the section's needs. The summary acknowledged that the district received "return water" below the Tornillo Canal heading. This water was "a direct diversion of drainage and waste waters of the Rio Grande Project" under a Warren Act contract. The contract applied "only to the return water as it occurs in the normal operation of the Rio Grande Project and puts no obligation upon the latter for delivery of any specific amounts of water."[207]

The report of the USDA Bureau of Agricultural Engineering specifically recognized the vital importance of this water for Hudspeth. It noted the "drain and tail water from the El Paso Valley system [of the project] becomes the irrigation supply for most of the remaining valley lands above Fort Quitman." Diversions to Hudspeth County lands were thus factored into the investigation's calculation of net diversion and stream-flow depletion between 1930 and 1936 for the Elephant Butte-Fort Quitman section. These diversions formed an essential part of the "necessary allowances for drain flow, wastes, arroyo inflow, and salinity control to derive the required diversion demand on Elephant Butte Reservoir." That diversion demand amounted to 736,000 af, but given the acres "actually irrigated" in the late 1920s into the early 1930s, 773,000 af was recommended to "be used as conservative estimate."[208]

As discussed in Opinion II above, the need to ensure a water supply of sufficient quality through the project lands and downstream to Ft. Quitman was precisely the reason Texas insisted upon 800,000 af from Elephant Butte. For the remainder of the compact negotiations, although no designated representatives from Hudspeth addressed the proceedings, Clayton and Hill advocated for both for the Rio Grande Project and the entire Elephant Butte-to-Ft. Quitman stretch. Barrows also included Hudspeth in his call for a dependable supply of low-alkali water for lands above Ft. Quitman.

Drafting of the compact itself focused on the "present uses of water" in the Rio Grande Basin above Ft. Quitman, a geographical area that included lands in Hudspeth County. New Mexico's own engineering advisor, John Bliss, recognized that Hudspeth was a part of the demand on Elephant Butte. In his own calculations of that demand, presented during the December 1937 meetings, he estimated the need for these lands between the project and Ft. Quitman as 70,000 af. As discussed in Opinion I above, at the commission's direction, the engineering advisors collectively prepared a report suggesting the schedule of deliveries to be specified in the compact, and in doing so "avoided discussion of the relative rights of water users in the three

[207] *JIR*, 7, 12, 23, 49, 62, 74, and 85-86.
[208] *JIR*, 99, 103-104, and 403.

States," and instead sought to protect the "present uses of water in each of the three States…because the usable water supply is no more than sufficient to satisfy such needs."[209]

When New Mexico State Engineer and Rio Grande Compact Commissioner Thomas McClure challenged some of the engineers' recommendations, Clayton defended their work as safeguarding Texas's entitlements to the waters of the Rio Grande. He argued in a January 1938 letter to Harper that "in the protection of Texas' water supply that the report contains no recommendations for the benefit of Texas than what she is plainly entitled to." Texas's commissioner insisted that the engineers had developed "a fairly workable basis for the equitable apportionment of the waters of the Rio Grande, without permitting further encroachments upon Texas' already inadequate supply." Indeed, Texas was "unwilling to recede from what we conceive to be the minimum requirements for the protection of Texas' water supply as embodied in the report."[210]

Texas eventually conceded to a lesser figure of 790,000 af, yet Clayton believed that he had secured the water to which all of the lands in Texas down to Ft. Quitman were entitled. As noted in Opinion II, after the conclusion of the compact negotiations, in a pamphlet "To Water Users Under The Rio Grande Compact," Clayton sought to reassure Texans anxious over the compact's provisions. The compact commissioner, the "engineering consultants who represented Texas in its lawsuit with New Mexico over the waters of the Rio Grande," and "the managers and attorneys of the Elephant Butte Irrigation District and the El Paso County Water Improvement District No. 1" were convinced "the Compact protects the water supply of users in New Mexico and Texas between Elephant Butte and Fort Quitman, and that it [the Compact] represents a fair and equitable solution of the controversy which has long existed between various interests in the three states." Clayton maintained that the compact "seeks primarily to protect vested uses of water above Fort Quitman, and guard them against future impairment, both as to quantity and quality." The commissioner explained further,

> Since the Rio Grande is essentially a torrential stream and its discharge varies widely from year to year, it is physically impossible to establish fixed and determinate deliveries into Elephant Butte Reservoir in terms of acre-feet per year. However, engineering

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[209] [Raymond Hill], "TEXAS COMPACT: John Bliss Estimate of Project Requirements at Elephant Butte," 12/17/37. CB-F-137-34, Box 4X215, RAHP, UTA; and "Report of Committee of Engineers to Rio Grande Compact Commissioners," December 27, 1937, in Proceedings of the Meeting of the Rio Grande Compact Commission…March 3rd to March 18th, inc., 1938, Appendix No. 1, 40. ff. 032.1, Box No. 936, Entry 7, RG 115, NARA Denver.

[210] Frank B. Clayton, Rio Grande Compact Commissioner for Texas, to Mr. S.O. Harper, Chairman, Rio Grande Compact Commission, January 27, 1938, in Proceedings of the Meeting of the Rio Grande Compact Commission…March 3rd to March 18th, inc., 1938, Appendix No. 3, 50-51. ff. 032.1, Box No. 936, Entry 7, RG 115, NARA Denver.

> investigation has shown that there have been in the past reasonably reliable relationships between the flow of the river and its tributaries above all principal points of diversion in Colorado and New Mexico, and at other points below all principal diversions in Colorado and New Mexico above Elephant Butte Reservoir. These relationships have been expressed in the Compact in tabular form, and this instrument imposes an obligation upon Colorado and New Mexico to maintain these schedules of relationship, regardless of any future development above the Rio Grande Project.

Colorado's obligation was to the Colorado-New Mexico state line (reflected in Article III), and New Mexico's was to San Marcial (reflected in Article IV). Clayton noted that the Compact established a debit-and-credit system, in recognition "that there will probably be departures from time to time from the schedules of relationship." A "definite limitation," however, existed on debits and credits "to insure a normal average release from the [Elephant Butte] Reservoir of 790,000 acre-feet of water per year, including the deliveries to Mexico."[211]

Clayton reiterated many of these same points at a May 1938 meeting of the Lower Rio Grande Water Users Association. Members of the association came from Cameron and Hidalgo counties, below Hudspeth County and Ft. Quitman. They were concerned that their water supply was not adequately protected by the compact. "From the legal standpoint," however, as Clayton explained, "our negotiations related to the division of the waters above Fort Quitman." Identifying the need to satisfy Mexican claims to water from the Rio Grande through the 1906 treaty as the essential background to the 1906 and 1908 filings made by Reclamation, he asserted that those filings were "for the purpose of impounding them in a storage dam [Elephant Butte] in the vicinity of Engle, New Mexico for the benefit of lands between that point and Fort Quitman" – not just for the lands within the project. He believed his "duty, as commissioner for Texas, [was] to see that Texas got every drop of water originating in Colorado and New Mexico that she was entitled to and to see that that water was delivered into the Elephant Butte Reservoir," and that he was successful: "By that compact Texas got all she is entitled to."[212]

Moreover, that water Texas received for its lands above Ft. Quitman was the same water that irrigated lands in New Mexico. "[A]s far as the Rio Grande project is concerned," Clayton told the attendees

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[211] Proceedings of the Meeting of the Rio Grande Compact Commission…March 3rd to March 18th, inc., 1938, 24. ff. 032.1, Box No. 936, Entry 7, RG 115, NARA Denver; and Frank B. Clayton, "To Water Users Under The Rio Grande Project," El Paso, Texas, March 25, 1938. Folder 1, Memos of Interior Department, 1913-1915, Box 14, APDP 1896-1952, AHC.

[212] *Proceedings of Meeting Held on Friday, May 27, 1938 at El Paso, Texas, between Representative of Lower Rio Grande Water Users and Representatives of Irrigation Districts Under the Rio Grande Project of the Bureau of Reclamation*, 10. ff. Proceedings and Minutes 1935-1938, Box 2F463, RGCC-FBCP, UTA; and Littlefield*, Conflict on the Rio Grande*, 209-210.

> the interests of the Elephant Butte District, in New Mexico, and the districts in Texas above Fort Quitman are common interests ... and because our interests are common we determined long ago that no satisfactory, practical, legal, or engineering way could be devised by which the waters could be allocated between these districts at the Texas line. As far as they and we are concerned, our source is the same. If the supply is impaired above Elephant Butte, we all suffer alike.[213]

Harwell also tried to clarify matters for the association. In the process, he emphasized both Reclamation's control over the waters that entered Elephant Butte Reservoir, and the dependence of lands downstream of the project on releases from the federal reservoir. The EP #1 manager stressed that while the water supply below Ft. Quitman was "wholly without our control," the "supply of water at the end of this project [i.e., the Rio Grande Project]...will be substantially as it has been in the past." He acknowledged that there would be "a certain amount of operating water and a certain amount of summer runoff" entering the river "entirely beyond our control." Roughly 16,000 acres of land in Hudspeth County benefitted from the water passed beyond the project; these lands were irrigated "in part by surplus waters which we [EP #1] deliver into their canal for a consideration, and in part by diversion from the river." Harwell went on to invoke the argument that Hill had made for water quality: "it is necessary to pass excess amounts of water in order to maintain the salt balance." Lands below the project and above Ft. Quitman were the beneficiaries of this operational necessity.[214]

Following the meeting with the Lower Rio Grande Water Users Association, Clayton yet again emphasized that Texas obtained all that it was entitled from the compact negotiations in an August 1938 letter to Homer L. Leonard, a state representative from McAllen on the lower Rio Grande. The compact commissioner sought to secure Leonard's support for ratification of the compact in the face of opposition from his constituents. "It was the opinion," Clayton explained, "of every one of the Texas representatives attending the meeting that by the Compact Texas secured all that she was entitled to, and, indeed, all that could physically be delivered to her." He acknowledged that the "upper and lower water users in Texas" differed "as to whether the districts under the Rio Grande Project were obligated to deliver any water past Fort Quitman and if so, the amount." Clayton and the rest of the Texas delegation to the compact proceedings nonetheless believed this "was a matter of internal negotiation" and raising before the Colorado and New Mexico commissioners and their advisors "would gravely prejudice our case and

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[213] *Proceedings of Meeting, held on Friday, May 27, 1938*, 11. ff. Proceedings and Minutes 1935-1938, Box 2F463, RGCC-FBCP, UTA.

[214] *Proceedings of Meeting, held on Friday, May 27, 1938*, 16, 17, and 25. ff. Proceedings and Minutes 1935-1938, Box 2F463, RGCC-FBCP, UTA.

perhaps result in the collapse of the negotiations." "Obviously," he attempted to reassure Leonard,

> Colorado and New Mexico could not be asked to guarantee that any certain quantity of water would be delivered to any particular locality in Texas. Their only responsibility was to see that Texas' equitable share was delivered at the state line, or, rather, delivered into Elephant Butte reservoir, which is the point of control.[215]

Federal control of Elephant Butte Reservoir as well as the water needs served by releases from the reservoir were two essential points that Clayton also stressed to attorney Sawnie B. Smith in October 1938. Smith had been hired by lower Rio Grande water users to file suit to stop ratification of the compact. In a letter to Clayton in late September 1938, he questioned the absence of provisions in the signed-yet-unratified compact concerning the "division of waters below Elephant Butte between the States of New Mexico and Texas" and "the amount of water to which Texas is entitled." Smith could "not find anything in the compact…which ties down and limits the use or division of the waters according to present usage and physical conditions, and nothing that would prevent controversy between the two States in the future regarding the division of the waters between the two States." "This omission," the attorney bluntly wrote, "is too obvious to have been inadvertent, and therefore unquestionably, the Commissioners had what they considered valid reason for it." On behalf of his clients, Smith asked for that reason.[216]

Writing back to Smith, Clayton insisted that New Mexico's delivery of water above Elephant Butte constituted the delivery of water to Texas and that all of the releases from Elephant Butte made in the course of federal project operations served requirements below the dam down to Ft. Quitman. As far back as the negotiations for the temporary compact, the commissioner noted, Elephant Butte had been the focus for deliveries to Texas. The parties had, in Clayton's words, "decided…that New Mexico's obligations as expressed in the compact must be with reference to deliveries at Elephant Butte reservoir, and this provision was inserted in the temporary compact [i.e., Article XII of the temporary compact]." He insisted that that the "reasons" for this were "numerous," and "the obstacles in the way of providing for any fixed flow at the Texas were considered insuperable." Clayton drew specific attention to federal operational control of Elephant Butte and the flow of the water through the project's canals and down the river itself:

> The Rio Grande Project, as you know, is operated as an administrative unit by the Bureau of Reclamation, and the dam and releases from the reservoir are controlled by the Bureau and will continue to be at least until the federal government is repaid its investment, and

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[215] Frank B. Clayton, Rio Grande Compact Commissioner for Texas, to Hon. Homer L. Leonard, August 3, 1938, 2. Box 2F466, RGCC-FBCP, UTA.

[216] Sawnie B. Smith to Mr. Frank B. Clayton, Rio Grande Compact Commissioner for Texas, September 29, 1938. Box 2F466, RGCC-FBCP, UTA.

> very probably even beyond that time. Obviously, neither Colorado nor New Mexico could be expected to guarantee any fixed deliveries at the Texas line when the operation of the dam is not within their control but is in control of an independent government agency.
>
> Moreover, measurements of the water passing the Texas state line would be very difficult and expensive, if not impossible. This, for the reason that irrigation canals, ditches and laterals cross the line, which is of a very irregular contour, at many different points, carrying water in addition to what is carries in the river itself, and it would require continual measurements in these various channels to make any reasonably accurate computations of the total flow.

Texas's commissioner nevertheless indicated that federal management of Elephant Butte facilitated ultimate delivery of the Rio Grande water allocated to Texas above Ft. Quitman. Clayton observed that lands below Elephant Butte Reservoir received water through project operations by either contract or treaty – lands in New Mexico in EBID; lands in El Paso County, in EP #1; lands in Hudspeth County in HCCRD #1; and lands in Mexico. Contractual arrangements between the two project districts, EBID and EP #1, established the irrigable acreages in each, and Clayton expressed his conviction "that there will never by any difficulty about the allocation of this water" as a result.[217] As for the "lands above Fort Quitman and below the Rio Grande Project," the commissioner observed, they

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[217] According to Clayton, under "contracts between the districts under the Rio Grande Project [i.e., EBID and EP#1] and the Bureau of Reclamation…the lands within the Project have equal water rights, and the water is allocated according to the areas involved in the two States." "By virtue of the contract recently executed" – the so-called interdistrict agreement of February 16, 1938 – he explained to Smith,

> the total area is "frozen" at the figure representing the acreage now actually in cultivation: approximately 88,000 acres for the Elephant Butte Irrigation District, and 67,000 for the El Paso County Water Improvement District No. 1, with a "cushion" of three per cent. [*sic*] for each figure.

This "arrangement," Clayton acknowledged, was "of course a private one between the districts involved, and for that reason it was felt neither necessary nor desirable that it be incorporated in the terms of the Compact."

Historian Douglas Littlefield argues that the interdistrict agreement "rendered irrelevant" a New Mexico-Texas state line delivery. Characterizing the congressional authorization of the Rio Grande Project in 1905 as providing for a de facto "allocation" of water between New Mexico and Texas, he contends that the agreement "verified the Bureau of Reclamation's determination that the maximum irrigable acreage of the Elephant Butte Irrigation District was 88,000 acres and that of El Paso County Water Improvement District No. 1 was 67,000 acres." Littlefield, *Conflict on the Rio Grande*, 203 and 207.

The agreement was nonetheless "private" as Clayton recognized. While it was given Interior Department approval, the agreement was executed solely by the two districts, and it was concerned with the allocation of costs for the Rio Grande Project. Federal law obligated project water users to repay the costs incurred by the United States in building, operating, and maintaining a reclamation project. The original 1906 joint construction contract between EBWUA and EPVWUA, and the United States had specified "ten equal annual payments," "apportioned equally per acre among those acquiring such rights [i.e., the water users]." In 1918 and 1920, following the dissolution of the water users' associations and

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their reconstitution as quasi-municipal entities with the power to tax individual members, new contracts were drafted that made irrigated acreage the basis for allocating shared projects costs between EBID and EP#1, respectively. Eight years later, in the summer of 1928, at the insistence of the water users and at the direction of Congress, the Interior Department extended the repayment schedule for the districts but retained acreage as the basis for repayments. See Construction Contract of Rio Grande Project, 6/27/06, section 4, page 4. ff. 430-A, Rio Grande Project. Joint Contract with Two Water Users Ass'ns, Box 818 Rio Grande 430- -430A, Entry 7; Department of the Interior, Bureau of Reclamation, Rio Grande Project-New Mexico-Texas, Contract Dated June 15, 1918 – between The United States of America and The Elephant Butte Irrigation For Repayment of Construction and Operation and Maintenance Charges, Article 6, Article 8, and Article 10; Department of the Interior, Bureau of Reclamation, Rio Grande Project-New Mexico-Texas, Contract Dated January 17, 1920 between The United States of America and The El Paso County Water Improvement District No. 1, For Repayment of Construction and Operation and Maintenance Charges, Article 7, Article 8, and Article 9, in Department of the Interior, Bureau of Reclamation, Rio Grande Irrigation Project, New Mexico-Texas, Contracts with Water User's Organizations (Copies), Compiled November 1, 1929. 232-29 RG Separate Folder, 249-H, Contracts with Water Users, Box 716 Old Box 509-510, Code 104.RG 37 through Code 402.RG 28, Engineering and Research Center, Project Reports, 1910-55, RG 115, NARA Denver; and *An Act Extending the time of construction payments on the Rio Grande Federal irrigation project, New Mexico-Texas*, May 28, 1928, chap. 815, 45 Stat. 785.

In early February 1929, facing the prospect of constructing additional drainage works for EP #1, Reclamation Chief Engineer R.F. Walter sought to determine more precisely the districts' respective obligations. He met with acting Rio Grande Project superintendent L.R. Fiock and EP #1 manager Roland Harwell; neither EBID's president nor its manager was able to appear but they made their opinions known. Harwell insisted that his district "wished to pay on 67,000 acres," with the caveat that nearly 2,000 acres currently in need of "river rectification or other work not provided by the district contract be delayed a reasonable length of time to permit such work being done by the land owners." As for EBID, its president "informally advised that 88,000 acres was desired by the district," and its manager telegrammed the same to Walter. Satisfied, federal reclamation officials agreed to a distribution of costs on the basis of these acreages: 88,000 acres for EBID and 67,000 acres for EP #1. Before a formal arrangement could be made, however, the global financial collapse precipitated by the US stock market crash of October 1929 cast into doubt the ability of any federal reclamation project's water users to meet their repayment obligations. See Elephant Butte Irrigation District, B.P. Fleming, Manager, telegram to R. F. Walter, Chief Engineer, Bureau of Reclamation, Feb. 16, 1929; Memorandum, From: Chief Engineer, To: Commissioner, Subject: Determination of irrigable acreage and total construction liability of the irrigation districts – Rio Grande Project, February 18, 1929. ff. 301. Rio Grande, Board & Engineering Reports on Construction Features, Oct. 1926 thru July 1929, Transfer Case, Box 913 Rio Grande 241.27—301; and Memorandum, From: Commissioner, To: Chief Engineer, Denver, Colo., Subject: Determination of irrigable acreage and total construction liability of the irrigation districts – Rio Grande Project, March 16, 1929. ff. 330. Rio Grande Project, Corres re Drainage of Seeped Lands. Thru December 31, 1928, Transfer Case, Box No. 921 Rio Grande 322.--430., Entry 7, RG 115, NARA Denver; and Donald J. Pisani, *Water and American Government: The Reclamation Bureau, National Water Policy, and the West, 1902-1935* (Berkeley: University of California Press, 2002), 149.

Congress twice extended the schedule for EBID and EP#1's repayments in the early 1930s, permitting continued deferment, and through 1936 both districts availed themselves of this opportunity. Execution of "adjustment contracts" in 1937, in which the districts relinquished their rights to hydroelectric power revenue at the newly-constructed Caballo Dam below Elephant Butte, reduced their obligations – but the allocation of repayment costs between the two districts remained outstanding. *An*

> receive only 'tail-end' or waste water, the land in the Hudspeth County district taking it water by virtue of a contract and the lands privately owned below the district lower boundary only by taking by gravity or pumps what happens to be in the river channel.

This was the "unavoidable waste" from the project-irrigated valleys above.[218]

Additional evidence that New Mexico's delivery of water at San Marcial was the delivery of water to Texas may be found in an undated "Analysis of the Terms of the Compact," authored by New Mexico State Engineer and Rio Grande Compact Commissioner Thomas B. McClure. In the piece, which summarizes the compact, McClure agrees with the explanation offered by Clayton to Smith regarding the absence of a state-line delivery to Texas, analogous to the state-line delivery to New Mexico from Colorado. "The subdivision of the basin at San Marcial," he stated

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Act For the temporary relief of water users on irrigation projects constructed and operated under the reclamation law, April 1, 1932, 47 Stat. 75, chapter 94; *An Act To extend the operation of the Act entitled, "An Act For the temporary relief of water users on irrigation projects constructed and operated under the reclamation law," approved April 1, 1932*, March 3, 1933, 47 Stat. 1427, chapter 200; *Project History, Rio Grande Project, Calendar Year 1932*, 20; and *Project History, Rio Grande Project, Calendar Year 1933*, 16; *Project History, Rio Grande Project, Calendar Year 1934*, 16; *Project History, Rio Grande Project, Calendar Year 1935*, 16; *Project History, Rio Grande Project, Calendar Year 1936*, 15. USBR PHRGP 1912-1988 (mf); Department of the Interior, Bureau of Reclamation, Contract Dated Nov. 9, 1937, Ilr-982, Elephant Butte Irrigation District (Adjustment of project construction charges and other purposes). ff. 222.- Rio Grande Project. Contracts with Elephant Butte Irrigation District, Separate Folder, Box No. 917, Rio Grande Pro. 222._222.-; Department of the Interior, Bureau of Reclamation, Contract Dated Nov. 10, 1937, Ilr-981, El Paso County Water Improvement District No. 1 (Adjustment of project construction charges and other purposes). ff. 222.- Rio Grande Project. Irrigation Districts, El Paso County Water Improvement District No. 1, Separate Folder, Box No. 918 Rio Grande Pro. 222._222.-, Entry 7, RG 115, NARA-Denver.

Resolution of the cost apportionment question finally came with signing of the interdistrict agreement, six months of negotiations between the districts and Reclamation and Interior Department officials. The agreement memorialized the historical distribution of repayment costs for storage and general project features between EBID and EP#1 on the basis of the respective irrigated acreages that the districts themselves had committed to back in 1929 and which Reclamation agreed to serve in proportion to the available water supply: 88,000 acres in New Mexico, in EBID, and 67,000 acres in Texas, in EP #1. Contract between Elephant Butte Irrigation District of New Mexico and El Paso County Water Improvement District No. 1 of Texas, signed February 16, 1938, and approved by Assistant Secretary of the Interior Oscar L. Chapman, April 11, 1938. ff. 400. Rio Grande, Lands-General, 1930 thru, Box 932 Rio Grande Pro. 400.__400.08, Entry 7, RG 115, NARA Denver.

Whether the interdistrict agreement accomplished a de facto allocation of water between New Mexico and Texas as Littlefield maintains or was focused solely on the allocation of the cost of the federal project between the districts, this agreement, prior contracts between the federal government and EBID and EP #1, the Hudspeth Warren Act contract, and the 1906 Mexican treaty all underscore federal management and control over the waters delivered by New Mexico at San Marcial.

[218] Frank B. Clayton, Rio Grande Compact Commissioner for Texas, to Mr. Sawnie B. Smith, October 4, 1938. Box 2F466, RGCC-FBCP, UTA; and Littlefield, *Conflict on the Rio Grande*, 213-214.

unequivocally, "is necessary because the Rio Grande Project of the Bureau of Reclamation must be operated as a unit."[219]

As these statements by Clayton and McClure, and the service to lands beyond the Rio Grande Project down to Ft. Quitman make plain, New Mexico's San Marcial delivery per the compact was the state-line delivery to Texas. Water captured and stored in Elephant Butte Reservoir on release and re-use served lands not only within the Rio Grande Project but also downstream to Ft. Quitman. Calculations of the demands on the federal reservoir by federal engineers and the engineering advisors to the Rio Grande Compact commissioners recognized the dependence of these lands on the reservoir's water supply. The commissioners themselves understood that that water delivered to the reservoir would be under federal control, and thus a state-line delivery by New Mexico to Texas, similar to the state-line delivery by Colorado to New Mexico, was impractical.

[219] Thomas B. McClure, State Engineer, "Analysis of the Compact," undated, 21-22. NM_00164500 – NM_00164501.

Opinion V: Although irrigation water was the prime concern of compact commissioners and their engineering advisors in the 1920s and 1930s, the 1938 Rio Grande Compact ultimately did not limit the uses to which water in the Upper Rio Grande Basin could be put in the future.

As noted at various points in the opinions above, irrigation for agricultural development was a central theme of the negotiations leading to both the temporary 1929 and permanent 1938 compacts. The recorded compact proceedings are filled with discussions of how much land could be irrigated in the San Luis Valley in Colorado with the construction of a drain or other works, for instance, and the impact that the Middle Rio Grande Conservancy District could have on the Rio Grande Project and the need to prevent a decline in the quantity and quality of water reaching already irrigated lands within the federal Rio Grande Project and beyond were of equal concern. However, other uses – domestic, industrial, and municipal – were addressed in those proceedings and the federal Rio Grande Joint Investigation. Actions and statements by federal and state negotiators and engineers following the compact, moreover, indicate that the drafters both recognized the potential for non-agricultural uses of the Rio Grande's waters and intended for the three states, pursuant to the schedules of delivery established by the compact, to have autonomy in the development of the waters within their borders, post-1938.

At the first meeting of the Rio Grande Compact Commission in October 1924, the possibility of El Paso seeking a water supply from the Rio Grande as part of a compact was raised. Joseph Taylor, an attorney with EBID, in fact argued for the inclusion of Texas in the compact negotiations initiated between Colorado and New Mexico precisely for this reason. He insisted,

> In my District, the one warning I get from the water users, in going ahead with this procedure, is the possibility that our interests at sometime may be different from the interest of the El Paso Valley, and that unless we are very careful, that we proceed with the full acquiescence of the people of the lower valley, there may be question of water supply which may at some time limit the project, and which might be interpreted by our friends below as being a limitation which would effect [*sic*] New Mexico's interests only. We have the City water supply of El Paso that may come up, and our people are a little doubtful of the propriety of going ahead unless Texas is fully and legally represented in every respect.[220]

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[220] First Meeting, Rio Grande River Compact Commission…October 26, 1924, 18-19. Folder 1. First Meeting Rio Grande Compact Commission. Oct. 26, 1924, Box 02-D.003, MS 0235, RGHC, NMSU Spec. Coll. As early as 1921, at the suggestion of consulting engineer John Lippincott, the City of El Paso was looking to the Rio Grande, and specifically the water stored in Elephant Butte Dam, to supplement its reliance on groundwater. For a brief overview of the early history of El Paso's municipal water development see A.N. Sayre and Penn Livingston, *Ground-water Resources of the El Paso Area, Texas*, prepared in cooperation with the El Paso Water Board and the Texas State Board of Water Engineers, United States Department of the Interior, Geological Survey, Water-Supply Paper 919 (GPO, 1945), 3 and 5-7.

Taylor was correct in his belief. When the Rio Grande Compact Commission met again in December 1928 with Texas "fully and legally represented," Major Richard F. Burges, legal advisor to Texas's compact commissioner T.H. McGregor and attorney for the City of El Paso, indicated that at the behest of "the municipal authorities at El Paso" he was there to present "before the commission the claims of the City of El Paso to a municipal water supply from the waters of the Rio Grande."[221]

Those claims were made in full at the next commission meeting in January 1929. El Paso mayor R.E. Thomason, appearing in person, read a statement asking for "consideration, recognition and establishment of [El Paso's] legal right to the municipal water supply from and out of the waters of the Rio Grande River…."[222] Noting that El Paso fronted on the river, the statement emphasized that the Rio Grande was "for many years…the source of the water supply of El Paso." It explained that "in recent years the City has obtained its water from wells, because the same could be more economically obtained than from the flow of the river." The supply from the wells was "limited

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EBID was aware of the city's interest, with president and manager H.H. Brook noting in March 1923 letter to the US Reclamation Service (more than a year before Taylor made his remarks) that it was (in the later words of Reclamation Chief Engineer F.E. Weymouth) "probable the City of El Paso, Texas will request water from the Rio Grande project for domestic purposes." In his letter, Brook had sought additional information on "contracts in existence between the United States and municipalities within and without Reclamation Service projects where water is furnished for similar purposes."

Weymouth obliged. In his reply, he enclosed a copy of a "standard form of contract for water service to incorporated towns," and pointed out that Section 4 of the 1906 Town Sites and Power Act (34 Stat. 116) "provides for water rights for towns and contracts therefor…." Reclamation was therefore authorized to supply water "for municipal purposes which would include the watering of lawns and such general irrigation as may be practiced within the town limits." Towns, the chief engineer emphasized, had to pay for such water as agricultural areas and could not secure "more favorable" terms. A handwritten note on the letter, most likely made by Brook, indicates that this letter was read to the EBID board, who expressed their desire to oppose such "schemes…as unsatisfactory." F.E. Weymouth, Chief Engineer, to Mr. H.H. Brook, President & General Manager, Elephant Butte Irrigation District, March 31, 1923. Folder 3, Box 023.016, Subject File, 1906-1925. Unclassified. H.H. Brook [9.21], MS 0235, RGHC, NMSU Spec. Coll. Federal reclamation authorities later determined that the 1920 Miscellaneous Purposes Act was the pertinent federal legislation, and as briefly discussed in footnote 234, the United States, EP #1, and one instance, EBID, entered into water service contracts with the City of El Paso in the 1940s, pursuant to that act.

[221] Proceedings of the Rio Grande Compact Conference...1928, 11-13. ff. ff. Proceedings of the Rio Grande Compact Conference Held Dec. 19-20-21, Box 2F471, RGCCR, 1924-1941, 1970, UTA.

[222] Thomason had telegrammed Burges on December 20, 1928, during the first meeting, asking him that "If water rights of City of El Paso are to be in any affected by proposed treaty or if any definite action is to be taken at present session please advise me so I can send McBroom or Woods to represent city." R.E. Thomason, Mayor, to Major Richard F. Burges, telegram, Dec. 20, 1928. ff. Rio Grande Compact Commission Records, 1927-1941, 1970, Richard Burges Papers: Correspondence, 1924-1935, 1927, Box 2F468, RGCCR, UTA.

and uncertain," which was why the City of El Paso believed "it will become necessary again to obtain its water supply from the waters of the Rio Grande River." El Paso had grown steadily since the turn of the nineteenth century, and within a generation was projected to "attain a population of at least 250,000," which would "require an annual municipal water supply of twelve billion gallons." Citing Texas's "riparian rights doctrine," the city asserted its rights to the waters of the Rio Grande as "necessity" to which it may have "to resort…in the future from failure or inadequacy of such other present available source of supply or from deleterious changes that may occur in such present source of supply."[223]

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[223] Proceedings of Rio Grande Compact Conference, Held January 21 to , 1929, At Santa Fe, New Mexico, 64-65. ff. Rio Grande Compact Commission Records, 1924-1941, 1970, Richard F. Burges Papers, Proceedings of Rio Grande Compact Conference, Held Jan. 21-, 1929 at Santa Fe, N.M. (84 pp.), Box 2F471, RGCC Records, UTA.

Thomason's efforts on behalf of his city were not limited to the submission of this statement. In December 1927, more than a year before he addressed the Rio Grande Compact Commission, Thomason and city water works superintendent A.H. Woods met with Interior Secretary Hubert Work to discuss the matter. Work advised him and Woods to meet with former Rio Grande Project superintendent and US International Boundary Commissioner L.M. Lawson. Lawson, in turn, recommended that the city wait until elections in EBID and EP#1 had been held. He also suggested that the city seek water within the project's operational 155,000-acre irrigable-acreage framework.

This suggestion, as Woods later explained to Work, was embodied in a letter that Thomason wrote to Work in February 1928. In that letter, Thomason noted that as much as 4,000 acres of the 67,000 acres allotted to Texas had not been brought under irrigation. He proposed for the City of El Paso to acquire those lands and thus obtain a right to water through the federal reclamation project. Woods for his part believed that this "should raise no objection on the part of the irrigation district, because of the fact that the City of El Paso would be expected to relieve the district of the construction repayments for such an area." Although the acting Rio Grande Project superintendent L.R. Fiock and EP#1 manager Roland Harwell were generally supportive of the city's proposal, before any further arrangements could be made, the temporary 1929 compact was adopted and progress towards the city obtaining Rio Grande water came to a halt. Footnote 234 below briefly discusses how the idea of securing Rio Grande project water was revived in 1940. See R.E. Thomason to Honorable Hubert Work, Secretary of the Interior, February 16, 1928; A.H. Woods to Hon. Hubert Work, Secretary of the Interior, February 17, 1928; Hubert Work, Secretary, to Hon. R.E. Thomason, Mayor of El Paso, Texas, Feb. 25, 1928; P.W. Dent, Acting Commissioner to Mr. A.H. Woods, Superintendent, City Water Works, March 2, 1928; Memorandum, From: Acting Superintendent [L.R. Fiock], To: The Secretary (Thru The Commissioner, Washington, D.C.), Subject: Water Supply for City of El Paso – Allotment of Irrigable Area to The Texas District – Rio Grande Project, El Paso, Texas, March 27th, 1928; A.H. Woods to Honorable Hubert Work, Secretary of the Interior, Department of the Interior, El Paso, Texas, April 13, 1928; Hubert Work, Secretary, to Mr. A.H. Woods, Superintendent, City Water Works, Apr. 20, 1928; Memorandum, From Commissioner [Elwood Mead], To Superintendent, El Paso, Tex., Subject: Proposed purchase of water by City of El Paso, April 21, 1928; and Memorandum, From: Acting Superintendent [L.R. Fiock], To: The Secretary (Thru The Commissioner, Washington, D.C.), Subject: Proposed purchase of water by City of El Paso – Rio Grande Project., El Paso, Texas, June 26th, 1928. ff. 223.02 Rio Grande, Corres re Lease or Sale of Water thru 1929, 1 of 2, Transfer Case, Box 907 Rio Grande 223.02, Entry 7, RG 115, NARA Denver.

Although there is no record of the commissioners discussing or deliberating El Paso's claim prior to congressional ratification of the 1929 temporary compact, the compact was intended to preserve existing water uses within the basin. It therefore recognized "domestic" and "municipal" purposes of water along with the "agricultural." Article XI, in particular, offered a strong statement of the relative importance of "domestic" and "municipal" uses:

> Subject to the provisions of this Compact, water of the Rio Grande or any of its tributaries, may be impounded and used for the generation of power, but such impounding and use shall always be subservient to the use and consumption of such waters for domestic, municipal and agricultural purposes. Water shall not be stored, detained nor discharged so as to prevent or impair use for dominant purposes.

For Colorado's compact commissioner and the father of the Colorado River Compact Delph Carpenter, the provision's meaning was clear. Article XI "provides for the development of power by use of waters of the Rio Grande but makes such use subservient to uses for domestic, municipal and agricultural purposes which are made dominant."[224]

When discussions towards a permanent compact resumed in December 1934, existing or present uses and needs of water for agriculture remained centerstage. Former Colorado governor George Corlett, for instance, under questioning from Texas commissioner T.H. McGregor argued for "parity" among the three states on the basis of "the present acreage now under cultivation." Pushed further by McGregor about what "parity" meant, Corlett clarified: "Present requirements, then."[225]

The federal Rio Grande Joint Investigation pushed the commissioners to think more expansively about the basin's water needs. In his first appearance before the commission in December 1935 to offer the assistance of the National Resources Committee, University of Chicago historical geographer and consultant Harlan H. Barrows posed pertinent questions as to future uses of the water to be equitably apportioned among the three states:

> What, in the long run, will be your needs for water, not for irrigation supply, but for all other purposes, for city and town water supply, for industry, and the like? What are the prospects with respect to growth in population, and the prospects for now and greater needs for water associated with that growth? What are the possibilities for decentralized

[224] *An Act Giving the consent and approval of Congress to the Rio Grande compact signed at Santa Fe, New Mexico, on February 12, 1929*, June 17, 1930, Public, No. 370, chap. 506, 46 Stat. 767; and Report of Delph E. Carpenter, Commissioner for the State of Colorado in re Rio Grande River Compact, March 1, 1929, 5. ff. WDEC 16-12, Rio Grande 1934, WDEC Box 16, Series 1: DEC Correspondence, 1895-1949 and undated, Subseries 1.2 Loose Correspondence, 1895-1949 and undated, PDECF, WRA, CSU-FC.

[225] Proceedings of the Rio Grande Compact Conference held at Santa Fe, New Mexico, December 10 & 11, 1934, 12-13. ff. 1 Proceedings of the Rio Grande Compact Conference held at Santa Fe, New Mexico, 1934-1935, Box 62, Series 7, Subseries 7.1, PDECF, WRA, CSU-FC.

> industry, involving the use of more or less water? What are your prospective, no less than your existing, aggregated needs? To what extent can these prospective needs be met effectively?[226]

The commissioners were not dismissive of learning more about their respective states' future needs, but did not immediately embrace a study as wide ranging as Barrows sought. Colorado State Engineer and compact commissioner M.C. Hinderlider, for one, expressed his desire to obtain

> all factual data…of an engineering character, as Mr. Barrows has intimated, having to do with availability of water supply, the demands upon those supplies, the deficiencies, the surpluses, when they occur, and, in fact, all matters pertaining to the efficient, and I believe, ultimate utilization of this entire natural resource provided by the Rio Grande.[227]

Texas's commissioner Frank Clayton, McGregor's successor, while concerned mostly with safeguarding the water supply to Texas via the Rio Grande Project, supported the idea of a federal study of the Rio Grande. The resolution he introduced to provide for that study emphasized "a determination of all salient facts bearing on the present and potential water resources of the Rio Grande Basin above Ft. Quitman, and bearing on past and present uses therein."[228]

Barrows and fellow NRC consultant and agricultural economist Frank Adams pressed the issue, seeking a more open investigative mandate. Their suggested resolution called for an "investigation of the water resources and of the irrigable and irrigated lands of the Rio Grande Basin above El Paso, and of the present and prospective uses of water for agricultural and other purposes in such basin." Hinderlider largely accepted this, but Clayton remained more interested in focusing the federal efforts. In a second draft resolution, the Texas commissioner acknowledged that the compact commission sought "a thorough finding of all facts," including those "relevant to the use of water for irrigation and other beneficial purposes," but he proposed

> that such investigation be restricted to the findings of facts relevant to the water supply available in said [Rio Grande] Basin, and which could be made available from outside thereof, and relative to the use and consumption of water within said basin….

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[226] Proceedings of Rio Grande Compact Commission…December 2-3, 1935, 6. ff. 032.1 (2/3), Box 1326, Entry 7, RG 115, NARA Denver.
[227] Proceedings of Rio Grande Compact Commission…December 2-3, 1935, 9. ff. 032.1 (2/3), Box 1326, Entry 7, RG 115, NARA Denver.
[228] Proceedings of Rio Grande Compact Commission…December 2-3, 1935, 20. ff. 032.1 (2/3), Box 1326, Entry 7, RG 115, NARA Denver.

Adams was concerned that this resolution, if adopted, would severely circumscribe the investigation and he instead urged "a broader study of this whole basin problem…."[229]

New Mexico State Engineer and compact commissioner Thomas McClure was more inclined to Clayton's position, that the federal investigation be directed to a "factual survey" that would address more directly the issue of equitable apportionment of the Rio Grande among the three states. Yet, he too recognized "other purposes" for the river's waters. McClure's proffered resolution read, in part,

> that the National Resources Committee, through the Water Resources Committee, be hereby requested to arrange immediately for some investigation of the water resources and of the irrigable and irrigated lands in the Rio Grande Basin, and of the respective uses for agricultural and other purposes in such Basin….[230]

The compromise resolution adopted by the commission expressly "limited" the "cooperative investigation…to the collection, correlation and presentation of factual data," unless the commissioners unanimously requested "recommendations." An early version defined that investigation to be "of the past, present and prospective uses of water for agricultural and other beneficial purposes in such basin." When Texas's engineer advisor Raymond Hill expressed concern that such language may "be construed as omitting consideration of natural losses," a consideration that he believed was "a major factor in any investigation," Barrows suggested that the phrase be revised to "read 'of the past, present and prospective uses of water and other consumption of water in such basin." Hill explained to the commissioners that this language was inclusive of "Domestic uses, and then consumption, which takes place naturally, striking out 'for agricultural and other beneficial uses.'"[231]

The resulting report of the federal investigation, the *JIR*, consequently considered "Uses and requirements other than for irrigation." These uses included municipal purposes, for "cities, towns, and villages" as well as "power purposes." The "General Report," which summarized the individual reports by various federal agencies, observed that these uses were "but a small fraction of the irrigation use" that was common from the Rio Grande's headwaters in Colorado to Fort Quitman, Texas. "As general average," the report noted, "the water requirement of cities and towns corresponds closely to the irrigation requirement of agricultural lands of an equivalent area." Nearly all the area cities, towns and villages derived their water supply from "pumping

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[229] Proceedings of Rio Grande Compact Commission…December 2-3, 1935, 25-28 and 30. ff. 032.1 (2/3), Box 1326, Entry 7, RG 115, NARA Denver.
[230] Proceedings of Rio Grande Compact Commission…December 2-3, 1935, 31-32. ff. 032.1 (2/3), Box 1326, Entry 7, RG 115, NARA Denver.
[231] Proceedings of Rio Grande Compact Commission…December 2-3, 1935, 37-38 and 42-43. ff. 032.1 (2/3), Box 1326, Entry 7, RG 115, NARA Denver.

ground water which, in turn, has its source in stream flow and in precipitation on the floor of the valleys," and the report determined that "[f]rom a basin-wide standpoint…this use constitutes a stream-flow depletion." To the USDA Bureau of Agricultural Engineering fell the task of assessing these depletions within the various sections of the basin. The agency included these urban and semi-urbanized areas within the "total area for which consumptive requirement [were] estimated," and thus "no special consideration of this use or allowance for it" was made. The City of Albuquerque, for example, was "included in the figures [of stream flow depletion]" for the so-called "Middle section" of the basin that extended "from the Colorado-New Mexico state line to San Marcial at the head of Elephant Butte Reservoir."[232]

The City of El Paso was excluded from this calculation of urban water consumption in the basin (which totaled 21,000 af) because of its dependence on wells located east of the city. These were, wells that drew upon groundwater fed by precipitation. Albuquerque likewise relied upon groundwater. Yet, the calculation of water consumption for the Middle section included the city because engineers involved with Albuquerque's proposed Jemez Creek development (which aimed to replace municipal wells with a direct diversion from one of the Rio Grande's tributaries) believed that the city's groundwater use was "undoubtedly a draft, direct or indirect, on Rio Grande; that therefore construction of the Jemez project amounts only to a change in point of diversion…."[233]

The *JIR* nevertheless made note that "the future of the water supply for El Paso" could include a direct diversion from the Rio Grande. It quoted at length from a letter that Harlowe Stafford, the federal engineer in charge of the investigation, received from the superintendent of El Paso's municipal waterworks:

> We are contemplating the drilling and construction of three additional wells within the very near future, said construction to be contingent upon the recommendations and advice which will be contained in a report of a survey of the underground water resources of El Paso and vicinity which was made during 1935 and 1936 by the United States Geological Survey.
>
> The records which this department has maintained over a period of years indicate that the static level of our ground-water supply is slowly receding. This, of course, can mean but one thing; that is, that the pumping in this area exceeds recharge.
>
> Should the static level continue to drop during the next 10 or 20 years as it has during the last 15 years, we believe that we shall find it necessary to seek another source of supply. Of course, there is but one other source of supply available and that is the Rio Grande.

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[232] *JIR*, 1, 20, and 104-105. The Bureau of Agricultural Engineering's data is offered in Part 3: Water Utilization: Report of the United States Bureau of Agricultural Engineering, Section 7 – Consumptive Use of Water Requirements, in *JIR*, 368, 370-371, and 422-423.
[233] *JIR*, 105-106.

> However, we do not think that it will be necessary for us to use water from that source for several years, it at all.[234]

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[234] *JIR*, 106.

The superintendent may have been optimistic in his assessment. In the summer of 1940, El Paso city officials, having had to cut back on water use on city-owned properties and confronting the possibility of having to supply the nearby US Army post, Fort Bliss, with additional water, approached federal reclamation authorities again. El Paso's new proposal was much like its previous proposal from the 1920s: to purchase land within EP#1 and thereby obtained water from the project. Working with the EP #1 manager Roland Harwell and El Paso City Attorney and former Texas compact commissioner Frank Clayton, Rio Grande Project Superintendent L.R. Fiock and Reclamation District Counsel H.J.S. Devries drafted a contract, pursuant to the 1920 Miscellaneous Purposes Act in November 1940. That contract, which EBID approved but did not join as a party, was finalized in February 1914 by the United States, EP #1, and the City of El Paso. A supplemental contract, with EBID as a party, was approved in 1944, and a third supplemental contract between EP #1 and the city (without either EBID or the US as a party, although the US approved the agreement) was prepared in 1949. See Ashley G. Classen and J.N. Hinyard, *Report on the Use of Rio Grande River Water as a Supplemental or Total Supply for the City of El Paso*, Lance Engineers, Inc., May, 1940), 1-8 and 13-124. 090-2000-028-W054, Box 090 028 W044-W054, El Paso Historical Society, El Paso, Texas; W.E. Robertson, Chairman, Water Development Commission of the City of El Paso, To the Honorable John C. Page, Commissioner, Bureau of Reclamation, June 8, 1940; Memorandum, From: Superintendent [L.R. Fiock], To: The Commissioner (Through Chief Engineer, Denver, Colorado), Subject: Negotiations by City of El Paso for municipal water supply from project sources – Rio Grande Project., El Paso, Texas, June 20, 1940; H.W. Bashore, Acting Commissioner, to Mr. W.E. Robertson, Chairman, Water Development Commission of the City of El Paso, Jul 25, 1940; City of El Paso, Texas, to The Honorable, The Secretary of the Interior, Statement as to the Water Supply of the City of El Paso in connection with its application for permission to supplement its supply from the Rio Grande, August 31, 1940; Memorandum, From: Acting Commissioner [H.W. Bashore], To: District Counsel, El Paso, Texas, Subject: Desire of city of El Paso to secure a municipal water supply from Rio Grande Project, September 30, 1940; H.J.S. Devries, District Counsel, to Hon. Edw. Mechem, October 5, 1940; Memorandum, From Superintendent [L.R. Fiock], To Commissioner (Through Chief Engineer, Denver, Colorado), Subject: Water supply for City of El Paso from project sources – Rio Grande Project, November 26, 1940; and United States Department of the Interior, Bureau of Reclamation, Rio Grande Project, New Mexico-Texas, Contract for Supplemental Water Supply for the City of El Paso, El Paso draft 11/18/40, Dec-9'40. ff. 223.02 - Rio Grande - Leases, Sales & Rentals of Water, El Paso, City of, thru Dec 1941. Box 920, Rio Grande Pro. 223.02, Entry 7, RG 115, NARA Denver; Memorandum, To: Secretary J.A. Krug, From: Commissioner [Michael W. Strass], Subject: Proposed supplemental contract with City of El Paso for municipal water supply – Rio Grande Project, May 13, 1949, Approved: May 19, 1949, (sgd) William E. Warne, Assistant Secretary of the Interior; Memorandum, To: The Solicitor, From: Acting Commissioner [Wesley R. Nelson], Subject: Proposed contract arrangements to supplement City of El Paso water supply--Rio Grande project, Sep 2 1949; and Memorandum, To: The Solicitor, From: Bruce Wright, Subject: Arrangements to supplement City of El Paso water supply--Rio Grande Project, Sep 14 1949. File No. 8-3 (Part 8), Reclamation Bureau - Rio Grande – Distribution of Waters, General. January 27, 1937 thru February 10, 1950, 8-3 Rio Grande – Distribution of Waters - General, Box 3623, 8-3 Rio Grande—Contracts-Nelson, J.P. 8-3 Rio Grande Flood Control, CCF 1937-1953, RG 48, NARA II; and Contract between the City of El Paso and El Paso County Water Improvement District Number One, dated August 10, 1949, approved J.A. Krug, Sec'y of the Interior, Sept. 23, 1949. ff. B-12.2.12.1 Water Control &

Neither in the December 1937 "Report of Committee of Engineers" nor in the recorded proceedings leading up to the formal drafting and signing of the permanent compact in March 1938 is there explicit discussion of other possible or future uses of compact water. As addressed in Opinion I, "present uses of water" was the focus of the engineering advisors' report and the predominant use of water in the basin circa 1938 was irrigation. The compact itself references "irrigation demands" and "irrigation."[235]

There is no language in the compact, however, explicitly precluding the use waters of the Rio Grande for domestic, municipal, and industrial uses. Historical evidence exists, moreover, that those most involved with the negotiations did not see the compact as foreclosing opportunities to use water for purposes other than irrigation within the basin. Bliss, for one, in reviewing the general outlines of the technical basis of the compact to McClure in December 1937, noted "Developments in the three valleys [i.e., the San Luis Valley, the Middle Rio Grande, and the Elephant Butte-Ft. Quitman section of the upper basin] will be limited only by certain restrictions in reservoir storage during period of extremely low run off and by limitation of debits which may be incurred at any time."[236]

Clayton, for another, construed his responsibility as Texas's commissioner to secure all the waters to which Texas was entitled – not just water for irrigation. A little over two months after signing the compact, at a May 1938 conference of water users below Ft. Quitman, he unequivocally stated that it was his duty "to try and get every drop of water Texas had a right to claim, irrespective of how or where it was to be used in Texas." Such a statement indicates that Clayton saw the uses to which the waters Texas obtained under the compact were put were immaterial.[237]

New Mexico's pursuit of the Jemez Creek project in the wake of the compact's signing similarly suggests that interests in that state did not see the waters of the Rio Grande as dedicated exclusively to agriculture. Clayton's response to that project also bolsters the notion that he and others saw other possible uses for the water within the confines of the compact. After the compact's signing but before its ratification by the states and Congress, the City of Albuquerque sought funds from the Public Works Administration to initiate the Jemez Creek Project. Federal

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Accounting 1 of 4, City & County of El Paso; El Paso, Hudspeth County Conservation District; Hudspeth County Conservation & Reclamation District No. 1; Elephant Butte Irrigation District, January 1906 thru September 1960, Box 22, Accession Number 076-69A-0928, RG 76, NARA Ft. Worth.

[235] "Rio Grande Compact," in Proceedings of the Meeting of the Rio Grande Compact Commission…March 3rd to March 18th, inc., 1938, Appendix No. 11, 73, 80. ff. 032.1, Box No. 936, Entry 7, RG 115, NARA Denver.

[236] Bliss to [McClure], December 22, 1937. Rio Grande Compact – July 7, 1937 to June 30, 1938, 26th Fiscal Year, NM_0015692 – NM_00156929.

[237] *Proceedings of Meeting, held on Friday, May 27, 1938*, 10. ff. Proceedings and Minutes 1935-1938, Box 2F463, RGCC-FBCP, UTA.

funds for water development within the Rio Grande Basin had been frozen by executive order pending the Rio Grande Joint Investigation, but now with the compact nearly in place long-contemplated projects were pushed forward in New Mexico and Colorado. Albuquerque consulting engineer H.C. Neuffer (who also played a pivotal role in the development of the compact as consultant to the Middle Rio Grande Conservancy District, as discussed in Opinion I) urged Clayton – as the Texas commissioner later related to engineering advisor Raymond Hill – "to clear the Jemez Creek water supply project for the City of Albuquerque."

Clayton demurred on giving Neuffer assent, not so much on the basis of the project itself but because the compact had not yet been adopted. This was a position that the Texas commissioner reportedly shared with EBID and EP #1 representatives, all of whom likewise opposed Colorado's Wagon Wheel Gap project for the same reason. For Wagon Wheel Gap, Clayton wrote Hill, "Our attitude was that until the compact had been ratified, we could not give clearance to any project involving the use of water of the Rio Grande," and he gave Neuffer "the same answer" as to Jemez Creek. Although the engineer and Colorado's representative Ralph Carr both "threaten[ed] to defeat ratification if our refusal to clear these projects result in the loss of federal funds," the Texas commissioner informed his engineering advisor that he could "not see my way to give them clearance, and this was the unanimous attitude of the officials of the Elephant Butte and El Paso County district." Should federal monies be "earmarked pending ratification of the compact," however, "we shall probably have no objection." For Clayton, EBID, and EP #1, it would appear that so long as the compact was in place, the nature of water use within the states was irrelevant.[238]

More compelling evidence of water use agnosticism in the compact comes from statements and analyses prepared by the compact drafters themselves following the compact's singing. As noted in Opinion I above, both Colorado commissioner M.C. Hinderlider and New Mexico commissioner Thomas McClure in letters to their respective governors urging adoption of the compact stated that the agreement safeguarded "present and future uses" of the Rio Grande waters in their states.

An undated "Analysis of the Terms of the Compact," authored by McClure, twice made the point that future, unspecified water uses were protected by the compact. Citing the "schedules of delivery of water at the Colorado-New Mexico State Line and at San Marcial at the head of Elephant Butte Reservoir," the New Mexico state engineer wrote,

> they provide that the three major basins [i.e., Colorado's San Luis Valley, New Mexico's Middle Rio Grande, and the Elephant Butte-Fort Quitman stretch] may make the best use

[238] Frank B. Clayton, Rio Grande Compact Commissioner for Texas, to Mr. Raymond Hill, August 24, 1938. Box 2F466, RGCC-FBCP, UTA.

> of their available supplies by the conservation and use of waters now being beneficially consumed and particularly by the construction of additional reservoirs to make use of waters which would otherwise spill from Rio Grande Project storage and be lost to the entire area [i.e., the Upper Rio Grande Basin, above Ft. Quitman].

Further in the "Summary" to the piece, McClure noted that among the compact's accomplishments,

> It permits each State to make the best possible use of her available supply and by means of storage, to conserve considerable flood waters which must otherwise spill from Project storage and be lost to the basin.[239]

Raymond Hill, recalling the compact negotiations three decades later, agreed. For a Supreme Court original action involving the three Rio Grande states in the late 1960s, Hill prepared a narrative account, "Development of the Rio Grande Compact of 1938," and sat for a deposition. His narrative largely summarizes the available engineers' reports and commission proceedings, yet much like the compact itself does not expressly deny water uses other than irrigation. In fact, in reviewing the events leading to the compact, Hill's narrative suggests that future water developments were not tied exclusively to irrigation:

> The Committee of Engineering Advisers was instructed to prepare schedules of deliveries by Colorado and by New Mexico that would insure [*sic*] maintenance of the relationships of stream inflow to stream outflow that had prevailed under the conditions existent when the Compact of 1929 was executed. The Committee of Engineering Advisers was also instructed to provide for freedom of development of all water resources in the drainage basin of Rio Grande above Elephant Butte subject only to compliance with these schedules.[240]

An exchange that Hill had with United States attorney Donald Redd at a December 1968 deposition further clarified the engineer's meaning as to "freedom of development":

> <u>By Mr. Redd</u>:
>
> Q. Mr. Hill, I call your attention to your statement on page 20 and on page 62 of your report [i.e., "Development of the Rio Grande Compact of 1938"] and on page 62 where you stated that the objective in the negotiations was to base the use on the 1929 conditions [i.e., the passage quoted above], is that correct?
>
> A. Yes, the primary instructions to the Committee of Engineers, of which I was a member, were to develop a relationship between the supply entering the valleys, each valley, and the outflows from the valley, and to development schedules which would reflect that relationship as near as possible. That was the first instruction.

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[239] McClure, "Analysis of the Compact," undated, 21 and 29. NM_00164500, NM_00164509.
[240] Hill, "Development of the Rio Grande Compact of 1938," 62.

> Q. But in doing so, you contemplated improvements that would make more water available or could make more water available?
>
> A. Yes, that's exactly what I referred to in the second instruction, and it was the clear intent, I am positive, that we were instructed in the development of the schedules and in the provision for operation. Article VI [of the compact, which addressed debits and credits for the states of Colorado and New Mexico], for example, as drafted by the engineers, almost no change in the final text, was to provide for freedom of development between these points of upper index and lower index in each case, so that each State would be free to change its use and the manner of use, each State would be free to provide storage, but subject always to the delivery in accordance with the schedules.
>
> Colorado, for example, had been promoting the Wagon Wheel Gap Reservoir for many, many years, and all of the provisions in the Compact that referred to storage of water in the Reservoirs and how they would be operated were all to make it possible – for example, Wagon Wheel Gap – so the 200,000 acre-feet could be stored in Wagon Wheel Gap that otherwise would have passed over Elephant Butte and down the river and have been of no value to anybody. Obviously, you could not store that flood water in Elephant Butt, then pump it back to San Luis, it had to be stored in Wagon Wheel Gap.
>
> So the whole theory of the thing, the premise under which the Compact was negotiated, that subject only to the maintenance of depletions that had occurred, subject only to not increasing those overall depletions, there is a freedom in each State to store, develop, improve or do anything else within that State. That was the whole intent.[241]

Hill's understanding of the intent of the compact aligned with McClure's: each state was free to utilize the waters of the Rio Grande within their borders as they saw fit, pursuant to the schedules of delivery adopted in the compact that allocated the available water supply of the Upper Rio Grande Basin.

The December 1937 report of the compact engineering advisors and the compact proceedings themselves indicate that "only present needs" within the basin could be considered in the formulation of a compact given the "usable water supply." Irrigation was the predominant use of water in the basin at time. The compact references "irrigation demands" and "irrigation," yet it does not specifically prohibit other uses of the Rio Grande water it apportioned. There is evidence, moreover, from direct participants in the negotiations that, pursuant to the schedules of delivery established by the 1938 compact, Colorado, New Mexico, and Texas were to have autonomy in the development of the waters within their borders – both at the time of the compact and in the future.

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[241] In the Supreme Court of the United States, October Term 1967, No. 29, Original, *State of Texas and New Mexico, Plaintiffs, vs. State of Colorado, Defendant,* Deposition of: Raymond A. Hill, Taken December 4, 1968, Denver, Colorado, 35-36. ff. Texas & New Mexico v. Colorado, w. Texas vs. Colorado 66-1061, Box 1989 41-240, LF-TAG, TSA.

Opinion VI: The Special Master fairly described the background history leading to the 1938 Rio Grande Compact on pages 31 through 187 and 203 through 209 of the *First Interim Report of the Special Master*, dated February 9, 2017.

Having reviewed the background history leading to the 1938 Rio Grande Compact presented on pages 31 through 187 and 203 through 209 of the *First Interim Report of the Special Master*, dated February 9, 2017 as well as the materials appended to it, it is my expert opinion that the Special Master fairly described that history. I base my opinion not only on my professional knowledge and expertise, but also on the historical records that I examined in the course of researching and analyzing the history of the 1938 Rio Grande Compact, many of which are cited in the opinions above.

Appendix

Resume of Scott A. Miltenberger, Ph.D. – May 31, 2019

Scott A. Miltenberger, Ph.D.

Partner / Consulting Historian

Summary

Dr. Miltenberger is a professional consulting historian, specializing in environmental and natural resources issues. Since joining JRP in 2006, he has researched alleged riparian and appropriative water rights, historical ground water rights, and Native American and federal reserved water rights in California and throughout the American West. Dr. Miltenberger has also led historical investigations of flood events, land ownership, survey / boundary disputes, and potentially-responsible parties for toxic clean-up under the provisions of CERCLA. His clients have included local, state, and federal agencies, as well as private parties. Dr. Miltenberger has qualified as an expert historian and given expert witness testimony in Sacramento County Superior Court, Santa Clara County Superior Court, and in Arizona's San Pedro-Gila River Adjudication.

Selected Professional Experience

Expert Witness Work, Deposition, and Trial Testimony over the Past 4 Years

State of Texas v. State of New Mexico and State of Colorado, No. 141, Original, Supreme Court of the United States. Preparation of expert historian report and anticipated expert witness deposition and trial testimony concerning the development of the Rio Grande Compact of 1938. Sacramento, CA: Somach Simmons & Dunn, 2012-Present.

Matt Pear and Mark Pear, Plaintiffs, vs. City and County of San Francisco, a municipal corporation, Does, 1-50, inclusive, Case No. 112CV227801, Superior Court of the State of California, County of Santa Clara. Provided expert witness testimony concerning historical land use and urban/suburban/industrial development of Santa Clara County in the 1950s as related to the Hetch Hetchy Aqueduct Right of Way. San Francisco, CA: City and County of San Francisco, City Attorney's Office, San Francisco Public Utilities Commission, 2017.

In Re the General Adjudication of All Rights to Use Water in the Gila River System and Source. Civil Nos. W-1, W-2, W-3, and W-

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Education

- Ph.D., United States History, University of California, Davis, 2006.
- M.A. United States History, University of California, Davis, 2001
- A.B. History, *summa cum laude* Colgate University, New York, 1999

Academic Honors, Fellowships, and Grants

- Agricultural History Center Dissertation Grant, University of California-Davis, 2005-2006
- Reed-Smith Dissertation-Year Fellowship, University of California-Davis, 2004-2005
- Jacob K. Javits Graduate Fellowship, United States Department of Education, 2000-2004
- Legacy Fellowship, American Antiquarian Society, 2004
- Distinction, Ph. D. Comprehensive Examinations, University of California-Davis, December 2001
- Reed-Smith Graduate Fellowship, University of California-Davis, 1999.
- Alumni Memorial Scholarship, Colgate University, 1995-1999
- Charles A. Dana Fellowship, Colgate University, 1997-1999
- Phi Beta Kappa, Colgate University, September 1998 (inducted)
- Phi Alpha Theta, Colgate University, September 1997 (inducted)

Professional Affiliations

- American Historical Association (Pacific Coast Branch)
- American Society for Environmental History
- National Council on Public History (Consultants' Committee)
- National Trust for Historic Preservation

4, Contested Case No. W-1-11-605, Maricopa County Superior Court, State of Arizona. Preparation of expert historian report, and expert witness deposition and trial testimony concerning the history of Fort Huachuca, Arizona, its changing missions, population, and water use, for the purposes of a federal reserved water right claim. Washington, DC and Denver, CO: United States Department of Justice, 2012-2016.

Modesto Irrigation District vs. Heather Robinson Tanaka, et al. Case No. 34-2011-00112886, Superior Court of the State of California, County of Sacramento. Expert witness deposition and trial testimony concerning the riparian status of a parcel in San Joaquin County and the historical land and water uses on that parcel. Sacramento, CA: O'Laughlin & Paris LLP for Modesto Irrigation District, 2014-2015.

Consulting Historican Services Since 2006

Clear Lake Littoral Rights Analysis, Lake County, CA. Woodland: Yolo County Flood Control and Water Conservation District, 2019-Present.

Riparian and Pre-1914 Appropriative Water Rights Investigation of Parcels along Merced River, Merced County, CA, 2018-Present.

Investigation of Historical Water Right Entitlements within the Kern River Basin, Kern County, CA, 2018-Present.

Riparian Water Rights Investigation of Parcels in San Joaquin County, 2018-Present.

Investigation of Historical Water Right Entitlements within the Stanislaus River Basin, 2018-Present.

Riparian and Pre-1914 Appropriative Water Rights Investigation of an Agricultural Parcel in Merced County, CA, 2017-Present.

Riparian and Pre-1914 Appropriative Water Rights Investigation of Agricultural Lands in the Kings River Basin, Fresno County, CA, 2017-Present.

Historical Research of Water Rights for a Parcel in Stanislaus County. Sacramento, CA: O'Laughlin & Paris, LLP, 2017-Present.

Riparian and Pre-1914 Appropriative Water Rights Investigation of Sacramento-San Joaquin Delta Islands, 2016-Present.

In Re the General Adjudication of Rights to the Use of Water from the Coeur d'Alene-Spokane River Basin Water System. District Court of the Fifth Judicial District of the State of Idaho, Twin Falls, ID. Assisted in the research, data management, and preparation of an expert report regarding water rights claims made in the general adjudication of water rights in the Coeur d'Alene-Spokane River Basin, Idaho. Boise, ID: Natural Resources Division, Office of the Attorney General, State of Idaho, 2010-Present.

Historical Research of California Public Utilities Records, 2018.

Historical Research of Military Operations at McClellan United States Air Force Base, Sacramento, CA, concerning use of chromium and chromium products, 2018.

Historical Research of Native American / Federal Reserved Water Rights Claims. Humboldt County, CA, 2017-2018.

Potentially Responsible Parties (CERCLA) Title Research for a Parcel in Tulare County. Rancho Cordova, CA: Geocon Consultants, Inc., 2017.

Historical Research of Water Rights acquired by the City of Santa Cruz. Santa Cruz, CA: Atchison, Barisone, Condotti & Kovacevich, 2016-2017.

Historical Research on Dams and Flood Control Operations on the Boise River. Boise, ID: Natural Resources Division, Office of the Attorney General, State of Idaho, 2015-2017.

Historical Research Concerning Reclamation District Assessments in Colusa County. Sacramento, CA: Somach Simmons & Dunn, 2016.

In Re the General Adjudication of Rights to the Use of Water from the Snake River Drainage Basin Water System, State of Idaho v. United States; State of Idaho; and all unknown claimants to the use of water from the Snake River Drainage Basin Water System, District Court of the Fifth Judicial District of the State of Idaho, Twin Falls, ID. Assisted in the research, data management, and preparation of several expert and consultant reports related to Idaho state water rights from statehood to the present of the more than 158,000 water claimants in the Snake River Drainage Basin, Idaho. These studies involved reservoir storage rights, appropriative water claims, groundwater use, submerged lands, hydro-electric power generation, municipal water uses, federal reserved water rights for military, forest, and Indian reservations, tribal water claims, and legislative histories. Boise, ID: Natural Resources Division, Office of the Attorney General, State of Idaho, 2006-2016.

Research regarding Pre-1914 Water Rights of Woods Irrigation Company, San Joaquin County, CA. Sacramento, CA: State Water Contractors and San Luis and Delta-Mendota Water Authority, 2015-2016.

Riparian Water Rights Investigation for Agricultural and Wetlands in the Cosumnes River watershed, Sacramento County, CA. Sacramento, CA: Sacramento County Counsel, 2015-2016.

Riparian and Pre-1914 Appropriative Water Rights Investigation of Agricultural Lands in the Salinas River Basin, Monterey County, CA, 2015-2016.

Riparian and Pre-1914 Appropriative Water Rights Investigation of Agricultural Lands adjacent to the Sacramento River, Yolo County, CA, 2015-2016.

Historical Research and Analysis of the Construction of Cline Falls Dam and Power Plant on Deschutes River, Oregon. Bend, OR: Holland & Knight, LLP, 2015.

Historical Research of Shipbuilding Operations at Swan Island Shipyards, Port of Portland, Oregon. San Francisco: Bassi, Edlin, Huie and Blum, 2015.

Historical Research of Land Uses and Development West of Hunters Point, San Francisco. San Francisco, CA: Bassi, Edlin, Huie and Blum, 2015.

Research Regarding Historical Background of Groundwater Pumping and Litigation in the 1950s among Orange County, Riverside, and San Bernardino Area Water interests in the Upper Santa Ana River Basin in Southern California. Redlands, CA: Thomas McPeters, Esq., McPeters McAlearney Shimoff & Hatt, 2013-2015.

Historical Investigation of Riparian and Pre-1914 Appropriative Water Right Claims for Three Parcels in eastern Contra County, CA, 2014.

Gallo Cattle Company v. Lincoln White Crane Hunter Farms; Merced Irrigation District, et. al. Case No. CV00105, Superior Court, State of California, County of Merced. Assisted in the collection of historical documentation in support of an expert witness deposition and planned testimony regarding Crocker Huffman Land and Water Company history, development of its irrigation and drainage system (later acquired by MID), and the background of a 1918 agreement to flow water from Merced County Drainage District (later acquired by MID) to a private landowner. Walnut Creek, CA: Miller Starr Regalia; and San Francisco, CA: Duane Morris, LLP, 2013-2014.

Land Use History, Union Lumber Company and adjacent properties, Fort Bragg, CA. San Francisco, CA: Bassi, Edlin, Huie and Blum, 2013-2014.

Reclamation and Land Use History Investigation: Roberts Island, San Joaquin Delta, CA. Sacramento, CA: O'Laughlin & Paris LLP for Modesto Irrigation District; Kronick, Moskovitz, Tiedemann & Girard for State Water Contractors; and Diepenbrock Harrison for San Luis and Delta-Mendota Water Authority, 2010-2014.

History of Groundwater Development and Use in Antelope Valley to Fulfill the Changing Military Missions of Edwards Air Force Base, Kern, San Bernardino and Los Angeles Counties, CA. Denver, CO: US Department of Justice, 2009, 2012-2014.

Research on a Pre-1914 Appropriative Water Rights Claim for a Ranch in Merced County, 2013.

Cortopassi Partners v. California Department of Water Resources, et al. Case No. CV034843, Superior Court, State of California, County of San Joaquin. Assisted in the collection of historical documentation in support of an expert witness deposition and planned testimony concerning public and private dredging on the Mokelumne River. Sacramento, CA: California Department of Justice, 2012-2013.

Investigation of Historical Reclamation and Land Use of Union Island, San Joaquin Delta, CA. Sacramento, CA: O'Laughlin & Paris LLP for Modesto Irrigation District; Kronick, Moskovitz, Tiedemann & Girard for State Water Contractors; and Diepenbrock Harrison for San Luis and Delta-Mendota Water Authority, 2011-2013.

Investigation of Historical Delineations of the Rialto Groundwater Basin, San Bernardino, CA. Redlands, CA: Thomas McPeters, Esq., McPeters McAlearney Shimoff & Hatt, 2010-2013.

Investigation of Historic Water Development at Two Well Sites: Chino Groundwater Basin. Rancho Cucamonga, CA: Cucamonga Valley Water District, 2010-2012.

Historical Research of Water Development on the Merced River for Irrigation, Mining, and Power Purposes Prior to the Organization of the Merced Irrigation District, 1860-1926. Merced, CA, 2008-2012.

Historical Research of US Army Corps of Engineers' dredging and flood control activities on the Yuba River. Sacramento: MBK Engineers, 2012.

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Research related to Water Storage, Diversion and Use by American Falls Reclamation District No. 2, *In Re the General Adjudication of Rights to the Use of Water from the Snake River Drainage Basin Water System, State of Idaho v. United States; State of Idaho; and all unknown claimants to the use of water from the Snake River Drainage Basin Water System*, Subcase No. 39576, District Court of the Fifth Judicial District of the State of Idaho, Twin Falls, ID. Boise, ID: Natural Resources Division, Office of the Attorney General, State of Idaho, 2011.

Historical Research regarding Operation of and Water Use at a Power Plant on Lytle Creek, San Bernardino County, CA for California Public Utilities Commission Hearings. Fontana, CA: Fontana Water District, and Rosemead: San Gabriel Water District, 2011.

Historical Water Rights Investigation – San Joaquin, Amador, and Calaveras counties, CA, 2011.

Susan River Pre-1914 Water Rights Investigation, Lassen County, CA. Chico, CA: O'Laughlin & Paris LLP, 2010.

Lower Lytle Creek Power Plant and Appurtenant Facilities: Construction and Water Use History. Redlands, CA: Thomas McPeters, Esq., McPeters McAlearney Shimoff & Hatt, 2010.

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Legislative history of California's "Area of Origins" laws (County of Origin, Water Code Sections 10500-10506, and the Watershed Protection Statute, Water Code Sections 11460-11465). Stockton, CA: Herum/Crabtree Attorneys, 2009-2010.

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Historic Meandering of the River Bend Section of the Russian River, Sonoma County, CA. Sacramento, CA: Lennihan Law, APC, 2008.

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Fort Boise Military Reservation Federal Reserved Water Rights Investigation. Boise, ID: Natural Resources Division, Office of the Attorney General, State of Idaho, 2007.

Historical Property Ownership Research for a Mine in Lake County, CA. Houston, TX: El Paso Corporation, 2006.

Publications Authored in the Previous 10 Years

"Viewing the Anthrozootic City: Humans, Domesticated Animals, and the Making of Early Nineteenth-Century New York," in *The Historical Animal*, ed. Susan Nance (Syracuse, NY: Syracuse University Press, 2015), pp. 261-271.

LAND IQ

May 31, 2019
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EXPERT REPORT OF:
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Land Use Classification and Consumptive Use Estimates for the Rincon, Mesilla, and El Paso Valleys from 1936 through 2018

In the matter of:

No. 141, Original
In the Supreme Court of the United States
State of Texas v. State of New Mexico and State of Colorado

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Expert Report

Land Use Classification and Consumptive Use Estimates for the Rincon, Mesilla, and El Paso Valleys from 1936 through 2018

Prepared for:
Texas Commission on Environmental Quality

Prepared by:

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MAY 31, 2019
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Contents

Acronyms and Initialisms

BOR	Bureau of Reclamation
CEA	Calculated EBID Acreage
CDL	Cropland Data Layer
CIR	Color Infrared (number of bands)
CUP+	Evapotranspiration Calculator Model
dS/m	Decisiemens Per Meter
EBID	Elephant Butte Irrigation District
EC	Electrical Conductivity
ECe	Soil Salinity
ECw	Irrigation Water Salinity
EPCWID	El Paso County Water Improvement District
ET	Evapotranspiration
ft	Feet
IOVD	In/Out Valley Distribution
JIR	Lower Rio Grande Joint Investigative Report
Kc	Crop Coefficient
m	Meter
NAIP	National Agriculture Imaging Program
NAPP	National Aerial Photograph Program
NASS	National Agricultural Statistics Service
NCDC	National Climatic Data Center
NDVI	Normalized Difference Vegetation Index
NHAP	National High Altitude Photography
NIR	Near Infrared
NOAA	National Oceanic and Atmospheric Administration
PET	Potential Daily Evapotranspiration
PFG	Plant Functional Group
ppm	Parts Per Million
SA	Service Area
SACD	Service Area Crop Distribution
TDS	Total Dissolved Solids
USDA	United States Department of Agriculture
USGS-Landsat	United States Geological Survey – Satellite Photography and Remote Sensing of Earth's Surface
WRCC	Western Regional Climate Center

Summary

This expert report documents the methods and results of estimating acreages and change from 1936 to 2018 for agricultural and riparian land uses. This report also documents methods for estimating agricultural and riparian consumptive use, and changes over the same time period.

Opinions

Expert opinions are at the beginning of each major section: agricultural land use, riparian land use, and agricultural consumptive use.

Purpose, Methodology Overview, and Image Resource Selection

The purpose in the extensive efforts to determine acreages of agricultural crops and riparian areas over time was to establish an accurate acreage of each crop or vegetation type for accurately estimating consumptive use for dominant land use types.

To generate comprehensive estimates of consumptive water use, accurate historical land use information was required. Proven methods were used to generate spatial land use mapping from 1936 through 2018 to inform and generate a comprehensive database of agriculture and riparian land uses within modeled service areas. This was performed annually either spatially or in a tabular format.

It was necessary to identify available and suitable image/photo resources covering the project area. The imagery was evaluated for the period 1936–2018, providing source data for the remotely sensed mapping and analytical efforts. Primary sources for these images included the U.S. Geological Survey (USGS-Landsat), online state archives, the U.S. Department of Agriculture (USDA) National Agriculture Imaging Program (NAIP), and commercial vendor products.

To analyze spatial land use on an approximate decadal time step, or more frequently in recent years, available images and photos were evaluated to select suitable dates and sources. Images were evaluated based on the following criteria:

- Year (target of approximately once every ten years or more frequently if available);
- Date of acquisition (within the primary growing season for most crops between April and August/September), and also for off-season rotational crops during more recent years;
- Completeness of coverage (for at least one or more of the valleys evaluated);

- Cloud-free over area of interest;
- Resolution/scale (resolution varied over time, but had to be suitable enough to at least verify permanent versus annual crops, and irrigated versus non-irrigated crops);
- Color (natural color, color infrared, and/or black and white);
- Quality (imagery containing the expected quality to allow for image processing or photo interpretation);
- Ability to distinguish/verify land use via photo interpretation; and
- Relationship to other non-spatial resources (e.g., crop reports, other historical documentation).

Various selected image dates and resources were used for this analysis (Exhibit 1). The complete list of evaluated images also is provided (Appendix 1).

Imagery Dates

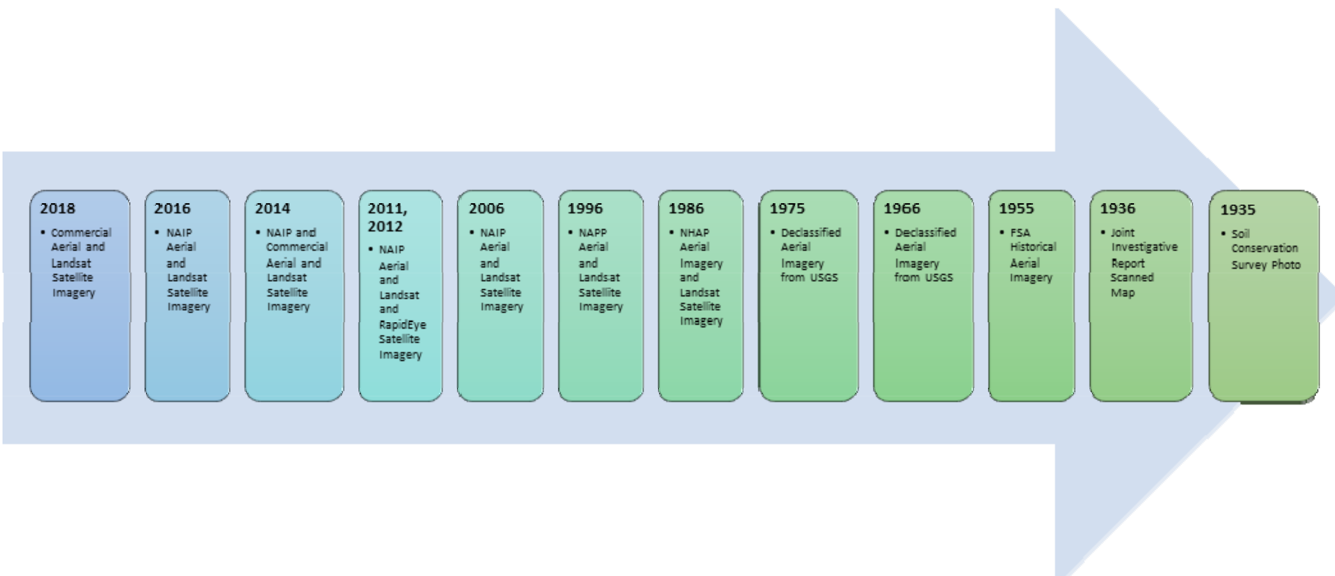


Exhibit 1. Image/photo sources selected for approximately decadal mapping efforts.

The initial year, 1936, was analyzed as a primary comparative year using a simple digital evaluation. The plates (figures) provided in the 1936 Lower Rio Grande Joint Investigative Report (JIR) were georeferenced to image resources. All fields were digitized to create a digital map of irrigated croplands throughout all valleys. These plates were based on field-by-field surveys included in the 1936 Lower Rio Grande JIR. Detailed crop acreages also were reported in the JIR that were the actual surveyed acreages by crop type for 1936. Therefore, for this key bookend year, both spatial and tabular survey data on crop type acreage were available and considered highly accurate.

The final bookend year in this analysis was 2018, when USDA NAIP and USGS-Landsat imagery were used. A rigorous ground truthing effort in 2014 (2x), 2016 (in office), and in 2018 (1X), coupled with these imagery sources, allowed for detailed field delineations and crop classifications to a high level of accuracy on a field-by-field basis.

Ground truthing allows for calibration of remotely sensed image processing algorithms to what is actually growing on the ground for a similarly timed image. Ground truthing also allows the analysis to be verified (i.e., accuracies can be determined) by setting aside a subset of the ground truth data, using the algorithms to classify crops by field, and then comparing that classification to the actual observation in the field. Accuracies are reported later in this report and are consistently in the mid-90s percentage or higher. For most minor misclassifications, the crops are similar (and, therefore, similar consumptive use), and the overall goal to accurately estimate consumptive use across a landscape is not compromised. For each of the three years that nearly one-week ground truth exercises were conducted, approximately 3,200 to 4,000 individual field data points were collected, depending on the year and season.

The 1936 and 2018 spatial analysis years, and other mapped years, allow for an accurate comparison between the differing cropping systems, crop change, and corresponding consumptive use change.

To provide a representative transition for crop changes over this 80-year span, additional image resources were used, when suitable, for analysis. The analysis years included 2018, 2016, 2014, 2012/2011, 2006, 1996, 1986, 1975, 1966, and 1955. USGS-Landsat satellite imagery was used (post 1984) whenever possible to help identify crop types and cropping systems throughout the year.

The selected imagery was acquired, processed, and georeferenced to various control points to ensure accuracy of location and consistency among years.

The result of this effort was a high-quality image dataset best representing the desired historical periods for temporal comparisons, analysis, and mapping.

Development of Spatial Land Use Database

1. Once the image analyses were completed for a selected year, a land use GIS spatial database was compiled for the period of study (1936-2018). Images were initially segmented into two main categories of land use: Agricultural Land Use

2. Riparian Land Use

For Rincon and Mesilla Valleys, agricultural land use was mapped approximately once per decade for the entire period of study and more frequently in recent years. Image quality and other constraints limited riparian mapping to three years: 1955, 2005, and 2014. Data from multiple years were combined to complete the analysis for El Paso Valley, again based on the availability of the image resources. Riparian areas were not classified in the El Paso Valley. A summary of image classifications is provided (Exhibit 2).

Exhibit 2. Summary of Spatial Land Use Analysis Completed by Year and Valley

	Agriculture			Riparian	
Year	Rincon	Mesilla	El Paso	Rincon	Mesilla
2018	X	X	X		
2016	X	X	X		
2014	X	X	X	X	X
2011	X	X	X		
2006	X	X	X	X 2005	X 2005
1996	X	X	X		
1986	X	X	no data		
1975/77	X	X	no data		
1966	X	X	no data		
1955	X	X	winter image	X	X
1936	X	X	X		

The resultant land use maps were interpolated with annual crop reports to generate a comprehensive, annual land use dataset that could be disaggregated spatially into model service areas. A summary of the agricultural and riparian mapping efforts follows. Annual database interpolations and completions follow the land use sections of this report (Appendix A).

Agricultural Land Use

Opinions

The following opinions are based on the results of the agricultural land use determination from 2018 through 1936. All crop acreages are provided in Appendix B.

- The overall irrigated agricultural land in the Rincon and Mesilla Valleys decreased from 98,130 acres in 1936, to 78,157 acres in 2018.
- The overall irrigated agricultural land in the Rincon Valley increased from 15,207 acres in 1936 to 18,238 acres in 2018.
- The overall irrigated agricultural land in the Mesilla Valley decreased from 82,923 acres in 1936 to 59,919 acres in 2018.
- From 1936 to 2018, specific crop acreages transitioned in both valleys; however, the major crop types that dominated the period were: alfalfa, chili peppers (chili), corn/silage, cotton, and pecans.
- Alfalfa in Rincon and Mesilla Valleys generally decreased from 20,310 acres in 1936 to 9,806 acres in 2018.
- Chili in Rincon and Mesilla Valleys increased from 397 acres in 1936 to 8,627 acres in 1989, and then decreased to 1,641 acres in 2018.
- Corn/Silage in Rincon and Mesilla Valleys generally increased from 6,862 acres in 1936 to 8,082 acres in 2018.
- Cotton acreage in Rincon and Mesilla Valleys decreased from 58,126 acres in 1936 to 11,679 acres in 2018.
- Pecan acreage in Rincon and Mesilla Valleys increased from near 0 acres in 1936 to 35,698 acres in 2018.
- The El Paso Valley is primarily dominated by alfalfa, cotton, and pecans. Other crops (e.g., chili, corn/silage, grain, etc.) exist, but in lesser acres consistently throughout time.
- Alfalfa in the El Paso Valley generally decreased from 16,649 acres in 1936 to 3,105 acres in 2018.
- Cotton in the El Paso Valley increased from 44,501 acres in 1936 to approximately 56,622 acres in 1951, and then decreased to 19,161 acres in 2018.
- Pecans in the El Paso Valley increased from almost 0 acres in 1936 to 15,412 acres in 2018.
- This spatial/agricultural land use investigation is the most comprehensive analysis that is known to exist to date.

Methods

Agricultural land use maps were developed for the following years: 2018, 2016, 2014, 2011, 2006, 1966, 1986, 1977/75 (1977 was a small portion of the Mesilla Valley not covered in 1975), 1966, 1955, and 1936.

The 1936 crops were extracted from a hardcopy map produced for the Rio Grande JIR and the JIR survey tabular acreages. Crop distribution maps for all other years were derived from aerial photos and/or satellite imagery. The crops were delineated and classified on a field-by-field basis. The level of detail of crop classes that could be mapped varied depending on the imagery sources and quality, but at a minimum, fields were determined to be irrigated or not irrigated. Crop reports from a number of sources provided information on the dominant types and relative percentages of crops in the different years. Individual crops were classified in the most recent years (1986–2018).

As a starting point for the mapping, field boundaries were digitized from the highest resolution imagery available for each year of analysis. The fields were then classified either using remote sensing techniques and/or traditional photo-interpretation methods. A variety of mapping methods were employed, depending on the imagery resources available and quality of images. The more recent dates were analyzed using a remote sensing approach in which automated classification techniques were used to map crop types. As verification, each classification was reviewed using a photo-interpretive approach. More traditional methods (i.e., photo-interpretation) were used for earlier years as much of the imagery was black and white, and usually of coarser spatial resolution. The classification legend also varied with image resolution. In earlier years, lower image resolution and quality only allowed for classification of broader cropping categories, while higher resolution–multispectral imagery available in more recent years and multi-temporal data resources–allowed classification of 26 individual crop and land use classes. The mapped classes for each year of the analysis are provided (Exhibit 3).

Exhibit 3. Classification Legend Crop Types and Associated Groupings by Spatial Analysis Year With Most Recent Years Listed First.

2018	2016	2014	2011	2006	1996	1986	1975	1966	1955	1936
Alfalfa	Alfalfa	Alfalfa	Alfalfa	Alfalfa/Fall Alf	Alfalfa/Spring Alf/Fall Alf	Alfalfa	Alfalfa	Alfalfa	Alfalfa	Alfalfa and Clover Hay
Developed Open Space	Developed Open Space	Developed Open Space	Developed/Open Space	Developed/Open Space	Developed/Open Space	Not Ag				Brush
Fallow	Fallow	Fallow	Fallow	Fallow	Fallow	Fallow				Annual Idle
Long Term Fallow	Long Term Fallow	Long Term Fallow	Fallow	Fallow	Fallow	Fallow	Fallow	Fallow	Fallow	Historically Irrigated
Non-Ag	Non-Ag	Non-Ag	Developed/Open Space	Ranchette/Shrubland/Urban	Not Ag	Not Ag				Brush
Ranchette	Ranchette	Ranchette	Shrubland	Ranchette/Shrubland/Urban	Developed/Open Space	Not Ag				
Summer Fallow	Summer Fallow	Summer Fallow	Summer Fallow	Summer Fallow	Summer Fallow	Summer Fallow				Annual Idle
Summer Annual	Summer Annual	Beans	Summer Annual	Beans	Beans	Irrigated Annuals				Late Season Annuals
Cabbage	Cabbage	Cabbage	Cabbage	Cabbage	Fall Lettuce/Spring Lettuce/Lettuce	Irrigated Annuals				Early Season Annuals
Corn	Corn	Corn	Corn	Corn/Milo/Sudan	Corn/Milo/Sudan	Corn/Cotton/Peppers				Late Season Annuals
Cotton	Cotton	Cotton	Cotton	Cotton	Cotton	Corn/Cotton/Peppers				Cotton
Grapes	Grapes	Grapes	Grapes	Grapes	Grapes					Miscellaneous
Grass Hay	Grass Hay	Grass Hay	Other Hay	Other Hay	Other Hay	Other Hay				Native Grass Hay
Melons	Melons	Melons	Melons	Melons	Melons/Squash	Irrigated Annuals				Early Season Annuals
Chili Pepper	Chili Pepper	Chili Pepper	Chili Pepper	Chili Pepper	Chili Pepper	Corn/Cotton/Chili			Irrigated Annuals	Late Season Annuals
		Pumpkins	Pumpkins	Annuals	Melons/Squash	Irrigated Annuals				Late Season Annuals
Sorghum	Sorghum	Sorghum	Sorghum	Corn/Milo/Sudan	Corn/Milo/Sudan	Corn/Cotton/Peppers				Late Season Annuals
Squash	Squash	Squash	Pumpkins	Annuals	Melons/Squash	Irrigated Annuals	Irrigated Annuals	Irrigated Annuals		Late Season Annuals
Sudangrass	Sudangrass	Sudangrass	Sorghum	Corn/Milo/Sudan	Corn/Milo/Sudan	Corn/Cotton/Peppers				Native Grass Hay
Irrigated Pasture	Irrigated Pasture	Irrigated Pasture	Irrigated Pasture	Irrigated Pasture	Irrigated Pasture	Irrigated Pasture				Native Grass Hay
Irrigated Playing Field	Irrigated Playing Field	Irrigated Playing Field	Irrigated Playing Field	Irrigated Playing Field	Irrigated Playing Field	Irrigated Parkland				Miscellaneous
Turf Grass	Turf Grass	Turf Grass	Turf Grass	Turf Grass	Turf	Irrigated Parkland				Miscellaneous
Fall Lettuce	Fall Lettuce	Fall Lettuce	Fall Lettuce	Fall Lettuce/Spring Lettuce/Lettuce	Fall Lettuce/Spring Lettuce/Lettuce	Fall Lettuce			Lettuce	Late Season Annuals
Spring Lettuce	Spring Lettuce	Spring Lettuce	Spring Lettuce	Spring Lettuce	Truck Crops	Spring Lettuce				Early Season Annuals
Nursery	Nursery	Nursery		Nursery	Nursery	Nursery			Nursery	Miscellaneous
Truck Crop	Truck Crop	Truck Crop		Truck Crops	Truck Crops	Irrigated Annuals				Early Season Annuals
Onions	Onions	Onions	Onions	Onions/Spring Onions	Onions	Onions			Onions	Early Season Annuals
Other Hay	Other Hay	Other Hay	Triticale	Other Hay	Other Hay	Other Hay			Other Hay	Native Grass Hay
		Teff								
Pecans	Pecans	Pecans	Pecans	Pecans	Pecans	Pecans	Pecans	Pecans	Pecans	
Young Pecans	Young Pecans	Young Pecans	Young Pecans	Young Pecans	Young Pecans	Young Pecans				Trees
Palms	Palms	Palms								
Oats	Oats	Oats	Oats	Small Grains	Small Grains	Small Grains				
Small Grains	Small Grains	Small Grains	Small Grains	Small Grains	Small Grains	Small Grains	Irrigated	Irrigated	Small Grains	Early Season Annuals
Spring Wheat	Spring Wheat	Spring Wheat	Small Grains	Wheat	Small Grains	Small Grains				
Winter Wheat	Winter Wheat	Winter Wheat	Small Grains	Wheat	Small Grains	Small Grains				

Annual Land Use Analyses

For each year of spatial analysis, a summary of the specific imagery resources, dates, resolution, quality, and other attributes follow. For each year, two or more mapping exhibits are provided (Exhibits 4-32). These exhibits also are provided in larger map size by valley in Appendix 2. The most recent years are listed first.

2018 Analysis

Data Sources

- **Imagery** - Images used for this analytical year are summarized below.

	Imagery	Date	Resolution	Color
Rincon	Planet Labs Landsat 8 Google Earth	Multiple dates Multiple dates Multiple dates	5 m 30 m Various	Natural Color Multispectral Natural Color
Mesilla	Planet Labs Landsat 8 Google Earth	Multiple dates Multiple dates Multiple dates	5 m 30 m Various	Natural Color Multispectral Natural Color

- **Field Data** – Ground truth data for summer crops in all three valleys was collected in August 2018 and used as training data for the 2018 classification.

- **Ancillary Data** - Ancillary data used to validate and assist the development of the 2018 crop map included the 2016 classification results, the closest available dates of the Elephant Butte Irrigation District (EBID) crop report (2013), and the El Paso County Water Improvement District #1 (EPCWID) crop report (2012). These data informed the analysts as to the likely dominant crop types and their relative percentages in the years immediately preceding the analysis date but were not used for spatial analysis.

Mapping Methodology

Planet Labs, Google Earth, and multiple dates of Landsat 8 imagery (30 m) from across the growing season were used as the image base. An object-based (i.e., field-based) image classification was used to map the crop types for Rincon and Mesilla Valleys with the 2018 imagery. Field data were stratified by crop type and divided into training and validation data. Mean values of the various image bands were extracted from each imagery date. The mean image values and training data were input to a random forest statistical classification algorithm that assigns a crop type to each field based on the field's statistical similarity to training data.

After the random forest classification was completed, an accuracy assessment was performed using independent validation field data. The resultant accuracy assessment matrix provides information on the overall 2018 classification accuracy and the accuracy of individual crop types (Appendix C).

Following the accuracy assessment, additional photo-interpretation editing was performed to refine the classification. Fields with low classification probability values were inspected and evaluated against the imagery. When a low probability was identified through expert photo-interpretation, the class label was corrected. The high resolution of the aerial imagery provided textural cues that were correlated to crop type. Row structures and even some plant structures could be discerned, allowing for a high level of discrimination between crop types during the review/editing phase.

Mapped Classes

Multiple dates of high-resolution imagery and ground truth data supported highly detailed crop mapping for 2018. The crop legend accounted for 34 individual crop types and land uses. Using the Landsat imagery in conjunction with the other imagery, early and late season crops were identified and mapped (e.g., small grains, onions, lettuce, cabbage, melons, etc.).

Exhibit 4. 2018 Crop Classification – Rincon Valley

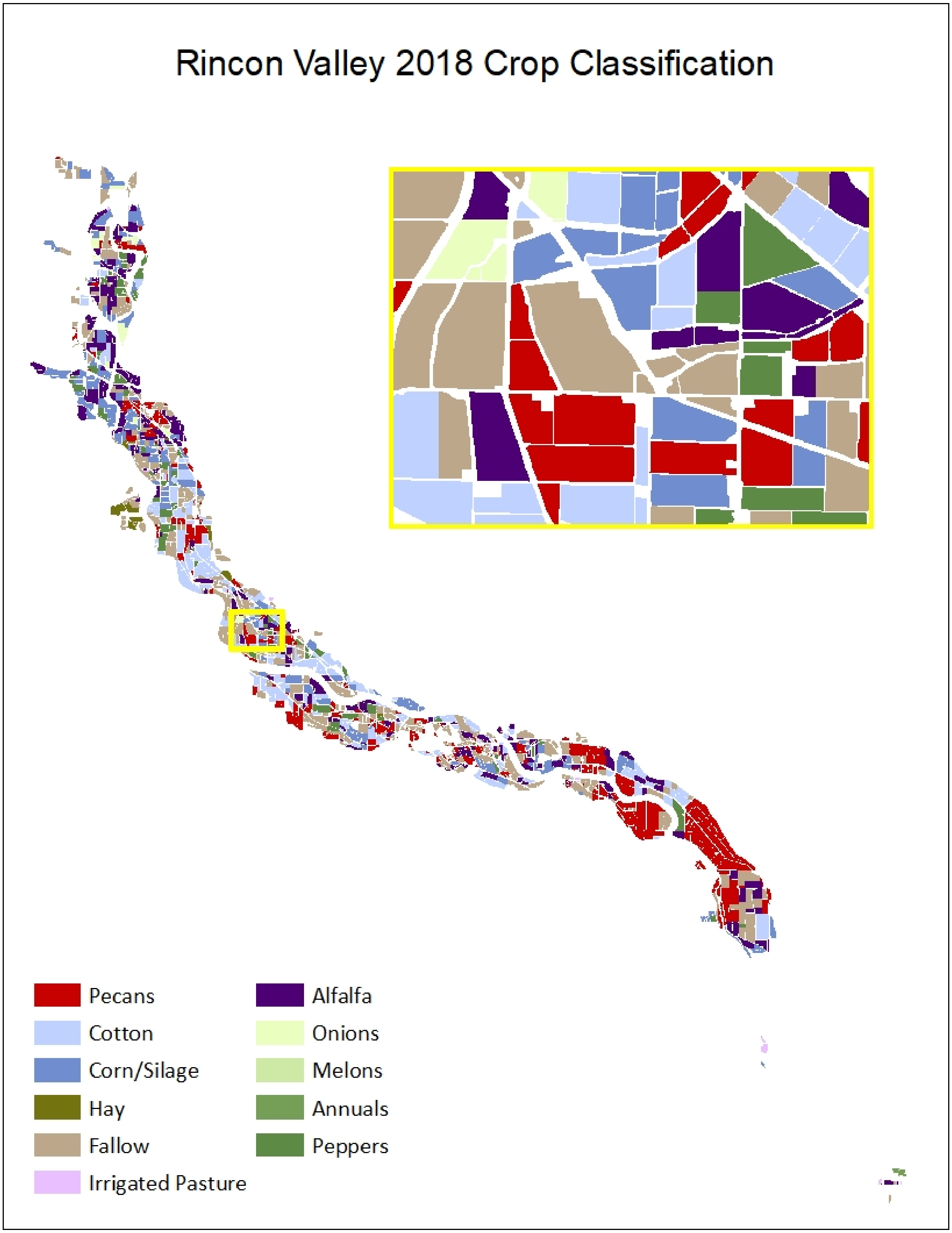


Exhibit 5. 2018 Crop Classification – Mesilla Valley

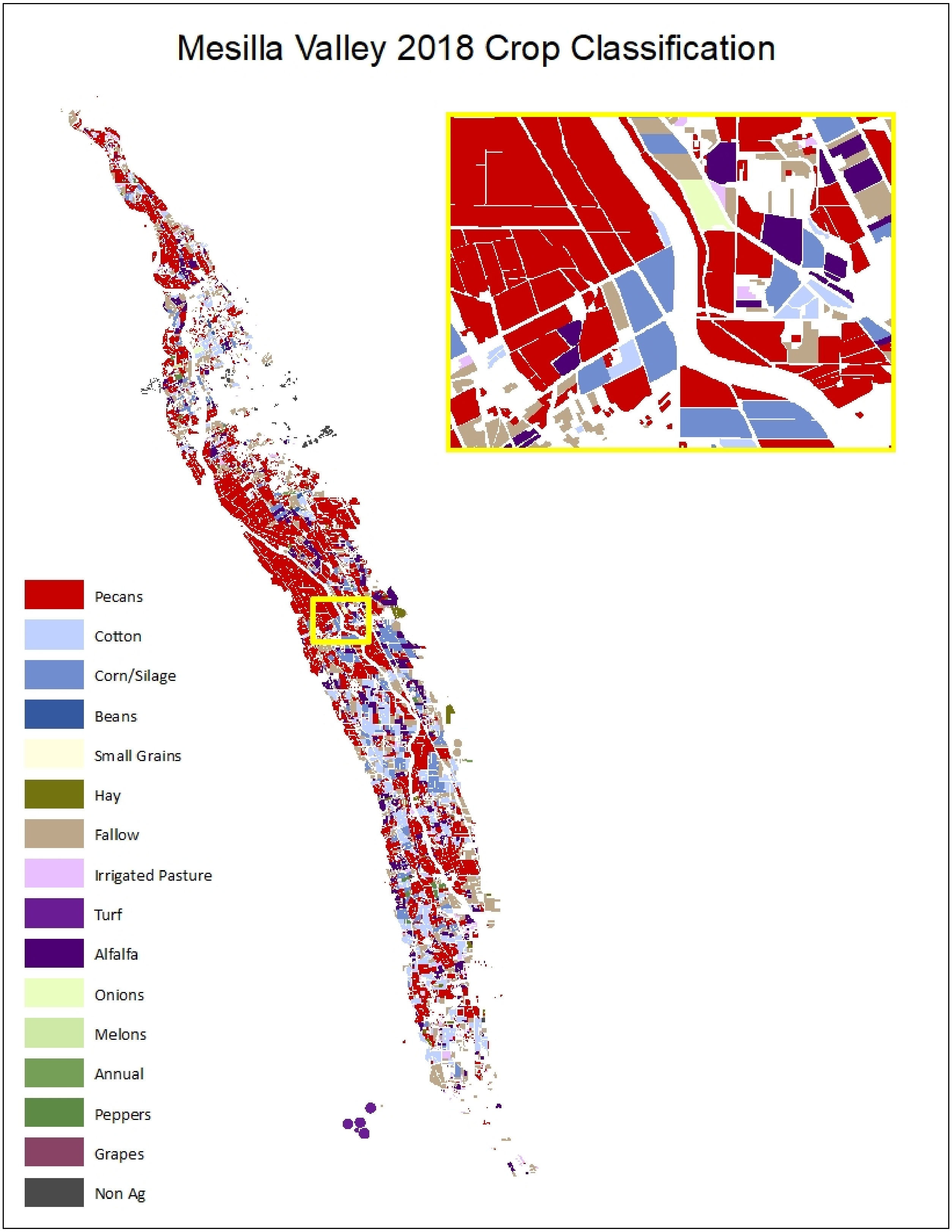
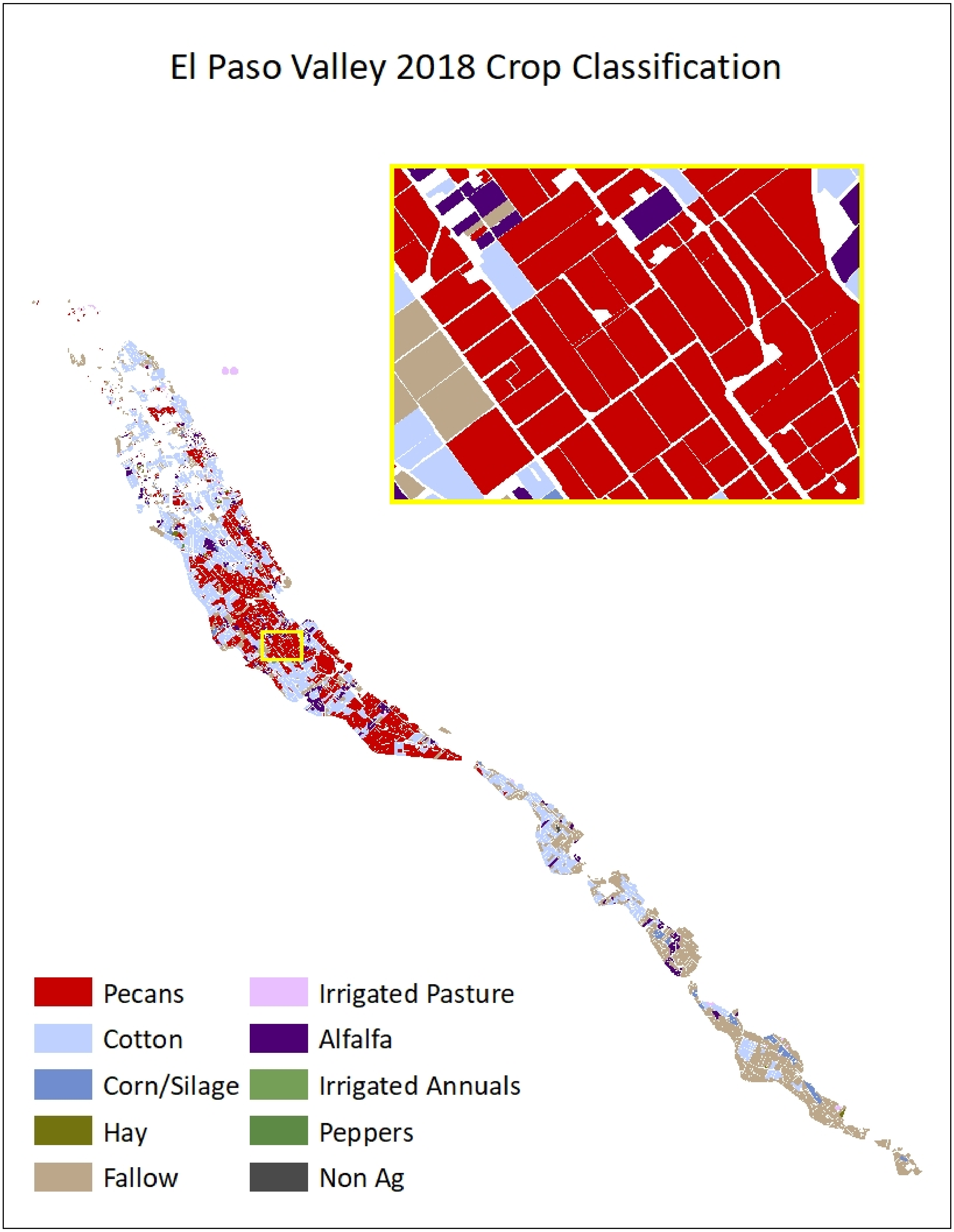


Exhibit 6. 2018 Crop Classification – El Paso Valley



2016 Analysis

Data Sources

- **Imagery** - Images used for this analytical year are summarized below.

	Imagery	Date	Resolution	Color
Rincon	NAIP Landsat 8	May/early June Multiple dates	1 m 30 m	Natural Color Multispectral
Mesilla	NAIP Landsat 8	May/June/August Multiple dates	1 m 30 m	Natural Color Multispectral

- **Field Data** – Ground truth data for summer crops in all three valleys was collected in June 2014 and used as training data for classification efforts.

- **Ancillary Data** - Ancillary data used to validate and assist the development of the 2016 crop map included the 2014 classification results, the 2013 Cropland Data Layer (CDL) produced by the National Agricultural Statistics Service (NASS) of the USDA, the closest available dates of the Elephant Butte Irrigation District (EBID) crop report (2013), and the El Paso County Water Improvement District #1 (EPCWID) crop report (2012). These data informed the analysts as to the likely dominant crop types and their relative percentages in the years immediately preceding the analysis date, but were not used for spatial analysis.

Mapping Methodology

Source imagery included NAIP imagery (1m) from late May/early June, and multiple dates of Landsat 8 imagery (30 m) from across the growing season. An object-based (i.e., field-based) image classification was performed to map the crop types for Rincon and Mesilla Valleys with the 2016 imagery. Field data were stratified by crop type and divided into training and validation data. Mean values of the various image bands were extracted from each image date. The mean image values and training data were input to a random forest statistical classification algorithm that assigns a crop type to each field based on the field's statistical similarity to training data.

After the random forest classification was completed, an accuracy assessment was performed using independent validation field data. The resultant accuracy assessment matrix provides information on the overall accuracy and the accuracy of individual crop types.

Following the accuracy assessment, additional photo-interpretation editing was performed to refine the classification. Fields with low classification probability values were inspected and evaluated against the imagery. When a low probability was identified through expert photo-interpretation, the class label was corrected. The high resolution of the aerial imagery provided textural cues that were correlated to crop type. Row structures and even some plant structures could be discerned, allowing for a high level of discrimination between crop types during the review/editing phase.

Mapped Classes

Multiple dates of high-resolution imagery and ground truth data supported detailed crop mapping for 2016 and 2014. The crop legend accounted for 34 individual crop types and land uses. Using the Landsat and NAIP imagery, early and late season crops were identified and mapped (e.g., small grains, onions, lettuce, cabbage, melons, etc.).

Exhibit 7. 2016 Crop Classification – Rincon Valley

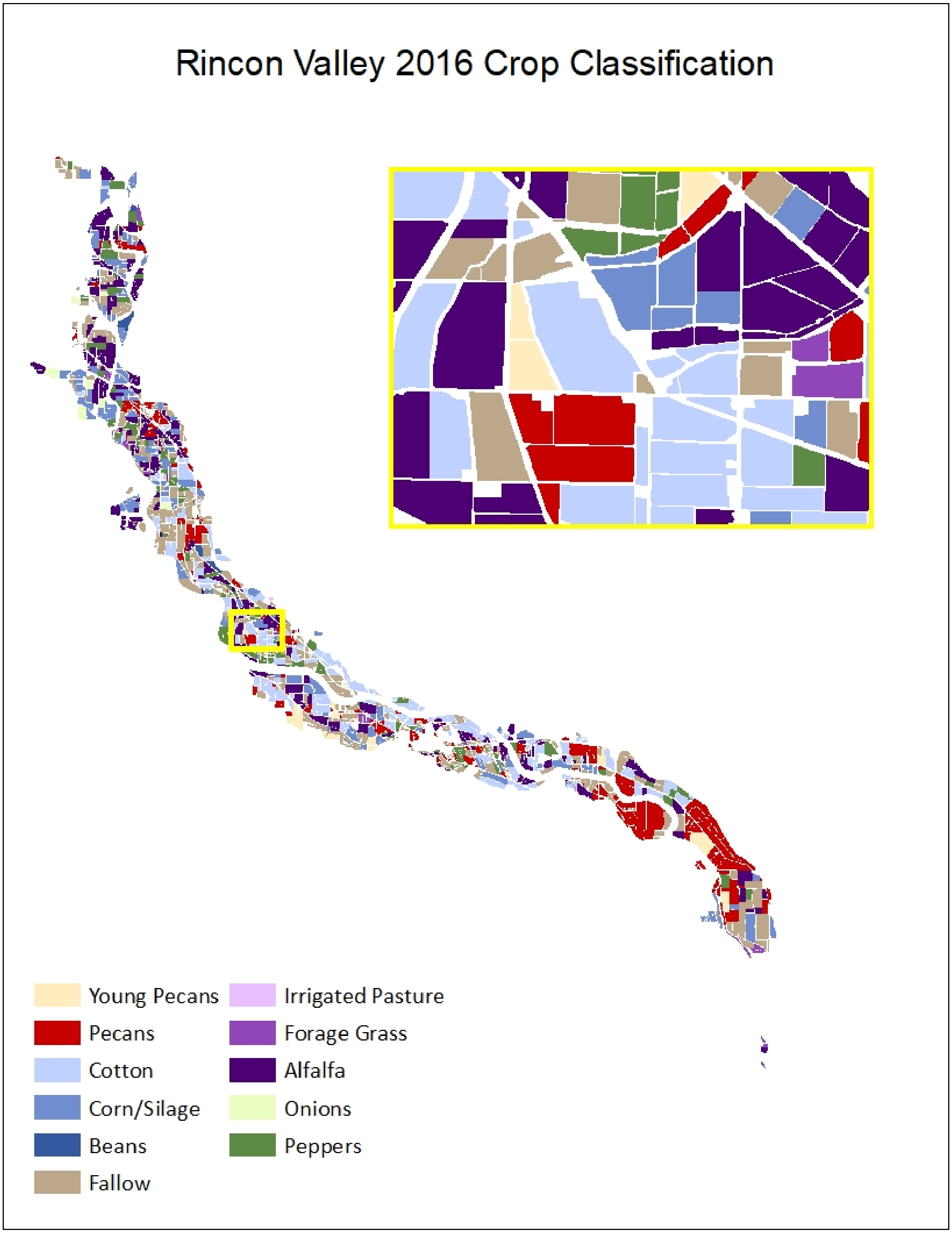


Exhibit 8. 2016 Crop Classification – Mesilla Valley

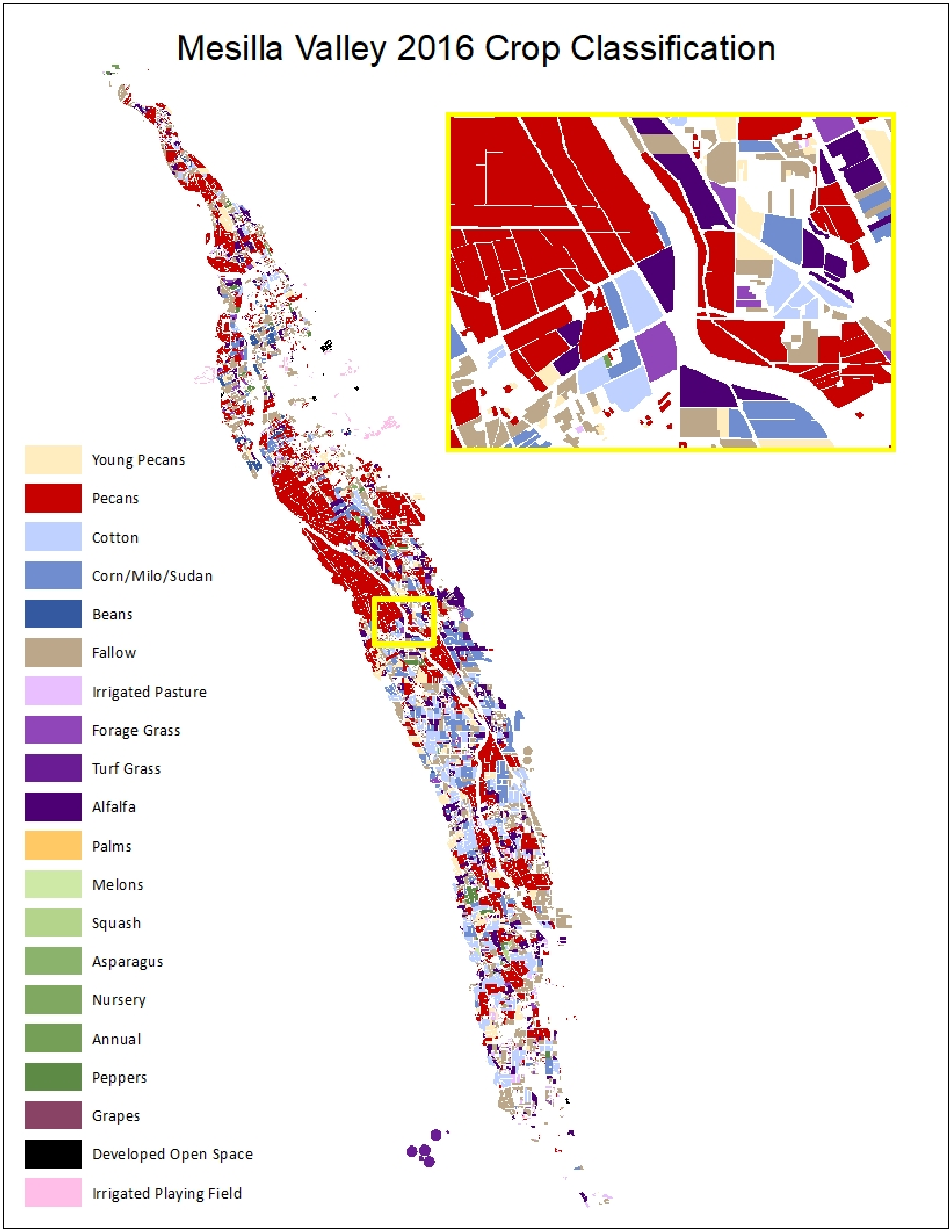
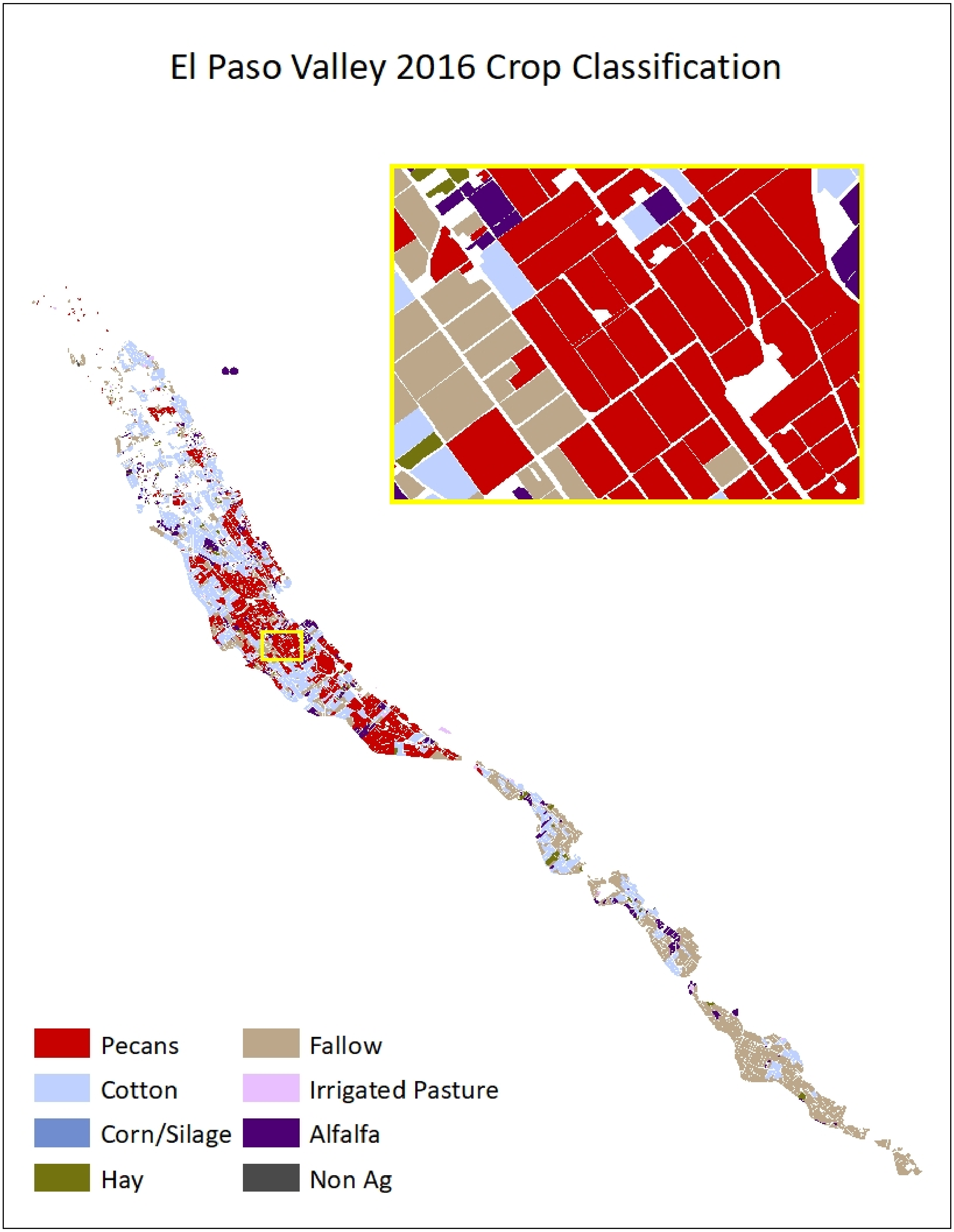


Exhibit 9. 2016 Crop Classification – El Paso Valley



2014 Analysis

Data Sources

- **Imagery** - Images used for this analytical year are summarized below.

	Imagery	Date	Resolution	Color
Rincon	Aerial Imagery NAIP Landsat 8	Aug 19-20, 2014 May/early June Multiple dates	0.33 feet 1 m 30 m	CIR (# bands) Natural Color Multispectral
Mesilla	Aerial Imagery NAIP Landsat 8	Aug 19-20, 2014 May/early June Multiple dates	0.33 feet 1 m 30 m	CIR (# bands) Natural Color Multispectral
El Paso	Aerial Imagery NAIP Landsat 8	Aug 19-20, 2014 Aug/Oct 2014 Multiple dates	0.33 feet 1 m 30 m	CIR (# bands) Natural Color Multispectral

- **Field Data** – Ground truth data for summer crops in all three valleys was collected in June 2014. Additional ground-truth data for fall annuals was collected during September 2014. A total of 3,812 ground truth points were collected, representing 25 crop classes. The resulting GIS dataset consisted of a point layer with attributes indicating crop, irrigation method, date of collection, and field comments.

- **Ancillary Data** - Ancillary data used to validate and assist the development of the 2014 crop map included the 2013 Cropland Data Layer (CDL) produced by the National Agricultural Statistics Service of the USDA, and the closest available dates of the Elephant Butte Irrigation District (EBID) crop report (2013) and the El Paso County Water Improvement District #1 (EPCWID) crop report (2012). These data informed the analysts as to the likely dominant crop types and their relative percentages in the years immediately preceding the analysis date but were not used for spatial analysis.

Mapping Methodology

Source imagery included high resolution aerial imagery (0.33 feet) from Aug. 2014, NAIP imagery (1m) from late May/early June, and multiple dates of Landsat 8 imagery (30 m) from across the growing season. An object-based (i.e., field-based) image classification was performed to map the crop types for Rincon and Mesilla Valleys with the 2014 imagery. Field data were stratified by crop type and divided into training and validation data. Eighty percent of the ground data sites for crop type were used for training, while 20% were set aside for independent validation/accuracy assessment. Mean values of the various image bands were extracted from each date of imagery. The mean image values and training data were input to a random forest statistical classification algorithm that assigns a crop type label to each field based on the field's statistical similarity to training data.

After the random forest classification was completed, an accuracy assessment was performed using independent validation. The resultant accuracy assessment matrix provides information on the overall

2014 classification accuracy and the accuracy of individual crop types (Appendix C). The year 2014 served as the baseline year for change analysis for historical years. It was also the only year for which detailed ground-truth data were available.

Following the accuracy assessment, additional photo-interpretation editing was performed to refine the classification. Fields with low classification probability values were inspected and evaluated against the imagery. When an error was identified through expert photo-interpretation, the class label was corrected. The extreme high resolution of the aerial imagery provided textural cues that were correlated to crop type. Row structures and even some plant structures could be discerned, allowing for a high level of discrimination between crop types during the review/editing phase.

Because of the relatively low crop type diversity and the level of detail provided by the very high resolution of the aerial imagery, the El Paso Valley was mapped solely based on photo-interpretation. The ground-truthing sites were used to guide the classification.

A rainfall event that occurred during the collection of the aerial imagery covering Rincon Valley resulted in a slight difference in the spectral characteristics of the aerial imagery between the north and south parts of Rincon Valley. Additionally, the aerial imagery showed some cloud shadows in the center of the Rincon Valley, and one data band (NIR) was missing from two small areas in this valley, resulting in small "holes" in the imagery. The inclusion of the other imagery sources (e.g., NAIP) mitigated the impact of these limitations.

Mapped Classes

Multiple dates of high-resolution imagery and ground truth data for 2014 supported a highly detailed crop mapping. The crop legend accounted for 36 individual crop types and land uses. Using the Landsat imagery in conjunction with the multiple high-resolution images, early and late season crops also were identified and mapped (e.g., small grains, onions, lettuce, cabbage, melons, etc.).

Exhibit 10. 2014 Crop Classification – Rincon Valley

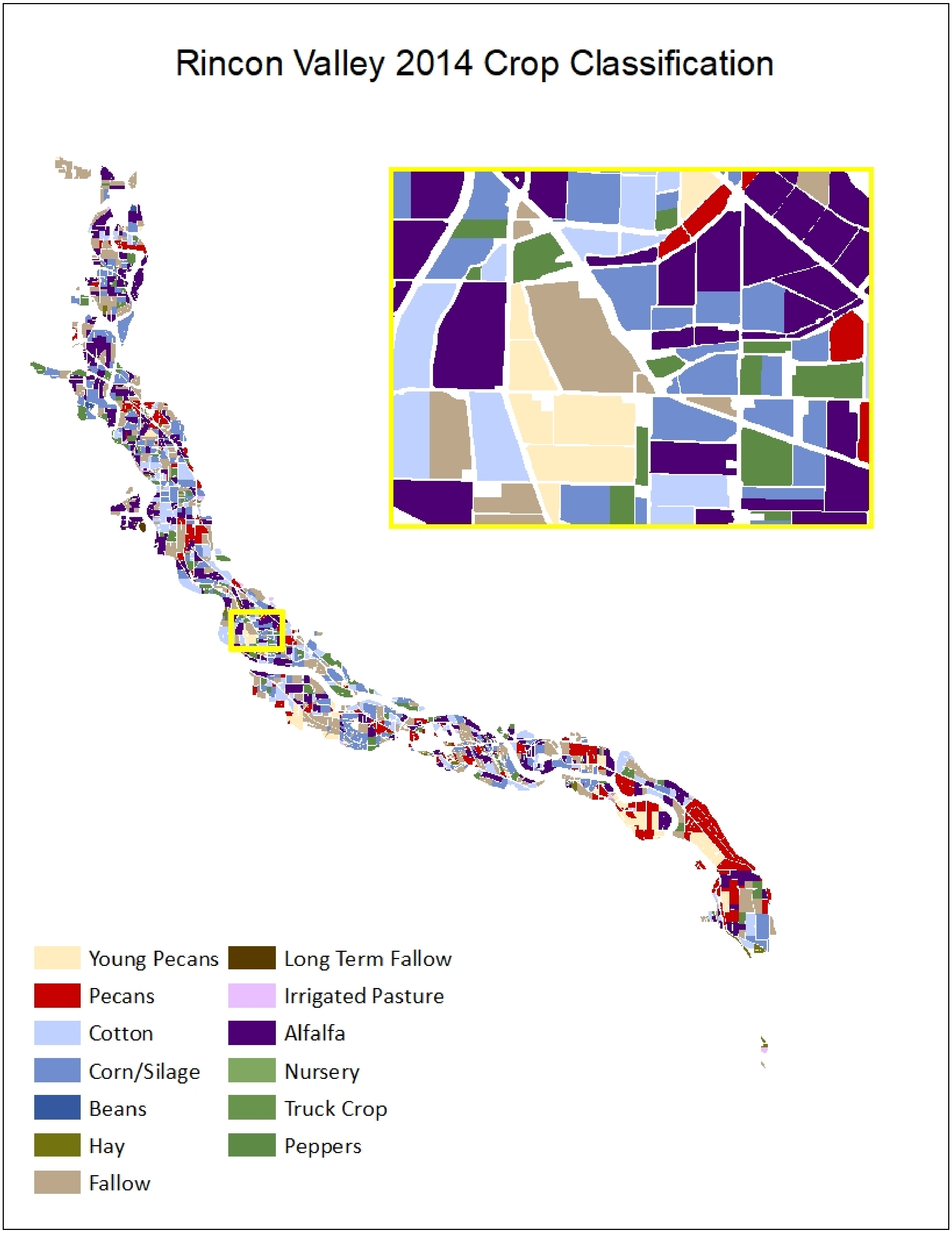


Exhibit 11. 2014 Crop Classification – Mesilla Valley

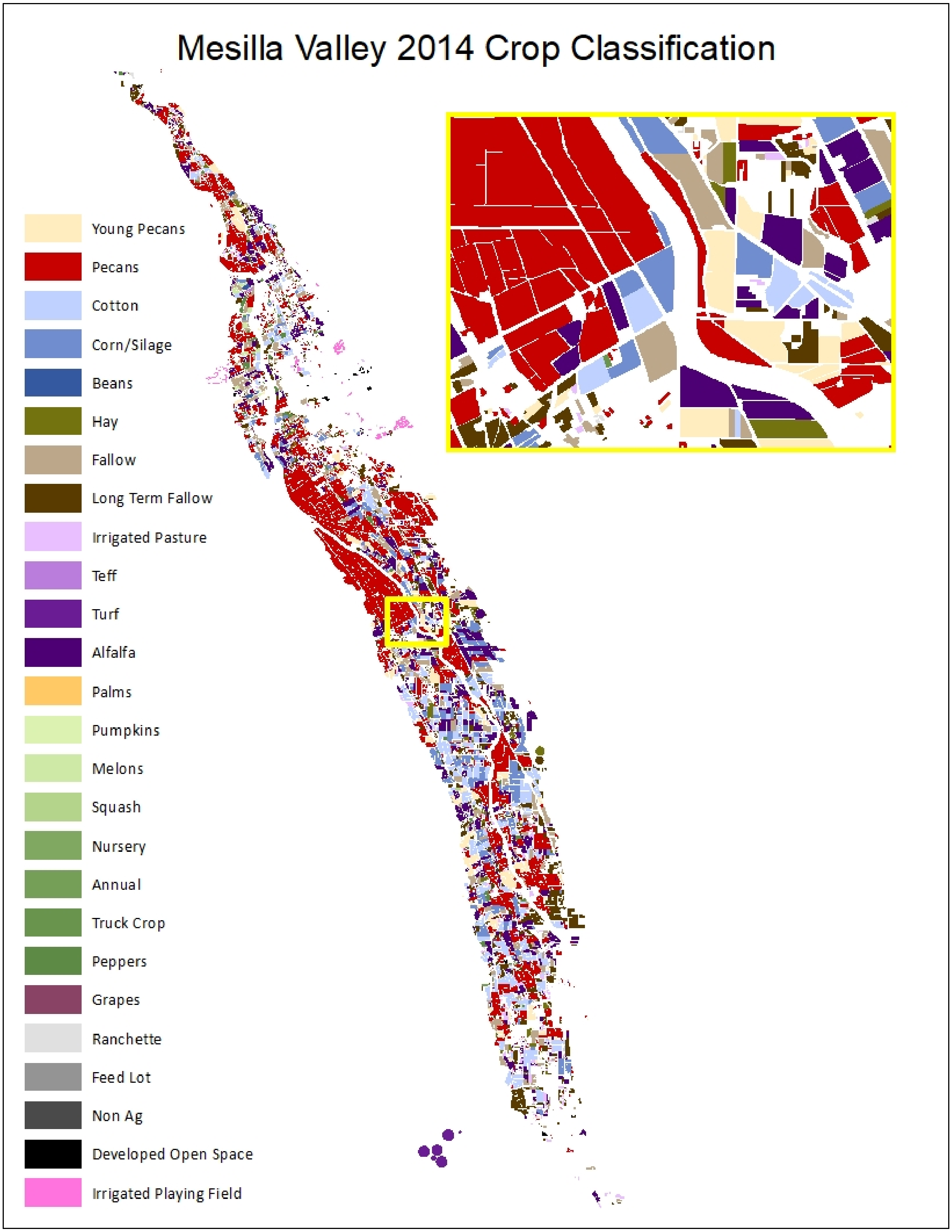
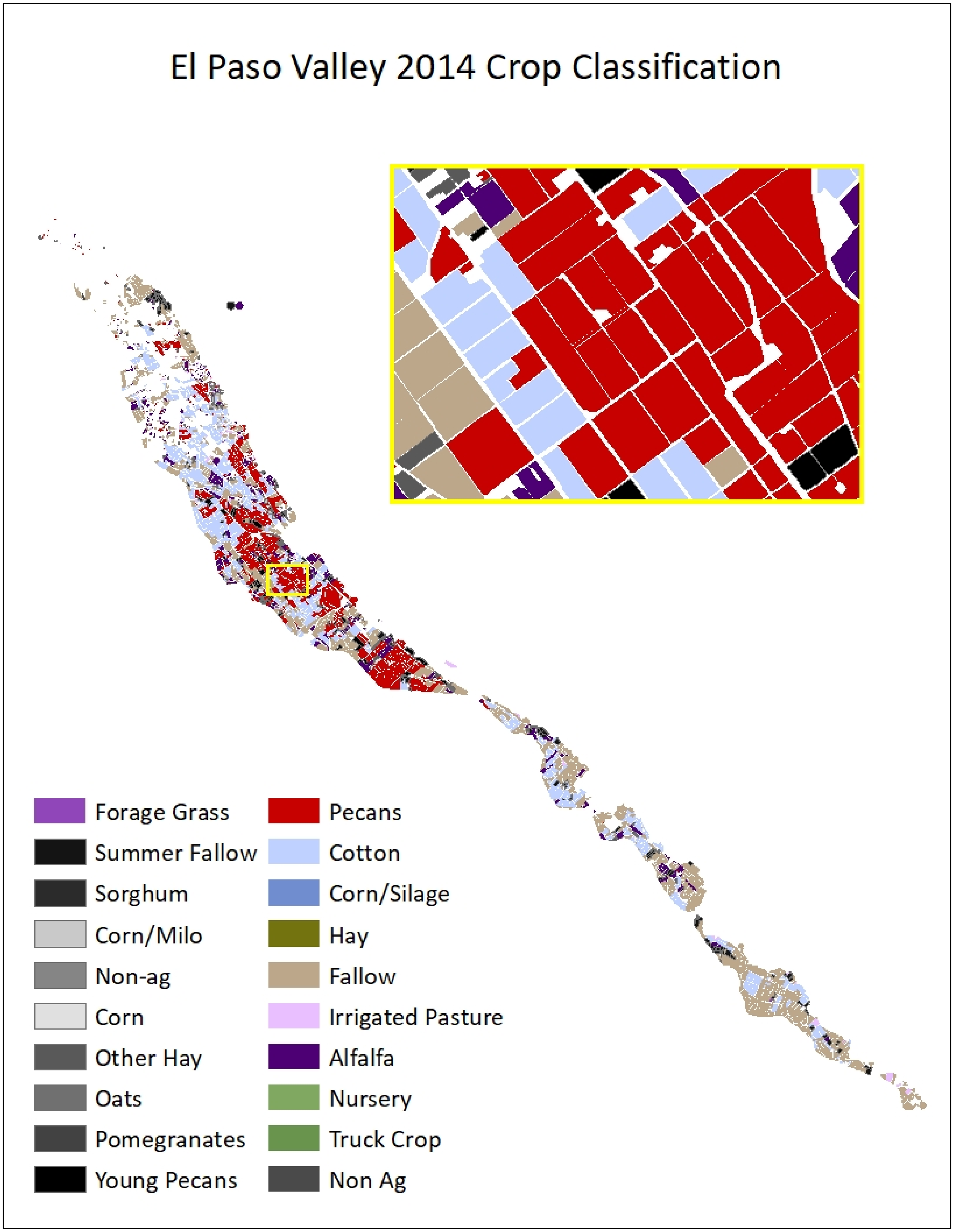


Exhibit 12. 2014 Crop Classification – El Paso Valley



2012/2011 Analysis

Data Sources

- **Imagery** - Images used for this analytical year are summarized below.

	Imagery	Date	Resolution	Color
Rincon	NAIP	May 2011/Nov 2011	1 m	CIR
	RapidEye	Aug 7 & 23, 2011	5 m	Multispectral
	Landsat 5	Multiple dates	30 m	Multispectral
Mesilla	NAIP	May 2011/Nov 2011	1 m	CIR
	RapidEye	Aug 6 & 23, 2011	5 m	Multispectral
	Landsat 5	Multiple dates	30 m	Multispectral
El Paso	NAIP	Aug 30, 2012	1 m	Natural Color
	RapidEye	May 24 & Jun 21, 2012	5 m	Multispectral
	Landsat 5	Multiple dates	30 m	Multispectral

- **Ancillary Data** - Ancillary data used to validate and assist development of the 2011/2012 crop map included 2011 Cropland Data Layer (CDL) produced by USDA and the EBID and EPCWID crop reports from 2011 and 2012. These data informed the analysts as to the dominant crop types and their relative percentages in 2011. Google Earth high-resolution imagery from November 2011, covering much of Rincon Valley and all of Mesilla Valley, provided a valuable source of additional photo-interpretation information.

Mapping Methodology

Source imagery for the 2011 agriculture mapping of Rincon and Mesilla Valleys consisted of:

- High resolution (1 m) NAIP imagery from May;
- RapidEye satellite imagery from late summer (August); and
- Landsat 5 imagery from throughout the growing season.

Similar imagery was used to map El Paso Valley, except that the NAIP imagery was from August and the RapidEye imagery was from May/June. Because no field data was available from 2011, training sites representing the different crop types were identified by photo-interpretation of the high-resolution imagery only when crop type was certain. A random forest classification was conducted to assign class labels to each field based on each field’s spectral similarity to the input training sites. The results of the random forest classification were inspected and refined based on photo-interpretation. The review/editing stage benefitted from Google Earth’s high-resolution, natural color image from November 11, 2011, covering all of Mesilla Valley and all but the northern 20% of Rincon Valley. This imagery was a valuable photo-interpretation resource for validating and refining the final crop map. In particular, this November imagery greatly facilitated the discrimination of cotton from other crops. The mature cotton bolls gave the cotton fields a distinct visual signature.

Mapped classes

The crop legend for 2011 was similar to the crop legend developed for 2014 because of the availability of timely, high resolution imagery sources. In total, 26 individual crop and land use classes were mapped.

Exhibit 13. 2011 Crop Classification – Rincon Valley

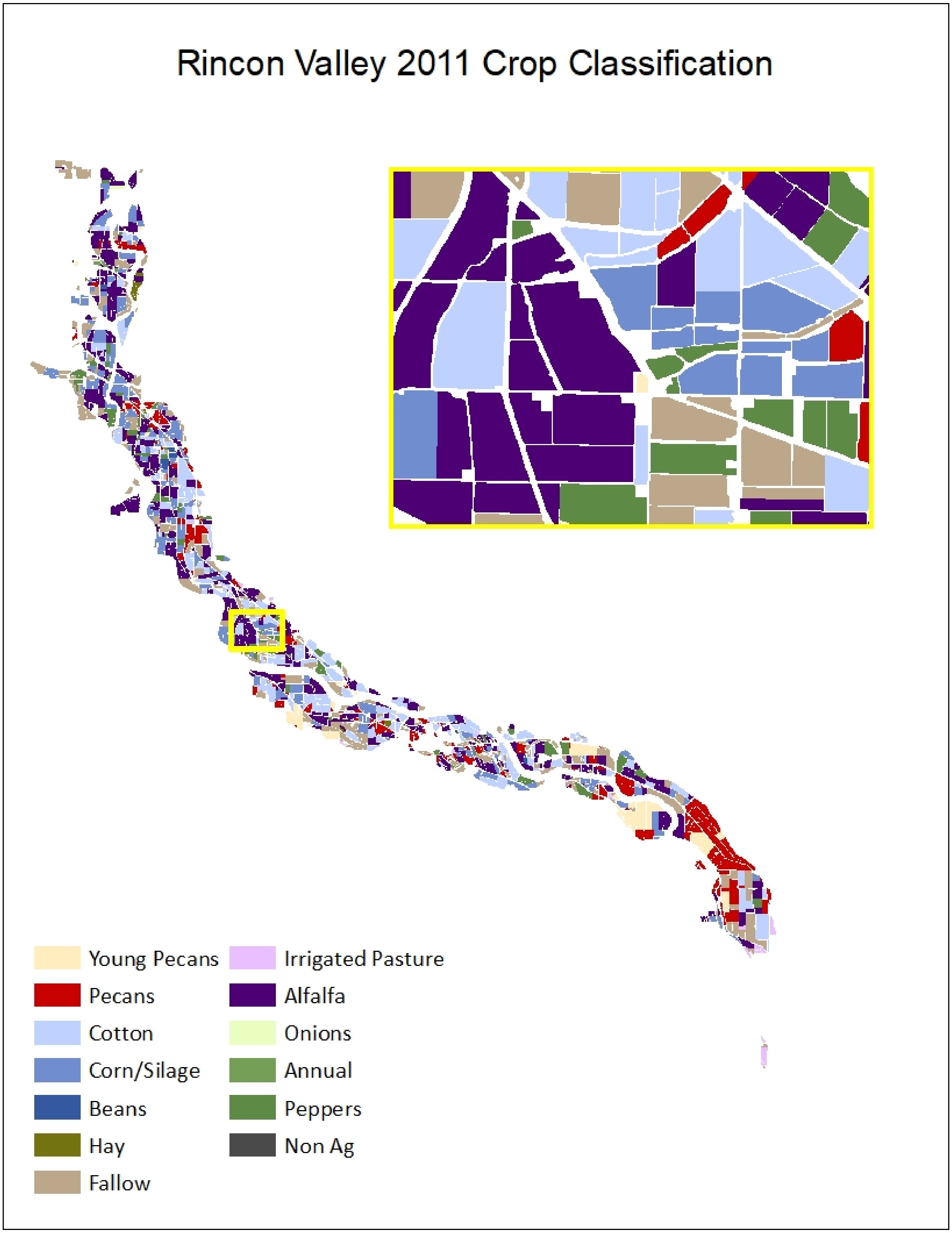


Exhibit 14. 2011 Crop Classification – Mesilla Valley

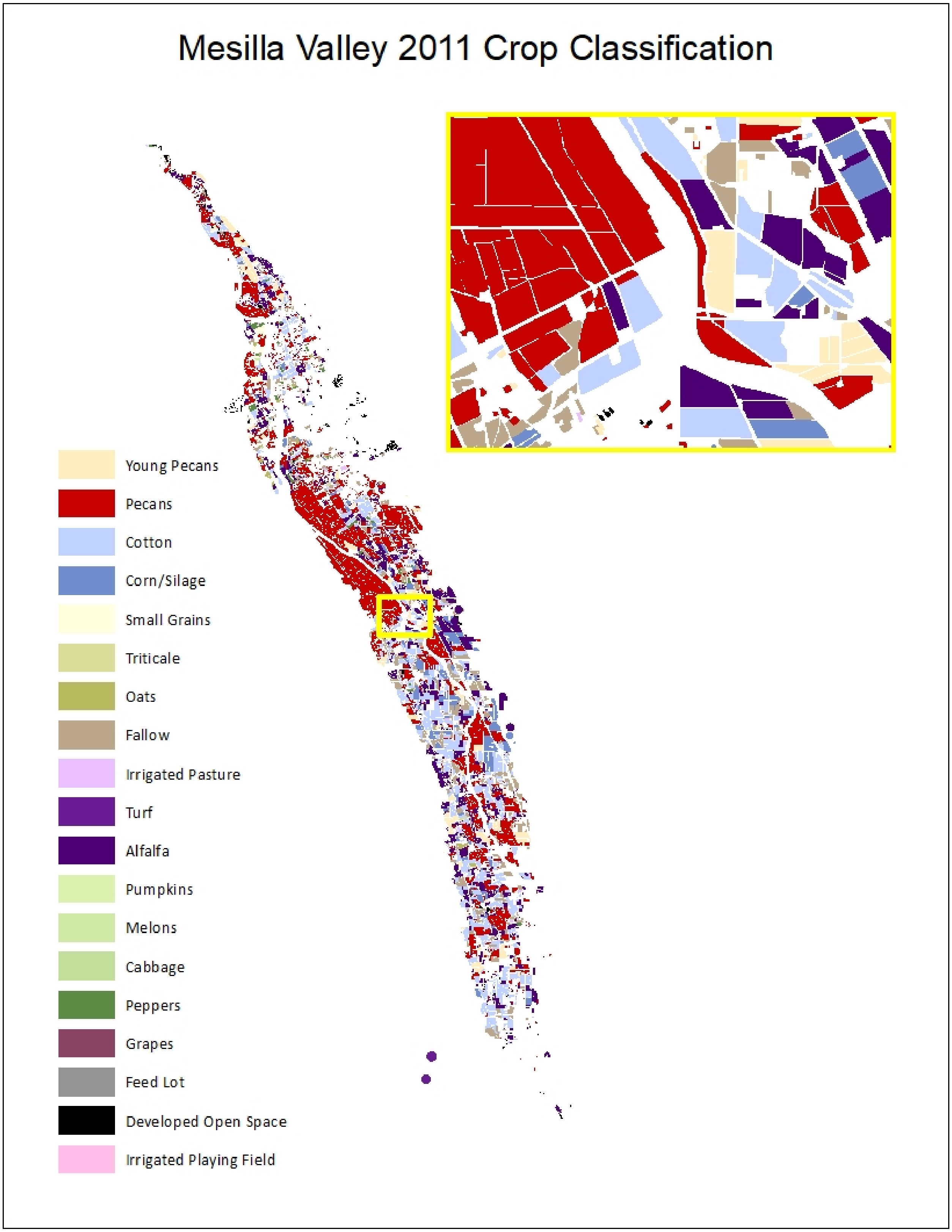
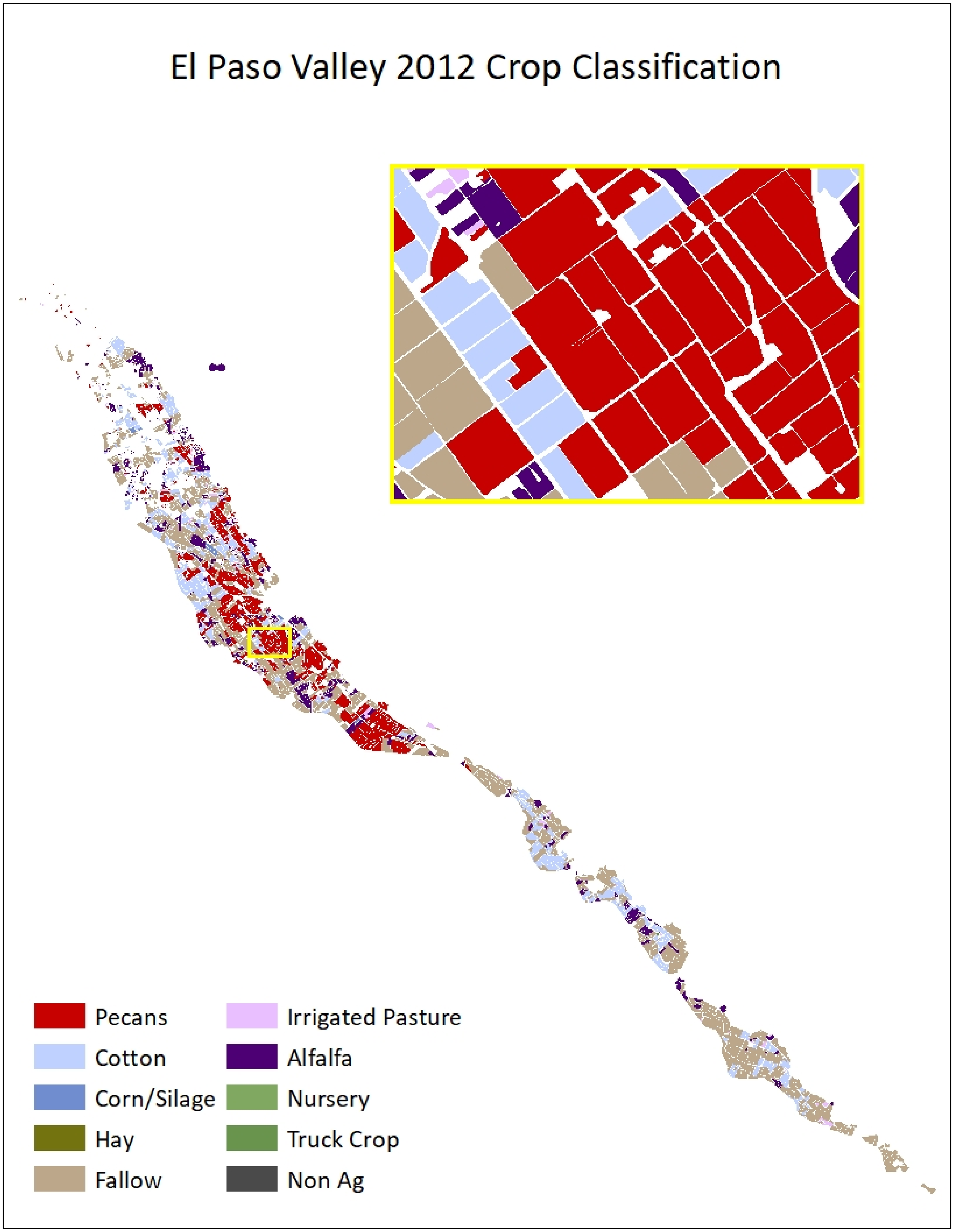


Exhibit 15. 2012 Crop Classification – El Paso Valley



2006 Analysis

Data Sources

- **Imagery** - Images used for this analytical year are summarized below.

	Imagery	Date	Resolution	Color
Rincon	NAIP	Aug 24, 2006	2 m	Natural Color
	Aster	July 20, 2006	15 m	CIR
	Landsat 5	Multiple dates	30 m	Multispectral
Mesilla	NAIP	Aug/Sept, 2006	2 m	Natural Color
		Aug 2006	15 m	CIR
	Landsat 5	Multiple dates	30 m	Multispectral
El Paso	NAIP	Sept, 2012	2 m	CIR
	Landsat 5	Multiple Dates	30 m	Multispectral
	Landsat 5	Multiple dates	30 m	Multispectral

- **Ancillary Data** - Ancillary data used to validate and assist the development of the 2006 crop map included the EBID 2006 crop report.

Mapping Methodology

Similar to the 2011 analysis, a random forest classification was conducted to map the individual crop types for all three valleys for 2006. Imagery sources included:

- High resolution NAIP imagery from August (Rincon and Mesilla) and September (El Paso);
- ASTER satellite imagery from various summer dates; and
- Landsat 5 satellite imagery from across the growing season.

Training sites representing the different crop types were identified by photo-interpretation.

Mapped classes

The level of detail and crop classes mapped for 2006 were similar to 2011 and 2014, with 26 individual crop and land use classes identified. For 2006, the late summer grain and silage were grouped together as the imagery resolution was not sufficient to separate corn, sorghum, and sudangrass. However, these three crops have similar consumptive use quantities.

Exhibit 16. 2006 Crop Classification – Rincon Valley

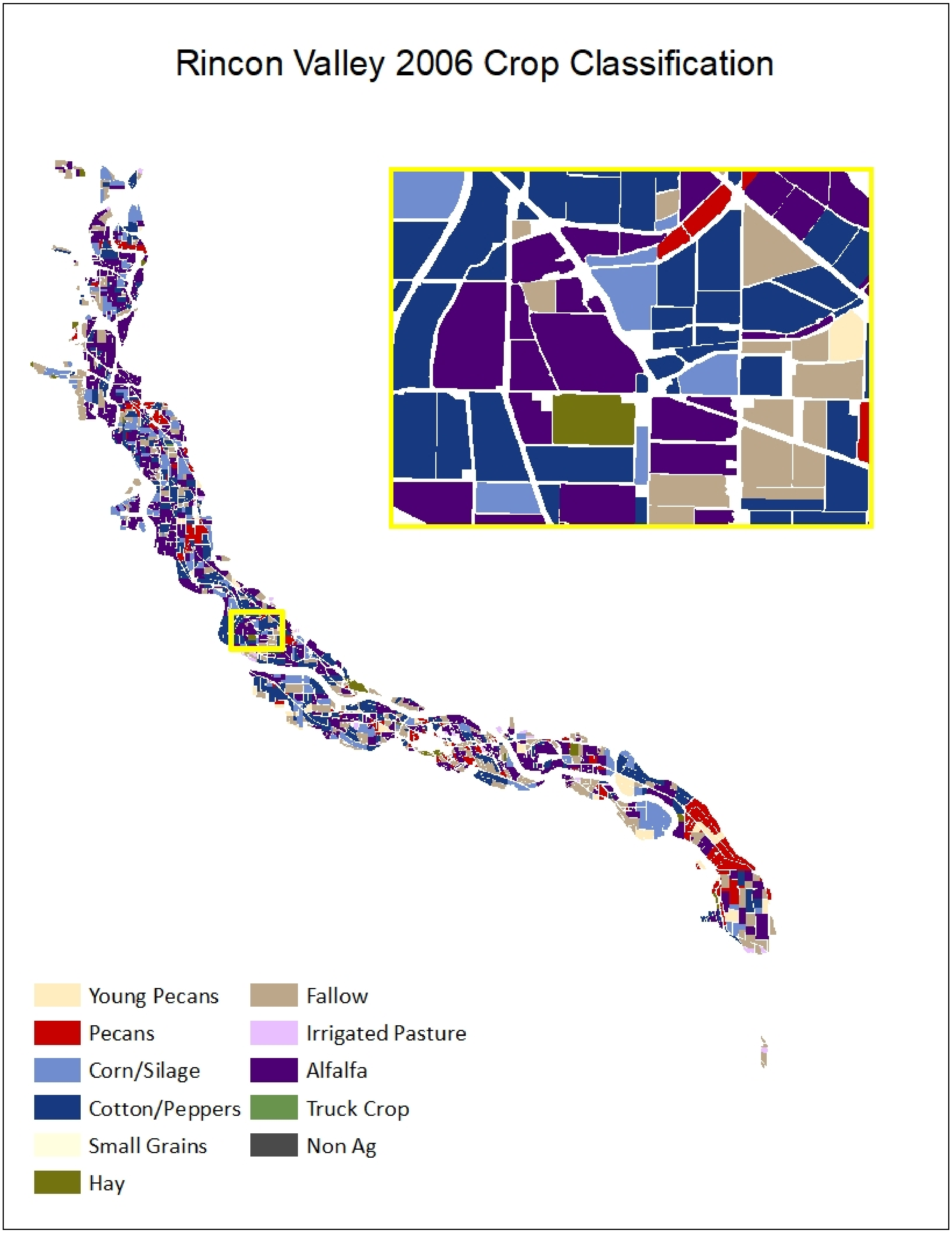


Exhibit 17. 2006 Crop Classification – Mesilla Valley

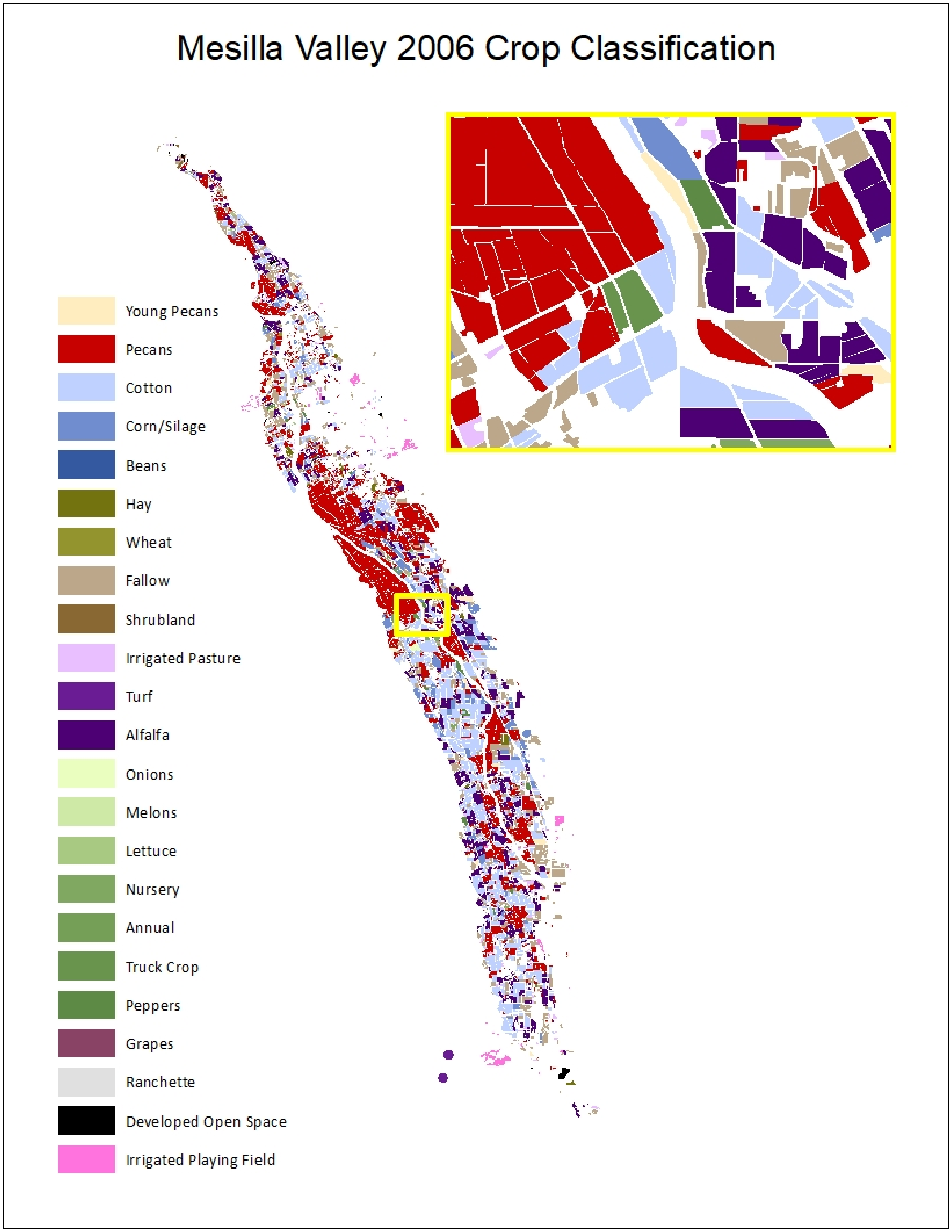
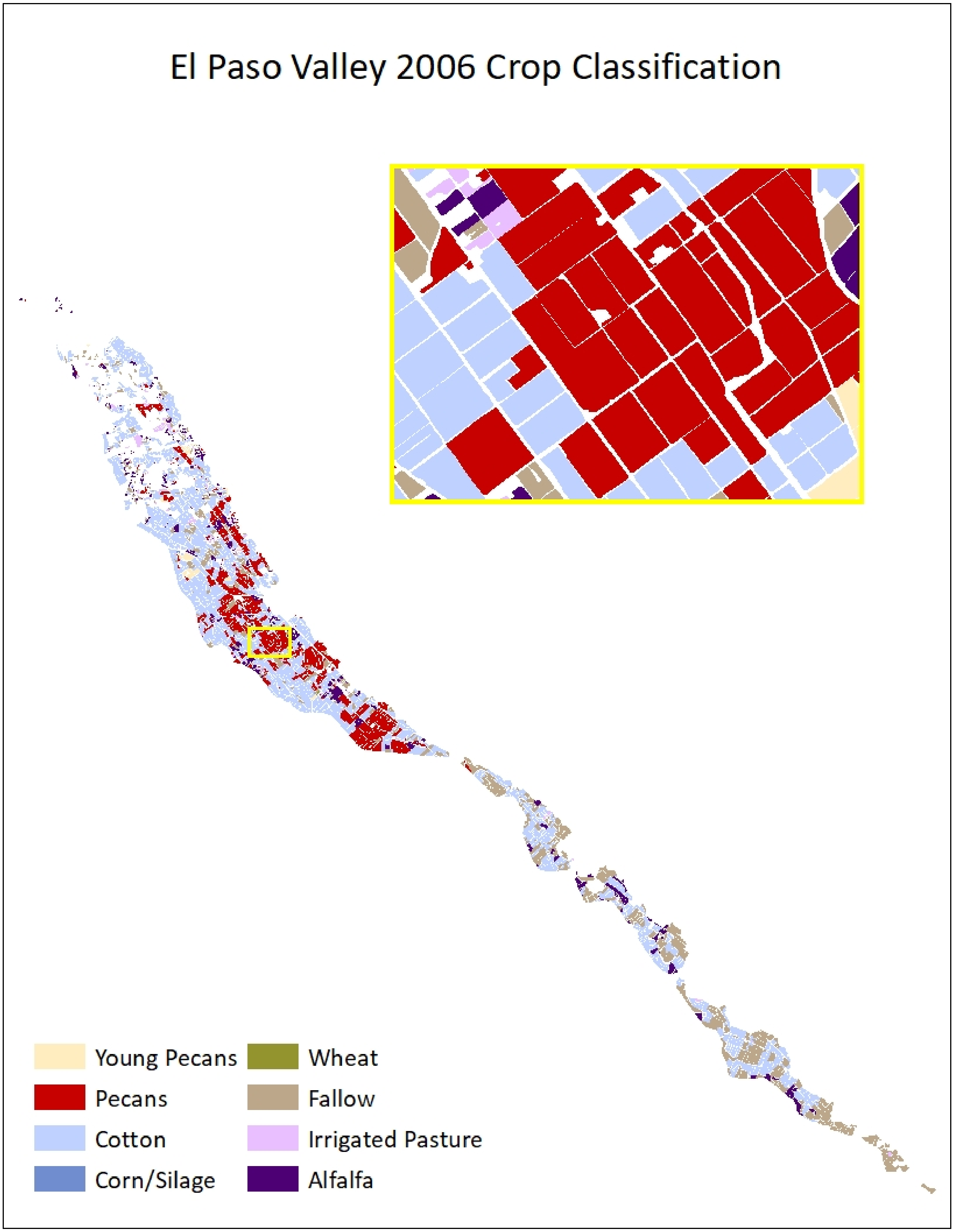


Exhibit 18. 2006 Crop Classification – El Paso Valley



1996 Analysis

Data Sources

- **Imagery** - Images used for this analytical year are summarized below.

	Imagery	Date	Resolution	Color
Rincon	NAPP Landsat 5	Sept/Oct, 1996 Multiple dates	1 m 30 m	CIR Multispectral
Mesilla	NAPP Landsat 5	March/Oct, 1996 Multiple dates	1 m 30 m	CIR Multispectral
El Paso	NAPP Landsat 5	Jan – March, 1996 Multiple dates	4 m 30 m	CIR Multispectral

- **Ancillary Data** - Ancillary data used to validate and assist development of the 1996 crop map included the EBID and Bureau of Reclamation (BOR) 1996 crop reports. These data informed the analysts as to the dominant crop types and their relative percentages in 1996.

Mapping Methodology

Data sources for the 1996 mapping consisted of:

- National Aerial Photograph Program (NAPP) aerial photos; and
- Landsat 5 imagery from across the growing season.

NAPP was captured in Sept./Oct. for Rincon Valley, and in March and October for Mesilla Valley. NAPP for El Paso Valley was captured between January and March.

Although the NAPP digital imagery had a spatial resolution (i.e., pixel size) of 1-square meter for Rincon and Mesilla, and 4-square meters for El Paso, the NAPP imagery was of lower quality than the 1-meter resolution NAIP imagery available for more recent dates. The NAPP imagery was collected as 1:40,000 scale film photographs from an altitude of 20,000 feet. The film was later scanned by USGS and orthorectified to produce the 1-meter resolution digital imagery.

A random forest classification was performed for mapping Rincon and Mesilla Valleys. While the NAPP imagery was used for some of the training site selection and to review/edit the classification results, they were not included in the random forest automated classification because the NAPP dates did not represent the summer growing season. Only the multiple dates of the Landsat imagery were included as independent variables for the random forest classification. Thus, the temporal and spectral patterns of the Landsat imagery were used to differentiate crop types. This corresponded to a crop calendar for yet another line of evidence resulting in a crop type designation. Although cotton and chilis have similar temporal and spectral characteristics, the late summer/early fall NAPP imagery allowed for confident differentiation of cotton and chili by photo-interpretation following the automated classification.

In addition, temporal NDVI values from each date of Landsat imagery were plotted for each field. These time series plots provided additional information for discriminating between different crop types, as certain crops have distinctive NDVI time profiles.

The El Paso Valley was manually classified in 1996, relying primarily on NDVI time series plots and photo-interpretation. Due to the limited number of crop types in the El Paso Valley, this was a suitable method to use to employ image resources during the growing season.

Mapped classes

Image resolution allowed for a crop and land use legend of 22 classes for Rincon and Mesilla Valleys, and a crop legend of 13 classes for the El Paso Valley, with the major crops of pecans, cotton, alfalfa, and corn/sorghum/milo all being separated into their own classes.

Exhibit 19. 1996 Crop Classification – Rincon Valley

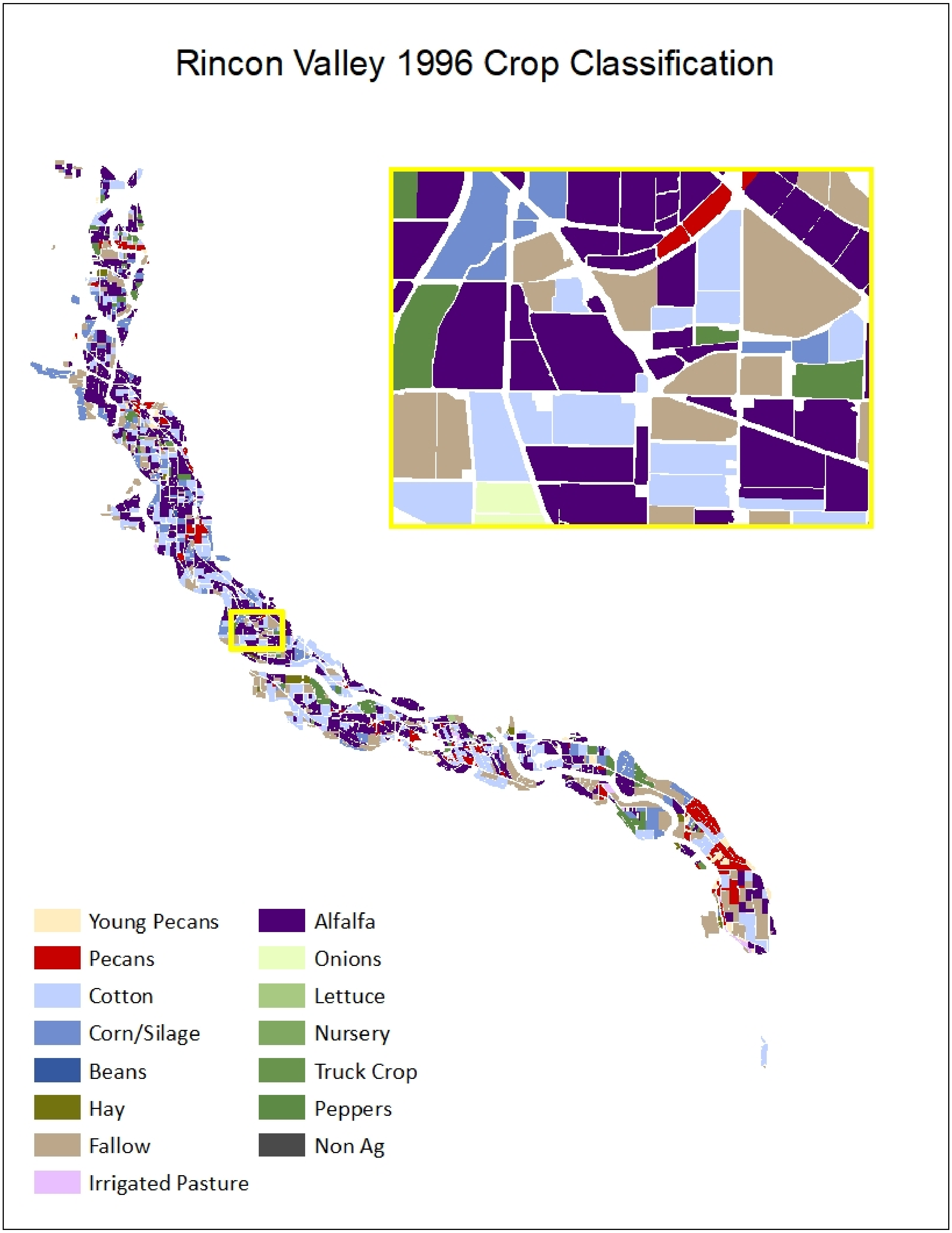


Exhibit 20. 1996 Crop Classification – Mesilla Valley

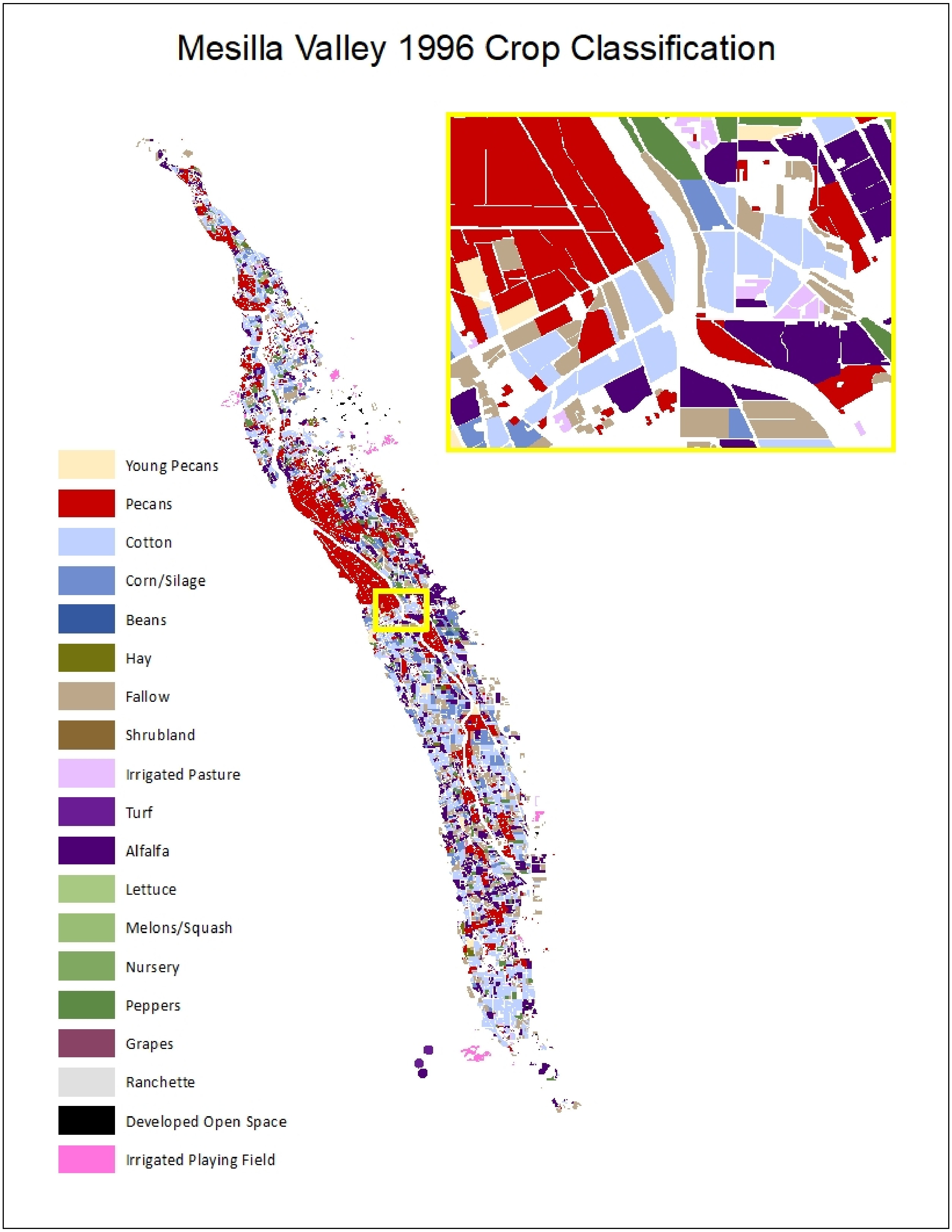
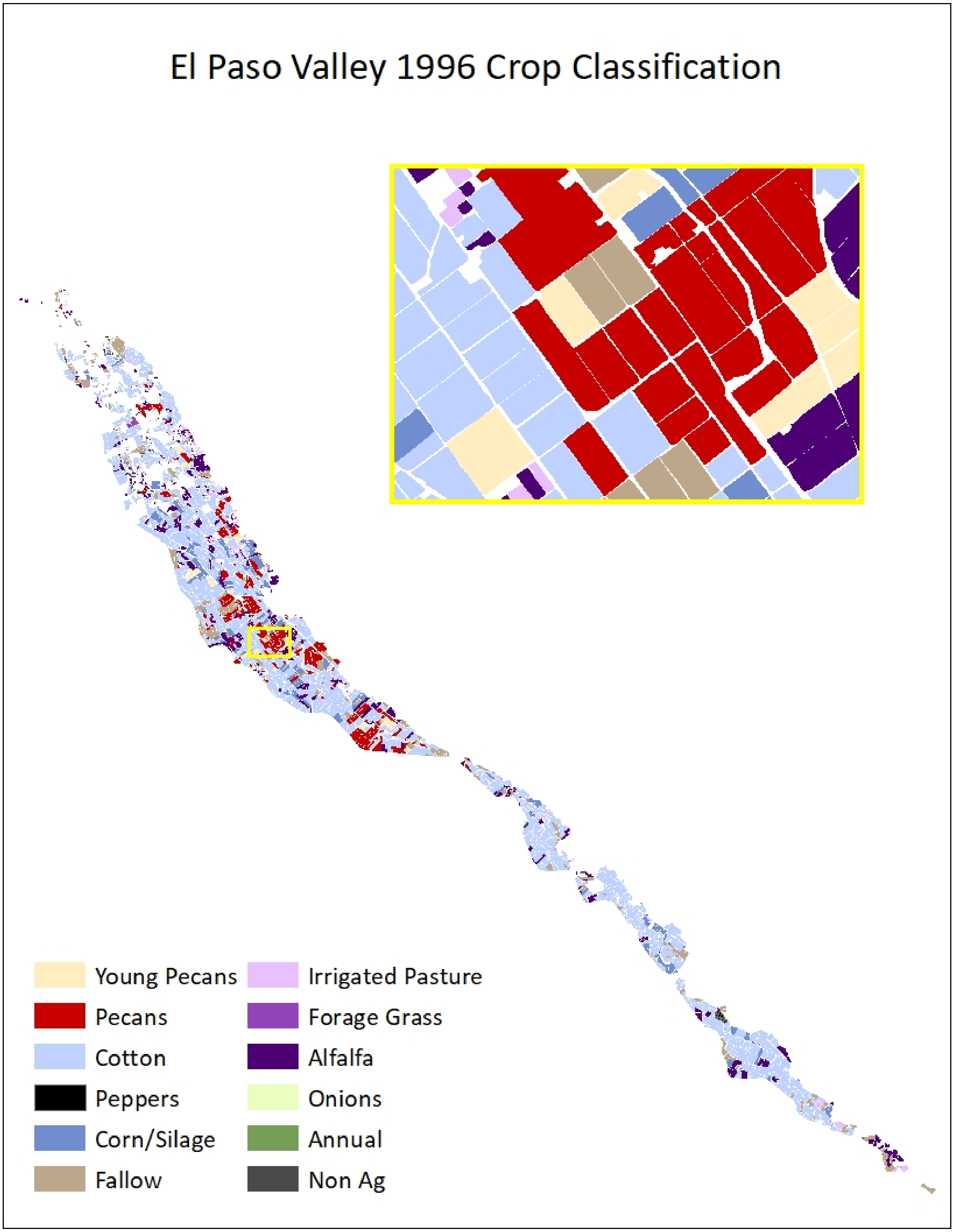


Exhibit 21. 1996 Crop Classification – El Paso Valley



1986 Analysis

Data Sources

- **Imagery** - Images used for this analytical year are summarized below.

	Imagery	Date	Resolution	Color
Rincon	NHAP Landsat 5	May & Sept, 1986 Multiple dates	4 m 30 m	CIR Multispectral
Mesilla	NHAP Landsat 5	June/July, 1996 Multiple dates	4 m 30 m	CIR Multispectral
El Paso	No appropriate imagery available			

- **Ancillary Data** - Ancillary data used to validate and assist the development of the 1986 crop map included the EBID and BOR 1986 crop reports.

Mapping Methodology

Source imagery for the 1986 analysis of Rincon and Mesilla consisted of:

- National High Altitude Photography (NHAP) program CIR aerial photos; and
- Landsat 5 imagery from multiple dates across the growing season.

The NHAP photos were originally acquired as film photos at an altitude of 40,000 feet, resulting in a scale of 1:58,000. The photos were then scanned by USGS and georeferenced with an output pixel resolution of 4 square meters.

The crop types were classified using a random forest classification methodology, with training sites selected via photo-interpretation and the Landsat data as independent variables. The 4-meter resolution of the NHAP imagery resulted in a classification with more grouped crop types compared to more recent years with higher resolution. The NHAP imagery for the Mesilla Valley was from June/July, and for both spring and late summer for the Rincon Valley. As in previous year classifications, time series profiles of the Landsat NDVI values were used to assist with the classification.

El Paso crops were not mapped in 1986 because no appropriate imagery was available.

Mapped classes

Decreased resolution of imagery resources for this date resulted in a reduced crop and land use classification legend; 17 individual classes were mapped. Textural, tonal, and structural differences of individual fields allowed for confident classification of alfalfa and pecans. Temporal and tonal differences allowed for some identification of spring and fall annuals, while the mid-summer annuals (corn, milo, sudangrass, cotton, and chili) had to be grouped as they could not be convincingly differentiated.

Exhibit 22. 1986 Crop Classification – Rincon Valley

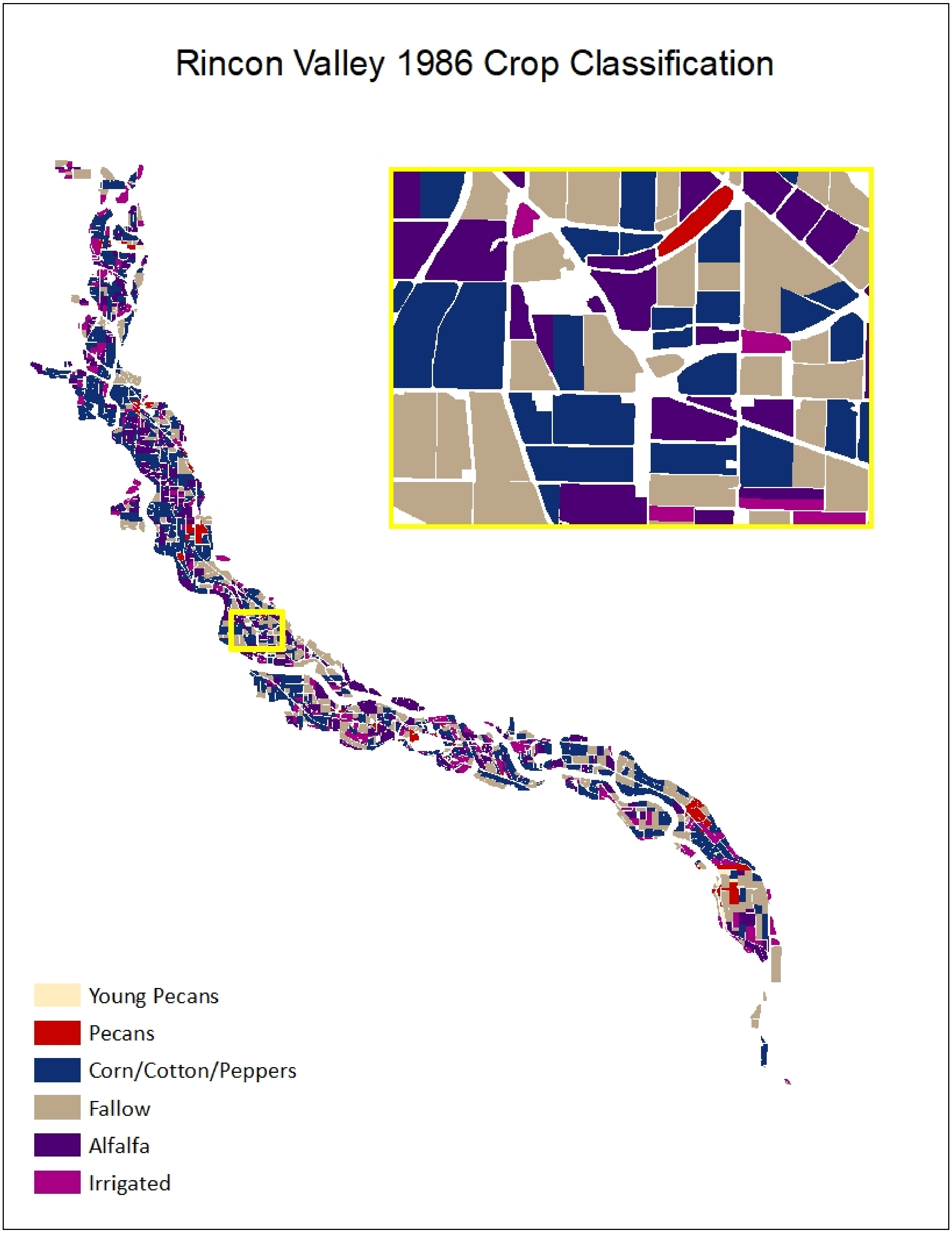
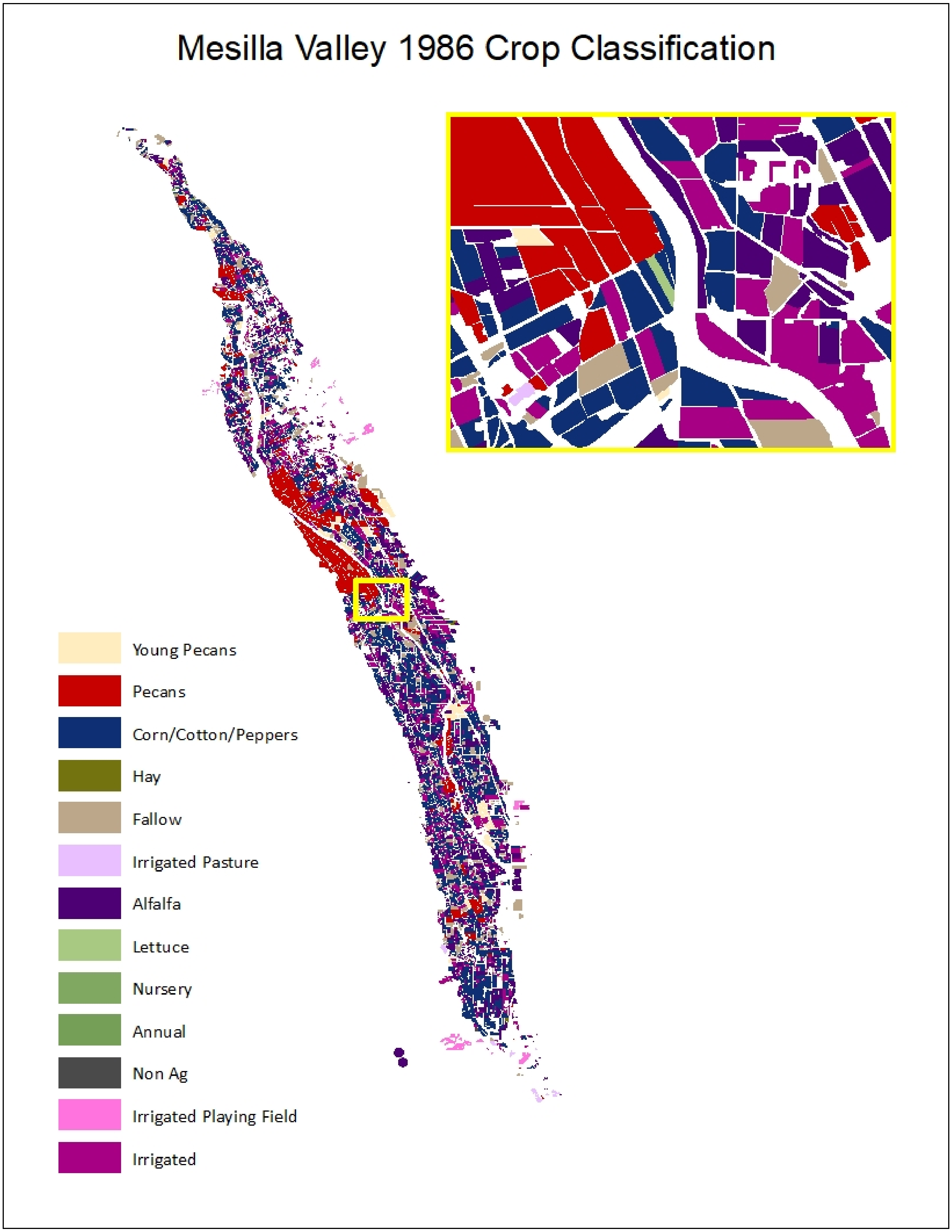


Exhibit 23. 1986 Crop Classification – Mesilla Valley



1977/1976/1975 Analysis

Data Sources

- **Imagery** - Images used for this analytical year are summarized below.

	Imagery	Date	Resolution	Color
Rincon	Declassified air photo	June 1976	4 m	B/W
Mesilla	Declassified air photo (only northern 60% of Mesilla covered)	June 1975	4 m	B/W
El Paso	Declassified air photo	Sept 1977 (not adequate for agricultural mapping		

- **Ancillary Data** - Ancillary data used to validate and assist the development of the crop map included the BOR 1975 crop report.

Mapping Methodology

The single image/photo source available for 1975 Rincon and Mesilla Valley was a declassified aerial photo from June 1975. The photo covered 100% of Rincon Valley and 60% of Mesilla Valley. The area was mapped accordingly. The remaining 40% of the Mesilla Valley was estimated from irrigated land classification, =with consideration of the distribution of crops from the prior and following decadal years, and the relative distribution of crop types from crop reports of that year. Due to the quality of the imagery, the classification was partitioned into crop groupings. The resolution was adequate to allow the distinction between pecans, alfalfa, and other field crops. Because of resolution limitations and the timing of the photo capture, the remaining field crops were not separated into individual crop types, but were instead grouped into a single irrigated crop class. For the purposes of estimating consumptive use and the knowledge of the distribution of the cropping systems from the crop reports, this was the most accurate approach. Fallow parcels were identified from surface tone and texture, and very light color (indicating increased reflectance of the land surface different from a cropped field). Fields that were prepared for planting, or had been planted, were clearly identifiable via photo interpretation.

Crop mapping was not completed for El Paso in 1977 because image collection dates for that period were outside of the growing season, and the few available image resources were of very poor coverage and quality. For example, a September 26, 1977, declassified image was of insufficient quality for this analytical effort.

Mapped Classes

Based on textural and field structure cues, four crop and land use classes were established. Alfalfa and pecans were identifiable, with the remaining fields grouped into either irrigated or fallow.

Exhibit 24. 1976 Crop Classification – Rincon Valley

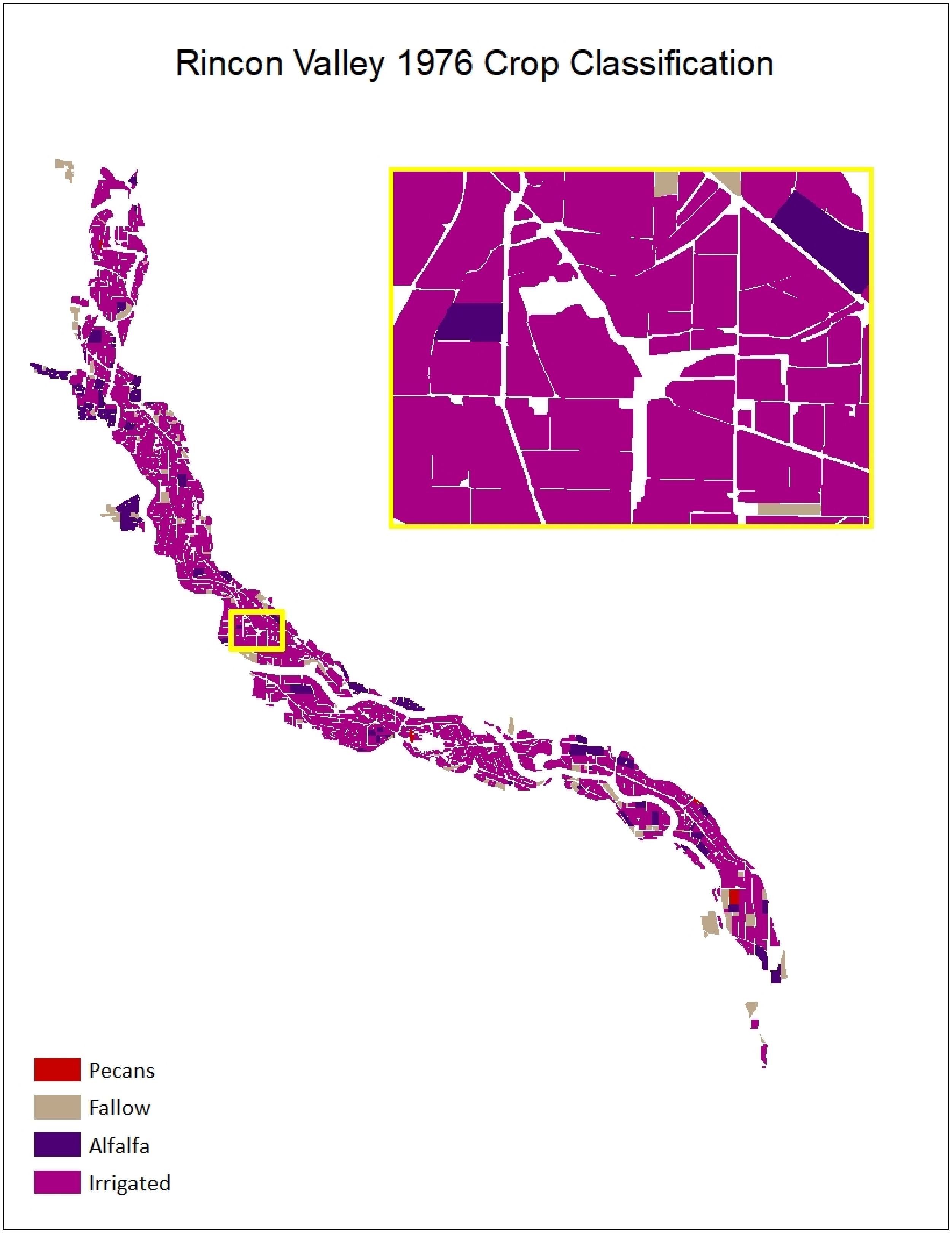
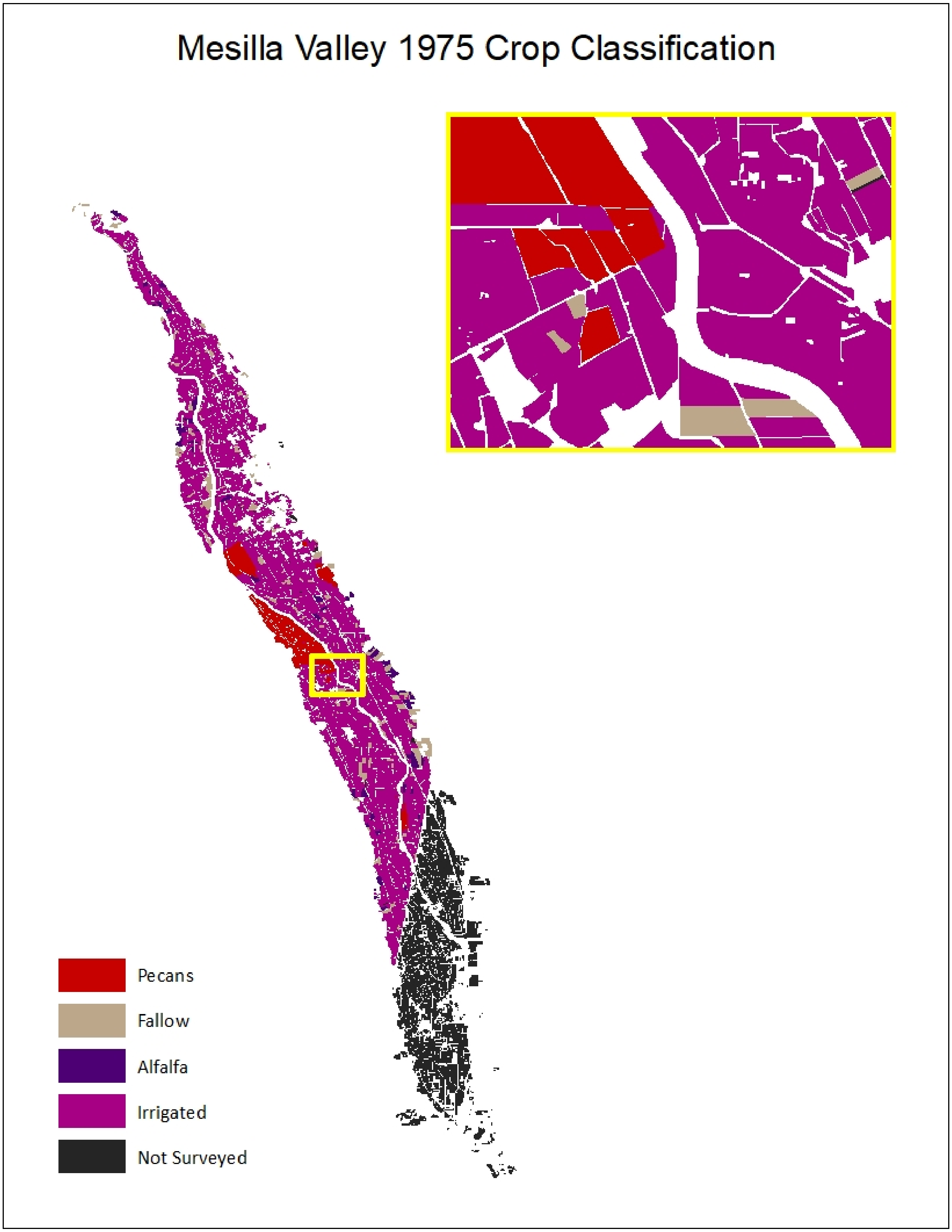


Exhibit 25. 1975 Crop Classification – Mesilla Valley



1966 Analysis

Data Sources

- **Imagery** - Images used for this analytical year are summarized below.

	Imagery	Date	Resolution	Color
Rincon	Declassified air photo	September 22, 1966	3 m	B/W
Mesilla	Declassified air photo	September 22, 1966	3 m	B/W
El Paso	Not mapped due to lack of sufficient image resources/coverage	September 22, 1966		

- **Ancillary data** – Ancillary data used to validate and assist the development of the 1966 crop map included the BOR 1966 crop report.

Mapping Methodology

Photo interpretation of the declassified photos was the sole method used to classify the 1966 Rincon and Mesilla crops. The resolution of the imagery was fine enough to allow the distinction between pecans and field crops. Alfalfa was primarily identified by expert photo-interpretation. Because of resolution limitations and the timing of the image capture, the remaining fields crops could not be separated into individual crop types (however, irrigated versus non irrigated, and/or cropped versus fallow was easily identifiable). Crops were instead grouped into a single irrigated crop class. Fallow parcels were identified via the surface tone and texture; fallow parcels appeared very light colored (indicating that the soil had not been disturbed by tillage) and may have had some heterogeneous weed growth throughout the field. Fields prepared for planting, or recently had been planted, appeared dark, homogeneous, and were weed free.

El Paso crops were not mapped in 1966 due to a lack of available imagery resources. The only dates that had complete coverage of the valley were two years prior to 1966, and those images were obscured with clouds/smoke/etc., preventing comprehensive photo interpretation.

Mapped classes

Much like 1975, based on textural and field structure cues, four crop and land use classes for 1966 were mapped. Alfalfa and pecans were generally identifiable, with the remaining fields grouped into either irrigated or fallow.

Exhibit 26. 1966 Crop Classification – Rincon Valley

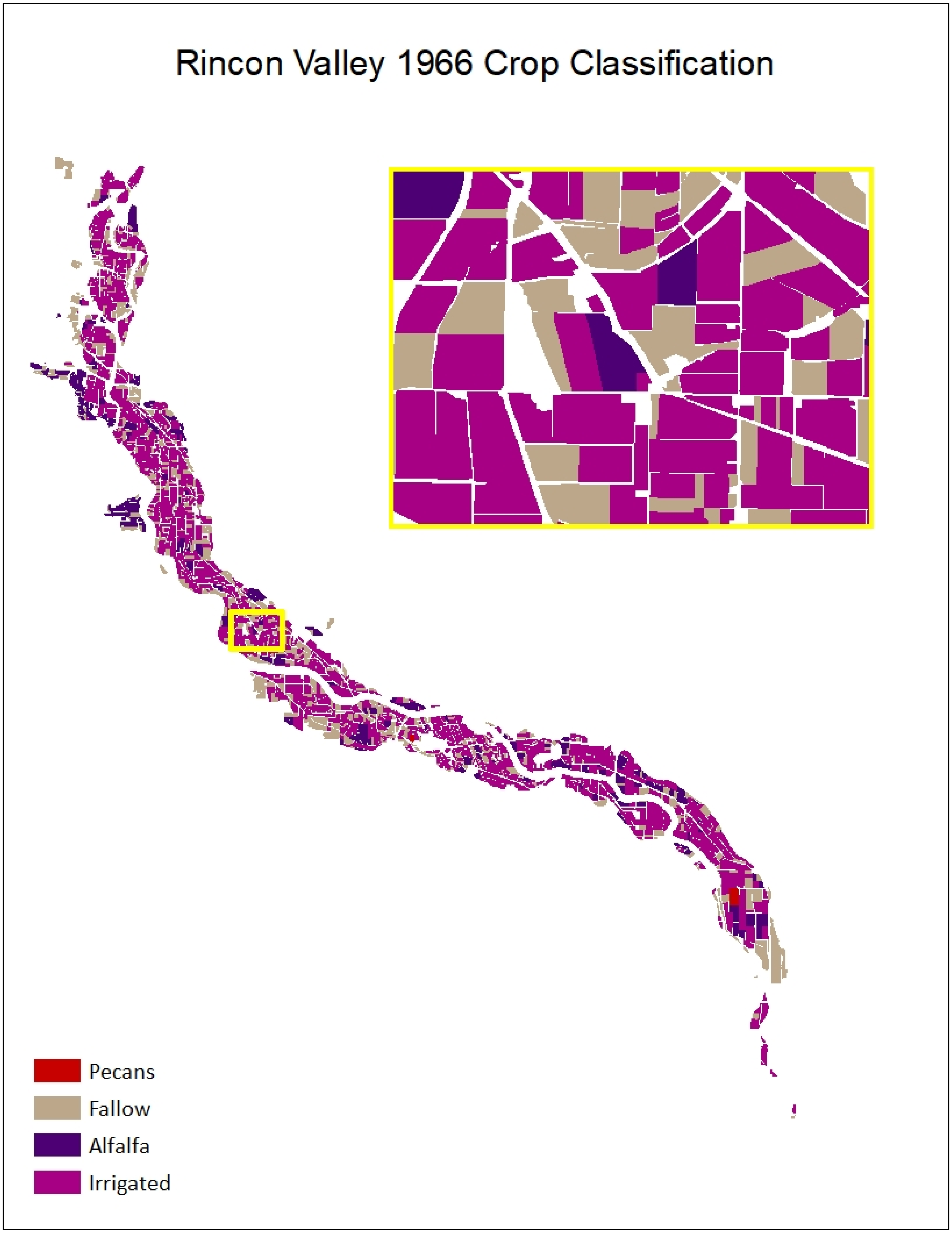
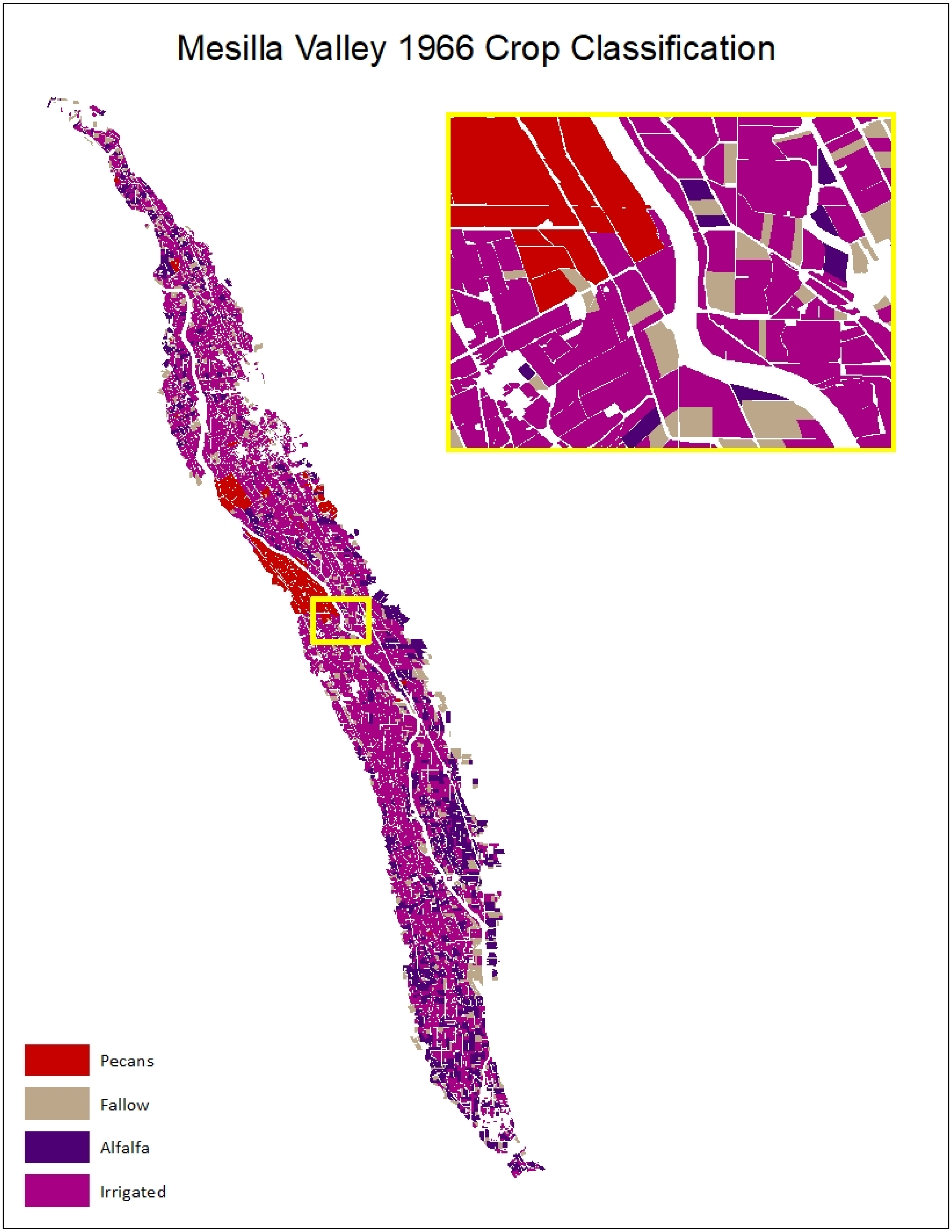


Exhibit 27. 1966 Crop Classification – Mesilla Valley



1955 Analysis

Data Sources

- **Imagery** - Images used for this analytical year are summarized below.

	Imagery	Date	Resolution	Color
Rincon	Farm Service Agency air photos	June 1955	0.5 m	B/W
Mesilla	Farm Service Agency air photos (only 90% of valley covered)	June 1955	0.5 m	B/W
El Paso	No appropriate imagery available			

- **Ancillary data** – Ancillary data used to validate and assist the development of the 1955 crop map included the BOR 1955 crop report.

Mapping Methodology

Data sources for Rincon and Mesilla Valleys in 1955 were limited to USDA Farm Service Agency black and white aerial photos from June 1955. The imagery covered all of Rincon Valley, and 90% of Mesilla Valley.

Despite the black and white imagery, the relatively high resolution of the aerial photos provided sufficient detail to confidently classify the two valleys. All of the mapping was done via photo-interpretation.

Final Classes

The analysis resulted in a legend of nine crop and land use classes. Textural and tonal quality allowed for the differentiation of alfalfa, pecans, lettuce, onions, and irrigated pasture, with remaining crops grouped into irrigated annuals, small grains, nursery, and other hay.

Exhibit 28. 1955 Crop Classification – Rincon Valley

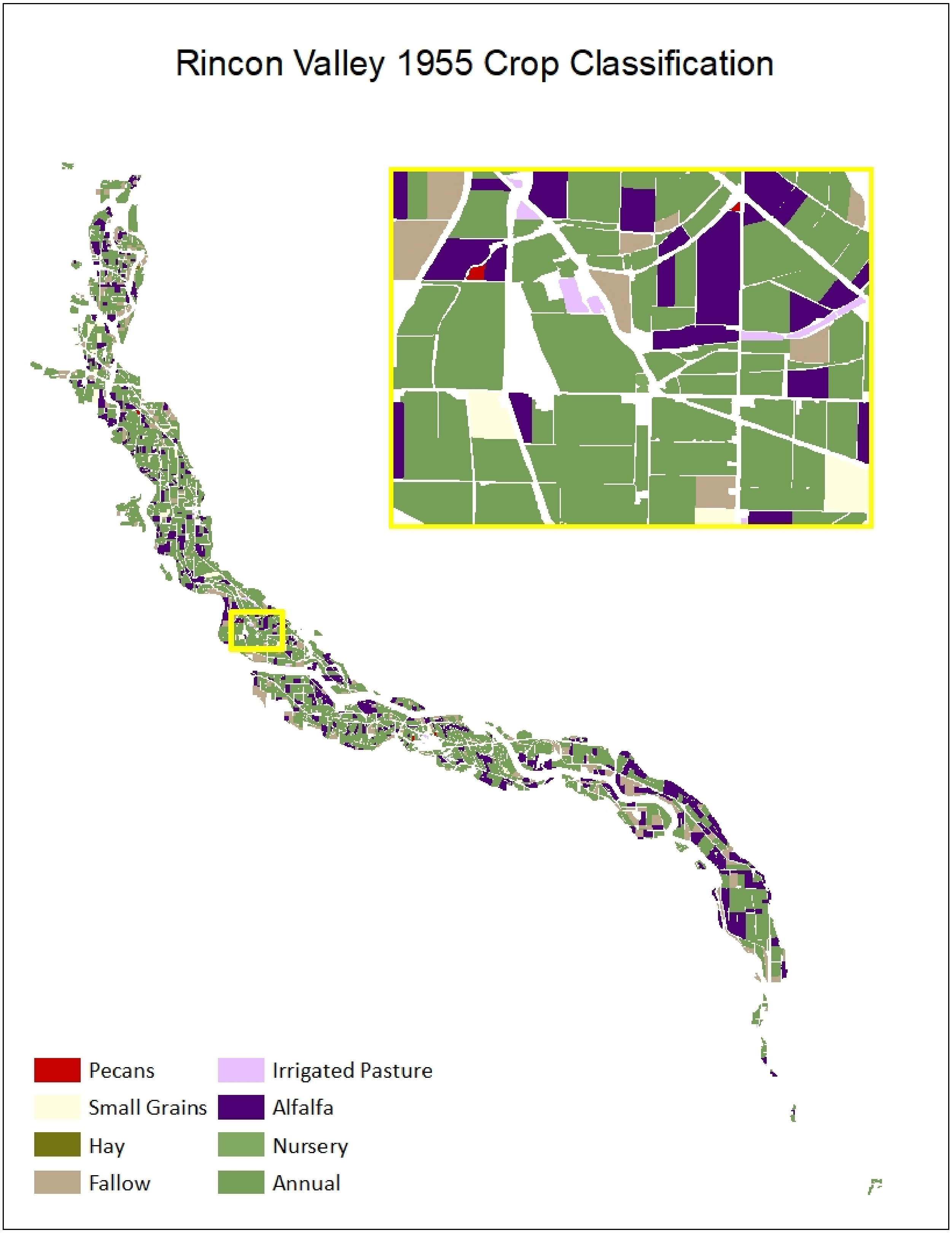
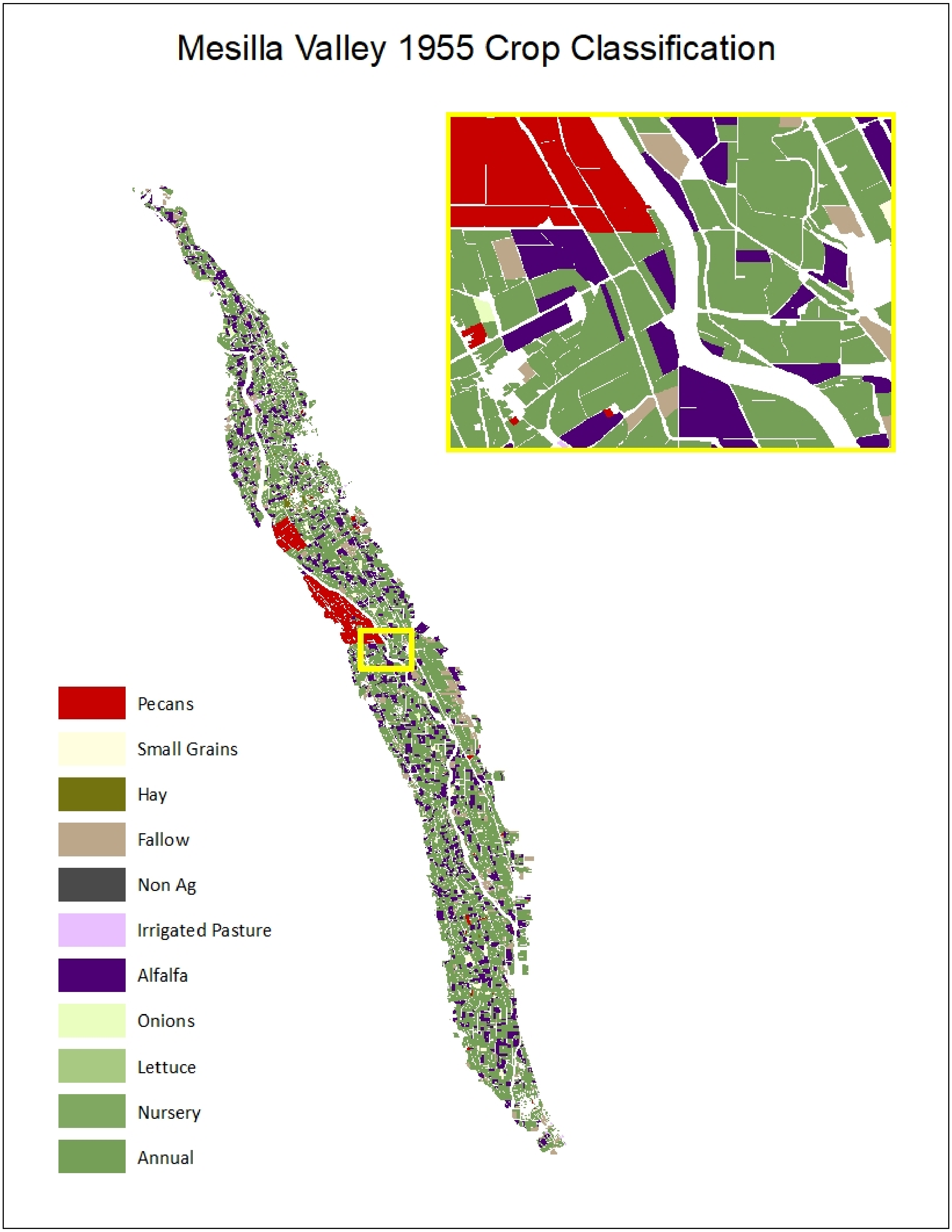


Exhibit 29. 1955 Crop Classification – Mesilla Valley



1936 Analysis

Data Sources

- 1936 maps from the Rio Grande Joint Investigation report; and
- 1935 imagery for general reference only.

Mapping Methodology

Although image resources existed that could be used to roughly determine general crop types, the plate maps and tabular acreages from the Rio Grande JIR were more accurate resources for analysis purposes. This was because the effort extended at the time of crop production in 1936 to survey and inventory all crops and acreages was far more accurate than any current-day photo interpretation or remotely sensed effort to classify crops from a 1935 image.

The JIR plate maps for Rincon, Mesilla, El Paso, and Hudspeth were scanned and georeferenced. The crop delineations were then digitized off the digital maps to produce a GIS crop map. The map digitization efforts produced similar acreages to those reported in tabular form, but were not identical due to limitations in the detail of the historical scanned maps. This mapping was therefore used to spatially distribute the tabular acreages from the report. This map and the tabular acreages then served as a highly accurate historical baseline data for determining change in consumptive use over time.

Final Classes

The crop classes from the 1936 maps included alfalfa, cotton, hay, idle, irrigated annuals, pasture, and miscellaneous /other.

Exhibit 30. 1936 Crop Classification – Rincon Valley

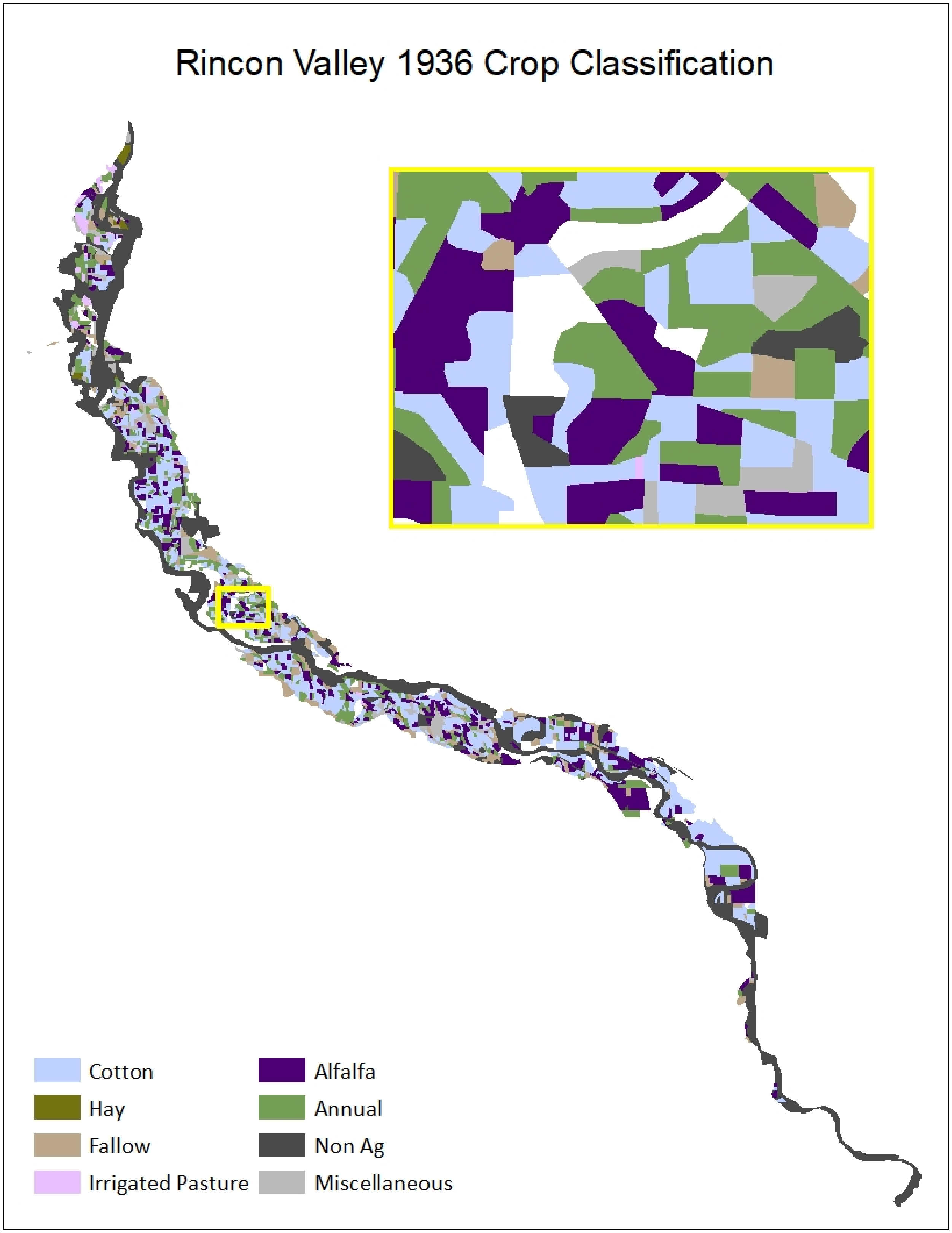


Exhibit 31. 1936 Crop Classification – Mesilla Valley

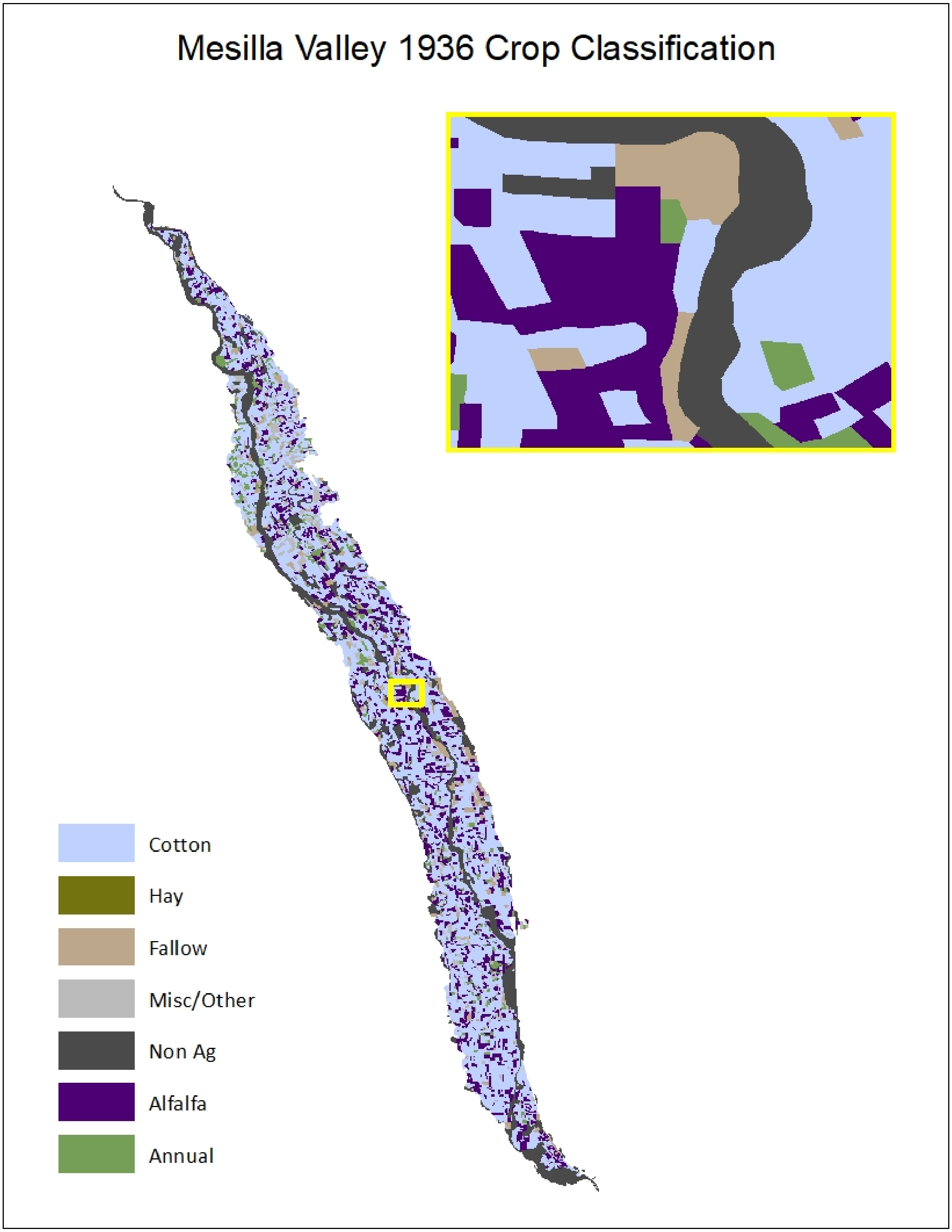
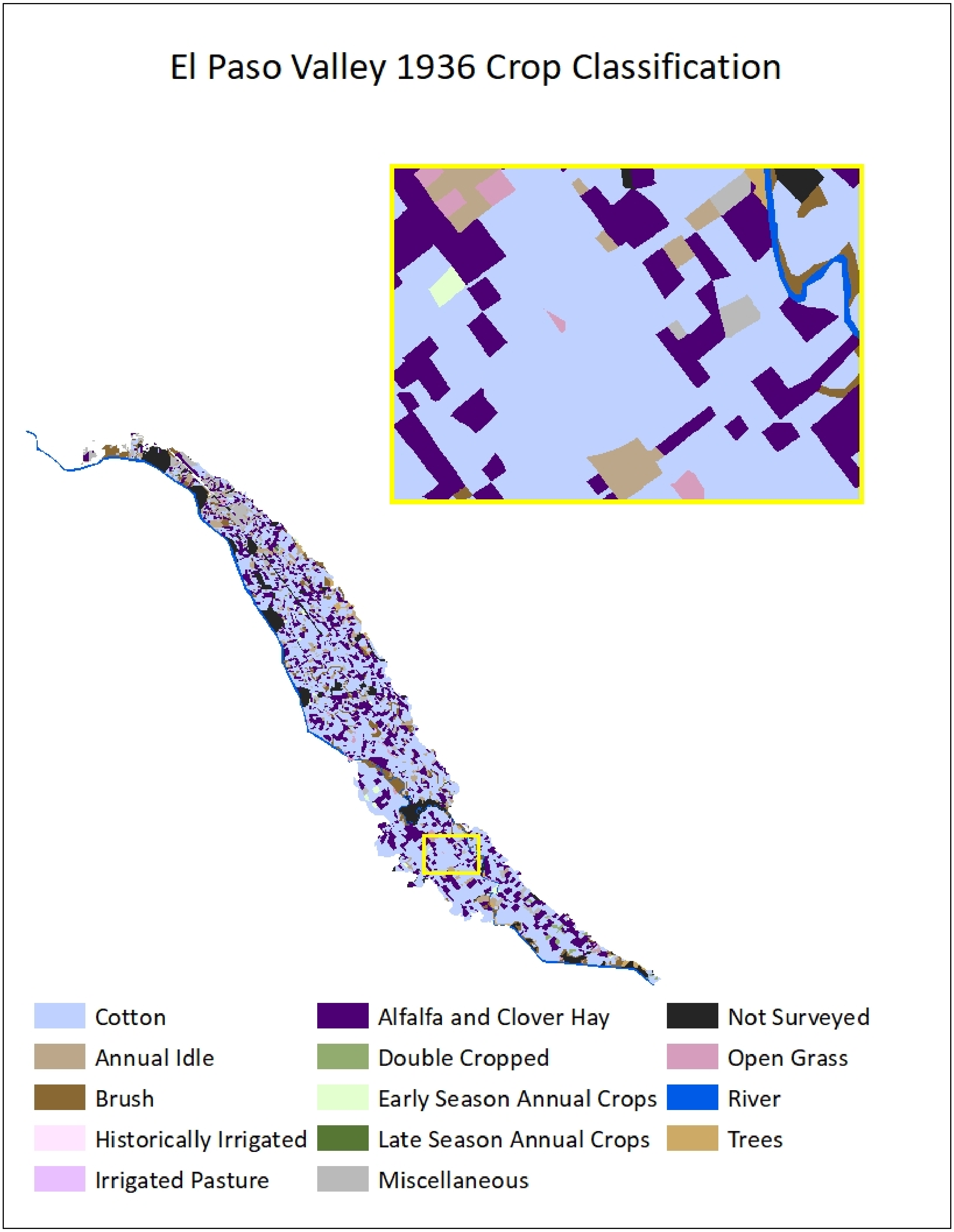


Exhibit 32. 1936 Crop Classification – El Paso Valley



US_MSJ_00001745

Pecan Spacing and Age Analysis

Purpose

A pecan age and spacing analysis was conducted to test the hypothesis that newer planted orchards contain more trees per acre than older planted orchards (i.e., are more densely planted). This has been a trend in all tree nut crops throughout the western United States, especially in California. Especially in earlier years of an orchard (until the canopy closes in), it is expected that more trees per acre will result in more consumptive use as compared to older, less dense orchards. The first step in conducting a density analysis by age was to establish the age component; then tree density by age of orchard was determined.

Spacing Procedure

An age analysis of pecans was performed within the area of interest (Rincon, Mesilla, and El Paso Valleys) dating from 1984 and to 2018. All orchards less than ten acres were removed from this analysis to ensure selection of a representative sample of commercial pecan production. Pecan orchards were grouped by age in two-year periods beginning in 1985 to create the following sample year classes:

- 2018-2017
- 2016-2015
- 2014-2013
- 2012-2011
- 2010-2009
- 2008-2007
- 2006-2005
- 2004-2003
- 2002-2001
- 2000-1999
- 1998-1997
- 1996-1995
- 1994-1993
- 1992-1991
- 1990-1989
- 1988-1987
- 1986-1985

- 1984

Within each sample year class, twenty-five orchards were randomly selected across all three valleys for analysis of pecan tree spacing, for a total of 450 orchards analyzed. Pecan tree spacing was measured by overlaying a one-acre digital fishnet over the area of interest. Within each orchard, the number of trees within each 1-acre square was counted, yielding the number of trees per acre within each orchard.

NAIP 2016 was the main source of imagery used for counting trees for sample year classes 2016-2015 and 2018-2017. Google Earth Pro was a secondary source of imagery as some orchards were not clearly visible in NAIP 2016, or had yet to be planted at the time of NAIP 2016 acquisition.

Rincon and Mesilla Valleys' 1955 imagery was obtained and used to analyze tree spacing of pecan orchards planted in 1955 or prior. Ninety orchards greater than 10 acres were analyzed in this group.

Spacing Results

During the spacing analysis, it was observed that some orchards had differing tree spacing between rows rather than a conventional grid-shaped planting pattern. These orchards are referred to as alternately spaced orchards. Exhibit 33 shows the relative frequency of alternately spaced orchards observed within each sample year class. Orchards planted between 1991–1992 had the most alternately spaced orchards at 28% of the total sample size. No alternately spaced orchards were observed after the sample year class of 1999–2000.

Two of the seventeen alternately spaced orchards were first planted in a traditional grid pattern, but were later thinned as observed in 2016 NAIP imagery. The trees per acre were counted as shown in 2016 NAIP imagery. It is hypothesized that these orchards were mostly planted at a 30-foot spacing within rows and were later thinned to a 60-feet spacing in thinned rows. Thinning mostly occurred in every other row.

More recent higher-resolution Google Earth imagery shows that many of these orchards are being replanted to the original 30-foot spacing in rows that were once thinned, while retaining the original tree-starting grid (Exhibit 34). In these replanted orchards, the youngest trees were not counted in the 1-acre square because 2016 NAIP imagery did not have high enough resolution to identify these young trees among older trees, although it is assumed that they existed.

The majority of orchards, however, are not thinned in this manner, and represent common pecan production practices (Exhibit 35).

Exhibit 33. Pecan Orchards with Alternately Spaced Tree Rows.

Sample Year Class	Sample Size	Count of Alternately Spaced Orchards	Frequency of Alternately Spaced Orchards (%)

2018-2017	25	0	0
2016-2015	25	0	0
2014-2013	25	0	0
2012-2011	25	0	0
2010-2009	25	0	0
2008-2007	25	0	0
2006-2005	25	0	0
2004-2003	25	0	0
2002-2001	25	0	0
1999-2000	25	1	4
1998-1997	25	0	0
1996-1995	25	0	0
1994-1993	25	1	4
1992-1991	25	7	28
1990-1989	25	2	8
1988-1987	25	1	4
1986-1985	25	3	12
1984	25	2	8
1955	90	0	0

Exhibit 34. An alternately spaced pecan orchard in (A) June 2010 and (B) May 2018. Images from various valleys.

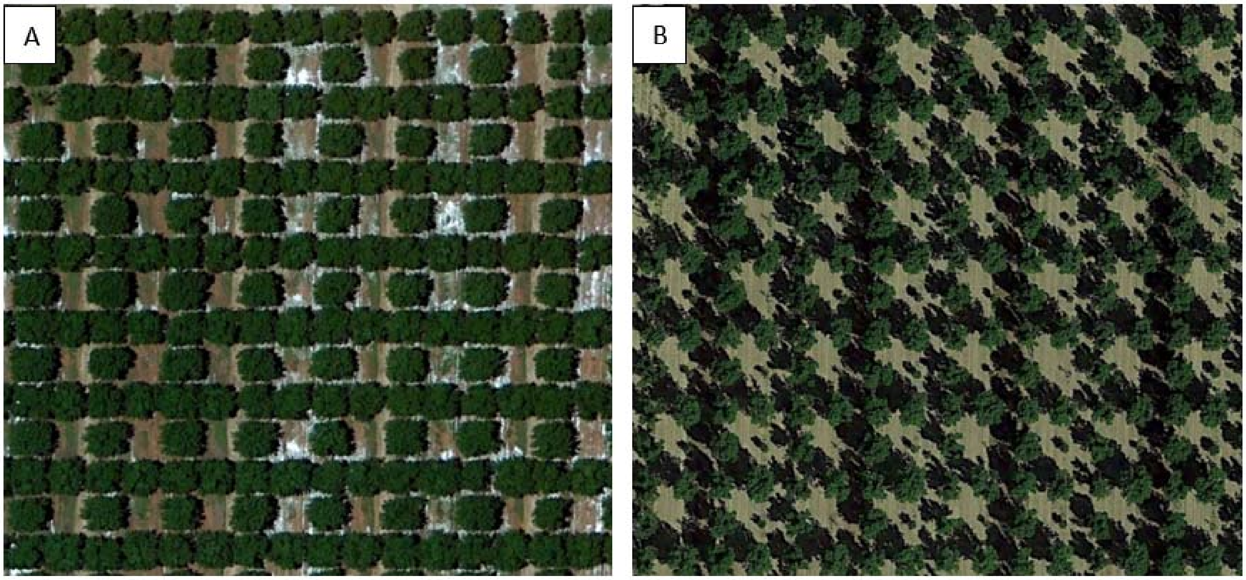
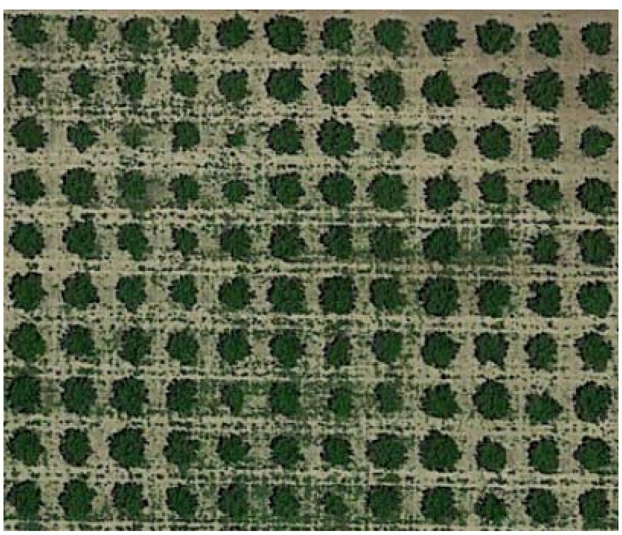


Exhibit 35. Image examples of common pecan spacing and production practices. Images from various valleys



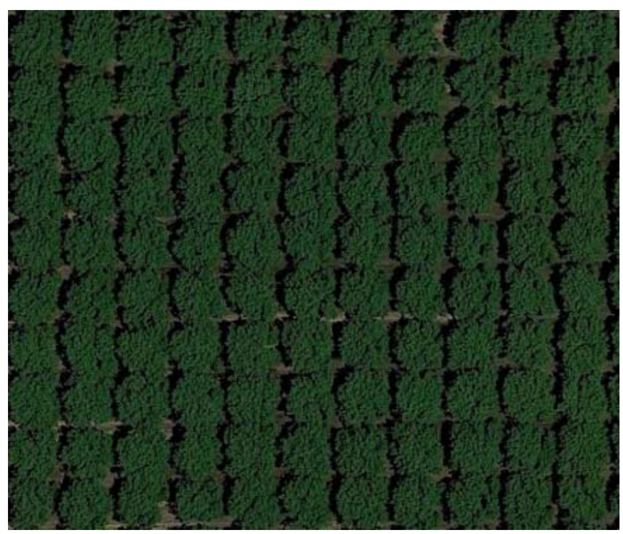


Exhibit 36 shows the results of the pecan spacing analysis. Older orchards tend to have more widely spaced trees, while younger orchards tend to have tighter spacings.

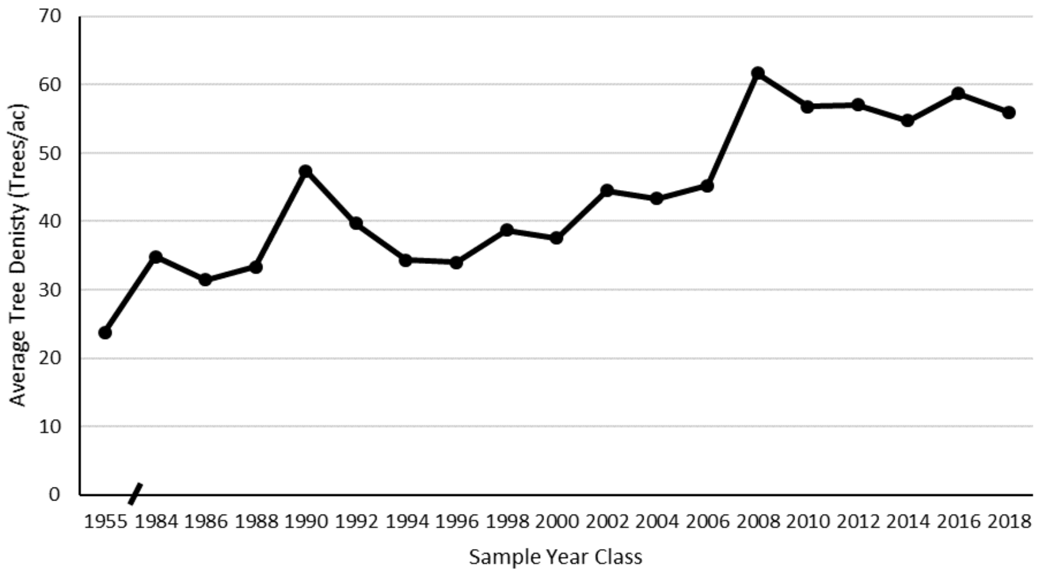


Exhibit 36. Pecan spacing analysis results by year planted.

Note: The sample year class axis label includes the year shown and the year prior. For example, the axis label 1986 included the year 1985–1986. The sample year class of 1955 represents orchards planted in the year 1955 or prior. The sample year class of 1984 represents orchards planted in 1984 or prior.

Pecan Age Analysis Results

An age analysis of pecans was performed in all three valleys from 1984 to 2018. The age analysis identifies the year that an orchard was planted and is based on the standing 2018 pecan acreage. Therefore, a pecan orchard planted in 1985 and removed in 2015 would not be included in this age analysis.

Exhibit 37 shows the cumulative acres of pecans planted by year. There were 15,420 acres planted in the year 1984 and prior and there are 49,877 acres standing in 2018 (Exhibit 37). Exhibit 38 shows the non-cumulative acreage planted by year. The year 1984 shows a much greater amount of planted acreage relative to other years because it includes pecans planted both in and prior to 1984. Because the remaining years are difficult to visually represent at the scale needed to display the acreage of 1984, Exhibit 39 shows the acreage planted without the year 1984.

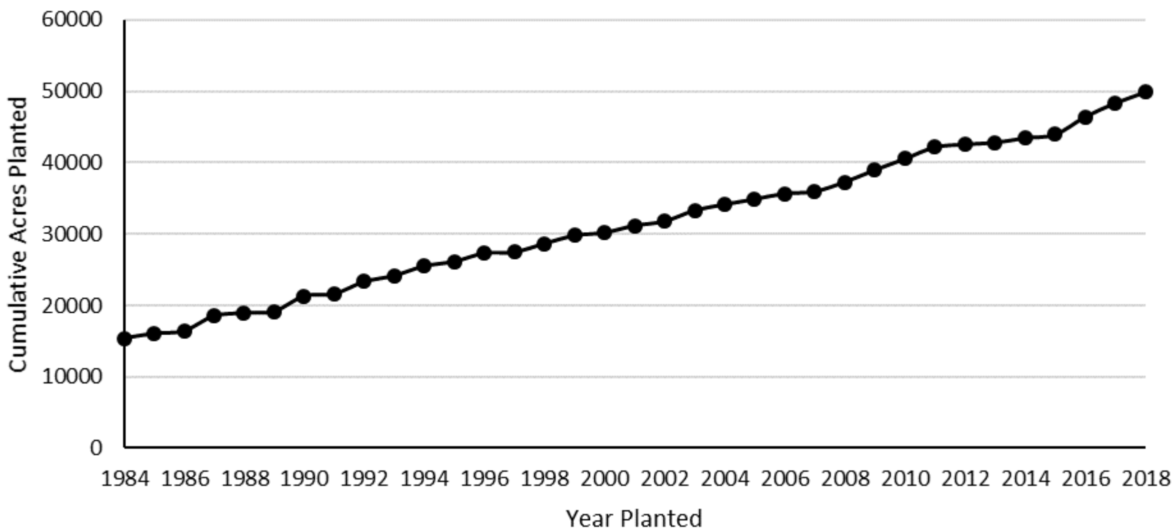


Exhibit 37. Cumulative Pecan Planted Acreage by Year from 2018-1984.

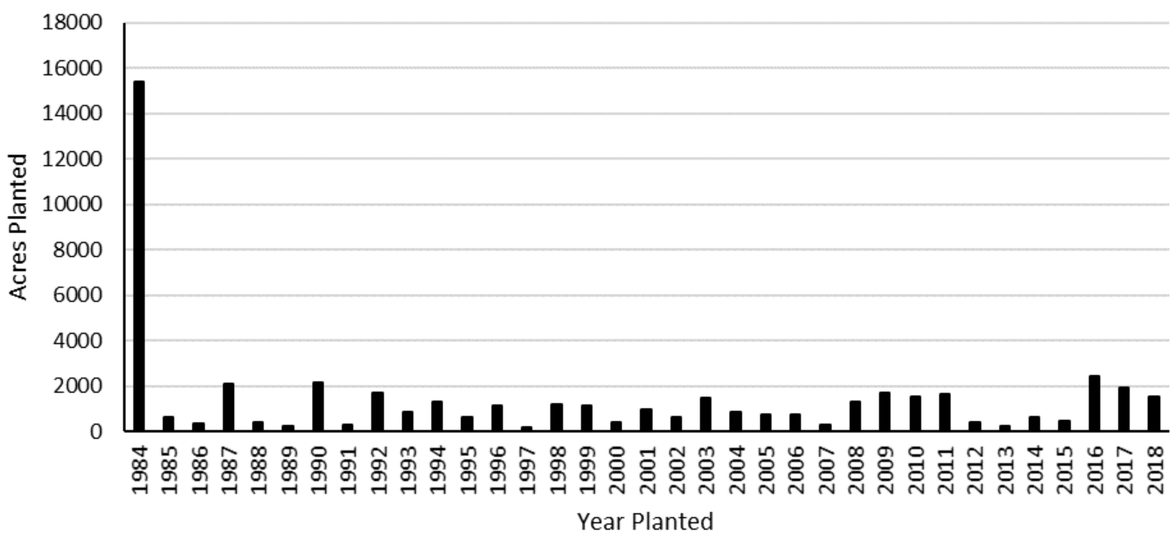


Exhibit 38. Pecan Planted Acreage by Year from 1984-2018.

Note: The year 1984 includes orchards planted in or prior to 1984.

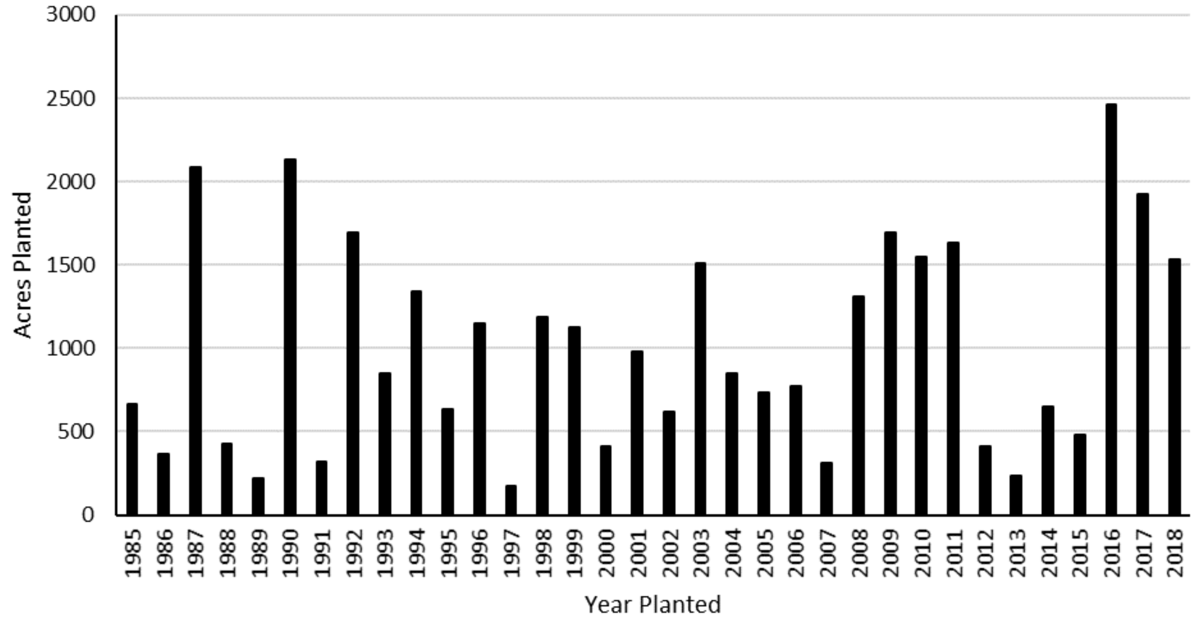


Exhibit 39. Pecan Planted Acreage by Year from 1985-2018.

Annual Land Use Interpolations and Area Determination by Valley

Methods

A detailed crop acreage report was used as one tool to determine annual crop acreages for calculating consumptive use. When suitable imagery resources were available, remote sensing and photo interpretation (coupled with other indicators and resources) were used to create spatial crop maps for multiple years. For years when this imagery did not exist, acreages had to be determined through other methods. Acreage values were assigned to each valley by use of the following data sources listed in descending order of importance:

- **i.** JIR spatial data.
- **ii.** Land IQ spatial crop mapping.
- **iii.** Area-specific crop report.
  - **1.** With or without In/Out Valley Distribution (IOVD) adjustment, depending on valley.
- **iv.** Calculated EBID acreage (CEA)–only valid for Rincon and Mesilla Valleys.
  - **1.** With or without IOVD adjustment, depending on valley.
- **v.** Linear interpolation between reliable values.

To assess time periods without spatial crop mapping, Project Histories of the Rio Grande Project documents written by the Bureau of Reclamation (crop reports) and other sources were consulted (Appendix A). Crop reports for the study area are aggregated to different levels. For the majority of the time period, the crop reports are aggregated to the irrigation district level. For certain periods of time, valley specific data were available and utilized. When valley level data was not available, assumptions had to be made about crop acreage. Due to the discrepancy between the valley boundary and the irrigation district boundary, some irrigated acreage falls outside the district boundary, but within the valley boundary. This acreage is not usually accounted for in the district service area and some project area crop reports. All irrigation district level crop reports were increased by the percent irrigated ground outside the irrigation district boundaries as applicable for Rincon and Mesilla Valleys respectively.

In years when a spatial dataset was available, an IOVD percentage was calculated for irrigated acreage within the valley boundary that was not inside the irrigation district boundary. A linear interpolation between spatial data years was used when no spatial data was available. The crop reports for the irrigation district can then be increased by the IOVD value, accounting for acreage outside the irrigation district boundary.

In years where there is no differentiation between Rincon and Mesilla Valleys (only reported as EBID), calculations and assumptions were used for a CEA. Distribution of total crop area was determined for 1989 and 1964 crop reports between Rincon and Mesilla Valleys (the only years EBID is broken down to valley level, otherwise they are reported on a project level); a relatively consistent 20/80 split between the two valleys. The distribution of crops within each valley also was calculated for 1989 and 1964 crop reports, and a linear interpolation of the 19 crop groups was calculated to provide acreage for 1988–1965. This provides a yearly crop distribution that is valley specific.

The EBID crop reports are given, but do not separate Rincon and Mesilla Valleys. The total EBID acreage is multiplied by the distribution between valleys (approximately 20/80 split) to arrive at the total acreage by year for each valley–distributing the total EBID acreage by year to the two valleys. Once the total acreage for each valley is calculated, this value is multiplied by the in-valley crop distribution linear interpolation, resulting in acreage by crop, by year, for each valley. These acreage distributions are then multiplied by the IOVD value to account for acreage outside district boundaries, but still within valley boundaries. During these years, pecans are not included in the CEA acreages because pecans are a permanent crop that do not change drastically from year to year. Therefore, a linear interpolation was calculated between the 1966 and 1976 spatial years, and the 1989 EBID crop report. The linear interpolation of this permanent crop matches known increases in pecan production over time from anecdotal resources and from years of spatial mapping results.

Acreage Disaggregation to Service Areas

The spatial extent of the project areas was distributed into 14 service areas (SA) over the Rincon and Mesilla Valleys (Exhibit 40) for project modeling through 2016. The results of spatial land use mapping were used to disaggregate the valley-wide annual land use datasets into land use acreage by SA (Appendix 3).

Exhibit 40. Service area distribution among valleys.

Service Area Number	Service Area Name	Valley
1	Arrey	Rincon
2	Eastside NM	Mesilla
3	Leasburg	Mesilla
4	Westside NM	Mesilla
5	Eastside TX	Mesilla
6	Westside TX	Mesilla
7	Outside Rincon N	Rincon
8	Outside Rincon W	Rincon
9	Outside Rincon E	Rincon
10	Outside Leasburg N	Mesilla
11	Outside Leasburg E	Mesilla
12	Outside East NM	Mesilla
13	Outside East TX	Mesilla
14	Outside West NM	Mesilla
99	Outside all Service Area Boundaries	Mesilla and Rincon

The Rincon Valley is comprised of four SAs and a small acreage outside the SA boundaries (SA 1 and 7–9). The Mesilla Valley is comprised of 10 SAs and a small acreage outside the SA boundaries (SAs 2–6 and 10–14) (Exhibit 41).

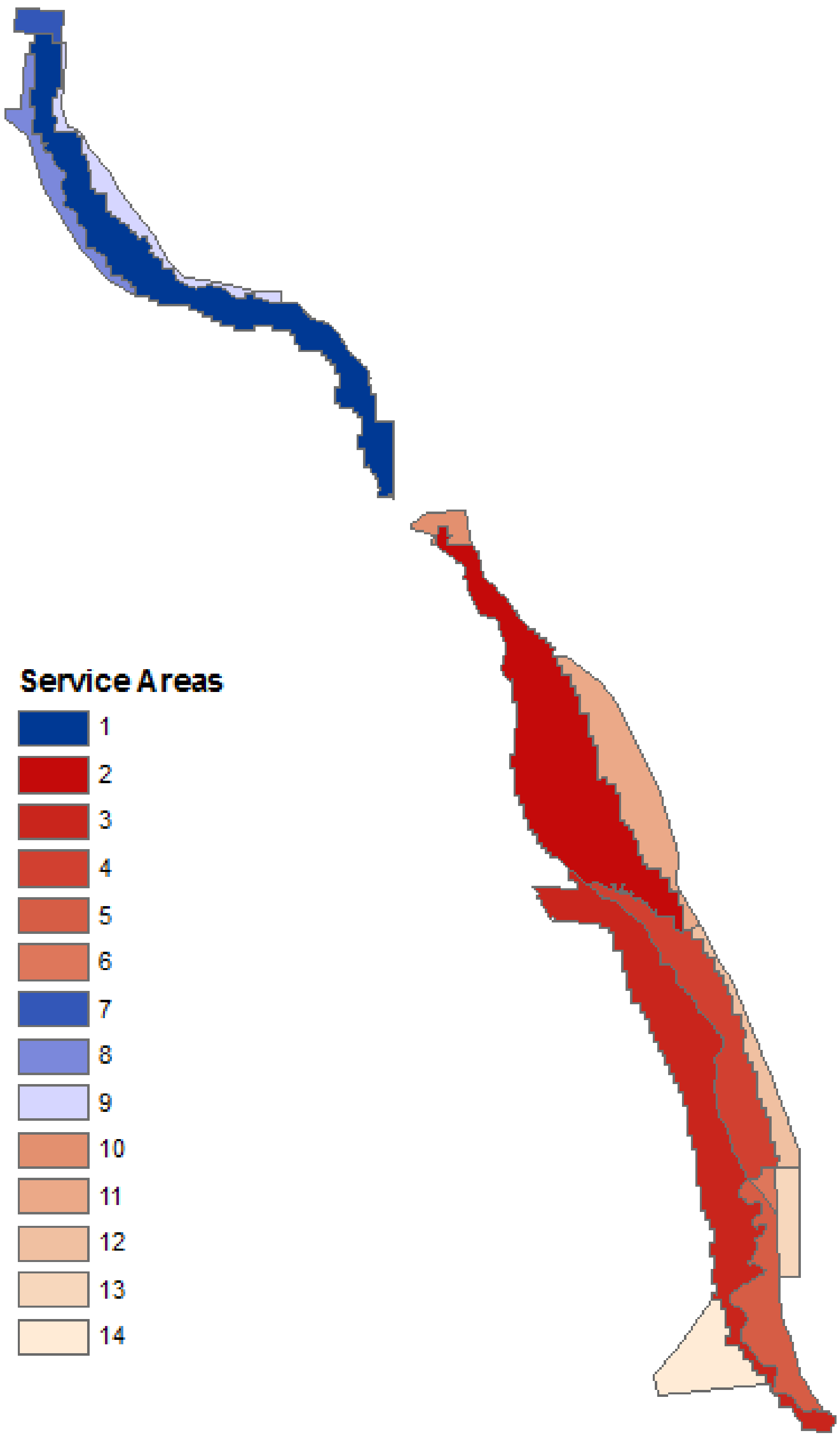


Exhibit 41. Service Areas in Rincon and Mesilla Valleys

Acreage Distribution

Remotely sensed crop mapping was completed in 2018, 2016, 2014, 2011, 2006, 1996, 1986, 1976/1975, 1966, and 1955 for the two valleys and in fewer years for the El Paso Valley. In 1936, there was a spatial map of crop types provided by the JIR (Appendix A). For Mesilla Valley, the 1975 crop mapping was not used because approximately 13,775 acres of agriculture was excluded from the southern portion of the imagery. The 1976 crop mapping was used for Rincon Valley. Spatial data from Land IQ crop mapping was digitally intersected with the SA boundaries (Exhibit 42). For fields situated within two SAs, the field acreage is split and each portion is assigned to one of the SAs (Exhibit 43). In some cases, small acreages fall outside the SA boundaries. These acreages were preserved and calculated as Service Area 99 (SA99) to reconcile total acreages.

The percent distribution of each crop within each service area (Service Area Crop Distribution–SACD) was calculated for years spatial data was available. For years that did not have spatial data, the crop distribution is unknown because the acreages are reported at the irrigation district level; they are never reported to the granularity of service areas. Therefore, a linear interpolation was used to calculate the percent distribution of each crop within each SA for non-spatial years:

- Rincon Valley
    - 2015
    - 2013-2011
    - 2010-2007
    - 2005-1997
    - 1995-1987
    - 1985-1977
    - 1975-1967
    - 1965-1956
    - 1954-1937
- Mesilla Valley
    - 2015
    - 2010-2007
    - 2005-1997
    - 1995-1987
    - 1985-1977
    - 1975-1967
    - 1965-1956
    - 1954-1937

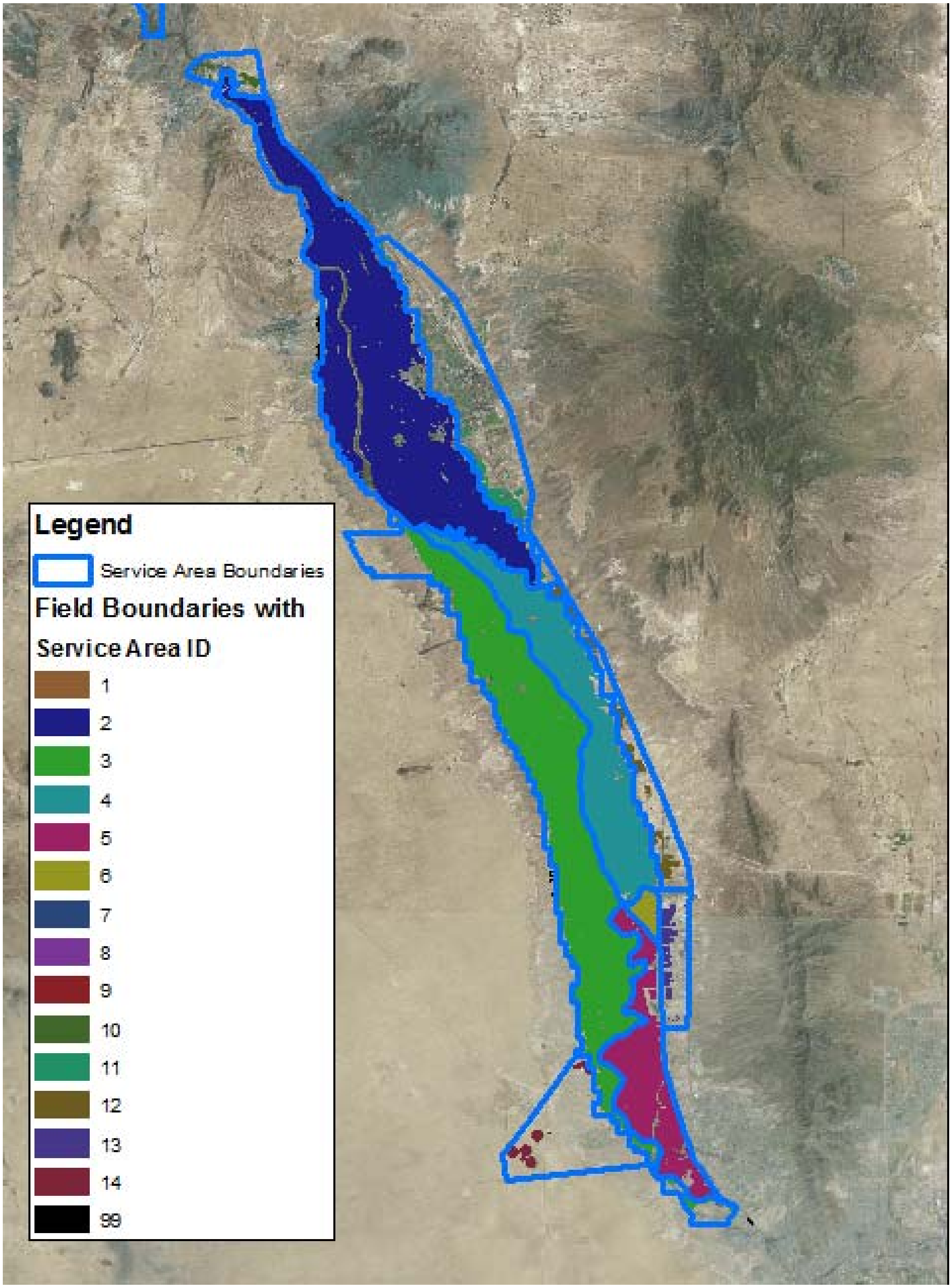


Exhibit 42. Results of Field Boundary spatial intersect with SAs, Mesilla Valley

Exhibit 43. Field intersection with SA boundaries; example of field overlapping service area boundary

Changes to the linear interpolation were made when acreage was present in the delivered acreages that were not present in one or both of the spatial years providing data for the linear interpolation. For example, if legumes are reported in the Rincon Valley crop report for 1963, but legumes are not present in the 1966 and/or 1955 crop mapping years, an assumption of distribution was made. The service area distribution for the closest year was applied. For the legume example, the 1963 crop distribution would be used from 1955 until 1966 as static values. These assumptions about crop distribution are listed (Exhibit 44).

Exhibit 44. Assumptions Made about Crop Acreage Service Area Distribution

Time Period	Crop	Valley	Distribution Assumption
2015-2018	All	Both	No distribution needed as 2015 was linearly interpolated between 2014 and 2016
2011-2014	Hay	Mesilla	2014 distribution used from 2012-2014
2011-2014	Irrig Annuals	Mesilla	2014 distribution used from 2012-2014
2011-2014	Legumes	Mesilla	2014 distribution used from 2012-2014
2006-2011	Chili	Rincon	2011 distribution used from 2007-2011
2006-2011	Legumes	Rincon	2011 distribution used from 2007-2011
2006-2011	Hay	Mesilla	2006 distribution used from 2006-2010
2006-2011	Irrig Annuals	Mesilla	2006 distribution used from 2006-2010
2006-2011	Legumes	Mesilla	2006 distribution used from 2006-2010
1996-2006	Chili	Rincon	1996 distribution used from 1996-2005
1996-2006	Legumes	Rincon	1996 distribution used from 1996-2005
1996-2006	Irrig Annuals	Mesilla	2006 distribution used from 2006-2010
1986-1996	Asparagus	Rincon	1986 distribution used from 1986-1995
1986-1996	Melon/Squash	Rincon	1986 distribution used from 1986-1995
1986-1996	Misc/Other	Rincon	1986 distribution used from 1986-1995
1986-1996	Root Crop	Rincon	1986 distribution used from 1986-1995
1986-1996	Tomatoes	Rincon	1986 distribution used from 1986-1995
1986-1996	Turf	Rincon	1986 distribution used from 1986-1995
1986-1996	Asparagus	Mesilla	1986 distribution used from 1986-1995
1986-1996	Irrig Annuals	Mesilla	1986 distribution used from 1986-1995
1986-1996	Misc/Other	Mesilla	1986 distribution used from 1986-1995
1986-1996	Root Crop	Mesilla	1986 distribution used from 1986-1995
1986-1996	Tomatoes	Mesilla	1986 distribution used from 1986-1995
1937-1954	Grapes	Rincon	100% are in SA1
1936-2014	Grapes	Mesilla	100% of grapes in SA2
1936-2014	Misc/Other	Mesilla	Assigned irrigated annuals distribution
1936-2014	Tomatoes	Mesilla	Assigned irrigated annuals distribution
1936-1955	Pecans	Rincon	1955 distribution used from 1936-1955
1936-1955	Pecans	Mesilla	1955 distribution used from 1936-1955

If there was no crop report for the given spatial year, a linear fill was calculated between the two adjacent years to provide acreages of the non-permanent crops. Using either the known crop report or the linearly-filled crop report, the distribution of other, non-permanent crops (excludes alfalfa, grapes, and pecans) was calculated for the spatial year. The large acreages were distributed based on the percent distribution calculated for each year. Acreages for all other years remained the same as the delivered values. The final delivered acreages were then multiplied by the SACD, producing acres of each crop in each area.

Calculated irrigated acres by crop and by SA were entered into a monthly consumptive use calculator. A separate iteration of the calculations was completed for each of the SAs and any acreage located outside the SA (i.e. SA 99).

All agricultural acreage summaries by valley, crop type, year, and SA are provided (Appendix 2).

Riparian Land Use

Opinions

- Phreatophytic or riparian vegetation exists within the study area, primarily along the edges of the Rio Grande. Riparian tree and shrub species depend on access to shallow groundwater for establishment and survival. Riparian vegetation group is small compared with agricultural production in the study area, but it consumes water directly from local riverine and groundwater sources, and thus is important to the overall assessment of consumption.
- Limited historical field survey information is available for riparian vegetation. The available information should be used to calibrate any remote or photo interpretation approaches.
- Total riparian vegetative cover decreased dramatically in the late 1930s due to clearing, decreasing from approximately 6,900 acres to approximately 350 acres between the Rincon and Mesilla Valleys. It remained at a similarly low level into the 1950s.
- Riparian vegetation has increased gradually since the 1950s to approximately 1,711 acres in 2018.

Methods

Riparian land cover was analyzed for Rincon and Mesilla Valleys. Because ground survey of native vegetation is highly intensive and was not available for much of the study period, previous studies informed by ground vegetation surveys were used. Qualitative ground observations of vegetation change in the study area were used in this analytical approach. Image resources could be analyzed with geospatial techniques to determine the relative cover of riparian vegetation classes. These results were then calibrated to the results of a historical study of vegetation cover change by Papadopulos (2008), which had similar assessment objectives and the benefit of ground survey data.

Papadopulos (2008) evaluated the years 2004, 1997, 1986, 1974, 1967, 1955, and 1936. Independent vegetative cover analyses were performed by Land IQ for two years (1955 and 2005) to evaluate Papadopulos' (2008) results to generate an annual riparian land use coverage. In addition, an analysis of riparian vegetation extent was conducted in 2014 to represent more recent conditions that could not be captured in the earlier study.

Riparian Area Delineation

Riparian corridors were delineated for 1955, 2005, and 2014 using digital mapping techniques and photo interpretation. The 2014 riparian land cover extent was delineated using photo interpretation of high-resolution, aerial images collected between August 13–20, 2014. Images used are summarized in Exhibit 45. The riparian boundary was further modified to exclude roadways, open-water features (e.g., river) and other land-use types (e.g., agriculture, urban). Complete riparian corridors were delineated and then segmented into areas with similar characteristics, such as vegetation cover, density of tree canopy, landscape features, and distribution of bare ground by visible elements in the image (e.g., color/tone, texture, shape, shadow) (Exhibit 46).

Exhibit 45. Imagery Used for Riparian Vegetation Mapping

Riparian Mapping Year	Image Source
1955	0.5 m Farm Service Agency aerial photography (June 1955)
2005	1 m NAIP (August 2005)
2014	1 m NAIP Aerial Imagery (June/July) 0.33 ft Aerial Imagery (August 13-20, 2014)
2016	1 m NAIP Aerial Imagery (May/June/August)

Vegetation Functional Group Classifications

The 2014 cover of riparian vegetation was assessed with NDVI, derived from the 2014 NAIP aerial imagery within the delineated riparian corridor areas. Using NDVI-based classification, the relative cover of three land cover classes, or plant functional groups (PFGs), was determined. Plant functional groups are groupings of plant species that exhibit similar growth and water use characteristics. The three PFGs assessed included:

1. Riparian Tree**:** Deep-rooted, woody riparian trees, including drought-intolerant phreatophytic trees that rely on shallow groundwater for establishment, growth, and transpiration.
2. Riparian Shrub: Phreatophytes with shallower rooting depths than riparian trees that also are reliant on shallow groundwater. One of the most common plant species in this group is *Baccharis* spp. (Mulefat).
3. Bare Ground**:** Includes areas that are bare year round and areas that may have seasonal vegetation cover (dominated by annual grasses and other herbaceous vegetation–the life cycle is driven by rainfall events and not to transpiration from deeper rooted perennials).

Papadopolus (2008) includes a fourth PFG for herbaceous riparian, which is relatively uncommon in the present day; however, it had significant historical extent as documented by Papadopolus (2008) for the year 1936, when it was estimated to be more than 57% (3,997 acres) of the riparian vegetation across the Rincon and Mesilla Valleys. Examples of common herbaceous riparian species include Curly Dock (*Rumex crispus*) and Deer Grass (*Muhlenbergia rigens*). For the purposes of this study, the Herbaceous Riparian PFG is insignificant from a consumptive water use perspective given its limited extent and relatively shallow rooting morphology.

For 2014, the relative cover of riparian trees, riparian shrubs, and bare ground was calculated for each delineated riparian polygon. This assessment was based on initial NDVI-analysis of cover groups in 2014 along with photo interpretative adjustments and calibration to the most recent 2004 results from Papadopulos (2008).

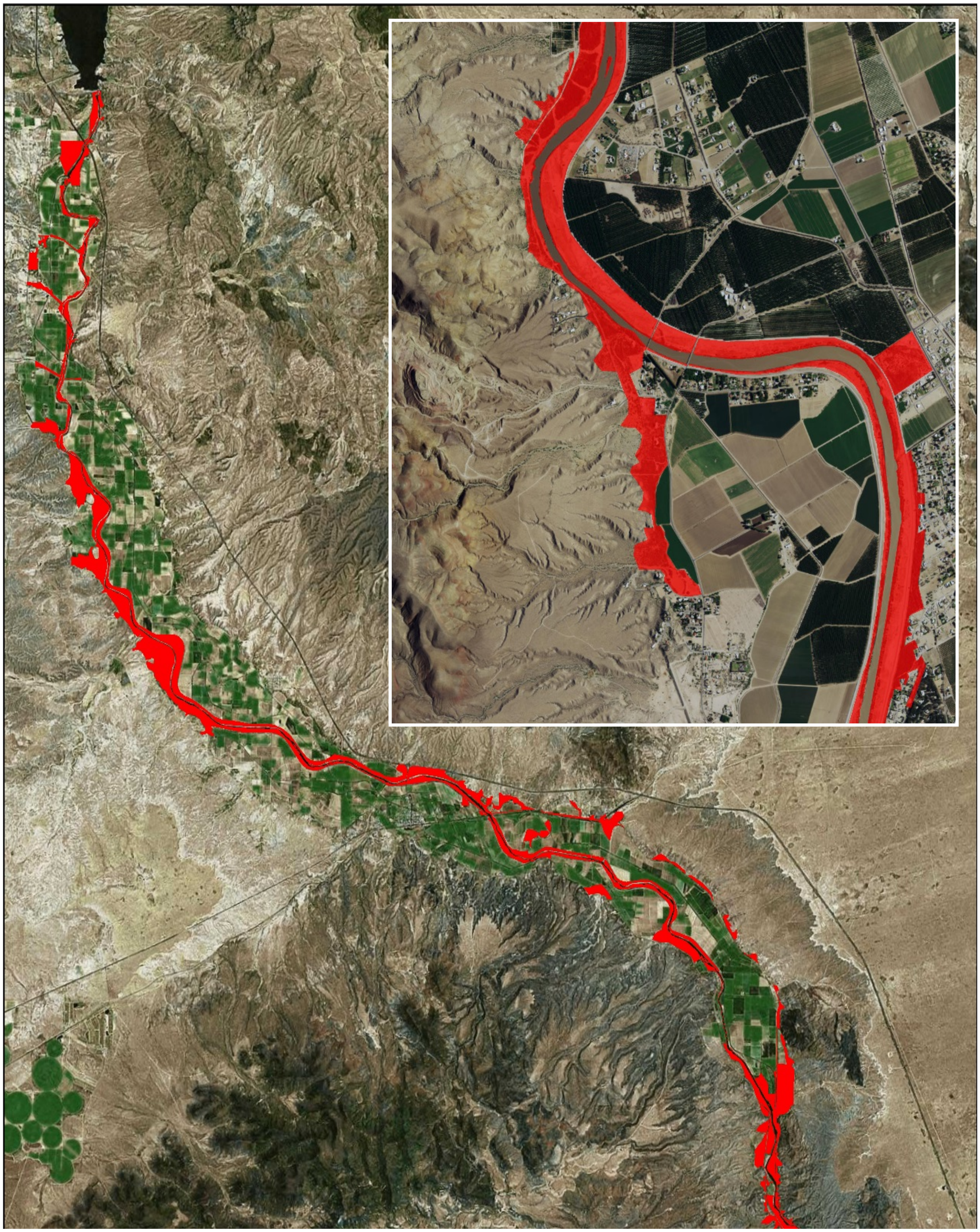


Exhibit 46. Example of Riparian Vegetation Mapping in 2014

The 4-Band June/July-2014 NAIP imagery was clipped to the Mesilla and Rincon Valleys, and used to generate NDVI using Image Analysis Model Builder in ArcGIS Desktop 10.2.2. Zonal statistics tools were used on the raster datasets to generate the number of pixels within the polygons for each riparian PFG, and were summed to determine fractional coverage (%) for each riparian PFG within each polygon.

Each 2014 riparian polygon was then reviewed using high resolution (0.3 ft) aerial imagery and Google Street View images (when available) to confirm the relative PFG cover for trees, shrubs, and bare ground in each polygon. Areas with misclassified vegetation were adjusted by photointerpretation to the appropriate PFG and cover value.

Relative change in riparian area extent and total vegetation versus bare ground between 2005 and 2014 was evaluated using retrospective photo-interpretive change analysis of the 4-band images. Cover of vegetation and bare ground were adjusted in increments of 5% to account for differences in canopy cover of trees or shrubs between the baseline year of 2014, derived from the NDVI and 2005.

Riparian Extent Comparisons and Calibrations

The accuracy of the following features of the Papadopulos (2008) report (Section 2.4 and Appendix K) were evaluated in two ways:

- By comparing the extent of the riparian area mapped by Papadopulos for 1955 and 2004 to the delineation of the years 1955 and 2005; and
- By comparing the amount of total vegetation and bare ground classified by Papadopulos in 2004 with the classification for the 2005 image.

NAIP 2005 imagery was used for comparative analysis with Papadopulos 2004 study year because it was the nearest suitable imagery available. The results of this comparison showed a 7% difference in total riparian area extent in 1955, and a 2% difference in 2004/2005 (Exhibit 47). These results were similar, indicating consistency in photo interpretative methods employed. Differences in delineated areas are likely attributable to the definition of the edge of riparian areas where they abut upland alluvial soils on the edge of the Rio Grande floodplain, and will not lead to significant differences in calculations of riparian plant cover area (as this excess will be classified as bare ground).

Exhibit 47. Comparison of Riparian Area Extent Mapped by Land IQ vs Papadopulos (2008) for 2004/2005 and 1955.

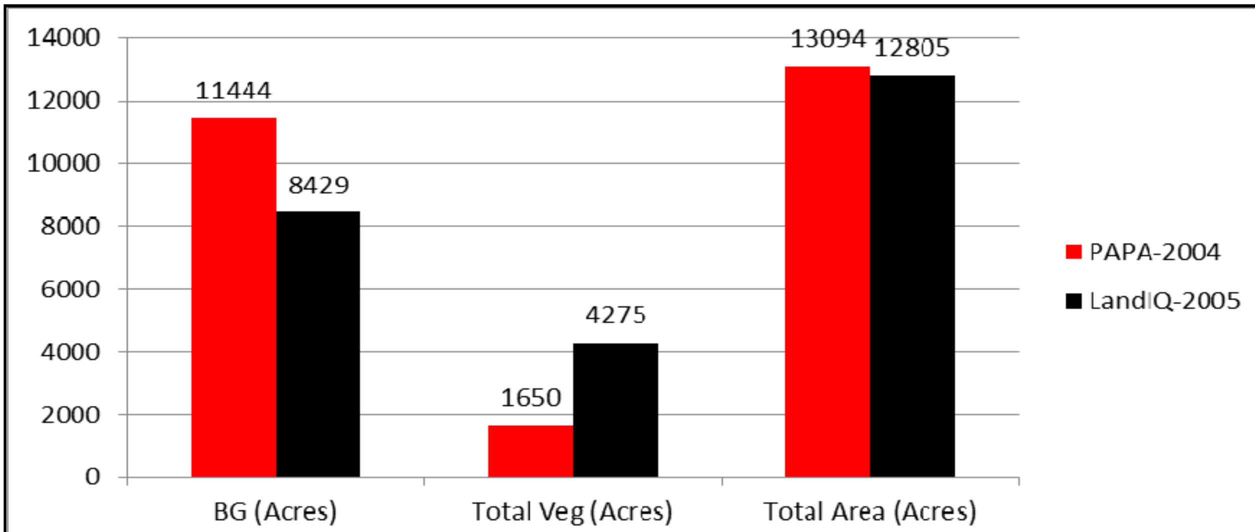
Comparison Year	Papadopulos Total Riparian Area (Acres)	Land IQ Check Total Riparian Area (Acres)	Difference (%)
2004/2005 [a]	13,094	12,805	2%
1955	13,160	12,186	7%

[a] Land IQ 2005 analysis was compared to Papadopulos 2004 analysis due to availability and suitability of aerial image resources.

The distinction between total vegetation and bare ground in both Papadopulos 2004 analysis and Land IQ 2005 analysis were compared. This comparison was made because 2004 was a year in which Papadopulos completed field vegetation surveys. The objective of this comparison was to establish scaling criteria to scale NDVI plant cover analysis to the Papadopulos 2004 results that were guided by ground surveys.

As discussed earlier, the 2014 NDVI-based total vegetation cover values were adjusted for 2005 by photointerpretation of differences in aerial cover of vegetation areas between the 2005 and 2014 imagery. The total vegetation cover calculated for 2005 was compared with the total vegetation result previously generated by Papadopulos in 2004. While total riparian extent was within 2% for these years, the Land IQ NDVI-based calculation of total riparian vegetation cover for 2005 was 159% greater than the Papadopolus (2008) total riparian vegetation cover calculated for 2004 (Exhibit 48). This difference is expected and due to the common overestimation of cover using NDVI values (pixel-based) compared with field survey data. The Papadopulos (2008) report had the benefit of field survey data to verify and measure riparian vegetation cover in 2004.

Therefore, the tabular 2014 total vegetation cover values were reduced by 159% to calibrate the 2014 NDVI-based cover observations to 2004 field-based observations in the Papadopulos (2008) report.



Comparison Year	Bare Ground (Acres)	Total Vegetation (Acres)	Total Riparian Extent (Acres)
2004 (Papadopulos)	11444	1650	13094
2005 (Land IQ)	8429	4275	12805
Difference used to generate scaling factor	-26%	159%	-2%

Exhibit 48. Comparison of 2004 Land IQ Analysis with 2004 Papadopulos Field-based Vegetative Cover.

Results

Results from both analytical efforts were used to compile a riparian land use dataset for the study period. Results of the comparative analysis showed similar relative change in vegetation cover. Therefore, cover values from Papadopulos (2008) were used for the years they were available and combined with the independent results for 2014 to comprise the riparian area dataset for consumptive use analysis purposes (Exhibit 49). The 2014 fraction of riparian tree, riparian shrub, and riparian herb based on Papadopulos 2004 report are values for the fraction of vegetated PFG cover, which are, in turn, based on field survey data (94.1% for tree; 5.6% for shrub; and 0.3% for herb). Photo-interpretation of the 2005 and 2014 high-resolution aerial images showed little to no detectable change in the relative PFG composition between 2005 and 2014 in the riparian areas.

Each analytical year was used to represent the approximate center point of the represented period between analytical years. For example, the values from the 1967 photo analysis were used for 1961 through 1970. Land IQ 2014 analysis results were used from 2014 back to 2010, and Papadopulos results were used for 2009 back to 1936. The completed annual riparian dataset is provided in Appendix 4.

Exhibit 49. Riparian PFG Cover for the Rincon and Mesilla Valleys.

Source	Year	Total Area (Acres)	Total Riparian Tree (Acres)	Total Riparian Shrub (Acres)	Total Riparian Herb (Acres)	Total Bare Ground (Acres)	Total Riparian Veg Area (Acres)	Riparian in Rincon[1](acres)	Riparian in Mesilla[1] (acres)
Land IQ	2016	12,882	1,619	96	5	11,161	1,721	1,149	572
Land IQ	2014	12,809	1,610	96	5	11,098	1,711	1,142	569
PAPA	2004	13,094	1,553	92	5	11,444	1,650	1,109	541
PAPA	1997	13,174	1,620	92	5	11,450	1,717	1,154	563
PAPA	1986	13,018	1,257	25	1	11,735	1,283	862	421
PAPA	1974	13,344	792	110	3	12,440	904	607	297
PAPA	1967	14,089	665	43	-	13,380	708	476	232
PAPA	1955	13,160	273	74	-	12,813	348	227	121
PAPA	1936	15,438	1,452	1,520	3,997	8,469	6,967	4,549	2,418

1. 1955 Fraction of Rincon-Mesilla Total Veg and PFGs is 0.653 of Total Riparian Veg in Rincon (based on Land IQ analysis of vegetation cover in 1955); 1935 to 1937, 1961 to 2014, assumed 0.672 of Total Veg and PFGs in Rincon (based on 2014 Land IQ analysis of vegetation cover)

Consumptive Use Evaluations

Extensive efforts were conducted to determine acreages of agricultural crops and riparian vegetation types for use in estimating consumptive use. Consumptive use for agriculture and riparian areas are presented below.

Agricultural Consumptive Use

Opinions

The following opinions are based on the results of the agricultural consumptive use determination as described below from 1936 through 2018. All crop consumptive use values are provided in Appendix D.

- The overall irrigated agricultural consumptive use in the Rincon and Mesilla Valleys increased from 238,870 acre-feet in 1936 to 275,162 acre-feet in 2018.
- The overall irrigated agricultural consumptive use in the Rincon Valley increased from 37,587 acre-feet in 1936 to 59,164 acre-feet in 2018.
- The overall irrigated agricultural consumptive use in the Mesilla Valley increased from 201,284 acre-feet in 1936 to 215,998 acre-feet in 2018.
- The increase in consumptive use can be attributed to the following:
    - Change in acreage to higher water use crops (e.g., cotton to pecans);
    - Development and production of higher yielding/larger biomass crops (e.g., new varieties of alfalfa developed since 1936);
    - Increase in double cropping and over-winter grain crops;
    - Improved farm management systems (e.g., land leveling, improved distribution uniformity, improved irrigation scheduling, etc.);
    - Incorporation of groundwater wells to provide an additional water supply and allow for a greater opportunity to meet crop water demand especially in years of limited surface water supplies; and
    - Higher density pecan plantings.

Methods

Modeling Approach

The CUP+ Evapotranspiration calculator model was used to determine the consumptive use of each crop per acre per year. The CUP+ was developed by Orang, Snyder, and Matyac, and calculates the potential daily evapotranspiration (PET) with weather and crop inputs. The CUP+ employs either the Hargreaves-Samani or the Penman-Monteith evapotranspiration model, depending on the amount of inputs available. The Penman-Monteith method was used when sufficient data were available. Potential evapotranspiration was calculated using CUP+ for the following 19 crop categories:

- Alfalfa
- Asparagus
- Chili
- Cole/Leafy Greens
- Corn/Silage
- Cotton
- Grain
- Grapes
- Hay
- Legumes
- Melons/Squash
- Misc/Other
- Onions
- Pasture
- Pecans/Other Trees
- Root Crops
- Tomatoes
- Turf
- Irrigated Annuals

Each of these crops has unique properties that influence consumptive use, including Kc values (PET modifier, based on crop and growth stage), percentage of the growing season in each development stage, rooting depth, allowable depletion factor, planting date, and harvest date (Appendix E).

Water Use of Mesilla Valley Crops

Crops

Chilis

Chili acreage in New Mexico peaked in the mid-1990s at about 35,000 acres. Although acreage has declined to approximately 10,000 acres, production has not decreased since that time (Western Farm Press, NASS). According to historical yield records, chili yield has increased from about 15,000 lb/ac in the mid-1990s to roughly 17,000 lb/ac in the Mesilla Valley. Akinbile and Yusoff (2011) demonstrated that chili grown at 50% ET (calculated using an energy balance model) yielded as much as chili irrigated at full ET, indicating that high yields can be achieved with less water than might have been previously used.

According to Bosland and Walker (2014), chilis require 48 to 60 inches of irrigation per season. Assuming that this value refers to applied water and that irrigation efficiency is less than 100%, chili consumptive use is some value lower than this amount. Skaggs and Samani (2005) reported that irrigation efficiency on chili in the Elephant Butte Irrigation District ranges from 83 to 94%; therefore, consumptive use of chili is estimated at 40 to 46 irrigation inches using this information.

Using standard methods to determine potential evapotranspiration (Penman-Monteith, when data was available, and Blainey-Criddle for other years in the study period) and crop coefficients from the New Mexico Climate Center (1996), and adjustments for historically lower yields, average consumptive use for chili from 1936 to 2016 was calculated at 32 inches. The study referenced for these crop coefficients was from Saddiq (1983).

Gencoglan et al. (2006) demonstrated that when chilis were deficit irrigated the crop water production function was linear, meaning that yield declines proportionally and at the same rate when water is decreased, regardless of how much water is applied.

The information above indicates:

- The crop coefficient from 1996 represents relatively high yielding crops compared to today's crops;
- Current crops are even higher yielding, but may also be more water efficient and likely don't need more water; and
- Historical crops within the study period yielded much lower.

Therefore, adjusting the crop coefficient downward going back in time is a reasonable approach to estimate consumptive use throughout the study period (Appendix G).

Onion

According to Cramer (2000), acreage, per acre yield, total production, and total value for the New Mexico onion crop increased from 1980 to 2000, which could be attributed in part to improved varieties and improved cultural practices. Yields have continued to increase until present day. Cramer (2000) documented yields in 2000 at approximately 460 cwt/ac, or 46,000 lb/ac. Current regional yields are approximately 900 bu/ac or 51,300 lb/ac.

Seasonal water use was documented at 23.3 inches by Erie et al. (1982). Walker et al. (2009) reported that the average yield for New Mexico (approximately 800 sacks/acre) was obtained with an efficiency of 80% and the application of 32 inches of water, implying that the crop used about 26 inches of water. Hall et al. (undated) estimated onion water use at 25 to 30 inches per season in Texas. Calculated crop ET using standard methods to calculate potential ET and crop coefficients from the New Mexico Climate Center (1999) resulted in an average estimated crop ET of 28.8 inches per growing season for the Mesilla Valley. Elsewhere, recent onion crop ET was documented at 27 inches per season (Hammond Conservancy 2011). These sources indicate that onion consumptive use is in the range of 26 to 29 inches of water. Onion ET in the Mesilla Valley is likely near the top of this range.

New Mexico State University (undated) cited the work of Al-Jamal et al. (1999) that provided the data for the water production function shown in Exhibit 50. Al-Jamal et al. (2001) investigated irrigation efficiencies of drip, sprinkler, and furrow irrigation on onion in the Mesilla Valley and concluded:

"The IWUE using the sprinkler system was higher compared to the subsurface drip and furrow irrigation methods, which indicates that if you are trying to conserve water, then a sprinkler irrigation system should be used with some form of irrigation scheduling. If you are trying to maximize yield, then this will be achieved by using a drip irrigation system."

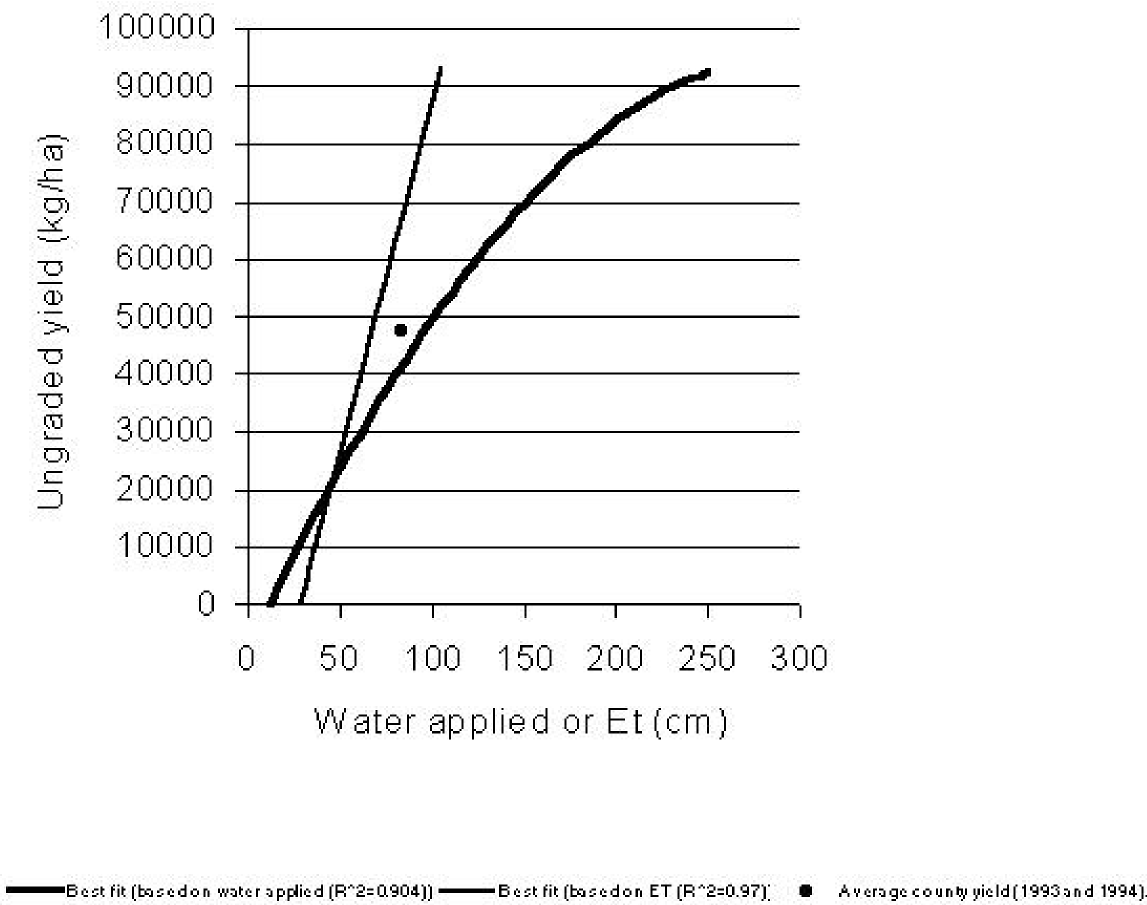


Exhibit 50. Onion Water Production Function. (Source: New Mexico State University. https://aces.nmsu.edu/aes/irrigation/onions.html)

De Oliveira's et al. (2002) Arizona study demonstrated that when Kc was measured on lettuce irrigated with drip, water use was significantly lower than previous crop coefficients (from 1965) indicated. The information above indicates:

- The crop coefficient from 1999 represents relatively high yielding crops compared to today's crops;
- Current crops may be higher yielding, but may also be more water efficient, and likely don't need more water; and
- Historical crops within the study period yielded much lower.

Therefore, adjusting the crop coefficient downward going back in time is a reasonable approach to estimate consumptive use throughout the study period.

Lettuce

Average seasonal crop water use estimated for the study period is 18 inches. While New Mexico State University documented the crop water production function and crop coefficients for chili and onion, there is no similar documentation for leafy greens or specific leafy greens such as lettuce. Therefore, calculations to estimate crop ET for the study period used crop coefficients from FAO Irrigation and Drainage Paper 56 (Allen et al. 1998) or California varieties.

Leafy greens vary widely in their water requirements, as shown in Exhibit 51.

Exhibit 51. Water Requirements of Leafy Greens in Texas (Source: Dainello, 2003)

Type of leafy green	Seasonal water requirement (inches)
Cabbage	20-30
Collards, kale	12-14
Lettuce	8-12
Mustard greens	10-15
Spinach	10-15

Using the water requirements in Exhibit 51 as a guideline, the calculated ET of 18 inches is representative as an average of recent cabbage and lettuce water requirements (the main leafy green crops in the Mesilla Valley).

Seasonal water use of lettuce was documented at 8.5 inches by Erie et al. (1982). This value does not differ from the value in Exhibit 51, indicating that the water requirement of lettuce may not have increased proportionally to yields, which have a little more than doubled during the study period. Martin et al. (2009) reported that head lettuce in Arizona uses 9 to 12 inches of water per season, which is also within the same range. However, De Oliveira et al. (2005) reported that lettuce irrigated with subsurface drip methods use less water than the surface irrigation that was studied in Erie et al. (1982).

The information above indicates:

- The crop coefficients used to estimate lettuce and cabbage ET are likely applicable; and
- Current crops may be higher yielding, but likely don't use much more water than crops grown during the time period when crop coefficients were developed.

Therefore, adjusting the crop coefficient downward going back in time is a reasonable approach to estimate consumptive use throughout the study period (Appendix G).

Climatic Data

Many climatic data resources were evaluated; however, only those resources with reliable climatic data spanning the historical period within the project area were chosen. When a station within a valley offered suitable data, those data were used for that valley. The three primary sources of climatic data identified were:

- NCDC/NOAA (National Climatic Data Center/National Oceanic and Atmospheric Administration);
- WRCC (Western Regional Climate Center); and
- Texas ET Network.

The following criteria were used to evaluate suitability of weather stations and data:

- Location/distance to agriculture fields;
- Immediate surroundings (e.g., irrigated surface vs. vacant lot);
- Measured values (preference for stations that have variables supporting Penman Monteith calculations); and
- Data reliability and consistency.

Weather stations were ranked on these criteria and any data gaps were filled with the next station meeting the selection criteria (Exhibit 52). Through the data evaluation process it was determined that data originating from weather stations located in each valley were sufficient for representing each of the three valleys, respectively. These included:

- Rincon and Mesilla Valleys
- EPCWID1/Hudspeth

Exhibit 52. Weather station ranking over time according to suitability of data.

Date Range	Valley	Most Desirable Data --------------------------------------Least Desirable Data				
2012-2016	EPCWID1/Hudspeth	Tornillo	Ysleta	Fort Hancock	-	-
2011-2012	EPCWID1/Hudspeth	Art Ivey	Tornillo	Ysleta	Fort Hancock	-
2007-2011	EPCWID1/Hudspeth	Tirres	Art Ivey	Tornillo	Ysleta	Fort Hancock
2004-2007	EPCWID1/Hudspeth	Art Ivey	Tornillo	Ysleta	Fort Hancock	-
2002-2004	EPCWID1/Hudspeth	Tornillo	Ysleta	Fort Hancock	-	-
1981-2002	EPCWID1/Hudspeth	Tornillo	Ysleta	Fort Hancock	El Paso International Airport	El Paso, TX
1977-1981	EPCWID1/Hudspeth	Ysleta	Fort Hancock	El Paso International Airport	El Paso, TX	-
1962-1977	EPCWID1/Hudspeth	Fabens	Ysleta	El Paso International Airport	El Paso, TX	-
1950-1962	EPCWID1/Hudspeth	Ysleta	El Paso International Airport	El Paso, TX	-	-
1936-1950	EPCWID1/Hudspeth	Socorro	Ysleta	El Paso International Airport	El Paso, TX	-
2001-2014	Rincon/Mesilla	Fabian Garcia	NMSU Main Campus	NMSU Turf Grass	Leyendecker PSRC	-
1944-2000	Rincon/Mesilla	Las Cruces, NM	State University, NM	La Tuna S, Tx	-	-
1936-1943	Rincon/Mesilla	State University, NM	La Tuna S, TX	-	-	-

Two potential ET calculation methods were evaluated and included the Penman-Monteith Method and the Hargreaves-Samani method. Climate data variables needed for ET calculation differ for each method.

Penman-Monteith variables required:

- Maximum temperature
- Minimum temperature
- Solar radiation
- Wind speed
- Dew point
- Precipitation

Hargreaves-Samani variables required:

- Maximum temperature
- Minimum temperature
- Precipitation

The available climate data did not include the data required for the Penman-Monteith ET calculation method for part of the time period. As a result, the Hargreaves-Samani ET calculation method was used when the Penman-Monteith parameters were not complete. In years that Penman-Monteith data were available, however, both methods were calculated to compare methods and generate adjustment factors for earlier years when only Hargreaves-Samani could be used (Appendix F).

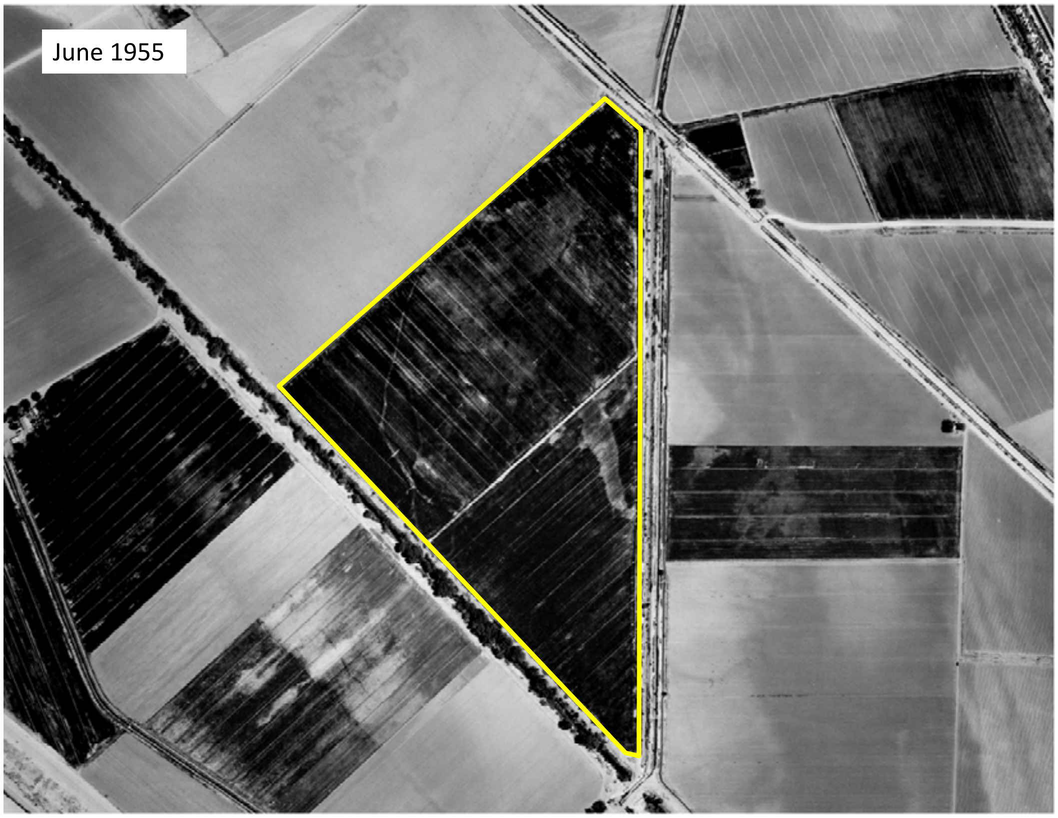
Monthly Adjusted Agricultural Consumptive Use

A crop calculator was created to adjust PET values produced by the CUP+ program. The PET results from the CUP+ program are in acre-feet of consumptive use per acre of planted acreage (acre-feet/acre). These PET values were adjusted due to difference in ET calculation methods. An average monthly adjustment factor was calculated for each of the two ET zones (Rincon/Mesilla and EPCWID1/Hudspeth) when data was available to compare the two ET methods.

PET was also adjusted for irrigation and production differences across time. This adjustment factor takes into account improvements in irrigation efficiency, land leveling, and increased yields/biomass. This factor reduces the PET of crops in historical years because the overall yield, vigor, density, and consistency of growth were proven (through historical yield records and image analysis) to be less in previous years. As a result, the consumptive use was correspondingly less. An adjustment factor was employed for many of the crop types (dominated by cotton and alfalfa) based on yield records and image analysis. These values were based on information obtained from various resources, including comparison of reported yield in the JIR and crop reports. Visual evidence of these crop growth differences also are seen when comparing image resources from different decades (Exhibit 53).

Once the final adjusted PET is calculated (CUP+ PET number * ET Adjustment Factor * Irrigation and Production Factor), it is then multiplied by the total number of acres of each crop on a monthly time step. This value is final consumptive use, by crop, by service area, by year.

Exhibit 53. Visual examples of variations in historical and modern crop production practices




June 1955


June 2014


June 1955


June 2014


June 1955


June 2014

Effects of Salinity and Specific Ion Toxicity on Crop Yield in the El Paso, Mesilla, and Rincon Valley

Introduction

The following technical literature review summarizes the current available literature on the direct and indirect impacts of salinity on the crops with the highest acreage in the El Paso, Mesilla and Rincon Valleys (study crops). Various sources have been consulted and the most current and/or established research available has been summarized. The review provides general information on salinity, sodicity (caused by sodium [Na^+]), and chloride (Cl^-) effects on soils and plants. General guidelines, relative tolerance thresholds and rankings are provided for the study crops. Finally, a brief review of scientific literature related to salinity and specific ion tolerance is provided for each study crop.

Summary

Excess soil salinity occurs when salts accumulate in the root zone, or upper layers of soil. Salts accumulate from natural soil conditions and from long-term irrigation, which precipitates salts when water evaporates from soil and transpires from plants. In many cases, crop growth and yield are reduced in saline conditions because plants need more energy to take up water from salty soil than from non-saline soil. This is called the osmotic effect. One of the most common salts in the environment is sodium chloride (NaCl), which separates into Na^+ and Cl^- ions. These ions, in excess, can also accumulate to toxic levels in plants, which is called specific ion toxicity. Sodium chloride, through all of these effects, is typically thought of as having the most impact on crops compared to other salts, such as calcium chloride (CaCl2).

To manage salinity stress, plants use physiological and biochemical responses and ecological strategies to either avoid or tolerate the stress. Some common strategies include (other) ion uptake by roots, ion exclusion from roots, ion accumulation in vacuoles of root or shoot cells, regulation of ion transport from root to shoot, increased tolerance to high concentrations of toxic ions, and accumulation of compatible solutes (Sandhu et al. 2017). These mechanisms have been studied to a great degree in some crops, such as alfalfa, and little in other crops, such as pecan.

The study crops include alfalfa, cabbage, chile pepper, corn, cotton, grains, lettuce onion and pecan. These crops differ in their tolerance to salinity and Na^+ and Cl^- ions specifically, and in some cases, exhibit a wide variety of tolerance between varieties within the same crop. In general, however, crops that are sensitive to salt are also relatively sensitive to one or both of these salt ions. Crops are only as tolerant as their lowest specific ion tolerance. For example, alfalfa is tolerant of Na^+, but much less tolerant of Cl^-, resulting in its moderate tolerance of salinity. Corn, on the other hand, is moderately sensitive to salinity largely because of its sensitivity to Na^+, even though it can tolerate Cl^- fairly well. Onions are neither tolerant of Na^+ nor Cl^-, and chili pepper tolerance differs so widely between varieties that a single ranking of relative salt tolerance is difficult to determine.

Adding sulfur (S) to soil achieves multiple benefits. First, the S will react with oxygen and water in the soil to produce sulfuric acid (H_2SO_4). This acid will reduce and better balance the pH in soils that may be alkaline (basic) in nature. The sulfuric acid will then react with any lime ($CaCO_3$) in the soil to produce gypsum ($CaSO_4$). Lastly, the $CaSO_4$ then reacts in a sodic soil to produce (tie up) sodium sulfate ($NaSO_4$) which then becomes mobile and is able to leach beyond the root zone. This creates a relative increase in the proportion of Calcium (Ca) and Magnesium (Mg) which tend to aid in soil flocculation, water penetration, and overall improved soil health. The ratio of Sodium (Na) to Ca and Mg is critical to keep in balance and thus one reason why growers will apply S and/or $CaSO_4$ to their fields.

Background Information

The following section summarizes general information on salinity, Na, and Cl^- and their effects on soil and crop growth and yield.

SALINITY

Excess soil salinity occurs when salts accumulate in the root zone, or upper layers of soil. Salts accumulate from natural soil conditions and from long-term irrigation, which precipitates salts when water evaporates from soil and transpires from plants. In many cases, crop growth and yield are reduced in saline conditions because plants need more energy to take up water from salty soil than from non-saline soil. This is called the osmotic effect. Ions that form salt compounds, such as Na^+ and Cl^-, can also accumulate to toxic levels in plants, which is called specific ion toxicity. In addition to these two main impacts of salinity, nutritional imbalances and oxidative stress also result from salinity stress.

To manage salinity stress, plants use physiological and biochemical responses and ecological strategies to either avoid or tolerate the stress. Some common strategies include (other) ion uptake by roots, ion exclusion from roots, ion accumulation in vacuoles of root or shoot cells, regulation of ion transport from root to shoot, increased tolerance to high concentrations of toxic ions, and accumulation of compatible solutes (Sandhu et al. 2017).

Crops vary in their ability to withstand and/or mitigate the multiple effects caused by salinity stress, and though the exact thresholds of salinity where crop yields are impacted are published, these values should only be viewed as guidelines. Actual salinity tolerance in the field may fluctuate or diverge from these values as a result of site specific conditions such as climate, soil type, and management practices, and/or improvements in crop salinity tolerance resulting from crop breeding aimed at increasing salt tolerance. Therefore, some assumptions and considerations associated with crop salt tolerance thresholds should be understood.

- Salinity threshold studies for some crops are more prevalent than others. Availability of salinity research depends on the degree of research funding and efforts conducted on the individual crop.
- Salinity impacts often occur over the period of several years, which demands multi-year studies to better assess the changes in and variability of these conditions.
- Yield factors such as nutrition are impacted by salinity, which has indirect and usually compounding effects on crop growth and production.

- Saline irrigation water affects soil quality as well as crop health, and it can be difficult to separate out these impacts, although the saline irrigation water is the main exacerbating issue to begin with.
- Field and farm management conditions and actions affect impacts of soil salinity.
- Salinity threshold studies can be exacerbated by specific ion toxicity, or the impacts of specific salt ions on plant growth.
- There is a variety of salinity tolerance among cultivars of crops, but in general the information contained in this document addresses the main production systems and should be considered representative.
- Seedlings are generally more sensitive to salt than later growth stages of a crop.
- Obvious injury symptoms usually don't appear unless salt stress is extreme, however impacts on production usually do occur prior to visual indicators.
- There are several parameters that influence crop response to salt stress, including:

  - Salt constituents and existing salt distribution in the soil profile
  - Soil water content, microorganisms, physical conditions, and fertility
  - Climate and air quality
  - Varieties, rootstocks, and stage of growth
  - Cultural practices such as irrigation methods, seed bed arrangements, and plant population density

The most recent data from Maas and Grattan (1999) (reproduced in Tanji and Kielen, 2002) is currently considered some of the best information available on crop salinity tolerance with a few exceptions for specific crops and varietals included. These thresholds are published in international publications such as the Irrigation and Drainage Papers published by the Food and Agriculture Organization of the United Nations (FAO), and aside from specific studies on particular crop varietals, they are considered the best crop salinity tolerance information available and are based on decades of thorough scientific research. Since these data were published, salinity tolerance research has focused on the following areas:

- Crop breeding/rootstock development to increase salinity tolerance.
- Determination of specific ion toxicity of salt constituents, such as Na^+, Cl^-, and sulfate.
- Salinity tolerance in crops for which no salinity threshold and/or impact function has been previously published.

These new studies coupled with the industry standard research results were considered in reviewing the salinity thresholds for the crops in the area.

Irrigation water salinity is often measured as total dissolved solids (TDS) in parts per million (ppm), however literature often describes soil and water salinity as electrical conductivity (EC) in decisiemens per meter (dS/m). A simple conversion for irrigation water from TDS in ppm to EC in dS/m is as follows (Equation 1):

EC = TDS/640 (up to an EC of 5 dS/m) **(EQUATION 1)**

When EC > 5.0 dS/m, research recommends dividing by 800 instead of 640.

This technical memorandum will discuss salinity in terms of irrigation water salinity (ECw) and soil salinity (ECe), which are both expressed in units of dS/m. ECe is the electrical conductivity of a soil saturated paste and is the standard method of measuring salinity in the soil. Crop salt tolerance thresholds are described as ECe thresholds and provide the maximum ECe of the soil at which 100% of crop yield can still be achieved. ECe thresholds are representative of crop salt tolerance at maturity. It is known that crop salt tolerance varies throughout different crop growth stages and is usually less tolerant during germination and seedling stages. In addition to the crop threshold ECe, a slope is often calculated which explains how quickly yield will decrease once the crop threshold ECe is reached per every 1 dS/m increase above the ECe threshold.

The following equation can be used to estimate soil salinity based on irrigation water salinity.

$$\mathbf{ECe = (ECw)(X)} \qquad \textbf{(Equation 2)}$$

Where: ECe = soil salinity

ECw = irrigation water salinity

X = soil concentration factor (a soil concentration factor of 1.5 is assumed by Maas and Grattan, 1999)

For reference, crops are generally categorized by their salinity tolerance, as shown in Exhibit 54.

Exhibit 54. Crop Salt Tolerance Generalized Categories (Adapted from Ayers and Westcot, 1994)

Crop Salinity Tolerance Category	Upper Limit Soil Salinity (ECe) Threshold (dS/m)	Irrigation Water Salinity (ECw) Threshold[a] (dS/m)
Sensitive	3.0	1.0 – 2.0
Moderately sensitive	5.0	1.7 – 3.3
Moderately tolerant	8.0	2.7 – 5.3
Tolerant	12.0	4.0 – 8.0

[a] Assuming 1.5 soil concentration factor, and 1 dS/m EC = 640 mg/L TDS.

Agricultural salinity impact functions are used to estimate the crop yield that results from soils possessing a specific salinity. The slope coefficient is the percentage decline in yield for every unit increase in soil salinity. In general, the more salt-sensitive a crop, the higher its slope coefficient. In other words, the lower the ECe threshold, the more crop damage will occur if salinity is increased above the threshold. The formula for a salinity impact function generally follows this format:

$$\mathbf{y = 100 - b(x - ECe\ Threshold)} \qquad \text{(Equation 3)}$$

Where: y = yield potential (%)

b = slope coefficient (%)

x = actual soil salinity (dS/m)

ECe Threshold = crop soil salinity threshold (ECe)

SODICITY

Typically, the most detrimental salt ion in a soil-plant-water system is Na^+ (Na). Na^+-specific ion toxicity can result in soil degradation and crop yield decline. The Na^+ adsorption ratio (SAR) is the ratio of Na to Ca (Ca) and magnesium (Mg) ions. This relationship is important because it is an indication of the potential impact Na can have on the soil. The SAR is determined by the following formula where ion concentrations are in meq/L:

$$SAR=\frac{[Na]}{\sqrt{\frac{1}{2}([Ca]+[Mg])}}$$

To manage the amount of salt ions in the root zone, excess irrigation water is often applied to leach salt ions lower in the profile. The amount of additional water needed to sufficiently remove the salts is termed the leaching requirement. However, in heavier soils (soils with more clay) with poor drainage, sufficient leaching is more difficult to achieve and salt accumulation can occur in the upper portion of the soil profile.

Sodicity is usually not a concern when the SAR is between 0 and 3 as long as the water salinity is greater than 0.7 dS/m (Ayers and Westcot, 1994). If the SAR is between 3 and 6, the ECw needs to be greater than 1.2 dS/m to ensure that soil degradation will not occur due to excess Na. A high SAR with a relatively low water salinity suggests that Na is the dominant salt forming cation which would likely result in degradation of soil structure, decreased infiltration, etc. Within the soil environment, Na^+ hazard is measured as the exchangeable Na^+ percentage (ESP). The relationship between the SAR and ESP is roughly linear, meaning water with a SAR of 2 will result in soil with an ESP of around 2. As long as soil ESP is below 15 there is unlikely to be any impact to soil drainage or structure.

SPECIFIC ION TOXICITY OF SODIUM AND CHLORIDE

As introduced previously, the two main responses of plants to salinity are the osmotic effect, which inhibits water uptake, and the specific ion effect, which results from accumulation of salt ions to toxic levels. Nutrient imbalance is another effect of excess salinity. The osmotic effect occurs within minutes to days of exposure to saline conditions, and results in oxidative stress and water and nutrient imbalances in the plant. The ion-dependent response to salinity, however, develops over days to weeks as a result of build-up of ions to toxic levels, such as Na^+ (Na) and Cl^- (Cl^-) in the shoots of plants. Both of these effects cause premature senescence of leaves (leaf drop), reduced yield, and ultimately plant death (Negrao et al. 2017). Though Cl^- is an essential plant nutrient and is required in small amounts, Na is not an essential nutrient but is often present in high concentrations, especially in irrigated agriculture.

Multiple mechanisms have been identified that plants use to survive saline conditions: 1) ion exclusion, or the ability of the plant to exclude ions like Na and Cl from the shoot; 2) tissue tolerance, or the compartmentalization of toxic ions in specific tissues; and 3) osmotic adjustment – the maintenance of growth and water uptake even when toxic ions accumulate in the shoot. However, Bartha et al. (2015)

cite multiple studies, including their own, that demonstrate that "*Although the ability to exclude Na^+ or Cl^- from the shoot is often a primary determinant of variability in salinity tolerance within a species, there is not necessarily an inverse relationship between shoot Na^+ or Cl^- concentration and salinity tolerance. There is rather a difference in the ability of ion homeostasis maintenance in the root, in the xylem sap and in the leaves*." Therefore, very specific parameters need to be measured to determine which effect, or which ion, ultimately causes yield reduction in each crop type.

SODIUM

Excess Na^+ is potentially problematic for both soils and plants. Na^+ is not an essential plant nutrient, so it is not required in any way for plant function, though too much Na^+ results in plant water and nutrient imbalances. As described above, excess Na^+ also causes dispersion of soil aggregates and inhibits water infiltration.

Most of the salinity tolerance studies conducted to determine thresholds were executed using Na^+ Cl^- (NaCl) as the imposed salt. Maas and Grattan's work (199…) is an example of such a study, where tolerance was determined but no attempt was made to compare salt species. However, scientific literature on salt ion tolerance in specific crops is sparse, because of the complexities of salinity tolerance and the difficulties in determining cause and effect relationships.

CHLORIDE

Chlorine is an essential plant nutrient that is required in small amounts. Chlorine converts to Cl^- in the soil, which is taken up by plants. Because it is a negatively charged ion, Cl^- moves readily with water similar to nitrate, and is easily consumed by plants. Because it is present in many salt compounds (eg. NaCl, KCl, $CaCl_2$), Cl^- can accumulate in amounts above what is needed by the plant and become toxic. Cl^- toxicity occurs when too much Cl^- accumulates in plant shoots, causing leaf chlorosis (yellowing) and necrosis (death), both of which are sometimes described as leaf "scorch" or "burn".

Again, because most salinity tolerance studies have been carried out using NaCl, it has not always been obvious which impacts to plant growth were caused by the osmotic stress induced by salinity, or by Cl toxicity. Even if Cl^- toxicity symptoms were present, few studies have compared the effects of different salts under the same saline conditions.

White and Broadley (2001) reported on a system of categorizing crops by growth responses to Cl^- as follows:

1. Halophytes – native flora of saline soils, in which 200 mM Cl^- (in external media, not tissue)
    a. Stimulates growth
    b. Affects growth very little
2. Halophytes and non-halophytes (glycophytes) whose growth is reduced substantially by 100 mM Cl^-
    a. Tolerant
    b. Intermediate
    c. Sensitive
3. Very salt-sensitive glycophytes

White and Broadley use (2001) this categorization system for salinity as well, and do not differentiate between Cl^- sensitivity and salt sensitivity. They state that sensitive and tolerant species have tissue Cl^- threshold ranges of 4 to 7 and 15 to 50 ppm dry weight, respectively; however, tissue concentration depends entirely on how well the plant can restrict Cl^- from roots to shoots, and cannot easily be related to specific Cl^- concentrations in irrigation water or soil.

Summary Exhibits of Salinity, Sodium and Chloride Tolerance

The following section provides exhibits of thresholds and guidelines found in the literature related to salinity, sodicity and chloride tolerance for the study crops. These sources do not all have information for each of the study crops; however, they represent the most complete information available.

SALINITY

Crop salinity impact functions have a zero slope until they reach their ECe threshold. Once the ECe threshold has been reached a linear relationship is assumed between ECe and crop yield percentage. Exhibit 55 summarizes the ECe thresholds, slope coefficients, and their resultant salinity impact functions for the most widely grown crops in the area. Additionally, Exhibit 55 shows each of the salinity impact functions. (Salinity thresholds for each crop are reviewed individually in the next section.) Onions are the most sensitive to salinity, while cotton and grains are the least sensitive (Exhibit 56).

Exhibit 55. Crop Salinity Impact Functions of the mostly widely grown crops in the El Paso, Mesilla and Rincon Valleys

Crop	Soil Salinity Threshold, ECe (dS/m)	Salinity Slope (%)	Salinity Impact Function
Alfalfa / Pasture	5	7.3	y = 100 - 7.3(x - 5.0)
Cabbage	1.8	9.7	y = 100 - 9.7(x - 1.8)
Chile Pepper	1.5	14	y = 100 - 14.0(x - 1.5)
Corn	1.8	7.4	y = 100 - 12.0(x - 1.7)
Cotton	7.7	5.2	y = 100 - 5.2(x - 7.7)
Grains	5.9	3.8	y = 100 - 3.8(x - 5.9)
Lettuce	1.3	13	y = 100 - 13.0(x - 1.3)
Onion	1.2	16	y = 100 - 16.0(x - 1.2)
Pecan	2.5	11.4	y = 100 - 11.4(x - 2.5)

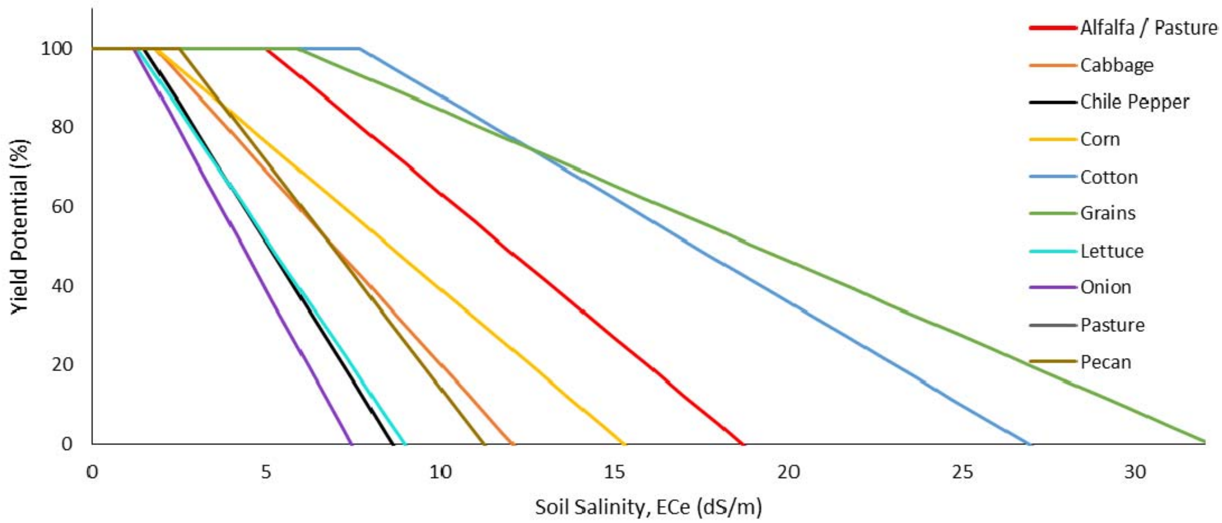


Exhibit 56. Crop Salinity Impact Functions of the mostly widely grown crops in the El Paso, Mesilla and Rincon Valleys

SODIUM

There are no specific thresholds published for Na tolerance, because Na excess typically causes soil infiltration problems long before Na ion toxic effects occur in agricultural fields. For this reason, The Food and Agriculture Organization (FAO) published relative Na tolerances for selected crops, with corresponding exchangeable Na^+ percentage (ESP) ranges (Exhibit 57).

Exhibit 57. Sodium (as ESP) tolerance of the mostly widely grown crops in the El Paso, Mesilla and Rincon Valleys.

Crop	Sensitive (< 15 ESP)	Semi-Tolerant (15-40 ESP)	Tolerant (>40 ESP)
Alfalfa / Pasture			X
Cabbage [1]			
Chile Pepper [1]			
Corn	X		
Cotton			X
Grains (durum wheat)		X	
Lettuce		X	
Onion		X	
Pecan[2]			

[1] Species of cabbage and pepper and cultivars of each species differ in their Na^+ (ESP) tolerance.
[2] Pecan is reported as sensitive to moderately sensitive in other sources.
Source: FAO

CHLORIDE

Some Cl tolerance thresholds or relative tolerance concentrations have been published for various crops, but is it unknown if these have been peer reviewed. For example, K&S Fertilizer ranks cereals, corn, cabbage and cotton as Cl^- tolerant crops, whereas chili pepper, onion, and lettuce are listed as Cl^- sensitive crops (ref). Alfalfa and pecan were not rated. Similarly, Spectrum Analytic lists Cl^- thresholds for selected crops as summarized in Exhibit 58. Some crops, such as alfalfa, cabbage, lettuce, and small grains, respond well to Cl^- fertilizer, while others are susceptible to toxicity.

Other sources rank irrigation water Cl^- concentration in terms of general safety for crops. An example from a fertilizer company (not peer reviewed) is shown in Exhibit 59.

Exhibit 58. Chloride tolerance of the mostly widely grown crops in the El Paso, Mesilla and Rincon Valleys

Crop	Relative Chloride Tolerance[1]	Soil Chloride Threshold (ppm)	Percent Yield decrease for every ppm above threshold (slope)
Alfalfa / Pasture	MT	700	0.020
Cabbage	MT	525	0.028
Chile Pepper	-	-	-
Corn	MT	525	0.034
Cotton	T	2,625	0.014
Grains (durum wheat)	T	1,925	0.014
Lettuce	S	350	0.037
Onion	S	350	0.046
Pecan	-	-	-

Source: Cl^- and Crop Production, Special Bulletin No. 2, Potash & Phosphate Institute (International Plant Nutrition Institute) via Spectrum Analytic.

[1] MT = moderately tolerant; T = tolerant; S = sensitive.

Exhibit 59. Chloride Classification of Irrigation Water for Crop Safety

Chloride concentration in irrigation water (ppm)	Effect on Crops
Below 70	Generally safe for all plants.
70-140	Sensitive plants show injury.
141-350	Moderately tolerant plants show injury.
Above 350	Can cause severe problems.

Source: Smart Fertilizer Management

Crops

The following section summarizes information on salinity and ion toxicity for each of the widely grown crops in the area. The amount of information available varies for each crop depending on how common it is and its economic importance. Therefore, this information is not necessarily conclusive; rather, it is included to provide more insight on crop specific tolerances and yield potential for each crop, and how these tolerances might be affected by environmental factors such as soil type and water quality, and cultural practices such as varietal selection and irrigation method.

ALFALFA

Alfalfa has been considered a crop that is moderately sensitive to salinity (threshold ECe=2 dS/m) with a slope of 7.3% since the 1960s (Tanji and Kielen 2002). However, in recent years researchers have demonstrated that alfalfa is more tolerant than previously thought (up to ECe=8 dS/m) (Putnam, pers. comm.). In addition, researchers in Arizona and California have been working on breeding more salt tolerant alfalfa varieties for the last 30 years (Sanden and Sheesley, 2007).

In some cases, field studies have demonstrated that low leaching fractions that result in soil salinity higher than the conventional threshold do not necessarily harm alfalfa growth and yield (Leinfelder-Miles, 2016), although these studies were conducted in a dissimilar climate to that of southern California and Arizona and have not been validated again in the research. Central Arizona alfalfa growers have also demonstrated that alfalfa grows without symptoms of salt stress in highly saline soils (ECe = 8 dS/m) (Land IQ, 2014). This is site specific, however and may or may not be applicable to southern New Mexico. Until repeated verification of these results occurs, the standards presented in this documentation memorandum should be used.

The irrigation water salinity threshold that would result from using the conventional soil salinity threshold of 2 dS/m and a soil concentration factor of 1.5 (as assumed by Mass and Grattan, 1999) would be 1.3 dS/m or 832 mg/L TDS. Salinity experts acknowledge that due to newer varieties, the conventional salinity threshold for alfalfa may be too low and a new one needs to be developed, but no official update to the alfalfa threshold or impact function has been developed to date (Putnam, 2018). However, recent studies performed in sand tanks, greenhouses, and field stations all corroborate a salinity threshold for alfalfa between 5 and 8 dS/m ECe, assuming that water management optimizes alfalfa growth and salinity mitigation (Benes et al., 2015; Putnam et al., 2014). Therefore, a threshold of 5 dS/m is recommended for alfalfa, which represents the minimum of this range.

According to Sanden and Sheesley (2007), alfalfa and other crops are 10 to 20 percent more tolerant of Ca and sulfate salts compared to NaCl. Al-Khateeb (2006) corroborated this perception for Ca by demonstrating that shoot and root growth declined under increasing treatments of NaCl, while the addition of Ca mitigated those effects.

However, Henning et al. (2004) found no difference between Cl uptake in the forms of ammonium Cl^-, calcium Cl^- or a mix of the two. Soltanpour et al. (1999) found no difference between Cl^- and sulfate salts, which both reduced alfalfa dry matter equally; however the slope (or impact function) they calculated was much lower (-3.37 percent) than that of Maas and Hoffman (1977) (-7.3 percent). Interestingly, they did not observe a salinity threshold. Potassium chloride (KCl), a commonly used fertilizer, has long been known to cause leaf burn and shoot death (Smith and Struckmeyer 1977). These authors showed that high Cl uptake caused thickened, yellowed and deformed shoots. Meyer and Matthews (1995) found that Cl^- application could prevent some disease, but large amounts applied as KCl caused toxicity.

Sandhu et al. (2017) tested 12 genotypes of alfalfa for salinity tolerance using different salt compounds, and also investigated mechanisms of salt tolerance in the most tolerant varieties. They found that Na exclusion was an important mechanism in the most tolerant alfalfa varieties. This may be the reason alfalfa is considered tolerant to Na (Ayers and Westcot 1994).

CABBAGE

The cabbage ECe threshold is cited at 1.8 dS/m with a 9.7% slope, being considered moderately sensitive (Tanji and Kielen, 2002). Varieties differ in their salt sensitivity. Sanoubar et al. (2016) found that Savoy cabbage was more tolerant of NaCl than white cabbage, likely because of greater concentrations of antioxidant enzymes accumulated in Savoy that mitigate oxidative stress. This mechanism results in better water relations and tissue adjustment/tolerance than that of white cabbage. The authors identified two thresholds – one at 100 millimoles (mmol)/L and one at 200 mmol/L where morphological and physiological changes took place. These values are similar to those found by Pavlovic et al. (2019), who reported a salinity threshold of 180 mmol/L, which is consistent with previously published values of Shannon and Grieve (1999) and others. These authors also investigated the salinity tolerance mechanisms of cabbage, but focused on Na^+ ion relations and biological responses, and did not study Cl^-. Maggio et al. (2005) found relatively high tolerance to NaCl in cabbage. They reported that despite some observed physiological responses, cabbage could still be grown in low to moderate saline soils up to 4.4 dS/m.

CHILE PEPPER

The published ECe threshold for pepper is 1.5 dS/m with a slope of 14% being considered moderately sensitive (Tanji and Kielen, 2002). Recent pepper salinity research has focused on the relative salinity tolerance of different varieties of peppers and seedling emergence (Niu and Sun, 2013; Niu et al., 2010).

Several studies have documented that chili peppers differ considerably between and within species in their salinity and ion tolerance. For example, habanero peppers exhibit a combination of stress tolerance mechanisms, but varieties range from sensitive to tolerant in their salinity tolerance overall (Bojorquez-Quintal et al. 2014). Iroka et al. (2016) also found that pepper varieties differ in their tolerance even at the germination stage from tolerant to highly sensitive.

CORN

The ECe threshold for corn is 1.7 dS/m with a 12% slope and is considered moderately sensitive (Tanji and Kielen, 2002). However, the salinity threshold for corn grown specifically for forage has been published as 1.8 dS/m ECe with a slope of 7.4% (Tanji and Kielen, 2002). It is recommended to use the corn, forage salinity impact function as corn is commonly grown for forage.

Eaton (1942) conducted outdoor sand tank and indoor greenhouse water culture experiments to evaluate the tolerance of corn to Cl^- and sulfate salts. The results of this experiment showed that corn was susceptible to Cl^- toxicity at relatively low concentrations. Parker et al. (1985), however, conducted greenhouse and field research to investigate the effect of Cl^- on one variety of corn (Trojan), and found that it was not very susceptible to Cl^- toxicity; they were not successful inducing Cl^- toxicity symptoms using imposed Cl^- treatments. One explanation for the difference in these results is the difference in corn varieties that were used, given that one study took place almost 80 years ago, whereas the other was fairly recent.

Farooq et al. (2015) contend that in the second phase of salt stress, when accumulation of Na and Cl^- has potential to become toxic, Cl^- is not as problematic as Na for corn. They also cite a study (Isla and Aragues 2010) the demonstrated that as salinity increased, Na accumulation was much higher than Cl−in maize, and maize productivity was more sensitive to Na accretion than Cl^- (Isla and Aragues2010). Farooq et al. (2015) also observed multiple exclusion and compartmentalization mechanisms that corn uses to mitigate the effects of Na, but no similar mechanisms for Cl^-. Therefore, corn is likely not very sensitive to Cl^-. This is supported by the fact that a positive response to Cl^- has been documented in numerous studies on corn in the Midwestern US, and application of low amounts of Cl^- is becoming part of a complete corn fertilization program (Kansas State University Extension). Ayers and Westcot (1994) also suggest that corn is sensitive to Na. The differences in corn tolerance to Na and Cl^- are reflected in Exhibits 57 and 58.

COTTON

Cotton is tolerant to salinity and has a relatively high salinity threshold. Therefore, the salinity threshold for cotton has not been challenged by new research. Sources agree on the threshold, published by Tanji and Kielen (2002) of a 7.7 dS/m ECe threshold with a slope of 5.2%.

White and Broadley (2001) list cotton as an example of a tolerant glycophyte. This assessment is corroborated by other sources that rank cotton as tolerant or moderately tolerant of salinity (Maas 1990), Na and Cl^- as well (Exhibits 57 and 58). However, varieties differ in their salt tolerance (Ashraf 2010), and these differences, which are largely genetic, are exploited in breeding programs designed to generate more salt tolerant cotton varieties (Akhtar 2010). Ayers and Westcot (1994) recommend that cotton is sensitive to Na during germination but tolerant as a mature crop.

GRAINS

Salinity thresholds and slope vary greatly between different types of grains, with barley being the most salt tolerant. Durum wheat is a representative variety grown in the area because it is the most widely grown grain. It is considered moderately tolerant to salinity and has a published ECe tolerance of 5.9 dS/m and a slope of 7.3% (Mass and Grattan, 1999).

However, Royo and Abio (2003) concluded, from their study of 17 durum wheat genotypes and their tolerance to salinity, that varieties differ in their salinity tolerance, and commonly accepted literature values are likely too high. While Ayers and Westcot (1985) list the salinity at which durum yield is reduced by half (ECe_{50})at 15 dS/m, Royo and Abio (2003) found that this value was, on average for several different varieties including some that were very tolerant, 11.3 dS/m. The maximum ECe_{50} they found in the most tolerant variety they tested was 16.6 dS/m, while the lowest was 7.5 dS/m. They also observed increasing Cl^- and Na in leaf sap with increasing salinity in the irrigation treatments. While the increase in Cl^- correlated to yield in six varieties, no correlation was found for Na. This led the authors to believe that Cl^- toxicity is more problematic than Na toxicity; however, the effects of Na could have been mitigated by Ca in the treatments and growth media.

Contrasting results were reported by Borrelli et al. (2011), who also tested several durum wheat varieties for salinity tolerance and Na uptake. In their case, little Na accumulation was observed, even in plants exposed to high salinity treatments. The authors concluded that low Na accumulation coupled with osmotic adjustment allowed durum wheat to resist ion toxicity and salinity effects.

During the last 10 years, crop breeders have improved salinity tolerance of durum wheat even more by an estimated 25 percent (CSIRO 2010). Interestingly, Genc et al. (2015) found that when durum varieties were bred with a Na exclusion gene in an attempt to develop more salt tolerant varieties, these varieties out-yielded others under sodic conditions. However, under saline conditions, and even though leaf Na was very low, the osmotic effect of salinity negated any benefits afforded the plant by Na exclusion. This research indicates that plants with an exclusion mechanism can tolerate sodicity alone, but may not be able to tolerate overall saline conditions.

LETTUCE

The ECe threshold for lettuce is 1.3 dS/m with a slope of 13% and is considered moderately sensitive (Tanji and Kielen, 2002). There is considerable variability in salt tolerance between varieties (Shannon and Grieve 1999; Xu and Mou 2015), but for the most part the values suggested here are considered reasonable. Unlukara et al. (2010), for example, observed a threshold salinity value of 1.1 dS/m but a slope of 9.3 percent in a study that included five varieties. However, in their study, they used a mixture of NaCl, MgSO4 and CaCl2, rather than NaCl alone, which likely accounts for the difference in slope. Cahn and Ajwa (ref date?), in their study of lettuce salinity tolerance in the Salinas Valley in California, found that the published thresholds may be overestimated because of their findings indicating that yield can be impacted before salinity symptoms are observable. At the published thresholds, a 10 percent reduction in marketable yield was observed (on average for two varieties). However, they noted that the response of lettuce to salinity can depend on other factors such as the weather regime, species of salts, irrigation practices, and varietal tolerance to salinity. Because of these factors, the published salinity threshold is still considered valid.

Ayers and Westcot (1994) list lettuce as semi-tolerant of exchangeable Na^+. Cahn and Ajwa (undated) also found that increased tissue Cl and Na was correlated with increasing soil salinity and SAR respectively, but not correlated to yield. Similarly, Bartha et al. 2015 found that the most salt tolerant lettuce variety they tested (with NaCl) also had the highest amount of Na in the shoot, whereas as the lowest amount of Na was found in the least tolerant variety. These findings indicate that in lettuce, Na^+ exclusion is not a main strategy for salt tolerance. They further concluded that lettuce is an example of a crop in which salinity tolerance is related not to ion exclusion, but to inclusion of Na in the shoot system. They also observed that for salt tolerant varieties, the marketable yield has a higher dry biomass percentage, and that leaves of plants grown under high salinity were crispier and darker green. Unlukara et al. (2010) also found that dry matter content increased with increasing salinity.

In their study of 178 lettuce varieties, Xu and Mou (2015) observed that in general, varieties with high growth potential were relatively salt sensitive based on the percentage of growth reduction, while those with relatively high salt tolerance commonly had low growth potential under control condition. This finding indicates that salt sensitivity is not necessarily related to lower yield when genetic potential is considered. They further submit that growers may choose high yielding potential over salt tolerance.

ONIONS

The published ECe threshold for onions is 1.2 dS/m with a 16% slope and is considered salt sensitive (Tanji and Kielen, 2002). Salt tolerance of onion varies during crop development, being the most sensitive to salinity during seedling growth. Chang and Randle (2004) observed that though onion is considered a salt sensitive vegetable, it is grown in saline soils throughout the world. However, they observed similar threshold values in their study of onion salinity sensitivity using NaCl. Sta-Baba et al. (2010) also corroborated this threshold value in their greenhouse study on onion salt sensitivity. Ayers and Westcot (1994) list onion as a semi-tolerant of exchangeable Na^+.

Shannon and Grieve (1999) reported that little genetic variability in salinity tolerance exists between onion varieties. Correa et al. (2013) found some differences in salt tolerance between varieties, and Sivritepe and Sivritepe (2007) found that when onion seeds were primed with NaCl, seedlings developed from them were more salt tolerant than their unprimed counterparts. However, study findings are consistent in finding that increasing NaCl tissue concentrations are related to decreased plant viability and vigor. Specifically, Correa et al. (2013) observed that antioxidant enzyme activity increased with these high ion concentrations. These findings indicate that onion is likely not able to exclude or compartmentalize Na and Cl, which may be the reason for its low salinity tolerance.

PASTURE

Because pasture crops are of relatively low-value, recent salinity research has not been focused on pasture. There is a wide variety in salt tolerance between various pasture and grain crops, ranging from about 640 mg/L TDS to more than 3,242 mg/L TDS (Tanji and Kielen, 2002). These crops include grains, forages, grasses, and legumes. Finding a representative average threshold for this group of crops would require specific information about pasture mixes and grains grown in the region, which is not available to that level of detail. We recommend using alfalfa as the representative crop for this pasture, as it is a common component of pasture mixes and is widely used.

PECANS

Tanji and Kielen (2002) did not publish a salinity tolerance for pecans, citing only that they are moderately sensitive to salinity. However, Miyamoto et al. (1986) conducted pecan salinity research in the El Paso Valley, finding that the ECe tolerance varied from 2.0 to 3.0 dS/m with a slope varying from 9.5% to 14.5% when correlated to tree trunk diameter and cross-sectional area. However, no studies have been found that describe the decrease in yield associated with increase in salinity. The slope in Exhibit 55 was derived by considering the change in growth parameters with salinity documented by Myamoto (1986), and by reviewing slope values for other deciduous woody crops. The most recent pecan salinity tolerance research has focused on relative salinity tolerance of pecan rootstocks and varieties, along with salinity management measures.

Walworth (undated) interpreted Miyamoto's work more conservatively, as a threshold of 2.0 to 2.5 dS/m, but also suggested that salinity thresholds for pecans depends on soil type, rationalizing that clay soils are more difficult to leach and warrant a lower salinity threshold. Though Walworth acknowledges that pecan varieties differ in their salt tolerance and that data is lacking for most cultivars, he recommends the guidelines shown in Exhibit 60.

Exhibit 60. Pecan Salinity Tolerance Guidelines

	Salinity Threshold	
Soil Texture	**ECe (dS/m)**	**mg/L (ppm)**
Clay, clay loam	< 1.0	<640
Loam	1.0-2.0	640-1,280
Sand, loamy sand	2.0-2.5	1,280-1,600

Source: Walworth undated.

Deb et al. (2013) investigated salinity tolerance on one rootstock/scion combination with a CaCl and NaCl mixture, and found that salinity tolerance was between 0.89 and 2.71 dS/m ECe. This range encompasses that of Walworth (undated), shown in Exhibit 60; however, they based their conclusion on leaf scorch symptoms, which occurred within this range of salinity, and did not measure yield. Deb et al. (2013) the accumulation of Cl^- in leaves and observed leaf burn with increasing salinity treatments. Myamoto (2006) states that pecan is especially sensitive to Na and Cl^-, and that these salts are potentially more harmful and calcium or sulfate salts.

Riparian Consumptive Use

Opinions

- Riparian vegetation can be categorized into plant functional groups (PFGs) that have similar water use and plant growth characteristics. The vegetation within the study areas was represented by three plant functional groups: dominantly riparian trees, and to a lesser extent riparian shrubs and riparian herbaceous. Evapotranspiration rates are available from literature resources and studies relevant to the study area for the three PFGs.

- Riparian consumptive use in the Rincon and Mesilla Valleys was highest at the start of the study period when historical reports and studies document that total riparian vegetation was much higher along the Rio Grande prior to anthropogenic activities and development. Consumptive use at this time was estimated to be approximately 17,975 acre-feet. Efforts to clear riparian vegetation in the late 1930s, and resulted in dramatic declines in vegetative cover and associated consumptive use by the 1940s to approximately 720 acre-feet in Rincon and Mesilla Valleys combined.

- Since the 1950s, total riparian vegetation cover has increased gradually from this level, resulting in similar increasing trends in riparian consumptive use with the total riparian consumptive use for Rincon and Mesilla Valleys increased to approximately 4,371 acre-feet.

Methods

Riparian consumptive use was calculated using riparian land use areas and average ET rates for the three evaluated PFGs–riparian shrub, riparian herbaceous, and riparian tree. Riparian consumptive use calculations focused on phreatophyte vegetation and do not address bare ground. Evapotranspiration rates depend on several factors, including the characteristics of the plant community species identification, height and age, vegetation health), stand densities, site conditions such as depth to groundwater, salinity, temperature, and precipitation (Tamarisk Coalition 2009, Johns 1989).

Estimated ET rates for the three functional groups were generated from available literature sources. The ET rates for riparian shrub and riparian herbaceous PFGs were taken from Papadopulos (2008) (Exhibit 61). Riparian ET rates were estimated for the dominant PFG type; riparian trees, by selecting published ET rates for the three most common tree sub-types in this group: Tamarisk, Mesquite, and Cottonwood-Willow. Using relative tree cover estimates from Papadopulos (2008) for those three tree groups for each year of analysis, an average riparian tree ET was developed. Due to changes over time in vegetative composition of this PFG, riparian tree group ET values also change slightly over time.

The selected riparian tree ET rates used in this analysis are shown (Exhibit 62). A summary of literature resources for the relevant tree sub-types is provided below.

Exhibit 61. Annual Consumptive use Rates for Riparian Shrub and Riparian Herbaceous Functional Groups (From Papadopulos 2008)

Riparian Plant Functional Group		Annual Consumptive Use	
Shrubs			
0.01	ft/day	3.65	ft/year
Herbaceous			
0.006	ft/day	2.19	ft/year

Exhibit 62. Annual Consumptive use Rates for Riparian Tree Subcategories.

Riparian Tree Type		Annual Consumptive Use	
Tamarisk			
0.94	m/year	3.08	ft/year
Mesquite			
0.47	m/year	1.54	ft/year
Cottonwood/Willow			
1300	mm/year	4.27	ft/year

Tamarisk ET

Estimates of ET for typical dense stands of Tamarisk are presented in Exhibit 63 (Tamarisk Coalition 2009). In general, lower density stands and stands experiencing water and salinity stress (such as stands on upper floodplain terraces) have lower ET rates (~0.7 m/year), while healthy, well-watered stands, such as those along water courses with access to groundwater, can use up to 1.45 m/year. The mean value of these reported literature references was selected for this study (0.95 m/year).

Exhibit 63. Literature Estimates of Tamarisk ET from Selected Studies

(From: Tamarisk Coalition 2009)

Table 3: Estimates of wide-area tamarisk ET from selected studies involving different river systems, measurement techniques and water table and cover conditions.

Location	ET (m/yr)	Method	References
Havasu NWR, Colorado River, AZ/CA	0.8	Bowen Ratio Flux Towers	Westenburg et al. 2006
Middle Rio Grande, NM	0.8 – 1.2	Eddy Covariance Flux Towers	Cleverly et al. 2002, 2006
Dolores River, UT	0.6 – 0.7	MODIS EVI/T_a	Dennison et al. 2008
Colorado River Delta, Mexico	1.1	MODIS EVI/ T_a	Nagler et al. 2007
Virgin River, NV	0.75 – 1.45	Bowen Ratio Flux Tower	Devitt et al. 1998
Cibola NWR, Colorado River, AZ	1.15	Sap Flow and MODIS EVI/ T_a	Nagler et al. 2008
Pecos and Rio Grande Rivers, TX	0.75	Sap Flow	Owens and Moore 2007
Bosque del Apache NWR, Rio Grande River, NM	1.0	Eddy Covariance Flux Towers	Hattori 2004
Mean	**0.94**		

Cottonwood/Willow ET

In the riparian floodplain zone, phreatophytic tree community vegetation (primarily Cottonwood-Willow) in western river systems, exhibit ET rates that are comparable to Tamarisk that has reached maturity (woody stems) and full canopy closure (Tamarisk Coalition 2009). Tamarisk vegetation cover has lower ET rates where it invades upper floodplain terraces, which are out of the mesic riparian fringe that supports Cottonwood-Willow riparian vegetation. Consequently, across a broad floodplain with a mix of upper and lower floodplain terraces, such as in the Lower Rio Grande Basin, the average ET for Tamarisk is expected to be lower than Cottonwood-Willow, assuming both are relatively mature stands. Younger stands of these communities, especially Tamarisk, will have higher ET rates, reflected by greener (photosynthesizing) plant material. The ET rates decrease to a relatively stable water consumption rate–assuming weather conditions are stable between years–as the biomass becomes woodier.

Annual ET rates for the Cottonwood-Willow riparian vegetation community were selected by reviewing Allen et al. (2005), which calculated average annual ET (mm) for Cottonwood (1380 mm) and Willow (1283 mm) for a study area in the Middle Rio Grande River Basin, with 2002 imagery and a satellite-based energy balance calculation method using Landsat imagery. The selected rate was 0.47 m/year.

Mesquite ET

The vegetation community of Bosque Mesquite in the Lower Rio Grande River Basin includes species such as Honey Mesquite and Velvet Mesquite. Examples of Mesquite ET rates are provided in research from Tamarisk Coalition (2009) (Exhibit 64). An ET rate of 0.5 m/year was selected for Mesquite.

Exhibit 64. Literature Estimates of Evapotranspiration for Vegetation Species in Upper Terrace Floodplains, Including Tamarisk. (From: Tamarisk Coalition 2009)

Table 2: Daily and/or annual evapotranspiration (ET) estimates for native, non-phreatophytic vegetation types (individual species and plant community associations) occurring in upper terrace floodplain sites, western United States (adapted from Shafroth et al. 2005, with additions.

Veg Type	ET[1] *mm d⁻¹* *(m yr⁻¹)* *[ac-ft yr⁻¹]*	Study Location	Method	Citation
Mesquite	(0.4)	San Pedro River, AZ	BR	Scott et al. 2000
(*Prosopis* spp.)	1.6 – 2.4	San Pedro River, AZ	BR	Scott et al. 2000
	(0.6 – 0.7)	San Pedro River, AZ	EC	Scott et al. 2004
	(1.02)	Arizona	??	Gatewood et al. 1950
	[2.1-2.3]	San Pedro River, AZ	EC/BR	Scott et al. 2006
Honey mesquite (*Prosopis glandulosa / P. juliflora*)	(0.47)	Lower Colorado River (near Blythe, CA)	BR	Wiesenborn 1995
	[2.9]	Acme-Artesia area, NM	??	USBR 1979
Velvet mesquite (*Prosopis velutina*) woodland	(0.64-0.69) ++	San Pedro River, AZ	SF / EC	Leenhouts et al. 2006
Velvet mesquite shrubland	(0.57) ++	San Pedro River, AZ	SF / EC	Leenhouts et al. 2006
Mixed saltcedar / Honey mesquite	(1.0)	Lower Colorado River (near Blythe, CA)	BR	Wiesenborn 1995
Mixed saltcedar / Screwbean mesquite (*Prosopis pubescens*)	(0.37)	Lower Colorado River (near Blythe, CA)	BR	Wiesenborn 1995
Savannah woodland: velvet mesquite / big sacaton mixed stand	3.5	Tucson, AZ	EC	Yepez et al. 2003
Arrowweed (*Pluchea sarothroides*)	(0.37)	Lower Colorado River (near Blythe, CA)	BR	Wiesenborn 1995
Quailbush (*Atriplex lentiformis*)	(0.69)	Lower Colorado River (near Blythe, CA)	BR	Wiesenborn 1995
Inland saltgrass	(0.3 - 1.2)	Various sites	LYS	Weeks et al. 1987
(*Distichlis spicata*)	1.1 – 4.5	Sonora, NM	LYS	Miyamoto et al. 1996
Inland saltgrass	(0.45 – 1.15)	Owens Valley, CA	LYS	Young and Blaney 1942
	(0.4 – 0.9)	Santa Ana, CA	LYS	Young and Blaney 1942
	(0.25 – 1.25)	Los Griegos, NM	LYS	Young and Blaney 1942
Inland saltgrass / alkali sacaton	[1.2]	Acme-Artesia area, NM	??	USBR 1979
Big sacaton	0.3 – 1.6	San Pedro River, AZ	BR	Scott et al. 2000
(*Sporobolus wrightii*)	(0.55) ++	San Pedro River, AZ	SF / EC	Leenhouts et al. 2006
	[1.8]	San Pedro River, AZ	EC/BR	Scott et al. 2006
	50% of mesquite shrubland site; 25% of cottonwood site	San Pedro River, AZ	SF / EC??	Qi et al. 1998
Alkali sacaton / desert seepweed	(1.05 – 1.2)	Carlsbad, NM	LYS	Blaney and Hanson 1965
(*Suaeda suffrutescens*)	(0.57 – 0.67)	Artesia & Bitter Lakes NWR, NM	BR	Weeks et al. 1987
	(0.40)	Artesia & Bitter Lakes NWR, NM	EC	Weeks et al. 1987
"Grassland" (saltgrass / alkali sacaton??)	[0-1.99]	Los Lunas, NM	??	USACE/USBR 2002

[1] Values without parentheses or brackets are reported in mm d^{-1} units; values within parentheses are reported in (m yr^{-1}) units; values within brackets are reported in [ac-ft yr^{-1}] units.
[2] Methods include Bowen Ratio (BR), Eddy Covariance (EC), Sap Flow (SF), and Lysimeter (LYS)
"??" symbol indicates that it was unclear what the specific ET measurement technique or plant species was

++ Growing season only.

Riparian Tree ET

Using the fractional cover of Mesquite, Tamarisk, and Cottonwood in the riparian area as reported by Papadopulos (2008), a compound ET value for riparian tree was calculated. The percent cover of riparian tree species presented in this report accounts for approximately all of the tree cover reported in the Riparian Tree PFG from 1955 to 2004. The year 2014 was assumed to have the same tree composition as documented in the 2004 field surveys. The 1936 tree composition was estimated. The tree distribution was used to weight relative tree type ET rates and generate a weighted ET for the Riparian Tree PFG in each evaluated timeframe. Exhibit 65 shows the resultant ET estimations that were used for consumptive use calculation in the riparian tree areas.

Exhibit 65. Riparian Tree Plant Functional Group relative tree type distribution and Resultant Consumptive Use Assumptions

Year	**Mesquite** Fraction of Riparian Tree PFG	**Tamarisk** Fraction of Riparian Tree PFG	**Cottonwood-Willow** Fraction of Riparian Tree PFG	**Annual Riparian Tree CU*** **(Acre-Feet/Acre)**
2016	38.8%	59.0%	1.7%	**2.49**
2014	38.8%	59.0%	1.7%	**2.49**
2004	38.8%	59.0%	1.7%	**2.49**
1997	40.7%	57.7%	1.6%	**2.48**
1986	62.1%	36.2%	2.1%	**2.16**
1974	59.0%	37.1%	4.2%	**2.23**
1967	73.1%	25.4%	1.7%	**1.98**
1955	96.3%	0.0%	3.9%	**1.65**
1936	63.8%	0.0%	36.3%	**2.53**
Annual Consumptive Use (Acre-Feet/Acre)	1.54	3.08	4.27	---

*based on mix of dominant species over time

In the analysis year, the selected annual ET rates were multiplied by the corresponding riparian plant functional group acreage to generate the annual consumptive use by category. The years of analysis– 2014, 2004, 1997, 1986, 1974, 1967, 1955, and 1936–were used as the condition for intervening years; with the analyzed year used as the center point (i.e., year 1986 was used for 1987–1991 and 1982–1985). The results are presented in Appendix 5, including total riparian area, PFG area, PFG ET rate, and PFG water consumption by year from 2014-1936.

Results

Riparian consumptive use was highest at the start of the study period when historical reports and studies document that total riparian vegetation was much higher along the Rio Grande (Papadopulos 2008). Efforts to clear this vegetation occurred in the late 1930s and 40s and resulted in significant declines in vegetative cover and associated consumptive use. Since the 1950s, total riparian vegetation cover has increased gradually, resulting in similar increasing trends in riparian consumptive use (Exhibit 66).

Complete annual consumptive use results are presented in Appendix 4, including total riparian area, PFG area, PFG ET rate, and PFG water consumption by year from 2014-1936.

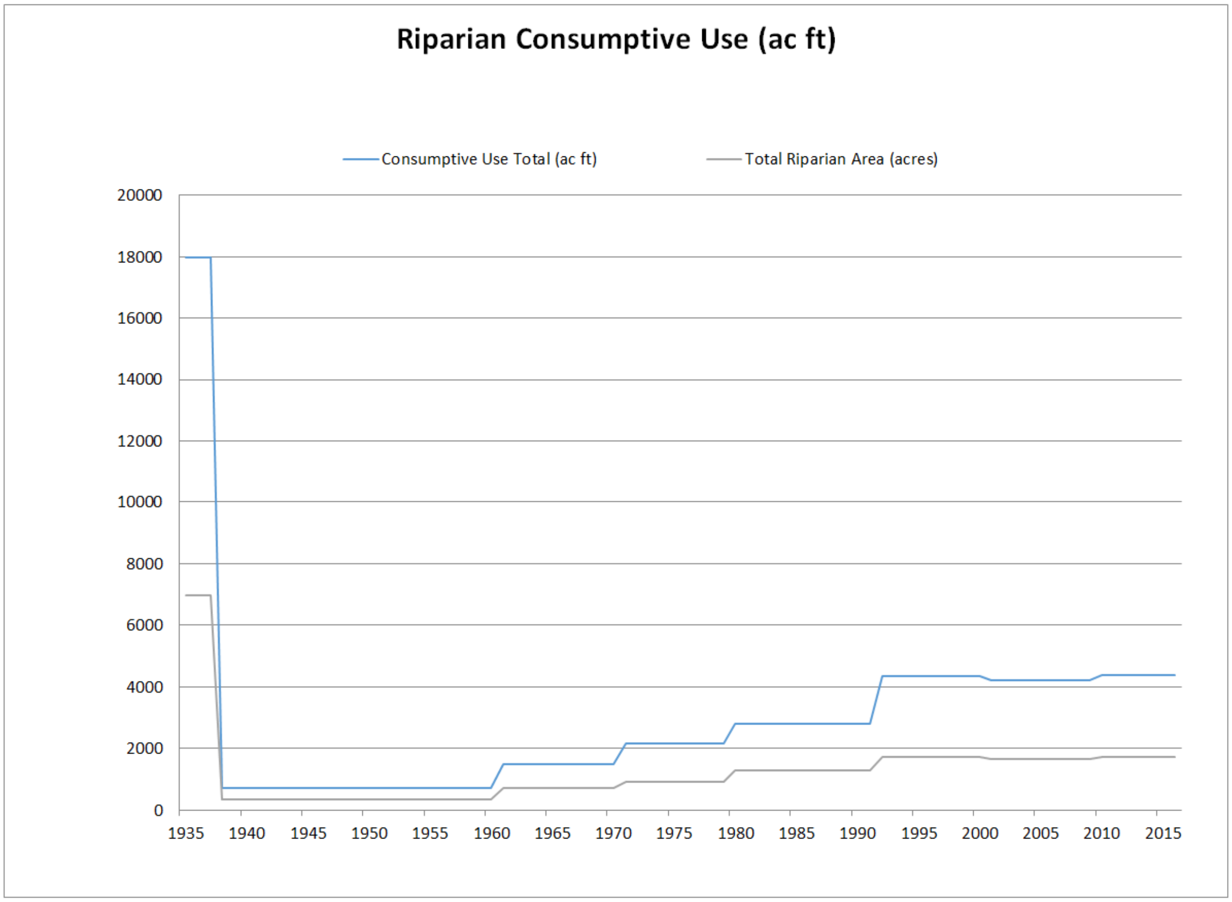


Exhibit 66. Riparian vegetation acreage and consumptive use from 1926 to 2016.

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Appendix 1

Evaluated Imagery

Electronic Files From 1955 - 2018

Summary of Imagery Resources Utilized

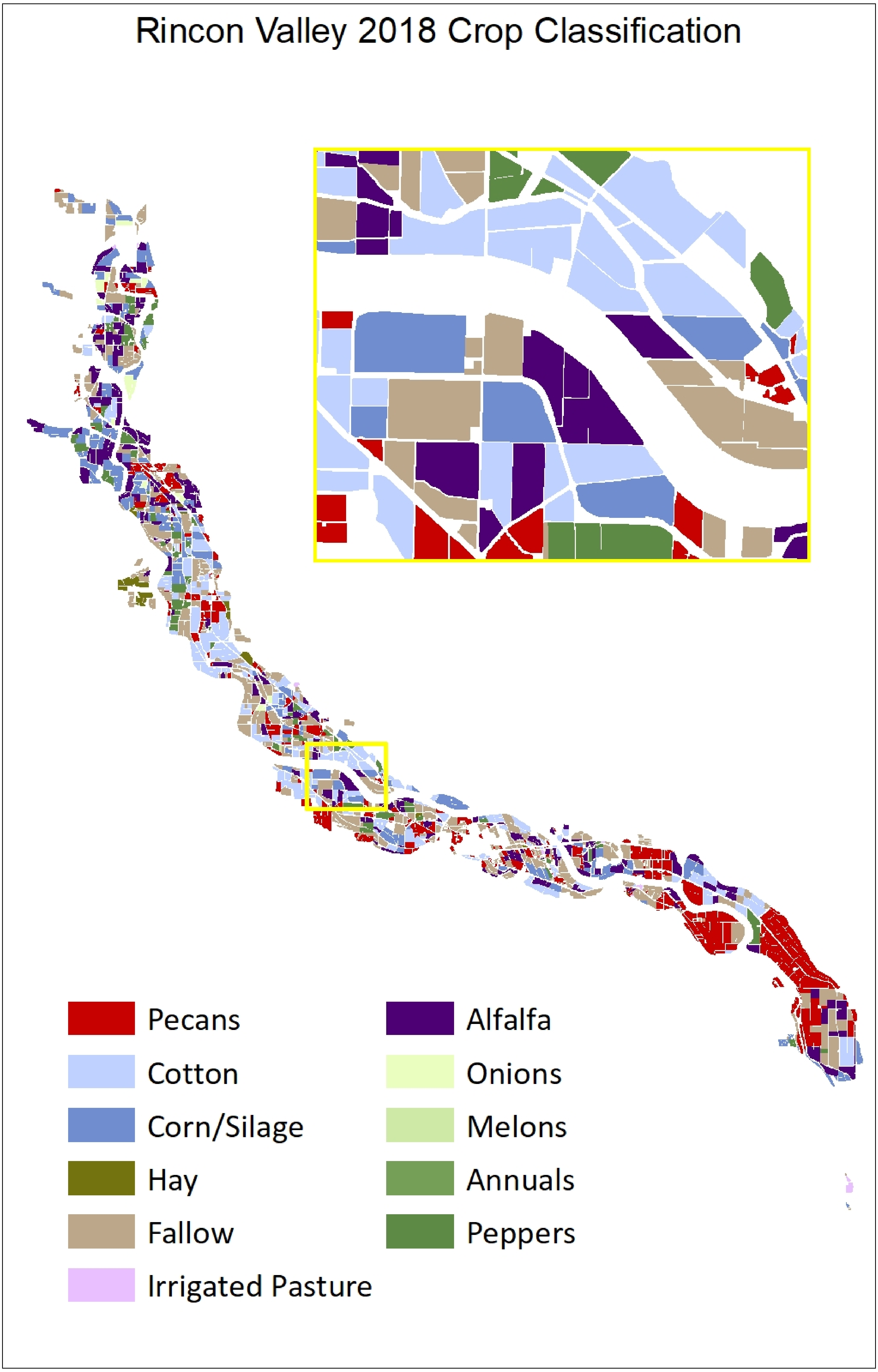
CONFIDENTIAL - ATTORNEY-CLIENT PRIVILEGE - Draft Work in Progress

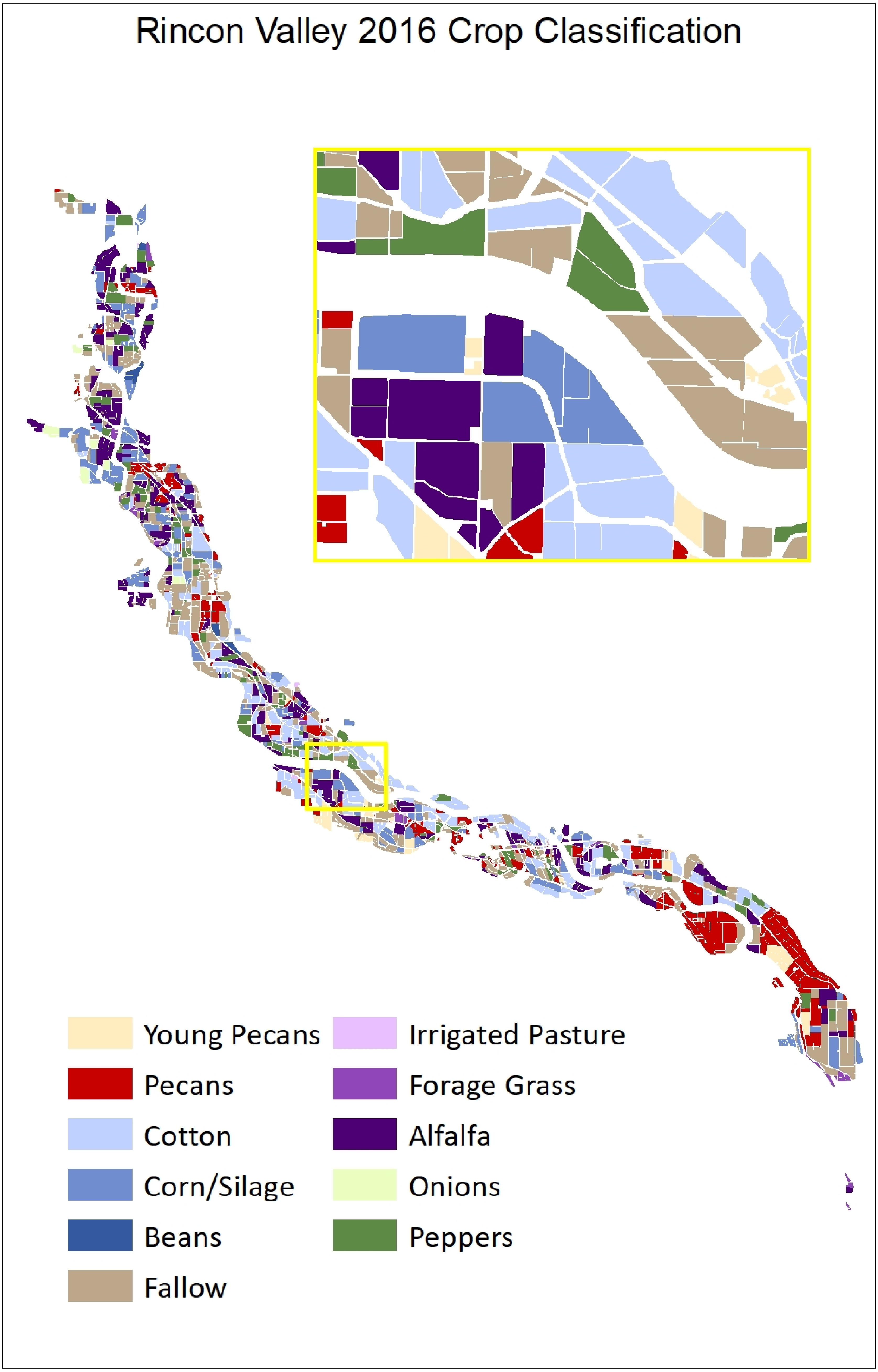
Year	Imagery Source
2018	NAIP Aerial and Landsat Satellite Imagery
2016	NAIP Aerial and Landsat Satellite Imagery
2014	NAIP and Commercial Aerial and Landsat Satellite Images
2010/2011	NAIP Aerial and Landsat and RapidEye Satellite Imagery
2006	NAIP Aerial and Landsat Satellite Images
1996	NAPP Aerial and Landsat Satellite Images
1986	NHAP Aerial Imagery and Landsat Satellite Imagery
1975	Declassified Aerial Imagery from USGS
1966	Declassified Aerial Imagery from USGS
1955	FSA Historical Aerial Imagery
1936	Joint Investigative Report Scanned Map
1935	Soil Conservation Survey Photo

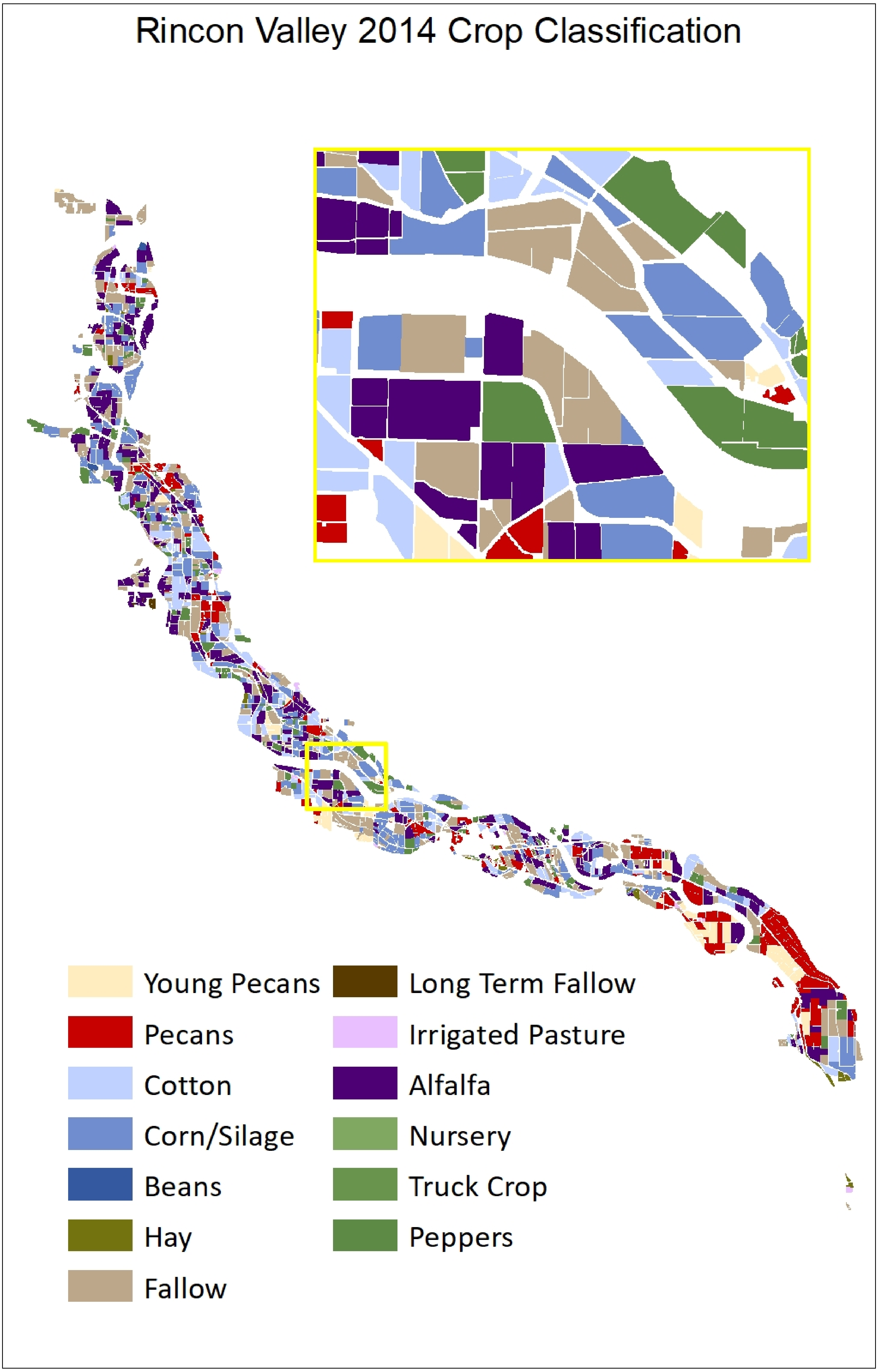
Appendix 2

Annual Land Use Analyses Maps – Large Print

- **Rincon Valley**
- **Mesilla Valley**
- **El Paso Valley**


Rincon Valley 2018 Crop Classification
Pecans
Alfalfa
Cotton
Onions
Corn/Silage
Melons
Hay
Annuals
Fallow
Peppers
Irrigated Pasture


Rincon Valley 2016 Crop Classification
Young Pecans
Pecans
Cotton
Corn/Silage
Beans
Fallow
Irrigated Pasture
Forage Grass
Alfalfa
Onions
Peppers



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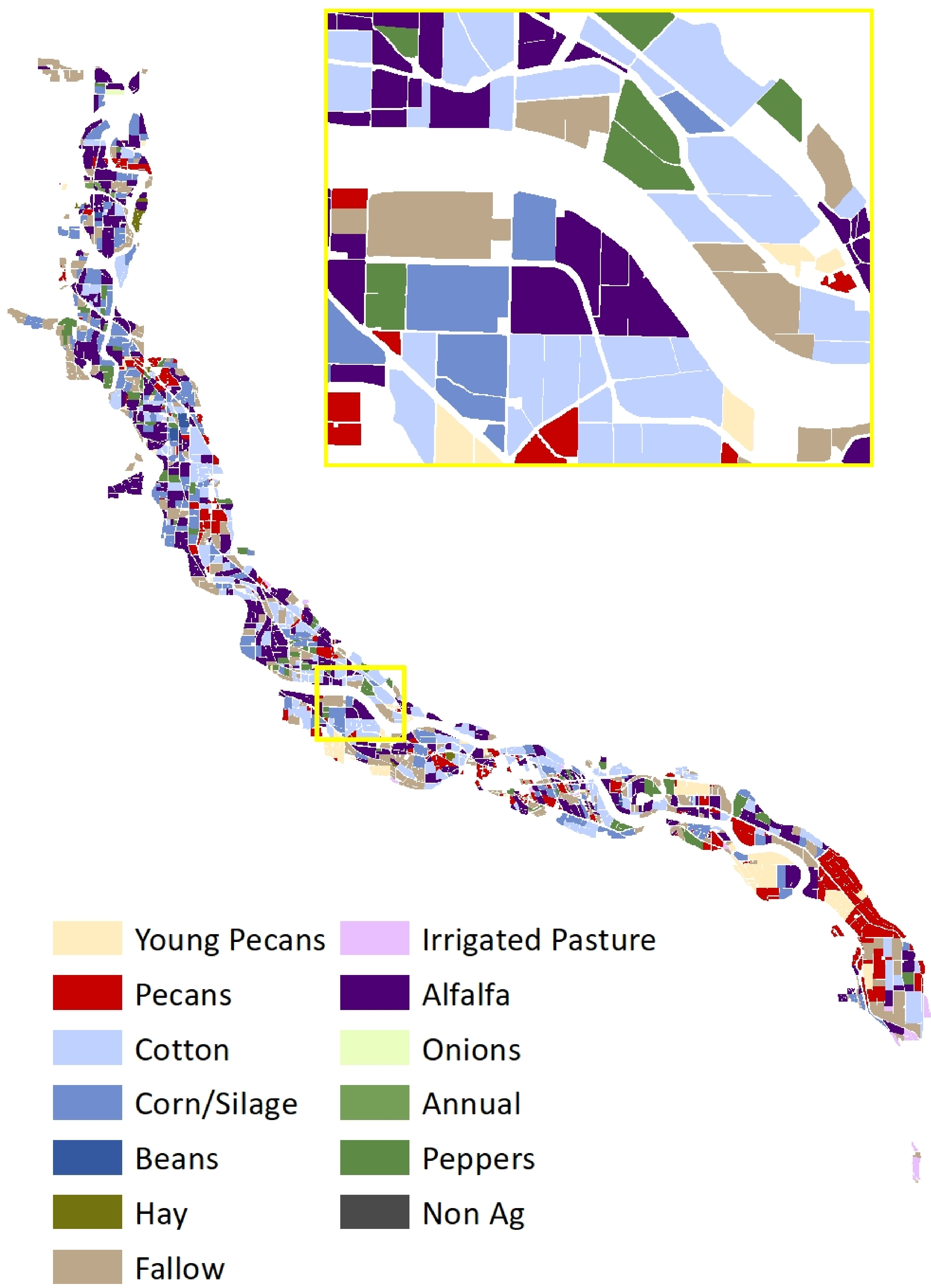
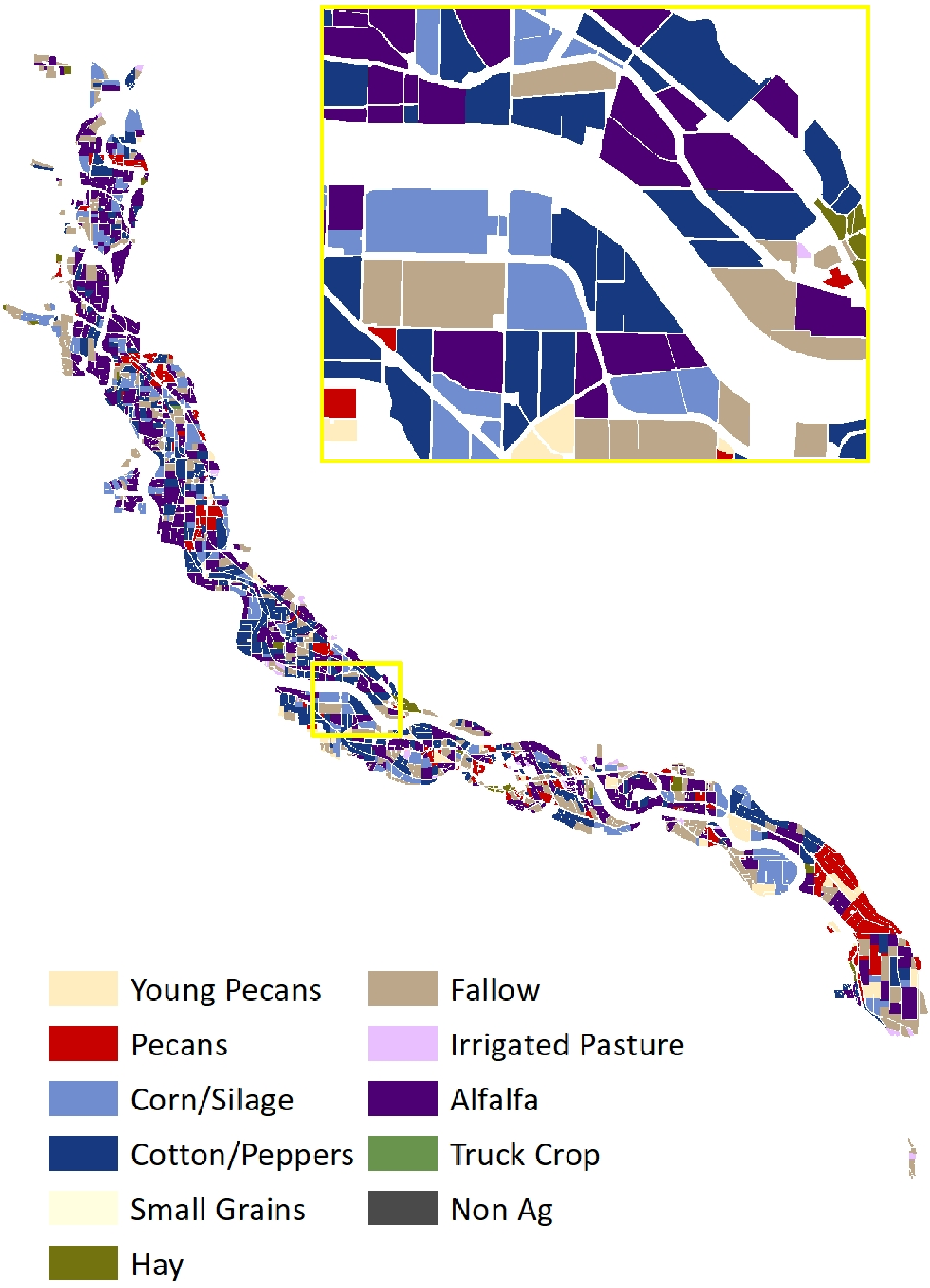
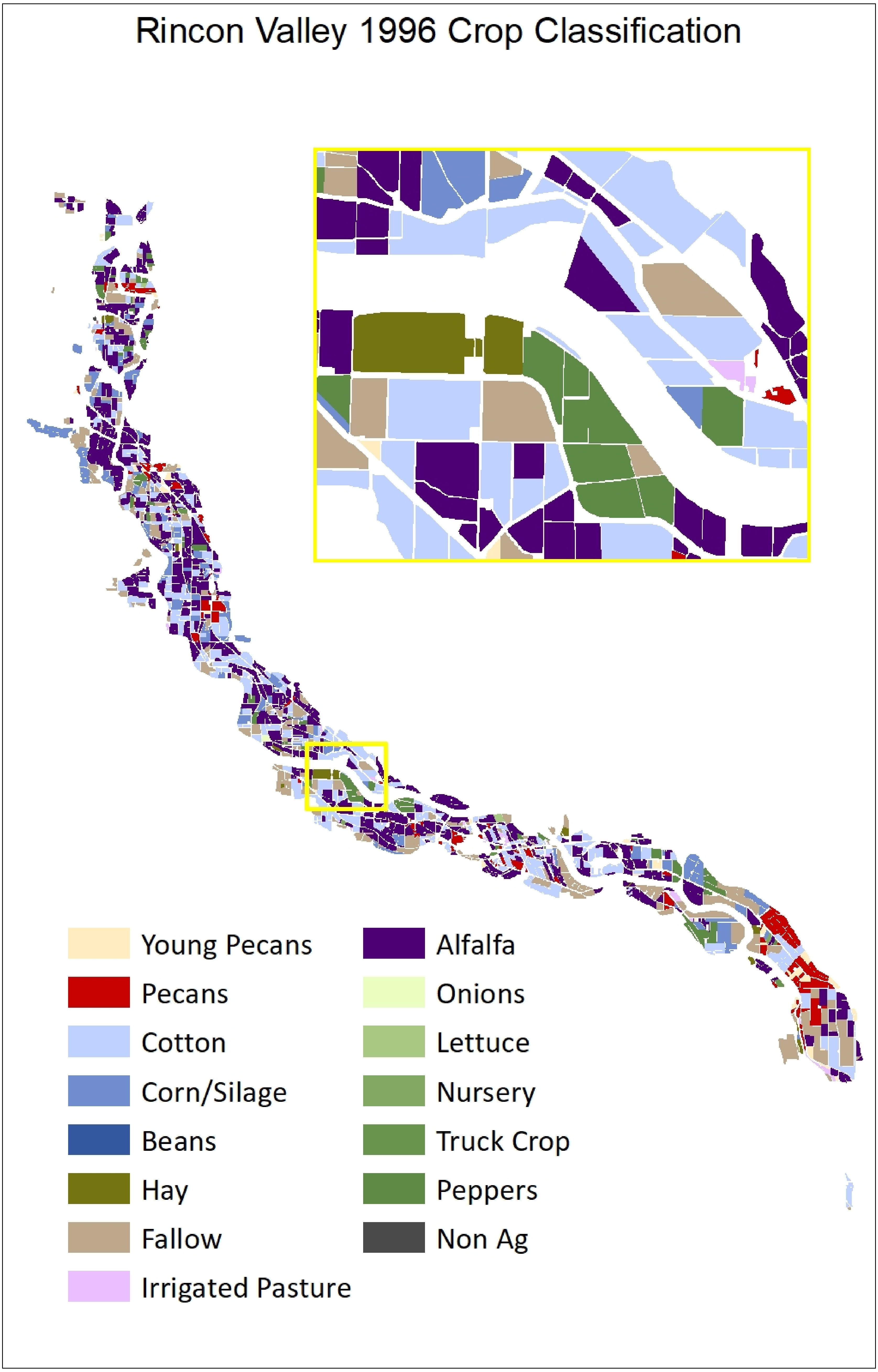
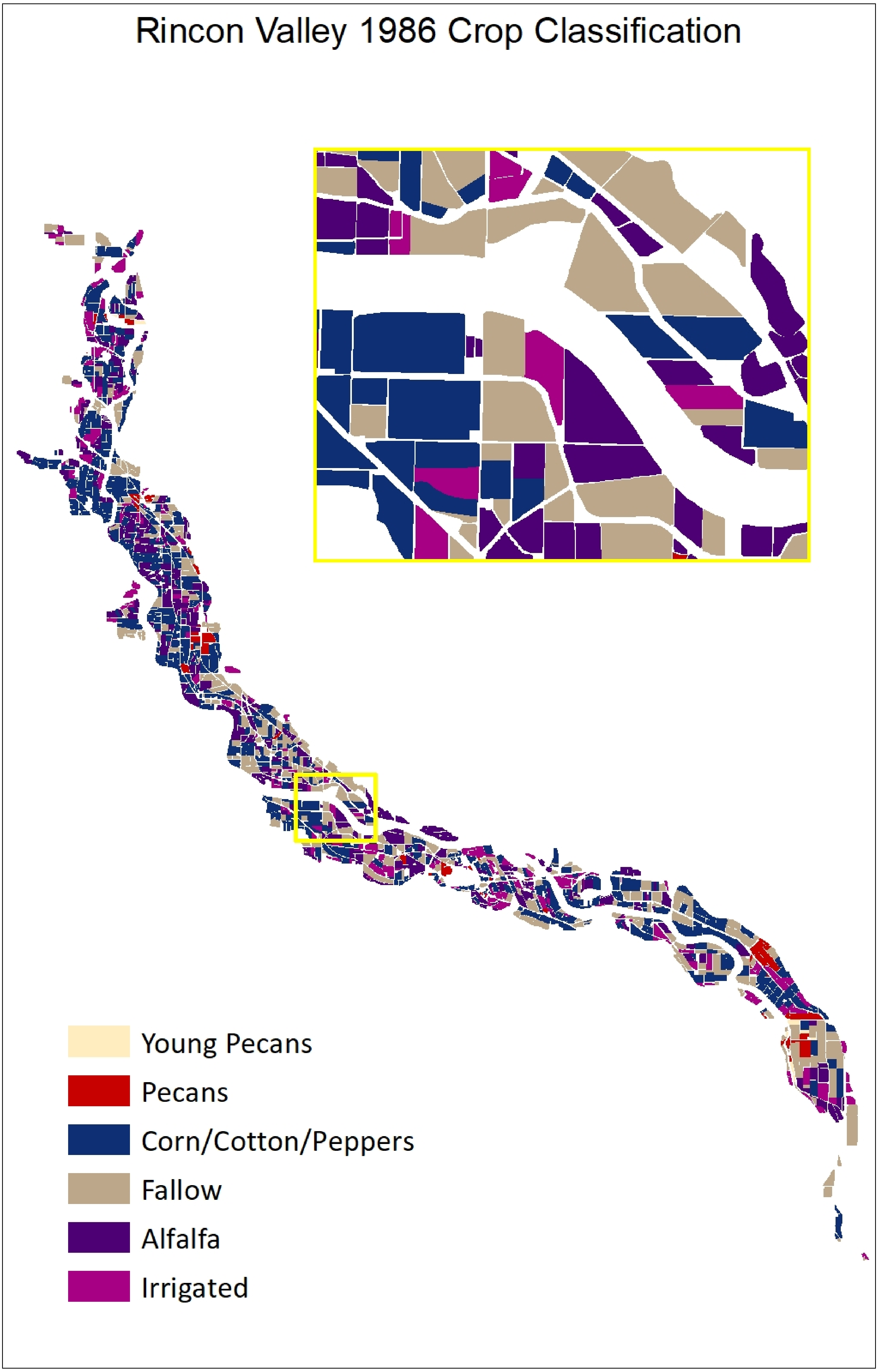
Rincon Valley 2011 Crop Classification



Rincon Valley 2006 Crop Classification




Rincon Valley 1996 Crop Classification
Young Pecans
Pecans
Cotton
Corn/Silage
Beans
Hay
Fallow
Irrigated Pasture
Alfalfa
Onions
Lettuce
Nursery
Truck Crop
Peppers
Non Ag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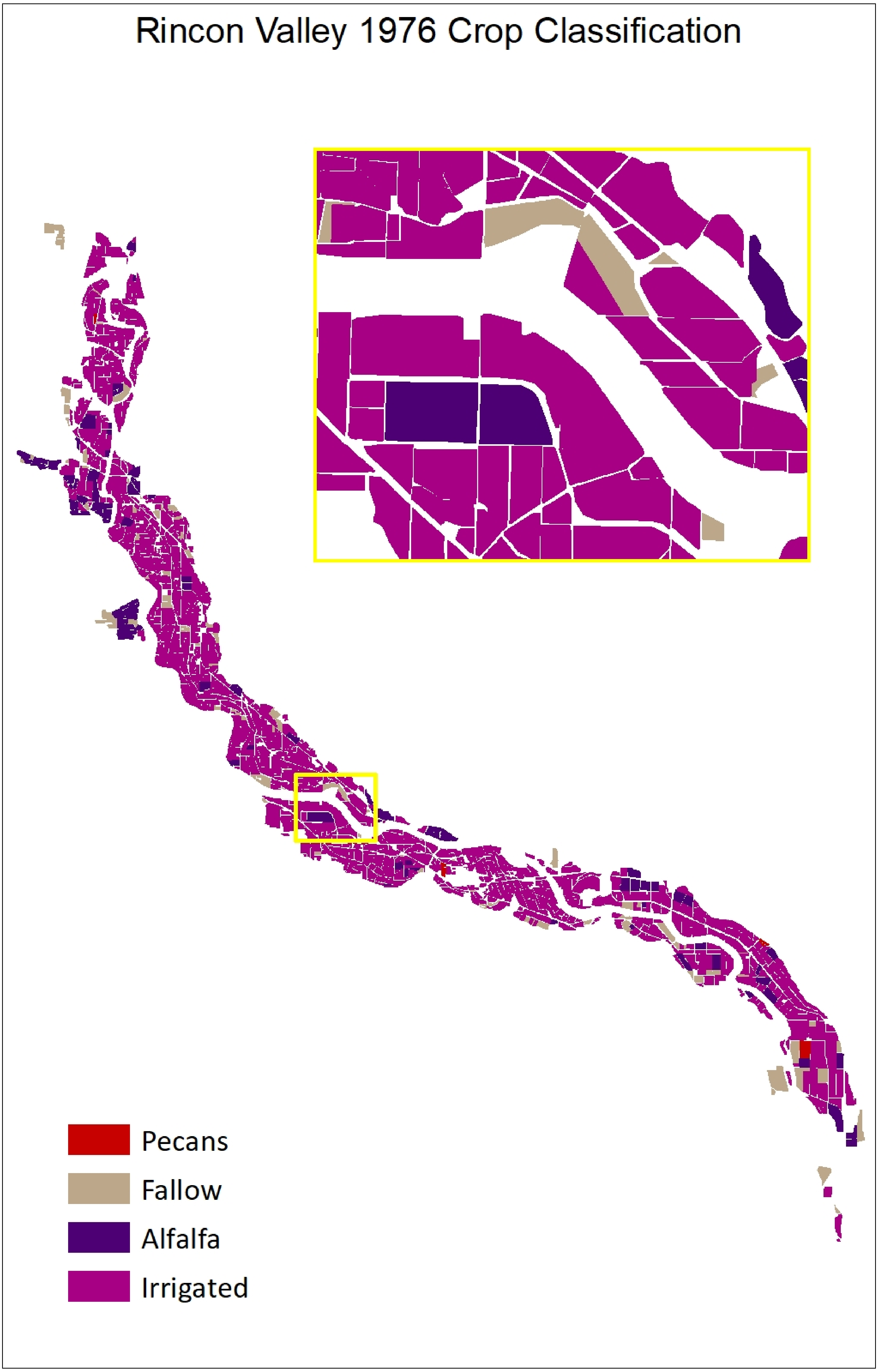
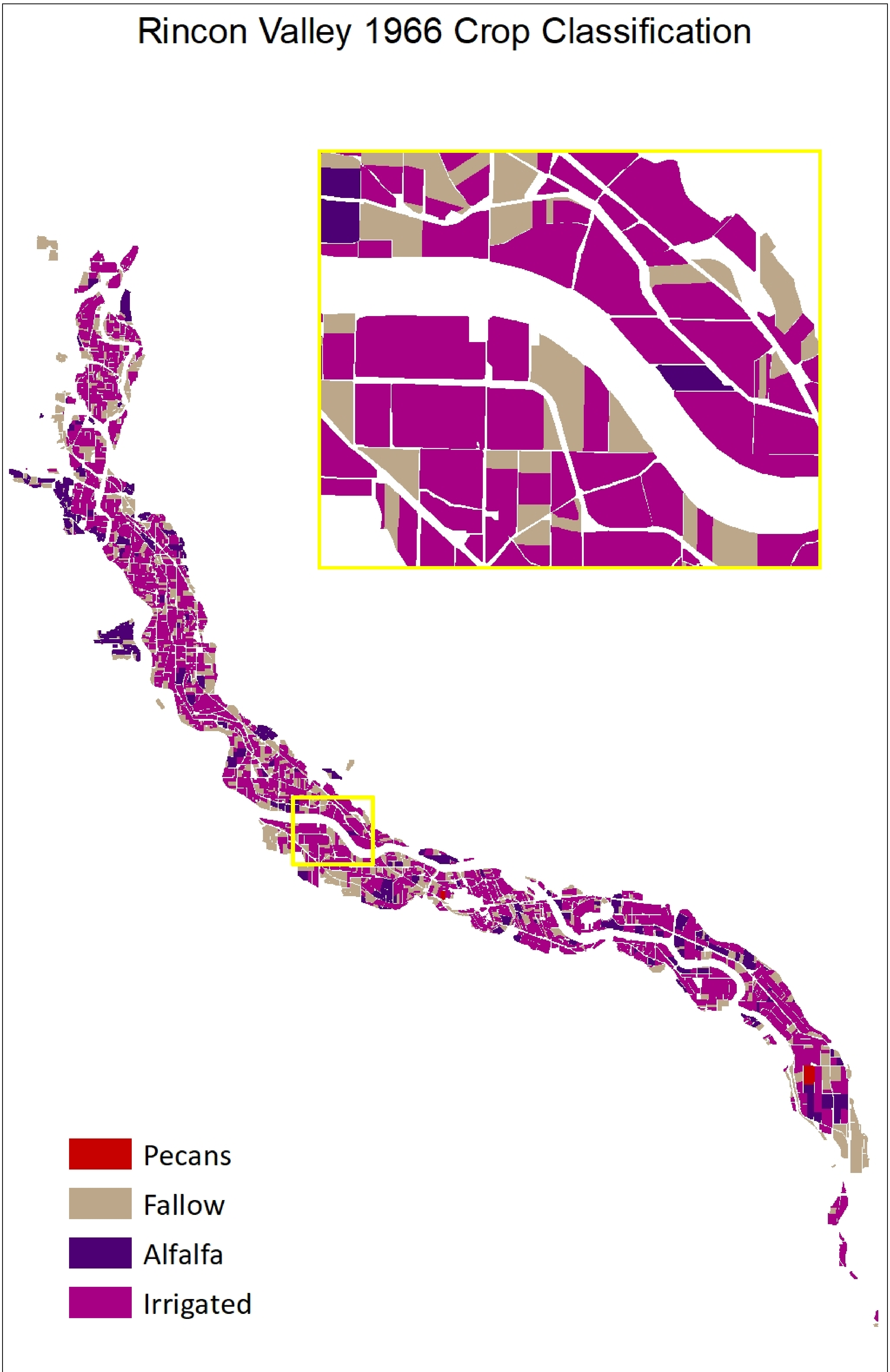
Young Pecans
Pecans
Corn/Cotton/Peppers
Fallow
Alfalfa
Irrigated



Rincon Valley 1976 Crop Classification
Pecans
Fallow
Alfalfa
Irrigated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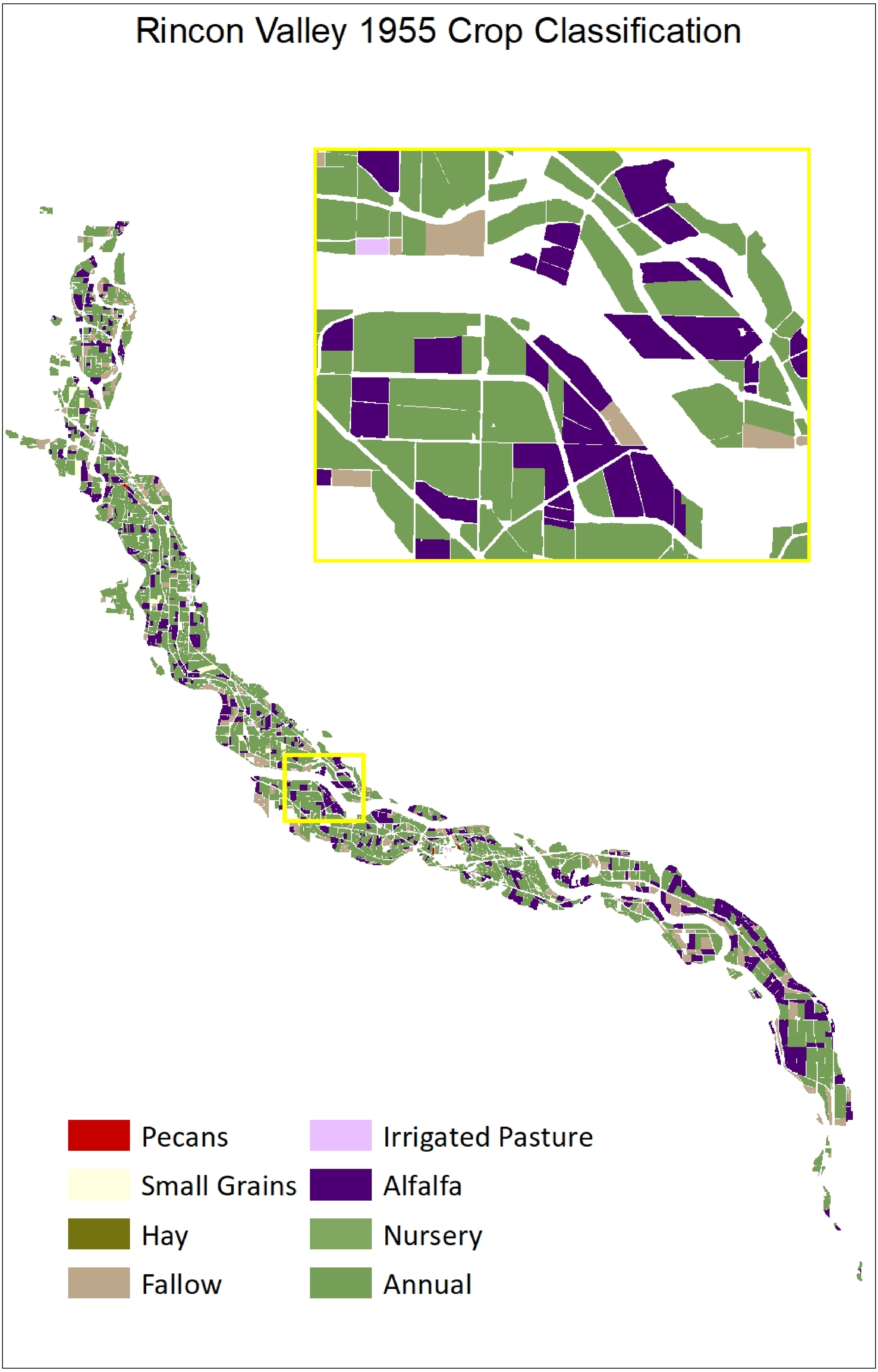
Pecans
Fallow
Alfalfa
Irrigated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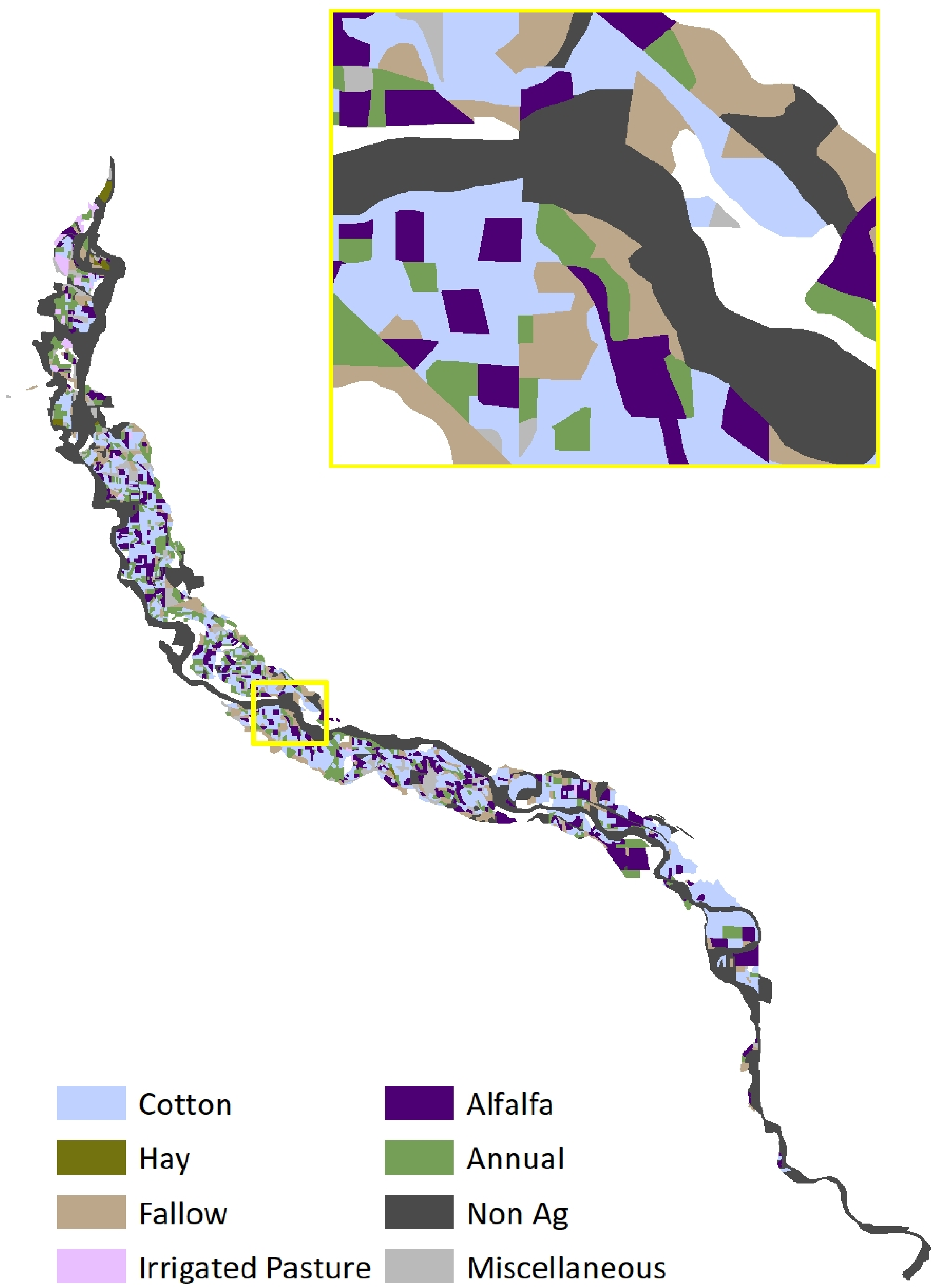
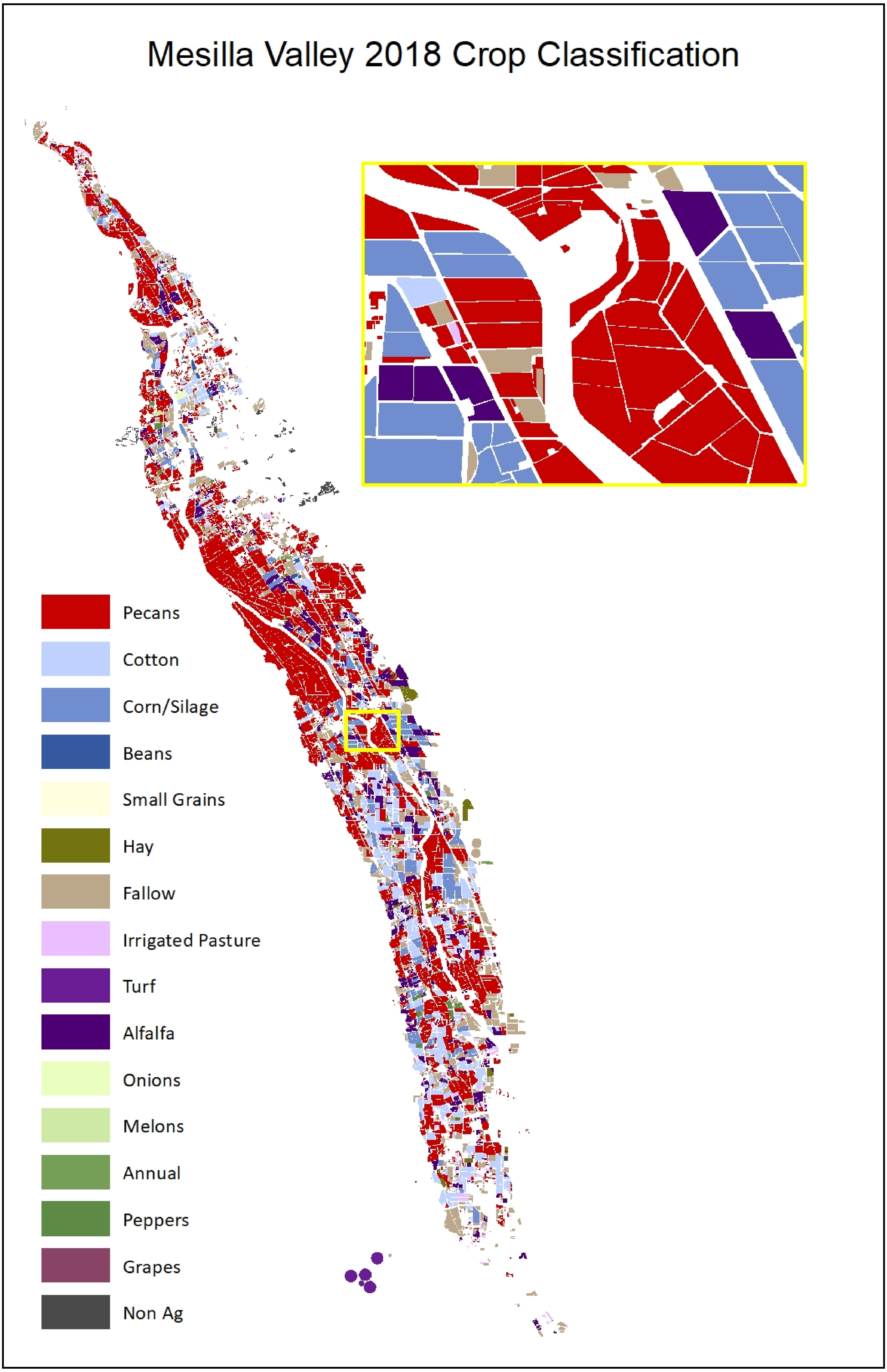
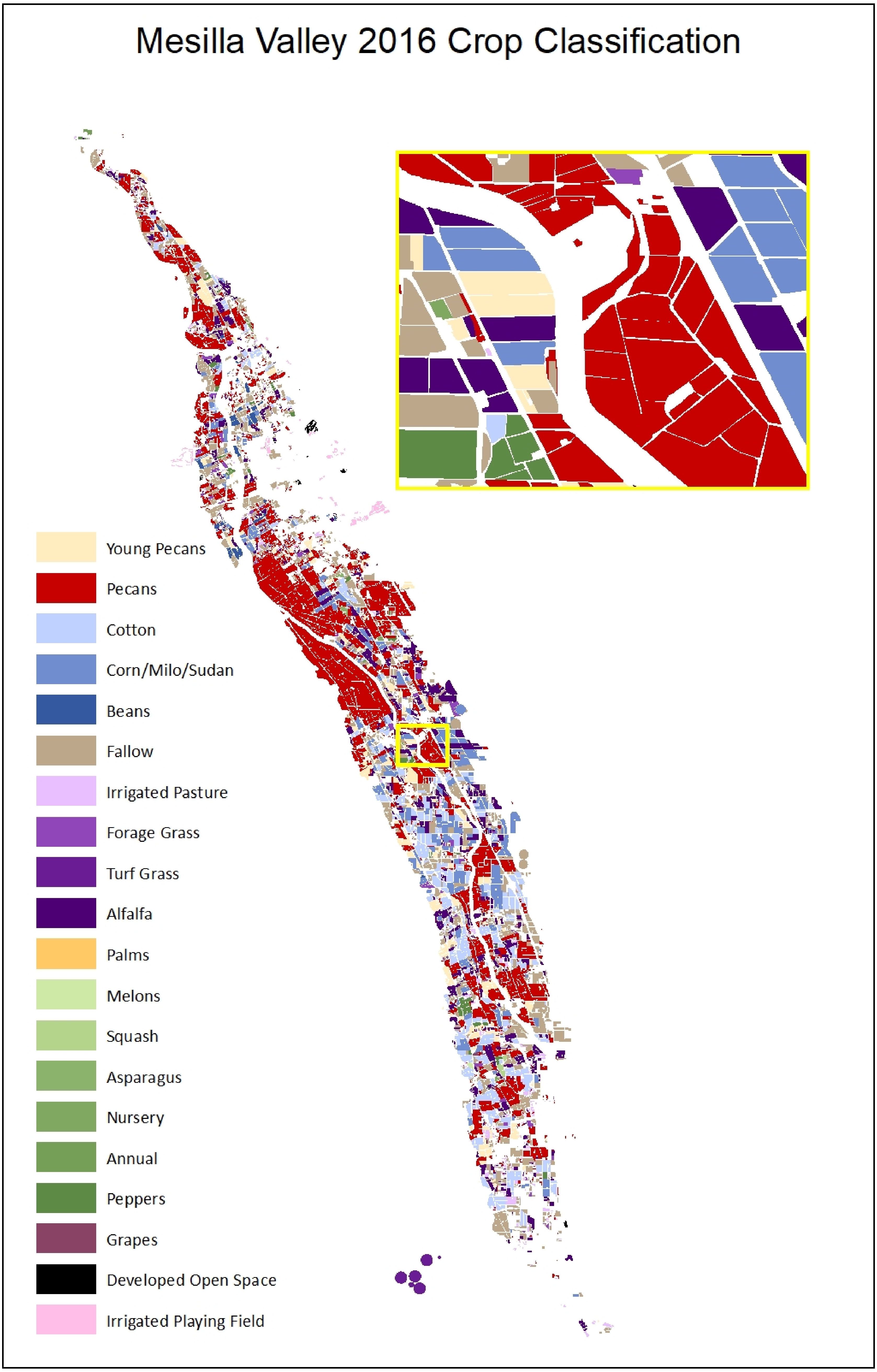
Pecans
Small Grains
Hay
Fallow
Irrigated Pasture
Alfalfa
Nursery
Annual

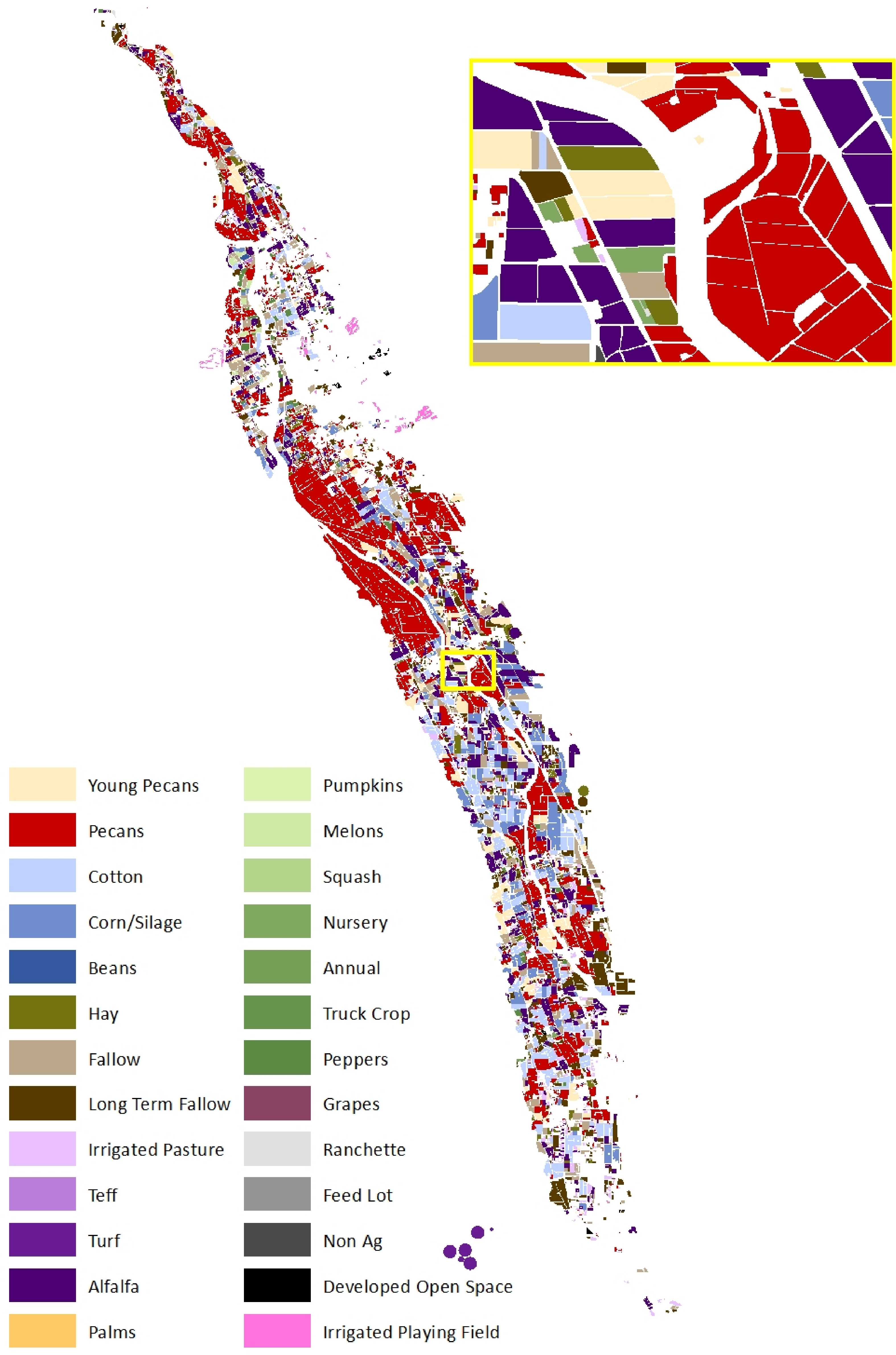
Rincon Valley 1936 Crop Classification



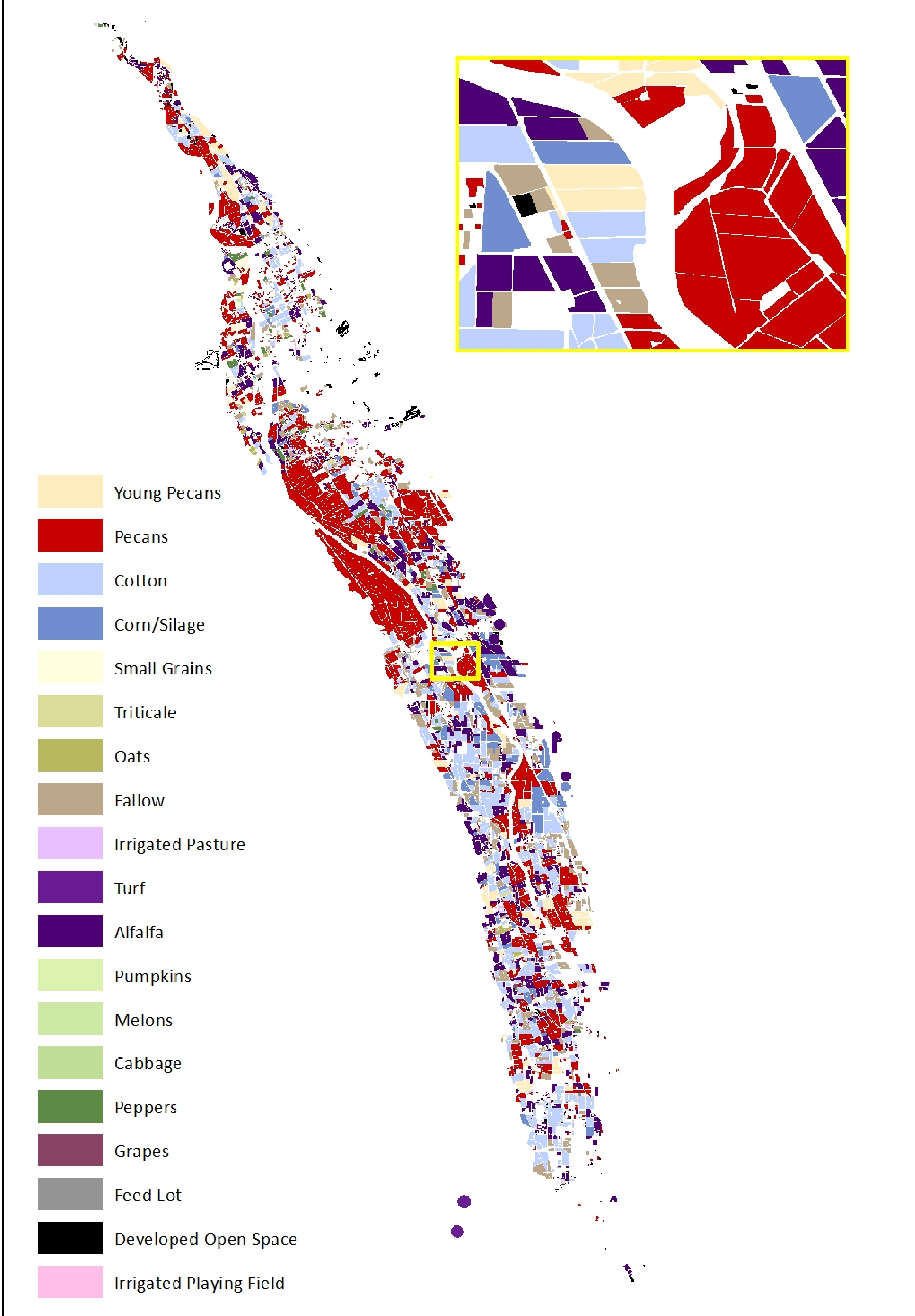

Mesilla Valley 2018 Crop Classification
Pecans
Cotton
Corn/Silage
Beans
Small Grains
Hay
Fallow
Irrigated Pasture
Turf
Alfalfa
Onions
Melons
Annual
Peppers
Grapes
Non Ag

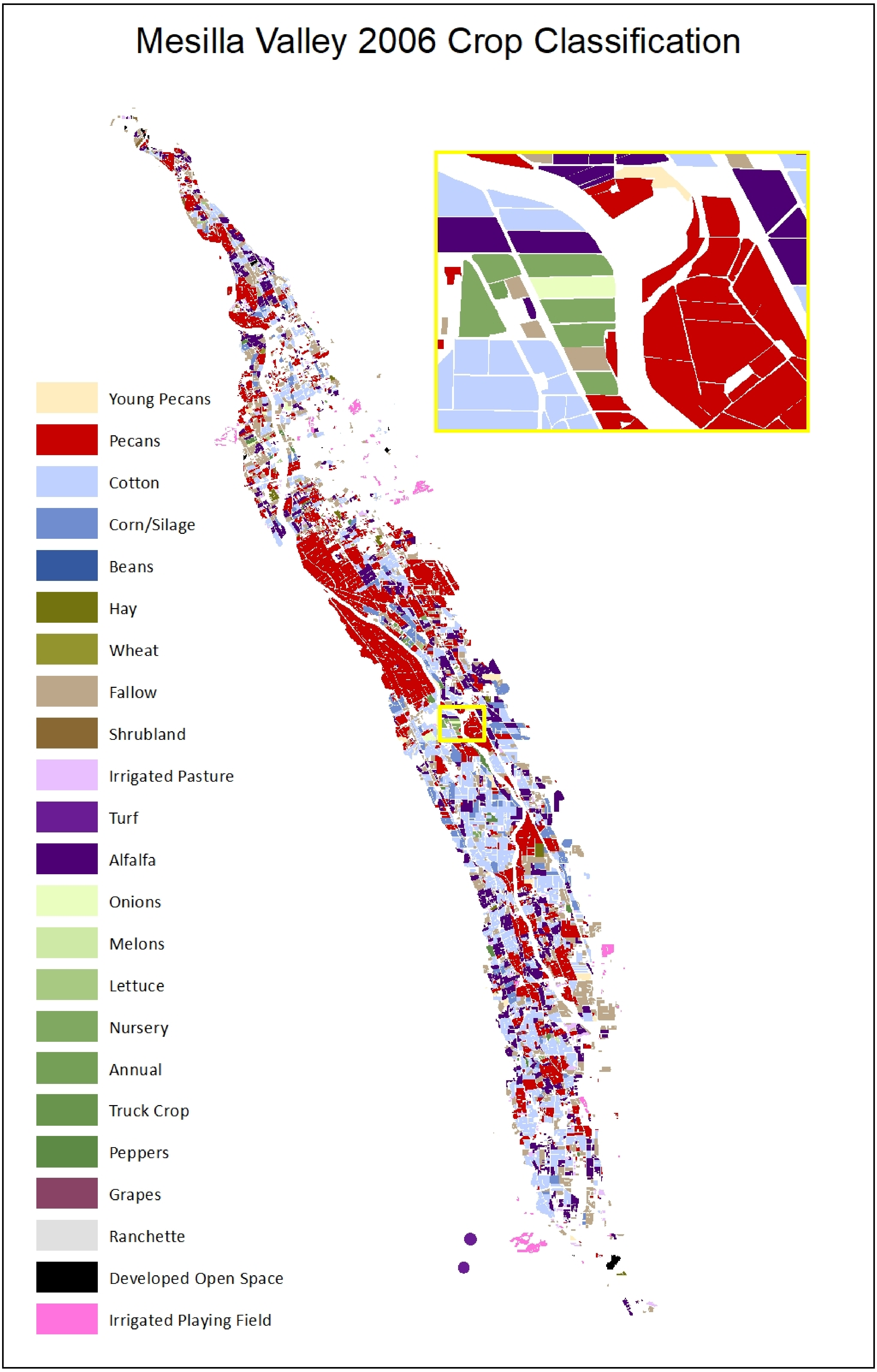

Mesilla Valley 2016 Crop Classification
Young Pecans
Pecans
Cotton
Corn/Milo/Sudan
Beans
Fallow
Irrigated Pasture
Forage Grass
Turf Grass
Alfalfa
Palms
Melons
Squash
Asparagus
Nursery
Annual
Peppers
Grapes
Developed Open Space
Irrigated Playing Field

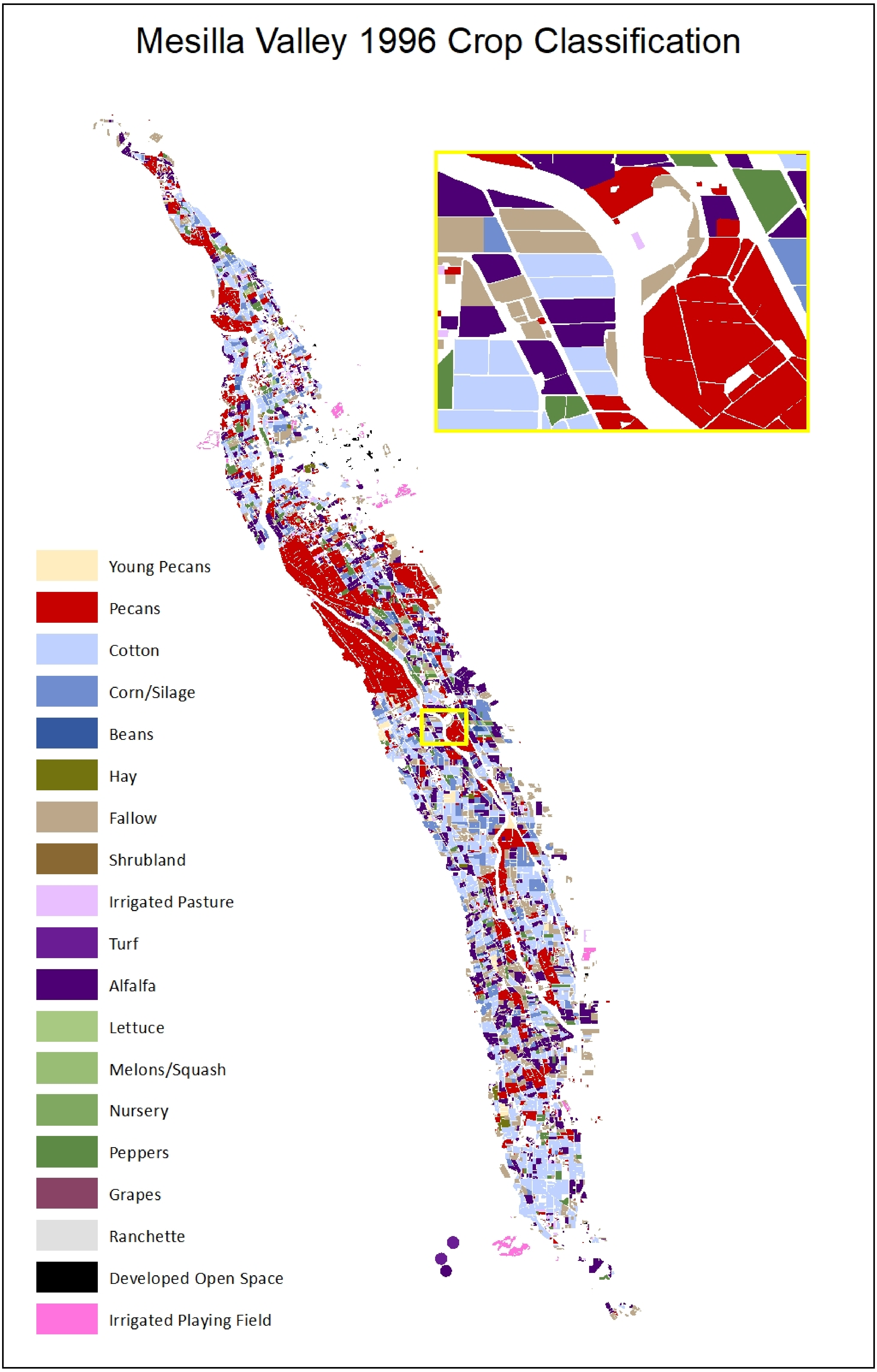
Mesilla Valley 2014 Crop Classification

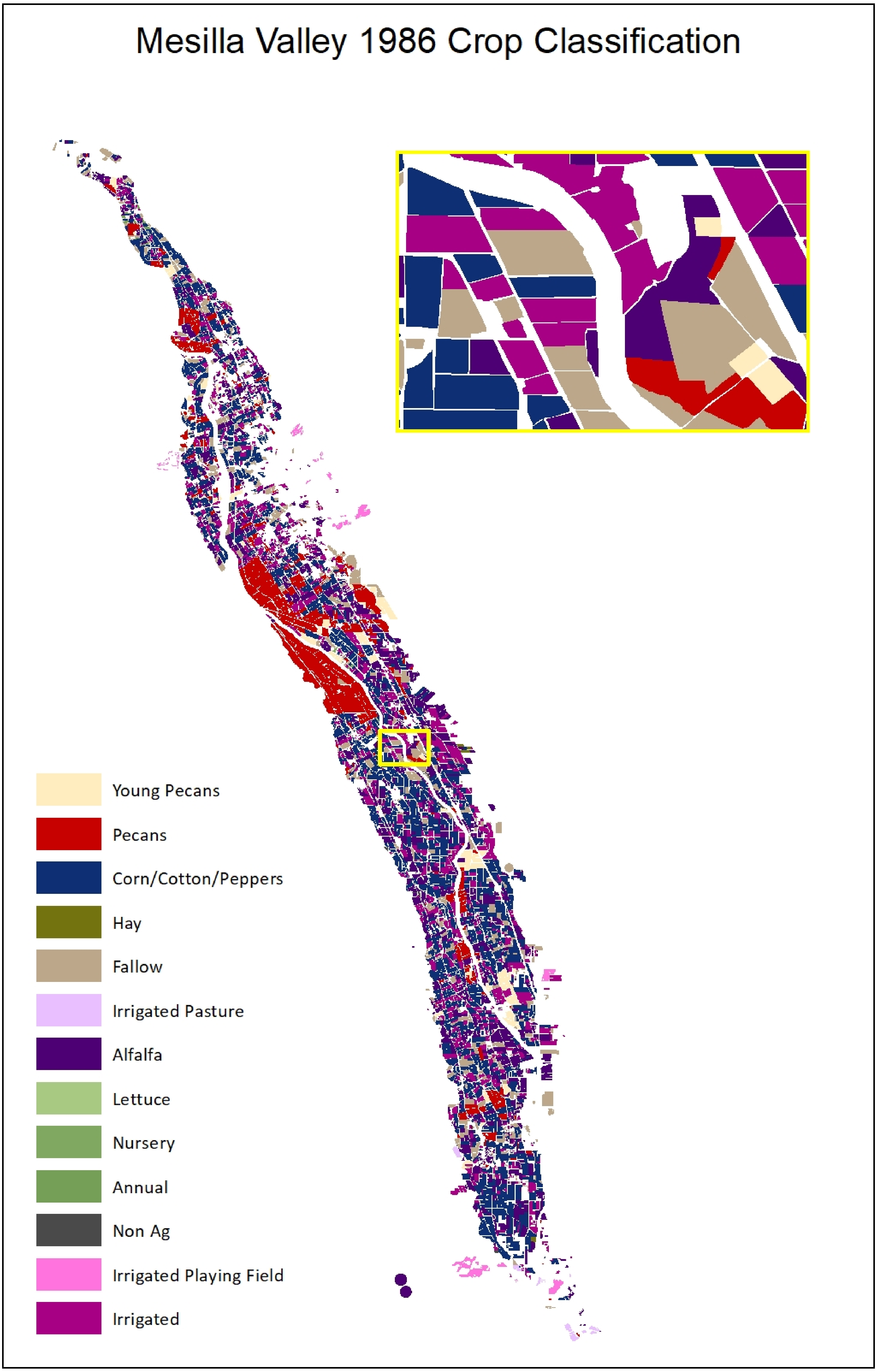


Mesilla Valley 2011 Crop Classification

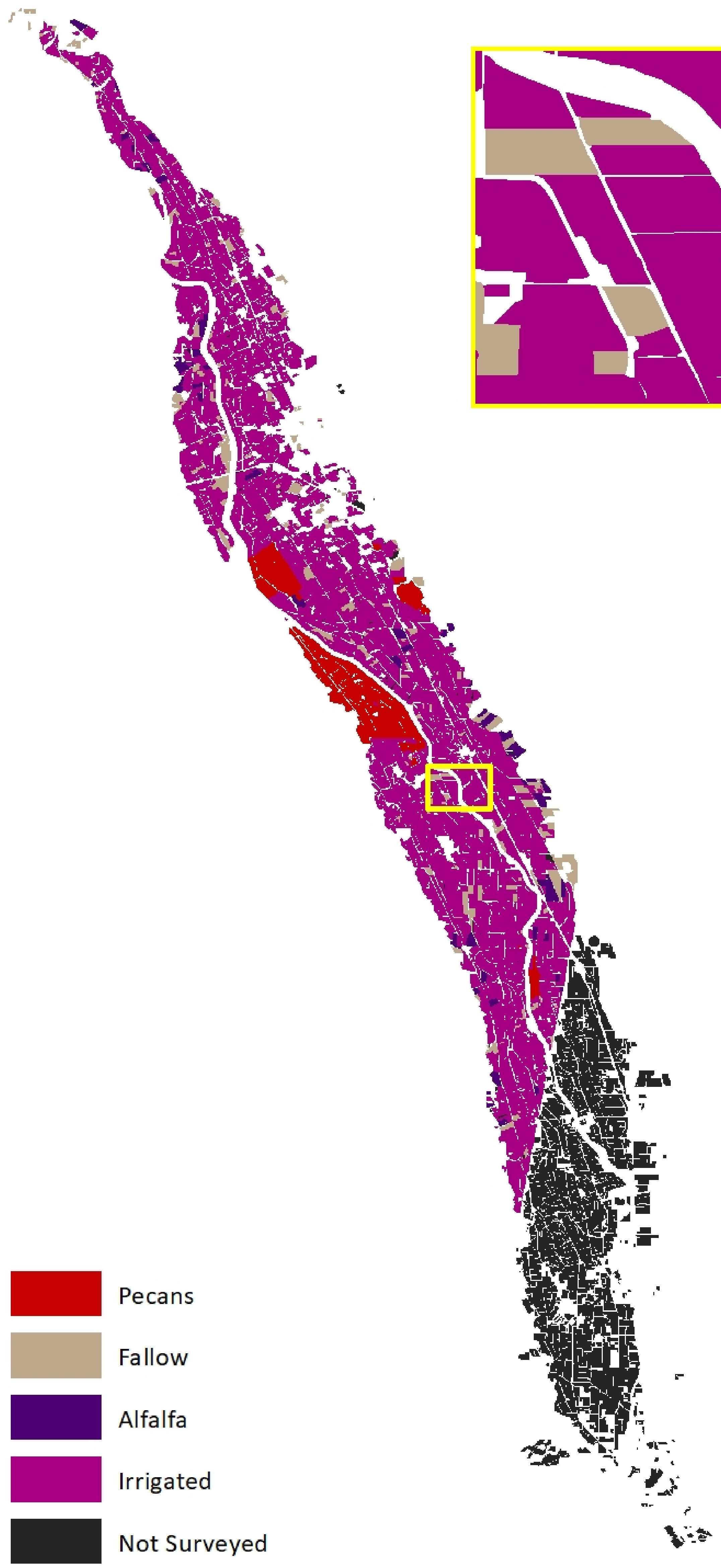



Mesilla Valley 2006 Crop Classification
Young Pecans
Pecans
Cotton
Corn/Silage
Beans
Hay
Wheat
Fallow
Shrubland
Irrigated Pasture
Turf
Alfalfa
Onions
Melons
Lettuce
Nursery
Annual
Truck Crop
Peppers
Grapes
Ranchette
Developed Open Space
Irrigated Playing Field

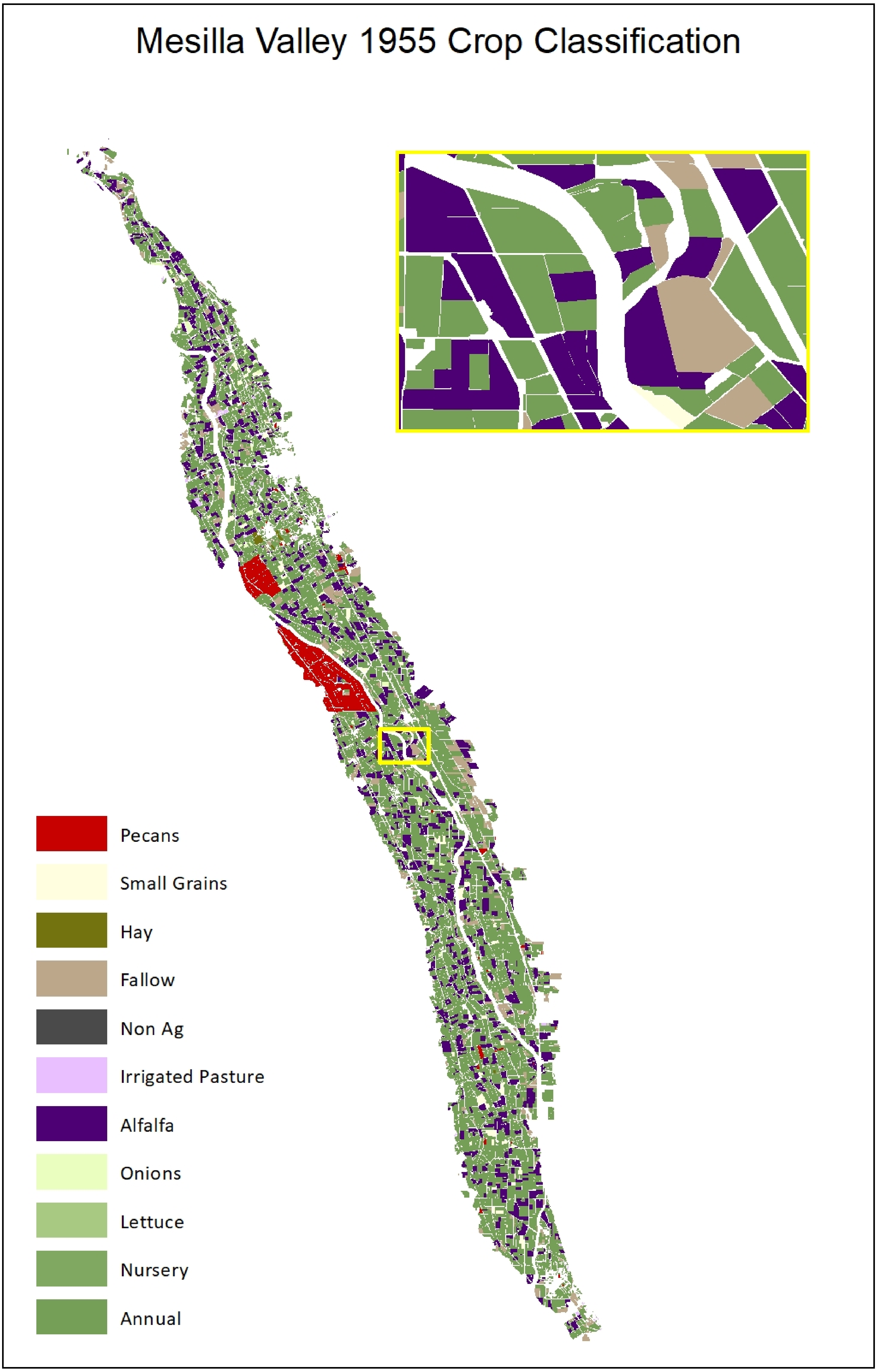

Mesilla Valley 1996 Crop Classification
Young Pecans
Pecans
Cotton
Corn/Silage
Beans
Hay
Fallow
Shrubland
Irrigated Pasture
Turf
Alfalfa
Lettuce
Melons/Squash
Nursery
Peppers
Grapes
Ranchette
Developed Open Space
Irrigated Playing Field


Mesilla Valley 1986 Crop Classification
Young Pecans
Pecans
Corn/Cotton/Peppers
Hay
Fallow
Irrigated Pasture
Alfalfa
Lettuce
Nursery
Annual
Non Ag
Irrigated Playing Field
Irrigated

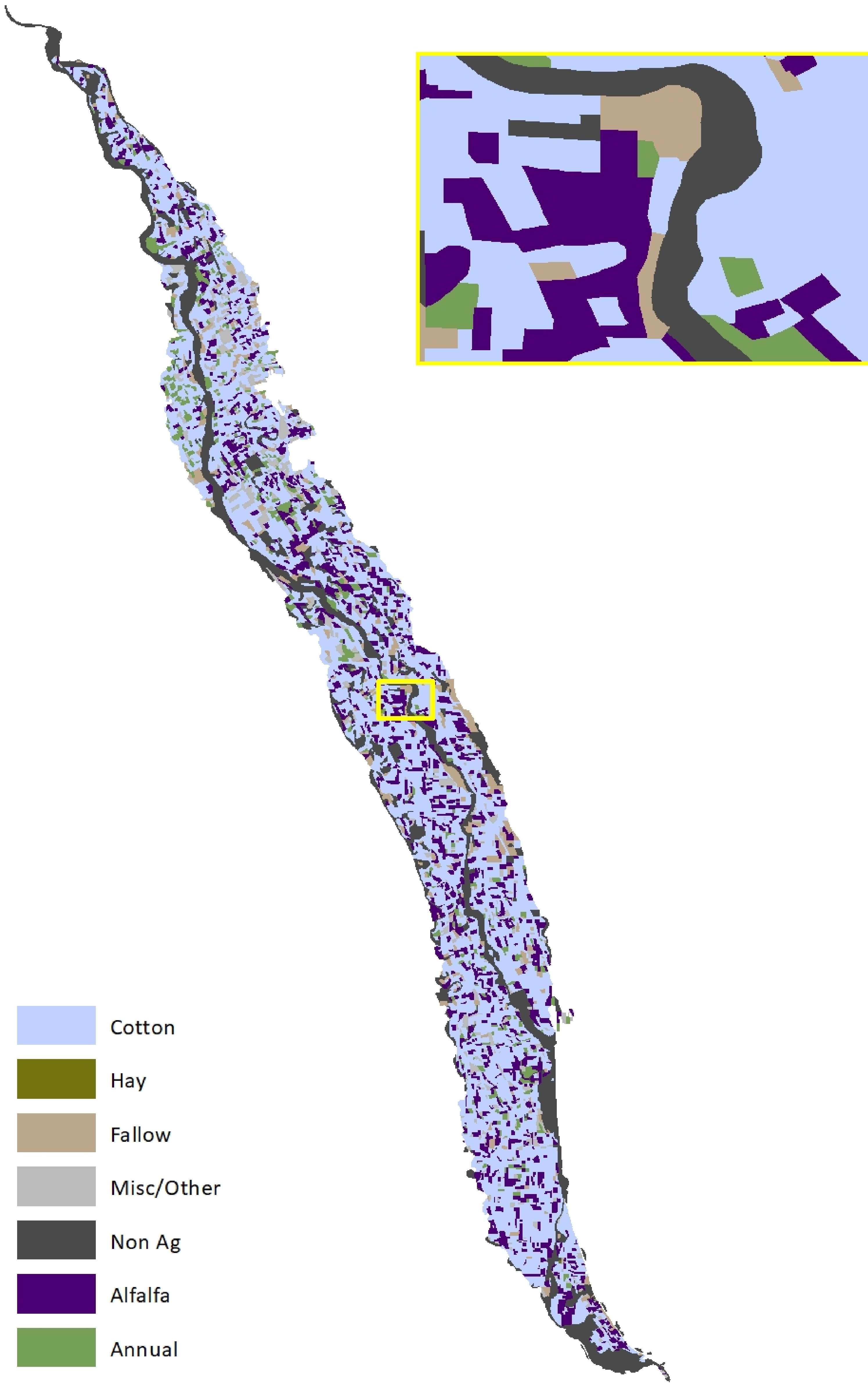
Mesilla Valley 1975 Crop Classification



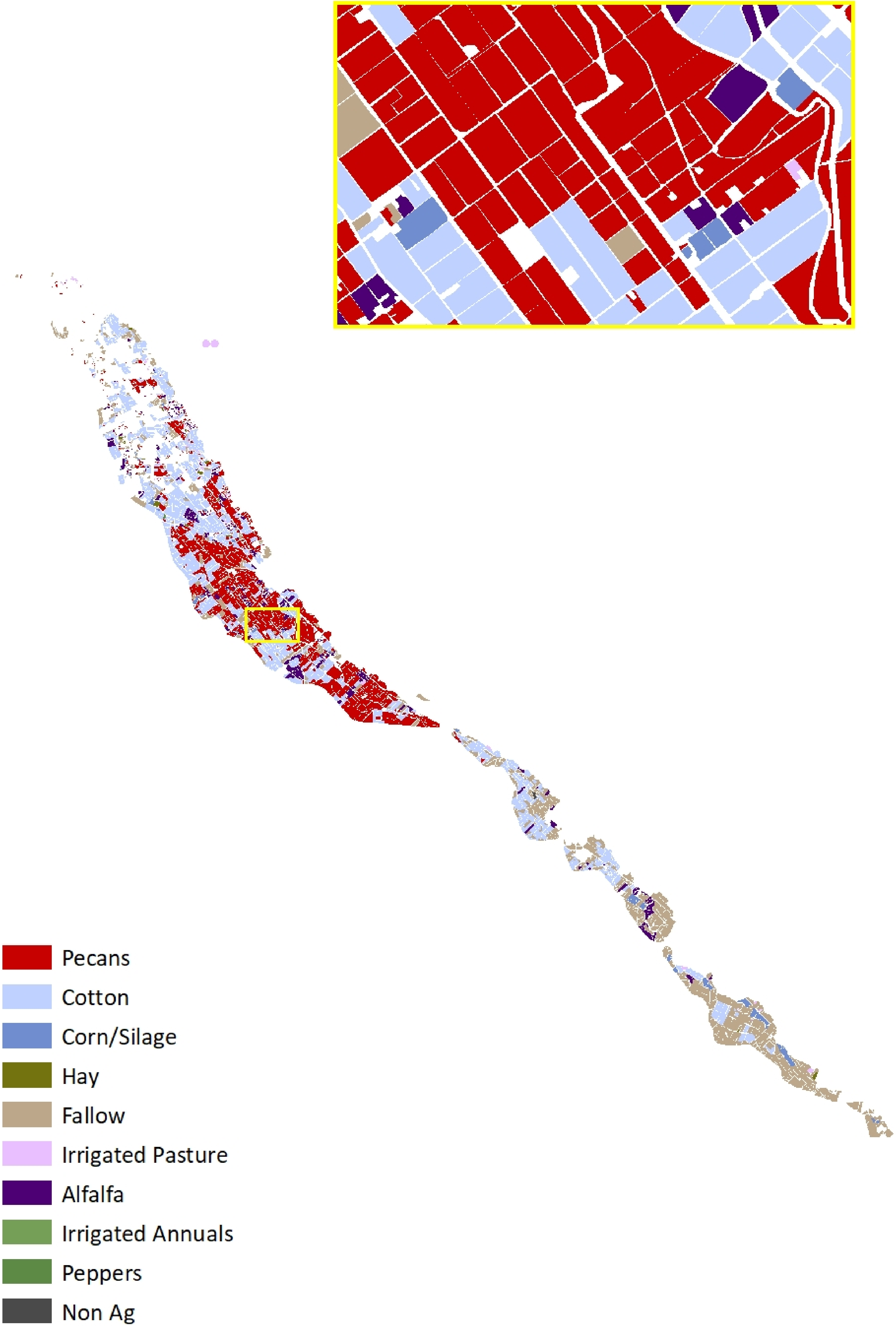

Mesilla Valley 1966 Crop Classification
Pecans
Fallow
Alfalfa
Irrigated

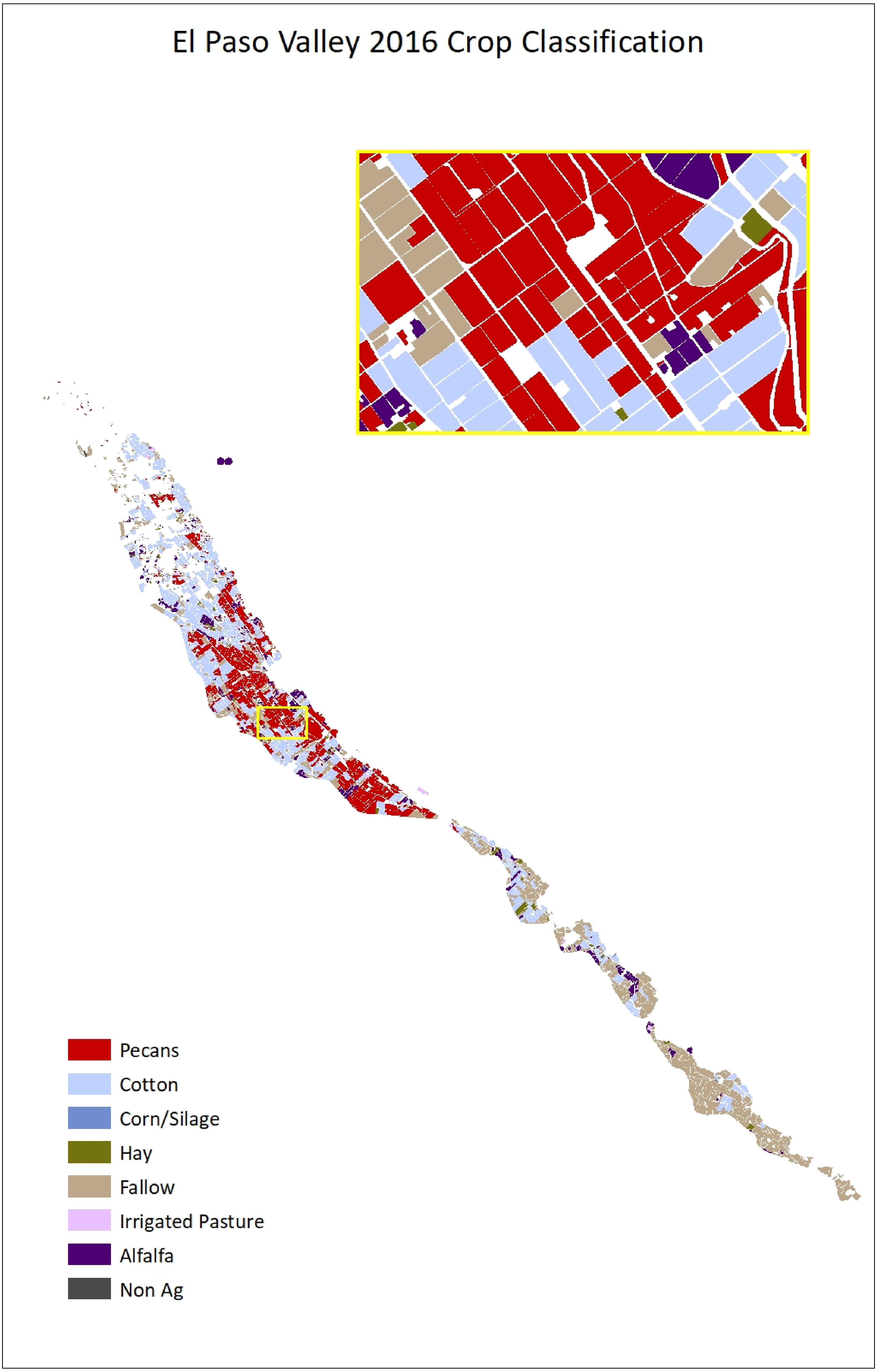

Mesilla Valley 1955 Crop Classification
Pecans
Small Grains
Hay
Fallow
Non Ag
Irrigated Pasture
Alfalfa
Onions
Lettuce
Nursery
Annual

Mesilla Valley 1936 Crop Classification

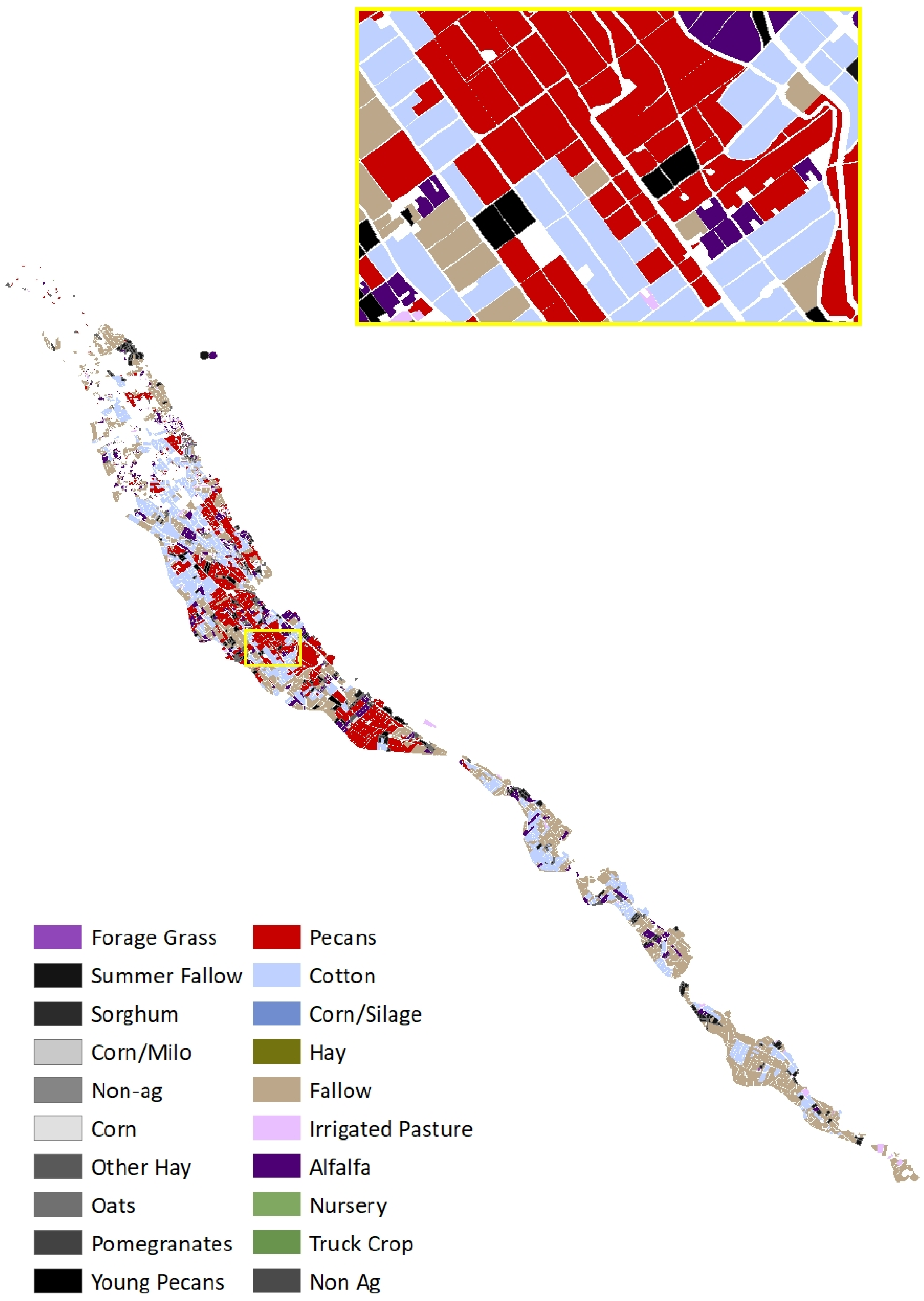


El Paso Valley 2018 Crop Classification

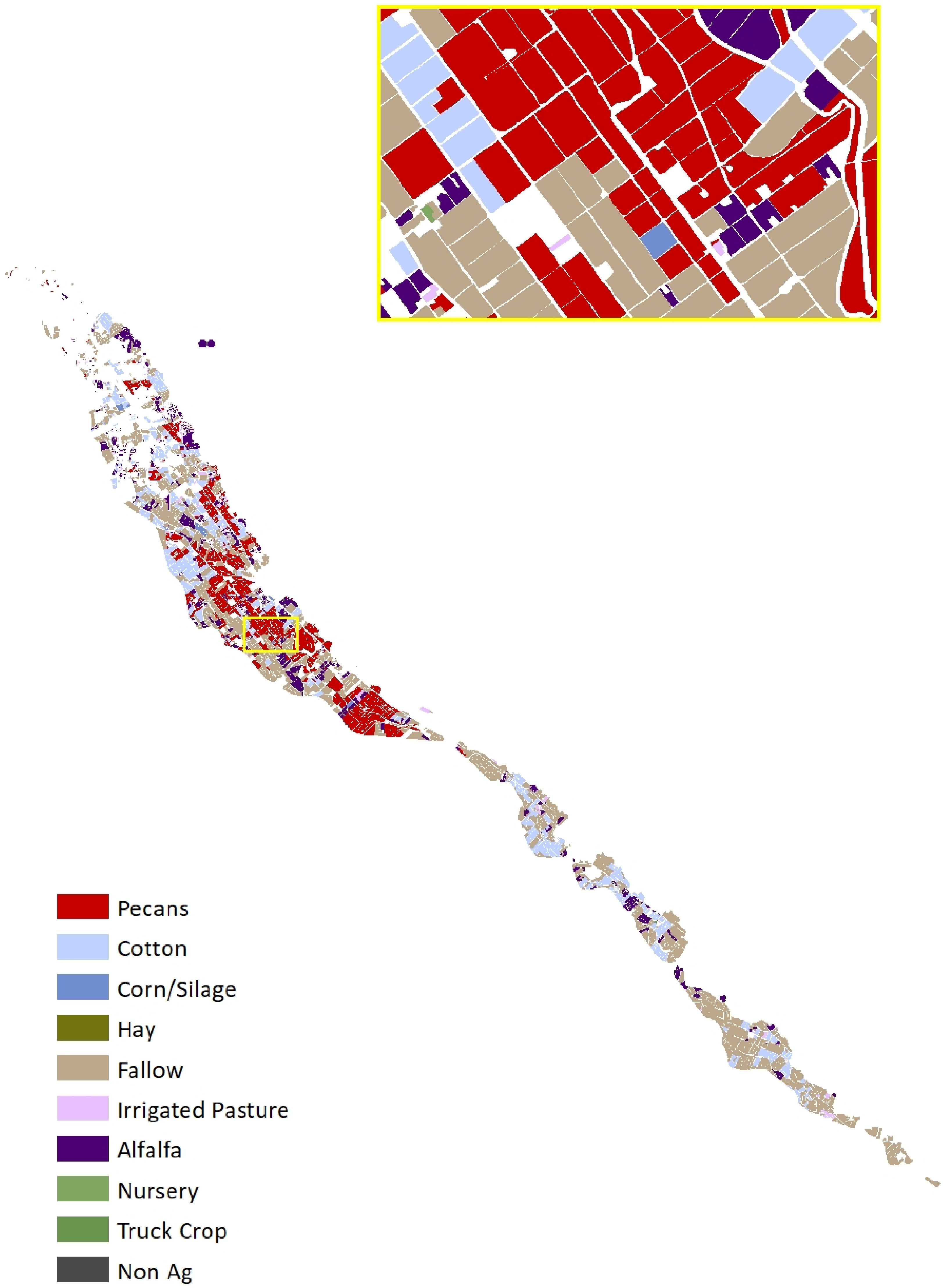



El Paso Valley 2016 Crop Classification
Pecans
Cotton
Corn/Silage
Hay
Fallow
Irrigated Pasture
Alfalfa
Non Ag

El Paso Valley 2014 Crop Classification

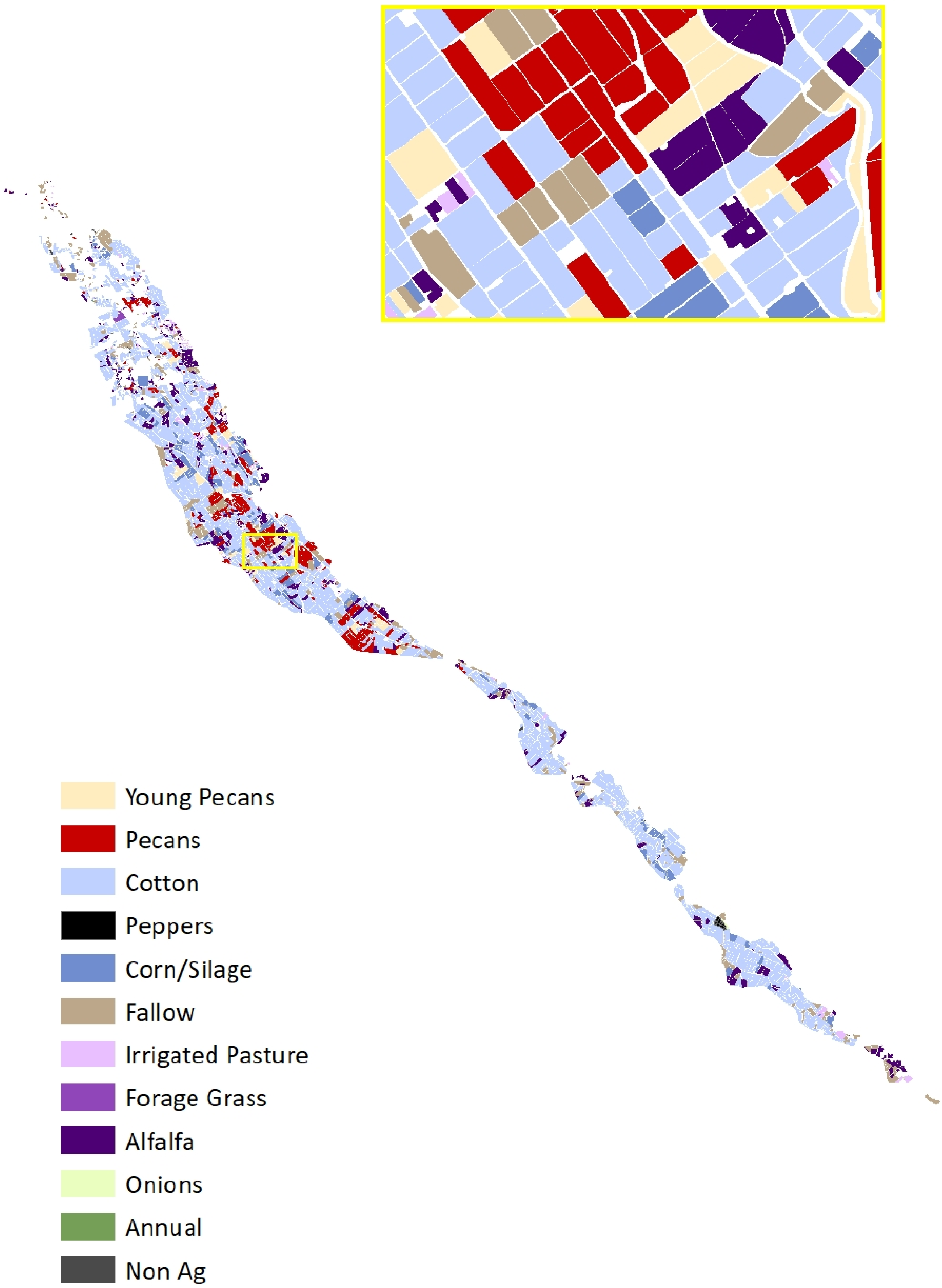


El Paso Valley 2012 Crop Classification

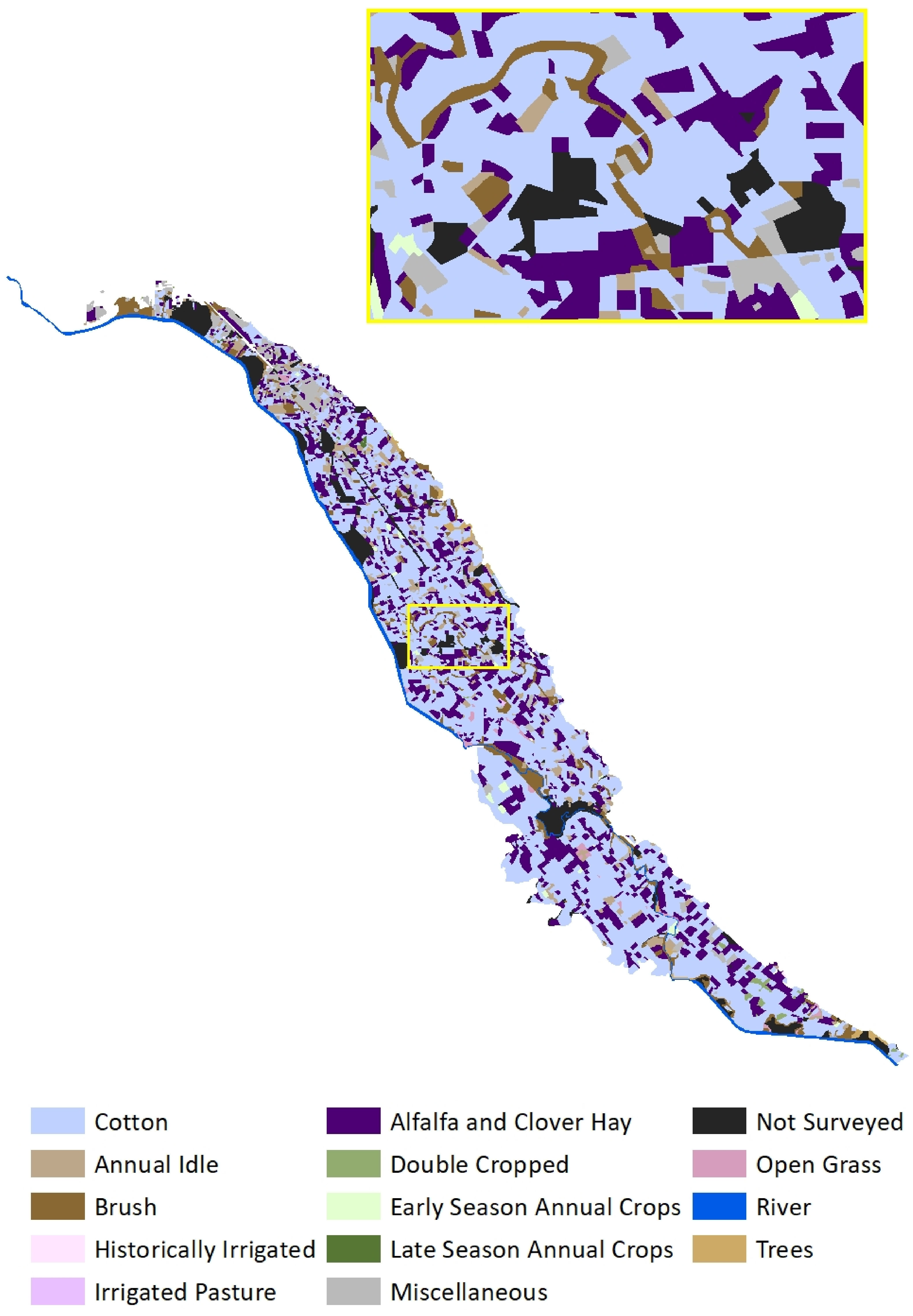



El Paso Valley 2006 Crop Classification
Young Pecans
Pecans
Cotton
Corn/Silage
Wheat
Fallow
Irrigated Pasture
Alfalfa

El Paso Valley 1996 Crop Classification



El Paso Valley 1936 Crop Classification



Appendix 3

Agricultural Land Use Results and Annual Land Use Dataset

Electronic File

Appendix 4

Disaggregated Agricultural Acreage and Consumptive Use by Service Area

Electronic File

Appendix 5

Riparian Land Use and Consumptive Use Results

Riparian Consumptive Use Results

							Total Riparian Area (acres)			Vegetation Acreage by Class - Rincon (acres)			Annual ET by Class - Rincon (acre-feet/acre)			Consumptive Use by Class - Rincon (acre-feet)			Vegetation Acreage by Class - Mesilla (acres)			Annual ET by Class - Mesilla (acre-feet/acre)			Consumptive Use by Class - Mesilla (acre-feet)			Both Valleys Consumptive Use (acre-feet)	
Source (1)	Year	Total Area (Acres)	Total Riparian Tree (Acres) (2)	Total Riparian Shrub (Acres) (2)	Total Riparian Herb (Acres) (2)	Total Bare Ground (Acres) (2)	Total Riparian Veg Area (Acres) (1)	Riparian in Rincon (acres) (3,4)	Riparian in Mesilla (acres) (3,4)	Riparian Tree (4)	Riparian Shrub (4)	Riparian Herb (4)	Riparian Tree	Riparian Shrub	Riparian Herb	Riparian Tree	Riparian Shrub	Riparian Herb	Riparian Tree (4)	Riparian Shrub (4)	Riparian Herb (4)	Riparian Tree	Riparian Shrub	Riparian Herb	Riparian Tree	Riparian Shrub	Riparian Herb	Year	Consumptive Use Total (ac ft)
PAPA-1936	1935	15438	1452	1520	3997	8469	6967	4549.5	2417.5	976	1021	2686	2.53	3.65	2.19	2469	3728	5882	476	499	1311	2.53	3.65	2.19	1205	1820	2871	1935	17975
PAPA-1936	1936	15438	1452	1520	3997	8469	6967	4549.5	2417.5	976	1021	2686	2.53	3.65	2.19	2469	3728	5882	476	499	1311	2.53	3.65	2.19	1205	1820	2871	1936	17975
PAPA-1936	1937	15438	1452	1520	3997	8469	6967	4549.5	2417.5	976	1021	2686	2.53	3.65	2.19	2469	3728	5882	476	499	1311	2.53	3.65	2.19	1205	1820	2871	1937	17975
PAPA-1955	1938	13160	273	74	0	12813	348	227.2	120.8	178	48	0	1.65	3.65	2.19	294	176	0	95	26	0	1.65	3.65	2.19	156	94	0	1938	720
PAPA-1955	1939	13160	273	74	0	12813	348	227.2	120.8	178	48	0	1.65	3.65	2.19	294	176	0	95	26	0	1.65	3.65	2.19	156	94	0	1939	720
PAPA-1955	1940	13160	273	74	0	12813	348	227.2	120.8	178	48	0	1.65	3.65	2.19	294	176	0	95	26	0	1.65	3.65	2.19	156	94	0	1940	720
PAPA-1955	1941	13160	273	74	0	12813	348	227.2	120.8	178	48	0	1.65	3.65	2.19	294	176	0	95	26	0	1.65	3.65	2.19	156	94	0	1941	720
PAPA-1955	1942	13160	273	74	0	12813	348	227.2	120.8	178	48	0	1.65	3.65	2.19	294	176	0	95	26	0	1.65	3.65	2.19	156	94	0	1942	720
PAPA-1955	1943	13160	273	74	0	12813	348	227.2	120.8	178	48	0	1.65	3.65	2.19	294	176	0	95	26	0	1.65	3.65	2.19	156	94	0	1943	720
PAPA-1955	1944	13160	273	74	0	12813	348	227.2	120.8	178	48	0	1.65	3.65	2.19	294	176	0	95	26	0	1.65	3.65	2.19	156	94	0	1944	720
PAPA-1955	1945	13160	273	74	0	12813	348	227.2	120.8	178	48	0	1.65	3.65	2.19	294	176	0	95	26	0	1.65	3.65	2.19	156	94	0	1945	720
PAPA-1955	1946	13160	273	74	0	12813	348	227.2	120.8	178	48	0	1.65	3.65	2.19	294	176	0	95	26	0	1.65	3.65	2.19	156	94	0	1946	720
PAPA-1955	1947	13160	273	74	0	12813	348	227.2	120.8	178	48	0	1.65	3.65	2.19	294	176	0	95	26	0	1.65	3.65	2.19	156	94	0	1947	720
PAPA-1955	1948	13160	273	74	0	12813	348	227.2	120.8	178	48	0	1.65	3.65	2.19	294	176	0	95	26	0	1.65	3.65	2.19	156	94	0	1948	720
PAPA-1955	1949	13160	273	74	0	12813	348	227.2	120.8	178	48	0	1.65	3.65	2.19	294	176	0	95	26	0	1.65	3.65	2.19	156	94	0	1949	720
PAPA-1955	1950	13160	273	74	0	12813	348	227.2	120.8	178	48	0	1.65	3.65	2.19	294	176	0	95	26	0	1.65	3.65	2.19	156	94	0	1950	720
PAPA-1955	1951	13160	273	74	0	12813	348	227.2	120.8	178	48	0	1.65	3.65	2.19	294	176	0	95	26	0	1.65	3.65	2.19	156	94	0	1951	720
PAPA-1955	1952	13160	273	74	0	12813	348	227.2	120.8	178	48	0	1.65	3.65	2.19	294	176	0	95	26	0	1.65	3.65	2.19	156	94	0	1952	720
PAPA-1955	1953	13160	273	74	0	12813	348	227.2	120.8	178	48	0	1.65	3.65	2.19	294	176	0	95	26	0	1.65	3.65	2.19	156	94	0	1953	720
PAPA-1955	1954	13160	273	74	0	12813	348	227.2	120.8	178	48	0	1.65	3.65	2.19	294	176	0	95	26	0	1.65	3.65	2.19	156	94	0	1954	720
PAPA-1955	1955	13160	273	74	0	12813	348	227.2	120.8	178	48	0	1.65	3.65	2.19	294	176	0	95	26	0	1.65	3.65	2.19	156	94	0	1955	720
PAPA-1955	1956	13160	273	74	0	12813	348	227.2	120.8	178	48	0	1.65	3.65	2.19	294	176	0	95	26	0	1.65	3.65	2.19	156	94	0	1956	720
PAPA-1955	1957	13160	273	74	0	12813	348	227.2	120.8	178	48	0	1.65	3.65	2.19	294	176	0	95	26	0	1.65	3.65	2.19	156	94	0	1957	720
PAPA-1955	1958	13160	273	74	0	12813	348	227.2	120.8	178	48	0	1.65	3.65	2.19	294	176	0	95	26	0	1.65	3.65	2.19	156	94	0	1958	720
PAPA-1955	1959	13160	273	74	0	12813	348	227.2	120.8	178	48	0	1.65	3.65	2.19	294	176	0	95	26	0	1.65	3.65	2.19	156	94	0	1959	720
PAPA-1955	1960	13160	273	74	0	12813	348	227.2	120.8	178	48	0	1.65	3.65	2.19	294	176	0	95	26	0	1.65	3.65	2.19	156	94	0	1960	720
PAPA-1967	1961	14089	665	43	0	13380	708	475.8	232.2	447	29	0	1.98	3.65	2.19	886	105	0	218	14	0	1.98	3.65	2.19	433	51	0	1961	1476
PAPA-1967	1962	14089	665	43	0	13380	708	475.8	232.2	447	29	0	1.98	3.65	2.19	886	105	0	218	14	0	1.98	3.65	2.19	433	51	0	1962	1476
PAPA-1967	1963	14089	665	43	0	13380	708	475.8	232.2	447	29	0	1.98	3.65	2.19	886	105	0	218	14	0	1.98	3.65	2.19	433	51	0	1963	1476
PAPA-1967	1964	14089	665	43	0	13380	708	475.8	232.2	447	29	0	1.98	3.65	2.19	886	105	0	218	14	0	1.98	3.65	2.19	433	51	0	1964	1476
PAPA-1967	1965	14089	665	43	0	13380	708	475.8	232.2	447	29	0	1.98	3.65	2.19	886	105	0	218	14	0	1.98	3.65	2.19	433	51	0	1965	1476
PAPA-1967	1966	14089	665	43	0	13380	708	475.8	232.2	447	29	0	1.98	3.65	2.19	886	105	0	218	14	0	1.98	3.65	2.19	433	51	0	1966	1476
PAPA-1967	1967	14089	665	43	0	13380	708	475.8	232.2	447	29	0	1.98	3.65	2.19	886	105	0	218	14	0	1.98	3.65	2.19	433	51	0	1967	1476
PAPA-1967	1968	14089	665	43	0	13380	708	475.8	232.2	447	29	0	1.98	3.65	2.19	886	105	0	218	14	0	1.98	3.65	2.19	433	51	0	1968	1476
PAPA-1967	1969	14089	665	43	0	13380	708	475.8	232.2	447	29	0	1.98	3.65	2.19	886	105	0	218	14	0	1.98	3.65	2.19	433	51	0	1969	1476
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PAPA-1974	1971	13344	792	110	3	12440	904	607.5	296.5	532	74	2	2.23	3.65	2.19	1188	270	4	260	36	1	2.23	3.65	2.19	580	132	2	1971	2177
PAPA-1974	1972	13344	792	110	3	12440	904	607.5	296.5	532	74	2	2.23	3.65	2.19	1188	270	4	260	36	1	2.23	3.65	2.19	580	132	2	1972	2177
PAPA-1974	1973	13344	792	110	3	12440	904	607.5	296.5	532	74	2	2.23	3.65	2.19	1188	270	4	260	36	1	2.23	3.65	2.19	580	132	2	1973	2177
PAPA-1974	1974	13344	792	110	3	12440	904	607.5	296.5	532	74	2	2.23	3.65	2.19	1188	270	4	260	36	1	2.23	3.65	2.19	580	132	2	1974	2177
PAPA-1974	1975	13344	792	110	3	12440	904	607.5	296.5	532	74	2	2.23	3.65	2.19	1188	270	4	260	36	1	2.23	3.65	2.19	580	132	2	1975	2177
PAPA-1974	1976	13344	792	110	3	12440	904	607.5	296.5	532	74	2	2.23	3.65	2.19	1188	270	4	260	36	1	2.23	3.65	2.19	580	132	2	1976	2177
PAPA-1974	1977	13344	792	110	3	12440	904	607.5	296.5	532	74	2	2.23	3.65	2.19	1188	270	4	260	36	1	2.23	3.65	2.19	580	132	2	1977	2177
PAPA-1974	1978	13344	792	110	3	12440	904	607.5	296.5	532	74	2	2.23	3.65	2.19	1188	270	4	260	36	1	2.23	3.65	2.19	580	132	2	1978	2177
PAPA-1974	1979	13344	792	110	3	12440	904	607.5	296.5	532	74	2	2.23	3.65	2.19	1188	270	4	260	36	1	2.23	3.65	2.19	580	132	2	1979	2177
PAPA-1986	1980	13018	1257	25	1	11735	1283	862.2	420.8	845	17	1	2.16	3.65	2.19	1828	61	1	412	8	0	2.16	3.65	2.19	892	30	1	1980	2814
PAPA-1986	1981	13018	1257	25	1	11735	1283	862.2	420.8	845	17	1	2.16	3.65	2.19	1828	61	1	412	8	0	2.16	3.65	2.19	892	30	1	1981	2814
PAPA-1986	1982	13018	1257	25	1	11735	1283	862.2	420.8	845	17	1	2.16	3.65	2.19	1828	61	1	412	8	0	2.16	3.65	2.19	892	30	1	1982	2814
PAPA-1986	1983	13018	1257	25	1	11735	1283	862.2	420.8	845	17	1	2.16	3.65	2.19	1828	61	1	412	8	0	2.16	3.65	2.19	892	30	1	1983	2814
PAPA-1986	1984	13018	1257	25	1	11735	1283	862.2	420.8	845	17	1	2.16	3.65	2.19	1828	61	1	412	8	0	2.16	3.65	2.19	892	30	1	1984	2814
PAPA-1986	1985	13018	1257	25	1	11735	1283	862.2	420.8	845	17	1	2.16	3.65	2.19	1828	61	1	412	8	0	2.16	3.65	2.19	892	30	1	1985	2814
PAPA-1986	1986	13018	1257	25	1	11735	1283	862.2	420.8	845	17	1	2.16	3.65	2.19	1828	61	1	412	8	0	2.16	3.65	2.19	892	30	1	1986	2814
PAPA-1986	1987	13018	1257	25	1	11735	1283	862.2	420.8	845	17	1	2.16	3.65	2.19	1828	61	1	412	8	0	2.16	3.65	2.19	892	30	1	1987	2814
PAPA-1986	1988	13018	1257	25	1	11735	1283	862.2	420.8	845	17	1	2.16	3.65	2.19	1828	61	1	412	8	0	2.16	3.65	2.19	892	30	1	1988	2814
PAPA-1986	1989	13018	1257	25	1	11735	1283	862.2	420.8	845	17	1	2.16	3.65	2.19	1828	61	1	412	8	0	2.16	3.65	2.19	892	30	1	1989	2814

Riparian Consumptive Use Results (cont.)

PAPA-1986	1990	13018	1257	25	1	11735	1283	862.2	420.8	845	17	1	2.16	3.65	2.19	1828	61	1	412	8	0	2.16	3.65	2.19	892	30	1	1990	2814
PAPA-1986	1991	13018	1257	25	1	11735	1283	862.2	420.8	845	17	1	2.16	3.65	2.19	1828	61	1	412	8	0	2.16	3.65	2.19	892	30	1	1991	2814
PAPA-1997	1992	13174	1620	92	5	11450	1717	1153.8	563.2	1089	62	3	2.48	3.65	2.19	2696	226	7	531	30	2	2.48	3.65	2.19	1316	110	4	1992	4359
PAPA-1997	1993	13174	1620	92	5	11450	1717	1153.8	563.2	1089	62	3	2.48	3.65	2.19	2696	226	7	531	30	2	2.48	3.65	2.19	1316	110	4	1993	4359
PAPA-1997	1994	13174	1620	92	5	11450	1717	1153.8	563.2	1089	62	3	2.48	3.65	2.19	2696	226	7	531	30	2	2.48	3.65	2.19	1316	110	4	1994	4359
PAPA-1997	1995	13174	1620	92	5	11450	1717	1153.8	563.2	1089	62	3	2.48	3.65	2.19	2696	226	7	531	30	2	2.48	3.65	2.19	1316	110	4	1995	4359
PAPA-1997	1996	13174	1620	92	5	11450	1717	1153.8	563.2	1089	62	3	2.48	3.65	2.19	2696	226	7	531	30	2	2.48	3.65	2.19	1316	110	4	1996	4359
PAPA-1997	1997	13174	1620	92	5	11450	1717	1153.8	563.2	1089	62	3	2.48	3.65	2.19	2696	226	7	531	30	2	2.48	3.65	2.19	1316	110	4	1997	4359
PAPA-1997	1998	13174	1620	92	5	11450	1717	1153.8	563.2	1089	62	3	2.48	3.65	2.19	2696	226	7	531	30	2	2.48	3.65	2.19	1316	110	4	1998	4359
PAPA-1997	1999	13174	1620	92	5	11450	1717	1153.8	563.2	1089	62	3	2.48	3.65	2.19	2696	226	7	531	30	2	2.48	3.65	2.19	1316	110	4	1999	4359
PAPA-1997	2000	13174	1620	92	5	11450	1717	1153.8	563.2	1089	62	3	2.48	3.65	2.19	2696	226	7	531	30	2	2.48	3.65	2.19	1316	110	4	2000	4359
PAPA-2004	2001	13094	1553	92	5	11444	1650	1108.8	541.2	1044	62	3	2.49	3.65	2.19	2599	226	7	509	30	2	2.49	3.65	2.19	1269	110	4	2001	4215
PAPA-2004	2002	13094	1553	92	5	11444	1650	1108.8	541.2	1044	62	3	2.49	3.65	2.19	2599	226	7	509	30	2	2.49	3.65	2.19	1269	110	4	2002	4215
PAPA-2004	2003	13094	1553	92	5	11444	1650	1108.8	541.2	1044	62	3	2.49	3.65	2.19	2599	226	7	509	30	2	2.49	3.65	2.19	1269	110	4	2003	4215
PAPA-2004	2004	13094	1553	92	5	11444	1650	1108.8	541.2	1044	62	3	2.49	3.65	2.19	2599	226	7	509	30	2	2.49	3.65	2.19	1269	110	4	2004	4215
PAPA-2004	2005	13094	1553	92	5	11444	1650	1108.8	541.2	1044	62	3	2.49	3.65	2.19	2599	226	7	509	30	2	2.49	3.65	2.19	1269	110	4	2005	4215
PAPA-2004	2006	13094	1553	92	5	11444	1650	1108.8	541.2	1044	62	3	2.49	3.65	2.19	2599	226	7	509	30	2	2.49	3.65	2.19	1269	110	4	2006	4215
PAPA-2004	2007	13094	1553	92	5	11444	1650	1108.8	541.2	1044	62	3	2.49	3.65	2.19	2599	226	7	509	30	2	2.49	3.65	2.19	1269	110	4	2007	4215
PAPA-2004	2008	13094	1553	92	5	11444	1650	1108.8	541.2	1044	62	3	2.49	3.65	2.19	2599	226	7	509	30	2	2.49	3.65	2.19	1269	110	4	2008	4215
PAPA-2004	2009	13094	1553	92	5	11444	1650	1108.8	541.2	1044	62	3	2.49	3.65	2.19	2599	226	7	509	30	2	2.49	3.65	2.19	1269	110	4	2009	4215
LandIQ-2014	2010	12809	1610	96	5	11098	1711	1142.0	569.0	1075	64	3	2.49	3.65	2.19	2677	233	8	535	32	2	2.49	3.65	2.19	1334	116	4	2010	4371
LandIQ-2014	2011	12809	1610	96	5	11098	1711	1142.0	569.0	1075	64	3	2.49	3.65	2.19	2677	233	8	535	32	2	2.49	3.65	2.19	1334	116	4	2011	4371
LandIQ-2014	2012	12809	1610	96	5	11098	1711	1142.0	569.0	1075	64	3	2.49	3.65	2.19	2677	233	8	535	32	2	2.49	3.65	2.19	1334	116	4	2012	4371
LandIQ-2014	2013	12809	1610	96	5	11098	1711	1142.0	569.0	1075	64	3	2.49	3.65	2.19	2677	233	8	535	32	2	2.49	3.65	2.19	1334	116	4	2013	4371
Land IQ-2014	2014	12809	1610	96	5	11098	1711	1142.0	569.0	1075	64	3	2.49	3.65	2.19	2677	233	8	535	32	2	2.49	3.65	2.19	1334	116	4	2014	4371
Land IQ-2014/:	2015	12846	1615	96	5	11130	1716	11231.0	12851.0	1078	64	3	2.49	3.65	2.19	2685	234	8	537	32	2	2.49	3.65	2.19	1338	117	4	2015	4384
Land IQ-2016	2016	12882	1619	96	5	11161	1721	1149.0	572.0	1081	64	3	2.49	3.65	2.19	2693	235	8	539	32	2	2.49	3.65	2.19	1342	117	4	2016	4398

Notes/Assumptions

1 Dates for which analysis is available were used as the midpoints of the years for which ET Consumption by Riparian Veg was to be calculated

2 2014 fraction of Riparian Tree, Riparian Shrub, Riparian Herb and Bare Ground are based on 2004 Papadopulos(2008) report values for fraction of vegetated cover - which are in turn based on field surveys (94.1% for Tree; 5.6% for Shrub; and 0.3% for Herb)

3 2014 Vegetation by NDVI-based method was divided by 2.59 (aka reducing it by 159%) to calibrate to survey-based method in Papadopulos (2008) report

4 1955 Fraction of Rincon-Mesilla total vegetation and Plant Functional Groups (PFGs) is 0.653 of total vegetation in Rincon (based on Land IQ analysis of vegetation cover in 1955); 1935 to 1937, 1961 to 2014, assumed 0.672 of Total Veg and PFGs in Rincon (based on 2014 Land IQ analysis of vegetation cover)

* Note: PAPA 2008 = Papadopulos & Associates (Papadopulos). 2008. Summary Documentation of the Calibrated Groundwater Flow Model for the Lower Rio Grande Basin, LRG_2007. November 2008. Prepared for New Mexico Office of the State Engineer.

Appendix 6

Joel Kimmelshue, PhD.

Resume

Joel Kimmelshue, Ph.D., CPSS
Principal Agricultural and Soil Scientist
jkimmelshue@landiq.com

Education

Ph.D., Soil Science (Water Resources concentration), North Carolina State Univ., Raleigh, 1996
M.S., Soil Science (Ag Engineering concentration), North Carolina State Univ., Raleigh, 1992
B.S., Soil Science (Crop Sci. concentration), California Polytechnic State Univ., San Luis Obispo, 1990

Professional Registrations and Organizations

Certified Professional Soil Scientist (CPSS - #18204) – American Registry of Certified Professionals in Agronomy, Crops and Soils; American Society of Agronomy; Soil Science Society of America

Distinguishing Qualifications

Expert/Specialist in the following areas:

- Land use assessments and crop identification
- Production agricultural systems
- Soil/water/plant relations in arid climates
- Irrigation and drainage management
- Crop consumptive use estimates
- Expert witness testimony
- Soil and land use evaluations for the implementation of irrigation systems and crop production
- Water resources
- Soil nutrient interactions and environmental issues in soils
- Agricultural land application and reuse systems for various liquid and solid byproducts
- Soil and water salinity management for agriculture
- Dust and Erosion Control
- Water quality for irrigated agriculture
- Regulatory support and negotiation for agriculture
- Policy, regulatory, and environmental influences on agricultural production systems
- Soil and water conservation
- Agricultural research

Relevant Experience

Dr. Kimmelshue is a Principal Soil and Agricultural Scientist for Land IQ. Dr. Kimmelshue is also a founding Owner in the firm. He has experience in agricultural and water resources consulting in the western United States (especially California), and agricultural research and crop production throughout the United States. This experience stretches to various locations in Europe and the Middle East. Dr. Kimmelshue has performed technical leadership and/or managed numerous projects and tasks of nearly $15 million dollars over the past 19 years.

Dr. Kimmelshue's consulting experience includes practical and applied solutions for development of water/soil management systems and agricultural systems, specifically with irrigated agriculture. This technical expertise also includes expert witness testimony, crop consumptive use estimates, erosion and dust control, regulatory support and negotiation, water resources science and planning, land reclamation, soil/plant nutrient dynamics, irrigation and drainage in arid and humid climates, soil classification, crop production, land application of municipal and agricultural wastes, and revegetation/reclamation efforts.

Predominantly, the objective scientific work that Dr. Kimmelshue performs is driven by ever-changing policy, legislative and environmental pressures on production agricultural systems. Dr. Kimmelshue thoroughly understands these drivers and applies sound scientific results to help his clients address these challenges.

Select Representative Projects – Domestic

(Complete work experience includes efforts in the states of: Alabama, Arizona, California, Colorado, Florida, Georgia, Idaho, Iowa, Louisiana, Montana, Nevada, New Mexico, North Carolina, Oklahoma, Oregon, Texas, Utah, Washington, and Wisconsin.)

- **Principal in Charge and Technical Lead – Nationwide Mapping of Pecans – American Pecan Council.** As a result of successful mapping of various other tree crops for multiple years primarily in California, the American Pecan Council contracted with Land IQ to map pecans nationwide. This ongoing project spans the states of California, Arizona, New Mexico, Texas, Oklahoma, Louisiana, Alabama, and Georgia. The mapping years currently are for 2017 and 2018 and also contain an orchard by orchard age analysis. The orchards are mostly classified as improved or organized plantings, however some of the pecan production consists of native areas. Applications of these efforts also focus on the impact of Hurricane Michael on losses of orchards in Georgia in late 2018.
- **Principal in Charge and Technical Lead – Statewide Crop and Land Use Mapping – California Department of Water Resources.** Land IQ is contracted by the state of California to conduct statewide crop mapping of approximately 50 different crop types on over 9.4 million acres of agricultural land for fields of 2.0 acres and larger (sometimes smaller depending on crop type – (e.g. avocados)). The entire dataset amounted to over 350,000 individual polygons and an average field size of 34 acres. The mapping spanned the entire state from the Mexico, Nevada, and Arizona borders to the Pacific Ocean. The ultimate accuracy of the 2014 mapping based on thousands of miles of ground truthing was 96.6%. The 2016 accuracy was 97.6%. Land IQ is now mapping multi-cropping systems throughout the state in addition to the main season cropping systems.
- **Principal in Charge and Technical Lead – Statewide Avocado Mapping – California Avocado Commission.** For the California Avocado Commission, Dr. Kimmelshue leads a technical team in mapping avocados statewide although primarily in southern California. The mapping is highly accurate (>97%) and ranges down to fields of 0.5 acres. The California avocado industry is a relatively small in the global market, however produces high quality fruit for a premium price. The purpose of this annual mapping is to always be aware of not only the number of acres in production for also the condition of each orchard (e.g. producing, young, stumped, abandoned).
- **Principal in Charge and Project Manager – Monthly Remotely Sensed Crop Consumptive Use – Semitropic Water Storage District, North Kern Water Storage District, Shafter Wasco Irrigation District.** As a part of the California Sustainable Groundwater Management Act (SGMA) regulatory requirements, highly accurate and timely evapotranspiration measurement are a key input to

hydrologic models and overall efficient water management. For these 3 irrigation districts spanning approximately 400,000 acres, a monthly remotely sensed ET field by field measurement is performed and delivered to the districts within 30 days following the end of the previous month. The results are created with a remotely sensed regression approach that integrates nearly 40 simple ground truthing stations that measure the climatic variables necessary to calculate actual ET. These calibration points are then used in the model to estimate ET from every irrigated and non-irrigated field, as well as native areas. The ground truthing stations are also used for validation datasets.

- **Project Manager and Technical Lead–Cold Water Rice Yield Loss Determination; Western Canal Water District, Richvale Irrigation District, Biggs West Gridley Irrigation District; Cold Water Influences on Rice Yield; Nelson, Richvale, and Gridley, CA.** This project centered on the development and implementation of Settlement Agreement technical protocols between the three Districts (approximately 100,000 acres) and the California Department of Water Resources. The implementation of this Agreement will result in payment by the State of California to the growers within the Districts for loss of rice yield due to cold water diversion from the State Water Project at Oroville Dam and the Thermalito afterbay. The determination of yield loss is being conducted using aerial, satellite and other remote sensing techniques. This approach is being correlated to field measured yield losses utilizing grower owned and operated, combine-equipped GPS yield monitors. Also, in-canal temperature measurements were taken at 125 locations throughout the Districts for a period of up to 90 days. A temperature interpolation map and equation has been developed and is a third method of estimating yield loss determination. These three methods are being correlated against each other for an ultimate yield loss estimate. This work involves consistent contact and interaction with Districts' managers and staff, representatives from the California Department of Water Resources in Sacramento and Red Bluff, cooperating growers, and sub-consultants.
- **Principal In Charge/Technical Specialist – Statewide Spatial Mapping of Almonds, Walnuts, Pistachios, and Dried Plums; Almond Board of California, California Walnut Commission, California Pistachio Research Board, California Dried Plum Board; Modesto/Sacramento/Fresno, CA.** Dr. Kimmelshue is currently leading an intensive state-wide, field by field mapping product of all almonds, walnuts, pistachios, and dried plums across the entire state of California. Due to the rapid expansion of these tree crops, understanding of actual acres, age, and location in comparison to water sources, environmentally sensitive areas, transportation corridors, other crop types, and many other attributes are increasingly important to these four commodity organizations. The resultant work is a highly accurate, timely, and cost-effective crop mapping product. The technology employed for this work is a combination of inherent agronomic knowledge of cropping systems in California, remotely sensed attributes, and use of multiple additional lines of evidence.
- **Technical Lead and Project Manager – Kern River Watershed Coalition Authority, Sub Basin Review of Agricultural Irrigation and Drainage Practices and Crop Impacts; Bakersfield, CA.** Dr. Kimmelshue was retained by the KRWCA as an expert in providing sound technical agronomic information related to the unique irrigation and crop production practices of the Kern Sub Basin area within the Southern San Joaquin Valley Water Quality Coalition. This work involved understanding and interpreting changes in cropping patterns, irrigation methods, salinity management, fertilization practices and overall water and nitrogen use efficiency. A portion of this work included intensive ground truthing for development of remotely sensed crop mapping products. Those ground truthing data included permanent crop irrigation method documentation for use in irrigation method change over time.

- **Technical Lead – San Joaquin River Restoration Program, Seepage Management Plan, Expert Review Panel Member; United States Bureau of Reclamation; Sacramento, CA.** Dr. Kimmelshue was retained as a salinity, agricultural production, and irrigation and drainage expert to review a completed current version of the Seepage Management Plan for seepage impacts to agriculture including acceptable water table depths, salinity management, yield decline, remotely sensed solutions and irrigation and drainage management considerations. This work will result in completion of a comprehensive management document offering a review of thresholds, solutions and mitigation opportunities as a result of future increased flows in the San Joaquin River.

- **Project Manager and Technical Lead–Historical and Present Crop Evaluation and Water Use Estimate; Brownstein, Hyatt, Farber, Schreck – Water Law Firm – representing a Confidential Client; Bakersfield, California.** This project involved the historical and present quantification of water use at a confidential site near Bakersfield. Historical remote sensing imagery was acquired to determine the irrigated area changes over time as well as the cropping pattern shifts from the early 1950s to present day. Water use estimates were determined for the current cropping patterns as well as diverted water quantities. A comprehensive site evaluation was performed with the client and area grower/owner to determine soil type, water conveyance, irrigation methods and management, storage, crop types, etc. This work was used to facilitate a potential substantial land purchase and water rights quantification.

- **Expert Witness and Technical Lead–Prepared Testimony for United States District Court – Eastern District of California; Judge Oliver W. Wanger; Tehama Colusa Canal Authority Water Deficit Evaluation; Willows and Fresno California.** Dr. Kimmelshue was retained to prepare a detailed evaluation of the influence of regulated deficit irrigation on a variety of crops including almonds, grapes, walnuts, rice, olives, alfalfa, tomatoes and a variety of other permanent and annual field and row crops. The preparation of this testimony was conducted to determine the influence of a deficit of irrigation water at predetermined periods of the growth cycles of the crops mentioned above – predominantly focusing on perennial crops such as almonds. The results of this work indicate the extreme detrimental influence of insufficient irrigation during key growth stages of the crop.

- **Expert Witness and Technical Lead–Prepared Testimony for Santa Clara County Superior Court; Judge Jack Komar; Crop Water Demand and Estimation of Return Flows in Irrigated and Nonirrigated Areas; Southern California Water Company; Santa Maria, California.** This project involved expert witness testimony, both in deposition and in trial settings, based on an 8-month effort to assess crop water use for an historical 58-year period over a 164,000-acre basin. The work focused on pumped water and return flows to groundwater under irrigated and nonirrigated areas. Crop and native vegetation evapotranspiration and soil storage modeling was conducted. Water was assessed to ensure adequate quality for sensitive crop production. The expert witness testimony included 2 days of deposition and 2 additional days of trial testimony, including cross-examination. The work was conducted as a component of a groundwater basin assessment focusing on the potential for overdraft. This was a multi-stakeholder case, which included agricultural, urban and local, state, and federal agencies.

- **Expert Witness and Technical Lead–Preparing Testimony for Los Angeles County Superior Court; Judge Jack Komar; Crop Water Demand and Estimation of Return Flows in Irrigated and Non-irrigated Areas; Antelope Valley Groundwater Agreement Association; Lancaster, California.** This work centered on the quantification of a water right adjudication of the Antelope Valley. Dr. Kimmelshue represented the agricultural interests in the Valley and conducted a detailed and comprehensive assessment of crop water use, irrigation methods and efficiencies, return flows, and other parameters to ultimately assess a component of the safe yield of the groundwater basin based on agricultural pumping. This work was prepared for expert witness testimony in early 2011. Modeling was conducted to assess not only a variety of crop types in irrigated agricultural, but also irrigated urban areas.

- **Project Manager and Technical Lead–Blending of Saline Mine Water with Central Arizona Project (CAP) Water for Irrigation to Cotton, Alfalfa, and Sod; Rio Tinto Mining Company – Resolution Copper; Superior and Queen Creek, Arizona.** Dr. Kimmelshue is leading an effort to create an acceptable blended water quality for irrigation to alfalfa, cotton and sod on approximately 5,500 acres of land within the New Magma Irrigation and Drainage District (NMID). This project involves direct working efforts with the USBR, the state of Arizona Lands Department, NMID, the University of Arizona Soil, Water and Environmental Science Department, and the Resolution Copper Company. Many of these multi-stakeholder meetings were for the purpose of obtaining permitting documents and satisfying the discharge requirements. The work involves real-time monitoring of treated mine water, CAP water, and the blended result. This monitoring network comprises in-canal Total Dissolved Solids (TDS), temperature, and pH probes. A web-based portal will be used for instantaneous water quality assessment and tracking. Also, a comprehensive soil, water, and tissue sampling program will take place at least quarterly during this 5-6 year project. Crop growth stages and tracking will also be conducted. The dewatering of this mine is necessary to make copper ore available from the largest copper mine in North America.

- **Technical Lead and Task Manager–Blackfeet Indian Reservation Water Right Adjudication; Bureau of Indian Affairs/Department of Justice; Browning, Montana.** Technical expert since 1997 leading efforts related to the establishment of a water rights claim for the Blackfeet Indian Tribe. These efforts have and continue to include determination of practicably irrigable acres, detailed land classification for the determination of arable and irrigable lands, present and historical irrigation delineations, water demand estimates of both agricultural and urban uses, drainage evaluations for the purpose of avoiding salinization of lands, and overall task management for nearly $1.7M of labor, sub consultants, and expenses.

- **Technical Specialist – Owens Lake Dust Control; Los Angeles Department of Water and Power; Los Angeles/Lone Pine, CA.** For more than a decade Dr. Kimmelshue has provided senior technical expertise on a large variety of dust control efforts on the Owens Lake Dust Control Project. Historically, this area was one of the largest dust emission sources in the western hemisphere. Over time, Dr. Kimmelshue has provided objective scientific leadership on development, testing and large-scale (thousands of acres) implementation of various dust control technics and methodologies. These efforts specifically focus on analysis of various environmental conditions including soil type, climate, seasonality of emissions, water quality, and relative land disturbance. Based on those analyses, various methodologies to control source areas and challenging surface emissions in harsh environmental conditions have been achieved. Control methodologies include source control, soil binders, revegetation, shallow flooding and various tillage operations.

- **Project Manager and Technical Lead–Irrigation Water Reuse – Water Demand Estimates and Water Quality Suitability; City of Hollister and San Benito County Water District; Hollister, California.** This project involved the quantification of water needs assessment from both a quantity and quality perspective for irrigation with treated wastewater. Dr. Kimmelshue led multiple public education sessions related to the water quality and worked closely with both the City and Water District to ensure acceptance by the farming community. Water quality and quantity estimates were determined and were coupled with appropriate crop types and practices. A key portion of this work involved an update of the Recycled Water Master Plan for approval by the Regional Water Quality Control Board and other entities.

- **Project Manager and Technical Lead–Santa Clara River Watershed Total Maximum Daily Load (TMDL) Collaborative Process; Agricultural Irrigation Thresholds for Chloride and Salinity; Los Angeles County Sanitation Districts; Fillmore, California.** This project included the development of a detailed literature review and evaluation for determination of the potential threshold of irrigation water quality constituents of concern, specifically chloride, on sensitive crops as a basis of a TMDL process in working with the California Regional Water Quality Control Board. This collaborative process included work with a multitude of stakeholders including the California Avocado Commission, the California Strawberry Commission, Nursery Crop Growers, Ventura County Farm Bureau, and Los Angeles County Sanitation Districts. A multitude of crops were evaluated for their individual tolerances to specific constituents of concern. Only the most susceptible crops were further evaluated and included avocados, strawberries, and nursery stock. This work involved detailed assessment of water quality, irrigation practices, cultural practices and drainage management for the overall determination of acceptable irrigation water quality. The work also included comprehensive public notification efforts with stakeholder groups, public officials, researchers, and farm managers. The ultimate outcome of the work has been highly influential in establishing a chloride TMDL for irrigation of sensitive species in the Santa Clara River Basin.

- **Principal In Charge/Technical Specialist – Dust Control in Almonds; Almond Board of California/California Department of Food and Agriculture, Modesto/Sacramento, CA.** Dr. Kimmelshue is currently providing senior technical expertise on a state-wide dust control testing project through the Almond Board of California as funded by the California Department of Food and Agriculture Specialty Crop Block Grant Program. This project is being conducted to ascertain the effectiveness of application of $MgCl_2$ as a dust suppressant in almond production. Different rates of application are being tested to assess relative dust suppression coupled with agronomic suitability and environmental protection. This project began in October of 2012 and will continue through June of 2015. Environmental testing including air emissions and comprehensive soil testing, analysis and interpretation. Expected results include determination of an acceptable range of application rates as related to soil type, irrigation method, and orchard floor management.

- **Technical Lead–Land Application of Former Fertilizer Processing Solids; ChevronTexaco; Fort Madison, Iowa.** This $1.2 million project included the land application of fertilizer pond wastewater (1.5 million gallons) and solids (16,000 cubic yards) to approximately 2,200 acres of suitable farmland in Lee County, Iowa. Roles and responsibilities included management of site suitability analysis, pilot testing with Iowa State University, and request for subcontractor proposal development, contract negotiations, and regulatory requirements.

- **Project Manager and Technical Lead–Detailed Nitrogen Balance Model as a Component to a Required Plan of Study (POS); Anheuser-Busch; Jacksonville, Florida.** This POS evaluated the nitrogen dynamics resulting from multiple-year application of brewery processing waters to more than 300 acres of sod grass through center-pivot irrigation systems. Products included the development of a detailed nitrogen balance historical and predictive model for improvement of site irrigation management. An assessment report and findings were presented to the Florida Department of Environmental Protection and approved for permit extension.

- **Project Manager and Technical Lead–Pilot Study and Full-scale Reuse Program; ChevronTexaco; Richmond, California.** This water quality effort included agricultural reuse of approximately 11 million gallons of processing rinse water from a former nitrogen fertilizer manufacturing facility. The processing rinse water was registered with the State of California Department of Food and Agriculture as an agricultural mineral and labeled as Nitro One. Nitro One contains approximately 4 percent total nitrogen. A pilot study was conducted on a cooperating farmer's land that evaluated the effects of different application rates, injection protocols, and handling techniques on corn production. A public relations campaign was conducted to educate the area farmers about the benefits of using Nitro One and the management considerations of the product.

- **Project Manager and Technical Lead–Coalbed Methane Produced Water Discharge and Irrigation Suitability; Petroglyph Operating Company; La Veta, Colorado.** Dr. Kimmelshue evaluated the suitability of highly concentrated sodium-rich water from a coalbed methane operation for discharge and irrigation to corn and alfalfa near Walsenburg, Colorado. This work involved evaluating soil and water amendments to compensate for the high sodium concentrations. This challenging project involved public presentations at local community forums as well as ongoing collaboration with Colorado State University and the Colorado Cooperative Extension Service.

- **Technical Lead–Nutrient Management for the City of Los Angeles Biosolids Land Application Farm; City of Los Angeles Bureau of Sanitation; Bakersfield, California**. Over the past 8 years, Dr. Kimmelshue has been the lead technical consultant for the City of Los Angeles biosolids land application program at Green Acres Farms. This project involved a multitude of nutrient management programs and land application recommendations including irrigation, crop and overall farm management (including a Comprehensive Farm Management Plan) for the 5,000-acre site. The farm receives and beneficially reuses Class A biosolids from multiple municipal treatment plants in the Los Angeles Basin. Recent work involved the refinement of soil and plant tissue monitoring plans, a phased soil amendment schedule, crop fair market value assessment, and customized biosolids database and agronomic loading rate calculation tool Cybersolids™ for use at Green Acres Farm.

- **Technical Lead–Feasibility Study to Determine the Chemical and Hydraulic Effects of Irrigating 420,000 Gallons per Day of Saline Wastewater to an 80-acre Orchard and 75 Acres of Landscaping; IBM; San Jose, California.** This evaluation included a detailed cost estimate of modifying the existing irrigation system and management plan to accept the reuse irrigation water. It also included a comprehensive water quality evaluation that reviewed different blending ratios to ensure adequate water quality according to plant species receiving this irrigation water.

- **Technical Lead–Soil Salinity Evaluation; Glenn Colusa Irrigation District (GCID); Willows, California.** This soil salinity evaluation took place over approximately 200,000 acres of within GCID and some neighboring Districts. Dr. Kimmelshue managed and worked with GCID staff to sample the entire District and adjacent areas for soil salinity within the root zone. Sampling and analysis results were compared with historical measurements by the U. S. Bureau of Reclamation (USBR). The trend of salinization was analyzed for its relationship to long-term irrigation management, including a regulatory drought during which irrigation was curtailed throughout the District.

- **Technical Lead; Water Resources Plan–Oakdale Irrigation District; Oakdale, California.** This effort involved detailed assessment of historical land use and projections for future trends based on agricultural market conditions and urban and environmental pressures. This project also involved the development of a comprehensive water resources planning model. Main inputs to this dynamic model were crop water use estimates, water storage and conveyance, deep percolation, losses, recycled water use, and overall long-term water management options for both agricultural and urban uses.

- **Technical Lead and Manager–Clark County Water Reclamation District Biosolids Management Study: Market Assessment; Las Vegas, Nevada.** This effort included a diverse evaluation of potential end-use for Exceptional Quality (EQ) biosolids (in pelletized and bulk form) in the Las Vegas area for the Clark County Water Reclamation District. A key end-use included land application to alfalfa in an arid environment. The end result included recommendations for loading, crop rotations, soil sampling and analysis, tissue sampling and analysis, and potential economic return.
- **Technical Lead–Central Utah Water Resources and Land Classification Project; Central Utah Water Conservancy District; Roosevelt, Utah.** Successfully mapped nearly 10,000 acres of lands slated for supplemental irrigation and drainage improvements. Responsibilities included quality control for soil sampling and data interpretation. Co-authored a report to the USBR for final project approval and certification by the United States Congress.

Select Representative Projects – International Work

(Complete work experience includes efforts in the countries of: Turkey, Malaysia, Germany, Egypt, Israel, Jordan, and The West Bank) Representative projects listed here include:

- **Project Manager and Technical Lead–Development of a Reuse Feasibility Assessment for Irrigation of Conventionally Treated Wastewater; Adana, Turkey**. This project was stimulated by the need to conserve on-base water supplies at the Incirlik Air Base. The feasibility study evaluated the needs associated with the conversion of some on-base irrigation water sources from potable water to treated wastewater. This $100,000 project limited the reliance on off-base water supplies through irrigation with treated wastewater and other conservation practices associated with landscape and crop irrigation. The use efficiency was maximized in this project because storage was limited. A nutrient and hydraulic management plan was constructed for this work to ensure that no over-application of treated wastewater takes place.
- **Project Manager and Technical Lead–Development of Evaluation Strategy for Agricultural Reuse at 19 Wastewater Treatment Plant Sites throughout the Country of Jordan; Amman, Jordan.** These efforts included a technical strategy development for agricultural reuse for the currently operating 19 wastewater treatment plants in Jordan. This involved an evaluation of influencing factors such as soils, climate, and crop production in the area, market conditions, cultural acceptance, wastewater quality, and crop recommendations. The technical report was used to preliminarily prioritize agricultural reuse development for specific areas.
- **Technical Lead–Development of a Feasibility Assessment for Agricultural Reuse of Treated Wastewater for the Hebron Wastewater Treatment Plant Improvements Project; Hebron, West Bank.** This project involved initial development and site location options for reuse of treated wastewater from the anticipated wastewater treatment plant serving Hebron and surrounding communities. Four main sites were evaluated according to land suitability; climatic regimes; proximity to markets; available land area; wadi discharge, potential storage areas and sizing; and impacts to the surrounding environment. Preliminary hydraulic and nutrient balance modeling was conducted for each site and for projected increases in treated wastewater production. This included development of water and nutrient balances for agricultural reuse with local cropping patterns.
- **Technical Lead–Development of a Master Planning Document for the Hebron Wastewater Treatment Plant Improvements Project; Hebron, West Bank.** This project involved a detailed hydraulic and nutrient loading modeling effort for the agricultural reuse component initially proposed in a previous Feasibility Assessment effort. This work was a component of an overall

wastewater master planning effort and was driven by environmental and economic concerns of the region.

- **Technical Lead–Development of a Feasibility Study for the Mafraq Wastewater Treatment Plant Improvements Project; Mafraq, Jordan.** This project involved development of water and nutrient balances for beneficial agricultural reuse of treated wastewater based on various scenarios of different cropping patterns, storage sizing, and wadi discharge for forecasted wastewater flows to 2025. Managing climatic influences and the seasonality of application were optimized to maximize the land base available for application.

Previous Experience

Before co-founding Land IQ, LLC, Dr. Kimmelshue spent over 11 years with CH2MHILL. During that time, Dr. Kimmelshue was the firm-wide leader for Agricultural Services Technology, which represented nearly 70 people throughout the firm. Dr. Kimmelshue was also the Business Development Lead for all water resources related projects for a 7-state southwestern region. Prior to that, Dr. Kimmelshue worked as a research associate at North Carolina State University and managed portions of an irrigated agricultural farm in northern California, producing a variety of tree, field, and row crops.

Professional Responsibilities and Accomplishments

State Committee Member – California Department of Food and Agriculture – Specialty Crop Block Grant Advisory Committee – A 6-year appointment for review and selection of proposals for up to $16M in United States Department of Agriculture funding annually. Sacramento, CA

Fellow – California Agricultural Leadership Program – Class 37 – a 2-year, intensive leadership development program designed for the advancement of current and future leaders in California agriculture. Sacramento, CA

National Committee Member – American Society of Agronomy Career Placement and Professional Development, Minneapolis, MN

Participant – California Water Education Foundation Tours – Sacramento Valley and Central Valley Tours.

Board Chair and Member – Advisory Board for California Polytechnic State University Earth and Soil Sciences Department, San Luis Obispo, CA

Board Member – Advisory Board for California State University Geosciences Department, Chico, CA

Board Member – Shasta Land Trust, Redding, CA

Select Publications

Kimmelshue, J., M. Heilmann, Z. Wang, S. Mulder, C. Stall, M. Twietmeyer, G. Ludwig, R. Klein, C. Eidsath, G. Obenauf. 2016. California Statewide Crop Mapping for Resource Management and Regulatory Compliance. Manuscript in Development. To be submitted to California Agriculture.

Ludwig, G., D. Hunter, J. Kimmelshue, M. Heilmann, Z. Wang, S. Mulder, C. Stall, M. Twietmeyer. 2016. Development of a Statewide Spatial/Mapping Database for Almonds, Walnuts, and Pistachios – Final Report. California Department of Food and Agriculture/United States Department of Agriculture – Specialty Crop Block Grant Program. USDA Project No. 26235.

Kimmelshue, J., M. Heilmann, Z. Wang, S. Mulder, M Twietmeyer, R. Spell, C. Stall. 2015. Statewide Tree Crop Mapping of Dried Plums. California Dried Plum Board – Research Reports 2015. http://ucanr.edu/repository/fileaccess.cfm?article=160095&p=BSKEQB&CFID=164917629&CFTOKEN=87232494 .

Kimmelshue, J., M. Heilmann, Z. Wang, S. Mulder, M Twietmeyer, R. Spell, C. Stall. 2015. Statewide Walnut Tree Crop Mapping and Age Determination. California Walnut Board Research Committee – Annual Research Report.

Kimmelshue, J., Z. Wang, M. Heilmann, S. Mulder, C. Stall, R. Spell, G. Ludwig, R. Klein, D. Balint. 2015. Development of a Statewide Spatial Database for Walnuts, Almonds, and Pistachios. Almond Board of California Final Research Report. 14-STEWCROP4-Kimmelshue. Almond Board of California 2014.2015 Annual Research Report. http://www.almonds.com/growers/resources/research-database .

Kimmelshue, J., M. Heilmann, Z. Wang, S. Mulder, M Twietmeyer, R. Spell, C. Stall. 2015. Statewide Pistachio Tree Crop Mapping and Age Determination. California Pistachio Research Board – Annual Research Report.

Kimmelshue, J., D. Smith, Z. Wang, S. Tillman. 2013. Mapping Spatial Distribution of Almonds Using Remote Sensing – Enhancements of Existing Methods and Product for Applications. 12-STEWCROP4-Kimmelshue. Almond Board of California 2012.2013 Annual Research Reports. http://www.almonds.com/growers/resources/research-database .

Kimmelshue, J., D. Williams, S. Tillman, T. DeJong, W. Salas. D. Smart. 2012. Remotely Sensed Determination of Orchard Removal Biomass – Assess Carbon Sequestration Potential of Applying Chipped Almond Prunings to the Orchard Floor. 11-STEWCROP4-Kimmelshue. Almond Board of California 2011.2012 Annual Research Reports. http://www.almonds.com/growers/resources/research-database.

Select Presentations

Kimmelshue, J., M. Heilmann, Z. Wang, S. Mulder, M. Twietmeyer, C. Stall. 2016. Statewide spatial mapping of almonds, walnuts, pistachios, and dried plums in California – results, interpretations, and applications. Featured Scientific Seminar. Invited for Presentation to the International Nut and Dried Fruit Council (INC) XXXV World Nut and Dried Fruit Congress. May 31, 2016. San Diego, CA.

Kimmelshue, J., M. Heilmann, Z. Wang. 2016. Results of Statewide Spatial Almond Mapping and Applications: Acreage, Age Determination, Recharge Suitability, Crop Change. Board of Directors for the Almond Board of California. April 12, 2016. Modesto, CA.

Stall, C., Z. Wang, S. Tillman, J. Kimmelshue. 2016. DWR Cold Water Rice Project Update and Introduction to a Web-Based Information System. Western Canal Water District and Richvale Irrigation District Grower Meeting. March 24, 2016. Richvale, CA.

Heilmann, M., J. Kimmelshue. 2016. 2015 Delta Land Use Mapping. In conjunction with Comparative Study of Methods for Measuring Consumptive Use of Water in the Delta. Office of the Delta Watermaster, State Water Resources Control Board. March 17, 2016. Sacramento, CA.

Kimmelshue, J., M. Heilmann, Z. Wang, S. Mulder, M. Twietmeyer, C Stall. 2016. Remote Sensed Evapotranspiration Estimates and Crop Mapping within the Sacramento/San Joaquin Delta and Beyond. University of California, Division of Agriculture and Natural Resources – UC Davis Evapotranspiration Remote Sensing Workshop. February 10, 2016. Davis, CA.

Kimmelshue, J., M. Heilmann, Z. Wang, S. Mulder, M. Twietmeyer, C. Stall. 2016. Results of Statewide Spatial Tree Crop Mapping and Applications: Acreage, Age Determination, Recharge Suitability, and Crop Change. American Society of Agronomy – California Chapter Annual Meetings. February 2, 2016. Visalia, CA.

Heilmann, M., J. Kimmelshue, M. Twietmeyer. 2015. Groundwater Recharge Suitability – Statewide Almond Production. The Almond Conference. December 5, 2015. Sacramento, CA.

Kimmelshue, J., M. Heilmann, Z. Wang, S. Mulder. 2015. Statewide Dried Plum Mapping – Final Results. California Dried Plum Research Committee. December 16, 2015. Sacramento, CA.

Kimmelshue, J., M. Heilmann, M. Twietmeyer. 2015. Almond Groundwater Recharge Suitability. BOD Reputation Management & Agriculture Issues Management (AIM) Taskforce. November 2, 2015. Modesto, CA

Heilmann, M., J. Kimmelshue, Z. Wang, S. Mulder, C. Stall, M. Twietmeyer. 2015. Walnut Mapping and Groundwater Recharge Suitability. Walnut Board of California. December 1, 2015. Folsom, CA.

Kimmelshue, J., M. Heilmann. 2015. Crop Mapping Progress Overview and Update. California Department of Water Resources. October 30, 2015. Sacramento, CA.

Stall, C., Z. Wang, J. Kimmelshue. 2015. Conventional and Wild Rice Mapping Statewide. California Wild Rice Advisory Board and Researchers. July 13, 2015. Yuba City, CA.

Heilmann, M., J. Kimmelshue, Z, Wang. 2015. Remotely Sensed Land Use Applications in Agricultural Systems. United States Congress on Irrigation and Drainage Technical Meetings. June 4, 2015. Reno, NV.

Kimmelshue, J., M. Heilmann, S. Mulder, C. Stall, Z. Wang. 2014. Preliminary Conclusions of Statewide Crop Mapping of Almonds. The Almond Conference. December 10, 2014. Sacramento, CA.

Kimmelshue, J., M. Heilmann. 2014. Results of Remote Sensing for Crop Identification – Citrus. Citrus Research Board and California Citrus Mutual. November 17, 2014. Visalia, CA

Kimmelshue, J., S. Mulder, M. Heilmann, S. Tillman. 2014. An Introduction to Scientific Approaches for Implementation of Future Regulations – A Spatial Approach. California Citrus Showcase. March 6, 2014. Visalia, CA.

Kimmelshue, J., M. Heilmann, Z. Wang. 2014. Results of Remote Sensing of Tree Crops. California Pistachio Research Board. January 30, 2014. Fresno, CA.

Appendix 7

Joel Kimmelshue, PhD.

Legal/Expert Witness Experience

Client	Dates of Work	State	Specific Location	Study Analysis Duration	Size of Area (approximate acres)	Crop Consumptive Use	Irrigability Land Classification	Ag Management Aspects Considered	PET/ET	Crop Coefficients	Estimation of Return Flow to Groundwater	Nutrient and/or Salinity Component	Image Analysis	Image Analysis Summary	Crops Analyzed	Degree of Legal Support	Judge	Law Firm/Entity	Project Description
Southern California Water Company	2004-2005	CA	Santa Maria Valley	1946-2004	165,000	Y	N	Y	Y	Y	Y	Y	Y	Photo interpretation as additional verification of CA DWR irrigated area crop mappings for cropped versus idle lands. Determination of boundaries of developed versus native areas.	Leafy Greens, Cole Crops, Strawberries, Berries, Grains, Fruit Trees, Grapes	Legal Preparation, Deposition, Court Testimony	Jack Komar	(Then) Hatch and Parent	This project involved expert witness testimony, both in deposition and trial settings, based on an 8-month effort to assess crop water use for an historical 58-year period over a 164,000-acre basin. The work focused on pumped water and return flows to groundwater under irrigated and nonirrigated areas. Crop and native vegetation evapotranspiration and soil storage modeling was conducted. Water was assessed to ensure adequate quality for sensitive crop production. The expert witness testimony included 2 days of deposition and 2 additional days of trial testimony, including cross-examination. The work was conducted as a component of a groundwater basin assessment focusing on the potential for overdraft. This was a multi-stakeholder case, which included agricultural, urban and local, state, and federal agencies.
Tehama Colusa Canal Authority	2010	CA	Sacramento Valley - West Side	1955-2010	155,000	Y	N	Y	Y	Y	N	Y	N	N/A	Almonds, Walnuts, Pistachios, Olives, Grapes, Alfalfa, Pasture, Tomatoes, Safflower, Beans, and various other crops	Legal Preparation, Attended Court, however Testimony Unnecessary	Oliver Wanger	Downey Brand	Dr. Kimmelshue was retained to prepare a detailed evaluation of the influence of regulated deficit irrigation on a variety of crops including almonds, grapes, walnuts, rice, olives, alfalfa, tomatoes and a variety of other permanent and annual field and row crops. The preparation of this testimony was conducted to determine the influence of a deficit of irrigation water at predetermined periods of the growth cycles of the crops mentioned above – predominantly focusing on perennial crops such as almonds. The results of this work indicated the extreme detrimental influence of insufficient irrigation during key growth stages of the crop.
Antelope Valley Growers	2011-2012	CA	Antelope Valley	1940-2011	1,600,000	Y	N	Y	Y	Y	Y	Y	Y	Aerial photo and satellite interpretation of irrigated urban areas (e.g. parks, playgrounds) and ag reuse sites.	Cherries, Peaches, Apricots, Alfalfa, Cotton, Pasture, Carrots, Potatoes, Tomatoes, and a variety of other annual row and field crops	Legal Preparation, Deposition, Court Testimony	Jack Komar	Brownstein Hyatt Farber Schreck	This work centered around the quantification of a water right adjudication of the Antelope Valley. Dr. Kimmelshue represented the agricultural interests in the Valley and conducted a detailed and comprehensive assessment of crop water use, irrigation methods and efficiencies, return flows, and other parameters to ultimately assess a component of the safe yield of the groundwater basin based on agricultural pumping. This work was prepared for expert witness testimony in early 2011. Modeling was conducted to assess not only a variety of crop types in irrigated agricultural, but also irrigated urban areas.
Los Angeles Department of Water and Power	2012-present	CA	Owens Valley	1913-2010	300,000	Y	Y	Y	Y	Y	N	Y	Y	Photo Interpretation for the assessment of supply infrastructure, irrigated area, and native vegetation extent.	Pasture, Alfalfa, Grains, Cherries, Peaches, Apricots, Potatoes and other historic fruit and row crops	Legal Preparation Only To Date	TBD	Internal LADWP Counsel, Various External	Dr. Kimmelshue was retained as the lead technical expert on estimating monthly and annual potential historic consumptive use as far back as the early 1900's for the Owens Valley if the aquaduct had not but constructed. This work involved the acquisition, review and interpretation of historic documentation as far back as 1904. The work resulted in a reasonable estimate of irrigable land based on USBR and USDA reports, local knowledge of the area and soils and past experience. The work then focused on estimation of consumptive use of likely crops to be grown as compared to other high desert valleys in California and Nevada that actually were developed. Crop evapotranspiration and crop coefficients were calculated where necessary based on historic climatic conditions and some CIMIS and LADWP information.
United States Department of Justice - Bureau of Indian Affairs	1998-2008	MT	Blackfeet Indian Reservation	1950-2006	1,500,000	Y	Y	Y	Y	Y	N	Y	Y	Detailed photo interpretation for current and historic irrigation, crop type, native vegetation, water supply infrastructure, and soil and irrigation suitability classification on over 1.5M acres.	Pasture, Alfalfa, Rangeland, Grain	Legal Preparation, Settled	N/A	USDOJ Legal	Technical expert from 1998 to 2008 leading efforts related to the establishment of a water rights claim for the Blackfeet Indian Tribe. These efforts determined practicably irrigable acres, detailed land classification for the determination of arable and irrigable lands, present and historic irrigation delineations, water demand estimates of both agricultural and urban uses, drainage evaluations for the purpose of avoiding salinization of lands, and overall task management for nearly $1.7M of labor, subconsultants, and expenses.
Kern River Watershed Coalition Authority	2012-present	CA	Kern Sub-Basin	1930-2012	900,000	Y	N	Y	Y	Y	Y	Y	Y	Evaluated satellite image resources to assess crop type and overall irrigated land extent. Detailed field delineations and crop identification	Cotton, Almonds, Pistachios, Citrus, Walnuts, Pomegranates, Persimmons, Cherries, Carrots, Potatoes, Corn, Sorghum, Sudan Grass, Grains, and other fruit, nut, row and field crops	Legal Preparation Only To Date	TBD	Young Wooldridge	Dr. Kimmelshue was retained by the KRWCA as an expert in providing sound technical agronomic information related to the unique irrigation and crop production practices of the Kern Sub Basin area within the Southern San Joaquin Valley Water Quality Coalition. This work involved understanding and interpreting changes in cropping patterns, consumptive use, irrigation methods, salinity management, fertilization practices and overall water and nitrogen use efficiency. A portion of this work included intensive ground truthing for development of remotely sensed crop mapping products. Those ground truthing data included permanent crop irrigation method documentation for use in irrigation method change over time.
United States Bureau of Reclamation	1996-1997	UT	Uintah Basin	1960-1995	10,000 (select areas of much larger basin)	Y	Y	Y	Y	Y	N	Y	Y	Detailed aerial photo interpretation for historic irrigated lands, supply infrastructure and irrigation suitability classification. Photo interpretive differentiation of crop type.	Pasture, Alfalfa, Rangeland, Grain	Legal Preparation, Certified	Certified by United States Congress	USBR Legal	Dr. Kimmelshue successfully mapped nearly 10,000 acres of lands slated for supplemental irrigation, drainage improvements, consumptive use estimates, etc. Responsibilities included quality control for soil sampling and data interpretation. Co-authored a report to the USBR for final project approval and certification by the United States Congress.
Confidential Client	2008	CA	Kern County, CA Area	1950-2008	15,000	Y	N	Y	Y	Y	Y	N	Y	Interpreted both aerial photo and satellite resources from 1950's to present day for the purposes of irrigated area delineation and crop type differentiation.	Pasture, Alfalfa, Rangeland, Grain	Legal Preparation, Settled	N/A	(Then) Hatch and Parent	This project involved the historic and present quantification of water use at a confidential site near Bakersfield. Historic remote sensing imagery was acquired to determine the irrigated area changes over time as well as the cropping pattern shifts from the early 1950s to present day. Water use estimates were determined for the current cropping patterns as well as diverted water quantities. A comprehensive site evaluation was performed with the client and area grower/owner to determine soil type, water conveyance, irrigation methods and management, consumptive use, storage, crop types, etc. This work was used to facilitate a potential substantial land purchase and water rights quantification.
Los Angeles Department of Water and Power	2000-present	CA	Owens Valley	1947-present	110,000	Y	N	Y	Y	Y	N	Y	Y	Interpreted both aerial photo and satellite resources from 1947 to present for evaluation of land cover including vegetation characterization, soil assessment and historic infrastructure	Native Saltgrass and other salt-tolerant vegetative communities	Technical Support of Multiple Legal Settlements and Regulatory Negotiations	N/A	City of Los Angeles	Efforts have included playa-wide soil and vegetation classification, monitoring of vegetation and wetness cover, and historic evaluation of anthropogenic activities and natural processes affecting the Owens Lake Playa and Keeler Sand Dunes. This project has involved several photo and satellite image analysis efforts for characterization and evaluation of playa surfaces for management, modelling and design purposes. Performed detailed photo interpretive evaluation of all infrastructure and activities on the playa from 1947 to present (e.g., water conveyance, mining, transportation, stormwater management, evaporation basins, structures).

Appendix 8

Statement of Compensation

Dr. Kimmelshue's compensation rate for deposition, trial preparation, and testimony is $500/hour.

Appendix A

Table A-1: Sources of Crop Acreage Data

<table>
<tr><th>Year</th><th colspan="2">Rincon</th><th>Mesilla-TX</th><th colspan="2">Mesilla-NM</th><th>EPCWID1</th><th>Hudspeth</th></tr>
<tr><td>1936</td><td colspan="2">JIR</td><td>JIR</td><td colspan="2">JIR</td><td rowspan="30">EPCWID No 1 Crop Report</td><td>JIR</td></tr>
<tr><td>1937</td><td colspan="2" rowspan="18">EBID-Rincon Crop report. Value adjusted by IOVD</td><td rowspan="18">EPCWID No. 1, Mesilla Valley, Texas Crop Report</td><td colspan="2" rowspan="18">EBID-Mesilla Crop report. Value adjusted by IOVD</td><td rowspan="4">Hudspeth Crop Report</td></tr>
<tr><td>1938</td></tr>
<tr><td>1939</td></tr>
<tr><td>1940</td></tr>
<tr><td>1941</td><td>Linear interpolation</td></tr>
<tr><td>1942</td><td rowspan="14">Hudspeth Crop Report</td></tr>
<tr><td>1943</td></tr>
<tr><td>1944</td></tr>
<tr><td>1945</td></tr>
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<tr><td>1953</td></tr>
<tr><td>1954</td></tr>
<tr><td>1955</td><td colspan="2">Land IQ Spatial year</td><td>Land IQ Spatial year</td><td colspan="2">Land IQ Spatial year</td></tr>
<tr><td>1956</td><td colspan="2" rowspan="2">Linear interpolation</td><td rowspan="2">Linear interpolation</td><td colspan="2" rowspan="2">Linear interpolation</td><td>Linear interpolation</td></tr>
<tr><td>1957</td><td rowspan="14">Hudspeth Crop Report</td></tr>
<tr><td>1958</td><td colspan="2" rowspan="7">EBID- Rincon Crop Report. Values adjusted by IOVD</td><td rowspan="7">EPCWID No. 1, Mesilla Valley, Texas Crop Report</td><td colspan="2" rowspan="7">EBID- Mesilla Crop Report. Values adjusted by IOVD</td></tr>
<tr><td>1959</td></tr>
<tr><td>1960</td></tr>
<tr><td>1961</td></tr>
<tr><td>1962</td></tr>
<tr><td>1963</td></tr>
<tr><td>1964</td></tr>
<tr><td>1965</td><td colspan="2">MEA numbers used and adjusted by IOVD</td><td>Linear interpolation</td><td>Pecans linearly interpolated between Land IQ spatial Years</td><td>MEA numbers used and adjusted by IOVD</td></tr>
<tr><td>1966</td><td colspan="2">Land IQ Spatial year</td><td>Land IQ Spatial year</td><td colspan="2">Land IQ Spatial year</td><td>Linear interpolation</td></tr>
<tr><td>1967</td><td rowspan="9">Pecans linearly interpolated between Land IQ spatial Years</td><td rowspan="4">MEA numbers used and adjusted by IOVD</td><td rowspan="12">Linear interpolation</td><td rowspan="8">Pecans linearly interpolated between Land IQ spatial Years</td><td rowspan="4">MEA numbers used and adjusted by IOVD</td><td rowspan="4">EPCWID No 1 Crop Report</td></tr>
<tr><td>1968</td></tr>
<tr><td>1969</td></tr>
<tr><td>1970</td></tr>
<tr><td>1971</td><td rowspan="5">Linear Interpolation</td><td rowspan="4">Linear Interpolation</td><td rowspan="5">Linear interpolation</td><td rowspan="5">Linear interpolation</td></tr>
<tr><td>1972</td></tr>
<tr><td>1973</td></tr>
<tr><td>1974</td></tr>
<tr><td>1975</td><td colspan="2">Land IQ Spatial year**</td></tr>
<tr><td>1976</td><td colspan="2">Land IQ Spatial year</td><td rowspan="3">Pecans linearly interpolated between Land IQ spatial Years</td><td>MEA numbers used and adjusted by IOVD</td><td>EPCWID No 1 Crop Report</td><td>Hudspeth Crop Report</td></tr>
<tr><td>1977</td><td rowspan="2">Pecans linearly interpolated between</td><td rowspan="2">Linear Interpolation</td><td rowspan="2">Linear interpolation</td><td rowspan="2">Linear interpolation</td><td rowspan="2">Linear interpolation</td></tr>
<tr><td>1978</td></tr>
</table>

Color Code

<table>
<tr><td>Valley specific crop report</td><td rowspan="5">Modified EBID Acreage (MEA) – In order to determine the distribution of crop acreages by valley, in the years where valley specific crop acreages were not provided in the crop reports, the following approaches were used: (1) the percentage of irrigated crop land present in each valley in spatially mapped years was used and linear interpolations of the ratios between valleys were applied in the intermediate years. (2) total acreage by valley was distributed into crop categories by linear interpolation between spatially mapped years and reliable crop reports using the percentage distribution by crop in those spatial mapping years and crop reports.</td></tr>
<tr><td>Valley specific crop report- adjusted by Inside/Outside Valley Distribution (IOVD) - see note below</td></tr>
<tr><td>** Spatial year not fully complete. Image did not encompass the entire AOI. Approximately 13,775 acres could not be classified. The same distribution that had been in the classified acres was applied to the non-classified acres</td></tr>
<tr><td>Land IQ Spatial year</td></tr>
<tr><td>Linear interpolation</td></tr>
</table>

Note:

Valley specific crop report- adjusted by Inside/Outside Valley Distribution (IOVD). IOVD accounts for the irrigated acreage that is inside the valley boundary but outside the district boundary and is not accounted for in district crop reports. In spatial mapping years, the percentage of irrigated acreage located outside the district boundary however inside the valley boundary was calculated. A linear interpolation of these percentages was implemented in the intermediate years when necessary.

Appendix A

Table A-1: Sources of Crop Acreage Data

Year	Rincon		Mesilla-TX	Mesilla-NM		EPCWID1	Hudspeth
1979	Pecans linearly interpolated between Land IQ spatial Years	MEA numbers used and adjusted by IOVD	Linear interpolation	Pecans linearly interpolated between Land IQ spatial Years	MEA numbers used and adjusted by IOVD	EPCWID No 1 Crop Report	Hudspeth Crop Report
1980							
1981							
1982							
1983							
1984							
1985		Linear Interpolation			Linear interpolation		
1986	Land IQ Spatial year		Land IQ Spatial year	Land IQ Spatial year			
1987	Pecans linearly interpolated between	MEA numbers used and adjusted by IOVD	Linear interpolation	Pecans linearly interpolated between Land IQ spatial Years	MEA numbers used and adjusted by IOVD		
1988							
1989	EBID- Rincon Crop Report. Values adjusted by IOVD				EBID-Mesilla Crop report. Value adjusted by IVOD		
1990	Pecans linearly interpolated between Land IQ spatial Years	Linear interpolation			MEA numbers used and adjusted by IOVD		
1991							
1992							
1993					Linear interpolation		
1994					MEA numbers used and adjusted by IOVD		
1995							
1996	Land IQ Spatial year		Land IQ Spatial year	Land IQ Spatial year			Land IQ Spatial year
1997	Pecans linearly interpolated between Land IQ spatial Years	EBID-Rincon Crop report. Value adjusted by IVOD	EPCWID No. 1, Mesilla Valley, Texas Crop Report	Pecans linearly interpolated between Land IQ spatial Years	EBID-Mesilla Crop report. Value adjusted by IVOD		Hudspeth Crop Report
1998							
1999							
2000							
2001					MEA numbers used and adjusted by IOVD		
2002							
2003		Linear interpolation	Linear interpolation		Linear interpolation		
2004			EPCWID No. 1, Mesilla Valley, Texas Crop Report				
2005		EBID-Rincon Crop report. Value adjusted by IVOD	Linear interpolation		EBID-Mesilla Crop report. Value adjusted by IVOD		
2006	Land IQ Spatial year		Land IQ Spatial year	Land IQ Spatial year			Land IQ Spatial year
2007	Linear interpolation		Linear interpolation	Pecans linearly interpolated between Land IQ spatial Years	EBID-Mesilla Crop report. Value adjusted by IVOD	Linear interpolation	Hudspeth Crop Report
2008						EPCWID No 1 Crop Report	
2009						Linear interpolation	Linear interpolation
2010						EPCWID No 1 Crop Report	Hudspeth Crop Report
2011	Land IQ Spatial year		Land IQ Spatial year	Land IQ Spatial year			Linear interpolation
2012	Linear interpolation		Linear interpolation	Linear interpolation		Land IQ Spatial year	Land IQ Spatial year
2013						Linear interpolation	Linear interpolation
2014	Land IQ Spatial year		Land IQ Spatial year	Land IQ Spatial year		Land IQ Spatial year	Land IQ Spatial year
2015	Linear Interpolation		Linear Interpolation	Linear Interpolation		Linear Interpolation	Linear Interpolation
2016	Land IQ Spatial year		Land IQ Spatial year	Land IQ Spatial year		Land IQ Spatial year	Land IQ Spatial year
2017	Linear Interpolation		Linear Interpolation	Linear Interpolation		Linear Interpolation	Linear Interpolation
2018	Land IQ Spatial year		Land IQ Spatial year	Land IQ Spatial year		Land IQ Spatial year	Land IQ Spatial year

Color Code

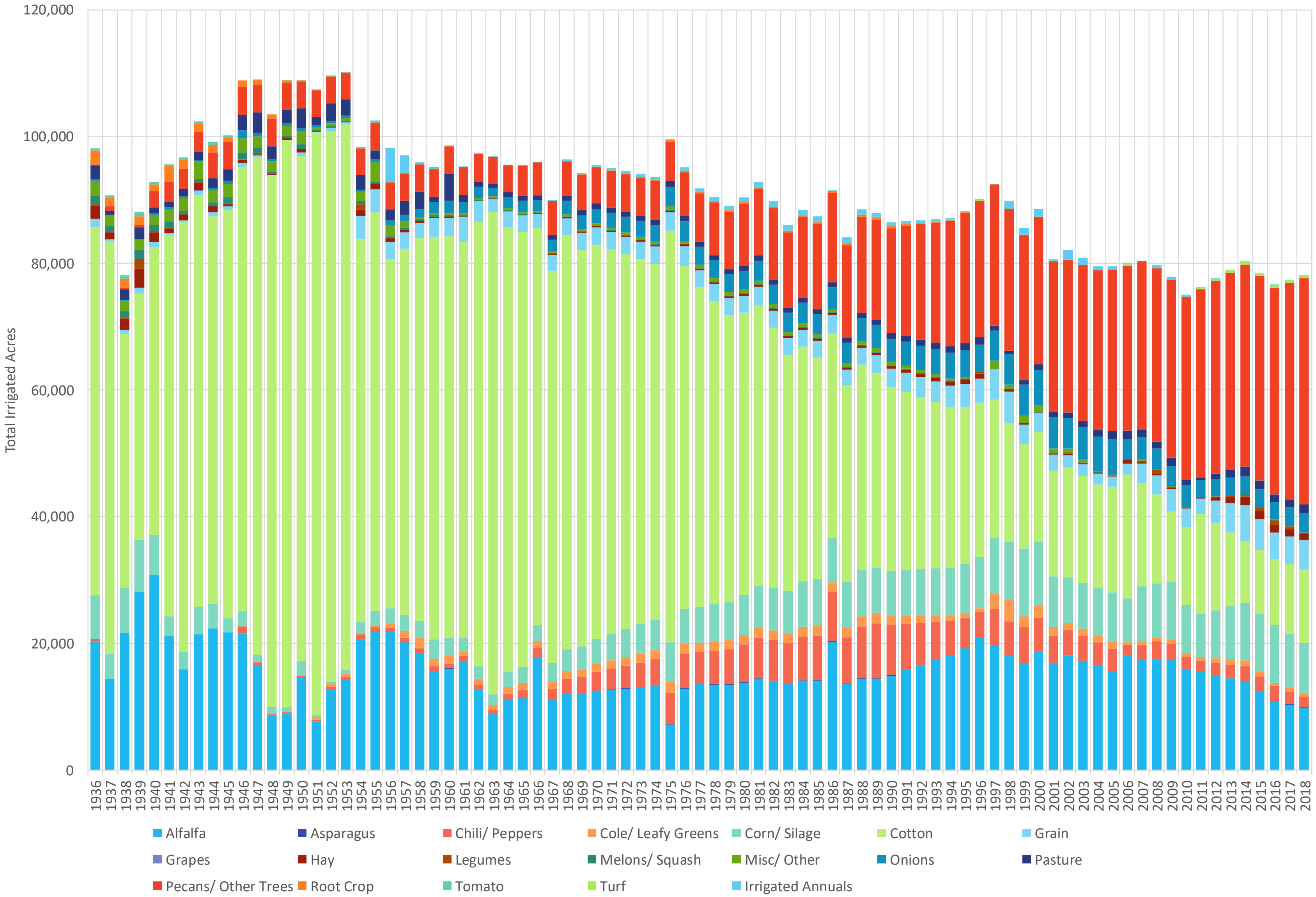
Valley specific crop report	Modified EBID Acreage (MEA) – In order to determine the distribution of crop acreages by valley, in the years where valley specific crop acreages were not provided in the crop reports, the following approaches were used: (1) the percentage of irrigated crop land present in each valley in spatially mapped years was used and linear interpolations of the ratios between valleys were applied in the intermediate years, (2) total acreage by valley was distributed into crop categories by linear interpolation between spatially mapped years and reliable crop reports using the percentage distribution by crop in those spatial mapping years and crop reports.
Valley specific crop report- adjusted by Inside/Outside Valley Distribution (IOVD) - see note below	
** Spatial year not fully complete. Image did not encompass the entire AOI. Approximately 13,775 acres could not be classified. The same distribution that had been in the classified acres was applied to the non-classified acres	
Land IQ Spatial year	
Linear interpolation	

Note:

Valley specific crop report- adjusted by Inside/Outside Valley Distribution (IOVD). IOVD accounts for the irrigated acreage that is inside the valley boundary but outside the district boundary and is not accounted for in district crop reports. In spatial mapping years, the percentage of irrigated acreage located outside the district boundary however inside the valley boundary was calculated. A linear interpolation of these percentages was implemented in the intermediate years when necessary.

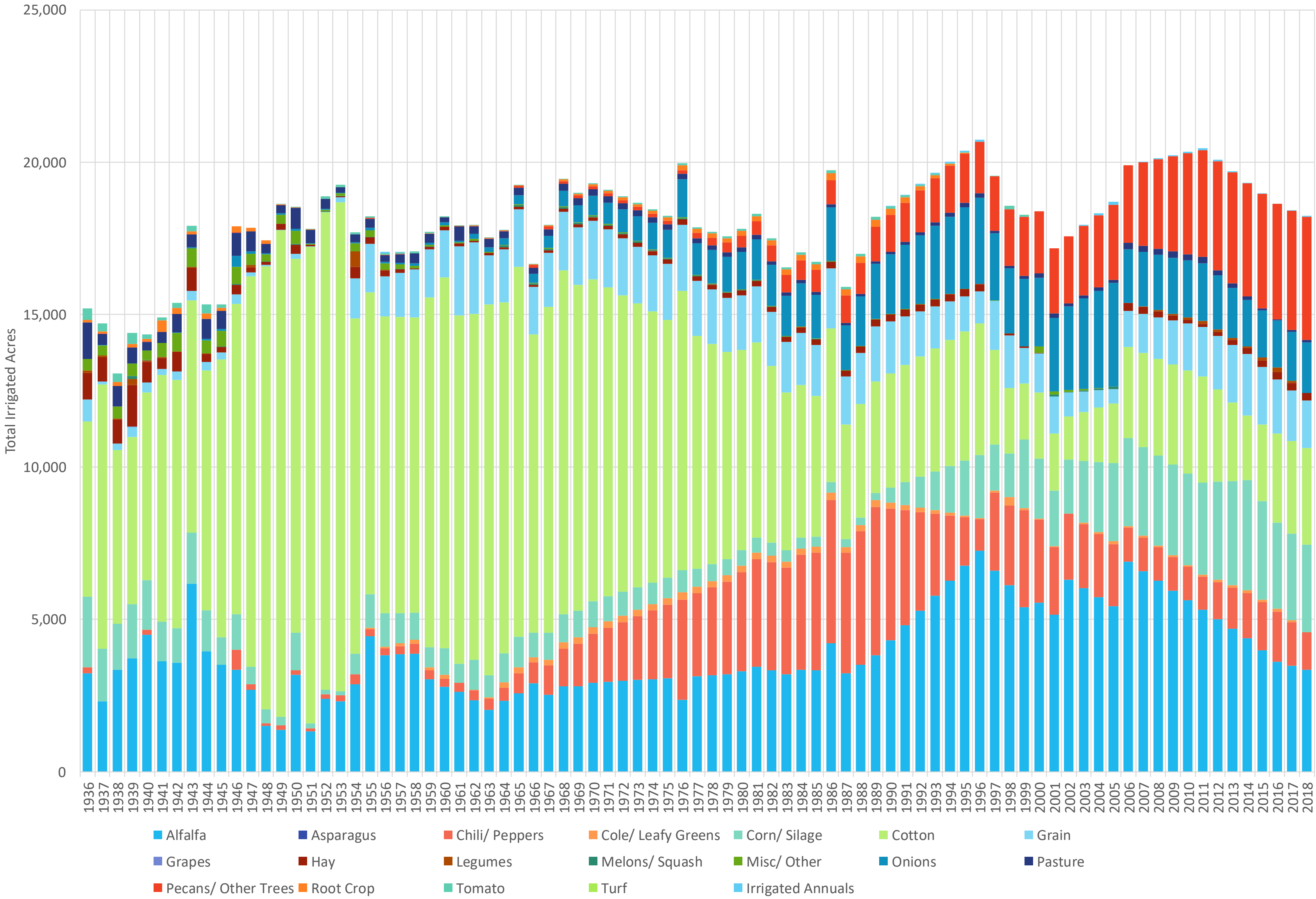
Appendix B

Figure B-1: Acres Irrigated Agricultural Land in Rincon and Mesilla Valleys, by Crop type



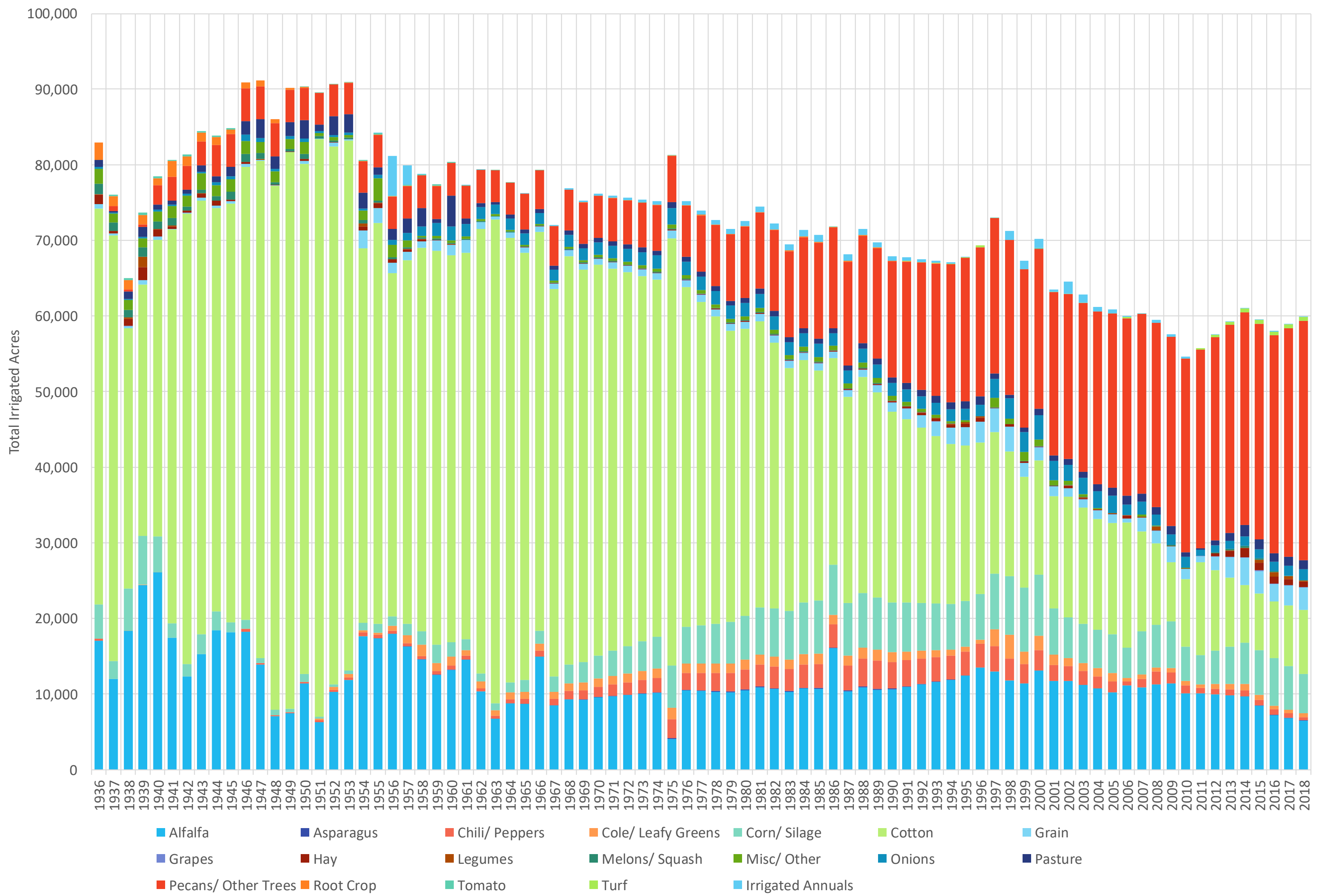
US_MSJ_00001862

Appendix B
Figure B-2: Acres Irrigated Agricultural Land in Rincon Valley, by Crop type



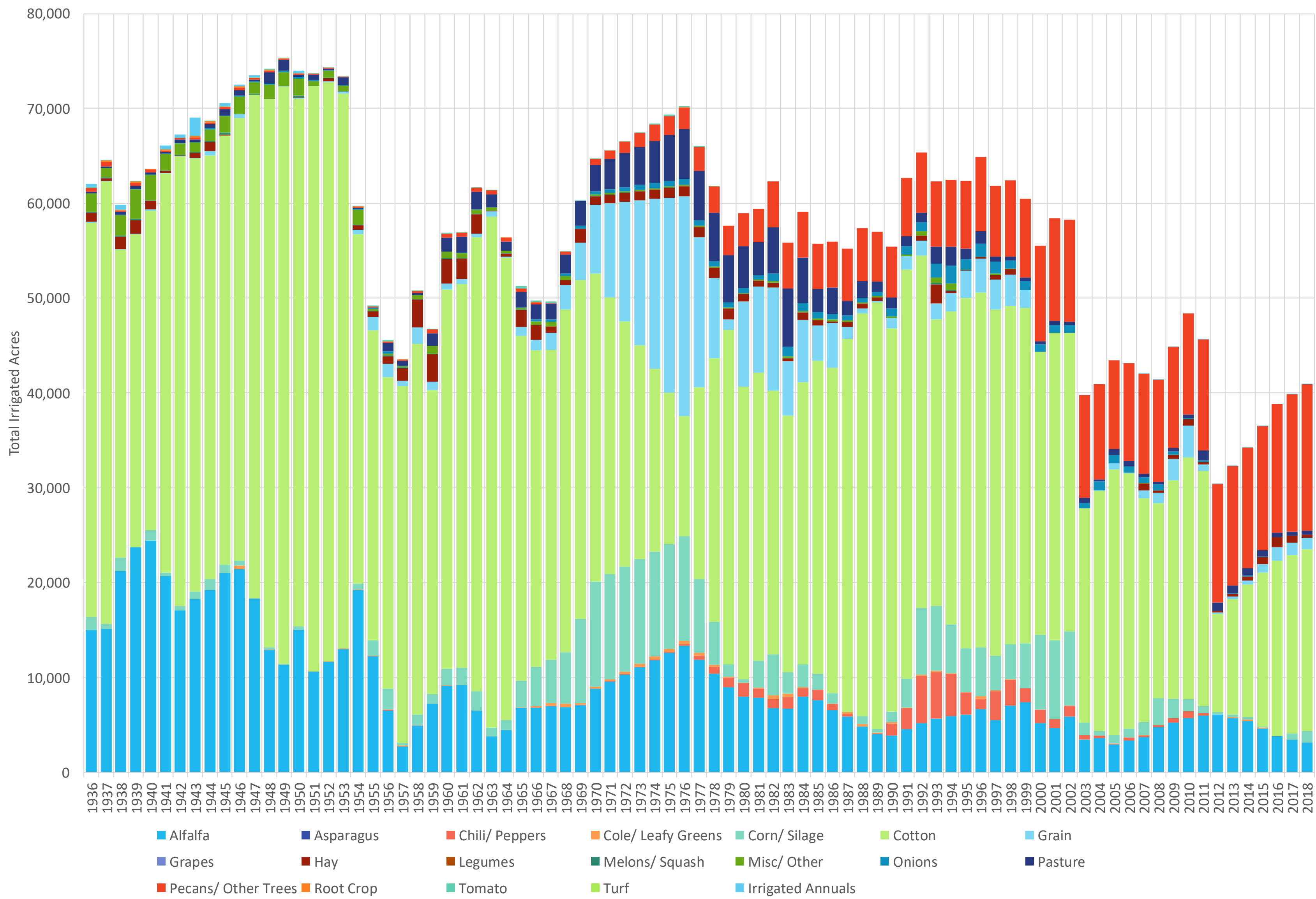
US_MSJ_00001863

Appendix B
Figure B-3: Acres Irrigated Agricultural Land in Mesilla Valley, by Crop type



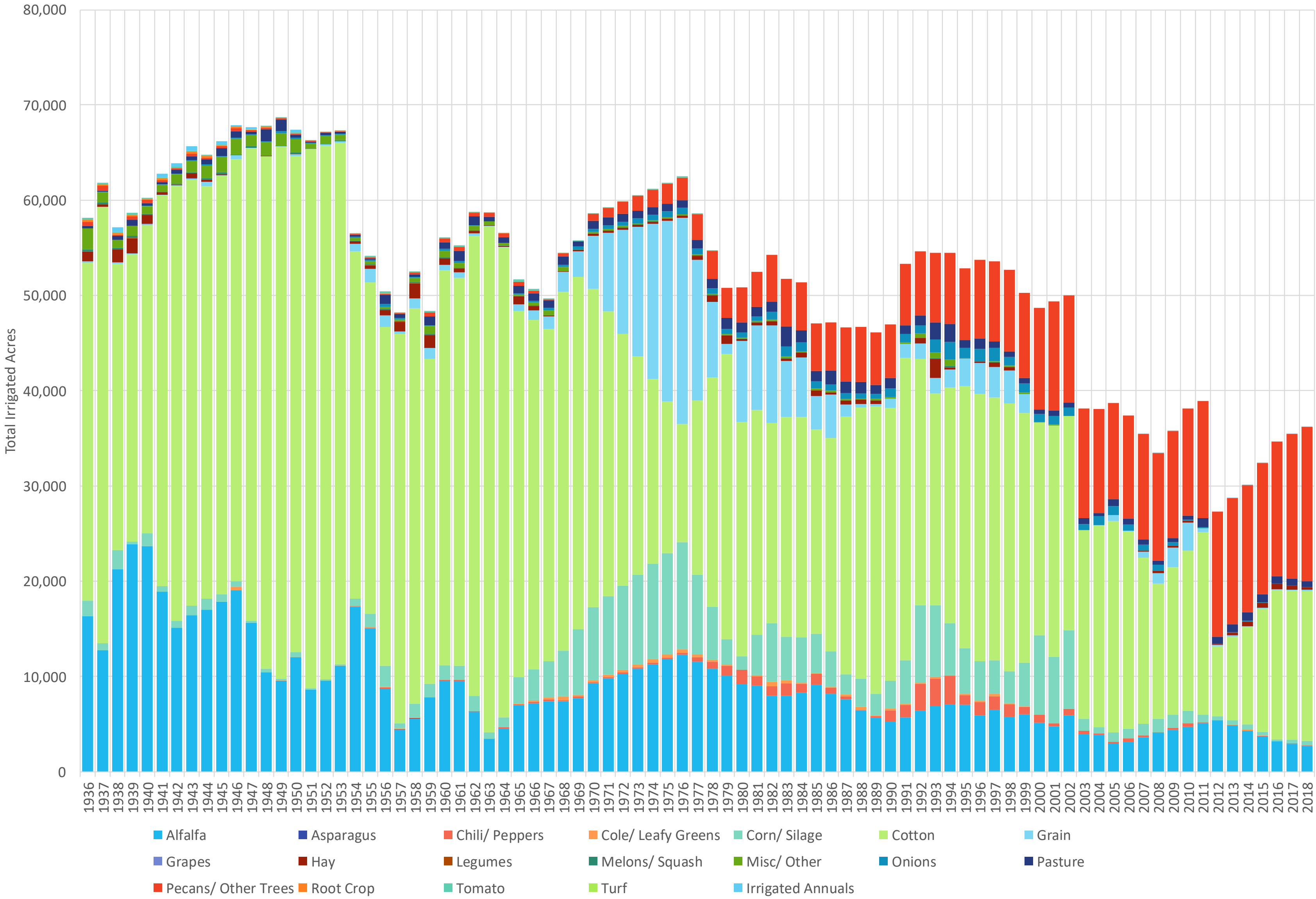
US_MSJ_00001864

Appendix B
Figure B-4: Acres Irrigated Agricultural Land in El Paso Valley, by Crop type

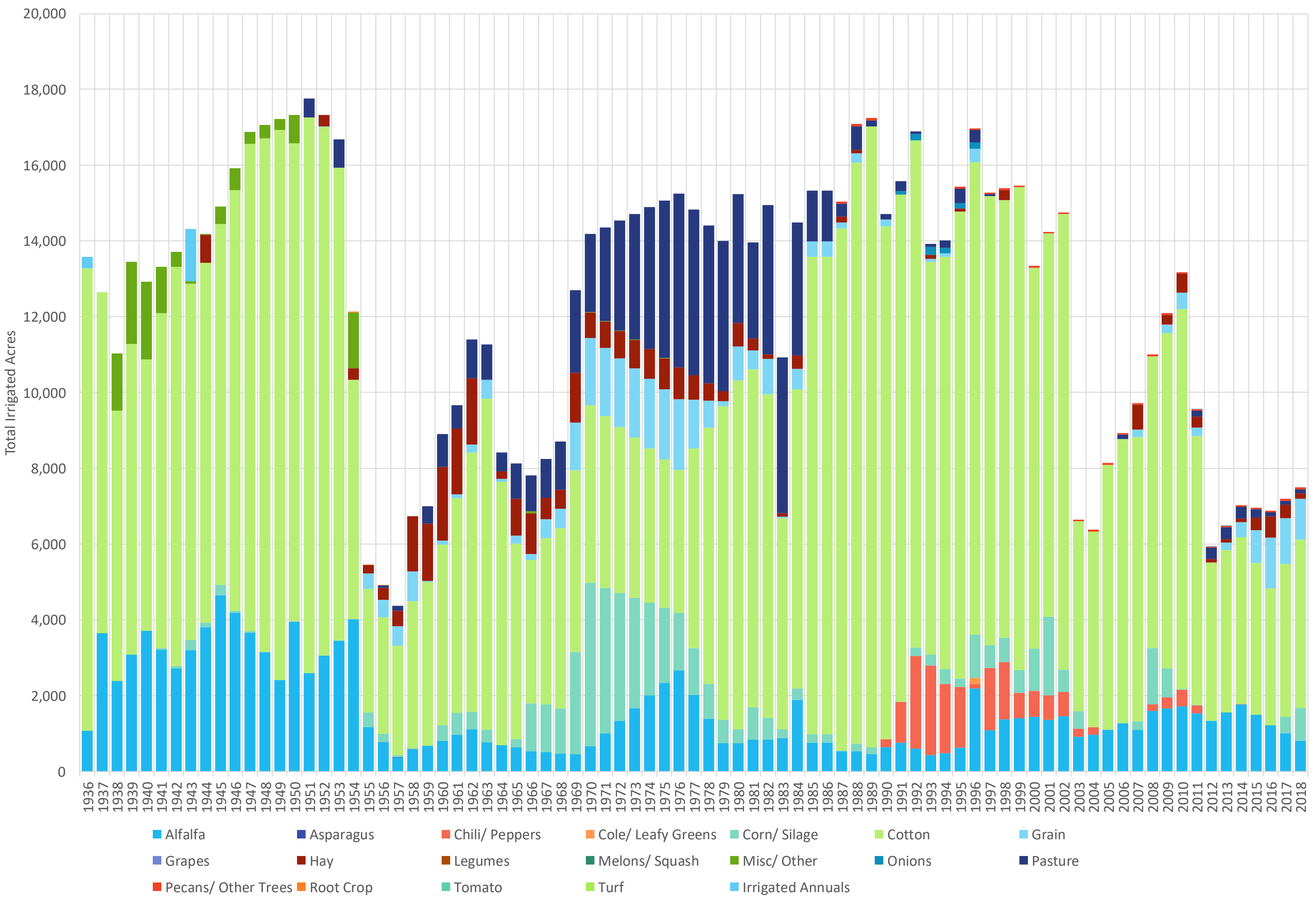


Appendix B

Figure B-5: Acres Irrigated Agricultural Land in EPCWID1, by Crop type



Appendix B
Figure B-6: Acres Irrigated Agricultural Land in Hudspeth, by Crop type



US_MSJ_00001867

Appendix B

Table B-1: Acres Irrigated Agricultural Land in Rincon and Mesilla Valleys, by Crop type

Year	Alfalfa	Asparagus	Chili/ Peppers	Cole/ Leafy Greens	Corn/ Silage	Cotton	Grain	Grapes	Hay	Legumes	Melons/ Squash	Misc/ Other	Onions	Pasture	Pecans/ Other Trees	Root Crop	Tomato	Turf	Irrigated Annuals	Total
1936	20,310	-	397	-	6,862	58,126	1,305	-	2,092	149	1,408	2,329	294	2,122	-	2,361	377	-	-	98,130
1937	14,275	-	-	-	4,085	65,012	347	1	1,129	77	1,058	1,548	108	613	668	1,340	461	-	-	90,723
1938	21,680	-	1	-	7,098	40,110	531	61	1,713	195	1,016	1,685	164	1,648	235	1,354	598	-	-	78,091
1939	28,123	-	-	67	8,193	38,746	925	21	3,046	1,558	1,403	1,560	205	1,800	384	1,350	659	-	-	88,040
1940	30,618	-	158	7	6,346	45,373	747	46	1,563	137	1,022	1,601	245	944	2,572	1,024	415	-	-	92,818
1941	21,074	-	-	-	3,204	60,152	289	-	726	139	971	2,008	216	905	3,144	2,485	240	-	-	95,555
1942	15,874	-	-	-	2,784	67,740	365	20	899	46	525	2,066	238	1,127	3,168	1,447	420	-	-	96,720
1943	21,442	-	-	-	4,329	64,915	752	10	1,269	66	483	2,766	216	1,296	3,174	1,251	366	-	-	102,337
1944	22,368	-	-	-	3,837	61,201	603	14	907	40	609	1,879	443	1,445	4,099	1,241	476	-	-	99,163
1945	21,692	-	-	-	2,210	64,446	602	7	346	12	1,068	2,116	485	1,843	4,317	730	256	-	-	100,131
1946	21,597	-	1,062	-	2,339	70,070	712	7	523	47	1,093	2,265	1,196	2,507	4,379	1,004	-	-	-	108,803
1947	16,587	-	390	-	1,231	78,529	263	10	180	228	748	1,799	613	3,189	4,337	866	-	-	-	108,972
1948	8,553	-	230	-	1,181	83,854	111	8	142	26	324	1,639	355	2,009	4,360	668	-	-	-	103,461
1949	8,803	-	322	-	736	89,585	26	5	250	8	302	1,636	421	2,117	4,253	335	6	-	-	108,806
1950	14,565	-	330	-	2,322	79,733	516	6	575	15	696	2,021	466	3,137	4,292	137	59	-	-	108,871
1951	7,602	-	365	205	432	92,040	70	3	48	3	268	453	301	1,274	4,196	56	54	-	-	107,371
1952	12,690	-	426	386	440	86,844	538	3	67	-	203	463	357	2,771	4,197	44	157	-	-	109,586
1953	14,197	-	518	451	575	86,108	392	2	55	8	166	427	376	2,549	4,183	40	118	-	-	110,165
1954	20,519	-	846	241	1,669	60,571	3,645	2	901	914	448	1,487	343	2,331	4,161	47	209	-	-	98,334
1955	21,823	1	658	326	2,294	62,919	3,589	-	862	82	254	3,194	478	1,318	4,313	51	249	-	2	102,413
1956	21,791	17	597	718	2,361	55,090	2,708	2	655	44	213	1,876	704	1,670	4,287	34	164	-	5,269	98,201
1957	20,112	34	671	1,178	2,520	57,748	2,566	2	462	47	204	1,093	1,015	2,206	4,306	20	176	-	2,636	96,995
1958	18,434	50	744	1,638	2,678	60,405	2,425	3	268	48	195	308	1,325	2,743	4,324	7	187	-	5	95,788
1959	15,559	30	777	1,177	3,073	63,544	2,988	2	109	9	248	350	1,792	809	4,362	20	306	-	-	95,157
1960	15,987	26	775	1,335	2,761	63,345	2,918	2	220	14	179	331	1,968	4,196	4,381	23	138	-	-	98,598
1961	17,140	14	830	721	2,083	62,526	3,973	1	95	2	172	321	1,681	1,207	4,346	27	62	-	21	95,224
1962	12,710	-	740	917	2,000	70,151	3,293	1	50	2	94	353	1,694	804	4,419	24	19	-	20	97,291
1963	8,759	1	742	761	1,657	76,185	2,011	1	81	-	61	295	1,360	596	4,248	20	13	-	-	96,792
1964	11,099	1	932	1,123	2,236	70,317	2,481	1	84	4	139	218	1,742	753	4,254	14	32	-	-	95,430
1965	11,307	7	1,282	1,144	2,546	68,640	2,624	3	101	4	142	236	1,812	768	4,754	29	35	-	43	95,478
1966	17,865	12	1,417	1,086	2,549	62,534	2,277	-	97	4	127	240	1,756	707	5,206	38	34	-	-	95,947
1967	11,021	18	1,814	1,123	2,897	61,956	2,485	6	117	4	131	260	1,861	735	5,346	55	38	-	128	89,994
1968	12,104	26	2,292	1,250	3,372	65,327	2,714	9	139	4	141	302	2,113	793	5,458	75	45	-	170	96,335
1969	12,070	32	2,569	1,251	3,574	62,612	2,672	11	148	4	137	317	2,157	782	5,569	88	47	-	213	94,253
1970	12,488	39	2,949	1,304	3,893	62,238	2,739	13	163	4	139	344	2,288	800	5,682	105	51	-	256	95,495
1971	12,667	45	3,254	1,332	4,158	60,695	2,738	15	174	3	138	366	2,367	804	5,794	119	53	-	298	95,022
1972	12,846	52	3,559	1,360	4,422	59,152	2,736	17	185	3	136	387	2,448	808	5,906	133	56	-	341	94,547
1973	13,025	59	3,864	1,388	4,687	57,609	2,735	19	196	3	136	410	2,527	812	6,018	147	58	-	383	94,075
1974	13,204	65	4,169	1,415	4,951	56,066	2,734	21	207	3	134	431	2,607	816	6,130	161	60	-	426	93,599
1975	7,141	88	4,941	1,723	6,243	64,931	2,935	-	236	3	156	550	3,085	965	6,242	189	65	-	-	99,493
1976	12,821	78	5,490	1,513	5,564	54,102	3,078	26	264	3	135	478	3,033	846	6,900	222	80	-	511	95,142
1977	13,515	83	5,024	1,466	5,655	50,430	2,708	27	237	2	129	484	2,801	812	7,622	200	67	-	554	91,815
1978	13,468	87	5,268	1,462	5,830	47,880	2,685	28	245	2	125	493	2,835	800	8,345	212	69	-	596	90,430

Appendix B

Table B-1: Acres Irrigated Agricultural Land in Rincon and Mesilla Valleys, by Crop type

Year	Alfalfa	Asparagus	Chili/ Peppers	Cole/ Leafy Greens	Corn/ Silage	Cotton	Grain	Grapes	Hay	Legumes	Melons/ Squash	Misc/ Other	Onions	Pasture	Pecans/ Other Trees	Root Crop	Tomato	Turf	Irrigated Annuals	Total
1979	13,421	91	5,512	1,456	6,003	45,331	2,662	30	255	2	122	503	2,869	789	9,067	224	71	-	639	89,047
1980	13,787	99	5,905	1,506	6,329	44,506	2,711	32	269	2	123	532	2,994	805	9,790	242	75	-	682	90,388
1981	14,333	108	6,398	1,579	6,724	44,251	2,801	35	288	1	125	569	3,166	832	10,512	263	80	-	724	92,792
1982	13,984	110	6,424	1,538	6,793	40,929	2,694	36	288	1	119	565	3,109	803	11,234	265	79	-	767	89,739
1983	13,505	110	6,356	1,479	6,805	37,323	2,559	36	283	1	112	554	3,013	766	11,957	264	76	-	809	86,007
1984	14,055	120	6,857	1,553	7,206	37,047	2,649	39	303	1	114	592	3,187	794	12,679	286	82	-	852	88,415
1985	14,024	124	7,018	1,551	7,382	34,981	2,613	40	308	1	112	602	3,204	785	13,402	294	82	-	895	87,417
1986	20,248	120	7,758	1,507	6,999	32,311	2,835	-	341	1	104	577	3,399	758	14,124	330	98	-	-	91,509
1987	13,573	129	7,239	1,522	7,238	30,972	2,486	41	310	0	105	608	3,180	767	14,653	303	82	-	844	84,052
1988	14,373	144	8,081	1,659	7,423	32,288	2,653	46	338	0	111	672	3,478	838	15,182	338	90	-	750	88,465
1989	14,350	145	8,627	1,655	7,130	30,800	2,748	47	357	-	106	672	3,618	838	15,710	363	99	-	656	87,921
1990	14,901	119	7,864	1,457	7,092	28,985	2,865	40	405	31	90	578	3,665	864	16,521	306	85	11	571	86,452
1991	15,738	99	7,228	1,309	7,219	28,080	3,009	34	456	64	77	508	3,772	914	17,334	255	71	22	488	86,675
1992	16,545	79	6,583	1,158	7,332	27,124	3,148	29	506	94	64	437	3,876	961	18,146	204	57	33	403	86,779
1993	17,354	59	5,944	1,012	7,447	26,216	3,283	23	556	125	52	368	3,982	1,009	18,958	152	43	43	319	86,943
1994	18,164	39	5,305	865	7,562	25,308	3,418	18	605	155	39	299	4,086	1,056	19,769	102	28	54	234	87,108
1995	19,203	20	4,729	734	7,798	24,808	3,602	13	664	190	27	236	4,225	1,122	20,581	51	14	66	151	88,232
1996	20,783	-	4,143	601	8,094	24,334	3,840	8	724	225	15	-	4,346	1,233	21,393	-	-	252	66	90,057
1997	19,591	-	5,866	2,324	8,855	21,830	4,786	14	53	-	49	1,259	4,704	811	22,310	-	66	-	-	92,517
1998	17,935	-	5,508	3,396	9,186	18,648	4,978	26	409	-	-	734	4,782	575	22,364	-	109	-	1,142	89,791
1999	16,779	-	5,760	1,679	10,746	16,496	2,985	37	255	-	28	1,185	4,849	723	22,858	-	66	-	1,142	85,587
2000	18,673	-	5,371	1,983	10,055	17,269	3,002	45	44	-	61	1,100	5,467	968	23,249	-	123	-	1,142	88,552
2001	16,906	-	4,257	1,448	7,950	16,699	2,519	37	15	55	113	724	4,983	858	23,753	-	83	-	231	80,632
2002	18,058	-	4,097	1,090	7,152	17,371	1,872	35	287	113	49	578	4,864	870	24,012	-	57	-	1,612	82,118
2003	17,250	-	3,893	1,115	7,254	16,919	1,787	34	149	127	63	368	5,136	939	24,624	-	40	-	1,106	80,802
2004	16,441	-	3,688	1,139	7,354	16,465	1,701	33	10	140	79	158	5,409	1,007	25,235	-	24	-	600	79,484
2005	15,659	-	3,494	1,163	7,674	16,689	1,616	33	16	154	94	2	5,672	1,184	25,482	-	7	2	598	79,539
2006	18,031	-	1,646	502	6,886	19,536	1,715	37	655	17	19	-	3,174	1,371	25,969	-	-	245	132	79,935
2007	17,448	-	2,202	672	8,636	16,317	3,051	31	258	113	18	275	3,493	1,227	26,529	-	-	3	15	80,289
2008	17,551	-	2,761	603	8,571	13,964	3,053	25	217	565	51	58	3,304	1,147	27,327	-	-	2	435	79,633
2009	17,370	-	2,504	686	9,121	11,115	3,529	1	175	143	95	41	3,213	1,289	28,126	-	-	2	400	77,810
2010	15,741	-	2,123	659	7,523	12,315	2,912	25	134	106	32	20	3,357	781	28,925	-	-	1	316	74,971
2011	15,396	-	1,835	535	6,885	15,718	2,444	53	93	95	43	-	2,677	398	29,724	-	-	241	71	76,208
2012	14,952	-	1,976	690	7,612	13,708	3,507	60	519	109	116	-	2,699	806	30,431	-	-	333	59	77,578
2013	14,508	-	2,117	843	8,341	11,698	4,569	67	945	122	190	-	2,722	1,214	31,139	-	-	425	48	78,948
2014	14,064	38	2,221	997	9,068	9,689	5,633	74	1,372	135	263	-	2,744	1,622	31,847	-	-	517	37	80,320
2015	12,417	54	2,320	749	9,105	10,045	4,857	76	1,261	450	189	-	2,753	1,394	32,226	-	-	517	78	78,489
2016	10,769	69	2,419	501	9,143	10,402	4,105	78	1,149	764	114	-	2,762	1,166	32,604	-	-	517	119	76,681
2017	10,288	62	2,030	504	8,612	11,041	4,287	69	1,059	454	83	-	2,929	1,228	34,151	-	-	513	96	77,407
2018	9,806	56	1,641	508	8,082	11,679	4,493	60	969	144	53	-	3,096	1,291	35,698	-	-	508	74	78,157

Appendix B
Table B-2: Acres Irrigated Agricultural Land in Rincon Valley, by Crop type

Year	Alfalfa	Asparagus	Chili/ Peppers	Cole/ Leafy Greens	Corn/ Silage	Cotton	Grain	Grapes	Hay	Legumes	Melons/ Squash	Misc/ Other	Onions	Pasture	Pecans/ Other Trees	Root Crop	Tomato	Turf	Irrigated Annuals	Total
1936	3,233	-	186	-	2,323	5,750	713	-	871	84	-	387	1	1,194	-	88	377	-	-	15,207
1937	2,303	-	-	-	1,732	8,671	101	1	793	51	-	339	5	367	18	63	256	-	-	14,701
1938	3,341	-	-	-	1,505	5,704	213	5	791	30	-	397	-	662	10	120	287	-	-	13,067
1939	3,718	-	-	-	1,775	5,482	340	7	1,364	196	102	410	1	516	7	111	362	-	-	14,391
1940	4,497	-	158	-	1,631	6,163	321	2	672	55	16	308	1	282	15	76	149	-	-	14,346
1941	3,614	-	-	-	1,298	8,109	192	-	366	30	-	455	2	359	10	361	104	-	-	14,902
1942	3,577	-	-	-	1,121	8,146	284	6	637	10	-	610	18	606	11	185	163	-	-	15,375
1943	6,173	-	-	-	1,674	7,608	323	1	742	43	2	610	21	427	7	101	182	-	-	17,916
1944	3,949	-	-	-	1,344	7,869	278	2	267	5	10	421	54	655	-	173	296	-	-	15,324
1945	3,507	-	-	-	903	9,108	238	-	174	2	10	509	79	579	4	97	112	-	-	15,323
1946	3,335	-	667	-	1,169	10,173	314	-	308	8	25	568	357	755	7	200	-	-	-	17,888
1947	2,687	-	183	-	578	12,805	132	2	154	80	1	367	78	662	1	108	-	-	-	17,840
1948	1,498	-	93	-	456	14,527	51	-	100	4	13	229	29	310	11	107	-	-	-	17,429
1949	1,367	-	152	-	278	15,970	14	-	193	3	-	286	53	272	5	25	6	-	-	18,625
1950	3,185	-	139	-	1,236	12,262	165	-	299	3	21	438	63	695	-	12	6	-	-	18,525
1951	1,320	-	108	-	164	15,633	5	-	48	1	1	43	7	446	5	4	3	-	-	17,789
1952	2,382	-	154	-	143	15,671	21	-	2	-	9	53	36	323	-	-	81	-	-	18,875
1953	2,308	-	196	-	140	16,037	165	-	39	-	8	90	18	169	7	4	74	-	-	19,255
1954	2,861	-	329	-	674	11,013	1,304	-	384	505	3	266	32	258	-	-	63	-	-	17,692
1955	4,441	-	225	49	1,115	9,896	1,597	-	208	4	8	226	69	307	23	1	51	-	-	18,219
1956	3,828	-	221	48	1,098	9,740	1,321	-	195	4	7	221	42	220	7	1	50	-	49	17,053
1957	3,849	-	270	97	989	9,720	1,446	-	110	3	7	152	60	275	7	0	53	-	24	17,061
1958	3,871	-	318	145	879	9,699	1,571	-	24	1	6	82	78	331	7	-	55	-	-	17,068
1959	3,030	-	293	108	655	11,475	1,569	-	94	1	5	54	66	297	-	6	64	-	-	17,719
1960	2,792	-	261	129	861	12,180	1,546	-	102	-	4	53	90	163	5	10	28	-	-	18,223
1961	2,613	-	304	3	612	11,430	2,279	-	95	1	2	31	49	466	9	18	7	-	-	17,921
1962	2,343	-	334	4	993	11,346	2,353	-	47	2	1	61	155	254	17	21	16	-	-	17,947
1963	2,033	-	352	52	724	12,170	1,613	-	78	-	3	30	150	271	17	15	3	-	-	17,512
1964	2,322	-	427	183	954	11,518	1,738	-	62	4	53	27	206	235	13	11	12	-	-	17,765
1965	2,577	-	651	200	1,003	12,137	1,884	-	74	4	56	28	291	248	61	21	16	-	-	19,252
1966	2,897	-	690	167	806	9,780	1,562	-	67	4	44	23	295	200	89	25	17	-	-	16,665
1967	2,523	-	960	190	879	10,705	1,765	-	82	4	48	25	399	219	92	37	22	-	-	17,949
1968	2,804	-	1,234	208	923	11,285	1,919	-	96	4	49	27	502	231	95	50	28	-	-	19,456
1969	2,804	-	1,394	205	872	10,699	1,879	-	101	4	46	26	559	219	97	58	31	-	-	18,994
1970	2,919	-	1,611	210	856	10,554	1,917	-	110	4	45	26	638	216	100	69	35	-	-	19,310
1971	2,949	-	1,771	210	819	10,137	1,901	-	115	3	42	25	695	208	103	77	38	-	-	19,095
1972	2,979	-	1,931	209	782	9,721	1,884	-	121	3	39	24	753	200	106	85	42	-	-	18,879
1973	3,009	-	2,091	209	745	9,304	1,868	-	126	3	37	24	810	191	109	94	45	-	-	18,664
1974	3,039	-	2,251	208	708	8,888	1,852	-	132	3	34	23	867	183	111	102	48	-	-	18,448
1975	3,069	-	2,411	208	671	8,471	1,836	-	137	3	32	22	924	174	114	110	51	-	-	18,233
1976	2,358	-	3,281	249	717	9,176	2,167	-	178	3	32	25	1,248	189	117	151	69	-	-	19,958
1977	3,129	-	2,731	207	597	7,638	1,804	-	148	2	27	21	1,039	158	184	126	57	-	-	17,867
1978	3,159	-	2,891	207	560	7,221	1,788	-	153	2	24	20	1,096	149	252	134	60	-	-	17,716

Appendix B
Table B-2: Acres Irrigated Agricultural Land in Rincon Valley, by Crop type

Year	Alfalfa	Asparagus	Chili/ Peppers	Cole/ Leafy Greens	Corn/ Silage	Cotton	Grain	Grapes	Hay	Legumes	Melons/ Squash	Misc/ Other	Onions	Pasture	Pecans/ Other Trees	Root Crop	Tomato	Turf	Irrigated Annuals	Total
1979	3,189	-	3,051	206	522	6,805	1,772	-	159	2	22	19	1,153	141	319	142	63	-	-	17,565
1980	3,286	-	3,267	210	499	6,566	1,795	-	167	2	20	19	1,232	136	387	153	68	-	-	17,806
1981	3,434	-	3,537	217	482	6,410	1,845	-	178	1	18	19	1,330	133	454	166	73	-	-	18,300
1982	3,332	-	3,547	209	431	5,797	1,762	-	177	1	15	17	1,332	121	521	167	73	-	-	17,503
1983	3,192	-	3,505	198	379	5,161	1,661	-	172	1	12	16	1,313	108	589	166	72	-	-	16,544
1984	3,340	-	3,777	205	362	5,005	1,711	-	184	1	10	16	1,413	105	656	179	78	-	-	17,041
1985	3,324	-	3,860	202	327	4,606	1,677	-	186	1	8	15	1,442	97	724	184	79	-	-	16,731
1986	4,208	-	4,705	238	351	5,042	1,963	-	224	1	7	17	1,755	106	791	224	96	-	-	19,729
1987	3,232	-	3,949	193	255	3,763	1,582	-	186	0	4	13	1,471	79	904	189	81	-	-	15,901
1988	3,505	-	4,383	208	245	3,714	1,690	-	205	0	2	13	1,631	79	1,017	210	89	-	-	16,992
1989	3,813	-	4,874	224	233	3,654	1,813	-	226	-	-	14	1,811	78	1,129	234	99	-	-	18,202
1990	4,305	-	4,325	197	494	3,750	1,704	-	227	1	-	12	1,957	87	1,210	200	85	-	9	18,565
1991	4,797	-	3,777	170	755	3,846	1,595	-	227	3	-	10	2,103	97	1,292	167	71	-	19	18,927
1992	5,289	-	3,228	142	1,017	3,941	1,487	-	227	4	-	8	2,249	106	1,373	134	57	-	28	19,290
1993	5,781	-	2,680	115	1,278	4,037	1,378	-	228	5	-	6	2,395	116	1,454	100	43	-	38	19,652
1994	6,273	-	2,131	88	1,539	4,133	1,269	-	228	6	-	4	2,540	125	1,535	67	28	-	47	20,015
1995	6,765	-	1,583	60	1,801	4,229	1,161	-	229	8	-	2	2,686	135	1,616	33	14	-	57	20,377
1996	7,257	-	1,034	33	2,062	4,325	1,052	-	229	9	-	-	2,832	144	1,697	-	-	-	66	20,740
1997	6,590	-	2,564	60	1,512	3,114	1,614	-	-	-	-	13	2,203	82	1,782	-	2	-	-	19,535
1998	6,117	-	2,607	285	1,434	2,144	1,730	-	56	-	-	8	2,139	70	1,867	-	107	-	-	18,563
1999	5,391	-	3,197	55	2,254	1,838	1,165	-	47	-	-	2	2,222	90	1,952	-	64	-	-	18,276
2000	5,541	-	2,728	30	1,967	2,177	1,286	-	2	-	-	216	2,261	135	2,037	-	-	-	-	18,380
2001	5,146	-	2,216	43	1,814	1,879	1,217	-	-	-	66	84	2,424	150	2,122	-	-	-	-	17,162
2002	6,302	-	2,157	6	1,767	1,426	782	-	-	-	9	67	2,749	91	2,207	-	-	-	-	17,564
2003	6,014	-	2,114	36	2,032	1,606	679	-	-	1	30	45	2,967	97	2,292	-	-	-	29	17,940
2004	5,725	-	2,070	66	2,296	1,785	575	-	-	1	52	22	3,185	103	2,377	-	-	-	58	18,316
2005	5,436	-	2,026	95	2,561	1,964	472	-	-	2	74	-	3,404	109	2,462	-	-	-	87	18,692
2006	6,898	-	1,105	53	2,894	2,987	1,182	-	268	-	-	-	1,753	206	2,547	-	-	-	-	19,893
2007	6,580	-	1,103	54	2,920	3,085	1,272	-	233	19	-	-	1,782	205	2,738	-	-	-	14	20,006
2008	6,262	-	1,102	55	2,946	3,184	1,362	-	198	38	-	-	1,811	205	2,928	-	-	-	28	20,118
2009	5,943	-	1,100	57	2,971	3,282	1,452	-	163	57	-	-	1,840	204	3,119	-	-	-	43	20,231
2010	5,625	-	1,098	58	2,997	3,380	1,541	-	128	76	-	-	1,869	204	3,310	-	-	-	57	20,344
2011	5,307	-	1,097	59	3,023	3,479	1,631	-	93	95	-	-	1,898	203	3,500	-	-	-	71	20,456
2012	4,998	-	1,225	71	3,220	3,022	1,763	-	129	77	-	-	1,775	172	3,573	-	-	-	48	20,074
2013	4,690	-	1,352	82	3,418	2,566	1,894	-	165	58	-	-	1,653	142	3,646	-	-	-	26	19,692
2014	4,381	-	1,480	94	3,615	2,110	2,026	-	201	39	-	-	1,530	111	3,719	-	-	-	4	19,309
2015	3,991	-	1,564	94	3,223	2,511	1,891	-	224	89	-	-	1,539	71	3,755	-	-	-	2	18,955
2016	3,601	-	1,648	95	2,832	2,913	1,781	-	246	139	-	-	1,548	31	3,790	-	-	-	-	18,624
2017	3,476	-	1,434	53	2,850	3,042	1,656	-	245	70	3	-	1,604	55	3,916	-	-	-	17	18,419
2018	3,350	-	1,219	11	2,867	3,170	1,555	-	245	-	5	-	1,659	79	4,043	-	-	-	35	18,238

Appendix B

Table B-3: Acres Irrigated Agricultural Land in Mesilla Valley, by Crop type

Year	Alfalfa	Asparagus	Chili/ Peppers	Cole/ Leafy Greens	Corn/ Silage	Cotton	Grain	Grapes	Hay	Legumes	Melons/ Squash	Misc/ Other	Onions	Pasture	Pecans/ Other Trees	Root Crop	Tomato	Turf	Irrigated Annuals	Total
1936	17,077	-	210	-	4,539	52,376	592	-	1,221	65	1,408	1,941	293	928	-	2,273	-	-	-	82,923
1937	11,972	-	-	-	2,353	56,341	246	-	336	26	1,058	1,209	103	246	650	1,277	205	-	-	76,022
1938	18,339	-	1	-	5,593	34,406	318	56	922	165	1,016	1,288	164	986	225	1,234	311	-	-	65,024
1939	24,405	-	-	67	6,418	33,264	585	14	1,682	1,362	1,301	1,150	204	1,284	377	1,239	297	-	-	73,649
1940	26,121	-	-	7	4,715	39,210	426	44	891	82	1,006	1,293	244	662	2,557	948	266	-	-	78,472
1941	17,460	-	-	-	1,906	52,043	97	-	360	109	971	1,553	214	546	3,134	2,124	136	-	-	80,653
1942	12,297	-	-	-	1,663	59,594	81	14	262	36	525	1,456	220	521	3,157	1,262	257	-	-	81,345
1943	15,269	-	-	-	2,655	57,307	429	9	527	23	481	2,156	195	869	3,167	1,150	184	-	-	84,421
1944	18,419	-	-	-	2,493	53,332	325	12	640	35	599	1,458	389	790	4,099	1,068	180	-	-	83,839
1945	18,185	-	-	-	1,307	55,338	364	7	172	10	1,058	1,607	406	1,264	4,313	633	144	-	-	84,808
1946	18,262	-	395	-	1,170	59,897	398	7	215	39	1,068	1,697	839	1,752	4,372	804	-	-	-	90,915
1947	13,900	-	207	-	653	65,724	131	8	26	148	747	1,432	535	2,527	4,336	758	-	-	-	91,132
1948	7,055	-	137	-	725	69,327	60	8	42	22	311	1,410	326	1,699	4,349	561	-	-	-	86,032
1949	7,436	-	170	-	458	73,615	12	5	57	5	302	1,350	368	1,845	4,248	310	-	-	-	90,181
1950	11,380	-	191	-	1,086	67,471	351	6	276	12	675	1,583	403	2,442	4,292	125	53	-	-	90,346
1951	6,282	-	257	205	268	76,407	65	3	-	2	267	410	294	828	4,191	52	51	-	-	89,582
1952	10,308	-	272	386	297	71,173	517	3	65	-	194	410	321	2,448	4,197	44	76	-	-	90,711
1953	11,889	-	322	451	435	70,071	227	2	16	8	158	337	358	2,380	4,176	36	44	-	-	90,910
1954	17,658	-	517	241	995	49,558	2,341	2	517	409	445	1,221	311	2,073	4,161	47	146	-	-	80,642
1955	17,382	1	433	277	1,178	53,023	1,992	-	654	77	246	2,968	409	1,012	4,290	50	198	-	2	84,194
1956	17,963	17	376	670	1,263	45,350	1,387	2	460	40	206	1,655	662	1,450	4,280	33	114	-	5,220	81,148
1957	16,263	34	401	1,081	1,531	48,028	1,120	2	352	44	197	941	955	1,931	4,299	20	123	-	2,612	79,934
1958	14,563	50	426	1,493	1,799	50,706	854	3	244	47	189	226	1,247	2,412	4,317	7	132	-	5	78,720
1959	12,529	30	484	1,069	2,418	52,069	1,419	2	15	8	243	296	1,726	512	4,362	14	242	-	-	77,438
1960	13,195	26	514	1,206	1,900	51,165	1,372	2	118	14	175	278	1,878	4,033	4,376	13	110	-	-	80,375
1961	14,527	14	526	718	1,471	51,096	1,694	1	-	1	170	290	1,632	741	4,337	9	55	-	21	77,303
1962	10,367	-	406	913	1,007	58,805	940	1	3	-	93	292	1,539	550	4,402	3	3	-	20	79,344
1963	6,726	1	390	709	933	64,015	398	1	3	-	58	265	1,210	325	4,231	5	10	-	-	79,280
1964	8,777	1	505	940	1,282	58,799	743	1	22	-	86	191	1,536	518	4,241	3	20	-	-	77,665
1965	8,730	7	631	944	1,543	56,503	740	3	27	-	86	208	1,521	520	4,693	8	19	-	43	76,226
1966	14,968	12	727	919	1,743	52,753	715	-	30	-	83	217	1,460	507	5,117	13	17	-	-	79,282
1967	8,498	18	854	933	2,018	51,251	720	6	35	-	83	235	1,462	516	5,254	18	16	-	128	72,045
1968	9,300	26	1,058	1,042	2,449	54,042	795	9	43	-	92	275	1,611	562	5,363	25	17	-	170	76,879
1969	9,266	32	1,175	1,046	2,702	51,913	793	11	47	-	91	291	1,598	563	5,472	30	16	-	213	75,259
1970	9,569	39	1,338	1,094	3,037	51,684	822	13	53	-	94	318	1,650	584	5,582	36	16	-	256	76,185
1971	9,718	45	1,483	1,122	3,339	50,558	837	15	59	-	96	341	1,672	596	5,691	42	15	-	298	75,927
1972	9,867	52	1,628	1,151	3,640	49,431	852	17	64	-	97	363	1,695	608	5,800	48	14	-	341	75,668
1973	10,016	59	1,773	1,179	3,942	48,305	867	19	70	-	99	386	1,717	621	5,909	53	13	-	383	75,411
1974	10,165	65	1,918	1,207	4,243	47,178	882	21	75	-	100	408	1,740	633	6,019	59	12	-	426	75,151
1975	4,072	88	2,530	1,515	5,572	56,460	1,099	-	99	-	124	528	2,161	791	6,128	80	14	-	-	81,260
1976	10,463	78	2,209	1,264	4,847	44,926	911	26	86	-	103	453	1,785	657	6,783	71	11	-	511	75,184
1977	10,386	83	2,293	1,259	5,058	42,792	904	27	89	-	102	463	1,762	654	7,438	74	10	-	554	73,948
1978	10,309	87	2,377	1,255	5,270	40,659	897	28	92	-	101	473	1,739	651	8,093	78	9	-	596	72,714

Appendix B

Table B-3: Acres Irrigated Agricultural Land in Mesilla Valley, by Crop type

Year	Alfalfa	Asparagus	Chili/ Peppers	Cole/ Leafy Greens	Corn/ Silage	Cotton	Grain	Grapes	Hay	Legumes	Melons/ Squash	Misc/ Other	Onions	Pasture	Pecans/ Other Trees	Root Crop	Tomato	Turf	Irrigated Annuals	Total
1979	10,232	91	2,461	1,250	5,481	38,526	890	30	96	-	100	484	1,716	648	8,748	82	8	-	639	71,482
1980	10,501	99	2,638	1,296	5,830	37,940	916	32	102	-	103	513	1,762	669	9,403	89	7	-	682	72,582
1981	10,899	108	2,861	1,362	6,242	37,841	956	35	110	-	107	550	1,836	699	10,058	97	7	-	724	74,492
1982	10,652	110	2,877	1,329	6,362	35,132	932	36	111	-	104	548	1,777	682	10,713	98	6	-	767	72,236
1983	10,313	110	2,851	1,281	6,426	32,162	898	36	111	-	100	538	1,700	658	11,368	98	4	-	809	69,463
1984	10,715	120	3,080	1,348	6,844	32,042	938	39	119	-	104	576	1,774	689	12,023	107	4	-	852	71,374
1985	10,700	124	3,158	1,349	7,055	30,375	936	40	122	-	104	587	1,762	688	12,678	110	3	-	895	70,686
1986	16,040	120	3,054	1,268	6,648	27,270	871	-	116	-	97	560	1,644	652	13,333	106	2	-	-	71,780
1987	10,341	129	3,290	1,329	6,983	27,209	904	41	124	-	101	595	1,709	688	13,749	114	1	-	844	68,151
1988	10,868	144	3,698	1,451	7,178	28,574	963	46	133	-	109	659	1,847	759	14,165	128	1	-	750	71,473
1989	10,537	145	3,753	1,431	6,897	27,146	935	47	131	-	106	658	1,807	760	14,581	129	-	-	656	69,719
1990	10,596	119	3,539	1,260	6,598	25,235	1,161	40	178	30	90	566	1,708	777	15,311	106	-	11	562	67,887
1991	10,941	99	3,451	1,139	6,464	24,234	1,414	34	229	61	77	498	1,669	817	16,042	88	-	22	469	67,748
1992	11,256	79	3,355	1,016	6,315	23,183	1,661	29	279	90	64	429	1,627	855	16,773	70	-	33	375	67,489
1993	11,573	59	3,264	897	6,169	22,179	1,905	23	328	120	52	362	1,587	893	17,504	52	-	43	281	67,291
1994	11,891	39	3,174	777	6,023	21,175	2,149	18	377	149	39	295	1,546	931	18,234	35	-	54	187	67,093
1995	12,438	20	3,146	674	5,997	20,579	2,441	13	435	182	27	234	1,539	987	18,965	18	-	66	94	67,855
1996	13,526	-	3,109	568	6,032	20,009	2,788	8	495	216	15	-	1,514	1,089	19,696	-	-	252	-	69,317
1997	13,001	-	3,302	2,264	7,343	18,716	3,172	14	53	-	49	1,246	2,501	729	20,528	-	64	-	-	72,982
1998	11,818	-	2,901	3,111	7,752	16,504	3,248	26	353	-	-	726	2,643	505	20,497	-	2	-	1,142	71,228
1999	11,388	-	2,563	1,624	8,492	14,658	1,820	37	208	-	28	1,183	2,627	633	20,906	-	2	-	1,142	67,311
2000	13,132	-	2,643	1,953	8,088	15,092	1,716	45	42	-	61	884	3,206	833	21,212	-	123	-	1,142	70,172
2001	11,760	-	2,041	1,405	6,136	14,820	1,302	37	15	55	47	640	2,559	708	21,631	-	83	-	231	63,470
2002	11,756	-	1,940	1,084	5,385	15,945	1,090	35	287	113	40	511	2,115	779	21,805	-	57	-	1,612	64,554
2003	11,236	-	1,779	1,079	5,222	15,313	1,108	34	149	126	33	323	2,169	842	22,332	-	40	-	1,077	62,862
2004	10,716	-	1,618	1,073	5,058	14,680	1,126	33	10	139	27	136	2,224	904	22,858	-	24	-	542	61,168
2005	10,223	-	1,468	1,068	5,113	14,725	1,144	33	16	152	20	2	2,268	1,075	23,020	-	7	2	511	60,847
2006	11,133	-	541	449	3,992	16,549	533	37	387	17	19	-	1,421	1,165	23,422	-	-	245	132	60,042
2007	10,868	-	1,099	618	5,716	13,232	1,779	31	25	94	18	275	1,711	1,022	23,791	-	-	3	1	60,283
2008	11,289	-	1,659	548	5,625	10,780	1,691	25	19	527	51	58	1,493	942	24,399	-	-	2	407	59,515
2009	11,427	-	1,404	629	6,150	7,833	2,077	1	12	86	95	41	1,373	1,085	25,007	-	-	2	357	57,579
2010	10,116	-	1,025	601	4,526	8,935	1,371	25	6	30	32	20	1,488	577	25,615	-	-	1	259	54,627
2011	10,089	-	738	476	3,862	12,239	813	53	-	-	43	-	779	195	26,224	-	-	241	-	55,752
2012	9,954	-	751	619	4,392	10,686	1,744	60	390	32	116	-	924	634	26,858	-	-	333	11	57,504
2013	9,818	-	765	761	4,923	9,132	2,675	67	780	64	190	-	1,069	1,072	27,493	-	-	425	22	59,256
2014	9,683	38	741	903	5,453	7,579	3,607	74	1,171	96	263	-	1,214	1,511	28,128	-	-	517	33	61,011
2015	8,426	54	756	655	5,882	7,534	2,966	76	1,037	361	189	-	1,214	1,323	28,471	-	-	517	76	59,534
2016	7,168	69	771	406	6,311	7,489	2,324	78	903	625	114	-	1,214	1,135	28,814	-	-	517	119	58,057
2017	6,812	62	596	451	5,763	7,999	2,631	69	814	385	81	-	1,325	1,174	30,235	-	-	513	79	58,988
2018	6,456	56	422	497	5,214	8,509	2,938	60	724	144	47	-	1,437	1,212	31,655	-	-	508	39	59,919

Appendix B

Table B-4: Acres Irrigated Agricultural Land in El Paso Valley, by Crop type

Year	Alfalfa	Asparagus	Chili/ Peppers	Cole/ Leafy Greens	Corn/ Silage	Cotton	Grain	Grapes	Hay	Legumes	Melons/ Squash	Misc/ Other	Onions	Pasture	Pecans/ Other Trees	Root Crop	Tomato	Turf	Irrigated Annuals	Total
1936	15,031	-	-	-	1,344	41,562	103	-	926	8	130	1,931	24	142	434	-	103	-	300	62,037
1937	15,113	-	-	-	518	46,695	40	-	226	25	114	978	24	130	468	160	50	-	-	64,541
1938	21,182	-	-	-	1,466	32,453	60	-	1,315	-	113	2,152	14	321	106	146	-	-	482	59,810
1939	23,727	-	-	-	-	33,015	-	33	1,431	12	118	3,131	28	331	315	144	91	-	-	62,375
1940	24,402	-	-	-	1,138	33,682	120	25	877	-	80	2,687	35	209	292	89	-	-	-	63,635
1941	20,674	-	-	-	353	42,119	38	24	218	-	41	1,733	43	135	164	130	43	-	360	66,074
1942	17,034	-	-	-	520	47,363	42	19	39	1	75	1,216	49	349	146	38	48	-	328	67,267
1943	18,247	-	-	-	831	45,654	45	-	530	13	87	977	46	280	235	159	53	-	1,874	69,031
1944	19,199	-	-	-	1,148	44,681	483	-	919	10	107	1,199	152	443	157	163	56	-	-	68,717
1945	20,978	-	-	-	896	45,257	15	-	113	8	181	1,734	50	687	189	71	43	-	309	70,530
1946	21,416	-	-	344	543	46,663	405	1	5	-	20	1,842	88	573	300	122	1	-	172	72,494
1947	18,251	-	-	-	139	53,040	-	9	5	-	113	1,211	93	185	143	39	57	-	212	73,497
1948	12,917	-	-	41	217	57,847	-	3	5	2	7	1,458	98	1,215	163	94	87	-	-	74,154
1949	11,313	-	-	26	82	60,866	36	5	-	-	-	1,469	178	1,139	119	36	63	-	-	75,332
1950	15,020	-	-	5	356	55,620	136	4	-	47	149	1,813	174	211	125	35	33	-	255	73,983
1951	10,595	-	-	14	42	61,732	7	5	-	-	11	469	94	577	112	-	10	-	-	73,668
1952	11,655	-	13	14	28	61,035	138	5	304	-	33	757	52	168	57	10	13	-	-	74,282
1953	12,983	-	8	12	57	58,494	170	10	-	-	81	552	57	840	73	12	11	-	-	73,360
1954	19,207	-	-	50	647	36,803	477	-	490	-	53	1,562	101	124	118	32	10	-	-	59,674
1955	12,210	-	28	45	1,642	32,679	1,400	-	578	24	35	189	128	52	109	17	96	-	-	49,232
1956	6,507	2	73	42	2,193	32,826	1,434	-	792	-	75	175	236	925	118	31	150	-	-	45,580
1957	2,723	3	-	94	254	37,609	569	5	1,364	-	68	123	50	526	77	12	-	-	-	43,477
1958	4,888	9	8	7	1,153	39,087	1,732	2	2,952	-	68	412	14	207	198	6	33	-	-	50,776
1959	7,232	-	-	4	975	32,097	868	3	2,894	-	63	799	-	1,337	407	-	37	-	-	46,716
1960	9,124	-	16	14	1,774	39,948	664	4	2,577	2	104	645	31	1,481	414	-	91	-	-	56,889
1961	9,148	2	16	31	1,839	40,432	532	-	2,153	-	61	511	73	1,666	414	4	76	-	-	56,958
1962	6,502	2	3	-	2,011	47,907	383	-	2,010	-	60	427	36	1,864	410	14	68	-	-	61,697
1963	3,765	2	-	-	928	53,889	551	2	44	-	37	350	5	1,351	410	8	49	-	-	61,391
1964	4,459	-	1	-	1,015	48,806	106	2	315	-	44	228	5	956	411	12	-	-	-	56,360
1965	6,818	-	-	54	2,752	36,409	921	-	1,799	-	36	150	89	1,588	390	17	267	-	-	51,289
1966	6,812	-	8	149	4,169	33,328	1,140	-	1,540	-	31	364	184	1,596	233	10	200	-	-	49,765
1967	6,963	-	61	243	4,562	32,722	1,773	-	660	-	26	471	278	1,651	77	3	131	-	-	49,620
1968	6,852	-	-	395	5,373	36,159	2,609	-	500	2	17	435	225	2,025	285	2	49	-	-	54,927
1969	7,069	-	76	157	8,843	35,772	3,902	-	1,494	-	22	-	308	2,602	-	-	68	-	-	60,312
1970	8,789	-	11	203	11,085	32,505	7,248	-	882	-	56	138	331	2,776	651	1	17	-	-	64,691
1971	9,545	-	32	233	11,077	29,182	9,922	-	907	5	51	130	384	3,191	920	1	37	-	-	65,617
1972	10,301	-	52	262	11,068	25,866	12,591	-	932	10	47	121	438	3,606	1,190	1	58	-	-	66,543
1973	11,057	-	72	292	11,058	22,556	15,254	-	957	15	43	113	491	4,020	1,459	1	78	-	-	67,468
1974	11,814	-	93	322	11,047	19,252	17,912	-	982	20	39	105	544	4,435	1,728	1	99	-	-	68,394
1975	12,570	-	113	352	11,036	15,955	20,565	-	1,007	26	35	97	597	4,850	1,997	1	119	-	-	69,319
1976	13,326	-	134	381	11,023	12,664	23,213	-	1,032	31	31	89	650	5,265	2,267	1	139	-	-	70,245
1977	11,867	-	420	289	7,781	20,238	15,820	-	1,058	20	34	92	601	5,184	2,532	1	93	-	-	66,031
1978	10,409	-	705	198	4,551	27,777	8,454	-	1,082	10	37	96	551	5,103	2,797	0	46	-	-	61,817

Appendix B
Table B-4: Acres Irrigated Agricultural Land in El Paso Valley, by Crop type

Year	Alfalfa	Asparagus	Chili/ Peppers	Cole/ Leafy Greens	Corn/ Silage	Cotton	Grain	Grapes	Hay	Legumes	Melons/ Squash	Misc/ Other	Onions	Pasture	Pecans/ Other Trees	Root Crop	Tomato	Turf	Irrigated Annuals	Total
1979	8,950	-	988	107	1,335	35,270	1,122	-	1,105	-	40	100	501	5,023	3,063	-	-	-	-	57,603
1980	7,983	-	1,411	50	365	30,833	8,970	-	815	-	29	99	508	4,390	3,494	-	-	-	-	58,947
1981	7,841	-	985	92	2,807	30,390	9,084	-	638	-	26	104	431	3,509	3,505	-	-	-	-	59,412
1982	6,731	-	948	459	4,317	27,787	10,860	-	503	-	47	151	755	4,922	4,811	-	-	-	-	62,290
1983	6,684	-	1,246	355	2,252	27,065	5,737	-	306	-	49	169	967	6,175	4,840	-	-	-	-	55,846
1984	7,945	-	912	118	2,414	29,746	6,569	-	803	-	19	122	856	4,746	4,872	-	-	-	-	59,121
1985	7,601	-	1,077	45	1,645	33,016	3,734	8	517	39	1	182	679	2,388	4,799	-	-	-	-	55,730
1986	6,543	-	633	72	1,099	34,283	4,733	11	147	-	1	219	599	2,745	4,869	-	-	-	-	55,953
1987	5,841	-	276	194	8	39,353	1,266	5	531	-	6	155	549	1,499	5,508	-	-	-	-	55,191
1988	4,792	-	-	306	793	42,503	495	4	528	-	9	120	436	1,785	5,577	-	-	-	-	57,347
1989	4,026	-	48	82	410	44,964	166	2	346	-	23	171	417	1,066	5,280	-	-	-	-	57,002
1990	3,883	-	1,231	182	1,116	40,389	1,107	2	-	-	7	163	828	1,166	5,338	-	-	-	-	55,412
1991	4,554	-	2,189	64	3,060	43,128	1,407	-	-	-	-	164	902	1,065	6,155	-	-	-	-	62,687
1992	5,177	-	5,011	91	7,063	37,105	1,588	3	551	-	-	474	944	990	6,379	-	-	-	-	65,374
1993	5,627	-	4,908	152	6,837	30,201	1,687	-	2,032	-	129	573	1,484	1,794	6,882	-	-	-	-	62,306
1994	5,932	-	4,474	37	5,134	33,006	1,940	2	216	-	118	680	1,905	1,969	7,071	-	-	-	-	62,485
1995	6,100	-	2,273	91	4,580	36,978	2,854	2	71	-	78	-	1,093	1,104	7,115	-	-	-	-	62,339
1996	6,662	-	1,091	282	5,148	37,390	3,578	2	186	-	7	-	1,393	1,294	7,836	-	-	-	-	64,870
1997	5,491	-	3,038	110	3,615	36,532	3,181	2	477	-	-	127	1,255	518	7,487	-	-	-	-	61,833
1998	7,013	-	2,713	80	3,686	35,690	3,266	1	607	-	-	58	835	411	8,022	-	-	-	-	62,382
1999	7,407	-	1,437	38	4,717	35,350	1,885	2	-	-	-	36	916	397	8,299	-	-	-	-	60,483
2000	5,174	-	1,417	-	7,910	29,814	-	-	-	-	-	-	789	336	10,092	-	-	-	-	55,531
2001	4,638	-	946	-	8,336	32,369	-	-	-	-	-	41	817	438	10,822	-	-	-	-	58,407
2002	5,880	-	1,160	-	7,820	31,466	-	-	-	-	-	-	817	336	10,764	-	-	-	-	58,244
2003	3,460	-	466	-	1,295	22,622	-	-	-	-	-	-	589	524	10,780	-	-	-	-	39,735
2004	3,589	-	275	-	493	25,318	64	-	-	-	-	-	904	250	10,018	-	-	-	-	40,911
2005	2,896	-	113	-	924	27,978	636	-	-	-	-	-	905	619	9,390	-	-	-	-	43,461
2006	3,323	-	334	-	951	26,881	115	1	-	-	8	10	637	542	10,304	-	-	-	-	43,107
2007	3,705	-	178	11	1,376	23,619	825	1	752	-	11	7	624	367	10,520	-	-	-	6	42,001
2008	4,776	-	180	23	2,839	20,514	1,134	-	233	-	15	4	611	311	10,725	-	-	-	12	41,377
2009	5,240	-	466	17	2,043	22,990	2,260	-	456	-	7	5	350	347	10,698	-	-	-	6	44,886
2010	5,704	-	752	12	1,248	25,467	3,385	-	679	-	-	6	90	383	10,672	-	-	-	-	48,397
2011	5,952	-	284	-	750	24,807	641	-	292	-	-	7	140	1,036	11,724	-	-	-	4	45,637
2012	6,071	-	-	-	257	10,377	138	-	153	-	-	-	-	895	12,521	-	-	-	8	30,418
2013	5,730	-	-	90	255	12,168	285	-	275	-	-	-	53	845	12,613	-	-	-	4	32,319
2014	5,390	-	-	179	254	13,959	432	-	398	-	-	-	106	796	12,706	-	-	-	0	34,220
2015	4,600	-	-	90	132	16,234	904	-	738	-	-	-	53	643	13,121	-	-	-	0	36,515
2016	3,810	-	-	-	10	18,509	1,376	-	1,079	-	-	-	-	490	13,537	-	-	-	-	38,811
2017	3,458	-	8	-	612	18,835	1,299	-	705	-	-	-	-	465	14,474	-	-	-	1	39,858
2018	3,105	-	15	-	1,215	19,161	1,222	-	331	-	-	-	-	441	15,412	-	-	-	3	40,905

Appendix B

Table B-5: Acres Irrigated Agricultural Land in EPCWID1, by Crop type

Year	Alfalfa	Asparagus	Chili/ Peppers	Cole/ Leafy Greens	Corn/ Silage	Cotton	Grain	Grapes	Hay	Legumes	Melons/ Squash	Misc/ Other	Onions	Pasture	Pecans/ Other Trees	Root Crop	Tomato	Turf	Irrigated Annuals	Total
1936	16,331	-	-	-	1,597	35,517	136	-	1,014	26	207	2,213	29	225	446	215	206	-	-	58,161
1937	12,762	-	-	-	719	45,788	53	-	235	25	176	1,090	24	139	491	191	140	-	-	61,833
1938	21,235	-	-	-	2,042	30,056	126	-	1,386	15	158	794	18	438	111	175	123	-	482	57,159
1939	23,896	-	-	-	269	30,162	83	33	1,575	52	195	1,037	33	597	375	180	172	-	-	58,659
1940	23,677	-	-	-	1,369	32,298	129	26	959	15	117	782	37	289	320	147	88	-	-	60,253
1941	18,905	-	-	-	582	41,024	40	24	242	16	61	740	51	188	204	208	104	-	360	62,749
1942	15,128	-	-	-	710	45,685	42	21	50	9	77	996	51	405	168	87	139	-	328	63,896
1943	16,449	-	-	-	960	44,722	144	1	530	16	87	1,241	49	396	278	221	81	-	493	65,668
1944	16,994	-	-	-	1,141	43,332	483	1	179	22	134	1,328	155	529	170	213	84	-	-	64,765
1945	17,857	-	-	-	757	43,954	24	-	113	18	187	1,632	68	860	215	94	77	-	309	66,165
1946	19,060	-	1	344	619	44,269	408	1	14	11	36	1,695	121	658	318	168	1	-	172	67,896
1947	15,630	-	-	-	223	49,627	10	12	5	13	122	1,199	95	243	152	63	57	-	212	67,663
1948	10,410	-	-	41	361	53,819	-	6	5	10	13	1,425	104	1,231	195	113	87	-	-	67,820
1949	9,568	-	-	26	161	55,869	36	5	-	5	1	1,362	185	1,228	139	56	63	-	-	68,704
1950	12,010	-	-	5	534	52,084	168	7	-	47	157	1,375	184	279	130	64	86	-	255	67,385
1951	8,584	-	-	15	153	56,622	7	5	-	2	13	519	96	123	112	7	13	-	-	66,271
1952	9,524	-	21	15	118	56,020	195	5	-	-	35	824	54	277	58	15	27	-	-	67,188
1953	11,109	-	8	13	148	54,746	170	10	1	-	83	608	59	233	75	16	16	-	-	67,295
1954	17,320	-	45	51	743	36,461	816	-	229	-	63	313	103	195	125	10	56	-	-	56,530
1955	15,048	-	69	53	1,390	34,829	1,376	-	409	34	43	336	154	131	126	11	139	-	-	54,148
1956	8,714	8	118	48	2,210	35,577	1,246	-	542	19	82	251	305	925	132	28	198	-	-	50,403
1957	4,415	15	35	98	502	40,898	247	6	1,029	3	74	156	146	448	88	12	37	-	-	48,209
1958	5,570	25	57	9	1,456	41,531	1,061	3	1,580	45	74	431	120	245	206	6	87	-	-	52,506
1959	7,810	-	11	7	1,397	34,094	1,157	3	1,390	-	70	854	80	945	415	-	155	-	-	48,388
1960	9,547	7	73	14	1,534	41,441	614	4	640	10	108	706	208	659	420	-	139	-	-	56,124
1961	9,505	2	119	32	1,462	40,729	563	-	425	-	65	532	212	1,056	416	4	118	-	-	55,240
1962	6,261	2	64	-	1,648	48,288	248	-	264	-	70	463	56	925	412	14	68	-	-	58,783
1963	3,430	2	22	16	684	53,087	57	2	47	-	37	381	5	497	415	8	49	-	-	58,739
1964	4,494	-	137	-	1,101	49,337	37	2	121	-	44	253	5	590	422	12	-	-	-	56,555
1965	6,987	-	96	54	2,755	38,459	721	-	825	-	36	174	91	797	409	17	268	-	-	51,689
1966	7,195	-	138	149	3,269	36,678	1,010	-	463	-	31	334	188	777	261	10	200	-	-	50,700
1967	7,403	-	179	244	3,783	34,896	1,298	-	100	-	26	494	284	756	113	3	131	-	-	49,710
1968	7,408	-	101	397	4,789	37,678	2,125	-	6	2	17	457	232	874	329	2	49	-	-	54,466
1969	7,712	-	182	158	6,912	36,962	2,687	-	191	-	22	2	318	539	12	-	68	-	-	55,765
1970	9,292	-	110	204	7,675	33,429	5,533	-	220	-	56	144	342	831	712	1	17	-	-	58,566
1971	9,791	-	125	234	8,265	29,926	8,222	-	217	5	52	137	398	821	990	1	38	-	-	59,220
1972	10,289	-	139	265	8,855	26,423	10,910	-	215	10	48	130	454	810	1,267	1	58	-	-	59,874
1973	10,788	-	154	295	9,446	22,921	13,599	-	212	16	44	123	510	800	1,545	1	79	-	-	60,528
1974	11,286	-	168	325	10,036	19,418	16,287	-	209	21	39	115	565	789	1,823	1	100	-	-	61,182
1975	11,785	-	183	356	10,626	15,915	18,976	-	207	26	35	108	621	779	2,100	1	120	-	-	61,836
1976	12,283	-	197	386	11,216	12,412	21,664	-	204	31	31	101	677	768	2,378	1	141	-	-	62,490
1977	11,540	-	482	294	8,381	18,249	14,804	-	428	21	34	104	629	885	2,652	1	94	-	-	58,598
1978	10,797	-	766	201	5,546	24,087	7,944	-	652	10	38	107	582	1,003	2,925	0	47	-	-	54,705

Appendix B
Table B-5: Acres Irrigated Agricultural Land in EPCWID1, by Crop type

Year	Alfalfa	Asparagus	Chili/ Peppers	Cole/ Leafy Greens	Corn/ Silage	Cotton	Grain	Grapes	Hay	Legumes	Melons/ Squash	Misc/ Other	Onions	Pasture	Pecans/ Other Trees	Root Crop	Tomato	Turf	Irrigated Annuals	Total
1979	10,054	-	1,051	109	2,711	29,924	1,084	-	876	-	41	110	534	1,120	3,199	-	-	-	-	50,813
1980	9,162	-	1,510	52	1,377	24,617	8,504	-	212	-	30	110	555	1,053	3,639	-	-	-	-	50,821
1981	8,999	-	1,037	94	4,226	23,626	8,845	-	345	-	27	112	466	1,031	3,658	-	-	-	-	52,466
1982	7,969	-	993	469	6,168	21,021	10,228	-	412	-	48	159	799	1,030	4,972	-	-	-	-	54,268
1983	7,957	-	1,296	364	4,542	23,063	5,917	-	237	-	50	177	1,021	2,122	5,010	-	-	-	-	51,756
1984	8,269	-	948	121	4,789	23,105	6,264	-	493	-	20	127	909	1,270	5,050	-	-	-	-	51,365
1985	9,141	-	1,118	46	4,197	21,425	3,517	8	555	40	1	189	733	1,092	4,985	-	-	-	-	47,047
1986	8,157	-	654	74	3,760	22,404	4,554	11	174	-	1	226	653	1,444	5,064	-	-	-	-	47,176
1987	7,582	-	329	207	2,127	27,061	1,247	5	418	-	6	162	613	1,194	5,675	-	-	-	-	46,626
1988	6,434	-	78	322	2,929	28,496	338	4	462	-	9	123	490	1,221	5,771	-	-	-	-	46,677
1989	5,664	-	169	97	2,265	30,155	241	2	369	-	23	175	474	969	5,501	-	-	-	-	46,104
1990	5,242	-	1,203	202	2,906	28,606	1,004	2	-	-	7	166	896	1,099	5,640	-	-	-	-	46,973
1991	5,699	-	1,324	86	4,596	31,716	1,482	-	-	-	-	166	869	890	6,484	-	-	-	-	53,312
1992	6,389	-	2,837	117	8,123	25,858	1,653	3	565	-	-	479	844	1,011	6,735	-	-	-	-	54,614
1993	6,924	-	2,835	183	7,553	22,200	1,662	-	1,955	-	130	578	1,342	1,827	7,265	-	-	-	-	54,454
1994	7,080	-	2,975	71	5,441	24,771	1,890	2	222	-	119	684	1,840	1,890	7,481	-	-	-	-	54,466
1995	7,010	-	1,033	130	4,769	27,549	2,889	2	-	-	78	-	1,027	845	7,506	-	-	-	-	52,838
1996	5,911	-	1,372	167	4,139	28,063	3,250	2	186	-	7	-	1,294	1,105	8,264	-	-	-	-	53,760
1997	6,514	-	1,401	241	3,547	27,577	3,227	2	477	-	11	146	1,327	704	8,399	-	-	-	-	53,573
1998	5,782	-	1,308	83	3,352	28,124	3,454	1	362	-	-	162	916	571	8,565	-	-	-	-	52,680
1999	6,011	-	822	39	4,572	26,233	1,958	2	-	-	-	157	979	579	8,913	-	-	-	-	50,265
2000	5,115	-	851	-	8,339	22,357	-	-	-	-	-	49	822	467	10,673	-	-	-	-	48,673
2001	4,738	-	321	-	7,010	24,277	-	-	-	-	-	111	905	550	11,484	-	-	-	-	49,396
2002	5,910	-	683	-	8,264	22,498	-	-	-	-	-	-	861	540	11,262	-	-	-	-	50,018
2003	3,909	-	383	-	1,255	19,803	-	-	-	-	-	-	623	672	11,466	-	-	-	-	38,111
2004	3,875	-	152	-	628	21,172	64	-	-	-	-	-	927	342	10,893	-	-	-	-	38,053
2005	2,969	-	152	-	1,026	22,148	638	-	-	-	-	-	927	763	10,089	-	-	-	-	38,711
2006	3,139	-	345	-	1,018	20,682	115	1	-	-	8	10	638	619	10,838	-	-	-	-	37,413
2007	3,616	-	190	12	1,218	17,414	626	1	126	-	12	7	625	527	11,053	-	-	-	6	35,429
2008	4,092	-	35	23	1,418	14,146	1,136	-	252	-	15	4	611	434	11,267	-	-	-	12	33,445
2009	4,412	-	187	18	1,355	15,496	2,041	-	223	-	8	5	351	434	11,250	-	-	-	6	35,783
2010	4,731	-	339	12	1,292	16,845	2,947	-	194	-	-	6	90	434	11,233	-	-	-	-	38,122
2011	5,083	-	90	-	810	19,142	424	-	-	-	-	7	140	899	12,300	-	-	-	-	38,895
2012	5,393	-	16	-	397	7,380	157	1	101	-	-	-	-	744	13,125	-	-	-	-	27,314
2013	4,839	-	10	83	462	8,796	122	1	267	-	-	-	53	822	13,240	-	-	-	0	28,696
2014	4,286	-	4	167	527	10,213	86	2	433	-	-	-	106	900	13,354	-	-	-	0	30,079
2015	3,726	-	18	83	373	12,919	91	3	520	-	-	-	53	826	13,764	-	-	-	0	32,378
2016	3,165	-	33	-	219	15,626	96	3	607	-	-	-	-	752	14,174	-	-	-	-	34,676
2017	2,944	-	24	-	363	15,664	116	3	432	-	-	-	-	704	15,179	-	-	-	1	35,431
2018	2,724	-	16	-	508	15,702	136	3	257	-	-	-	-	656	16,183	-	-	-	3	36,187

Appendix B
Table B-6: Acres Irrigated Agricultural Land in Hudspeth, by Crop type

Year	Alfalfa	Asparagus	Chili/ Peppers	Cole/ Leafy Greens	Corn/ Silage	Cotton	Grain	Grapes	Hay	Legumes	Melons/ Squash	Misc/ Other	Onions	Pasture	Pecans/ Other Trees	Root Crop	Tomato	Turf	Irrigated Annuals	Total
1936	1,078	-	-	-	-	12,201	-	-	-	-	-	-	-	-	-	-	-	-	300	13,579
1937	3,650	-	-	-	-	9,000	-	-	-	-	-	-	-	-	-	-	-	-	-	12,650
1938	2,387	-	-	-	-	7,134	-	-	-	-	-	1,512	-	-	-	-	-	-	-	11,033
1939	3,077	-	-	-	-	8,201	-	-	-	-	-	2,167	-	-	-	-	-	-	-	13,445
1940	3,708	-	-	-	-	7,165	-	-	-	-	-	2,053	-	-	-	-	-	-	-	12,926
1941	3,213	-	-	-	34	8,849	-	-	-	-	-	1,223	-	-	-	-	-	-	-	13,318
1942	2,718	-	-	-	68	10,532	-	-	-	-	-	392	-	-	-	-	-	-	-	13,710
1943	3,206	-	-	-	259	9,407	-	-	-	-	-	63	-	-	-	-	-	-	1,381	14,316
1944	3,808	-	-	-	116	9,491	-	-	740	-	-	32	-	-	-	-	-	-	-	14,187
1945	4,652	-	-	-	274	9,524	-	-	-	-	-	456	-	-	-	-	-	-	-	14,905
1946	4,182	-	-	-	57	11,098	-	-	-	-	-	580	-	-	-	-	-	-	-	15,917
1947	3,659	-	-	-	41	12,866	-	-	-	-	-	316	-	-	-	-	-	-	-	16,882
1948	3,151	-	-	-	-	13,553	-	-	-	-	-	356	-	-	-	-	-	-	-	17,060
1949	2,412	-	-	-	-	14,510	-	-	-	-	-	290	-	-	-	-	-	-	-	17,212
1950	3,953	-	-	-	15	12,601	-	-	-	-	-	749	-	-	-	-	-	-	-	17,318
1951	2,599	-	-	-	-	14,653	-	-	-	-	-	-	-	500	-	-	-	-	-	17,752
1952	3,060	-	-	-	-	13,951	3	-	304	-	-	-	-	-	-	-	-	-	-	17,318
1953	3,443	-	-	-	-	12,488	-	-	-	-	-	-	-	744	-	-	-	-	-	16,675
1954	4,019	-	-	-	-	6,308	-	-	310	-	-	1,465	-	-	-	25	-	-	-	12,127
1955	1,163	-	-	-	393	3,254	417	-	220	-	-	-	-	-	-	8	-	-	-	5,455
1956	765	2	-	-	227	3,073	461	-	316	-	-	-	-	65	-	4	-	-	-	4,912
1957	366	3	-	-	60	2,892	505	-	412	-	-	-	-	130	-	-	-	-	-	4,368
1958	580	3	-	-	31	3,874	794	-	1,452	-	-	-	-	-	-	-	-	-	-	6,734
1959	677	-	-	-	-	4,326	25	-	1,509	-	-	-	-	455	-	-	-	-	-	6,992
1960	815	-	-	-	407	4,764	104	-	1,939	-	-	-	-	878	-	-	-	-	-	8,907
1961	971	-	-	-	573	5,667	105	-	1,728	-	-	-	-	617	-	-	-	-	-	9,661
1962	1,106	-	-	-	464	6,844	214	-	1,746	-	-	-	-	1,030	-	-	-	-	-	11,404
1963	770	-	-	-	324	8,742	494	-	-	-	-	-	-	938	-	-	-	-	-	11,268
1964	693	-	-	-	-	6,951	77	-	196	-	-	-	-	504	-	-	-	-	-	8,421
1965	633	-	-	-	215	5,159	213	-	979	-	-	-	-	924	-	-	-	-	-	8,123
1966	539	-	-	-	1,258	3,787	147	-	1,082	-	-	54	-	948	-	-	-	-	-	7,815
1967	511	-	-	-	1,256	4,394	499	-	565	-	-	-	-	1,019	-	-	-	-	-	8,244
1968	470	-	-	-	1,195	4,749	517	-	500	-	-	-	-	1,270	-	-	-	-	-	8,701
1969	457	-	-	-	2,690	4,798	1,260	-	1,311	-	-	-	-	2,177	-	-	-	-	-	12,693
1970	671	-	-	-	4,296	4,691	1,780	-	671	-	-	13	-	2,055	-	-	-	-	-	14,177
1971	1,003	-	-	-	3,835	4,536	1,795	-	700	-	-	11	-	2,476	-	-	-	-	-	14,355
1972	1,335	-	-	-	3,373	4,382	1,809	-	728	-	-	9	-	2,896	-	-	-	-	-	14,532
1973	1,668	-	-	-	2,912	4,227	1,824	-	757	-	-	7	-	3,317	-	-	-	-	-	14,710
1974	2,000	-	-	-	2,450	4,072	1,838	-	786	-	-	4	-	3,737	-	-	-	-	-	14,887
1975	2,332	-	-	-	1,989	3,918	1,853	-	814	-	-	2	-	4,158	-	-	-	-	-	15,065
1976	2,664	-	-	-	1,527	3,763	1,867	-	843	-	-	-	-	4,578	-	-	-	-	-	15,242
1977	2,023	-	-	-	1,225	5,268	1,286	-	649	-	-	-	-	4,375	-	-	-	-	-	14,826
1978	1,381	-	-	-	922	6,773	706	-	456	-	-	-	-	4,173	-	-	-	-	-	14,411

Appendix B
Table B-6: Acres Irrigated Agricultural Land in Hudspeth, by Crop type

Year	Alfalfa	Asparagus	Chili/ Peppers	Cole/ Leafy Greens	Corn/ Silage	Cotton	Grain	Grapes	Hay	Legumes	Melons/ Squash	Misc/ Other	Onions	Pasture	Pecans/ Other Trees	Root Crop	Tomato	Turf	Irrigated Annuals	Total
1979	740	-	-	-	620	8,278	125	-	262	-	-	-	-	3,970	-	-	-	-	-	13,995
1980	740	-	-	-	365	9,211	893	-	628	-	-	-	-	3,400	-	-	-	-	-	15,237
1981	835	-	-	-	857	8,922	496	-	317	-	-	-	-	2,536	-	-	-	-	-	13,963
1982	829	-	-	-	590	8,540	924	-	117	-	-	-	-	3,945	-	-	-	-	-	14,945
1983	869	-	-	-	247	5,563	45	-	93	-	-	-	-	4,102	-	-	-	-	-	10,919
1984	1,892	-	-	-	294	7,894	549	-	342	-	-	-	-	3,520	-	-	-	-	-	14,491
1985	751	-	-	-	233	12,591	414	-	-	-	-	-	-	1,335	-	-	-	-	-	15,324
1986	751	-	-	-	233	12,591	414	-	-	-	-	-	-	1,335	-	-	-	-	-	15,324
1987	532	-	-	-	8	13,791	157	-	150	-	-	-	-	350	55	-	-	-	-	15,043
1988	538	-	-	-	197	15,333	242	-	95	-	-	-	-	620	55	-	-	-	-	17,080
1989	450	-	-	-	194	16,377	-	-	-	-	-	-	-	163	55	-	-	-	-	17,239
1990	637	-	207	-	-	13,539	184	-	-	-	-	-	-	144	-	-	-	-	-	14,711
1991	759	-	1,080	-	-	13,378	-	-	-	-	-	-	100	262	-	-	-	-	-	15,579
1992	599	-	2,440	-	232	13,378	-	-	-	-	-	-	169	77	-	-	-	-	-	16,895
1993	422	-	2,374	-	285	10,365	80	-	99	-	-	-	218	76	-	-	-	-	-	13,919
1994	479	-	1,834	-	393	10,874	94	-	-	-	-	-	145	198	-	-	-	-	-	14,017
1995	624	-	1,602	-	223	12,331	-	-	71	-	-	-	144	389	46	-	-	-	-	15,430
1996	2,193	-	120	158	1,135	12,474	347	-	-	-	-	-	179	330	36	-	-	-	-	16,970
1997	1,080	-	1,650	-	600	11,852	-	-	-	-	-	-	-	50	46	-	-	-	-	15,278
1998	1,380	-	1,500	-	650	11,552	-	-	257	-	-	-	-	-	46	-	-	-	-	15,385
1999	1,400	-	675	-	600	12,740	-	-	-	-	-	-	-	-	46	-	-	-	-	15,461
2000	1,444	-	675	-	1,126	10,050	-	-	-	-	-	-	-	-	46	-	-	-	-	13,341
2001	1,363	-	638	-	2,085	10,104	-	-	-	-	-	-	-	-	46	-	-	-	-	14,236
2002	1,450	-	650	-	585	12,017	-	-	-	-	-	-	-	-	46	-	-	-	-	14,748
2003	920	-	200	-	460	5,018	-	-	-	-	-	-	-	-	46	-	-	-	-	6,644
2004	973	-	190	-	-	5,167	-	-	-	-	-	-	-	-	46	-	-	-	-	6,376
2005	1,102	-	-	-	-	6,988	-	-	-	-	-	-	-	-	46	-	-	-	-	8,136
2006	1,275	-	-	-	-	7,496	-	-	-	-	-	-	-	119	36	-	-	-	-	8,926
2007	1,094	-	-	-	225	7,505	200	-	651	-	-	-	-	-	46	-	-	-	-	9,721
2008	1,602	-	160	-	1,490	7,700	-	-	-	-	-	-	-	-	46	-	-	-	-	10,998
2009	1,660	-	296	-	759	8,860	221	-	246	-	-	-	-	-	46	-	-	-	-	12,088
2010	1,718	-	432	-	28	10,019	442	-	492	-	-	-	-	-	46	-	-	-	-	13,177
2011	1,528	-	216	-	14	7,094	221	-	292	-	-	-	-	151	41	-	-	-	4	9,561
2012	1,338	-	-	-	-	4,169	-	-	92	-	-	-	-	302	36	-	-	-	8	5,946
2013	1,552	-	-	6	-	4,286	198	-	90	-	-	-	-	311	38	-	-	-	4	6,486
2014	1,766	-	-	12	-	4,403	397	-	87	-	-	-	-	320	39	-	-	-	-	7,026
2015	1,490	-	-	6	-	4,006	869	-	329	-	-	-	-	215	38	-	-	-	-	6,954
2016	1,214	-	-	-	-	3,610	1,340	-	572	-	-	-	-	109	38	-	-	-	-	6,882
2017	1,009	-	-	-	435	4,023	1,213	-	355	-	-	-	-	107	49	-	-	-	-	7,191
2018	805	-	-	-	869	4,437	1,086	-	139	-	-	-	-	104	60	-	-	-	-	7,499

Appendix C
Table C-1: Accuracy Matrix 2018

Ground Truth Points (columns) / **Predicted** (rows)

	Alfalfa	Chili/ Peppers	Corn/ Silage	Cotton	Fallow	Grain	Grapes	Hay	Melons/ Squash	Onions	Pasture	Pecans/ Other Trees	Misc/ Other	Total
Alfalfa	72		1											73
Chili/Peppers		16												16
Corn/Silage			56											56
Cotton				127	3									130
Fallow			1	1	78	3			1	1		4		89
Grain						0								0
Grapes							2							2
Hay								5						5
Melons/Squash									2					2
Onions										3				3
Pasture								1			13			14
Pecans/Other Trees	2		1								2	232	3	240
Misc/Other													0	0
Total	74	16	59	128	81	3	2	6	3	4	15	236	3	630

Correctly Predicted	606	96.2%
Incorrectly Predicted	24	3.8%

Appendix C

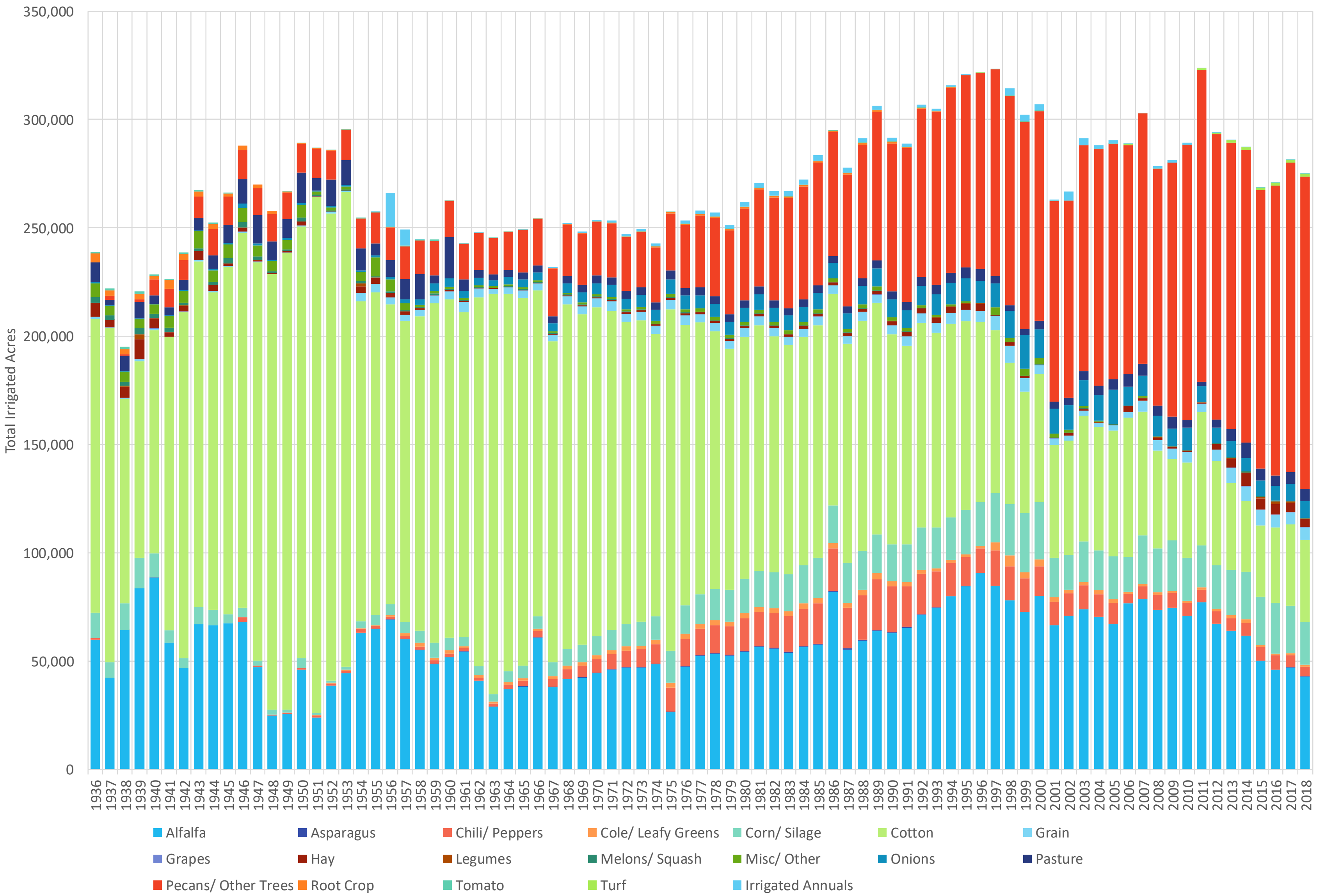
Table C-2: Accuracy Matrix 2014

Ground Truth Points

Predicted	Alfalfa	Chili/ Peppers	Cole/ Leafy Greens	Corn/ Silage	Cotton	Fallow	Grain	Grapes	Hay	Melons/ Squash	Misc/ Other	Onions	Pasture	Pecans/ Other Trees	Total
Alfalfa	105														105
Chili/Peppers		13		1	1										15
Cole/Leafy Greens			3												3
Corn/Silage				30		5	1								36
Cotton				1	120										121
Fallow						130									130
Grain							16		2						18
Grapes								2							2
Hay	1			1		1	1		15						19
Melons/Squash										1					1
Misc/Other									1		2				3
Onions			2	1		1	1					17			22
Pasture	1					1							22		24
Pecans/Other Trees														255	255
Total	107	13	5	34	121	138	19	2	18	1	2	17	22	255	754

Correctly Predicted	731	96.9%
Incorrectly Predicted	23	3.1%

Appendix D
Figure D-1: Annual Consumptive Use (ac-ft) in Rincon and Mesilla Valleys, by Crop type



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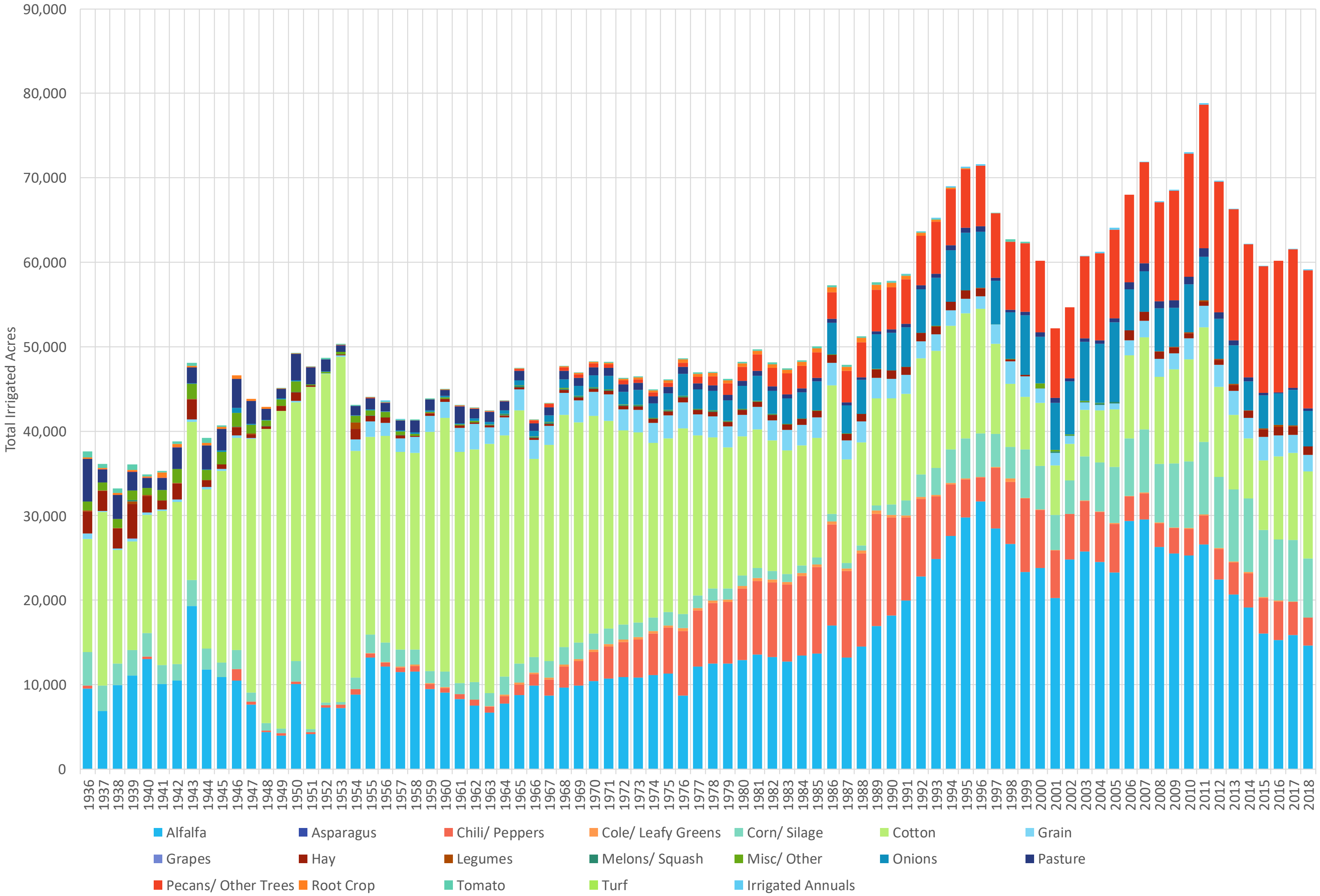
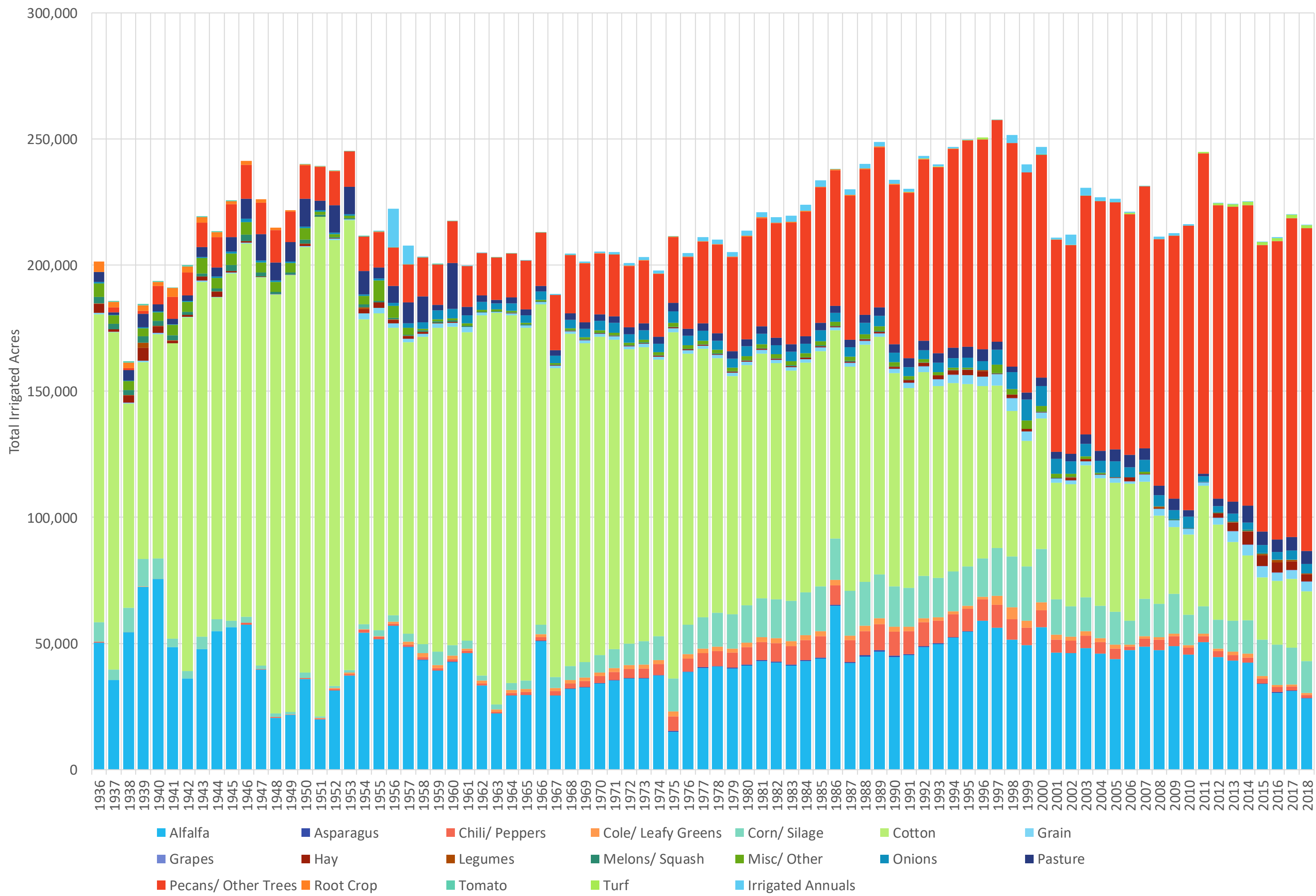
Appendix D
Figure D-2: Annual Consumptive Use (ac-ft) in Rincon Valley, by Crop type



US_MSJ_00001883

Appendix D
Figure D-3: Annual Consumptive Use (ac-ft) in Mesilla Valley, by Crop type



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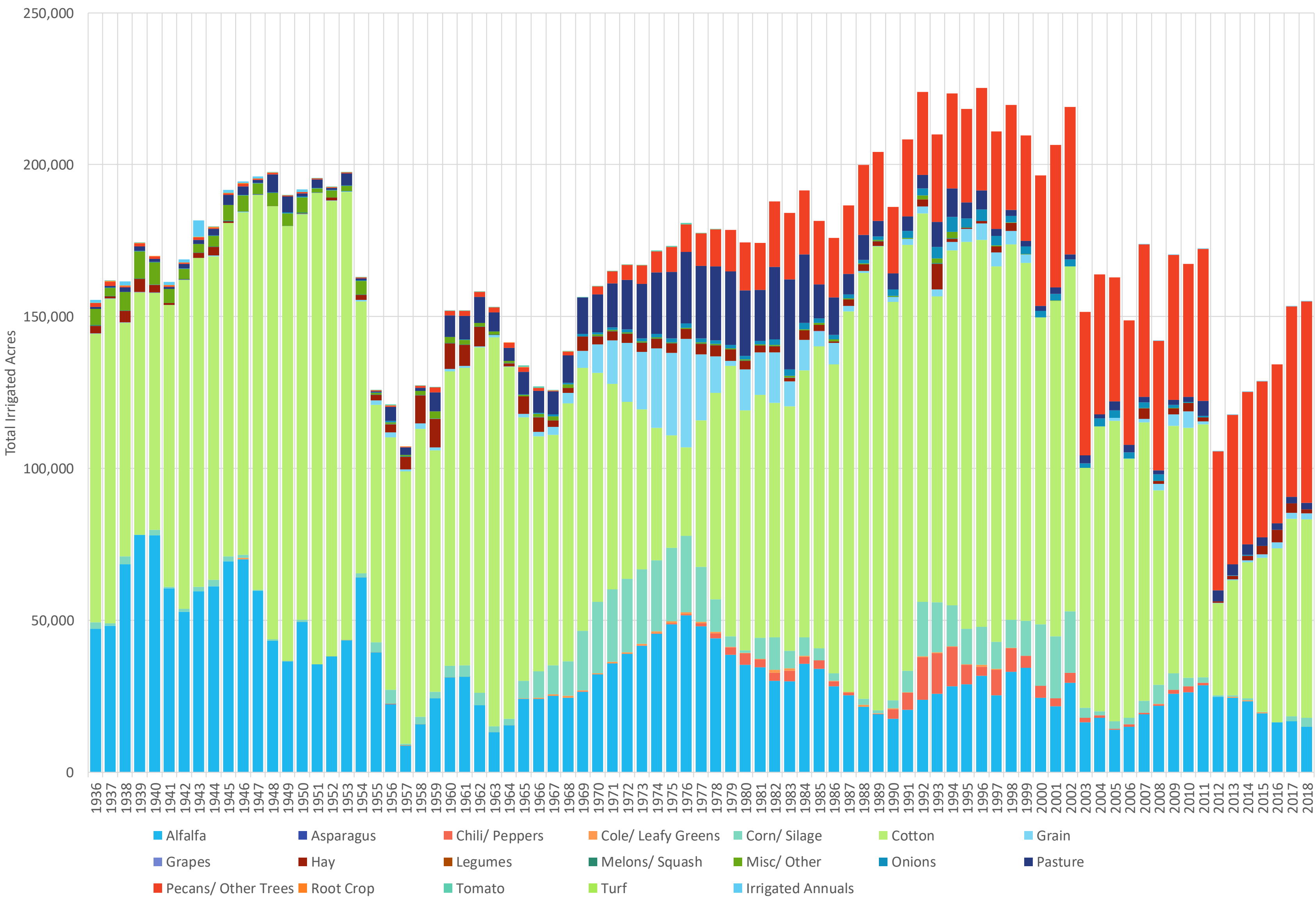
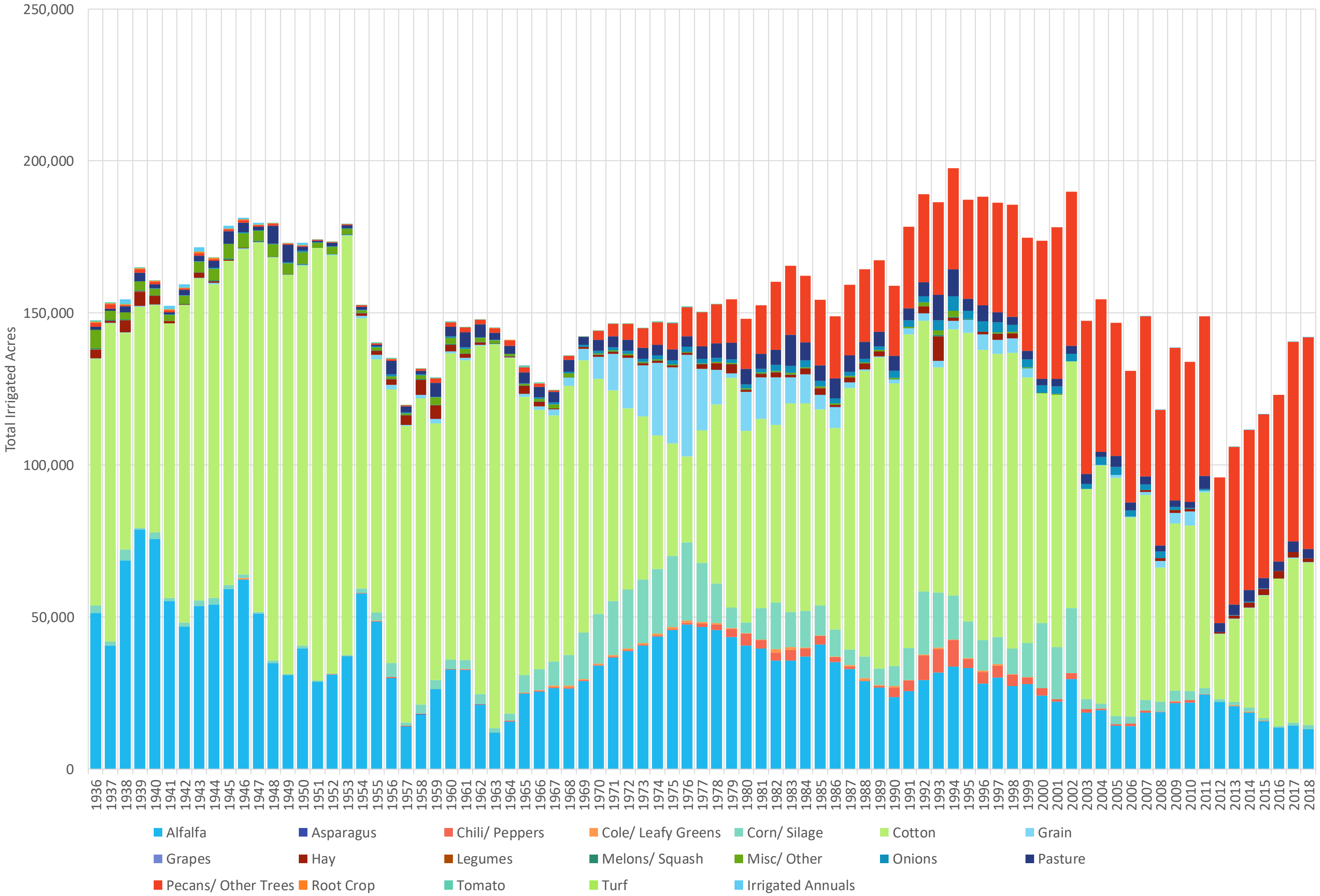
Appendix D
Figure D-4: Annual Consumptive Use (ac-ft) in El Paso Valley, by Crop type



Appendix D
Figure D-5: Annual Consumptive Use (ac-ft) in EPCWID1, by Crop type



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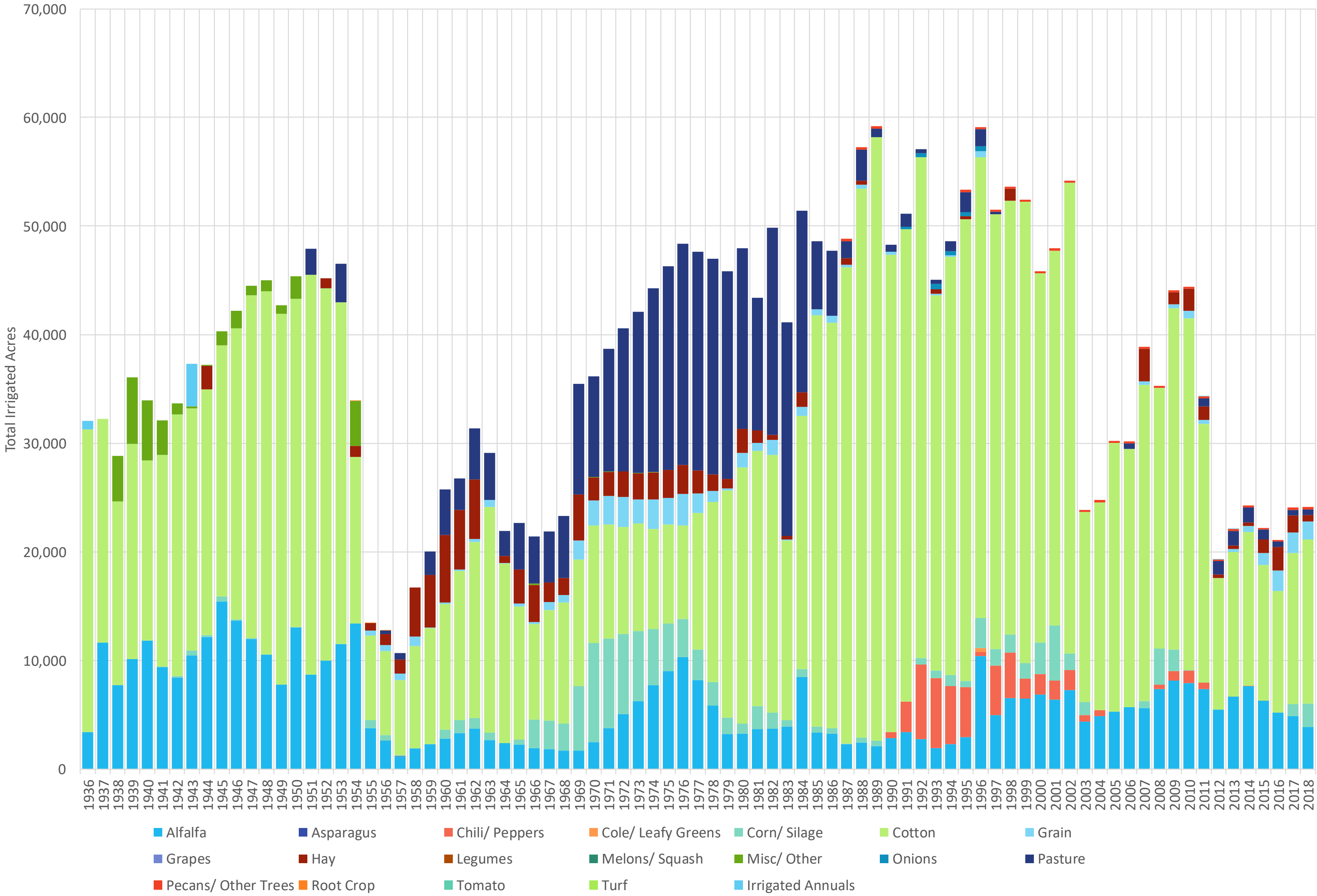
Appendix D
Figure D-6: Annual Consumptive Use (ac-ft) in Hudspeth, by Crop type



US_MSJ_00001887

Appendix D
Table D-1: Annual Consumptive Use (ac-ft) in Rincon and Mesilla Valleys, by Crop type

Year	Alfalfa	Asparagus	Chili/ Peppers	Cole/ Leafy Greens	Corn/ Silage	Cotton	Grain	Grapes	Hay	Legumes	Melons/ Squash	Misc/ Other	Onions	Pasture	Pecans/ Other Trees	Root Crop	Tomato	Turf	Irrigated Annuals	Total
1936	59,853	-	764	-	11,683	135,382	1,222	-	6,164	225	2,687	6,406	552	9,021	-	4,219	692	-	-	238,870
1937	42,373	-	-	-	7,166	154,197	328	3	3,362	113	2,065	4,287	190	2,606	1,970	2,400	849	-	-	221,908
1938	64,364	-	2	-	12,236	94,319	486	180	5,119	288	1,989	4,539	284	7,042	678	2,406	1,091	-	-	195,022
1939	83,524	-	-	73	14,021	90,862	888	62	9,133	2,202	2,805	4,245	358	7,717	1,113	2,389	1,193	-	-	220,586
1940	88,599	-	292	8	10,806	102,961	727	132	4,581	207	1,991	4,222	405	3,932	7,218	1,740	721	-	-	228,544
1941	58,556	-	-	-	5,612	135,259	291	-	2,049	206	1,893	5,366	371	3,593	8,632	4,164	410	-	-	226,402
1942	46,616	-	-	-	4,823	159,481	372	60	2,690	64	1,119	5,634	447	4,724	9,192	2,644	774	-	-	238,642
1943	66,982	-	-	-	8,035	159,386	719	31	4,055	105	1,073	7,995	370	5,816	9,767	2,342	688	-	-	267,365
1944	66,609	-	-	-	7,176	146,370	601	42	2,772	60	1,345	5,220	792	6,212	12,113	2,329	878	-	-	252,520
1945	67,344	-	-	-	4,242	160,262	593	22	1,105	19	2,450	6,126	899	8,185	13,128	1,424	486	-	-	266,285
1946	67,960	-	2,154	-	4,450	173,032	626	22	1,700	73	2,622	6,559	1,921	11,383	13,330	2,014	-	-	-	287,846
1947	47,204	-	742	-	2,305	183,847	220	29	530	340	1,625	4,892	941	13,120	12,509	1,587	-	-	-	269,892
1948	24,912	-	459	-	2,276	200,940	91	24	430	41	749	4,675	538	8,479	12,803	1,297	-	-	-	257,712
1949	25,609	-	613	-	1,391	210,873	28	14	759	12	677	4,449	801	8,761	12,182	633	11	-	-	266,813
1950	45,957	-	659	-	4,639	199,218	545	19	1,896	23	1,710	5,756	858	14,179	13,201	276	115	-	-	289,052
1951	23,976	-	778	229	912	238,365	75	10	160	5	703	1,379	533	5,832	13,566	123	113	-	-	286,758
1952	38,719	-	872	416	930	215,687	567	9	215	-	509	1,353	648	12,195	13,549	90	307	-	-	286,067
1953	44,527	-	1,070	486	1,218	219,250	444	6	182	13	433	1,261	720	11,492	14,068	86	242	-	-	295,498
1954	63,159	-	1,673	275	3,365	147,654	3,776	6	2,934	1,402	1,164	4,203	618	10,275	13,657	99	420	-	-	254,681
1955	64,990	4	1,246	348	4,558	148,923	4,084	-	2,726	120	628	8,646	940	5,629	14,130	102	480	-	6	257,561
1956	69,120	72	1,210	838	5,006	138,380	3,120	6	2,214	68	586	5,431	1,319	7,651	15,193	75	350	-	15,250	265,889
1957	60,078	136	1,323	1,288	5,129	139,016	2,877	6	1,474	70	547	3,079	1,877	9,492	15,002	44	366	-	7,428	249,231
1958	55,026	201	1,482	1,775	5,470	145,103	2,947	9	859	72	543	876	2,648	11,709	15,423	16	406	-	14	244,580
1959	48,661	123	1,551	1,320	6,702	156,747	3,623	6	361	14	688	999	3,545	3,595	15,906	46	656	-	-	244,541
1960	51,744	108	1,552	1,542	5,914	156,134	3,572	6	749	22	511	947	3,925	18,988	16,493	52	305	-	-	262,564
1961	54,398	57	1,616	838	4,376	149,594	4,996	3	313	3	482	892	3,342	5,324	16,230	62	138	-	58	242,722
1962	40,908	-	1,467	1,061	4,267	170,054	4,258	3	166	3	263	999	3,503	3,523	16,998	56	42	-	57	247,628
1963	28,904	4	1,434	927	3,539	184,629	2,436	3	272	-	172	814	2,656	2,646	16,759	47	30	-	-	245,274
1964	37,156	4	1,872	1,305	4,938	174,126	3,067	3	284	6	395	625	3,484	3,354	17,375	33	74	-	-	248,100
1965	38,299	29	2,540	1,353	5,646	169,702	3,407	9	342	7	399	669	3,653	3,398	19,569	70	82	-	122	249,294
1966	60,846	49	2,791	1,329	5,709	150,296	3,237	-	328	6	351	675	3,807	3,108	21,537	89	77	-	-	254,235
1967	38,039	73	3,567	1,445	6,398	148,002	3,157	18	397	6	357	720	3,629	3,254	22,262	131	87	-	354	231,896
1968	41,638	105	4,574	1,554	7,511	159,168	3,732	27	466	6	388	833	4,416	3,454	23,616	182	105	-	469	252,245
1969	42,423	131	5,354	1,590	8,122	152,401	3,700	34	502	6	384	898	4,518	3,445	23,825	218	113	-	603	248,266
1970	44,529	159	6,293	1,693	8,846	151,796	4,038	40	556	5	387	981	5,057	3,524	24,629	262	124	-	730	253,651
1971	45,977	184	6,981	1,797	9,509	147,108	4,505	46	600	5	384	1,033	5,454	3,571	24,854	299	130	-	841	253,278
1972	46,993	212	7,601	1,971	10,206	139,631	3,651	52	636	5	381	1,072	4,783	3,584	24,857	334	135	-	943	247,047
1973	46,858	233	8,349	1,740	11,021	139,104	3,916	56	658	5	358	1,129	5,583	3,473	25,491	356	136	-	1,056	249,521
1974	48,454	261	9,096	1,999	10,928	130,320	3,552	64	701	4	367	1,181	5,181	3,541	25,343	408	147	-	1,168	242,716
1975	26,371	350	11,065	2,233	14,716	157,660	4,373	-	799	4	419	1,524	6,615	4,155	26,387	480	160	-	-	257,310
1976	47,357	308	12,753	2,122	13,174	129,531	4,349	77	886	4	365	1,353	6,393	3,626	28,852	560	196	-	1,448	253,355
1977	52,367	340	12,223	2,029	13,850	125,456	3,725	84	829	3	360	1,414	6,196	3,585	33,249	523	174	-	1,620	258,026
1978	53,228	361	13,023	2,142	14,680	118,850	3,742	88	869	3	362	1,443	5,994	3,588	36,116	575	187	-	1,746	256,997

Appendix D
Table D-1: Annual Consumptive Use (ac-ft) in Rincon and Mesilla Valleys, by Crop type

Year	Alfalfa	Asparagus	Chili/ Peppers	Cole/ Leafy Greens	Corn/ Silage	Cotton	Grain	Grapes	Hay	Legumes	Melons/ Squash	Misc/ Other	Onions	Pasture	Pecans/ Other Trees	Root Crop	Tomato	Turf	Irrigated Annuals	Total
1979	52,472	368	13,247	2,037	14,718	111,190	3,764	91	886	3	332	1,412	6,046	3,466	38,757	578	185	-	1,794	251,345
1980	54,148	400	15,277	2,156	15,998	111,723	3,827	99	933	2	352	1,585	6,559	3,506	42,307	658	204	-	2,033	261,768
1981	56,452	429	15,825	2,289	16,705	113,372	3,999	105	1,028	2	343	1,598	7,102	3,571	44,825	681	210	-	2,035	270,572
1982	55,714	439	15,992	2,273	16,478	109,025	3,645	108	1,061	2	327	1,577	6,400	3,493	47,468	685	208	-	2,140	267,036
1983	53,900	442	16,528	2,127	17,074	105,805	3,702	110	1,072	1	305	1,593	6,919	3,288	50,802	684	202	-	2,327	266,881
1984	56,443	474	17,174	2,484	17,693	105,281	3,777	116	1,177	1	309	1,618	6,925	3,391	52,072	727	211	-	2,330	272,206
1985	57,603	494	18,625	2,389	18,526	107,414	3,820	123	1,250	1	310	1,721	7,610	3,395	56,766	764	218	-	2,559	283,588
1986	81,876	463	19,687	2,424	17,394	97,655	3,844	-	1,390	1	275	1,556	7,224	3,211	56,996	805	245	-	-	295,049
1987	55,340	500	18,825	2,226	18,402	101,155	3,510	120	1,302	0	279	1,661	7,182	3,229	60,855	760	209	-	2,305	277,861
1988	59,351	553	20,392	2,610	18,007	106,189	3,907	134	1,423	0	289	1,760	8,487	3,521	61,748	820	224	-	1,963	291,379
1989	63,656	599	23,543	2,833	17,925	106,844	3,717	144	1,600	-	303	1,879	8,180	3,770	68,271	970	271	-	1,834	306,338
1990	62,819	463	21,181	2,244	17,156	97,063	3,978	118	1,706	44	242	1,575	8,345	3,654	68,298	771	219	27	1,558	291,461
1991	65,387	383	18,802	2,052	17,200	91,789	4,248	98	1,895	89	205	1,321	8,386	3,818	70,967	639	181	55	1,269	288,784
1992	71,344	320	18,706	1,765	19,432	94,599	4,257	88	2,184	140	174	1,242	8,820	4,184	77,716	522	148	84	1,146	306,870
1993	74,665	236	16,401	1,576	18,811	89,721	4,660	69	2,391	184	142	1,015	9,461	4,370	79,798	388	111	108	879	304,987
1994	79,956	159	15,193	1,356	19,707	89,351	4,993	55	2,664	233	110	856	9,807	4,687	85,515	269	77	138	671	315,796
1995	84,534	81	13,480	1,167	20,474	86,973	5,282	40	2,921	304	75	673	10,680	4,939	88,665	133	37	169	429	321,055
1996	90,654	-	11,385	1,006	20,332	83,084	5,245	24	3,158	338	42	-	10,251	5,401	90,266	-	-	643	181	322,010
1997	84,628	-	16,445	3,613	22,847	75,049	6,712	42	229	-	133	3,529	10,996	3,525	95,430	-	174	-	-	323,352
1998	78,073	-	15,543	5,205	23,781	65,149	7,635	80	1,779	-	-	2,070	12,304	2,507	96,639	-	291	-	3,223	314,279
1999	72,637	-	15,641	2,739	27,287	56,008	6,136	110	1,104	-	74	3,218	15,370	3,120	95,555	-	168	-	3,101	302,268
2000	80,120	-	13,630	3,288	26,332	59,094	4,048	127	189	-	145	2,791	13,291	4,055	96,737	-	280	-	2,898	307,025
2001	66,588	-	10,745	2,071	18,205	52,016	3,095	101	59	72	285	1,828	11,344	3,409	92,493	-	199	-	583	263,094
2002	71,005	-	10,294	1,658	15,951	52,761	2,305	95	1,128	149	122	1,453	11,106	3,463	91,030	-	137	-	4,050	266,708
2003	73,938	-	10,956	1,706	18,587	57,999	2,342	102	639	198	175	1,035	12,042	4,057	104,322	-	106	-	3,113	291,315
2004	70,396	-	10,526	1,763	18,484	56,715	2,017	100	43	214	222	452	11,851	4,351	109,188	-	65	-	1,712	288,100
2005	67,090	-	9,875	1,637	19,793	57,956	2,431	99	69	233	257	6	15,693	5,062	108,488	-	18	5	1,690	290,401
2006	76,746	-	4,320	838	16,198	64,172	2,614	109	2,788	22	52	-	8,786	5,835	105,646	-	-	607	348	289,082
2007	78,395	-	6,133	1,158	22,193	57,345	4,776	95	1,159	163	50	766	9,416	5,562	115,669	-	-	8	42	302,930
2008	73,621	-	7,042	988	20,290	45,128	4,822	70	910	788	130	148	9,276	4,759	109,401	-	-	5	1,111	278,488
2009	74,511	-	6,911	1,103	23,266	37,548	4,643	3	751	216	251	113	8,025	5,571	117,236	-	-	5	1,103	281,255
2010	70,828	-	6,025	1,058	19,798	43,957	4,736	77	603	159	90	57	10,253	3,515	127,185	-	-	3	896	289,240
2011	77,127	-	5,788	1,015	19,510	61,346	3,819	182	466	157	137	-	7,303	2,010	143,928	-	-	693	224	323,705
2012	67,110	-	5,800	1,187	19,993	48,311	5,125	187	2,330	171	338	-	7,214	3,648	131,684	-	-	872	174	294,144
2013	63,918	-	5,922	1,415	20,818	40,078	6,922	203	4,164	178	532	-	7,485	5,400	132,262	-	-	1,085	134	290,515
2014	61,476	154	6,023	1,706	21,867	32,718	6,608	224	5,998	182	739	-	6,080	7,133	134,953	-	-	1,309	99	287,270
2015	49,899	202	6,248	1,028	22,328	32,994	7,132	219	5,066	667	487	-	6,988	5,632	128,378	-	-	1,237	209	268,714
2016	45,713	269	6,646	796	23,378	34,983	5,699	227	4,877	1,148	307	-	6,668	4,972	133,864	-	-	1,263	327	271,137
2017	47,041	248	5,489	822	21,928	37,483	5,510	205	4,350	640	227	-	7,692	5,617	142,870	-	-	1,290	260	281,673
2018	42,849	216	4,452	802	19,568	37,994	5,750	178	3,808	219	144	-	7,807	5,641	144,188	-	-	1,266	200	275,083

Appendix D

Table D-2: Annual Consumptive Use (ac-ft) in Rincon Valley, by Crop type

Year	Alfalfa	Asparagus	Chili/ Peppers	Cole/ Leafy Greens	Corn/ Silage	Cotton	Grain	Grapes	Hay	Legumes	Melons/ Squash	Misc/ Other	Onions	Pasture	Pecans/ Other Trees	Root Crop	Tomato	Turf	Irrigated Annuals	Total
1936	9,527	-	359	-	3,955	13,393	667	-	2,567	127	-	1,066	1	5,075	-	157	692	-	-	37,587
1937	6,837	-	-	-	3,038	20,567	96	3	2,362	75	-	939	9	1,560	54	112	471	-	-	36,122
1938	9,920	-	-	-	2,595	13,413	195	15	2,364	45	-	1,070	-	2,829	29	213	524	-	-	33,211
1939	11,043	-	-	-	3,038	12,856	326	21	4,089	276	204	1,116	2	2,213	21	196	655	-	-	36,057
1940	13,013	-	292	-	2,777	13,984	312	6	1,970	83	32	813	2	1,174	43	128	259	-	-	34,889
1941	10,043	-	-	-	2,274	18,235	193	-	1,032	44	-	1,215	4	1,426	28	606	178	-	-	35,277
1942	10,504	-	-	-	1,942	19,179	290	18	1,906	14	-	1,663	35	2,540	33	338	301	-	-	38,762
1943	19,284	-	-	-	3,107	18,681	309	3	2,371	68	5	1,764	35	1,917	22	189	343	-	-	48,098
1944	11,760	-	-	-	2,514	18,820	277	6	817	8	23	1,170	96	2,817	-	325	546	-	-	39,178
1945	10,889	-	-	-	1,734	22,650	234	-	556	3	24	1,474	146	2,570	13	190	212	-	-	40,694
1946	10,495	-	1,353	-	2,225	25,122	276	-	1,001	13	60	1,644	573	3,429	22	402	-	-	-	46,614
1947	7,648	-	349	-	1,083	29,979	110	6	454	119	2	999	120	2,723	3	198	-	-	-	43,792
1948	4,363	-	185	-	878	34,812	42	-	303	6	29	654	44	1,308	34	208	-	-	-	42,867
1949	3,977	-	289	-	526	37,592	15	-	587	5	-	777	101	1,125	15	47	11	-	-	45,067
1950	10,049	-	278	-	2,470	30,638	174	-	986	5	52	1,248	116	3,142	-	23	12	-	-	49,193
1951	4,162	-	231	-	346	40,486	6	-	160	2	3	131	13	2,041	17	9	7	-	-	47,613
1952	7,269	-	315	-	303	38,920	22	-	7	-	24	154	65	1,420	-	-	159	-	-	48,657
1953	7,240	-	404	-	296	40,834	187	-	129	-	22	265	34	762	25	9	152	-	-	50,360
1954	8,807	-	650	-	1,359	26,847	1,351	-	1,250	775	8	752	57	1,135	-	-	126	-	-	43,118
1955	13,225	-	426	52	2,217	23,423	1,817	-	657	6	19	611	136	1,309	75	1	98	-	-	44,073
1956	12,141	-	449	56	2,328	24,466	1,522	-	660	7	20	641	79	1,007	25	1	107	-	141	43,650
1957	11,498	-	532	106	2,012	23,398	1,621	-	351	4	19	427	111	1,185	25	1	109	-	69	41,467
1958	11,554	-	634	157	1,796	23,298	1,909	-	78	2	18	233	155	1,413	27	-	120	-	-	41,394
1959	9,478	-	585	121	1,429	28,307	1,902	-	311	2	15	155	131	1,320	-	14	137	-	-	43,905
1960	9,035	-	523	149	1,844	30,021	1,892	-	348	-	12	152	179	738	20	22	61	-	-	44,998
1961	8,293	-	592	4	1,286	27,347	2,866	-	313	2	6	86	98	2,056	32	41	16	-	-	43,038
1962	7,540	-	662	5	2,118	27,504	3,042	-	156	3	3	172	320	1,113	66	49	36	-	-	42,789
1963	6,710	-	681	64	1,546	29,494	1,954	-	262	-	9	83	292	1,204	67	35	7	-	-	42,408
1964	7,774	-	858	212	2,107	28,521	2,148	-	210	6	151	77	412	1,047	52	26	27	-	-	43,630
1965	8,729	-	1,290	236	2,224	30,007	2,446	-	251	7	156	80	587	1,097	252	51	38	-	-	47,451
1966	9,867	-	1,358	204	1,804	23,506	2,221	-	226	6	122	65	641	879	368	59	38	-	-	41,364
1967	8,709	-	1,887	244	1,941	25,572	2,242	-	278	6	130	70	778	969	382	88	51	-	-	43,348
1968	9,647	-	2,463	258	2,056	27,496	2,639	-	322	6	136	75	1,050	1,006	409	122	66	-	-	47,749
1969	9,856	-	2,905	260	1,981	26,041	2,602	-	343	6	129	73	1,171	965	417	144	74	-	-	46,967
1970	10,409	-	3,438	273	1,946	25,741	2,826	-	375	5	125	74	1,410	953	434	172	85	-	-	48,266
1971	10,704	-	3,799	283	1,874	24,570	3,128	-	397	5	117	71	1,602	924	442	193	93	-	-	48,202
1972	10,898	-	4,124	303	1,805	22,947	2,514	-	416	5	110	67	1,471	886	445	214	101	-	-	46,306
1973	10,825	-	4,518	262	1,752	22,466	2,675	-	423	5	97	65	1,789	817	460	227	105	-	-	46,487
1974	11,152	-	4,911	294	1,563	20,659	2,406	-	447	4	94	63	1,723	793	461	258	118	-	-	44,946
1975	11,334	-	5,400	270	1,581	20,569	2,735	-	464	4	85	61	1,982	751	483	278	125	-	-	46,122
1976	8,710	-	7,621	349	1,697	21,968	3,062	-	597	4	87	70	2,630	811	489	381	169	-	-	48,646
1977	12,124	-	6,644	287	1,461	19,001	2,482	-	517	3	75	60	2,298	696	804	329	148	-	-	46,930
1978	12,485	-	7,147	303	1,409	17,925	2,492	-	543	3	70	58	2,317	669	1,090	363	163	-	-	47,036

Appendix D
Table D-2: Annual Consumptive Use (ac-ft) in Rincon Valley, by Crop type

Year	Alfalfa	Asparagus	Chili/ Peppers	Cole/ Leafy Greens	Corn/ Silage	Cotton	Grain	Grapes	Hay	Legumes	Melons/ Squash	Misc/ Other	Onions	Pasture	Pecans/ Other Trees	Root Crop	Tomato	Turf	Irrigated Annuals	Total
1979	12,468	-	7,333	288	1,281	16,691	2,505	-	552	3	59	53	2,430	619	1,364	367	164	-	-	46,177
1980	12,907	-	8,452	301	1,262	16,483	2,534	-	580	2	56	56	2,698	593	1,671	416	185	-	-	48,196
1981	13,526	-	8,748	315	1,198	16,423	2,634	-	636	2	49	52	2,984	571	1,936	430	192	-	-	49,698
1982	13,276	-	8,830	309	1,046	15,442	2,384	-	652	2	41	48	2,742	525	2,203	432	193	-	-	48,124
1983	12,739	-	9,115	285	950	14,631	2,402	-	652	1	33	45	3,016	462	2,502	430	191	-	-	47,454
1984	13,414	-	9,460	328	888	14,223	2,440	-	714	1	28	43	3,070	447	2,695	455	201	-	-	48,408
1985	13,653	-	10,244	312	821	14,144	2,452	-	754	1	23	43	3,425	418	3,065	478	210	-	-	50,041
1986	17,016	-	11,939	384	872	15,238	2,663	-	915	1	19	45	3,730	450	3,192	547	241	-	-	57,251
1987	13,177	-	10,270	283	649	12,289	2,233	-	782	0	10	36	3,322	334	3,754	474	207	-	-	47,820
1988	14,474	-	11,060	327	594	12,215	2,489	-	863	0	5	35	3,980	331	4,135	509	222	-	-	51,240
1989	16,914	-	13,301	384	585	12,675	2,452	-	1,013	-	-	39	4,095	351	4,908	625	271	-	-	57,612
1990	18,148	-	11,649	303	1,195	12,557	2,366	-	956	2	-	32	4,456	369	5,004	504	219	-	26	57,787
1991	19,930	-	9,825	266	1,800	12,571	2,252	-	943	4	-	26	4,675	404	5,288	418	181	-	49	58,632
1992	22,806	-	9,173	217	2,695	13,746	2,010	-	981	6	-	23	5,118	462	5,879	342	148	-	80	63,686
1993	24,872	-	7,394	179	3,228	13,817	1,956	-	980	8	-	16	5,690	501	6,119	255	111	-	104	65,232
1994	27,613	-	6,103	137	4,011	14,592	1,854	-	1,005	10	-	11	6,097	555	6,639	177	77	-	135	69,017
1995	29,780	-	4,512	96	4,728	14,827	1,702	-	1,006	12	-	6	6,790	593	6,962	86	37	-	161	71,298
1996	31,654	-	2,842	55	5,180	14,767	1,437	-	999	14	-	-	6,680	631	7,160	-	-	-	181	71,599
1997	28,467	-	7,188	93	3,900	10,704	2,263	-	-	-	-	36	5,150	355	7,622	-	6	-	-	65,786
1998	26,627	-	7,357	437	3,713	7,490	2,654	-	243	-	-	21	5,503	304	8,068	-	286	-	-	62,702
1999	23,338	-	8,681	89	5,724	6,240	2,394	-	204	-	-	6	7,043	388	8,160	-	163	-	-	62,430
2000	23,775	-	6,923	50	5,152	7,449	1,734	-	9	-	-	548	5,497	564	8,476	-	-	-	-	60,177
2001	20,269	-	5,593	61	4,154	5,853	1,495	-	-	-	167	213	5,519	597	8,263	-	-	-	-	52,184
2002	24,781	-	5,420	10	3,941	4,333	963	-	-	-	21	169	6,276	361	8,367	-	-	-	-	54,641
2003	25,777	-	5,949	55	5,206	5,504	890	-	-	1	84	126	6,956	418	9,710	-	-	-	82	60,758
2004	24,513	-	5,908	102	5,771	6,147	682	-	-	2	146	64	6,979	445	10,285	-	-	-	165	61,210
2005	23,291	-	5,726	134	6,605	6,819	710	-	-	3	202	-	9,418	467	10,482	-	-	-	246	64,103
2006	29,360	-	2,900	88	6,808	9,812	1,802	-	1,141	-	-	-	4,852	877	10,362	-	-	-	-	68,002
2007	29,564	-	3,072	93	7,503	10,843	1,991	-	1,047	27	-	-	4,803	931	11,937	-	-	-	39	71,852
2008	26,266	-	2,810	91	6,973	10,289	2,151	-	831	53	-	-	5,084	850	11,723	-	-	-	72	67,194
2009	25,494	-	3,036	91	7,579	11,087	1,910	-	699	86	-	-	4,595	883	13,001	-	-	-	117	68,580
2010	25,310	-	3,116	93	7,887	12,065	2,507	-	576	114	-	-	5,708	917	14,553	-	-	-	161	73,009
2011	26,586	-	3,460	112	8,566	13,577	2,549	-	466	157	-	-	5,178	1,025	16,949	-	-	-	224	78,849
2012	22,434	-	3,595	122	8,458	10,651	2,576	-	580	120	-	-	4,744	780	15,463	-	-	-	142	69,665
2013	20,662	-	3,782	138	8,530	8,792	2,869	-	728	85	-	-	4,545	630	15,487	-	-	-	73	66,321
2014	19,151	-	4,014	160	8,717	7,125	2,376	-	880	53	-	-	3,390	488	15,760	-	-	-	10	62,123
2015	16,039	-	4,212	129	7,904	8,249	2,777	-	899	132	-	-	3,907	287	14,957	-	-	-	5	59,497
2016	15,286	-	4,528	151	7,241	9,797	2,473	-	1,044	209	-	-	3,737	132	15,561	-	-	-	-	60,158
2017	15,892	-	3,876	86	7,256	10,326	2,128	-	1,008	98	7	-	4,211	250	16,384	-	-	-	47	61,572
2018	14,638	-	3,308	17	6,943	10,314	1,990	-	962	-	15	-	4,184	343	16,329	-	-	-	94	59,137

Appendix D
Table D-3: Annual Consumptive Use (ac-ft) in Mesilla Valley, by Crop type

Year	Alfalfa	Asparagus	Chili/ Peppers	Cole/ Leafy Greens	Corn/ Silage	Cotton	Grain	Grapes	Hay	Legumes	Melons/ Squash	Misc/ Other	Onions	Pasture	Pecans/ Other Trees	Root Crop	Tomato	Turf	Irrigated Annuals	Total
1936	50,325	-	405	-	7,728	121,989	554	-	3,597	99	2,687	5,340	551	3,945	-	4,062	-	-	-	201,284
1937	35,536	-	-	-	4,127	133,631	232	-	1,001	38	2,065	3,347	181	1,046	1,916	2,287	377	-	-	185,786
1938	54,444	-	2	-	9,641	80,906	291	165	2,755	243	1,989	3,470	284	4,213	649	2,193	567	-	-	161,811
1939	72,481	-	-	73	10,983	78,007	561	41	5,044	1,926	2,602	3,128	356	5,504	1,092	2,192	538	-	-	184,529
1940	75,586	-	-	8	8,029	88,977	415	126	2,612	124	1,960	3,409	403	2,758	7,175	1,612	462	-	-	193,655
1941	48,513	-	-	-	3,338	117,025	97	-	1,017	162	1,893	4,151	368	2,167	8,604	3,559	232	-	-	191,124
1942	36,112	-	-	-	2,881	140,302	83	41	784	50	1,119	3,971	413	2,184	9,159	2,306	474	-	-	199,880
1943	47,698	-	-	-	4,928	140,706	410	28	1,684	36	1,068	6,231	335	3,899	9,745	2,153	346	-	-	219,267
1944	54,850	-	-	-	4,663	127,549	324	36	1,955	52	1,322	4,050	696	3,395	12,113	2,003	332	-	-	213,342
1945	56,456	-	-	-	2,508	137,612	358	22	550	16	2,426	4,652	753	5,615	13,116	1,234	274	-	-	225,591
1946	57,466	-	801	-	2,226	147,910	350	22	699	60	2,562	4,915	1,348	7,954	13,308	1,612	-	-	-	241,231
1947	39,556	-	394	-	1,222	153,868	109	23	77	220	1,623	3,893	821	10,398	12,506	1,389	-	-	-	226,100
1948	20,549	-	273	-	1,397	166,128	49	24	127	34	720	4,021	493	7,171	12,769	1,088	-	-	-	214,845
1949	21,632	-	324	-	865	173,281	13	14	173	7	677	3,673	699	7,636	12,167	586	-	-	-	221,746
1950	35,908	-	381	-	2,169	168,580	371	19	910	18	1,659	4,508	742	11,037	13,201	253	103	-	-	239,859
1951	19,814	-	548	229	566	197,879	70	10	-	3	700	1,248	520	3,791	13,549	113	106	-	-	239,145
1952	31,450	-	557	416	628	176,767	544	9	209	-	485	1,199	583	10,775	13,549	90	149	-	-	237,410
1953	37,287	-	666	486	922	178,416	257	6	53	13	411	995	685	10,730	14,043	77	90	-	-	245,138
1954	54,352	-	1,023	275	2,006	120,807	2,425	6	1,684	627	1,156	3,451	561	9,139	13,657	99	294	-	-	211,563
1955	51,764	4	820	295	2,342	125,500	2,267	-	2,069	113	610	8,035	804	4,321	14,055	101	383	-	6	213,488
1956	56,979	72	762	782	2,678	113,914	1,598	6	1,554	61	566	4,790	1,241	6,644	15,167	74	244	-	15,109	222,240
1957	48,580	136	791	1,182	3,116	115,618	1,256	6	1,123	66	528	2,651	1,767	8,307	14,977	44	256	-	7,360	207,764
1958	43,472	201	848	1,618	3,674	121,805	1,038	9	780	71	525	643	2,493	10,296	15,397	16	286	-	14	203,186
1959	39,184	123	966	1,199	5,274	128,440	1,720	6	50	12	674	844	3,414	2,275	15,906	31	519	-	-	200,636
1960	42,708	108	1,029	1,393	4,069	126,113	1,680	6	401	22	499	795	3,747	18,250	16,473	30	244	-	-	217,566
1961	46,105	57	1,024	834	3,090	122,247	2,130	3	-	2	476	806	3,244	3,268	16,198	21	121	-	58	199,684
1962	33,368	-	805	1,056	2,149	142,550	1,215	3	10	-	260	827	3,183	2,410	16,933	7	7	-	57	204,838
1963	22,195	4	753	864	1,992	155,135	482	3	10	-	163	731	2,364	1,442	16,692	12	23	-	-	202,866
1964	29,383	4	1,014	1,093	2,831	145,604	919	3	74	-	243	548	3,071	2,307	17,323	7	46	-	-	204,470
1965	29,570	29	1,250	1,117	3,422	139,695	961	9	91	-	242	589	3,066	2,301	19,317	19	44	-	122	201,843
1966	50,979	49	1,432	1,125	3,905	126,790	1,016	-	102	-	229	610	3,166	2,230	21,169	30	39	-	-	212,871
1967	29,330	73	1,680	1,201	4,457	122,431	915	18	119	-	227	649	2,851	2,285	21,880	43	37	-	354	188,547
1968	31,992	105	2,112	1,295	5,455	131,672	1,093	27	144	-	253	758	3,366	2,448	23,207	61	40	-	469	204,496
1969	32,567	131	2,449	1,330	6,141	126,360	1,098	34	159	-	255	824	3,347	2,480	23,408	74	38	-	603	201,298
1970	34,120	159	2,856	1,420	6,900	126,055	1,212	40	181	-	263	907	3,646	2,572	24,195	90	39	-	730	205,385
1971	35,272	184	3,182	1,514	7,636	122,538	1,377	46	203	-	267	963	3,852	2,648	24,412	105	36	-	841	205,076
1972	36,095	212	3,477	1,668	8,401	116,684	1,137	52	220	-	271	1,004	3,313	2,699	24,412	120	34	-	943	200,741
1973	36,033	233	3,831	1,478	9,269	116,637	1,241	56	235	-	261	1,064	3,793	2,656	25,031	129	31	-	1,056	203,033
1974	37,302	261	4,185	1,705	9,366	109,661	1,146	64	255	-	273	1,118	3,458	2,748	24,883	150	30	-	1,168	197,771
1975	15,037	350	5,666	1,963	13,134	137,091	1,637	-	334	-	334	1,463	4,633	3,404	25,904	202	35	-	-	211,189
1976	38,647	308	5,132	1,773	11,477	107,563	1,287	77	289	-	278	1,283	3,763	2,815	28,363	179	27	-	1,448	204,709
1977	40,243	340	5,578	1,743	12,389	106,455	1,244	84	311	-	285	1,354	3,898	2,889	32,444	193	26	-	1,620	211,096
1978	40,744	361	5,876	1,840	13,271	100,925	1,250	88	326	-	292	1,385	3,677	2,919	35,026	211	24	-	1,746	209,961

Appendix D
Table D-3: Annual Consumptive Use (ac-ft) in Mesilla Valley, by Crop type

Year	Alfalfa	Asparagus	Chili/ Peppers	Cole/ Leafy Greens	Corn/ Silage	Cotton	Grain	Grapes	Hay	Legumes	Melons/ Squash	Misc/ Other	Onions	Pasture	Pecans/ Other Trees	Root Crop	Tomato	Turf	Irrigated Annuals	Total
1979	40,004	368	5,915	1,749	13,437	94,498	1,259	91	334	-	273	1,359	3,616	2,847	37,393	211	21	-	1,794	205,168
1980	41,241	400	6,825	1,855	14,736	95,240	1,293	99	354	-	295	1,529	3,861	2,913	40,636	242	19	-	2,033	213,571
1981	42,926	429	7,077	1,974	15,507	96,949	1,365	105	392	-	294	1,546	4,118	2,999	42,889	251	18	-	2,035	220,874
1982	42,438	439	7,161	1,964	15,433	93,583	1,261	108	410	-	286	1,529	3,659	2,968	45,265	253	16	-	2,140	218,912
1983	41,161	442	7,414	1,842	16,124	91,174	1,299	110	420	-	272	1,548	3,903	2,826	48,300	254	11	-	2,327	219,427
1984	43,029	474	7,715	2,156	16,805	91,058	1,338	116	463	-	281	1,575	3,855	2,944	49,377	272	10	-	2,330	223,798
1985	43,950	494	8,381	2,077	17,705	93,271	1,368	123	496	-	288	1,679	4,185	2,977	53,701	286	8	-	2,559	233,547
1986	64,861	463	7,748	2,040	16,522	82,417	1,182	-	475	-	256	1,511	3,494	2,761	53,804	258	5	-	-	237,799
1987	42,163	500	8,556	1,943	17,752	88,866	1,276	120	520	-	269	1,625	3,859	2,895	57,101	286	3	-	2,305	230,041
1988	44,878	553	9,331	2,283	17,413	93,973	1,418	134	560	-	284	1,725	4,507	3,190	57,614	311	2	-	1,963	240,138
1989	46,742	599	10,242	2,450	17,340	94,169	1,265	144	587	-	303	1,840	4,085	3,419	63,363	345	-	-	1,834	248,726
1990	44,670	463	9,531	1,941	15,961	84,506	1,612	118	750	42	242	1,543	3,889	3,285	63,294	267	-	27	1,532	233,673
1991	45,457	383	8,977	1,786	15,401	79,218	1,996	98	951	86	205	1,295	3,710	3,413	65,679	220	-	55	1,220	230,152
1992	48,537	320	9,533	1,548	16,738	80,853	2,246	88	1,203	134	174	1,219	3,703	3,722	71,837	179	-	84	1,066	243,184
1993	49,792	236	9,006	1,397	15,583	75,904	2,704	69	1,411	177	142	999	3,771	3,869	73,679	133	-	108	775	239,754
1994	52,343	159	9,090	1,219	15,695	74,758	3,139	55	1,660	224	110	845	3,710	4,131	78,875	93	-	138	536	246,779
1995	54,754	81	8,969	1,071	15,746	72,146	3,580	40	1,915	292	75	667	3,890	4,347	81,703	46	-	169	268	249,758
1996	58,999	-	8,544	951	15,152	68,317	3,808	24	2,159	324	42	-	3,571	4,770	83,106	-	-	643	-	250,411
1997	56,161	-	9,257	3,519	18,946	64,345	4,449	42	229	-	133	3,493	5,846	3,171	87,807	-	168	-	-	257,567
1998	51,446	-	8,186	4,768	20,068	57,659	4,981	80	1,537	-	-	2,049	6,801	2,203	88,571	-	5	-	3,223	251,577
1999	49,299	-	6,960	2,650	21,563	49,768	3,742	110	900	-	74	3,212	8,327	2,732	87,395	-	5	-	3,101	239,838
2000	56,346	-	6,707	3,238	21,180	51,645	2,314	127	180	-	145	2,243	7,794	3,490	88,261	-	280	-	2,898	246,848
2001	46,320	-	5,151	2,010	14,051	46,163	1,599	101	59	72	118	1,615	5,826	2,812	84,230	-	199	-	583	210,910
2002	46,224	-	4,874	1,649	12,009	48,429	1,342	95	1,128	149	101	1,284	4,830	3,103	82,663	-	137	-	4,050	212,067
2003	48,161	-	5,007	1,651	13,381	52,495	1,452	102	639	197	91	909	5,086	3,639	94,611	-	106	-	3,031	230,557
2004	45,883	-	4,618	1,661	12,713	50,568	1,335	100	43	211	76	388	4,873	3,906	98,903	-	65	-	1,547	226,890
2005	43,799	-	4,149	1,503	13,188	51,136	1,721	99	69	230	55	6	6,276	4,595	98,006	-	18	5	1,444	226,298
2006	47,386	-	1,420	749	9,390	54,360	813	109	1,647	22	52	-	3,933	4,959	95,284	-	-	607	348	221,080
2007	48,831	-	3,060	1,064	14,689	46,502	2,785	95	112	135	50	766	4,612	4,631	103,732	-	-	8	3	231,077
2008	47,355	-	4,232	897	13,316	34,839	2,671	70	80	735	130	148	4,192	3,909	97,677	-	-	5	1,038	211,294
2009	49,017	-	3,875	1,012	15,687	26,461	2,733	3	51	129	251	113	3,429	4,688	104,235	-	-	5	985	212,675
2010	45,517	-	2,908	965	11,911	31,892	2,230	77	27	45	90	57	4,545	2,598	112,632	-	-	3	735	216,231
2011	50,542	-	2,328	903	10,944	47,769	1,270	182	-	-	137	-	2,125	984	126,978	-	-	693	-	244,856
2012	44,676	-	2,205	1,066	11,535	37,660	2,549	187	1,750	50	338	-	2,469	2,868	116,221	-	-	872	32	224,479
2013	43,256	-	2,140	1,277	12,288	31,286	4,052	203	3,436	94	532	-	2,940	4,770	116,775	-	-	1,085	62	224,194
2014	42,326	154	2,009	1,546	13,150	25,593	4,232	224	5,119	129	739	-	2,690	6,645	119,193	-	-	1,309	89	225,147
2015	33,859	202	2,036	899	14,424	24,745	4,355	219	4,167	535	487	-	3,081	5,345	113,420	-	-	1,237	205	209,217
2016	30,427	269	2,118	645	16,137	25,186	3,227	227	3,833	939	307	-	2,931	4,840	118,303	-	-	1,263	327	210,979
2017	31,149	248	1,613	736	14,672	27,156	3,381	205	3,342	542	220	-	3,481	5,367	126,486	-	-	1,290	213	220,101
2018	28,211	216	1,145	785	12,625	27,681	3,760	178	2,846	219	129	-	3,623	5,298	127,859	-	-	1,266	105	215,946

Appendix D
Table D-4: Annual Consumptive Use (ac-ft) in El Paso Valley, by Crop type

Year	Alfalfa	Asparagus	Chili/ Peppers	Cole/ Leafy Greens	Corn/ Silage	Cotton	Grain	Grapes	Hay	Legumes	Melons/ Squash	Misc/ Other	Onions	Pasture	Pecans/ Other Trees	Root Crop	Tomato	Turf	Irrigated Annuals	Total
1936	47,162	-	-	-	2,180	94,945	68	-	2,612	11	263	5,247	44	634	1,237	-	184	-	815	155,401
1937	48,165	-	-	-	849	106,829	38	-	648	33	235	2,644	45	591	1,364	308	89	-	-	161,840
1938	68,416	-	-	-	2,594	76,928	56	-	3,838	-	232	5,997	26	1,479	312	278	-	-	1,343	161,499
1939	78,178	-	-	-	-	79,764	-	102	4,267	17	255	8,861	52	1,556	949	281	167	-	-	174,447
1940	77,892	-	-	-	1,896	77,926	117	75	2,543	-	171	7,240	66	952	850	168	-	-	-	169,896
1941	60,503	-	-	-	590	92,639	37	67	584	-	82	4,515	74	563	447	227	73	-	938	161,342
1942	52,860	-	-	-	866	108,309	39	56	111	1	163	3,241	87	1,545	419	72	85	-	874	168,729
1943	59,532	-	-	-	1,464	108,260	46	-	1,586	20	199	2,751	88	1,303	696	314	96	-	5,277	181,632
1944	61,170	-	-	-	2,123	106,395	458	-	2,697	14	246	3,346	272	2,014	466	324	102	-	-	179,628
1945	69,478	-	-	-	1,644	109,717	15	-	346	12	430	5,015	96	3,247	573	145	80	-	893	191,691
1946	70,008	-	-	532	1,015	112,613	413	3	15	-	48	5,245	169	2,672	895	249	2	-	489	194,367
1947	59,747	-	-	-	272	130,039	-	28	15	-	273	3,446	173	864	431	81	104	-	603	196,078
1948	43,229	-	-	66	428	142,666	-	10	16	3	18	4,256	185	5,801	500	204	166	-	-	197,544
1949	36,518	-	-	39	150	143,088	36	15	-	-	-	4,022	327	5,245	349	75	115	-	-	189,979
1950	49,525	-	-	8	674	133,413	148	12	-	69	369	4,991	348	992	375	73	61	-	702	191,760
1951	35,451	-	-	22	85	155,165	7	16	-	-	29	1,391	178	2,754	358	-	20	-	-	195,477
1952	38,122	-	27	21	57	149,839	145	16	939	-	86	2,221	98	784	184	22	26	-	-	192,587
1953	43,377	-	17	19	117	147,413	195	31	-	-	217	1,629	110	4,003	245	27	23	-	-	197,422
1954	64,073	-	-	79	1,284	89,549	539	-	1,550	-	146	4,444	209	590	392	73	20	-	-	162,948
1955	39,393	-	54	68	3,233	78,138	1,521	-	1,775	34	93	526	246	241	360	38	189	-	-	125,910
1956	22,338	6	151	69	4,614	83,035	1,631	-	2,590	-	218	516	480	4,530	425	75	318	-	-	120,996
1957	8,649	12	-	141	508	89,683	700	16	4,161	-	188	346	101	2,387	265	27	-	-	-	107,183
1958	15,749	38	17	11	2,364	94,785	1,870	6	9,189	-	199	1,215	27	952	725	15	72	-	-	127,232
1959	24,380	-	-	6	2,052	79,460	1,061	9	9,277	-	185	2,311	-	6,345	1,515	-	80	-	-	126,683
1960	31,248	-	32	22	3,687	96,963	795	13	8,306	3	304	1,832	63	7,048	1,564	-	196	-	-	152,076
1961	31,321	8	32	49	3,784	97,892	662	-	6,877	-	182	1,447	151	7,822	1,575	10	168	-	-	151,981
1962	21,990	8	6	-	4,101	113,638	474	-	6,287	-	172	1,188	74	8,541	1,558	34	147	-	-	158,218
1963	13,095	8	-	-	1,940	128,138	686	6	140	-	107	960	11	6,284	1,600	20	106	-	-	153,100
1964	15,496	-	2	-	2,112	115,832	122	6	990	-	126	634	10	4,387	1,632	30	-	-	-	141,379
1965	24,186	-	-	89	5,773	86,733	1,161	-	5,721	-	103	414	187	7,348	1,569	42	594	-	-	133,921
1966	24,163	-	15	244	8,735	77,387	1,405	-	4,857	-	87	988	382	7,294	935	24	439	-	-	126,953
1967	25,099	-	117	405	9,565	75,846	2,626	-	2,096	-	72	1,261	615	7,575	314	7	285	-	-	125,881
1968	24,534	-	-	667	11,316	84,878	3,455	-	1,569	3	47	1,163	462	9,125	1,200	5	110	-	-	138,534
1969	26,534	-	159	278	19,522	86,626	5,474	-	4,860	-	64	-	682	12,144	-	-	160	-	-	156,504
1970	32,199	-	23	354	23,574	75,217	9,381	-	2,775	-	157	381	707	12,497	2,699	3	39	-	-	160,004
1971	35,821	-	65	418	23,817	67,615	14,400	-	2,898	7	144	354	853	14,552	3,805	3	86	-	-	164,838
1972	38,904	-	107	477	24,185	58,262	19,334	-	2,982	14	132	324	1,019	16,360	4,830	3	132	-	-	167,066
1973	41,650	-	152	509	24,397	52,763	18,826	-	3,017	22	116	303	997	17,985	6,049	3	180	-	-	166,970
1974	45,582	-	197	608	23,292	43,698	26,115	-	3,154	28	110	281	1,247	20,110	7,013	3	237	-	-	171,676
1975	48,734	-	245	644	24,187	37,113	27,018	-	3,210	35	97	259	1,280	21,854	8,234	3	285	-	-	173,198
1976	51,636	-	299	724	25,167	29,029	35,724	-	3,275	42	85	242	1,488	23,459	9,202	3	339	-	-	180,712
1977	48,018	-	980	554	17,994	48,329	21,677	-	3,465	29	97	259	1,345	23,853	10,687	2	232	-	-	177,522
1978	43,994	-	1,726	419	10,709	68,010	11,984	-	3,685	16	113	279	1,270	24,273	12,162	1	125	-	-	178,766

Appendix D
Table D-4: Annual Consumptive Use (ac-ft) in El Paso Valley, by Crop type

Year	Alfalfa	Asparagus	Chili/ Peppers	Cole/ Leafy Greens	Corn/ Silage	Cotton	Grain	Grapes	Hay	Legumes	Melons/ Squash	Misc/ Other	Onions	Pasture	Pecans/ Other Trees	Root Crop	Tomato	Turf	Irrigated Annuals	Total
1979	38,654	-	2,479	219	3,319	89,143	1,497	-	3,806	-	119	293	1,124	24,162	13,665	-	-	-	-	178,480
1980	35,415	-	3,695	109	904	78,968	13,477	-	2,864	-	90	298	1,228	21,457	15,828	-	-	-	-	174,332
1981	34,579	-	2,550	204	6,876	80,039	13,932	-	2,286	-	80	306	1,079	16,879	15,326	-	-	-	-	174,137
1982	30,160	-	2,489	998	10,780	77,172	16,624	-	1,871	-	141	445	1,814	23,806	21,632	-	-	-	-	187,934
1983	29,937	-	3,438	762	5,779	80,416	8,236	-	1,169	-	146	517	2,199	29,562	21,993	-	-	-	-	184,153
1984	35,608	-	2,427	263	6,129	87,818	9,982	-	3,132	-	57	353	2,109	22,510	21,040	-	-	-	-	191,429
1985	33,982	-	2,800	100	3,881	99,309	5,085	25	2,054	54	3	510	1,637	11,186	20,792	-	-	-	-	181,418
1986	28,280	-	1,585	153	2,559	101,600	7,045	32	578	-	3	583	1,475	12,310	19,641	-	-	-	-	175,845
1987	25,368	-	706	409	19	125,202	1,742	15	2,127	-	16	416	1,264	6,690	22,507	-	-	-	-	186,481
1988	21,566	-	-	675	1,929	140,112	694	12	2,176	-	25	322	1,073	8,179	23,068	-	-	-	-	199,831
1989	19,101	-	128	194	985	152,583	238	6	1,486	-	67	470	1,088	5,099	22,687	-	-	-	-	204,133
1990	17,499	-	3,207	401	2,558	131,119	1,576	6	-	-	19	430	2,040	5,248	21,905	-	-	-	-	186,009
1991	20,501	-	5,711	140	7,022	140,092	1,982	-	-	-	-	427	2,210	4,789	25,460	-	-	-	-	208,334
1992	23,764	-	14,125	198	18,048	127,836	2,248	9	2,272	-	-	1,337	2,223	4,539	27,356	-	-	-	-	223,955
1993	25,843	-	13,354	336	16,341	100,691	2,330	-	8,355	-	367	1,560	3,697	8,230	28,755	-	-	-	-	209,858
1994	28,273	-	13,060	85	13,579	116,773	2,781	6	927	-	353	1,986	4,917	9,370	31,282	-	-	-	-	223,392
1995	28,854	-	6,493	205	11,575	127,479	4,252	6	302	-	227	-	2,853	5,215	30,865	-	-	-	-	218,326
1996	31,679	-	3,052	656	12,544	127,208	5,492	6	794	-	21	-	3,840	6,146	33,725	-	-	-	-	225,162
1997	25,378	-	8,391	242	8,957	123,429	4,610	6	1,979	-	-	351	3,157	2,391	32,062	-	-	-	-	210,952
1998	33,127	-	7,651	182	9,208	123,471	4,566	3	2,571	-	-	164	2,162	1,938	34,515	-	-	-	-	219,557
1999	34,378	-	3,867	82	11,524	117,832	2,773	6	-	-	-	96	2,479	1,839	34,637	-	-	-	-	209,514
2000	24,507	-	4,011	-	20,214	100,902	-	-	-	-	-	-	2,243	1,590	42,967	-	-	-	-	196,434
2001	21,710	-	2,611	-	20,370	110,499	-	-	-	-	-	113	2,166	2,047	46,963	-	-	-	-	206,480
2002	29,423	-	3,320	-	20,238	113,496	-	-	-	-	-	-	2,333	1,679	48,417	-	-	-	-	218,906
2003	16,497	-	1,339	-	3,328	78,955	-	-	-	-	-	-	1,595	2,495	47,344	-	-	-	-	151,553
2004	17,930	-	836	-	1,311	93,725	99	-	-	-	-	-	2,577	1,248	46,049	-	-	-	-	163,775
2005	13,918	-	324	-	2,463	98,945	927	-	-	-	-	-	2,544	2,971	40,749	-	-	-	-	162,841
2006	14,893	-	839	-	2,175	85,186	186	3	-	-	21	25	1,919	2,427	41,050	-	-	-	-	148,724
2007	19,048	-	536	26	3,907	91,604	1,241	2	3,467	-	34	21	1,771	1,882	50,136	-	-	-	18	173,690
2008	21,940	-	446	52	6,370	63,982	2,130	-	962	-	40	10	2,058	1,423	42,508	-	-	-	30	141,952
2009	25,781	-	1,345	39	5,384	81,500	3,748	-	2,011	-	22	14	1,076	1,705	47,587	-	-	-	17	170,229
2010	26,294	-	1,962	27	2,830	82,282	5,349	-	2,806	-	-	16	269	1,762	43,749	-	-	-	-	167,347
2011	28,667	-	773	-	1,785	83,300	1,023	-	1,259	-	-	18	429	4,978	50,034	-	-	-	12	172,277
2012	24,821	-	-	-	560	30,140	206	-	560	-	-	-	-	3,650	45,630	-	-	-	21	105,588
2013	24,566	-	-	187	562	37,841	377	-	1,060	-	-	-	132	3,620	49,334	-	-	-	11	117,689
2014	23,324	-	-	372	583	44,842	608	-	1,550	-	-	-	268	3,441	50,123	-	-	-	1	125,113
2015	19,461	-	-	178	299	50,548	1,161	-	2,811	-	-	-	128	2,717	51,348	-	-	-	0	128,650
2016	16,360	-	-	-	21	57,363	1,912	-	4,163	-	-	-	-	2,101	52,337	-	-	-	-	134,257
2017	16,770	-	22	-	1,544	64,988	2,056	-	3,068	-	-	-	-	2,254	62,668	-	-	-	4	153,373
2018	14,923	-	44	-	2,988	65,303	1,864	-	1,428	-	-	-	-	2,140	66,221	-	-	-	7	154,918

Appendix D

Table D-5: Annual Consumptive Use (ac-ft) in EPCWID1, by Crop type

Year	Alfalfa	Asparagus	Chili/ Peppers	Cole/ Leafy Greens	Corn/ Silage	Cotton	Grain	Grapes	Hay	Legumes	Melons/ Squash	Misc/ Other	Onions	Pasture	Pecans/ Other Trees	Root Crop	Tomato	Turf	Irrigated Annuals	Total
1936	51,239	-	-	-	2,591	81,136	91	-	2,860	35	416	6,013	52	1,005	1,273	413	370	-	-	147,492
1937	40,673	-	-	-	1,178	104,754	51	-	674	33	362	2,947	45	632	1,431	368	250	-	-	153,399
1938	68,587	-	-	-	3,614	71,245	117	-	4,045	24	325	2,213	33	2,018	327	333	221	-	1,343	154,445
1939	78,735	-	-	-	468	72,870	79	102	4,697	75	421	2,935	62	2,806	1,129	352	316	-	-	165,046
1940	75,578	-	-	-	2,281	74,725	125	78	2,782	21	250	2,107	70	1,316	931	278	155	-	-	160,697
1941	55,326	-	-	-	973	90,232	39	67	649	21	122	1,929	88	785	556	364	177	-	938	152,265
1942	46,945	-	-	-	1,183	104,472	39	62	142	12	168	2,655	91	1,793	482	166	246	-	874	159,328
1943	53,666	-	-	-	1,692	106,050	146	3	1,586	25	199	3,495	94	1,843	823	436	147	-	1,388	171,592
1944	54,144	-	-	-	2,110	103,183	458	3	525	32	308	3,706	278	2,405	505	423	153	-	-	168,233
1945	59,143	-	-	-	1,389	106,559	23	-	346	26	444	4,719	131	4,064	652	192	144	-	893	178,726
1946	62,306	-	2	569	1,158	106,836	416	3	42	16	86	4,826	232	3,068	949	342	2	-	490	181,344
1947	51,167	-	-	-	437	121,671	10	37	15	20	295	3,412	177	1,135	458	131	104	-	603	179,673
1948	34,839	-	-	70	712	132,731	-	19	16	15	33	4,160	196	5,877	598	245	166	-	-	179,676
1949	30,885	-	-	42	295	131,340	36	15	-	7	2	3,730	340	5,655	408	117	115	-	-	172,987
1950	39,600	-	-	8	1,010	124,932	183	21	-	69	389	3,785	368	1,312	390	133	158	-	702	173,061
1951	28,722	-	-	25	309	142,321	7	16	-	3	35	1,539	182	587	358	16	27	-	-	174,147
1952	31,152	-	43	24	242	137,527	206	16	-	-	92	2,418	101	1,293	187	33	54	-	-	173,387
1953	37,115	-	17	22	303	137,967	195	31	3	-	223	1,794	114	1,110	252	36	33	-	-	179,215
1954	57,778	-	90	86	1,474	88,717	922	-	725	-	173	890	214	928	415	23	113	-	-	152,547
1955	48,549	-	134	85	2,737	83,279	1,496	-	1,256	49	114	934	296	603	417	24	273	-	-	140,247
1956	29,913	35	243	84	4,650	89,993	1,417	-	1,773	28	238	738	619	4,530	476	68	421	-	-	135,226
1957	14,024	60	69	157	1,004	97,527	304	18	3,140	4	205	439	292	2,031	303	28	76	-	-	119,681
1958	17,947	104	118	15	2,985	100,712	1,146	10	4,918	72	216	1,271	229	1,126	754	15	190	-	-	131,827
1959	26,329	-	22	12	2,940	84,403	1,415	9	4,456	-	206	2,470	164	4,485	1,544	-	334	-	-	128,790
1960	32,697	29	145	24	3,188	100,587	735	13	2,063	15	316	2,005	420	3,136	1,587	-	300	-	-	147,259
1961	32,543	8	236	54	3,008	98,611	701	-	1,358	-	194	1,507	440	4,958	1,583	10	261	-	-	145,471
1962	21,175	8	125	-	3,361	114,542	307	-	826	-	201	1,288	115	4,239	1,566	34	147	-	-	147,932
1963	11,930	8	42	28	1,430	126,231	71	6	150	-	107	1,045	11	2,312	1,620	20	106	-	-	145,115
1964	15,617	-	267	-	2,291	117,092	43	6	380	-	126	704	10	2,708	1,676	30	-	-	-	140,949
1965	24,787	-	186	95	5,779	91,616	909	-	2,623	-	103	481	190	3,688	1,647	43	596	-	-	132,744
1966	25,522	-	261	261	6,849	85,163	1,244	-	1,458	-	87	906	389	3,549	1,045	24	439	-	-	127,197
1967	26,685	-	341	434	7,932	80,884	1,923	-	318	-	72	1,323	628	3,469	461	7	286	-	-	124,763
1968	26,523	-	196	718	10,086	88,443	2,814	-	19	3	48	1,223	477	3,939	1,388	5	110	-	-	135,991
1969	28,947	-	380	300	15,259	89,509	3,770	-	621	-	64	6	704	2,516	52	-	161	-	-	142,288
1970	34,044	-	227	381	16,323	77,354	7,162	-	692	-	158	397	731	3,741	2,952	3	39	-	-	144,204
1971	36,743	-	258	450	17,772	69,339	11,933	-	694	7	145	373	883	3,742	4,092	3	87	-	-	146,520
1972	38,859	-	286	514	19,351	59,518	16,753	-	687	14	133	346	1,057	3,675	5,146	3	134	-	-	146,474
1973	40,634	-	322	550	20,840	53,616	16,783	-	668	22	118	328	1,035	3,577	6,406	3	181	-	-	145,082
1974	43,547	-	357	658	21,159	44,073	23,746	-	672	28	112	308	1,296	3,578	7,397	3	239	-	-	147,172
1975	45,690	-	395	698	23,289	37,019	24,929	-	659	35	98	290	1,331	3,508	8,658	3	288	-	-	146,889
1976	47,594	-	441	783	25,607	28,451	33,341	-	647	42	86	276	1,549	3,422	9,653	3	343	-	-	152,238
1977	46,693	-	1,124	602	19,381	43,579	20,285	-	1,402	30	98	292	1,409	4,074	11,192	2	236	-	-	150,398
1978	45,636	-	1,877	456	13,051	58,974	11,261	-	2,220	16	115	310	1,342	4,769	12,719	1	127	-	-	152,872

Appendix D

Table D-5: Annual Consumptive Use (ac-ft) in EPCWID1, by Crop type

Year	Alfalfa	Asparagus	Chili/ Peppers	Cole/ Leafy Greens	Corn/ Silage	Cotton	Grain	Grapes	Hay	Legumes	Melons/ Squash	Misc/ Other	Onions	Pasture	Pecans/ Other Trees	Root Crop	Tomato	Turf	Irrigated Annuals	Total
1979	43,423	-	2,638	238	6,740	75,632	1,445	-	3,017	-	121	323	1,199	5,388	14,273	-	-	-	-	154,437
1980	40,643	-	3,955	121	3,412	63,049	12,777	-	745	-	94	332	1,342	5,146	16,483	-	-	-	-	148,098
1981	39,685	-	2,685	223	10,351	62,225	13,566	-	1,236	-	82	330	1,167	4,959	15,995	-	-	-	-	152,505
1982	35,710	-	2,608	1,091	15,401	58,382	15,656	-	1,534	-	144	468	1,920	4,982	22,358	-	-	-	-	160,254
1983	35,638	-	3,576	837	11,656	68,525	8,494	-	907	-	150	540	2,320	10,158	22,764	-	-	-	-	165,565
1984	37,061	-	2,524	289	12,157	68,213	9,518	-	1,923	-	59	369	2,241	6,023	21,809	-	-	-	-	162,186
1985	40,864	-	2,907	111	9,902	64,444	4,790	25	2,203	56	3	529	1,768	5,115	21,599	-	-	-	-	154,317
1986	35,257	-	1,637	169	8,757	66,396	6,779	32	682	-	3	602	1,607	6,477	20,426	-	-	-	-	148,825
1987	32,929	-	841	468	5,084	86,096	1,715	15	1,675	-	17	435	1,412	5,329	23,187	-	-	-	-	159,202
1988	28,959	-	202	761	7,128	93,938	474	12	1,902	-	25	330	1,207	5,593	23,869	-	-	-	-	164,399
1989	26,873	-	453	245	5,435	102,329	345	6	1,584	-	69	480	1,236	4,636	23,635	-	-	-	-	167,326
1990	23,623	-	3,134	478	6,665	92,866	1,429	6	-	-	20	438	2,207	4,945	23,147	-	-	-	-	158,956
1991	25,652	-	3,454	202	10,548	103,022	2,088	-	-	-	-	433	2,130	4,004	26,823	-	-	-	-	178,355
1992	29,328	-	7,998	273	20,757	89,088	2,340	9	2,331	-	-	1,350	1,989	4,635	28,884	-	-	-	-	188,982
1993	31,799	-	7,713	433	18,052	74,016	2,295	-	8,039	-	370	1,573	3,344	8,379	30,357	-	-	-	-	186,369
1994	33,743	-	8,683	175	14,390	87,638	2,709	6	950	-	355	1,996	4,750	8,995	33,097	-	-	-	-	197,489
1995	33,160	-	2,951	312	12,053	94,974	4,304	6	-	-	228	-	2,681	3,991	32,561	-	-	-	-	187,220
1996	28,109	-	3,836	416	10,085	95,475	4,989	6	794	-	21	-	3,566	5,247	35,569	-	-	-	-	188,114
1997	30,106	-	3,870	567	8,788	93,173	4,677	6	1,979	-	31	403	3,338	3,249	35,968	-	-	-	-	186,155
1998	27,312	-	3,689	202	8,374	97,296	4,828	3	1,534	-	-	457	2,372	2,692	36,851	-	-	-	-	185,610
1999	27,899	-	2,212	91	11,170	87,443	2,881	6	-	-	-	422	2,650	2,683	37,200	-	-	-	-	174,657
2000	24,228	-	2,409	-	21,311	75,666	-	-	-	-	-	139	2,338	2,209	45,441	-	-	-	-	173,740
2001	22,178	-	886	-	17,129	82,875	-	-	-	-	-	306	2,400	2,571	49,836	-	-	-	-	178,182
2002	29,573	-	1,954	-	21,386	81,149	-	-	-	-	-	-	2,459	2,698	50,657	-	-	-	-	189,876
2003	18,640	-	1,101	-	3,226	69,115	-	-	-	-	-	-	1,687	3,199	50,359	-	-	-	-	147,328
2004	19,359	-	462	-	1,669	78,377	99	-	-	-	-	-	2,643	1,707	50,071	-	-	-	-	154,387
2005	14,269	-	435	-	2,732	78,328	929	-	-	-	-	-	2,606	3,663	43,782	-	-	-	-	146,744
2006	14,068	-	866	-	2,328	65,540	186	3	-	-	21	25	1,923	2,771	43,176	-	-	-	-	130,906
2007	18,588	-	573	28	3,459	67,539	941	2	581	-	34	21	1,771	2,702	52,674	-	-	-	18	148,931
2008	18,798	-	87	52	3,182	44,121	2,134	-	1,039	-	40	10	2,058	1,990	44,657	-	-	-	30	118,196
2009	21,706	-	540	39	3,570	54,931	3,386	-	982	-	22	14	1,076	2,133	50,041	-	-	-	17	138,457
2010	21,811	-	885	27	2,930	54,424	4,656	-	799	-	-	16	269	1,996	46,050	-	-	-	-	133,864
2011	24,481	-	245	-	1,927	64,277	677	-	-	-	-	18	429	4,321	52,490	-	-	-	-	148,865
2012	22,049	-	39	-	867	21,434	235	2	372	-	-	-	-	3,034	47,832	-	-	-	-	95,864
2013	20,747	-	25	187	1,017	27,355	161	4	1,029	-	-	-	132	3,521	51,783	-	-	-	0	105,961
2014	18,548	-	11	372	1,210	32,808	122	6	1,686	-	-	-	268	3,892	52,681	-	-	-	1	111,605
2015	15,762	-	47	178	848	40,226	117	8	1,980	-	-	-	128	3,492	53,863	-	-	-	0	116,648
2016	13,592	-	82	-	488	48,426	133	9	2,344	-	-	-	-	3,225	54,799	-	-	-	-	123,099
2017	14,281	-	68	-	916	54,045	183	10	1,881	-	-	-	-	3,409	65,717	-	-	-	4	140,516
2018	13,090	-	46	-	1,248	53,514	207	11	1,110	-	-	-	-	3,182	69,535	-	-	-	7	141,950

Appendix D
Table D-6: Annual Consumptive Use (ac-ft) in Hudspeth, by Crop type

Year	Alfalfa	Asparagus	Chili/ Peppers	Cole/ Leafy Greens	Corn/ Silage	Cotton	Grain	Grapes	Hay	Legumes	Melons/ Squash	Misc/ Other	Onions	Pasture	Pecans/ Other Trees	Root Crop	Tomato	Turf	Irrigated Annuals	Total
1936	3,382	-	-	-	-	27,872	-	-	-	-	-	-	-	-	-	-	-	-	815	32,070
1937	11,633	-	-	-	-	20,590	-	-	-	-	-	-	-	-	-	-	-	-	-	32,223
1938	7,710	-	-	-	-	16,911	-	-	-	-	-	4,214	-	-	-	-	-	-	-	28,834
1939	10,138	-	-	-	-	19,813	-	-	-	-	-	6,134	-	-	-	-	-	-	-	36,085
1940	11,836	-	-	-	-	16,577	-	-	-	-	-	5,532	-	-	-	-	-	-	-	33,945
1941	9,403	-	-	-	57	19,462	-	-	-	-	-	3,186	-	-	-	-	-	-	-	32,108
1942	8,434	-	-	-	113	24,085	-	-	-	-	-	1,045	-	-	-	-	-	-	-	33,677
1943	10,460	-	-	-	456	22,307	-	-	-	-	-	177	-	-	-	-	-	-	3,889	37,289
1944	12,133	-	-	-	215	22,600	-	-	2,172	-	-	89	-	-	-	-	-	-	-	37,208
1945	15,406	-	-	-	502	23,088	-	-	-	-	-	1,320	-	-	-	-	-	-	-	40,316
1946	13,671	-	-	-	107	26,783	-	-	-	-	-	1,651	-	-	-	-	-	-	-	42,212
1947	11,978	-	-	-	80	31,544	-	-	-	-	-	899	-	-	-	-	-	-	-	44,502
1948	10,545	-	-	-	-	33,425	-	-	-	-	-	1,039	-	-	-	-	-	-	-	45,010
1949	7,786	-	-	-	-	34,111	-	-	-	-	-	794	-	-	-	-	-	-	-	42,691
1950	13,034	-	-	-	28	30,226	-	-	-	-	-	2,062	-	-	-	-	-	-	-	45,350
1951	8,696	-	-	-	-	36,831	-	-	-	-	-	-	-	2,386	-	-	-	-	-	47,913
1952	10,009	-	-	-	-	34,249	3	-	939	-	-	-	-	-	-	-	-	-	-	45,200
1953	11,504	-	-	-	-	31,472	-	-	-	-	-	-	-	3,545	-	-	-	-	-	46,521
1954	13,407	-	-	-	-	15,349	-	-	981	-	-	4,168	-	-	-	57	-	-	-	33,961
1955	3,752	-	-	-	774	7,781	453	-	676	-	-	-	-	-	-	18	-	-	-	13,453
1956	2,624	6	-	-	477	7,773	524	-	1,034	-	-	-	-	318	-	10	-	-	-	12,767
1957	1,163	12	-	-	120	6,896	621	-	1,257	-	-	-	-	589	-	-	-	-	-	10,658
1958	1,869	13	-	-	64	9,394	857	-	4,520	-	-	-	-	-	-	-	-	-	-	16,716
1959	2,282	-	-	-	-	10,709	31	-	4,838	-	-	-	-	2,159	-	-	-	-	-	20,019
1960	2,791	-	-	-	846	11,563	125	-	6,249	-	-	-	-	4,178	-	-	-	-	-	25,753
1961	3,324	-	-	-	1,179	13,721	131	-	5,520	-	-	-	-	2,897	-	-	-	-	-	26,772
1962	3,741	-	-	-	946	16,234	265	-	5,461	-	-	-	-	4,720	-	-	-	-	-	31,367
1963	2,678	-	-	-	677	20,787	615	-	-	-	-	-	-	4,363	-	-	-	-	-	29,120
1964	2,408	-	-	-	-	16,497	89	-	616	-	-	-	-	2,313	-	-	-	-	-	21,923
1965	2,246	-	-	-	451	12,290	269	-	3,113	-	-	-	-	4,276	-	-	-	-	-	22,644
1966	1,912	-	-	-	2,636	8,793	181	-	3,411	-	-	146	-	4,332	-	-	-	-	-	21,413
1967	1,842	-	-	-	2,634	10,185	739	-	1,794	-	-	-	-	4,675	-	-	-	-	-	21,869
1968	1,683	-	-	-	2,517	11,148	685	-	1,568	-	-	-	-	5,723	-	-	-	-	-	23,323
1969	1,715	-	-	-	5,939	11,619	1,768	-	4,264	-	-	-	-	10,162	-	-	-	-	-	35,467
1970	2,458	-	-	-	9,136	10,855	2,304	-	2,110	-	-	36	-	9,250	-	-	-	-	-	36,150
1971	3,765	-	-	-	8,245	10,511	2,605	-	2,235	-	-	30	-	11,289	-	-	-	-	-	38,678
1972	5,043	-	-	-	7,371	9,870	2,778	-	2,330	-	-	23	-	13,140	-	-	-	-	-	40,555
1973	6,281	-	-	-	6,424	9,888	2,251	-	2,387	-	-	17	-	14,836	-	-	-	-	-	42,084
1974	7,716	-	-	-	5,166	9,243	2,680	-	2,524	-	-	12	-	16,945	-	-	-	-	-	44,284
1975	9,041	-	-	-	4,358	9,113	2,434	-	2,596	-	-	6	-	18,735	-	-	-	-	-	46,282
1976	10,322	-	-	-	3,486	8,626	2,873	-	2,675	-	-	-	-	20,400	-	-	-	-	-	48,383
1977	8,184	-	-	-	2,832	12,580	1,763	-	2,127	-	-	-	-	20,133	-	-	-	-	-	47,619
1978	5,839	-	-	-	2,170	16,583	1,000	-	1,551	-	-	-	-	19,847	-	-	-	-	-	46,991

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Appendix D
Table D-6: Annual Consumptive Use (ac-ft) in Hudspeth, by Crop type

Year	Alfalfa	Asparagus	Chili/ Peppers	Cole/ Leafy Greens	Corn/ Silage	Cotton	Grain	Grapes	Hay	Legumes	Melons/ Squash	Misc/ Other	Onions	Pasture	Pecans/ Other Trees	Root Crop	Tomato	Turf	Irrigated Annuals	Total
1979	3,196	-	-	-	1,541	20,922	167	-	902	-	-	-	-	19,098	-	-	-	-	-	45,827
1980	3,283	-	-	-	904	23,591	1,342	-	2,205	-	-	-	-	16,617	-	-	-	-	-	47,942
1981	3,682	-	-	-	2,099	23,498	761	-	1,136	-	-	-	-	12,198	-	-	-	-	-	43,375
1982	3,715	-	-	-	1,473	23,718	1,414	-	436	-	-	-	-	19,082	-	-	-	-	-	49,838
1983	3,892	-	-	-	634	16,529	65	-	356	-	-	-	-	19,636	-	-	-	-	-	41,111
1984	8,480	-	-	-	746	23,305	834	-	1,334	-	-	-	-	16,695	-	-	-	-	-	51,395
1985	3,357	-	-	-	550	37,873	564	-	-	-	-	-	-	6,254	-	-	-	-	-	48,597
1986	3,246	-	-	-	543	37,315	616	-	-	-	-	-	-	5,988	-	-	-	-	-	47,707
1987	2,310	-	-	-	19	43,877	216	-	601	-	-	-	-	1,562	225	-	-	-	-	48,810
1988	2,421	-	-	-	479	50,546	339	-	391	-	-	-	-	2,840	227	-	-	-	-	57,245
1989	2,135	-	-	-	466	55,574	-	-	-	-	-	-	-	780	236	-	-	-	-	59,191
1990	2,871	-	539	-	-	43,953	262	-	-	-	-	-	-	648	-	-	-	-	-	48,272
1991	3,416	-	2,817	-	-	43,455	-	-	-	-	-	-	245	1,179	-	-	-	-	-	51,113
1992	2,750	-	6,879	-	593	46,091	-	-	-	-	-	-	398	353	-	-	-	-	-	57,063
1993	1,938	-	6,459	-	681	34,557	110	-	407	-	-	-	543	349	-	-	-	-	-	45,045
1994	2,283	-	5,353	-	1,039	38,471	135	-	-	-	-	-	374	942	-	-	-	-	-	48,598
1995	2,952	-	4,577	-	564	42,511	-	-	302	-	-	-	376	1,837	200	-	-	-	-	53,317
1996	10,427	-	335	367	2,765	42,439	533	-	-	-	-	-	494	1,565	153	-	-	-	-	59,077
1997	4,991	-	4,557	-	1,487	40,044	-	-	-	-	-	-	-	231	197	-	-	-	-	51,507
1998	6,519	-	4,230	-	1,624	39,964	-	-	1,089	-	-	-	-	-	198	-	-	-	-	53,624
1999	6,498	-	1,816	-	1,466	42,467	-	-	-	-	-	-	-	-	192	-	-	-	-	52,438
2000	6,840	-	1,911	-	2,878	34,014	-	-	-	-	-	-	-	-	196	-	-	-	-	45,838
2001	6,380	-	1,761	-	5,095	34,492	-	-	-	-	-	-	-	-	200	-	-	-	-	47,928
2002	7,256	-	1,860	-	1,514	43,344	-	-	-	-	-	-	-	-	207	-	-	-	-	54,180
2003	4,387	-	575	-	1,182	17,514	-	-	-	-	-	-	-	-	202	-	-	-	-	23,860
2004	4,861	-	578	-	-	19,128	-	-	-	-	-	-	-	-	211	-	-	-	-	24,778
2005	5,296	-	-	-	-	24,714	-	-	-	-	-	-	-	-	200	-	-	-	-	30,209
2006	5,713	-	-	-	-	23,755	-	-	-	-	-	-	-	534	142	-	-	-	-	30,144
2007	5,624	-	-	-	639	29,108	301	-	3,000	-	-	-	-	-	219	-	-	-	-	38,891
2008	7,359	-	396	-	3,343	24,016	-	-	-	-	-	-	-	-	182	-	-	-	-	35,297
2009	8,168	-	855	-	2,000	31,407	367	-	1,084	-	-	-	-	-	205	-	-	-	-	44,084
2010	7,920	-	1,128	-	63	32,370	698	-	2,033	-	-	-	-	-	189	-	-	-	-	44,402
2011	7,360	-	588	-	33	23,821	353	-	1,259	-	-	-	-	726	175	-	-	-	12	34,327
2012	5,472	-	-	-	-	12,108	-	-	338	-	-	-	-	1,233	131	-	-	-	21	19,303
2013	6,655	-	-	13	-	13,329	262	-	345	-	-	-	-	1,333	147	-	-	-	11	22,095
2014	7,645	-	-	25	-	14,145	559	-	339	-	-	-	-	1,385	154	-	-	-	-	24,252
2015	6,304	-	-	12	-	12,475	1,115	-	1,254	-	-	-	-	908	150	-	-	-	-	22,218
2016	5,211	-	-	-	-	11,186	1,863	-	2,206	-	-	-	-	469	145	-	-	-	-	21,080
2017	4,895	-	-	-	1,096	13,881	1,920	-	1,546	-	-	-	-	516	212	-	-	-	-	24,066
2018	3,868	-	-	-	2,138	15,120	1,656	-	600	-	-	-	-	503	259	-	-	-	-	24,145

Appendix E

Table E-1: Crop Variables Used in CUP+ Modeling

	Planting Date	Harvest Date	KcAB	KcCD	KcE	% Season in Stage B	% Season in Stage C	% Season in Stage D
Alfalfa	3/1	12/1	0.95	0.95	0.95	25	50	75
Asparagus	3/1	10/31	0.50	0.95	0.30	12	25	95
Chili/ Peppers	4/1	10/1	0.30	1.20	0.50	25	65	82
Cole/ Leafy Greens	2/1	6/1	0.80	0.80	0.80	25	63	88
Corn/ Silage	5/1	11/15	0.20	1.05	0.60	20	45	75
Cotton	4/15	11/30	0.35	1.00	0.50	15	25	85
Grain	11/1	5/1	0.33	1.10	0.15	20	45	75
Grapes	4/1	11/1	0.45	0.80	0.35	0	25	75
Hay	3/1	12/1	0.85	0.85	0.85	25	50	75
Legumes	6/15	9/30	0.20	1.00	0.10	24	40	91
Melons/ Squash	4/1	8/14	0.75	1.05	0.75	21	50	83
Misc/ Other	4/1	10/1	0.30	1.20	0.50	25	65	82
Onions	11/1	6/1	0.55	1.20	0.55	10	26	75
Pasture	3/1	10/31	0.90	0.90	0.90	25	50	75
Pecans/ Other Trees	3/1	11/30	0.20	1.10	0.35	0	45	90
Root Crop	4/15	8/15	0.80	1.10	0.70	20	45	78
Tomato	4/1	8/31	0.30	1.10	0.65	25	50	80
Turf	4/1	10/31	0.60	0.60	0.60	25	50	75
Irrigated Annuals	4/1	10/1	0.30	1.20	0.50	25	65	82

	Source(s)
Alfalfa	Kc estimated from FAO24 and CA research
Asparagus	FAO56
Chili/ Peppers	NM Climate Center estimated from figure (https://aces.nmsu.edu/aes/irrigation/documents/crop-coefficient.pdf)
Cole/ Leafy Greens	Lettuce California
Corn/ Silage	Adjusted CUP+ value, lowered KcE to FAO56 value
Cotton	Adjusted FAO 56- not as high as 1.15-1.2, not as low as CUP+ (0.95); Evaluating on-farm irrigation efficiency across the watershed: A case study of New Mexico's Lower Rio Grande Basin Rasool Ahadi a,1, Zohrab Samani b,∗, Rhonda Skaggs b,2 (Says 904 mm avg cotton use)
Grain	CUP+
Grapes	CUP+
Hay	Dates same as alfalfa - Kc 0.1 < Alfalfa
Legumes	CUP+
Melons/ Squash	CUP+
Misc/ Other	Based on chili peppers
Onions	(NMSU CE CR 563) Plant: 15 Sep-1 Feb Harvest: 9 May - 10 Aug (Split the difference of fall planting dates sept/Jan)
Pasture	For dry climate FAO 24
Pecans/ Other Trees	(Sammis, Mexal, Miller, 2004); (Samani et al., 2012)
Root Crop	CUP+, Based on potato (CA)
Tomato	CUP+
Turf	CUP+
Irrigated Annuals	Based on chili peppers

Color Code
CUP+ value used
Rick Snyder communication
Specific Reference
Same as Chili/ Peppers

Appendix F

Table F-1: Reference Evapotranspiration Adjustment Factors

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rincon & Mesilla Valleys	1.09	1.14	1.15	1.15	1.08	1.03	1.03	1.01	1.02	0.98	1.00	1.04
El Paso Valley	1.28	1.34	1.31	1.26	1.14	1.03	1.02	0.95	0.99	1.01	1.12	1.26

Notes:

- For Rincon and Mesilla Valleys:
  - Factors were used to scale ETo calculated using the Hargreaves-Samani method when data required to compute ETo using the Penman-Montieth method was unavailable. The evapotranspiration adjustment factors were applied in all months for the years 1936 through 1999.
- For El Paso Valley:
  - Factors were used to scale ETo calculated using the Hargreaves-Samani method when data required to compute ETo using the Penman-Montieth method was unavailable. The evapotranspiration adjustment factors were applied in all months for the years 1936 through 2003 and 2013 through 2018. Additionally, the factors were applied to December 2005, 2006, and 2008, and January 2007 through April 2007.

Appendix G

Table G-1: Irrigation Management, Distribution Uniformity, and Production Adjustment Values, by Crop type (Used for all Regions)

Year	Alfalfa	Asparagus	Chili/ Peppers	Cole/ Leafy Greens	Corn/ Silage	Cotton	Grain	Grapes	Hay	Legumes	Melons/ Squash	Misc/ Other	Onions	Pasture	Pecans/ Other Trees	Root Crop	Tomato	Turf	Irrigated Annuals
1936	0.70	1.00	0.70	0.70	0.70	0.70	0.70	1.00	0.70	1.00	0.70	1.00	0.70	1.00	0.70	0.70	0.70	1.00	1.00
1937	0.70	1.00	0.70	0.70	0.70	0.70	0.70	1.00	0.70	1.00	0.71	1.00	0.70	1.00	0.70	0.70	0.70	1.00	1.00
1938	0.70	1.00	0.70	0.70	0.70	0.70	0.70	1.00	0.70	1.00	0.73	1.00	0.70	1.00	0.70	0.70	0.70	1.00	1.00
1939	0.70	1.00	0.70	0.70	0.70	0.70	0.70	1.00	0.71	1.00	0.74	1.00	0.70	1.00	0.70	0.70	0.70	1.00	1.00
1940	0.70	1.00	0.70	0.70	0.70	0.70	0.70	1.00	0.71	1.00	0.75	1.00	0.70	1.00	0.70	0.70	0.70	1.00	1.00
1941	0.70	1.00	0.70	0.70	0.71	0.70	0.70	1.00	0.71	1.00	0.77	1.00	0.70	1.00	0.70	0.70	0.70	1.00	1.00
1942	0.70	1.00	0.70	0.70	0.71	0.70	0.70	1.00	0.71	1.00	0.78	1.00	0.70	1.00	0.70	0.71	0.70	1.00	1.00
1943	0.70	1.00	0.70	0.70	0.72	0.70	0.70	1.00	0.72	1.00	0.79	1.00	0.70	1.00	0.70	0.72	0.70	1.00	1.00
1944	0.70	1.00	0.70	0.70	0.72	0.70	0.70	1.00	0.72	1.00	0.80	1.00	0.70	1.00	0.70	0.73	0.70	1.00	1.00
1945	0.70	1.00	0.70	0.70	0.73	0.70	0.70	1.00	0.72	1.00	0.82	1.00	0.70	1.00	0.70	0.74	0.70	1.00	1.00
1946	0.70	1.00	0.70	0.70	0.74	0.70	0.70	1.00	0.72	1.00	0.83	1.00	0.70	1.00	0.70	0.74	0.70	1.00	1.00
1947	0.70	1.00	0.70	0.70	0.74	0.70	0.71	1.00	0.73	1.00	0.84	1.00	0.70	1.00	0.70	0.75	0.70	1.00	1.00
1948	0.70	1.00	0.70	0.70	0.75	0.70	0.72	1.00	0.73	1.00	0.86	1.00	0.71	1.00	0.70	0.76	0.71	1.00	1.00
1949	0.70	1.00	0.70	0.70	0.76	0.70	0.74	1.00	0.73	1.00	0.87	1.00	0.71	1.00	0.70	0.77	0.72	1.00	1.00
1950	0.70	1.00	0.70	0.70	0.76	0.70	0.75	1.00	0.73	1.00	0.88	1.00	0.72	1.00	0.70	0.78	0.73	1.00	1.00
1951	0.70	1.00	0.70	0.70	0.77	0.70	0.76	1.00	0.73	1.00	0.90	1.00	0.72	1.00	0.72	0.79	0.74	1.00	1.00
1952	0.70	1.00	0.70	0.70	0.77	0.70	0.77	1.00	0.74	1.00	0.91	1.00	0.73	1.00	0.73	0.80	0.74	1.00	1.00
1953	0.70	1.00	0.70	0.70	0.78	0.70	0.78	1.00	0.74	1.00	0.92	1.00	0.73	1.00	0.75	0.81	0.75	1.00	1.00
1954	0.70	1.00	0.70	0.70	0.79	0.70	0.80	1.00	0.74	1.00	0.93	1.00	0.74	1.00	0.77	0.81	0.76	1.00	1.00
1955	0.70	1.00	0.70	0.70	0.79	0.70	0.81	1.00	0.74	1.00	0.95	1.00	0.74	1.00	0.78	0.82	0.77	1.00	1.00
1956	0.70	1.00	0.70	0.70	0.80	0.70	0.82	1.00	0.75	1.00	0.96	1.00	0.75	1.00	0.80	0.83	0.78	1.00	1.00
1957	0.70	1.00	0.70	0.70	0.80	0.70	0.83	1.00	0.75	1.00	0.97	1.00	0.75	1.00	0.82	0.84	0.79	1.00	1.00
1958	0.70	1.00	0.70	0.70	0.81	0.70	0.84	1.00	0.75	1.00	0.99	1.00	0.76	1.00	0.83	0.85	0.80	1.00	1.00
1959	0.71	1.00	0.70	0.70	0.82	0.70	0.86	1.00	0.75	1.00	1.00	1.00	0.76	1.00	0.85	0.86	0.81	1.00	1.00
1960	0.72	1.00	0.70	0.70	0.82	0.70	0.87	1.00	0.75	1.00	1.00	1.00	0.77	1.00	0.87	0.87	0.81	1.00	1.00
1961	0.73	1.00	0.70	0.70	0.83	0.70	0.88	1.00	0.76	1.00	1.00	1.00	0.77	1.00	0.88	0.88	0.82	1.00	1.00
1962	0.74	1.00	0.70	0.71	0.83	0.70	0.89	1.00	0.76	1.00	1.00	1.00	0.78	1.00	0.90	0.89	0.83	1.00	1.00
1963	0.75	1.00	0.70	0.72	0.84	0.70	0.90	1.00	0.76	1.00	1.00	1.00	0.78	1.00	0.92	0.89	0.84	1.00	1.00
1964	0.76	1.00	0.70	0.74	0.85	0.70	0.92	1.00	0.76	1.00	1.00	1.00	0.79	1.00	0.93	0.90	0.85	1.00	1.00
1965	0.77	1.00	0.70	0.75	0.85	0.70	0.93	1.00	0.77	1.00	1.00	1.00	0.79	1.00	0.95	0.91	0.86	1.00	1.00
1966	0.78	1.00	0.70	0.76	0.86	0.70	0.94	1.00	0.77	1.00	1.00	1.00	0.80	1.00	0.97	0.92	0.87	1.00	1.00
1967	0.78	1.00	0.71	0.77	0.87	0.70	0.95	1.00	0.77	1.00	1.00	1.00	0.80	1.00	0.98	0.93	0.88	1.00	1.00
1968	0.79	1.00	0.72	0.78	0.87	0.70	0.96	1.00	0.77	1.00	1.00	1.00	0.81	1.00	1.00	0.94	0.89	1.00	1.00
1969	0.80	1.00	0.74	0.80	0.88	0.70	0.98	1.00	0.78	1.00	1.00	1.00	0.81	1.00	1.00	0.95	0.89	1.00	1.00
1970	0.81	1.00	0.75	0.81	0.88	0.70	0.99	1.00	0.78	1.00	1.00	1.00	0.82	1.00	1.00	0.96	0.90	1.00	1.00
1971	0.82	1.00	0.76	0.82	0.89	0.70	1.00	1.00	0.78	1.00	1.00	1.00	0.82	1.00	1.00	0.96	0.91	1.00	1.00
1972	0.83	1.00	0.77	0.83	0.90	0.70	1.00	1.00	0.78	1.00	1.00	1.00	0.83	1.00	1.00	0.97	0.92	1.00	1.00
1973	0.84	1.00	0.78	0.84	0.90	0.70	1.00	1.00	0.78	1.00	1.00	1.00	0.83	1.00	1.00	0.98	0.93	1.00	1.00
1974	0.85	1.00	0.80	0.86	0.91	0.70	1.00	1.00	0.79	1.00	1.00	1.00	0.84	1.00	1.00	0.99	0.94	1.00	1.00
1975	0.86	1.00	0.81	0.87	0.91	0.70	1.00	1.00	0.79	1.00	1.00	1.00	0.84	1.00	1.00	1.00	0.95	1.00	1.00
1976	0.87	1.00	0.82	0.88	0.92	0.70	1.00	1.00	0.79	1.00	1.00	1.00	0.85	1.00	1.00	1.00	0.96	1.00	1.00
1977	0.88	1.00	0.83	0.89	0.93	0.70	1.00	1.00	0.79	1.00	1.00	1.00	0.85	1.00	1.00	1.00	0.96	1.00	1.00
1978	0.89	1.00	0.84	0.90	0.93	0.70	1.00	1.00	0.80	1.00	1.00	1.00	0.86	1.00	1.00	1.00	0.97	1.00	1.00

Appendix G

Table G-1: Irrigation Management, Distribution Uniformity, and Production Adjustment Values, by Crop type (Used for all Regions)

Year	Alfalfa	Asparagus	Chili/ Peppers	Cole/ Leafy Greens	Corn/ Silage	Cotton	Grain	Grapes	Hay	Legumes	Melons/ Squash	Misc/ Other	Onions	Pasture	Pecans/ Other Trees	Root Crop	Tomato	Turf	Irrigated Annuals
1979	0.90	1.00	0.86	0.92	0.94	0.70	1.00	1.00	0.80	1.00	1.00	1.00	0.86	1.00	1.00	1.00	0.98	1.00	1.00
1980	0.91	1.00	0.87	0.93	0.94	0.70	1.00	1.00	0.80	1.00	1.00	1.00	0.87	1.00	1.00	1.00	0.99	1.00	1.00
1981	0.92	1.00	0.88	0.94	0.95	0.74	1.00	1.00	0.83	1.00	1.00	1.00	0.87	1.00	1.00	1.00	1.00	1.00	1.00
1982	0.93	1.00	0.89	0.95	0.96	0.78	1.00	1.00	0.86	1.00	1.00	1.00	0.88	1.00	1.00	1.00	1.00	1.00	1.00
1983	0.93	1.00	0.90	0.96	0.96	0.81	1.00	1.00	0.89	1.00	1.00	1.00	0.88	1.00	1.00	1.00	1.00	1.00	1.00
1984	0.94	1.00	0.92	0.98	0.97	0.85	1.00	1.00	0.91	1.00	1.00	1.00	0.89	1.00	1.00	1.00	1.00	1.00	1.00
1985	0.95	1.00	0.93	0.99	0.98	0.89	1.00	1.00	0.94	1.00	1.00	1.00	0.89	1.00	1.00	1.00	1.00	1.00	1.00
1986	0.96	1.00	0.94	1.00	0.98	0.93	1.00	1.00	0.97	1.00	1.00	1.00	0.90	1.00	1.00	1.00	1.00	1.00	1.00
1987	0.97	1.00	0.95	1.00	0.99	0.96	1.00	1.00	1.00	1.00	1.00	1.00	0.90	1.00	1.00	1.00	1.00	1.00	1.00
1988	0.98	1.00	0.96	1.00	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.91	1.00	1.00	1.00	1.00	1.00	1.00
1989	0.99	1.00	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.91	1.00	1.00	1.00	1.00	1.00	1.00
1990	1.00	1.00	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.92	1.00	1.00	1.00	1.00	1.00	1.00
1991	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.92	1.00	1.00	1.00	1.00	1.00	1.00
1992	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.93	1.00	1.00	1.00	1.00	1.00	1.00
1993	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.93	1.00	1.00	1.00	1.00	1.00	1.00
1994	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.94	1.00	1.00	1.00	1.00	1.00	1.00
1995	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.94	1.00	1.00	1.00	1.00	1.00	1.00
1996	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.95	1.00	1.00	1.00	1.00	1.00	1.00
1997	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.95	1.00	1.00	1.00	1.00	1.00	1.00
1998	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.96	1.00	1.00	1.00	1.00	1.00	1.00
1999	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.96	1.00	1.00	1.00	1.00	1.00	1.00
2000	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.97	1.00	1.00	1.00	1.00	1.00	1.00
2001	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.97	1.00	1.00	1.00	1.00	1.00	1.00
2002	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98	1.00	1.00	1.00	1.00	1.00	1.00
2003	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98	1.00	1.00	1.00	1.00	1.00	1.00
2004	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00	1.00	1.00	1.00
2005	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00	1.00	1.00	1.00
2006	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2007	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2008	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2009	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2010	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2011	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2012	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2013	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2014	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2015	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2016	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2017	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2018	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

May 31, 2019

EXPERT REPORT OF:

Staffan W. Schorr and Colin P. Kikuchi

WATER BUDGET ESTIMATES IN SUPPORT OF GROUNDWATER MODEL DEVELOPMENT: RINCON AND MESILLA BASINS, NEW MEXICO, TEXAS, AND NORTHERN MEXICO, 1938 THROUGH 2016

In the matter of:

No. 141, Original
In the Supreme Court of the United States
State of Texas v. State of New Mexico and State of Colorado

Prepared for:

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1 INTRODUCTION

1.1 Statement of Qualifications for Staffan W. Schorr

1. My name is Staffan W. Schorr. I am a principal hydrogeologist and partner at Montgomery & Associates in Tucson, Arizona, where I have been employed since 2006. I have 19 years of professional experience as a hydrogeologist and geospatial data analyst.
2. My education includes a Bachelor of Science degree in Geosciences from the University of Arizona, and a Master's of Science degree in hydrogeology from the University of Arizona.
3. Prior to working for Montgomery & Associates, I was employed by Pima Association of Governments in Tucson, Arizona where I worked as a watershed planner from 1998 to 2006.
4. In December 2010, I became a shareholder at Montgomery & Associates.
5. I have developed more than a dozen conceptual hydrogeologic models for regional and local scale characterization projects and numerical groundwater models.
6. Montgomery & Associates is being compensated for my work on this assignment at a rate of $146 per hour.
7. My professional resume, including publications authored in the previous 10 years, is included in Appendix H.

1.2 Statement of Qualifications for Colin P. Kikuchi

1. My name is Colin P. Kikuchi. I am a groundwater hydrologist at Montgomery & Associates in Tucson, Arizona. I have 10 years of professional experience as a hydrologist.
2. My education includes a Bachelor of Arts degree in Environmental Studies and Geography from Middlebury College and Master of Science and Doctoral degrees in Hydrology and Water Resources from the University of Arizona.
3. From September 2009 through August 2014, I was employed by the U.S. Geological Survey in Tucson, Arizona and Anchorage, Alaska.
4. From August 2014 through present I have been employed by Montgomery & Associates in Tucson, Arizona.
5. Montgomery & Associates is being compensated for work on this assignment at the rate of $117 per hour.
6. My professional resume, including publications authored in the previous 10 years, is included in Appendix H.

1.3 Assignment and Summary of Opinions

We were asked by counsel to prepare multiple products in support of expert analyses related to New Mexico's compliance with the Rio Grande Compact:

1. We developed water budgets for Rincon and Mesilla basins over the period from 1938 through 2016. We refer to this period of time as the study period. A major component of the water budget assignment was to develop a farm soil water balance model for estimating agricultural groundwater pumping, deep percolation, and return flows related to crop operations in the basins. The water budgets were developed in part to characterize changes in groundwater storage and streamflow depletions over time in the basins. Details of these water budgets are described in the body of this report.
2. We developed and implemented a web-based database for basic hydrologic data obtained from public sources for all experts to use, if needed, for their respective analyses. The database serves as an archive of raw public data used to prepare the water budgets and other expert analyses. The database is summarized in Appendix D of this report.
3. We provided technical support to William R. Hutchison for developing a numerical groundwater flow model for Rincon and Mesilla basins. We prepared model input datasets from the associated water budgets. We also prepared the streamflow routing package for model input. Datasets prepared for model input are described in Appendix E of this report. In addition, we prepared a hydrogeologic framework for Rincon and Mesilla Basins to define aquifer layering for the groundwater model. Source data and methods used for developing the aquifer framework are described in Appendix F of this report.
4. We developed a farm water budget for El Paso Valley for estimating agricultural groundwater pumping in the valley for economic analysis by David Sunding and water quality analyses by Lydia Dorrance. The El Paso Valley farm water budget is described in Appendix G of this report.

Opinions by Staffan Schorr on Non-Farm Water Budgets, Surface Water Budgets, and Groundwater Budgets

For any water budget, the sum of inflows minus the sum of outflows equals changes in storage. For the water budgets described herein, I use a simple "bucket" model approach, which provides useful insight on the general functional behavior of the system. A bucket model approach considers all inflows and outflows during a time step (monthly in for this water budget) and computes a change, if any, in water stored within the system. Complex interactions and feedback loops between water budget components are not included in this bucket water budget, such phenomenon are better handled by distributed parameter simulations.

5. The water budgets presented herein are prepared to the basin scale for aggregating inflows and outflows. I used a basin scale approach because important components of the water system, such as surface water deliveries to farms and groundwater exchange between sub-areas within the basins, could not be estimated on a localized monthly scale for the entire study period. Although this basin scale water budget ignores the spatial distribution of individual components, it does provide useful insight on the general functional behavior of the system.

6. I prepared separate water budgets for Rincon Basin and Mesilla Basin because the basins are separated by a bedrock constriction, which limits the hydrologic connection between the basins.

7. The overall water budget for each basin comprises three types of budgets: Land-Surface Water Budget, Surface Water Budget, and Groundwater Budget. I used this approach to facilitate budget development by compartmentalizing common components.

8. The Land-Surface Water Budget comprises a Farm Water Budget and Non-Farm Water Budget. The Non-Farm Water Budget was prepared for lands outside farm lands. Water inflows to the Non-Farm Water Budget include precipitation and groundwater withdrawals. The Non-Farm Water Budget is split into three sub-budgets to account for the source of water supply and land use. An Urban Applied Water Budget was prepared for urban use of applied groundwater. An Urban Precipitation Water Budget was prepared for urban use of precipitation. An Upland Watershed Water Budget was prepared for all native or undeveloped lands in the upland portions of the watershed, outside farm and urban lands. Although the Non-Farm Water Budget could be prepared as a single water budget, I used this approach to facilitate budget development by compartmentalizing components based on water supply and land use.

9. The number of groundwater production wells located in Rincon and Mesilla basins has increased since 1938, shown on Figures 4.6 and 4.7. I obtained well databases from the states of New Mexico and Texas for water product well information and well installation history. In 1939, less than 60 New Mexico wells existed in the basins, with vast majority used for domestic purposes and five wells for irrigation purposes. By 2016, the number of New Mexico wells located in the basins increased to more than 7,700, with about 465 wells for municipal and industrial purposes, 1,300 for irrigation purposes, and majority still for domestic purposes. A substantial number of well records in the New Mexico wells database are missing installation dates and are not included in these well counts; these undated wells may or may not exist. The number of water production wells located in Texas portions of Mesilla Basin increased from 3 wells in 1938 to 239 wells in 2016, with about half being used for irrigation purposes.

10. Historic groundwater withdrawals from water production wells in Rincon and Mesilla basins have been estimated for previous groundwater flow models for the basins. We relied heavily on pumping model input datasets from the groundwater model developed by S.S. Papadopolus & Associates in 2007 for the New Mexico Office of the State Engineer. Pumping rates specified in that model are based on pumping records from Las Cruces and El Paso, metered pumping, and estimates by a USGS study by Frenzel and Kaehler in 1992. The USGS study estimated pumping in the basins using pumping records and per capita water use and population data. In the absence of another data source, we used the Papadopolus model input dataset to represent pumping in the Groundwater Budget described herein.

11. Groundwater is exported from Mesilla Basin as treated wastewater discharged downstream from the basin outlet at the Rio Grande at El Paso streamflow gage and as pumped groundwater conveyed to Ciudad Juarez from a municipal wellfield located in the southern portions of the basin in Mexico. The treated effluent that is discharged from the El Paso Hickerson Wastewater Treatment Plant originates as groundwater pumped from El Paso wells. I assigned the treated effluent as exported groundwater simply because the discharge point is downstream from the Rio Grande at El Paso streamflow gage, which is the outlet point along the river for the Mesilla Basin water budget.

12. Watershed runoff models require detailed streamflow data and information on physical characteristics for drainages and sub-watersheds. The lack of streamflow gages on the majority of drainages to the Rio Grande within the study area prevents the use of surface water modeling for determining tributary runoff. Instead of using a runoff model, I specified runoff to be 3 percent of monthly precipitation, which is consistent with the results of a runoff study for a smaller watershed in the adjacent Jornada del Muerto Basin. I made an attempt at estimating runoff using daily streamflow data from gages located at the upstream and downstream ends of Rincon Basin. That evaluation resulted in runoff estimates that could not be accommodated by the water budgets, as indicated by unrealistic surface water-groundwater exchanges and groundwater storage changes. It is my opinion that the approach that specifies runoff as percentage of precipitation provides reasonable estimates for the regional water budget analysis.

13. The only source of reported data for surface water deliveries to farms in the area is crop reports and water distribution tables compiled by the U.S. Bureau of Reclamation (USBR). It is my opinion that the USBR data are generally reliable based on information learned from interviews with Bert Cortez at USBR.

14. A net loss of surface water to the groundwater system in Mesilla Basin occurred during most years since 1950. This loss of surface water coincides with the timing of substantial increase in groundwater pumping in the basin. The net surface water-groundwater interactions were more variable in Rincon Basin and fluctuated around net exchange of zero.

15. I used the Hearne-Dewey equation for estimating mountain-front/mountain-block recharge for the groundwater budget because natural recharge is not measured in the basins. It is my opinion that the Hearne-Dewey equation is a reasonable method to use for the groundwater budget because (1) it was developed to estimate basin water yield based on hydrologic data from basins in northern New Mexico and (2) the same method was previously used in the groundwater model developed for Rincon and Mesilla basins by S.S. Papadopulos & Associates for the New Mexico Office of the State Engineer.

16. When groundwater inflows are not equal to outflows there is a change in the amount of groundwater stored in the aquifer. For this analysis, changes in groundwater storage were estimated as the quantity required to close the Groundwater Budget. Changes in groundwater storage were used as a calibration metric for this analysis. Calibration of the water budgets was accomplished by adjusting components, such as tributary runoff inflows, until the estimated changes in groundwater storage were in reasonable agreement with simulated changes in groundwater storage from the calibrated numerical groundwater flow model developed by William Hutchison for this litigation project. My water budget results indicate that there has been a steady cumulative loss of groundwater in storage in both Rincon and Mesilla basins since the early 1950s. The rate of decline in cumulative groundwater storage in Mesilla Basin increased after 2010 when the Ciudad wellfield began pumping from the Conejos-Medanos wellfield in Mexico.

17. My water budget analysis included evaluating and comparing patterns during wet and dry time periods in Rincon and Mesilla basins since 1938. Agricultural groundwater pumping in both basins increased during dry periods when surface water deliveries to farms were small. This occurs even though total crop consumptive use remained generally constant during the wet and dry periods. In my opinion, supplemental agricultural groundwater is used by farmers to maintain agricultural production when surface water allotments are small.

18. In forming my opinions, I have relied in part on findings by William R. Hutchison. Dr. Hutchison simulates riparian evapotranspiration in his numerical groundwater flow model. Riparian evapotranspiration varies with changes in depth to groundwater at a location. Our water budget does not include changes in groundwater levels over time. I

used his preliminary model results for riparian evapotranspiration as input to the Groundwater Budget.

Opinions by Colin Kikuchi regarding Farm Water Budgets

19. In forming my opinions, I have relied in part on the findings of Dr. Joel Kimmelshue. In his report, Dr. Kimmelshue developed historical estimates of crop consumptive use, and changes in consumptive use that have occurred due to improvements in irrigation water management and crop variety. As an example, Dr. Kimmelshue determined that in 1938, consumptive use of alfalfa, cotton, and pecans in the Rincon and Mesilla Basins was about 70% of consumptive use of the same crops in 2016.

20. In this report, I present Farm Water Budget analyses that provide a complete accounting for all water entering and leaving the maximum extent of agricultural lands – meaning lands on which irrigated crops are grown. I provide separate Farm Water Budgets for the Rincon and Mesilla Basins. Water inflows to agricultural lands consist of precipitation, surface water deliveries, and groundwater applied to the land surface. Water outflows from agricultural lands consist of crop consumptive use, consumptive use from fallow lands, surface water return flows of applied irrigation water, and agricultural deep percolation which ultimately becomes groundwater recharge. Agricultural deep percolation includes percolation along on-farm conveyance structures and percolation beneath irrigated fields.

21. An important consideration in the preparation of any water budget is determination of the spatial scale at which to aggregate inflows and outflows of water. The Farm Water Budgets presented in this report have been prepared at the basin scale. The spatial resolution of historical surface water delivery data is the primary reason for deciding to prepare Farm Water Budgets at the basin scale. Specifically, official records of Rio Grande Project and similar records of EBID do not consistently resolve surface water deliveries to the scale of the EBID divisions served by the main canals, namely the Leasburg Division, Mesilla Eastside Division, and Mesilla Westside Division. The same official records do, however, consistently resolve surface water deliveries to the basin scale.

22. Some of the Inflow and Outflow components in the Farm Water Budgets are readily calculated from available datasets. Procedures for calculating these components are described in this report:
    a. The section ‘Precipitation Routing’ describes datasets and procedures used to quantify precipitation on farms.
    b. The section ‘Surface Water Deliveries to Farms’ describes datasets and procedures used to quantify surface water deliveries to farms.

c. The section ‘Surface Runoff of Applied Water’ describes datasets and procedures used to quantify farm tailwater.
d. The section ‘Surface Runoff of Precipitation from Agricultural Lands’ describes datasets and procedures used to quantify precipitation runoff from agricultural lands.
e. The section ‘On-Farm Conveyance Losses’ describes datasets and procedures used to quantify on-farm conveyance losses.
f. The section ‘Crop Evapotranspiration’ describes datasets and procedures used to quantify crop consumptive use. Crop consumptive use in the Farm Budget is calculated by a soil water balance model that I describe in this report. Therefore, exact values of crop consumptive use as reported in Dr. Kimmelshue’s report are not used directly as input in the Farm Water Budget. However, crop consumptive use datasets provided by Dr. Kimmelshue form the basis for model calculations of crop consumptive use, and crop consumptive use in the Farm Water Budget is very similar to crop consumptive use calculated by Dr. Kimmelshue.

23. Some of the Inflow and Outflow components in the Farm Water Budgets cannot be quantified from available data over the full study period. For example, the New Mexico Office of the State Engineer currently reports irrigation pumping volumes that are measured under the authority of the Lower Rio Grande Water Master. However, reliable historical records of irrigation pumping volumes extend only as far back as 2010. Agricultural deep percolation at the basin-scale cannot be measured directly. The two quantities listed above must be estimated. I estimate agricultural groundwater pumping and agricultural deep percolation over the study period using a soil water balance model.

24. The soil water balance model is a set of mathematical equations that describe the average soil moisture in the root zone of agricultural lands in the Rincon and Mesilla Basins. A soil water balance model is an appropriate way to calculate agricultural groundwater pumping, deep percolation, and crop consumptive use because these Farm Water Budget components depend on soil moisture content in the root zone. The model equations calculate crop consumptive use, the groundwater that must be applied to sustain crop consumptive use, and the agricultural deep percolation beneath the root zone, as a function of simulated soil moisture conditions.

25. In both the Rincon and Mesilla Basins, a portion of the total agricultural land is located outside EBID and EPCWID boundaries. These lands outside the District boundaries do not receive surface water deliveries. The agricultural lands within each basin therefore fall into one of two zones: inside and outside the Districts. Corresponding to these zones, two soil water balance models are developed for each groundwater basin: one model representing land inside District boundaries and the other representing land outside the

District boundaries. Simulated agricultural groundwater pumping and deep percolation from the two models are summed to provide totals by groundwater basin.

26. Crop consumptive use in the Rincon and Mesilla Basins is satisfied by precipitation and applied irrigation water. For lands within District boundaries, applied irrigation water consists of surface water deliveries to farms and supplemental groundwater pumping. For lands outside District boundaries, groundwater pumping provides applied irrigation water.

27. During certain times of the year throughout the study period, a portion of the agricultural lands within each basin were fallow, or non-cropped. During the winter, for example, any lands cultivated exclusively during the growing season will be fallow. However, soil moisture conditions within seasonally fallowed land determine in part the consumptive use and irrigation requirements during the subsequent growing season. Furthermore, irrigation water applied to crops near the end of the growing season may not be completely consumed by crops, and instead is consumed as soil evaporation after the growing season, when the land is again fallow. For these reasons, a complete accounting of the Farm Water Budget requires tracking soil moisture both on lands that are actively cultivated, and lands that are fallow. The soil water balance model developed for the Farm Water Budget accounts for both cropped and fallow land areas.

28. Nearly all acreage within the Rincon and Mesilla Basins is irrigated using surface irrigation methods. However, irrigation water management and by extension, soil moisture uniformity, have both improved substantially over the study period due to development and adoption of technologies such as high precision land leveling. Based on these two factors – the widespread use of surface irrigation and the long historical period of interest – the most appropriate approach for estimating agricultural groundwater pumping and deep percolation is to explicitly represent changes in soil moisture uniformity through time, as described in the section 'Non-uniform moisture distribution'.

29. It is not possible to directly measure some of the parameters of the soil water balance model that control moisture distribution at the basin scale. Such parameters must therefore be estimated. The process of estimating these parameters is called model calibration, and consists of adjusting the parameter values in such a way as to most closely match both historical data and qualitative historical trends. The section 'Soil Water Balance Model Calibration' in this report describes the calibration process in detail.

30. In his report, Dr. Kimmelshue quantifies increases in crop consumptive use due in large part to improvements in irrigation water management. The soil water balance model

explicitly represents those improvements in irrigation water management through time as more uniform moisture distribution and farm tailwater reductions. The soil water balance model also accounts for the effects of water stress on crop consumptive use based on a mathematical relationship defined in the section, 'Crop Evapotranspiration'. Consequently, the soil water balance model is simulates the effects of improvements in irrigation water management on crop consumptive use. Crop consumptive use simulated using the soil water balance model matches crop consumptive use reported in Dr. Kimmelshue's report very closely, with average percent discrepancy less than 0.01%.

31. The portion of crop consumptive use satisfied by precipitation varies from year to year. Over the study period, precipitation satisfied about 20% of consumptive use in the Rincon Basin, and 19% of consumptive use in the Mesilla Basin, on average. The remaining portion of crop consumptive use is satisfied by applied irrigation water.

32. Average surface water deliveries to farms within EBID boundaries in the Rincon Basin were about 36,000 acre-feet per year over the study period. Average surface water deliveries to farms within EBID and EPCWID boundaries in the Mesilla Basin were about 169,000 acre-feet per year.

33. Some of the surface water delivered to farms is lost to percolation along on-farm conveyance structures between the farm headgate and the field inlet. Average on-farm conveyance losses were about 17,000 acre-feet per year over the study period. Most of the remaining surface water delivered to farms is applied to the field and replenishes soil moisture in the crop root zone. A percentage of surface water entering the field is lost as tailwater leaving the end of the field, and ultimately re-enters the surface water network. However, this percentage has declined with time due to improvements in irrigation management.

34. Groundwater pumping supplies a portion of applied irrigation water in both the Rincon and Mesilla Basins, and the groundwater portion varies from year to dependent primarily on the availability of surface water. From 1951 through 2016, average groundwater pumping for irrigation supply was about 29,000 acre-feet per year in the Rincon Basin, and 265,000 acre-feet per year in the Mesilla Basin. Over the same time period, groundwater contributed on average about 46% and 43% of the total irrigation water supply in the Rincon and Mesilla Basins, respectively.

35. A portion of irrigation water applied to cropped field is lost to deep percolation below the root zone. From 1938 through 2016, average field losses were about 9,000 acre-feet per year in the Rincon Basin and 39,000 acre-feet per year in the Mesilla Basin.

36. From 1938 through 2016, on-farm irrigation efficiency was about 70% in both the Rincon and Mesilla Basins. This represents the percentage of the irrigation water supply that ultimately sustains crop consumptive use.

1.4 Objective and Scope for Water Budget Analysis

Montgomery & Associates developed monthly, basin-wide land-surface water, surface water, and groundwater budgets for Rincon and Mesilla basins for 1938 through 2016. Water budgets were developed to provide conceptual inputs to a numerical groundwater flow model being developed separately by William R. Hutchison, as well as inputs to other expert analyses. Monthly time steps. This report summarizes the data sources, methodology, and results of this water budget analysis.

Rincon Basin refers to the southern portion of the Palomas Basin from below Caballo Reservoir in the north to Selden Canyon in the south. Selden Canyon is part of Rincon Basin for this analysis. Mesilla Basin extends southward from Selden Canyon in the north to the El Paso Narrows in El Paso, Texas in the south. Las Cruces, New Mexico is located in the northern portions of Mesilla Basin. The southern portion of Mesilla Basin extends southward across the international border with Mexico; this portion of the basin is referred to as the Conejos-Medanos Aquifer and is hydraulically connected to the Mesilla Basin north of the border. The Rincon and Mesilla basins comprise alluvial valleys along the Rio Grande, regional groundwater basins, and the surrounding watershed. The study areas for this water budget analysis are shown on **Figure 1.1**.

Water budgets are described by the basic mathematical relationship:

$$[\text{Inflow}] - [\text{Outflow}] = [\text{Storage Change}] \quad (1)$$

A change in storage occurs when inflows are not equal to outflows during a specific time period. Changes in inflows and outflows through time generally result in changes in storage through time. The inflow and outflow terms in this analysis comprise multiple components.

A diagram of the water budget components of this analysis and their relationships is shown on **Figure 1.2**. Each component of the water budgets is summarized in subsequent chapters of this report. The land-surface water budget represents the agricultural and urban lands within the basins, as well as the surrounding upland watershed. The principal land-surface water budget components include water supply, consumptive use, and deep percolation. The surface water budget represents the Rio Grande, irrigation canal network, and drains within the basins. The principal surface water budget components include Rio Grande inflows and outflows, surface water deliveries to farms (farm deliveries), and groundwater-surface water exchanges. The groundwater budget represents the groundwater systems in the basins. The principal groundwater budget components include groundwater-surface water exchanges, groundwater withdrawals (pumping), and deep percolation from land surface.

A number of components link among the three water budgets. Deep percolation outflows (irrigation, urban, and mountain-front recharge) from the land water budget are inflows to the groundwater budget. Return flows (runoff) from urban lands, agricultural lands, and tributary arroyos, as well as wastewater discharges, are outflows from the land water budget and inflows to the surface water budget. Farm delivery outflows from the surface water budget are inflows to the land water budget. Groundwater-surface water exchanges are inflows and outflows between the surface water budget and the groundwater budgets. Groundwater withdrawal outflows from the groundwater budget are inflows to the land water budget.

Volume units of acre-feet are used for all of the terms defined in the land water budget, surface water budget, and groundwater budget. One acre-foot is equal to the volume of water required to cover one acre of land to a depth of one foot; it is also equal to 325,851 gallons. For general reference, **Figure 1.3** provides a graphical depiction of the meaning of the term acre-foot.

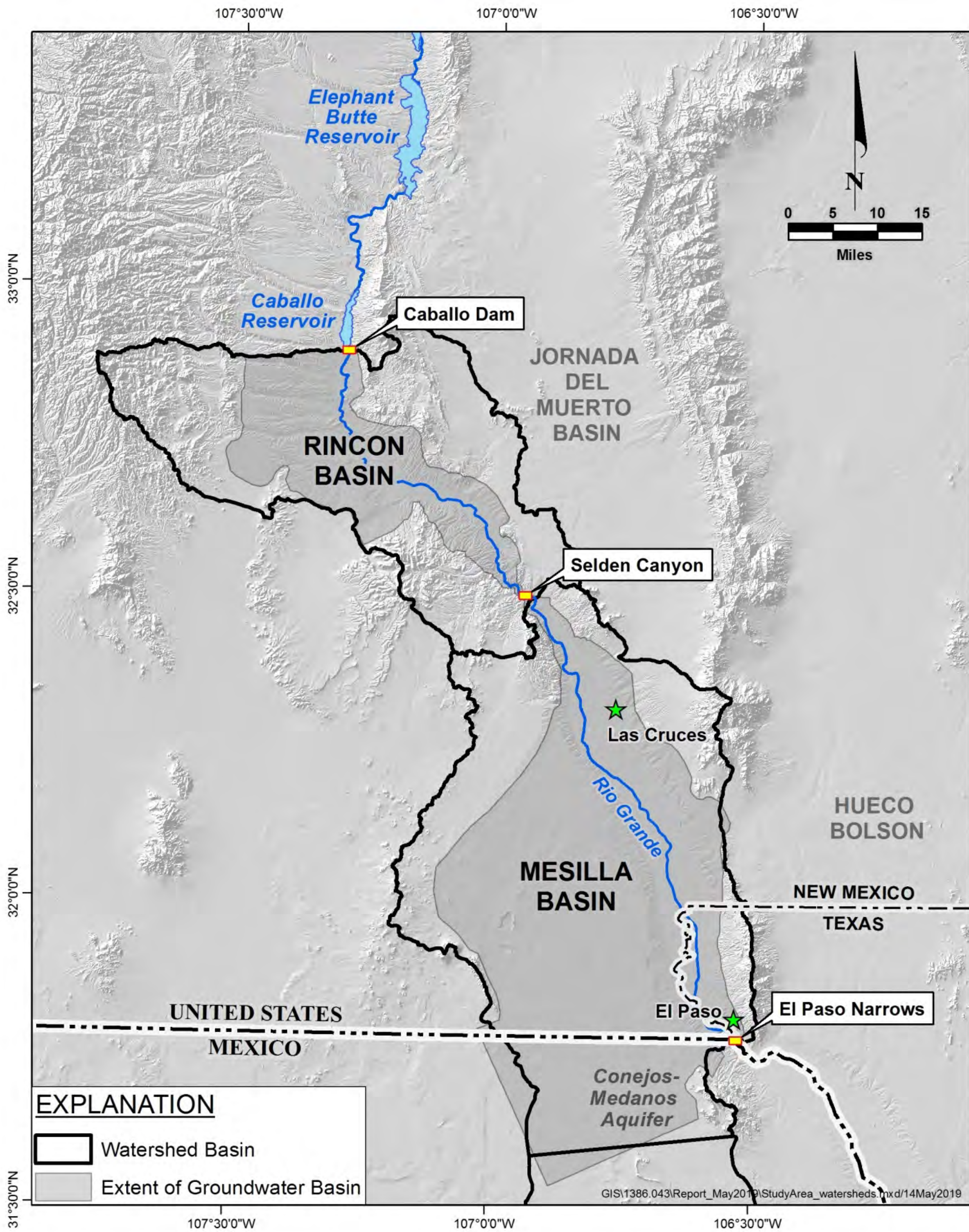

Figure 1.1. Locations of Rincon and Mesilla Basins

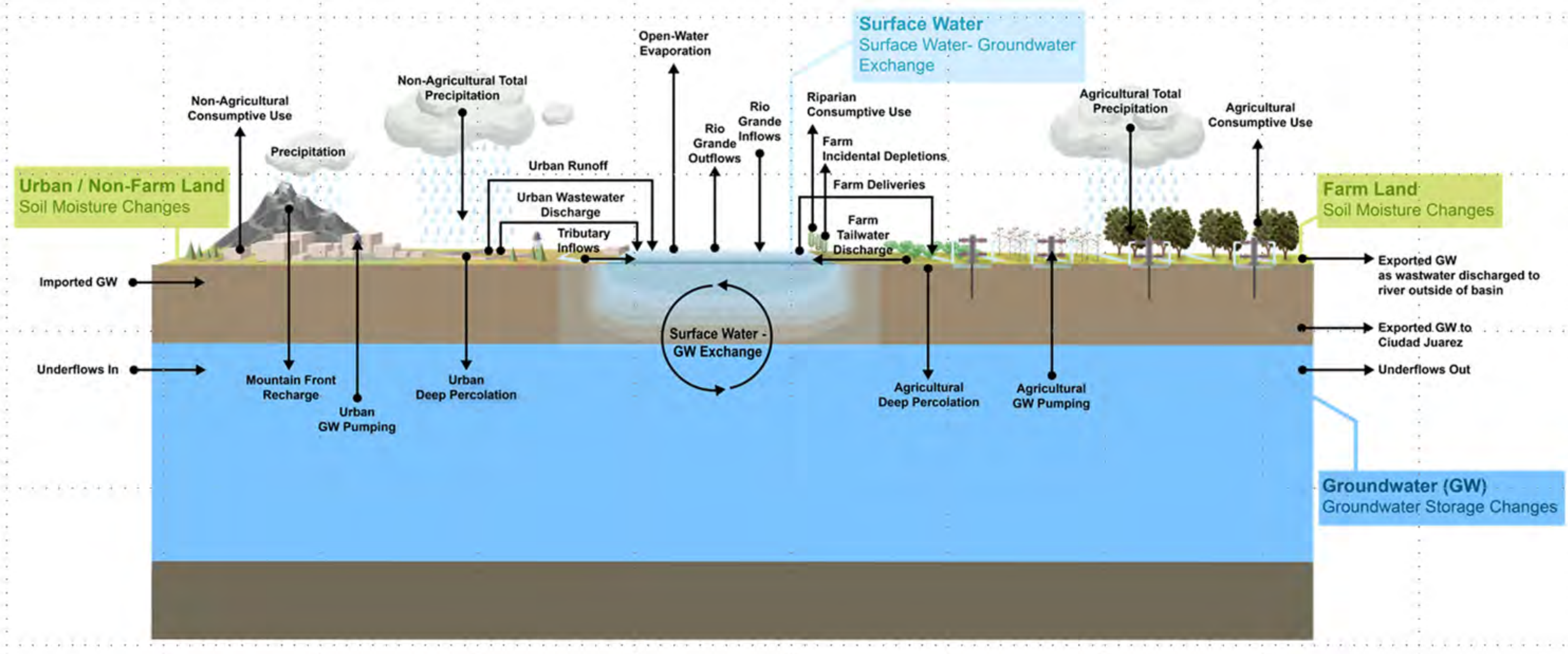

Figure 1.2. Water Budget Diagram for Rincon and Mesilla Basins

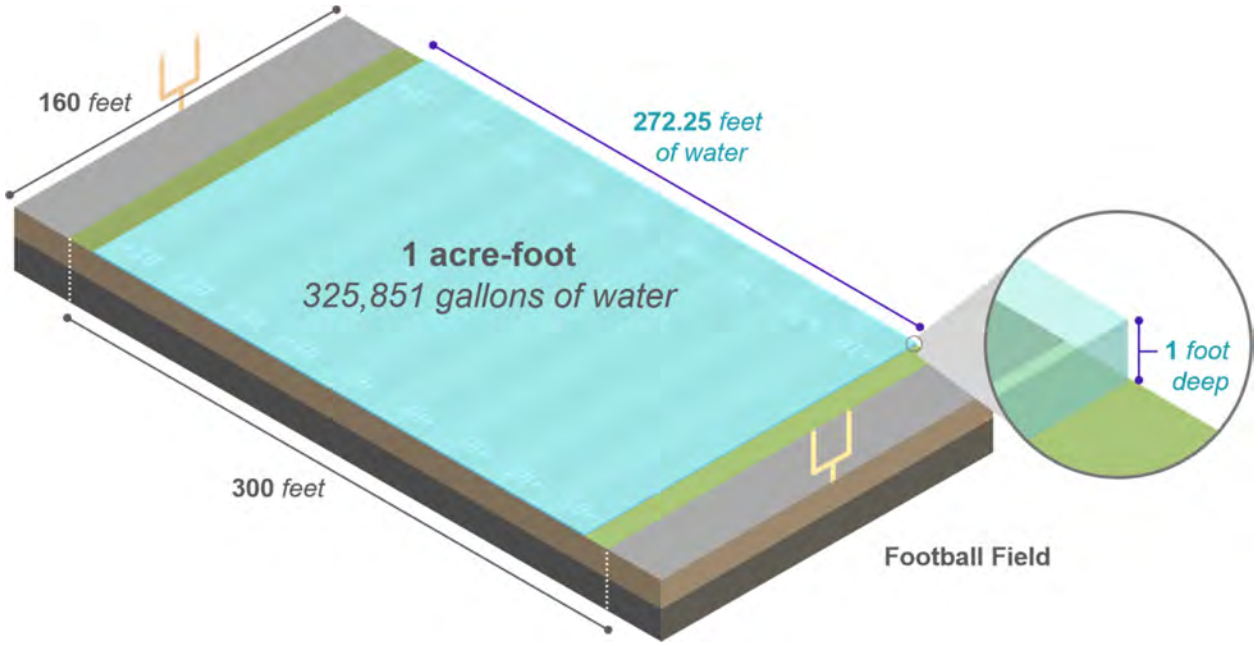

Figure 1.3. Graphical Depiction of 1 Acre-Foot of Water

2 LAND-SURFACE WATER BUDGET

When applied to the land-surface budget, Equation (1) becomes:

$$[Q_{LW\text{-}in}] - [Q_{LW\text{-}out}] = \Delta S_{SM} \quad (2)$$

Where,

$Q_{LW\text{-}in}$ is the sum of land-surface water inflows;
$Q_{LW\text{-}out}$ is sum of land-surface water outflows; and
ΔS_{SM} is change in soil moisture.

The land-surface water budget comprises a farm (agricultural) water budget and a non-farm water budget. The farm water budget represents farm lands, defined as areas where irrigated crops are grown. Considering all components of the land-surface water budget, Equation (2) becomes:

$$[P_f+P_{nf}+SW_f+GW_{app\text{-}f}+GW_{app\text{-}nf}] - [CU_f+CU_{nf}+QSW_f+QSW_{nf}+WW+DP_f+DP_{nf}+GW_e] = \Delta S_{SM} \quad (3)$$

Where,

P_f is precipitation on agricultural (farm) lands;
P_{nf} is precipitation on non-farm lands (urban and undeveloped);
SW_f is applied surface water to farms (farm deliveries);
$GW_{app\text{-}f}$ is applied groundwater to farm lands (agricultural pumping);
$GW_{app\text{-}nf}$ is applied groundwater to urban (non-farm) lands, includes imported;
CU_f is agricultural crop consumptive use;
CU_{nf} is urban consumptive use;
QSW_f is agricultural surface water return flow, including runoff both applied surface water and precipitation;
QSW_{nf} is surface water return flow from non-farm lands (runoff);
WW is urban wastewater discharges;
DP_f is deep percolation to groundwater from farm lands (agricultural);
DP_{nf} is deep percolation to groundwater from non-farm lands; and
GW_e is exported groundwater.

All components of the land-surface water budget can be derived from available data or the analysis of available data. **Figure 2.1** provides a graphical depiction of Equation (3).

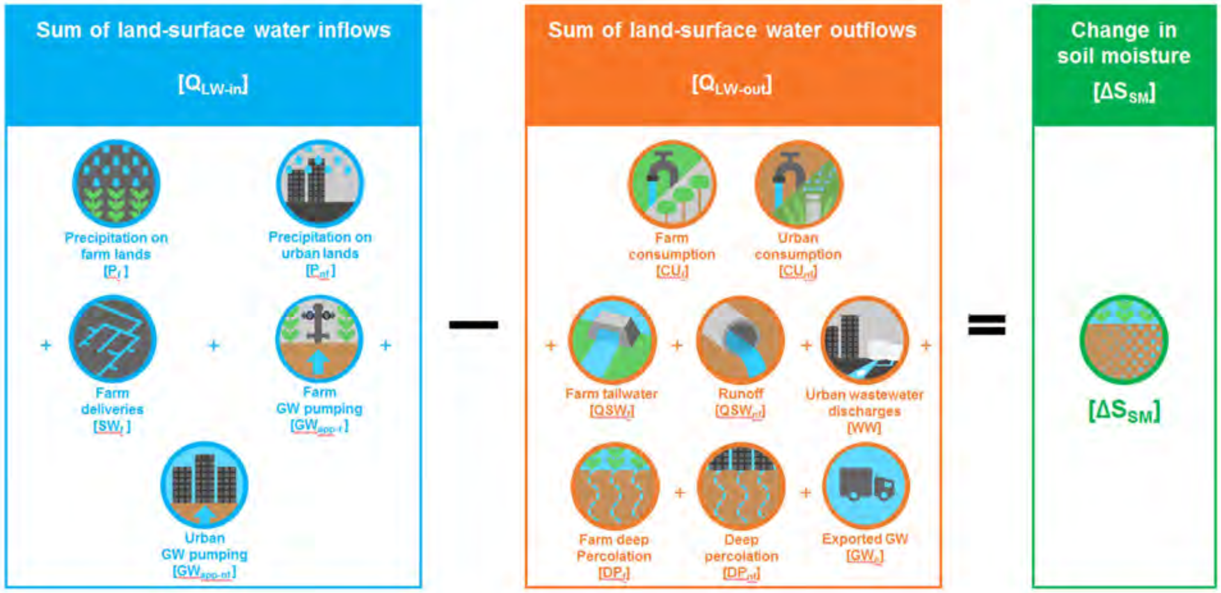

Figure 2.1. Graphical Depiction of the Land-Surface Water Budget Equation

A farm water budget analysis was conducted to estimate monthly farm deep percolation and agricultural applied groundwater pumping in each basin. In addition, estimates for change in agricultural soil moisture storage and agricultural surface water return flows were also determined by the farm water budget analysis. A non-farm water budget analysis was conducted to estimate consumptive use, runoff, and deep percolation for urban and non-urban (upland watershed) areas in the basins, based on measured or estimated water supply and wastewater discharges.

The land-surface water budget and relationships with the surface water and groundwater budgets are shown on **Figure 1.2**. Deep percolation and mountain-front recharge are inputs to the groundwater budget. Urban runoff, tributary inflows to the river, surface water runoff from farm and non-farm lands, and wastewater discharge are inputs to the surface water budget.

The monthly, basin-wide land-surface water budgets for Rincon and Mesilla basins are summarized in the accompanying dataset named IntegratedWaterBudgets.xlsx. Annual land-surface water budgets for Rincon Basin and Mesilla Basin are summarized in this chapter of the report and tabulated in **Appendices A1 and A2**.

2.1 Farm Water Budget

The farm water budget quantifies precipitation on agricultural (farm) lands (P_f), surface water deliveries to farms (SW_f), agricultural applied groundwater (GW_{app-f}), agricultural consumptive use (CU_f), agricultural surface return flows (QSW_f), agricultural deep percolation (DP_f), and monthly change in soil moisture (ΔS_{SM}) in the Rincon and Mesilla basins. The maximum extent of agricultural lands included in this analysis is shown on **Figure 2.2** and acreages are described in the subsequent Model Inputs section of this report.

For this analysis, farm lands in each basin are represented by two categories: lands inside an irrigation district (Elephant Butte Irrigation District and El Paso County Water Improvement District #1) and lands outside an irrigation district. For lands inside the irrigation districts, crop irrigation is supplied by both surface water (farm deliveries) and supplemental groundwater. For lands outside the districts, crop irrigation is supplied solely by groundwater.

We calculated precipitation on farm lands, surface water deliveries, and agricultural surface water return flows from available precipitation and surface water delivery data described in the Model Inputs section of this report. Equivalent data are not available quantifying farm groundwater pumping and deep percolation. Instead, we developed a soil water balance model for the purpose of estimating agricultural groundwater pumping and deep percolation.

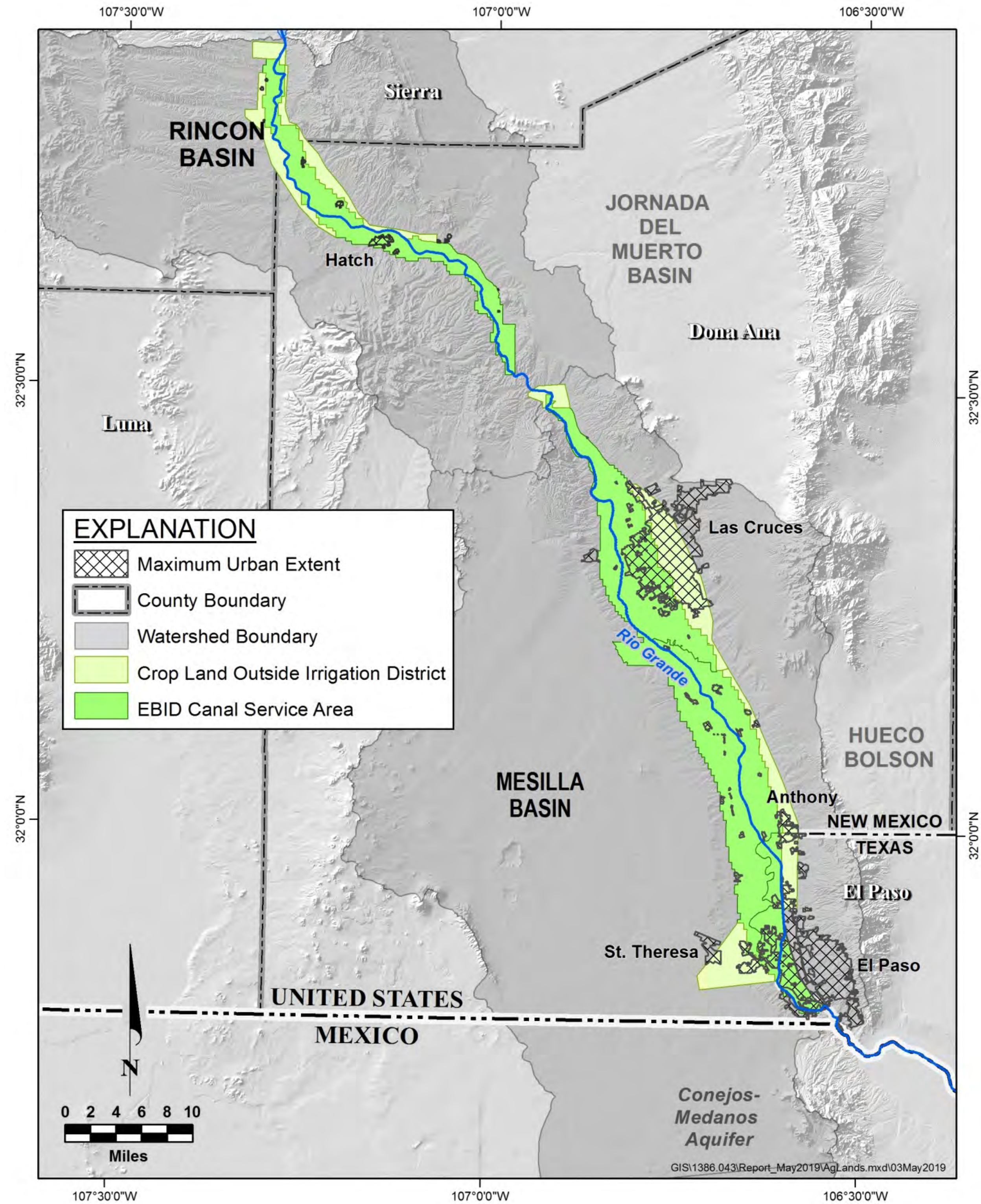

Figure 2.2. Maximum Extents of Agriculture and Urban Lands in Rincon and Mesilla Basins

2.1.1 Description of Soil Water Balance Model

A soil water balance model was developed to estimate agricultural groundwater pumping and deep percolation over the time period of interest, 1938 through 2016. The model tracks soil moisture within the maximum extent of irrigated agricultural lands of the Rincon and Mesilla basins on a monthly time step. The maximum extents of irrigated agricultural lands are described in the 'Model Input' section of this report. Four separate models were developed for this analysis: lands inside District boundaries in Rincon Basin, lands outside District boundaries in Rincon Basin, lands inside District boundaries in Mesilla Basin, and lands outside District boundaries in Mesilla Basin. The models follow identical governing equations and differ only in their respective data inputs.

The monthly soil water balance of the crop root zone is defined as follows:

$$S^t = S^{t-1} + \Delta S_a{}^t + INFPCP^t + INFSW^t + AGW^t - DP^t - AET^t \quad (4)$$

Where,

S is the total volume of water in the root zone;
ΔS_a is change in root zone water storage due to changing cropped acreage;
INFPCP is infiltration of precipitation;
INFSW is the portion of surface water delivery to farms that infiltrates into the root zone;
AGW is agricultural groundwater pumping;
DP is deep percolation, including field losses and on-farm conveyance losses;
AET is crop evapotranspiration; and
t is the time step counter, with t-1 representing previous time step (month).

For each month, the average soil moisture content in the root zone is computed as:

$$\theta^t_{avg} = S^t / V_{rz}{}^t \quad (5)$$

Where,

θ_{avg} is the average soil moisture content; and
V_{rz} is the volume of the crop root zone.

V_{rz} in Equation (5) is computed as the product of the total cropped acreage for a given month and the average root zone depth. Both the acreage and average root zone depth are described in greater detail in the Model Inputs section of this report.

The effect of changing cropped acreage is accounted for by ΔS_a in Equation (4), and is defined as follows:

$$\Delta S_a^{\,t} = 0, \qquad \text{if } A^t = A^{t-1}$$
$$\Delta S_a^{\,t} = Z_{r\text{-}avg} \times \theta_{nc}^{\,t-1} \times (A^t - A^{t-1}), \quad \text{if } A^t > A^{t-1} \qquad (6)$$
$$\Delta S_a^{\,t} = Z_{r\text{-}avg} \times \theta_{c}^{\,t-1} \times (A^t - A^{t-1}), \quad \text{if } A^t < A^{t-1}$$

Where,

A is cropped acreage;

θ_c is the average moisture content inside the cropped area; and

θ_{nc} is the average moisture content outside the cropped area (non-cropped area)

$Z_{r\text{-}avg}$ is the average root zone depth.

In the model, cropped acreage is defined to include cropped area during the growing season, and the month prior to the growing season for cotton and pecans. This definition accommodates the water management practice of pre-irrigation of the soil profile prior to cotton planting and the onset of the pecan growing season. With the exception of cotton and pecan pre-irrigation, land is defined as non-cropped outside of the growing season.

The monthly soil water balance for the non-cropped area is nearly identical to Equation (4), differing only in that infiltration of surface water, INFSW, and applied groundwater, AGW, are not included.

2.1.1.1 On-Farm Conveyance Losses

Some of the surface water delivered to the farm head gate is lost to percolation along on-farm laterals. The soil water balance model routes these conveyance losses directly to deep percolation. The model specifies zero conveyance losses of supplemental groundwater because wells could be installed in close proximity to, or piped to field inlets. The percentage of the farm delivery remaining after on-farm conveyance losses is defined as the farm conveyance efficiency (FCE). Therefore, on-farm conveyance losses are computed as follows:

$$CL^t = (1\text{-}FCE) \times FD^t \qquad (7)$$

FCE is estimated to be 90 percent, based on 10 percent on-farm lateral losses for medium loam soils reported by Blaney and Hanson (1965). It is likely that some improvements to on-farm conveyance structures have been undertaken on large farms since the 1960s; however, Skaggs and Samani (2004) note that the condition of on-farm conveyance structures on small farms remains generally inadequate and inefficient. For this reason, it is important to consider on-farm conveyance losses both historically and in current times.

Conveyance losses are added to field losses to calculate total farm deep percolation in Equation (4).

2.1.1.2 Surface Runoff of Applied Water

Some of the surface water delivered to the farm headgate is lost as surface runoff from the end of the field, and is called surface runoff of applied water or farm tailwater. Such tailwater loss does not infiltrate into the crop root zone, but instead returns to the surface water network. Blaney and Hanson (1965) estimated surface runoff loss for medium loam soils in New Mexico to be about 10% of surface water delivered at the farm headgate.

The soil water balance model computes surface runoff of applied water, SRO_{AW}, as a percentage of surface water delivered to the field, to account for on-farm conveyance losses:

$$SRO^{t}_{AW} = PCT_{TW} \times FCE \times FD^{t} \qquad (8)$$

In equation (8), PCT_{TW}, or tailwater percentage, is the percentage of surface water delivered to the field that is lost as surface water runoff. The tailwater percentage was adjusted as part of the soil water balance model calibration to match estimated actual crop evapotranspiration (ET) and metered groundwater pumping.

Surface runoff of applied water, SRO_{AW}, is added to surface runoff of precipitation – described in the section 'Precipitation Routing' – to calculate total surface water return flows from farm lands, QSW_{f}, in Equation (3).

Infiltration of surface water into the root zone, INF_{SW}, as defined in Equation (4), is the remaining portion of surface water delivered to the farm head gate after subtracting on-farm conveyance losses and farm tailwater as defined by Equations (7) and (8) respectively.

2.1.1.3 Non-uniform moisture distribution

The primary purpose of the soil water balance model is to estimate agricultural groundwater pumping and deep percolation. The disposition of irrigation water delivered to the fields, and specifically the relative proportions of the irrigation water that satisfy crop consumptive use or are lost to deep percolation below the root zone, depend on both the irrigation method and site-specific irrigation practices. Reliable calculations of agricultural groundwater pumping and deep percolation require that both factors be accounted for.

Nearly all irrigated acreage in the study area is surface-irrigated. This irrigation method can lead to spatially uneven, or non-uniform water application over the field if the cropped area is improperly leveled. In this situation, some portions of the field receive a disproportionately large amount of irrigation water; in these areas, crop consumptive use demands are fully satisfied and excess soil moisture sustains relatively high rates of deep percolation past the root zone. Conversely, other portions of the field receive a disproportionately small amount of irrigation water, and consequently are characterized by smaller rates of both crop consumptive use and deep percolation. Analysis of historical aerial imagery by Land IQ has demonstrated the effects on non-uniform water application on crop growth during the 1950s, prior to improvements in land-leveling technologies and their subsequent adoption in the Rincon and Mesilla basins.

The soil water balance model explicitly accounts for irrigation non-uniformity by distributing the monthly volume of irrigation water – derived from both surface and groundwater – over the field according to a common model for the distribution of infiltration over furrow- or basin-irrigated fields. This is called the power distribution model (Karmeli, 1978; Warrick, 1983):

$$(z_U - z) / (z_U - z_L) = x^{\beta} \quad (9)$$

Where,

z is the infiltration rate at a point;

z_U is the infiltration rate near the inlet to the field;

z_L is the infiltration rate at the end of the field;

x is the dimensionless distance from the inlet (fraction of total distance); and

β is the power law exponent controlling the curvature of the distribution.

The left-hand side of Equation (9) represents continuous reduction in infiltration rates moving from the field inlet to the end of the field, as illustrated in **Figure 2.3**.

It is assumed that the soil moisture distribution over the field corresponds to the infiltration distribution in Equation (9) because soil moisture depends on infiltration. One side of the field serves as the field inlet, so that x in Equation (9) is proportional to the percentage of the total field area.

The soil water balance model considers a collection of fields with different acreages. However, for a collection of fields with arbitrary and variable size, the infiltration distribution over the entire cropped area is identical to what would be obtained by separately adding up individual distributions over the collection of fields, provided that the average infiltration rate is the same.

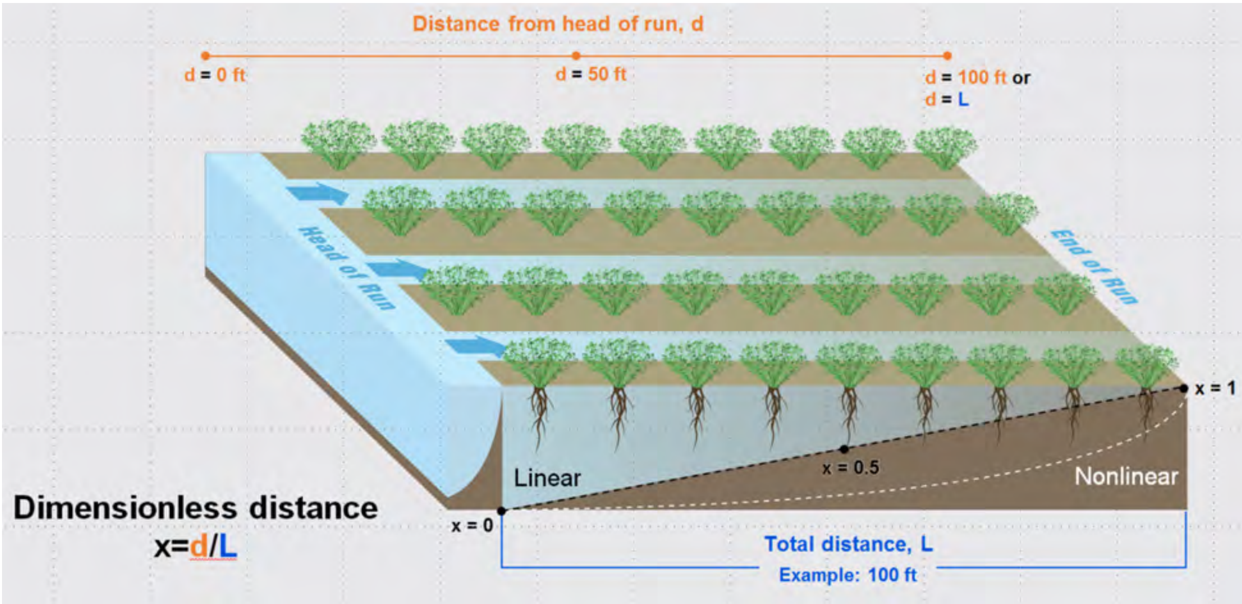

Figure 2.3. Diagram of Irrigation Non-Uniformity Showing Depth Infiltrated as a Function of Dimensionless Distance from Source

Based on Equation (9) and the assumptions outlined above, the following power distribution model is used to define moisture distribution over the cropped area:

$$(\theta_U - \theta) / r_\theta = a^\beta \qquad (10)$$

Where,

$r_\theta = \theta_U - \theta_L$ is the range of soil moisture content;

θ_L is the minimum soil moisture content over the cropped area;

θ_U is the maximum soil moisture content over the cropped area;

a is the fraction of the total cropped area; and

β is the power constant.

The range of soil moisture content over the field, r_θ, is specified as an input to the model. The left hand side of Equation (10) is the percent difference between θ_U and θ, and ranges from zero to one, since the fraction of the total cropped area also ranges from zero to one. The average percent soil moisture, PCT_{avg}, is therefore computed by integrating Equation (10) from zero to one, and subtracting from 1:

$$PCT_{avg} = 1 - 1/(\beta+1) \qquad (11)$$

When $\beta=1$, PCT_{avg} is one-half; this represents a linear distribution. When $\beta>1$, PCTavg is greater than one-half. This is representative of a typical infiltration distribution in which most of the area receives infiltration is exceeding the average infiltration rate (Burt and others, 1997). **Figure 2.3** illustrates linear and non-linear moisture distributions.

Given the average moisture content over the cropped area as defined in Equation (5), the power constant β, and the soil moisture range, r_θ, the upper and lower limits of the moisture distributions are computed as follows:

$$\theta_U = \theta_{avg} + r_\theta \times (1\text{-}PCT_{avg}) \quad (12)$$
$$\theta_L = \theta_U - r_\theta \quad (13)$$

Combining equation (10) with equation (12) yields an expression for the soil moisture at a point as a function of the percent area:

$$\theta_{point} = \theta_{avg} + r_\theta \times (1/(\beta+1) - a^\beta) \quad (14)$$

The parameters β and r_θ control the shape of the soil moisture distribution. Given these parameters, the lower bound on soil moisture, θ_L, controls the total volume of soil moisture in the root zone. All three parameters were adjusted as part of the soil water balance calibration, as discussed in the section 'Soil Water Balance Calibration'.

The distribution of irrigation water over the field controls the distribution of crop consumptive use and deep percolation, as discussed above. The soil water balance model also explicitly calculates variation in crop consumptive use and deep percolation over the field, as discussed in the following sections, 'Field Losses and Total Farm Deep Percolation' and 'Crop Evapotranspiration'.

2.1.1.4 Field Losses and Total Agricultural Deep Percolation

Field losses (FL) are defined as water flux from the base of the root zone (deep percolation at the field). If the moisture distribution in the root zone is relatively uniform, then the vertical water flux from the root zone is approximately equal to the unsaturated hydraulic conductivity, $K(\theta)$. This condition is also referred to as unit hydraulic gradient or gravity drainage, and is relatively common in a deeply wetted soil profile as would be found beneath an irrigated field.

The unsaturated hydraulic conductivity is calculated according to the widely-used model of van Genuchten (1980):

$$K(\theta) = K_{sat} \times \Theta^{1/2} \times [1\text{-}(1\text{-}\Theta^{1/m})^m]^2 \quad (15)$$

Where,

$\Theta = (\theta-\theta_r)/(\theta_{sat}-\theta_r)$ is the dimensionless moisture content;

θ_r is the residual moisture content of the soil;

θ_{sat} is the saturated moisture content, or total porosity of the soil;

K_{sat} is the saturated hydraulic conductivity of the soil;

$m = \lambda/(\lambda+1)$; and

λ is the pore-size distribution index of the soil.

Under the assumption of gravity drainage, Equation (14) defines water flux as a function of moisture content at a point. To calculate to total field losses over the cropped area, Equation (15) must be integrated over the cropped area:

$$FL^t = A^t \times \int K[\theta_{point}(a)]\, da \quad (16)$$

Equation (16) is computed in the soil water balance model using trapezoidal integration, with θ(a) defined based on Equation (15). Total deep percolation (DP) from farms is the sum of field losses (FL) and on-farm conveyance losses (CL).

Non-cropped areas are not irrigated, so deep percolation beneath non-cropped areas (DPnc) is simply calculated as:

$$DP_{nc} = A_{nc}^t \times K(\theta_{nc}^t) \quad (17)$$

Where,

A_{nc}^t is the non-cropped area;
θ_{nc}^t is the average moisture content of the non-cropped area.

2.1.1.5 Crop Evapotranspiration

Land IQ calculated crop evapotranspiration under standard conditions – referred to in this report as theoretical crop evapotranspiration – based on meteorological data and representative crop coefficients. Land IQ also estimated historical actual evapotranspiration (AET) based on reported crop yield, with lower AET earlier in the study period. Lower rates of AET were due primarily to poor irrigation water management and distribution uniformity, with better irrigation water management in current times. The historical AET therefore represents crop ET under soil water stress conditions.

The soil water balance model uses theoretical crop ET as input data, and computes AET based on simulated moisture conditions in the root zone. Under soil water stress conditions, root zone moisture is too low, and AET will be reduced below the theoretical crop ET. Allen (1998) provides a simple model of AET under water stress conditions, which is used in the soil water balance model:

$$AET_{point} = K_s \times K_c \times ET_o \quad (18)$$

Where,

AET_{point} is actual ET at a point;
K_s is the water stress coefficient;
K_c is the crop coefficient; and
ET_o is the reference ET.

The quantity $K_c \times ET_o$ is the theoretical crop ET provided as a data input to the model. The section 'Model Inputs' discusses the ET dataset in greater detail. When $K_s = 1$, then AET_{point} is equal to the theoretical crop ET.

The water stress coefficient is computed as follows:

$$K_s = 0, \text{ if } \theta \leq \theta_{wp}$$
$$K_s = (\theta - \theta_{wp}) / (\theta_{crit} - \theta_{wp}), \text{ if } \theta_{wp} < \theta < \theta_{crit} \quad (19)$$
$$K_s = 1, \text{ if } \theta \geq \theta_{crit}$$

Where,

θ_{wp} is the moisture content at wilting point; and
θ_{crit} is the critical soil moisture.

The critical soil moisture is defined:

$$\theta_{crit} = \theta_{fc} - DF \times (\theta_{fc} - \theta_{wp}) \quad (20)$$

Where,

θ_{fc} is the moisture content at field capacity; and
DF is a soil water depletion factor.

The section 'Model Inputs' describes data inputs used to calculate θ_{crit} according to Equation (20).

Equations (18) and (19) show how AET depends on soil moisture. These equations define AET at a point. To calculate total AET over the cropped area requires integrating Equation (18) over the total cropped area:

$$AET = A^t \times \int AET_{point} [\ \theta_{point}(a)\ ]\ da \quad (21)$$

Equation (21) is computed in the soil water balance model using trapezoidal integration, with $\theta_{point}(a)$ defined based on Equation (14).

AET in cropped areas is calculated using Equation (21). AET in the non-cropped area is defined as bare soil evaporation, and is described in Section 2.1.3.

2.1.1.6 Agricultural Groundwater Pumping

The availability of supplemental groundwater for irrigation provides farmers with the flexibility to increase crop AET and therefore yield by alleviating soil water stress conditions as described above. For this analysis, the year 1951 represents the time when farmers within the districts began pumping substantial amounts of groundwater for irrigation purposes, concurrent with curtailed RGP surface water deliveries to farms. New Mexico and Texas well records indicate that irrigation well installations began to increase in the 1950s, as described in the Groundwater Outflows section of this report. Lands outside the districts do not receive surface water deliveries and thus have relied solely on groundwater for the entire study period.

Prior to the adoption of supplemental groundwater pumping for irrigation within District lands in the 1950s, the lower bound on soil moisture, θ_L, is unconstrained in the soil water balance model. Beginning in 1951, θ_L is estimated in order to reproduce adjusted AET, which incorporates information on historic changes in crop yield (Land IQ). Section 2.1.5 describes the method for estimating θL to match adjusted AET. The estimated value of θ_L is called θ_L^*. Inserting θ_L^* into Equations (13) and (14) provides an expression for average moisture content of the root zone beginning in 1950:

$$\theta^*_{avg} = \theta_L^* + r_\theta \times (PCT_{avg}), \qquad \text{if } \theta_L < \theta_L^* \qquad (22)$$

As implemented in the soil water balance model, θ_{avg} is calculated according to Equations (4) and (5) without supplemental pumping – that is, AGW = 0 in Equation (7). Then, θ^*_{avg} is calculated according to Equation (22) if $\theta_L < \theta_L^*$. Otherwise, supplemental pumping is not required to satisfy $\theta_L \geq \theta_L^*$, and $\theta^*_{avg} = \theta_{avg}$ as calculated in Equation (5).

Agricultural groundwater pumping is calculated by substituting θ^*_{avg} into Equation (4) and rearranging:

$$AGW^t = \theta^{t}*_{avg} \times V^t_{rz} - S^{t-1} - \Delta S_a{}^t - INFPCP^t - INFSW^t + DP^t(\theta^t*_{avg}) + AET^t(\theta^t*_{avg}) \qquad (23)$$

The last two terms in Equation (23) implicitly require determining the upper and lower limits on moisture content over the cropped area based on θ^{t*}_{avg} with Equations (12) and (13), and numerical integration over the corresponding moisture interval according to Equations (16) and (21).

Given the required infiltration of applied water to achieve θ^*_{avg}, the corresponding agricultural groundwater pumping, AGW, can then be calculated from Equation (23).

2.1.2 Precipitation Routing

Precipitation is the natural source of soil moisture in the study area. Precipitation that falls on the ground infiltrates into the soil at a rate depending on ground cover, physical characteristics of the soil, and antecedent moisture. The portion of precipitation that is in excess of the infiltration rate becomes surface runoff.

Monthly precipitation time series were developed for the Rincon and Mesilla basins based on historical datasets from the Precipitation-Regression on Independent Slopes Model (PRISM) (Daly and others, 2008). The PRISM historical datasets (available for download from the PRISM Climate Group at Oregon State University) consist of continuous, spatially distributed precipitation surfaces with grid cell size of 4 square kilometers (km2) (or about 1.5 square miles). For each basin, monthly precipitation was calculated as the area-weighted average precipitation of the monthly PRISM surface for grid cells within the study area. **Figure 2.4** shows historic annual precipitation used in the Rincon and Mesilla basin water budgets. Annual precipitation amounts recorded at weather stations at Caballo Reservoir Dam and at the New Mexico State University were assessed to verify the accuracy of the interpolated, basin-wide PRISM estimates. The station data are generally consistent with PRISM estimates (**Figure 2.4**), indicating that PRISM estimates are reasonable to use for this analysis.

Total precipitation falling on agricultural lands, urban lands, and the upland watershed are summarized in **Table 2.1**.

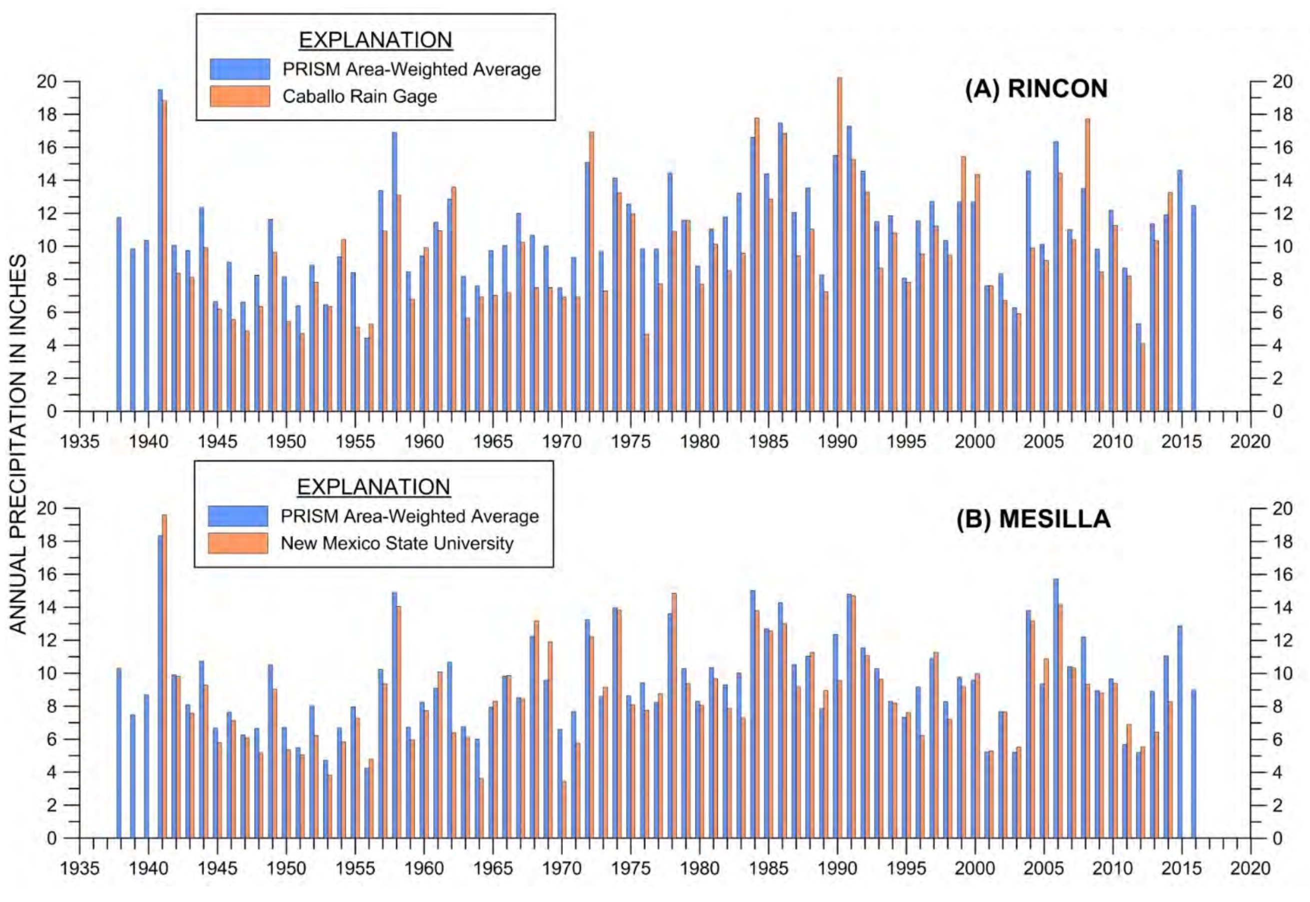

Figure 2.4. Annual Precipitation in Rincon and Mesilla Basins

Table 2.1. Summary of Annual Precipitation

YEAR	PRECIPITATION IN RINCON BASIN (in acre-feet)				PRECIPITATION IN MESILLA BASIN (in acre-feet)			
	Agriculture Lands	Urban Lands	Upper Watershed	Total	Agriculture Lands	Urban Lands	Upper Watershed	Total
1938	18,896	487	607,694	627,076	76,403	22,528	836,893	935,824
1939	15,191	394	510,397	525,982	52,677	15,532	613,121	681,330
1940	13,501	347	538,911	552,760	66,109	19,195	706,138	791,442
1941	31,370	830	1,009,419	1,041,618	140,611	41,207	1,488,478	1,670,296
1942	15,293	414	521,844	537,551	73,149	22,009	807,262	902,420
1943	14,284	390	506,339	521,013	58,477	17,748	660,582	736,807
1944	17,024	474	643,056	660,554	78,730	23,967	875,498	978,194
1945	9,933	277	344,854	355,064	47,795	14,833	544,996	607,624
1946	12,863	391	469,445	482,699	51,381	16,041	627,861	695,283
1947	9,896	293	343,287	353,476	45,212	13,971	510,258	569,441
1948	12,255	382	428,373	441,010	48,250	14,635	543,431	606,316
1949	17,402	540	604,215	622,156	75,862	23,212	858,146	957,220
1950	12,641	419	421,583	434,643	47,605	15,119	548,338	611,062
1951	8,536	272	332,828	341,636	38,953	11,843	447,741	498,537
1952	12,660	402	460,516	473,578	55,837	17,366	658,101	731,304
1953	10,135	336	335,191	345,661	32,687	10,057	386,340	429,085
1954	15,233	515	484,124	499,871	47,891	14,967	544,981	607,839
1955	12,542	441	436,504	449,486	59,521	18,328	647,229	725,078
1956	6,603	230	230,459	237,291	31,761	10,011	345,399	387,170
1957	21,493	763	692,346	714,602	71,523	22,294	838,545	932,362
1958	25,662	898	876,213	902,773	106,370	33,047	1,218,377	1,357,794
1959	12,620	441	438,532	451,593	45,875	14,255	553,709	613,840
1960	14,343	470	488,489	503,303	60,749	19,198	670,788	750,735
1961	18,508	639	593,343	612,490	67,921	20,673	740,911	829,506
1962	20,651	693	665,993	687,336	75,884	23,994	873,586	973,463
1963	11,157	387	425,329	436,873	44,904	14,127	557,877	616,909
1964	10,456	342	395,687	406,485	39,406	12,886	495,526	547,817
1965	13,520	465	507,082	521,067	57,767	18,384	647,145	723,296
1966	15,111	528	521,077	536,716	73,396	23,415	800,031	896,841
1967	17,702	613	623,363	641,678	59,640	18,892	697,997	776,530
1968	15,624	537	554,166	570,326	92,548	28,966	993,950	1,115,464
1969	14,517	500	520,081	535,098	74,645	23,292	774,231	872,167
1970	11,244	383	387,872	399,499	44,017	14,786	542,187	600,990
1971	14,057	481	484,145	498,683	54,171	17,629	627,624	699,425
1972	22,730	778	782,851	806,359	94,820	30,934	1,081,125	1,206,879
1973	16,075	585	501,516	518,176	65,403	21,057	695,773	782,232
1974	23,888	838	731,416	756,142	103,933	34,095	1,134,599	1,272,627
1975	19,989	697	650,905	671,591	59,748	19,609	708,249	787,605
1976	14,332	517	511,334	526,183	67,443	22,300	768,887	858,630
1977	14,460	517	510,211	525,188	59,892	19,871	670,353	750,116
1978	21,440	787	749,853	772,080	102,886	33,991	1,104,359	1,241,237
1979	18,789	681	598,958	618,429	75,146	24,767	835,891	935,804
1980	13,831	521	455,794	470,146	61,829	20,904	673,793	756,527
1981	17,164	628	573,177	590,968	76,553	26,239	839,256	942,048
1982	17,262	638	611,613	629,513	65,705	23,038	758,057	846,801
1983	18,464	699	687,374	706,538	68,096	23,648	821,301	913,045
1984	26,612	997	859,561	887,170	107,732	37,175	1,222,565	1,367,472
1985	20,863	777	746,659	768,298	91,893	30,932	1,034,452	1,157,277

YEAR	PRECIPITATION IN RINCON BASIN (in acre-feet)				PRECIPITATION IN MESILLA BASIN (in acre-feet)			
	Agriculture Lands	Urban Lands	Upper Watershed	Total	Agriculture Lands	Urban Lands	Upper Watershed	Total
1986	26,982	1,022	905,248	933,252	103,136	35,840	1,161,970	1,300,946
1987	19,045	735	624,011	643,791	75,163	26,403	857,199	958,765
1988	20,006	761	702,517	723,285	80,285	27,958	896,983	1,005,226
1989	12,540	474	428,587	441,601	58,548	20,719	635,826	715,094
1990	25,694	937	802,178	828,810	86,298	30,264	1,008,656	1,125,218
1991	28,603	1,123	894,175	923,902	110,337	38,223	1,200,435	1,348,996
1992	22,706	874	753,049	776,628	81,827	28,909	941,045	1,051,780
1993	15,715	584	598,094	614,392	73,869	26,061	835,576	935,506
1994	17,772	655	614,872	633,299	59,621	20,693	676,035	756,349
1995	12,158	452	418,410	431,021	51,379	18,722	599,169	669,270
1996	17,862	676	598,414	616,952	62,750	23,001	749,886	835,637
1997	19,479	744	659,237	679,459	82,778	29,629	880,206	992,613
1998	15,425	592	536,733	552,750	60,263	21,892	672,028	754,183
1999	20,582	771	655,672	677,025	74,069	26,406	790,029	890,504
2000	20,188	783	655,746	676,717	71,899	25,000	775,486	872,385
2001	10,715	406	396,030	407,151	37,888	13,939	425,815	477,641
2002	12,369	499	432,915	445,784	55,019	20,148	623,415	698,582
2003	9,198	368	326,426	335,993	38,927	13,998	422,779	475,704
2004	22,658	953	754,636	778,246	103,470	37,437	1,117,969	1,258,876
2005	15,641	635	524,918	541,195	71,286	25,958	753,992	851,236
2006	26,481	1,104	845,698	873,283	115,517	43,289	1,274,103	1,432,909
2007	15,918	638	572,914	589,470	75,386	27,734	845,437	948,558
2008	22,158	941	698,006	721,106	88,165	33,539	989,926	1,111,630
2009	15,862	669	508,026	524,557	63,446	23,854	727,081	814,380
2010	18,432	793	631,882	651,107	66,649	24,935	789,900	881,484
2011	14,367	647	448,862	463,877	44,835	15,745	455,763	516,343
2012	8,243	370	275,517	284,130	38,726	14,486	420,463	473,675
2013	17,618	796	589,273	607,687	67,019	25,225	718,193	810,438
2014	18,832	821	616,489	636,142	80,673	29,234	896,751	1,006,658
2015	21,658	1,039	758,036	780,733	99,242	34,531	1,039,937	1,173,710
2016	19,229	841	646,414	666,484	66,685	23,707	728,425	818,818

Annual values are based on monthly PRISM precipitation data.

2.1.2.1 Surface Runoff of Precipitation from Agricultural Lands

Return flows of excess precipitation water falling on agricultural lands is called surface runoff of precipitation. We used the Soil Conservation Service (SCS) curve number method (USDA, 2004) to develop an empirical relationship between monthly total precipitation and monthly surface runoff.

Developing the empirical relationship consisted of two steps. First, we used the curve number equation to calculate daily surface runoff based on daily precipitation data recorded at Caballo Dam and New Mexico State University. These calculations used a curve number value of 85 for both the Rincon and Mesilla basins, based on curve number values for hydrologic soil group C (which is representative of loam soil) tabulated by Rawls (1993).

Second, we summed daily precipitation and runoff by month, and used a best-fit line to approximate the relationship between monthly precipitation and monthly runoff. A separate best-fit line was developed for the Rincon Basin based on precipitation data from Caballo Dam, and for the Mesilla Basin based on precipitation data from New Mexico State University. The monthly precipitation-runoff relations are based on characteristics of precipitation at the daily time scale such as intensity and frequency, and the assumed SCS curve number. The empirical relationships for Rincon and Mesilla are:

$$SRO_{PCP\text{-}RIN} = 0.0144\times(PCP_{RIN})^{2.649}\ ;\ (R^2=0.5312) \qquad (24)$$

$$SRO_{PCP\text{-}MES} = 0.0133\times(PCP_{MES})^{2.727}\ ;\ (R^2=0.5007) \qquad (25)$$

Where,

$SRO_{PCP\text{-}RIN}$ is monthly surface runoff of precipitation on agricultural lands in the Rincon Basin
PCP_{RIN} is monthly precipitation in the Rincon Basin
$SRO_{PCP\text{-}MES}$ is monthly surface runoff of precipitation on agricultural lands in the Mesilla Basin
PCP_{MES} is monthly precipitation in the Mesilla Basin

Figure 2.5 illustrates the approximated empirical relationship between monthly precipitation and monthly runoff.

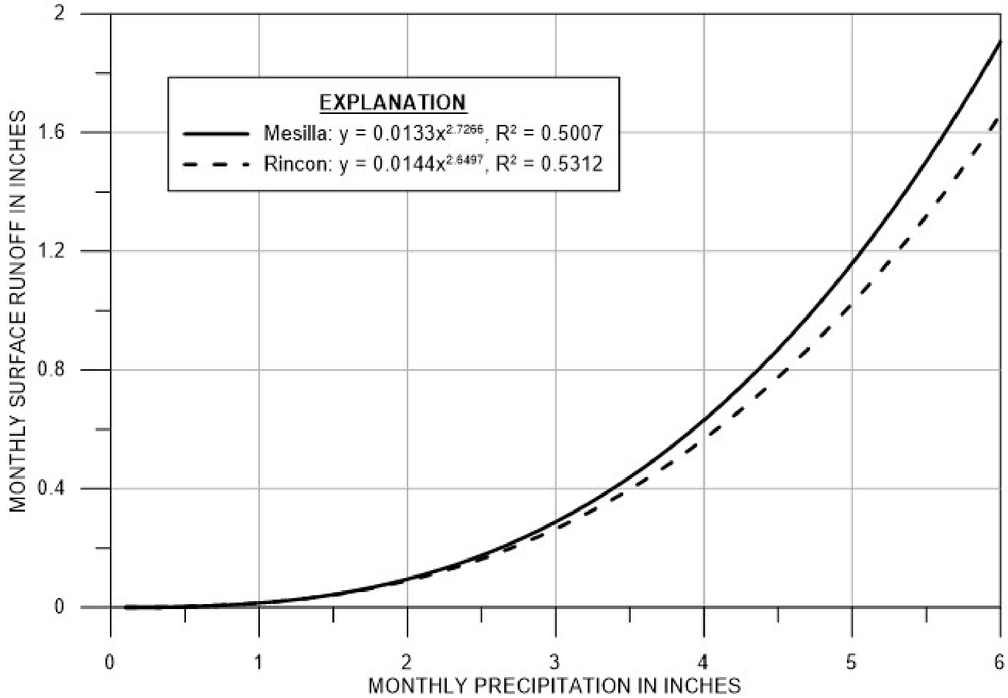

Figure 2.5. Empirical Monthly Rainfall-Runoff Relationship for Rincon and Mesilla Basins

2.1.2.2 Effective Precipitation on Agricultural Lands

A portion of the monthly crop ET and off-season bare soil evaporation is satisfied by precipitation – this is known as effective precipitation. Effective precipitation was estimated using empirical equations adopted by the U.S. Bureau of Reclamation (USBR) – referred to herein as the USBR method. The USBR method is recommended for arid and semi-arid regions. Percent of precipitation that is effective precipitation is provided in increments of monthly rainfall, as shown in **Table 2.2**.

Table 2.2. Empirical Equations Used to Estimate Effective Precipitation

Equation	Range
$P_{eff} = 0.95 \times P$	$P \leq 1$
$P_{eff} = 0.95 + 0.90 \times (P-1)$	$1 < P \leq 2$
$P_{eff} = 1.85 + 0.82 \times (P-2)$	$2 < P \leq 3$
$P_{eff} = 2.67 + 0.65 \times (P-3)$	$3 < P \leq 4$
$P_{eff} = 3.32 + 0.45 \times (P-4)$	$4 < P \leq 5$
$P_{eff} = 3.77 + 0.25 \times (P-5)$	$5 < P \leq 6$
$P_{eff} = 4.02 + 0.05 \times (P-6)$	$P > 6$

Where,

P is precipitation in inches; and

P_{eff} is effective precipitation, in inches.

We used basin-wide precipitation estimates from PRISM, as previously described, for effective precipitation calculations. Monthly effective precipitation was subtracted from total monthly crop ET rates, with the remaining monthly ET supplied to the soil water balance model as crop ET demand to be satisfied by applied irrigation water.

For months when the total precipitation exceeded the sum of effective precipitation and surface runoff, the remaining precipitation was assigned as infiltration to the root zone – INFPCP as described in Equation (4). This ensures that all precipitation is accounted for.

2.1.3 Model Inputs

2.1.3.1 Crop Acreage and Evapotranspiration

The farm soil water balance models encompass the maximum cropped acreages provided by Land IQ for this analysis. The Rincon farm budget encompasses an area of 20,726 acres (about 32 square miles): 18,828 acres within the Elephant Butte Irrigation District's (EBID) Arrey canal service area, and 1,898 acres outside the district boundaries. The Mesilla farm budget encompasses an area of 92,648 acres (about 145 square miles): 89,814 acres within EBID's Leasburg, Eastside, and Westside canal service areas and the portion of El Paso County Water Improvement District #1 (EPCWID #1) located in Mesilla Basin, and 2,834 acres outside the districts' boundaries. These outside areas represent agricultural lands that are supplied solely by groundwater pumping. Agricultural lands in the basins are shown on **Figure 2.1**.

Crop distribution and evapotranspiration (ET) (crop consumptive use) datasets for the Rincon and Mesilla valleys prepared by Land IQ (delivered January 26, 2018) were used in this farm water budget analysis. The Land IQ datasets contain annual acreages and monthly ET data for nineteen crop categories, along with annual ET adjustment factors computed based on analysis of historic crop yield. Disaggregated crop acreages for canal service areas and areas outside district boundaries were provided by Land IQ.

We used crop acreage data provided by Land IQ for 1938-2014, and we estimated disaggregated acreages for 2015 and 2016 by applying the 2014 crop proportions from the Land IQ dataset to the reported total acres for the respective year.

We processed the crop consumptive use dataset from Land IQ to prepare input files for the soil water balance model. The soil water balance model simulates total ET from all the crops, and so we computed total crop ET as a summation over all crop types over the study period; these totals represent historical actual crop ET accounting for changes in crop yield. We also calculated theoretical crop ET rates for each crop by dividing adjusted crop ET by the corresponding crop ET adjustment factor. The adjusted Land IQ AET rates are referred to herein as target AET rates, meaning that they reflect the best available estimates, and should be reproduced by the soil water balance model to the extent possible.

Annual total crop consumptive use volumes calculated by Land IQ for Rincon and Mesilla basins are shown on **Figure 2.6 and Figure 2.7**. Annual crop consumptive use in the Mesilla Basin varied between about 166,000 AF in 1938 to about 257,000 AF in 1997, with an average of about 220,000 AF. Annual crop consumptive use in the Rincon Basin varied between about 31,000 AF in 1938 to about 78,000 in 2011, with an average of about 52,000 AF. Effective precipitation satisfied between about 8% to 43% of crop consumptive use in both basins, although the highest effective precipitation as a percentage of consumptive use occurred in 1941 and was associated with anomalously high precipitation that year. From 1938 through 2016, precipitation satisfied, on average, about 20% and 19% of crop consumptive use in the Rincon and Mesilla Basins, respectively; remaining crop consumptive use was satisfied by applied water, either surface water or groundwater.

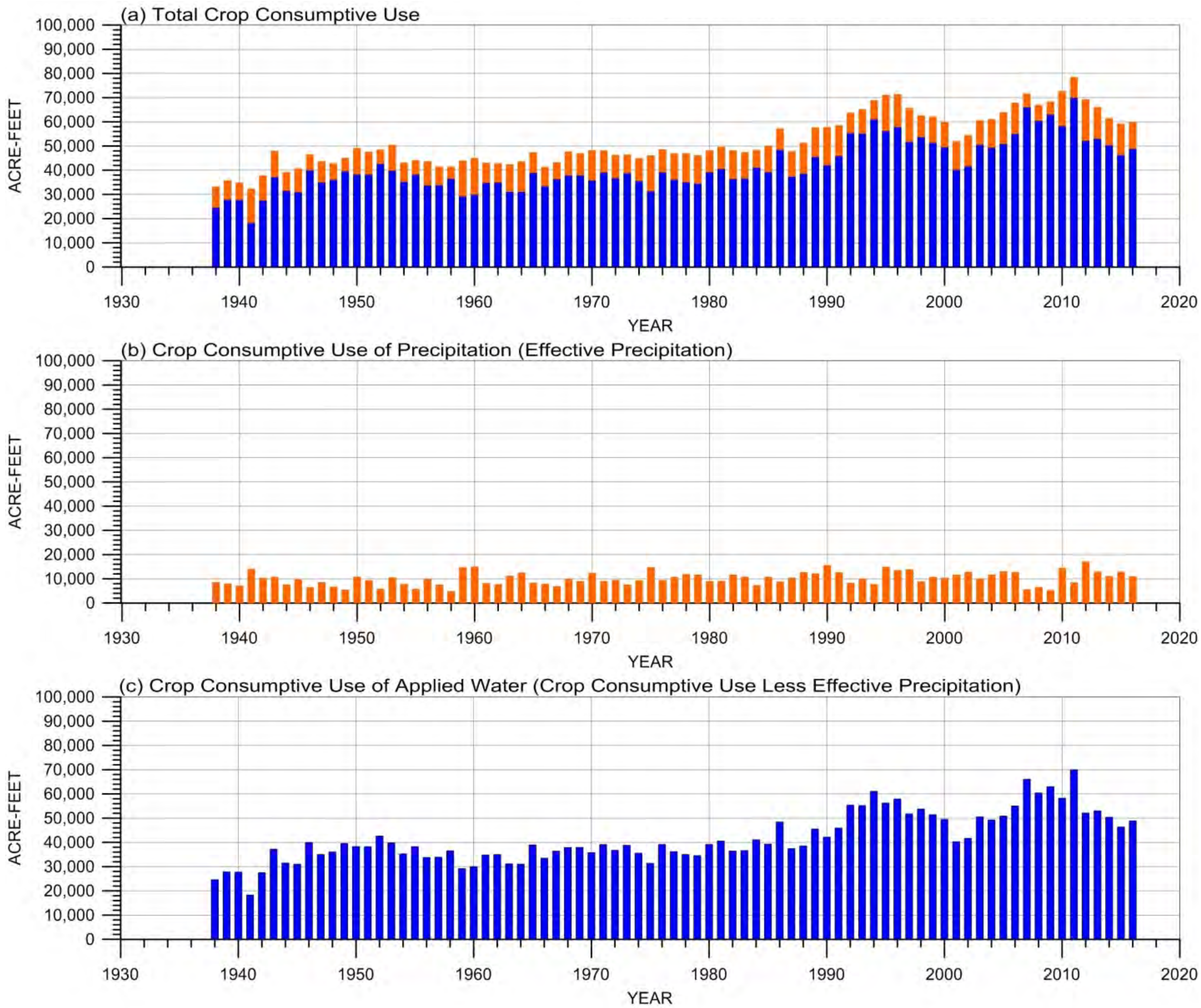

Figure 2.6. Annual Crop Consumptive Use Occurring on Agricultural Lands in Rincon Valley

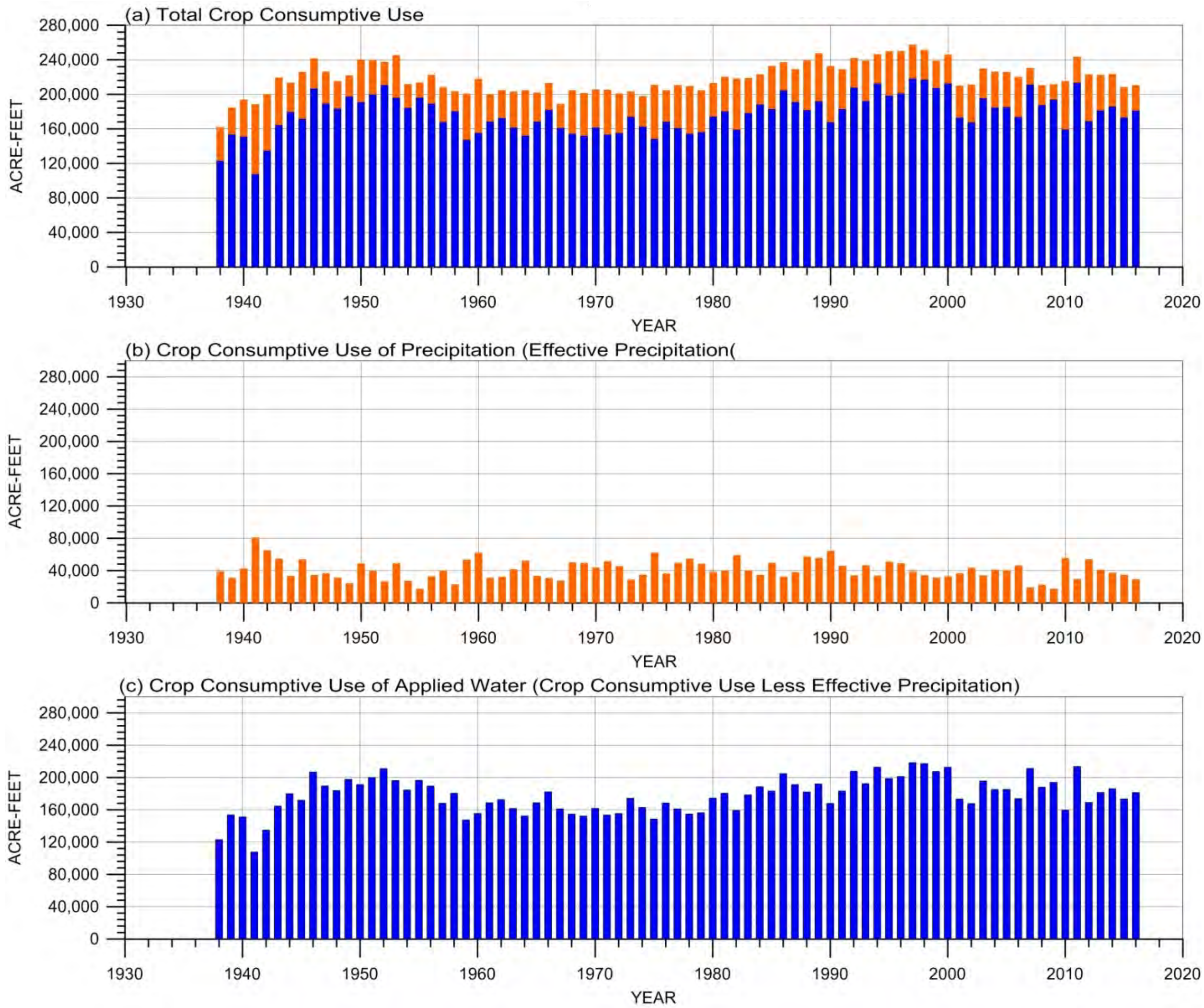

Figure 2.7. Annual Crop Consumptive Use Occurring on Agricultural Lands in Mesilla Valley

2.1.3.2 Double-Cropping

Most of the crops grown in the study area follow a single-cropping pattern, with land remaining fallow outside of the growing season. However, double-cropping is also practiced in a small portion (approximately 2% of total cropped acreage, on average) of the study area. The Land IQ datasets includes tabulation of total annual double cropped acreage within EBID, and determination of four main double-cropping systems. These four double-crop systems are Corn-Grain, Corn-Onion, Corn-Alfalfa, and Melons/Squash-Cole/Leafy Greens. The estimated proportions of total double cropped acreage dedicated to each of these four categories are 60%, 25%, 10% and 5%, respectively. Land IQ calculated the acreage associated with each of the four double-cropped systems based on total annual double cropped acreage and the representative proportions listed above.

We modified double-cropped acreage after checking to ensure that the double-cropped acreage did not exceed the reported harvest acreage of its components. If this constraining condition occurred in a given year, then the proportions were modified to be equal to the reported harvest acreage so that the double-cropped acreage would not exceed the harvest acreage of its components. Specifically, excess double-cropped acreage for a given system was re-assigned to the other double cropped systems in the order Corn-Grain, Corn-Onion, Corn-Alfalfa, and Melons/Squash-Cole/Leafy Greens.

Total monthly ET rates were calculated by aggregating all crop categories within each basin. ET rates for the double-cropped systems were determined based on the monthly ET rates of the component crops.

Evaluation of spatial crop datasets from Land IQ indicate that double-cropping is minor outside of the EBID and EPCWID district boundaries. Double-cropping is specified in the models to solely occur within the district boundaries.

2.1.3.3 Non-Crop Acreage and Evapotranspiration

The soil water balance model tracks all root zone soil moisture, including in cropped and non-cropped areas. For non-cropped areas, this requires the computation of bare soil evaporation. To represent bare soil evaporation, a monthly crop coefficient is calculated using a methodology described by the U.S. Department of Agriculture (1993). The method depends on the frequency between precipitation events and the reference crop ET during each month. When event frequency is less than four days:

$$K_a = (1.286-0.27\times f_p)\times \exp\{[0.254-1.07\times \ln(f_p)]\times ET_o\} \quad (26)$$

When event frequency is greater than or equal to four days:

$$K_a = 2\times f_p^{-0.49\times}\exp\{[-0.51-1.02\times \ln(f_p)]\times ET_o\} \quad (27)$$

Where,

K_a is average monthly crop coefficient for bare soil evaporation;
f_p is average monthly interval between precipitation events; and
ET_o is average reference crop ET (inches per day).

Daily precipitation data for the Caballo Dam weather station were analyzed to determine the appropriate interval between precipitation events for each month. The Caballo dataset was used because of its long record of daily data. These monthly estimates were used for both the Rincon and Mesilla basins, assuming that storm frequencies are comparable between basins.

The average monthly crop coefficients for bare soil evaporation in Mesilla Basin during non-growing season months range from 0.188 in May to 0.464 in September, with an average of about 0.356. Average monthly crop coefficients for Rincon Basin are virtually the same as for Mesilla Basin, with an average of about 0.359. Winter bare soil evaporation is calculated for areas where crops are grown exclusively during the primary growing season, whereas summer bare soil evaporation is calculated for areas where crops are grown exclusively during the secondary growing season.

2.1.3.4 Soil Properties

Soil properties required for the soil water balance model include the residual moisture content, permanent wilting point, critical soil moisture, field capacity, total porosity, pore size distribution index, and saturated hydraulic conductivity (K_{sat}). Distribution of soils classes within the Rincon and Mesilla Valleys were determined based on the Soil Survey Geographic Database (SSURGO) (NRCS, 2016). The dominant soil types in the Mesilla Valley are clay loam, loam, loamy sand, in order of dominance. In the Rincon Valley, dominant soil types are sandy loam, clay loam, and loamy sand, in order of dominance. Collectively, these soils make up at least 70% of their respective basin. A loam soil was chosen as the representative soil type for the soil water balance analysis based on the dominant soils present in these basins. Values of the total porosity (θs), wilting point (θ_{wp}), soil field capacity (θ_{fc}), pore-size distribution index (λ), and K_{sat} were obtained from published data by Rawls and others (1982) for loam soil. The critical soil moisture was calculated according to Equation (19), using area-weighted depletion fractions as reported by Allen (1998) for each crop type.

Table 2.3 shows the soil property values represented in the farm soil water balance models for Rincon and Mesilla basins. Values are reported using units of feet and months, for consistency with the model units and water budget analysis.

Table 2.3. Soil Hydraulic Property Values Used in Farm Soil Water Balance Calculations for Rincon and Mesilla Basins

Soil Property	Value
Residual moisture, θ_r (ft^3/ft^3)	0.027
Wilting point, θ_{wp} (ft^3/ft^3)	0.117
Critical soil moisture, θ_c (ft^3/ft^3)	0.184 (Rincon), 0.182 (Mesilla)
Field capacity, θ_{fc} (ft^3/ft^3)	0.27
Total porosity θ_s (ft^3/ft^3)	0.463
Pore-size distribution index, λ (-)	0.252
Saturated hydraulic conductivity, K_{sat} (ft/month)	31.17

Source: Rawls and others (1982), for loam soil, critical soil moisture calculated based on soil depletion factors for specific crops reported by Allen (1998)

2.1.3.5 Rooting Depth

The root zone volume defined in Equation (5) depends on crop acreage and average root zone depth. The average root zone depth used in Equation (5) is averaged twice: over crop types, and over time.

The soil water balance model simulates total ET from all the crops, and so we first calculated a monthly time series of average root zone depth as an area-weighted average over the different crop types over the study period. **Figure 2.8** provides a graphical depiction of area-weighted average root zone depth considering three crop types. The soil water balance model treats root zone thickness as constant in time to minimize perturbations to root zone volume associated with start and end of the growing season for different crops. We calculated the time-averaged root zone depth as the average value of the monthly time-series of crop area-weighted average rooting depth.

Rooting depths for each crop type were defined based on field and laboratory studies of crop root development in southern New Mexico, where available, and based on literature values when specific studies were not available. Double-cropped rooting depths assumed the larger depth between the crops included in each double-crop system. **Table 2.4** summarizes crop rooting depths used for the soil water balance model.

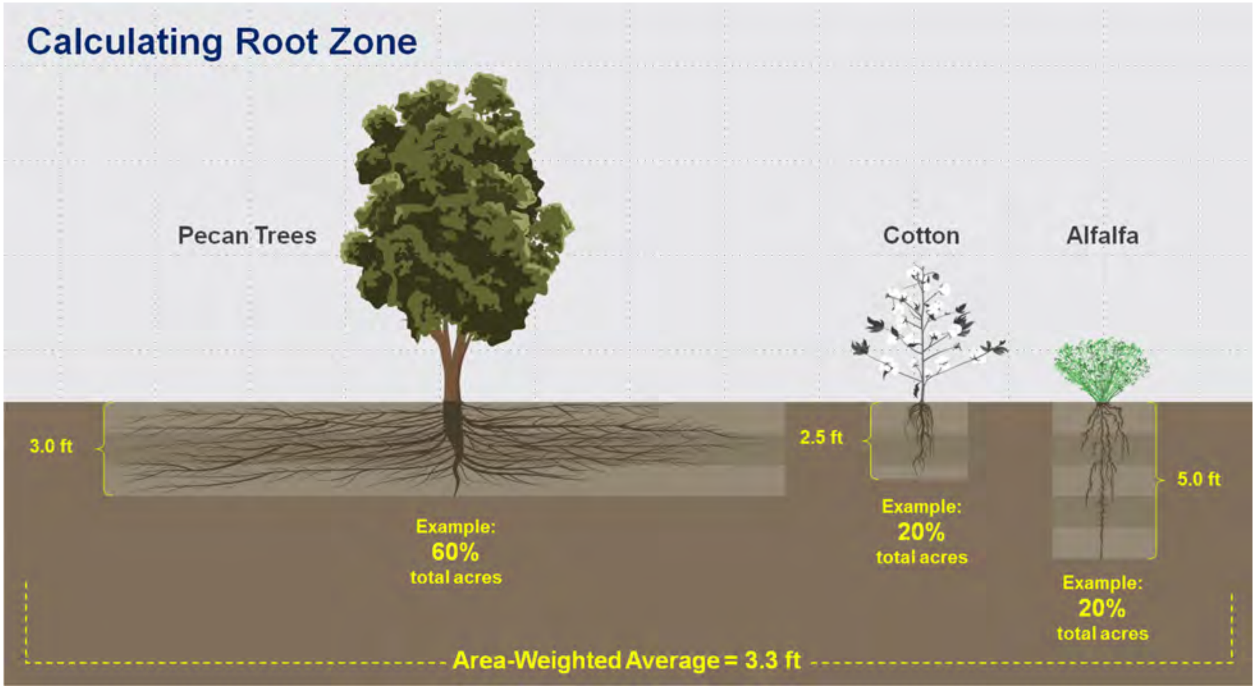

Figure 2.8. Example Calculation of Area-Weighted Average Rooting Depth Over Three Crop Types

Table 2.4. Crop Rooting Depths Used in Farm Soil Water Balance Models for Rincon and Mesilla Basins

Crop Type	Rooting Depth (feet)	Data Source
Alfalfa	4.92	Abdul-Jabbar and others (1982)
Asparagus	5.00	NRCS (1997)
Chili/Peppers	2.00	NRCS (1997)
Cole/Leafy Greens	2.00	NRCS (1997)
Corn/Silage	4.00	NRCS (1997)
Cotton	2.46	Al-Khafaf and others (1979)
Grain	4.00	NRCS (1997)
Grapes	5.00	NRCS (1997)
Hay	4.00	NRCS (1997)
Legumes	3.00	NRCS (1997)
Melons/Squash	3.00	NRCS (1997)
Misc/Other	2.95	Calculated as average rooting depth over annual crops
Onions	2.00	NRCS (1997)
Pasture	4.00	NRCS (1997)
Pecans/Other Trees	3.00	Herrera and Sammis (2001)
Root Crop	3.00	NRCS (1997)
Tomato	3.00	NRCS (1997)
Turf	0.49	Leinauer and Smeal (2012)
Irrigated Annuals	2.95	Calculated as average rooting depth over annual crops
Corn-Grain (Double Crop)	4.00	Maximum of individual components
Corn-Onions (Double Crop)	4.00	Maximum of individual components
Corn-Alfalfa (Double Crop)	4.92	Maximum of individual components
Melons/Squash – Cole/Leafy Greens (Double Crop)	3.00	Maximum of individual components

2.1.4 Implementation of Model Equations

The farm water budget was implemented using GoldSim simulation software developed by GoldSim Technology Group. GoldSim provides a general-purpose platform for simulation of dynamic systems. The software was originally developed for water balance analyses.

Four GoldSim models were developed for Rincon and Mesilla basins, each with models for crop lands inside and outside district boundaries. Farm water budget variables and equations were implemented as defined in the previous sections. Equations in which the state variables are dependent on the outputs (Equations (14) and (17)) are solved using standard explicit iteration methods. Data inputs are loaded into the GoldSim models using an Excel spreadsheet named Inputs.xlsx. Model results for cropped (c) and non-cropped (nc) areas in lands inside (in) and outside (out) district boundaries within each basin are exported from the GoldSim model as Excel spreadsheets named *Results_c_Rincon_in.xlsx, Results_c_Rincon_out.xlsx, Results_c_Mesilla_in.xlsx, Results_c_Mesilla_out.xlsx, Results_nc_Rincon_in.xlsx, Results_nc_Rincon_out.xlsx, Results_nc_Mesilla_in.xlsx, and Results_nc_Mesilla_out.xlsx*.

2.1.5 Soil Water Balance Model Calibration

The soil water balance model was calibrated to match available historic data as closely as possible. The calibration consisted of adjusting surface runoff of applied water, or farm tailwater, and the soil moisture uniformity parameters within reasonable ranges to simultaneously match historic data and conceptual trends.

Historic data used in the model calibration are described below. The main conceptual trends considered in the model calibration were:

- Improvements in irrigation uniformity
- Reductions in farm tailwater losses from surface water deliveries

2.1.5.1 Data Used for Model Calibration

Historic data used in the model calibration include:

- Adjusted crop AET rates (Land IQ) accounting for observed historical trends in crop yield
- Recent metered groundwater pumping at registered irrigation wells
- Estimates of on-farm irrigation efficiency

Metered pumping data are described in the Section 4.2.3 of this report. Reported crop efficiency estimates range from 0.64 to 0.76 for chiles (Al-Jamal and others, 1997), 0.88 to 0.97 for cotton (Deras, 1999), 0.72 to 0.95 for pecans (NM Pecan Grower Settlement Agreement, 2008; Samani and Al-Katheeri, 2001), and 0.97 for alfalfa (Al-Jamal and others, 1997). Ahadi and others (2013) estimated basin-wide average farm efficiency to be about 64%.

2.1.5.2 Adjustment of Soil Moisture Uniformity Parameters

The shape of the soil moisture distribution is described by the parameters β and r_θ defined in the section 'Non-uniform moisture distribution'. These parameters control the curvature and the range of soil moisture in the cropped area, respectively.

The power constant, β, determines the relative portion of the cropped area receiving above-average infiltration. It is therefore expected that the value of β should increase over the study period, reflecting improvements in irrigation management. The value of β was estimated to fall between 1 and 2 over the historical period.

The soil moisture range, r_θ, determines the bounds on soil moisture. Given the average soil moisture over the cropped area, increasing r_θ means that the moisture conditions will be wetter near the source end, and drier at the tail end of the field. It is therefore expected that the value of r_θ should decrease over the study period, reflecting improved irrigation uniformity due to changes in irrigation management practices such as land leveling. Given the uniformity parameters β and r_θ, the average soil moisture, and correspondingly, the required application of supplemental groundwater, is controlled by the lower bound on the moisture distribution, θ_L. We estimated a time-series of θ_L that, when used as input to the soil water balance model, would best reproduce the adjusted crop AET rates developed by Land IQ. The estimated value of θ_L is called θ_L^* and is used with Equations (22-23) to calculate supplemental groundwater pumping for the period of time beginning in 1951 through present.

No crop AET occurs in portions of the cropped area where $\theta \leq \theta_{wp}$. Crop AET computed by the soil water balance model can be therefore be partitioned into two parts, consistent with Equation (19): AET from land where $\theta \geq \theta_{crit}$, and AET from land where $\theta_{crit} > \theta > \theta_{wp}$:

$$AET = A \times K_c \times ET_o \times [a_{crit} + \overline{K_s} \times (a_{wp} - a_{crit})] \quad (28)$$

$\overline{K_s}$ in Equation (28) is the average water stress coefficient in land where $\theta_{crit} > \theta > \theta_{wp}$. a_{crit} refers to the fraction of the cropped area for which $\theta \leq \theta_{crit}$. a_{wp} refers to the fraction of the cropped area for which $\theta \geq \theta_{wp}$. Dividing the computed AET in Equation (28) by the theoretical ET provides an expression for the simulated bulk ET adjustment factor, α:

$$\alpha = a_{crit} + \overline{K_s} \times (a_{wp} - a_{crit}) \quad (29)$$

To reproduce the total adjusted crop AET (Land IQ) requires that α match the ratio of total adjusted AET to total theoretical ET over all crop types. This can be accomplished by adjusting a_{crit} and $\overline{K_s}$, both of which are functions of the irrigation uniformity parameters.

Substituting θ_{crit} into Equation (10) and solving for the fraction of the total cropped area, a, provides an expression for a_{crit}. Similarly, substituting θ_{wp} into Equation (10) and solving for the fraction of the total cropped area, a, provides an expression for a_{wp}.

$a_{crit} = [1 – (\theta_{crit} - \theta_L)/r_\theta]$^$(1/\beta)$ (30)

$a_{wp} = [1 – (\theta_{wp} - \theta_L)/r_\theta]$^$(1/\beta)$ (31)

An expression for $\overline{K_s}$ is obtained by integrating $K_s[\theta(a)]$ with respect to the fraction of the cropped area, a, over the range from a_{crit} to a_{wp}:

$\overline{K_s}$ = [1 / (1 – a_{crit})] × [C_1 × (a_{wp} – a_{crit}) + (C_2 / (β + 1)) × (a_{crit}^(β+1) + β × (a_{wp} – a_{crit}) + a_{wp} – a_{crit} – a_{wp}^(β+1)] (32)

Where,

$C_1 = (\theta_L – \theta_{wp}) / (\theta_{crit} – \theta_{wp})$ (33)

$C_2 = r_\theta / (\theta_{crit} – \theta_{wp})$ (34)

After fixing the estimated time series of β and r_θ, we used Equations (29-34) to compute α as a function of θ_L, and in this way, to compute the lower bound on soil moisture, θ_L^*,that would be required to match the adjusted crop AET rates developed by Land IQ.

2.1.5.3 Estimation of Farm Tailwater

Prior to the widespread use of supplemental groundwater for irrigation, the average soil moisture inside the irrigation district boundaries depended on precipitation and the availability of surface water deliveries. During the early years of the study period (1938-1950) with full project allocation, simulated soil moisture is relatively high, and simulated AET is also higher than the adjusted AET rates provided by Land IQ, even with a relatively low value of β, and a relatively high value of r_θ. It is therefore assumed that farm tailwater was higher early during the study period (1938-1950), which is consistent with the general observation that irrigation management during this period of time was poor relative to current irrigation management practices.

Farm tailwater as a percentage of surface water delivered to the field was adjusted to reproduce the crop AET rates developed by Land IQ, with the expectation that the percentage of tailwater would decrease with time due to improvements in irrigation management.

2.1.6 Results of Soil Water Balance Model

This section of the report summarizes the results of the farm soil water balance models. Results of the soil water models and overall farm water budgets are compiled for numerical model development into Excel files named *FarmBudget_Zoned_in.xlsx* (inside districts) and *FarmBudget_Zoned_out.xlsx* (outside districts).

2.1.6.1 Agricultural Groundwater Pumping

Agricultural groundwater pumping is calculated based on Equations (22) and (23); these pumping rates are referred to as simulated groundwater pumping, meaning that they are computed within an individual simulation using the soil water balance model. Prior to 1951, the applied water demand within districts is satisfied exclusively by surface water deliveries to farms. In 1951 and later, the applied water demand within districts is satisfied by surface water deliveries and supplemental groundwater pumping. The applied water demand outside districts is satisfied exclusively by groundwater pumping.

Annual surface water deliveries to farms (farm deliveries) and agricultural groundwater pumping in Rincon and Mesilla basins are shown on **Figures 2.9 and 2.10**, respectively. Farm deliveries were compiled as part of the Surface Water Budget preparation, and are discussed in greater detail in the section 'Surface Water Deliveries to Farms'.

For reference, **Figures 2.9 and 2.10** also show metered annual irrigation groundwater pumping volumes reported by the New Mexico Office of the State Engineer (NMOSE) at metered points of groundwater diversion associated with irrigation water rights, grouped by basin. Simulated agricultural groundwater pumping shown in **Figure 2.10** includes on lands in both New Mexico and Texas, whereas metered irrigation groundwater pumping data is available only for irrigation wells located in New Mexico. It is expected that simulated agricultural groundwater pumping for New Mexico and Texas should be greater than metered irrigation groundwater pumping for New Mexico only, and this is demonstrated in **Figure 2.10**.

Total simulated pumping for Rincon irrigation wells in the study area is on average 4 percent smaller than metered groundwater pumping. A similar comparison cannot be done for the Mesilla Basin, because metered pumping data for irrigation wells in the Texas portion of the Mesilla Basin are not available.

Agricultural groundwater pumping in Rincon and Mesilla basins varied through time depending principally on surface water availability. Groundwater pumping generally increased during years when surface water deliveries were low, and vice versa. The largest groundwater withdrawals occurred during the early to mid-1950s, and from 2003 through 2016, when surface water deliveries to farms were small for a multiple consecutive years. The smallest amount of groundwater pumping occurred during the period of full Project allotment from 1979 through 2002.

From 1938 through 2016, average annual groundwater pumping was about 100,000 AF in the Rincon Basin and 100,000 AF in the Mesilla Basin. However, widespread installation of irrigation wells to provide supplemental groundwater for irrigation did not begin in earnest until the 1950s drought, and it is therefore more meaningful to provide statistical summaries on groundwater pumping for crop irrigation beginning in the 1950s. From 1951 through 2016, average annual groundwater pumping was about approximately 29,000 AF in Rincon Basin and 265,000 AF in Mesilla Basin. From 1951 through 2016, groundwater contributed about 46% of total applied irrigation water supply in the Rincon Basin, and 43% of the total applied irrigation water supply in the Mesilla Basin.

During periods of limited surface water deliveries in the 1950s and from 2010 to 2016, the relative contribution of groundwater to the total applied water demand is substantially greater than during periods of full allocation, as occurred during the 1990s. During 2011, for example, groundwater contribution to total irrigation water supply exceeded 90% for both the Rincon and Mesilla Basins.

Monthly agricultural groundwater pumping to satisfy crop water demand is used directly as input to the groundwater budget for the entire study period from 1938 through 2016.

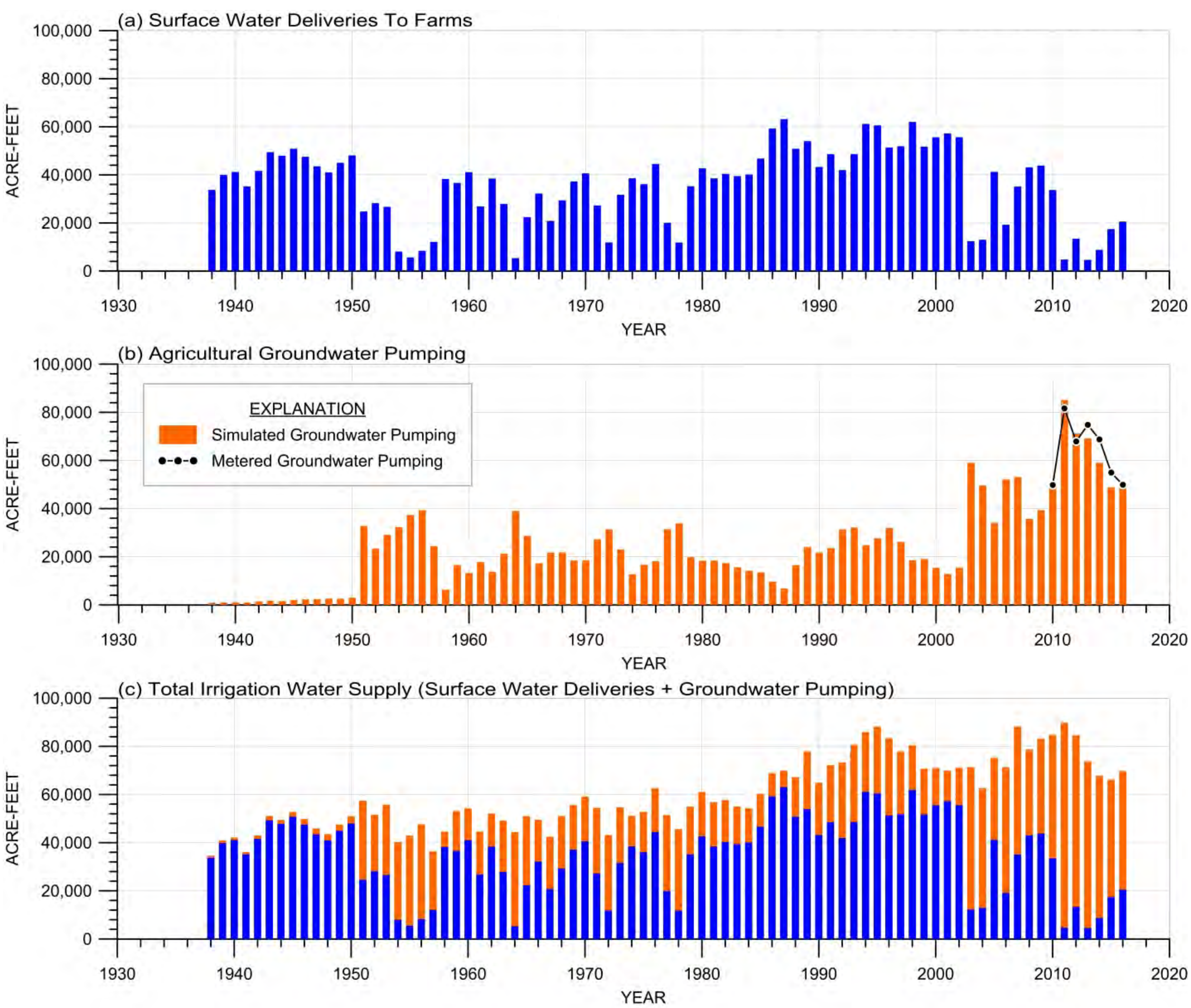

Figure 2.9. Annual Irrigation Water Supply, Rincon Basin: 1938 through 2016

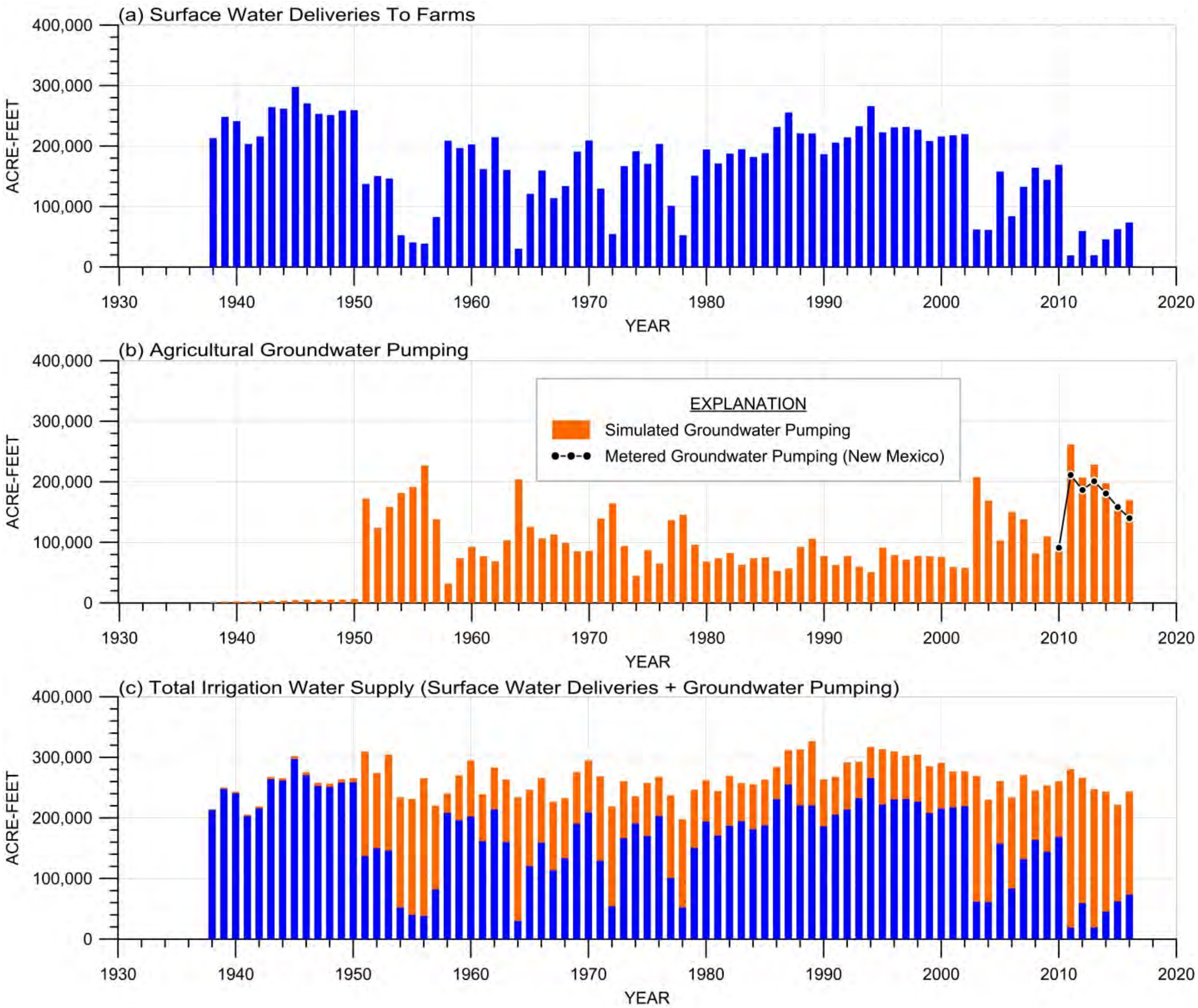

Figure 2.10. Annual Irrigation Water Supply, Mesilla Basin: 1938 through 2016

2.1.6.2 Agricultural Deep Percolation

Within the soil water balance model, monthly deep percolation is calculated as the sum of on-farm conveyance losses and field losses. From 1938 through 2016, field losses made up between 31% to 97% of total deep percolation annually in the Rincon Basin, and 47% to 95% in the Mesilla Basin. The average contribution of field losses to total deep percolation during this time was about 69% in the Rincon Basin and 70% in the Mesilla Basin. Average annual field losses were about 9,000 AF in the Rincon Basin and 39,000 AF in the Mesilla Basin.

Average annual total deep percolation – including both on-farm conveyance losses and field losses – was about 12,000 AF in the Rincon Basin and 55,500 AF in the Mesilla Basin.

Annual agricultural deep percolation in Rincon and Mesilla basins is shown on **Figures 2.11a and 2.12a**. Field losses include soil moisture derived from both applied irrigation water and precipitation; however, the contribution from applied irrigation water is substantially greater than contributions from precipitation. Monthly values of agricultural deep percolation calculated by the soil water balance model are used directly as input to the groundwater budget for the entire study period from 1938 through 2016.

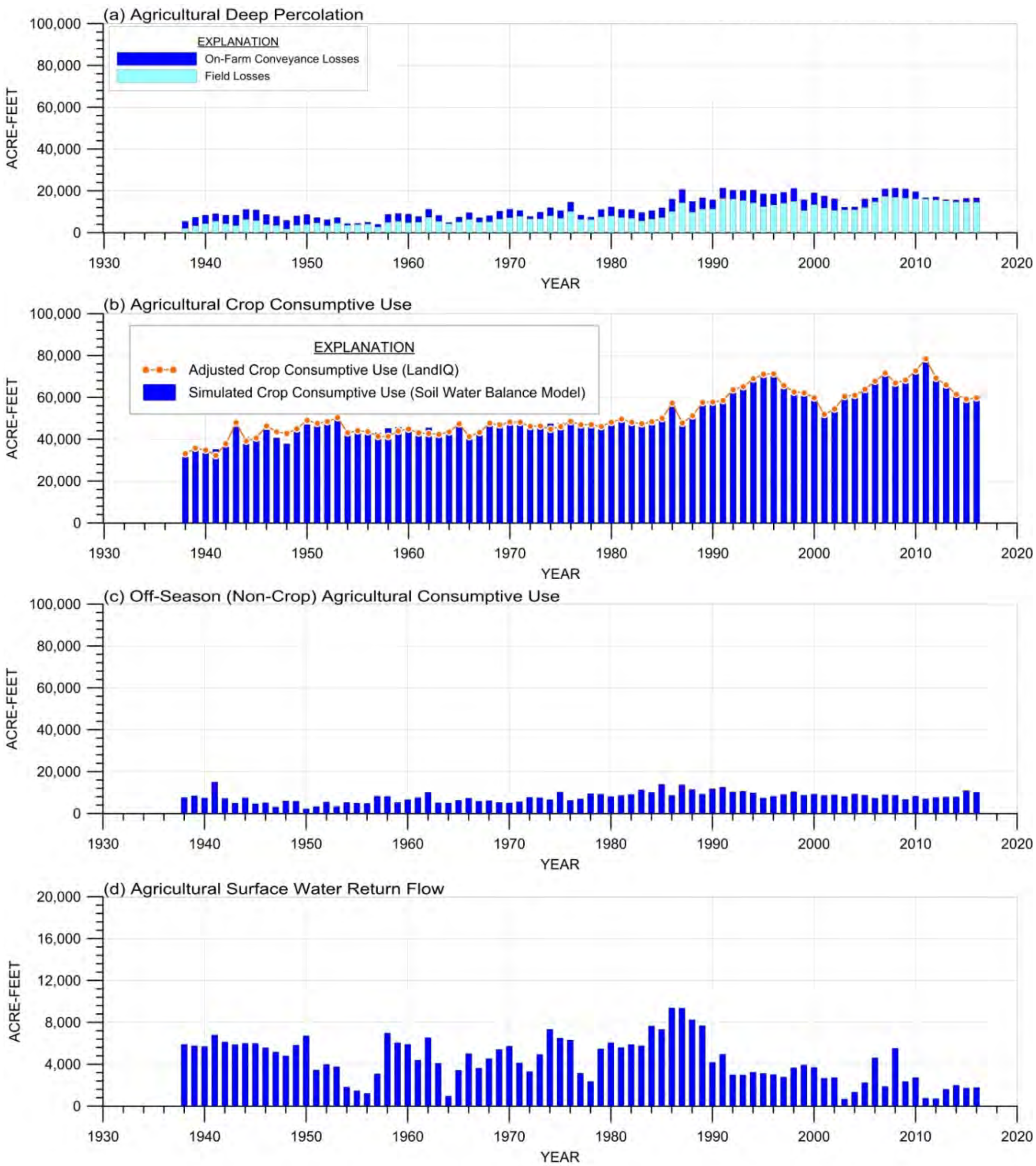

Figure 2.11. Annual Farm Water Budget Outflows in Rincon Basin

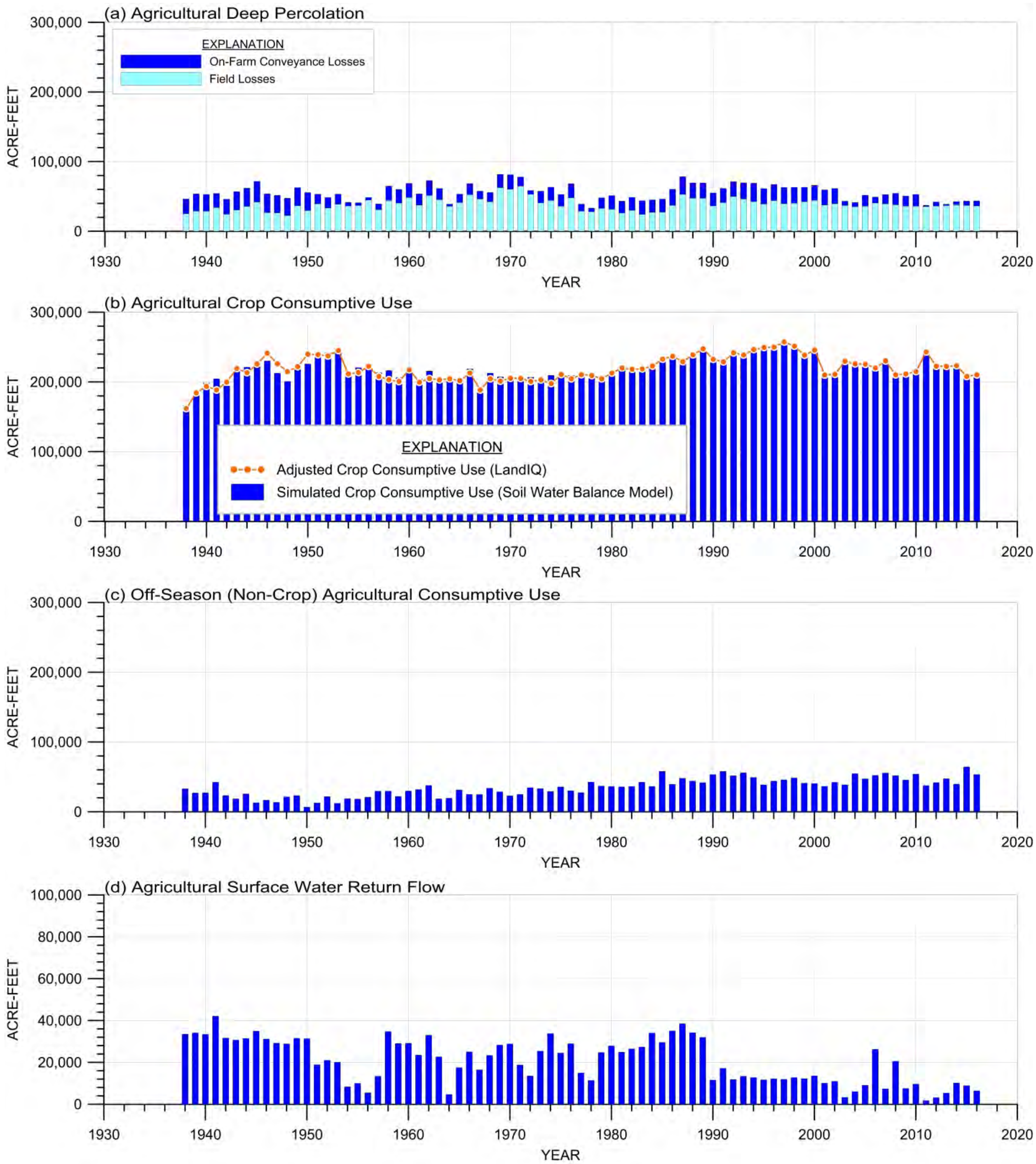

Figure 2.12. Annual Farm Water Budget Outflows in Mesilla Basin

2.1.6.3 Crop Consumptive Use

The soil water balance model computes crop consumptive use based on theoretical crop evapotranspiration rates and simulated soil moisture conditions. For this analysis, the monthly theoretical evapotranspiration rates are from crop consumptive use datasets prepared by Land IQ.

Crop AET is equal to the theoretical evapotranspiration when soil moisture is greater than or equal to critical soil moisture, as defined in Section 2.1.1. For non-cropped areas, bare soil ET is calculated as the product of the bare soil coefficients defined in Equations (26-27) and the reference ET rate, ET_o.

Annual crop consumptive use for Rincon and Mesilla basins are shown on **Figures 2.11b and 2.12b**. For reference, **Figures 2.11b and 2.12b** also show adjusted crop consumptive use, or AET, developed by Land IQ for the Rincon and Mesilla Basins, respectively. From 1938 through 2016, average simulated annual crop AET is about 52,000 AF for the Rincon Basin and about 220,000 AF for the Mesilla Basin.

Estimated annual volumes of off-season consumptive use, or soil evaporation from fallow farm lands in the Rincon and Mesilla basins are shown on **Figures 2.11c and 2.12c**. Average annual off-season consumptive use is estimated to be about 8,000 AF in Rincon Basin and about 35,000 AF in Mesilla Basin.

2.1.6.4 Agricultural Surface Water Return Flow

Surface runoff from agricultural land is assumed to occur both during irrigation events and in response to large storm events, during which rainfall rates would exceed the storage and infiltration capacity of on-farm infrastructure to capture and retain water flowing off of irrigated fields. Surface runoff of applied water was initially set based on typical values for New Mexico (Blaney and Hanson, 1965), and later adjusted as part of the soil water balance model calibration. Surface runoff of precipitation is estimated with empirical relationships for precipitation and runoff using the SCS curve number method (USDA, 2004), as previously described.

Agricultural surface water return flow to the surface water system is shown on **Figures 2.11d and 2.12d**. Runoff discharges from precipitation are highly variable due to varying precipitation. Average annual agricultural surface water return flow is estimated to be about 4,400 AF in the Rincon Basin and 20,600 AF in the Mesilla Basin.

2.1.6.5 Irrigation Efficiency

Water-resources studies in agricultural areas sometimes use the concept of farm irrigation efficiency both to forecast irrigation water demands and also to estimate historical rates of unmetered groundwater pumping. The term farm irrigation efficiency as used here is defined as the percentage of irrigation water applied that is available for crop consumptive use, based on irrigation water delivered to the farm headgates. Farm irrigation efficiency is not known with great precision for farm lands in the Rincon and Mesilla Basins.

The soil water balance model described in this report does not specify a value for the farm irrigation efficiency, but instead calculates the average farm irrigation efficiency over all farm lands in each basin. Farm efficiency is calculated on an annual time-scale to remove effects of soil moisture carryover between months.

Farm irrigation efficiencies are computed from soil water balance model results by dividing simulated crop AET by the total volume of applied water, including farm deliveries and farm groundwater pumping. The theoretical evapotranspiration provided as input to the soil water balance model was adjusted to remove effective precipitation, so that simulated crop AET reflects demands satisfied by applied irrigation water. These farm irrigation efficiencies are referred to as simulated irrigation efficiency because they are not specified as inputs to the model, but are instead calculated based on monthly rates of crop ET and groundwater pumping simulated using the soil water balance model. Differences between simulated crop AET and applied irrigation water are due to on-farm conveyance losses, farm tailwater losses, and field losses consisting of deep percolation past the base of the root zone.

Figure 2.13 shows simulated irrigation efficiency for the Rincon and Mesilla Basins. Simulated farm irrigation efficiency for the Rincon Basin varies between 55 percent and 85 percent, with an average value of about 70 percent. Simulated farm irrigation efficiency for the Mesilla Basin varies between 59 percent to 80 percent, with an average value of about 69 percent. These computed efficiencies are consistent with previously published values of irrigation efficiency at the basin scale, as discussed in the section 'Data Used for Model Calibration'.

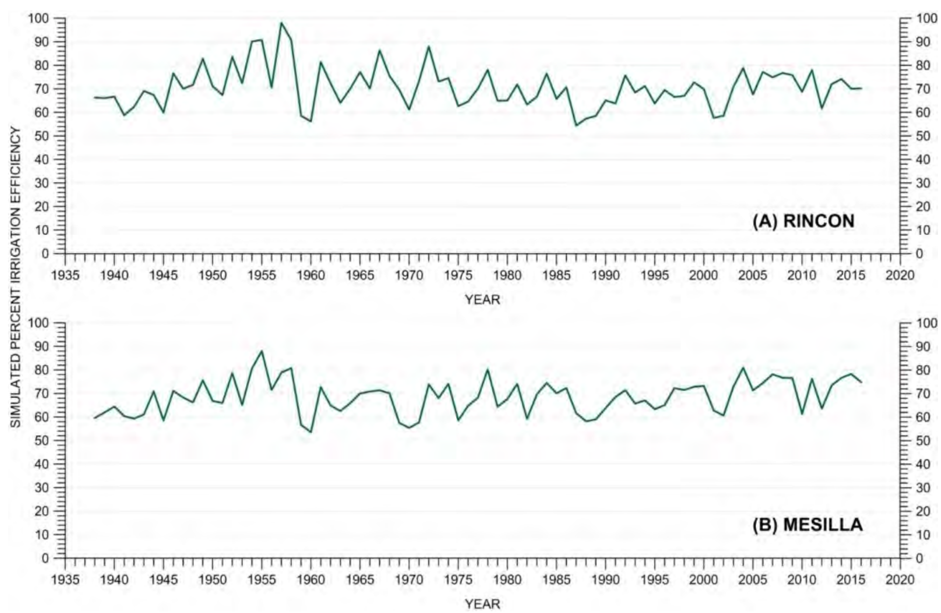

Figure 2.13. Simulated Irrigation Efficiency for Rincon and Mesilla Basins

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2.2 Non-Farm Water Budget

The terms P_{nf}, $GW_{app\text{-}nf}$, CU_{nf}, QSW_{nf}, WW, DP_{nf}, and GW_e in Equation 3 were quantified by developing non-farm water budgets. Non-farm lands in the study area include urban areas and undeveloped areas consisting primarily of native vegetation. The non-farm water budget is subdivided into urban lands and upland areas that are not classified as farm (agricultural) or urban (i.e., watershed area minus farm and urban areas) (**Figure 2.1**). The urban water budget is evaluated by water source: applied water and precipitation water. The applied water budget analysis is based on measured or estimated groundwater withdrawals (pumping), measured or estimated wastewater discharges, and estimates for consumptive use and deep percolation. The precipitation water budget analysis uses monthly precipitation and estimates for consumptive use (i.e., effective urban precipitation) and runoff to estimate urban deep percolation of precipitation. Use of surface water deliveries for non-farm purposes is minor compared to groundwater use and considered negligible for this analysis.

2.2.1 Urban Applied Water Budget

The urban (non-farm (nf)) applied water budget is defined by the following equation:

$$GW_{app\text{-}nf} = CU_{app\text{-}nf} + WW + DP_{nf} + GW_e \quad (35)$$

Each term contains several components, as follows:

$$GW_{app\text{-}nf} = GW_{MI} + GW_{DOM} + GW_{IMP} \quad (36)$$

$$CU_{app\text{-}nf} = CU_{POU} + CU_{WW} + CU_{DOM} \quad (37)$$

$$WW = WW_{SW} + WW_{EXP} \quad (38)$$

$$DP_{nf} = DP_{AW} + DP_{CL} + DP_{Septic} \quad (39)$$

Where,

GW_{MI} is municipal and industrial groundwater pumping;

GW_{DOM} is domestic groundwater pumping;

GW_{IMP} is imported groundwater from adjacent basins;

GW_e is exported groundwater to adjacent basins;

CU_{POU} is urban consumptive use of applied water at point of use;

CU_{WW} is consumptive use of wastewater;

CU_{DOM} is consumptive use of domestic pumping;

WW_{SW} is wastewater discharge to surface water;

WW_{EXP} is exported wastewater;

DP_{AW} is deep percolation of applied water.

DP_{CL} is deep percolation of conveyance losses; and

DP_{Septic} is deep percolation of domestic pumping via septic discharge.

The urban applied water budget was developed for specific municipal entities and rural users using reported or estimated groundwater pumping and wastewater datasets and estimates for consumptive use and deep percolation based on relevant information in available reports for the study area.

2.2.1.1 Urban Applied Water Inflows

Inflow terms for the urban applied water budget include urban groundwater pumping from wells within the basins and imported groundwater from wells outside the basins. The amount of surface water used to satisfy urban consumptive use is negligible compared to groundwater use in study area.

2.2.1.1.1 Urban Groundwater Pumping

Urban applied groundwater is the total volume of pumped groundwater that is used internally in the Rincon and Mesilla basins for non-irrigation purposes. Urban pumping in Rincon and Mesilla basins is described in Section 4.2.2 of this report. Urban groundwater inflows from the land-surface water budgets are outflows from the groundwater budgets.

2.2.1.1.2 Imported Groundwater

Imported groundwater is pumped groundwater that is conveyed into the Rincon or Mesilla basins from wells located outside the alluvium basin designated for this water budget analysis. In Rincon Basin, imported groundwater is served to the communities of Hatch and Rincon. Hatch receives groundwater from wells in the adjacent Nutt-Hockett basin to the west and Rincon receives groundwater from wells in the Jornada Basin to the east. In Mesilla Basin, a portion of water treated at the Las Cruces wastewater treatment facility is groundwater pumped from Moongate Water Company wells located in the adjacent Jornada Basin to the east. Montgomery & Associates tabulated imported groundwater volumes from metered pumping data reported in the NMOSE W.A.T.E.R.S. database for specific wells owned by the communities. According to metered pumping records, pumping from the wells identified as the sources of imported water began in 2000 in Rincon Basin and in 2003 in Mesilla Basin. The volumes of imported groundwater to Rincon Basin increased from about 55 AF in 2000 to about 475 AF in 2014. The volumes of imported groundwater to Mesilla Basin increased from about 20 AF in 2003 to about 650 AF in 2014. Imported groundwater is a minor source of water to the study area.

2.2.1.2 Urban Applied Water Outflows

Outflow terms for the urban applied water budget include wastewater discharge, consumptive use, deep percolation, and exported groundwater.

2.2.1.2.1 Urban Wastewater Discharge

The wastewater discharge term (WW) of the urban applied water budget equation consists of wastewater discharge to the surface water network (Rio Grande) and exported wastewater.
A portion of urban groundwater pumping is discharged to the surface water system as treated wastewater. Treated wastewater is discharged into the surface water system from multiple discharge facilities in the Rincon and Mesilla basins. Information on monthly wastewater discharges was obtained from the United States Environmental Protection Agency (EPA) (2016) for 2000 through 2016. For years without EPA discharge data, we estimated wastewater discharges for the selected facilities using relationships between pumping and wastewater discharges during years when both datasets were available. Wastewater discharges were assumed to begin during the year when each facility was constructed.

According to the U.S. EPA's online Discharge Monitoring Report (DMR) Pollutant Loading Tool, the largest wastewater discharge facilities in the Rincon and Mesilla basins include:
City of Las Cruces - Utilities (Jacob Hands WTF), Sunland Park WWTP, Anthony Water and Sanitation District, El Paso Electric – Rio Grande Generating Station, Dona Ana County Utilities Department, El Paso's Northwest WWTP (John T. Hickerson Reclamation Facility), Salem WWTP, and Village of Hatch. The Hatch and Salem facilities are located within Rincon Basin; the remaining facilities are located within Mesilla Basin. We obtained wastewater discharge data and reclaimed water use data from El Paso Water Utilities for this analysis. Discharge data for 1989 through 2016 were used for the El Paso WWTF.

Annual estimated and reported wastewater discharges into the surface water network in each basin is shown on **Figures 2.14a and 2.15a**. Wastewater discharges in Mesilla Basin steadily increased through time from the 1950s through 2016. Wastewater treatment plants in Rincon Basin were built in in the late 1990s and discharge a relatively small amount of treated wastewater into the surface water system.

The El Paso WWTF discharges treated wastewater to the Rio Grande downgradient from the Mesilla basin outlet specified for this study, which is located at the USGS Rio Grande at El Paso stream gaging station. Because they occur downgradient from the study area, the El Paso wastewater discharges are categorized as exported groundwater for this water budget analysis, as described in subsequent sections of this report.

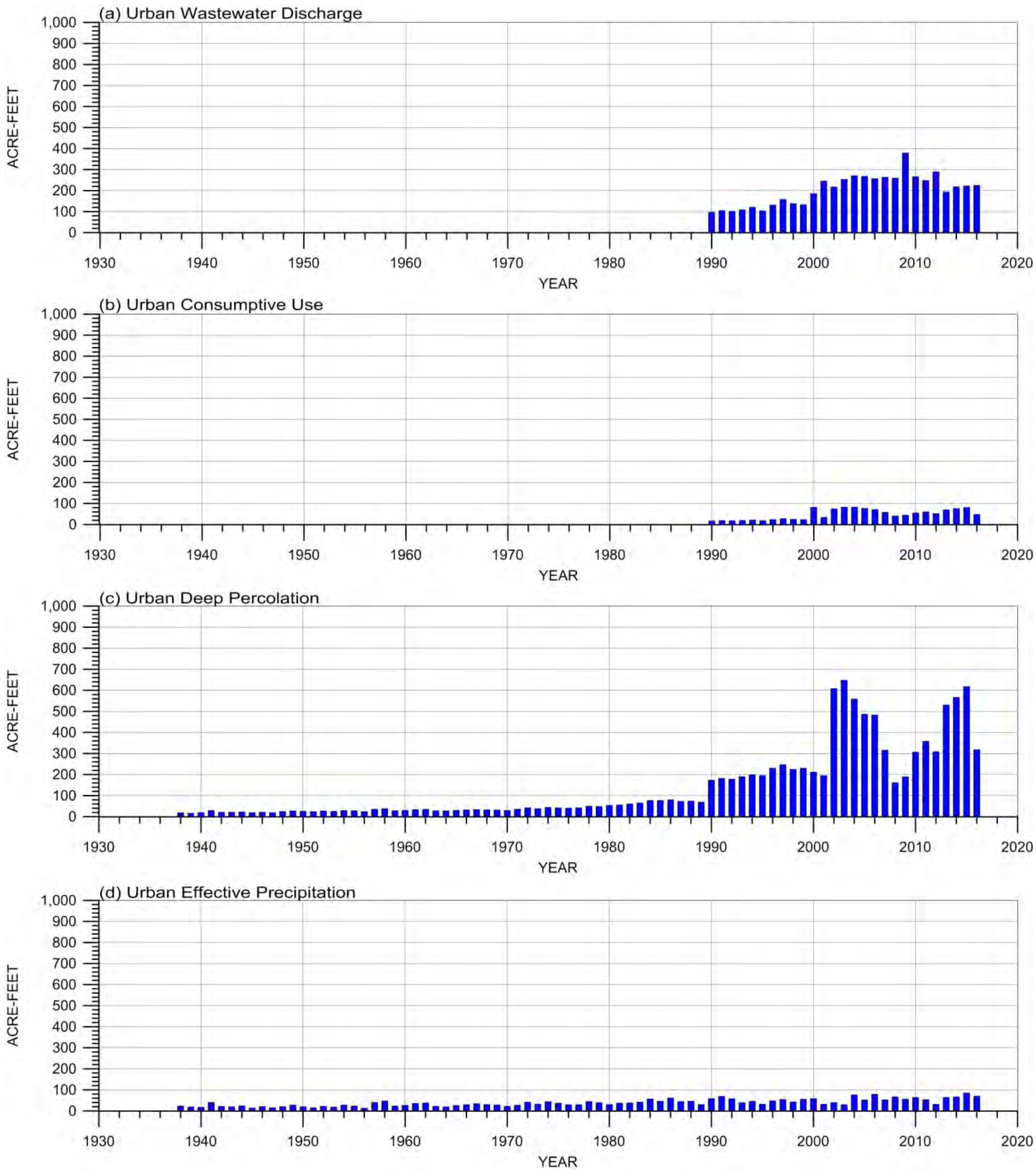

Figure 2.14. Selected Estimated Annual Urban Water Budget Components for Rincon Basin

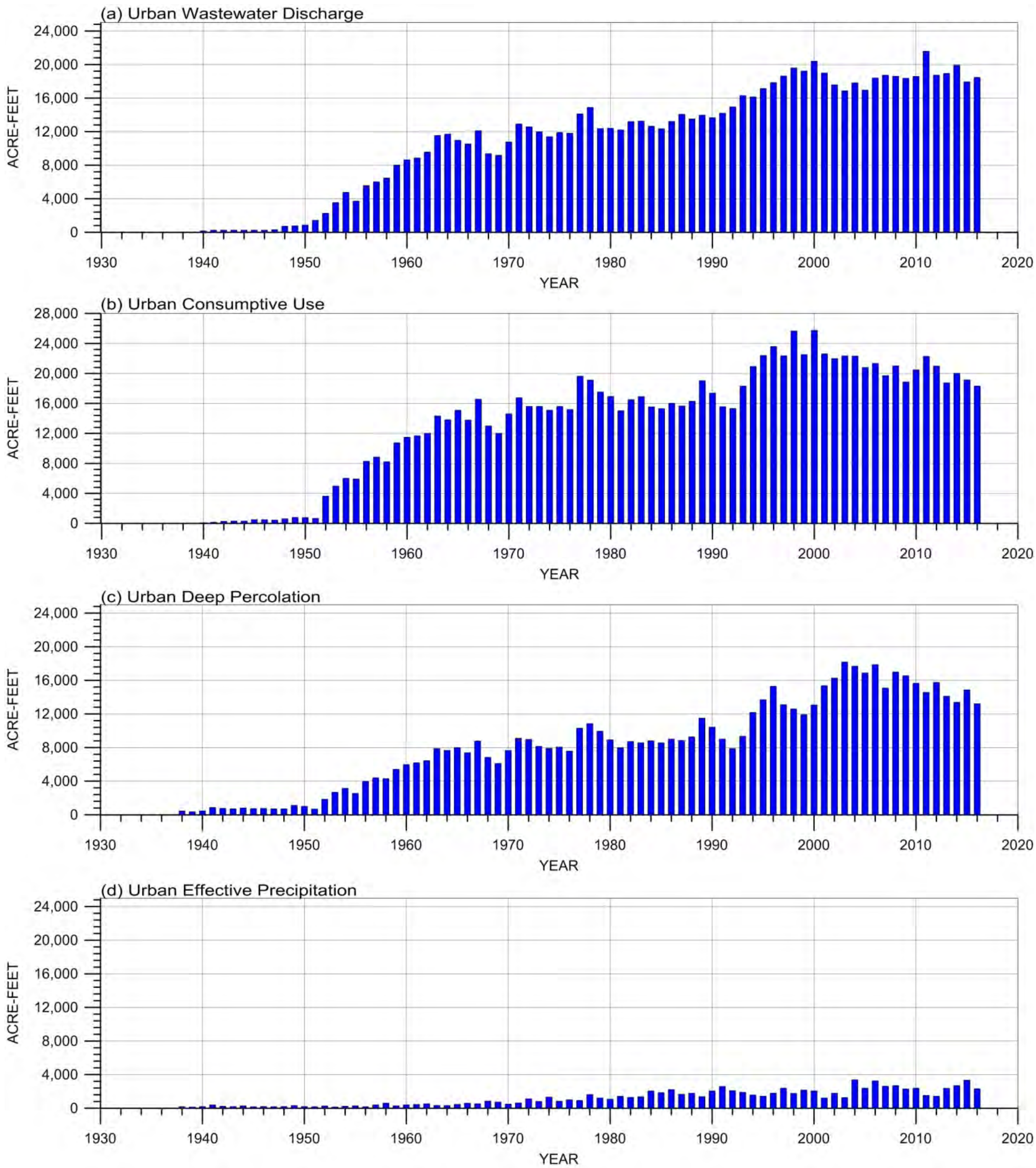

Figure 2.15. Selected Estimated Annual Urban Water Budget Components for Mesilla Basin

2.2.1.2.2 Urban Consumptive Use

The urban consumptive use of applied water term ($CU_{app\text{-}nf}$) of the urban applied water budget equation consists of consumptive use at point-of-use, consumptive use of treated wastewater, and consumptive use of domestic pumping. Consumptive use at point-of-use of applied water is calculated as a percentage of urban applied groundwater (municipal and industrial (M&I) pumping) for each municipal entity. For Las Cruces, a consumptive use estimate of about 36 percent of applied groundwater is used for this analysis for 1938 through 1951, and 47 percent of applied groundwater for 1952 through 2016 based on the Las Cruces 40-Year Plan prepared by JSAI (2008; 2017) and third party review by Greg Young. The increase in percent of applied water represents an increase in irrigation for outdoor landscaping. These percentage estimates were initially applied as constant values during the analysis period. However, they were reduced for months when data show that applied groundwater supplies were smaller than estimated urban consumptive use. For a given month when the percent estimate was larger than groundwater supply, urban consumptive use was estimated as the residual of the urban applied water budget (with zero going to deep percolation of applied water). Based on this approach, on average, annual urban consumptive use of applied water is approximately 27 percent of applied groundwater for 1938 through 1951 and approximately 38 percent for 1952 through 2016. For El Paso, consumptive use estimates of 40 percent (pre-2000) and 33 percent (post-2000) of applied groundwater are specified based on results of a study by Mermitte and Mace (2012). For urban entities without reported consumptive use data, consumptive use of applied water is assumed to be on the order of 10 to 50 percent of the total applied water supply for those entities, based on the Las Cruces 40-Year Plan and adjusted to account for other water budget components for the communities. Groundwater used by the El Paso Electric plant is assumed to be 100 percent consumed; for this analysis, wastewater discharges from this facility are assumed to be from reclaimed water supplied by El Paso Water Utilities. Outdoor urban applied water is assumed to be 100 percent consumed.

Consumptive use of wastewater occurs when the water is discharged into lined ponds where it is fully consumed by evaporation processes, or when the water is reused by reclaimed water programs. Groundwater that is pumped from a few Las Cruces supply wells is conveyed to the West Mesa wastewater treatment facility where it is treated and discharged by sprinklers over a patch of land and fully consumed by evapotranspiration processes (JSAI, 2008). A portion of El Paso wastewater is consumed by reuse as reclaimed water. Wastewater from the town of Anthony, Texas and all other entities are fully consumed unless otherwise previously described for Urban Wastewater Discharges. Prior to the construction of the El Paso Northwest WWTF, wastewater is assumed to have been discharged to lined ponds where the water was fully consumed by evaporation processes.

Consumptive use of septic discharge from domestic pumping is calculated as 55 percent of pumped groundwater if the pumped well is within 1 mile from the Rio Grande. Groundwater withdrawals from domestic wells located outside the 1-mile corridor are 100 percent consumed by evaporation processes. This approach is based on methods described in a domestic well study for New Mexico by NMOSE (2000).

Estimated annual urban consumptive use of applied water (groundwater) for Rincon and Mesilla basins is shown on **Figures 2.14b and 2.15b**. Urban consumptive use of groundwater is relatively small in Rincon Basin. Urban consumptive use of groundwater in Mesilla Basin has gradually increased through time from the 1950s until about 2000. After about 2000, urban consumptive use stabilized or slightly declined through 2016.

2.2.1.2.3 Urban Deep Percolation

Deep percolation term consists of deep percolation of applied water, domestic pumping septic discharge, and conveyance losses.

Deep percolation of applied water is calculated as a residual from the difference between total applied groundwater and all the losses from total consumptive use, total wastewater discharge, conveyance losses, and deep percolation of septic discharge from domestic wells. In some instances, the residual calculation resulted in negative deep percolation, which is physically impossible. For these times, urban consumptive use and deep percolation of urban conveyance losses were adjusted in a manner that prevented the deep percolation estimate from being negative.

Estimated annual deep percolation of urban applied groundwater for Rincon and Mesilla basins is shown on **Figures 2.14c and 2.15c**. Urban deep percolation of applied water in Mesilla Basin gradually increased from smaller than 1,000 AF in the 1950s to larger than 15,000 AF by 2005.

Deep percolation from domestic well septic discharge is calculated as 45 percent of pumped groundwater if the domestic well is within 1 mile of the Rio Grande. Deep percolation of domestic well septic discharge does not occur outside the 1-mile corridor because all the water is fully consumed by evaporation process. This approach is based on methods described in a domestic well study for New Mexico by NMOSE (2000).

Deep percolation from conveyance losses are calculated as a percentage of applied groundwater. Conveyance losses occur from leaks along the distribution pipelines and booster stations.
No evidence exists for substantial flows of groundwater into the water or wastewater conveyance systems, presumably because depths to groundwater are relatively large in the urban areas with substantial conveyance infrastructure. Las Cruces conveyance losses are approximately 13 percent of applied groundwater according to the Las Cruces 40-Year Plan by JSAI (2008). El Paso has conveyance losses of approximately 7 percent, based on average of reported percentages from the EPWU 2014 Conservation Plan. All other entities have an assumed conveyance loss of 5 or 10 percent of applied groundwater, which is generally within the range

of Las Cruces and El Paso values. Conveyance loss percentages for the other entities were adjusted in their respective applied water budgets to prevent deep percolation of applied water from being negative, as previously described.

2.2.1.2.4 Exported Groundwater

Groundwater exports occur as wastewater discharges downstream from the basin outlet and as groundwater from the Mexico portions of Mesilla Basin conveyed to Ciudad Juarez outside the basin.

Wastewater discharges occur from the John T. Hickerson Water Reclamation Facility in northwest El Paso at the southern end of Mesilla Basin. This facility is supplied by pumped groundwater from wells in Mesilla Basin. The majority of wastewater treated at this facility is discharged directly to the Rio Grande downstream from the Mesilla Basin outlet designated for this analysis. The portion of treated effluent that is not discharged to the river is used in El Paso's Northwest Wastewater Reclamation Facilities Project in northwest El Paso. We obtained monthly effluent discharge data from the City of El Paso for the Hickerson facility. According to the wastewater data, effluent discharges to the river began in 1989 and continue through present day. This effluent discharge is treated as groundwater export because the water is Mesilla groundwater that is discharged to the river outside the Mesilla Basin water budget study area. These exported groundwater rates ranged from about 5,000 AF in 1990 to about 9,700 AF in 2000, and then declined slightly after 2000 when the reclaimed water project began operations.

In 2010, Ciudad Juarez began pumping groundwater from its constructed wellfield in the Conejos-Medanos aquifer for supplemental municipal water supply. Water is conveyed from the wellfield to Ciudad Juarez, located approximately 15 miles to the east in the adjacent Hueco Bolson (or El Paso Valley), via the Conejos-Medanos Aqueduct. Pumping from the Conejos-Medanos wellfield is summarized in Chapter 4.2.3 of this report.

2.2.2 Urban Precipitation Water Budget

The urban precipitation water budget was developed over a control area defined by the maximum extent of urban land in the basins. For this analysis, urban lands are spatially defined as the extent of high-density urban areas as developed by Land IQ. The increasing acreage of urban lands through time is incorporated into this analysis. The maximum urban extent for each basin was defined as the maximum spatial extent of areas delineated for high density urban mapping years by Land IQ: 1,021 acres for Rincon Basin and 38,209 acres for Mesilla Basin. The maximum extents of urban lands are shown on **Figure 2.2**. The cities of Las Cruces and El Paso are the most prominent urban areas in Mesilla Basin; the village of Hatch is the main urban area in Rincon Basin.

For each high density urban mapping year, the disposition of lands within the fixed maximum urban extent was defined. Specifically, the acreage of agricultural, non-agricultural/non-urban, and high-density urban lands were defined for this analysis. Changes in land use composition within the Rincon and Mesilla basins has resulted in declining acreage of agricultural and non-agricultural/non-urban lands and increasing acreage of high-density urban lands. For this analysis, the maximum extent of urban lands is referred to as the urban control area, where the total area remains constant but relative proportions of land uses change through time. Representative changes in land use within the urban control area are shown on **Figure 2.16**.

Changes in land use within the maximum urban extent for Rincon and Mesilla basins are pertinent to the non-farm water budget because the land use type directly determines the acreages to be considered in certain components of the urban precipitation water budgets. The urban precipitation water budget is defined by the following equation:

$$P_{urb} = P_{eff\text{-}urb} + CU_{P\text{-}urb} + QSW + DP_P \qquad (40)$$

Where,

P_{urb} is total precipitation falling on urban lands;

$P_{eff\text{-}urb}$ is effective precipitation for urban landscaped areas (consumptive use);

$CU_{P\text{-}urb}$ is consumptive use of precipitation on undeveloped areas within the urban lands control area;

QSW is surface water return flows from urban lands (urban runoff); and

DP_P is deep percolation of precipitation falling on urban lands.

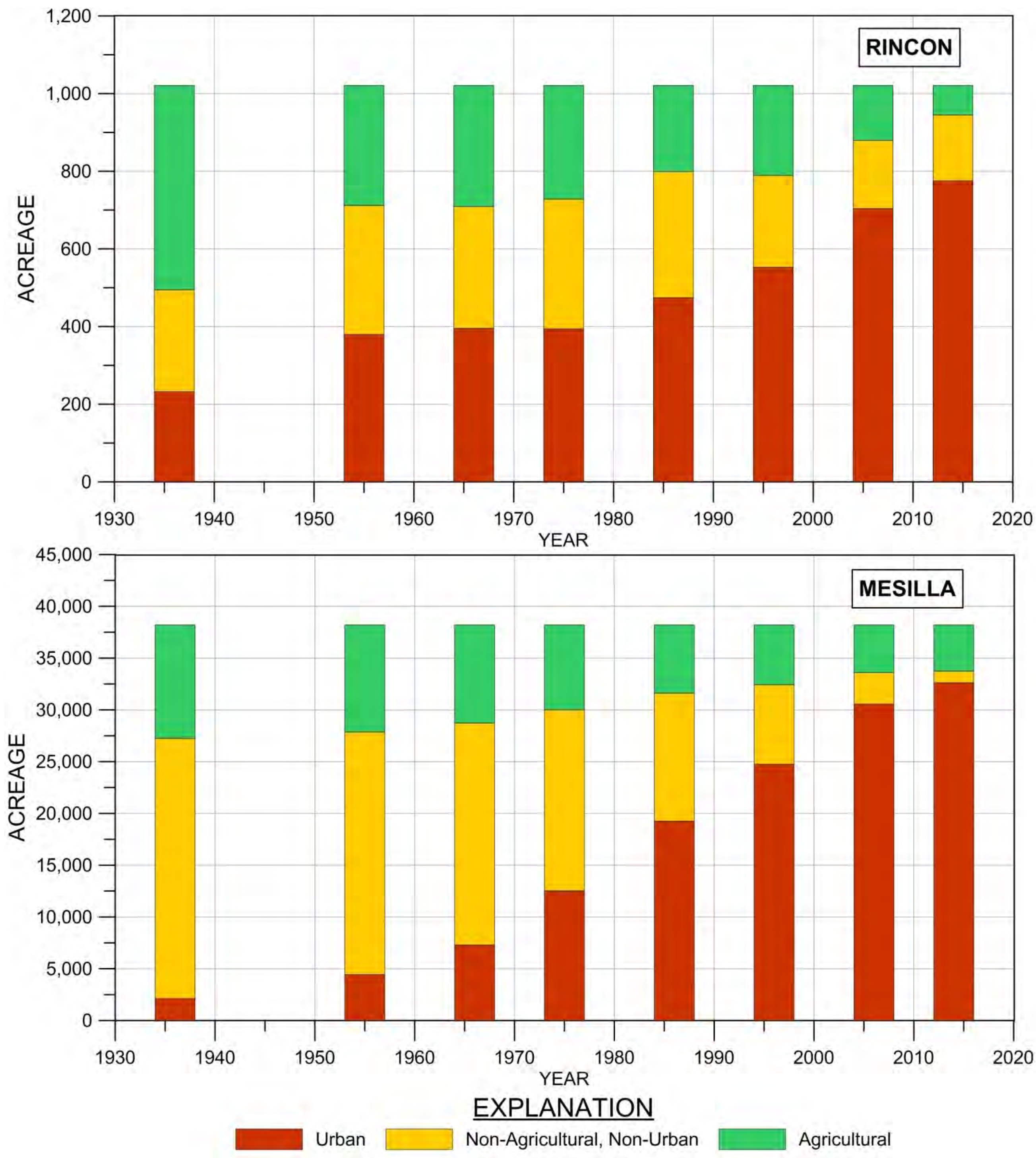

Figure 2.16. Changes in General Land Use Acreages within Maximum Extents of Agriciltural and High-Density Urban Lands in Rincon and Mesilla Basins

2.2.2.1 Total Precipitation

Some of the precipitation falling on urban lands contributes toward satisfying urban consumptive use in the form of irrigated landscaping such as turfgrass in parks and playing fields, gardens, trees, and shrubs – this is defined as urban effective precipitation, and occurs by definition within urbanized areas. The remaining precipitation falling on urban lands either produces return flows to the surface water network, urban deep percolation, or is lost to the atmosphere as evapotranspiration from undeveloped, non-agricultural lands. Total monthly volumetric urban precipitation is calculated as the area-weighted average monthly precipitation rate from PRISM for lands within the maximum extent of urban area, multiplied by the urban control area. The PRISM dataset is previously described in Section 2.1.1 of this report and annual urban precipitation is included in **Table 2.1**. Acreages were estimated by linear interpolation between high density urban mapping years.

2.2.2.2 Effective Precipitation on Developed Urban Lands

Effective precipitation is the amount of rainfall that is used to meet evapotranspiration of growing vegetation. Urban effective precipitation is conceptualized for this analysis as the portion of precipitation falling on urban areas that satisfies a portion of urban consumptive use. For this analysis, irrigated landscaping is the only category of urban consumptive use that can be satisfied by effective precipitation. Other urban consumptive uses are satisfied by applied water and are incorporated into the urban applied water budgets described in previous sections of this report. Monthly rates of urban effective precipitation were calculated separately for the Rincon and Mesilla Valleys based on the USBR method (Stamm, 1967) previously described in Section 2.1.2 of this report. These relations require as data inputs the total monthly precipitation, the depth of usable soil water storage, and the total monthly evapotranspiration that may be satisfied by precipitation.

Monthly precipitation rates were used as developed from the PRISM dataset, and described previously in section 2.1.2. Warm-season turfgrass is judged to be representative of urban consumptive use for landscaping. The soil water storage depth (1.5 inches) and monthly ET (range from 0 to 0.265 inches per month, total of 3.1 feet per year) are defined based on rooting depth and seasonal ET reported by Leinauer and Smeal (2012).

Volumetric monthly effective precipitation is calculated by multiplying the effective precipitation rate and the total area over which precipitation can contribute to urban consumptive use. That area is defined in turn by the total area of high-density urban land for the Rincon and Mesilla basins, as determined by Land IQ, multiplied by a coefficient representing the fraction of high-density urban land that consists of landscaped area. The fraction of high-density urban lands that consists of landscaped vegetation was estimated using point sampling and remote sensing methods. This assessment used a LANDSAT 8 multispectral satellite image with Normalized Difference Vegetation Index (NDVI) data from July 2013 to identify the type of urban vegetation within each 90-foot by 90-foot pixel of the image. This analysis does not attempt to characterize detailed changes in land use through time. Instead, the July 2013 image is used to represent a regional approximation of percentage of lands in each basin with dense vegetation. The image was clipped to the mapped high-density urban lands shown on **Figure 2.2**. Each image pixel contains an NDVI value representing the average vegetation type within the pixel area. The NDVI value for each pixel was extracted to a point location located at the center of the pixel. A total of 292,969 uniformly-spaced pixel points are located within the mapped urban areas within the study area. Points with NDVI values equal to or greater than 0.3 are considered to be dense landscape vegetation for this analysis. A NDVI value of 0.6 was initially applied for dense vegetation, based on estimates by the USGS Remote Sensing Phenology program (USGS, 2017). However, the value was decreased to 0.3 based on comparisons with vegetation visible in aerial imagery. Higher NDVI values result in substantial turf and other heavily vegetated areas not being assigned as dense vegetation.

The percent landscaped area was determined by dividing the number of points classified as "dense vegetation" by the total number of points located within the mapped high-density urban lands. The results of this point sampling assessment indicates that approximately 11 percent of all high-density urban acreage in Rincon and Mesilla basins is landscaped and contributes to urban consumptive use of precipitation. **Figure 2.17** shows the point sampling results for an example area in the City of Las Cruces in Mesilla Basin. **Figures 2.14d and 2.15d** show the time-series of volumetric urban effective precipitation as calculated by the procedure previously described.

Figure 2.17. Example Results of Point Sampling for Estimating Landscaped Urban Vegetation Acreage

2.2.2.3 Urban Runoff (Return Flows)

Average annual pre-development return flows to the surface water network, including direct runoff and lateral flow in soils, were estimated by Tetra Tech (2015) for the Las Cruces area to be 0.18 inches per year (in/yr), or 1.9 percent of average annual precipitation, with 0.52 percent direct runoff and 1.35 percent lateral flow. These percentages were applied to all mapped urban lands in the basins. Adjusting the analysis to account for different watershed characteristics in the El Paso area would result in only slight changes in total basinwide estimates, and thus was not incorporated into this analysis. Expansion of impervious surfaces such as pavement and roofing, associated with urbanization, increases surface runoff. The effect of urbanization on surface runoff in southern New Mexico has not been previously quantified. The effect of urbanization on surface runoff due to residential expansion in southern Arizona, for which climate, vegetation, and soils are similar, showed that surface runoff is 26 times greater in a residential area than in undeveloped land (Kennedy and others, 2013). Using this estimate, it is assumed that surface runoff increases from 0.52 percent to 14 percent of average annual precipitation. It is further assumed that lateral flow in soils is eliminated due to urbanization. The net effect is that return flows to the surface water network increase from 1.9 percent to 14 percent of precipitation.

2.2.2.4 Urban Deep Percolation of Precipitation

Precipitation water at the land surface that is not consumptively used or returned to the surface water network is assumed to percolate below the root zone, ultimately becoming groundwater recharge. Average annual pre-development deep percolation rate in Las Cruces was estimated by Tetra Tech (2015) to be 0.13 in/yr, or about 1.35 percent of average annual precipitation. These percentages were applied to all mapped urban lands in the basins. Adjusting the analysis to account for different watershed characteristics in the El Paso area would result in only slight changes in total basinwide estimates, and thus was not incorporated into this analysis. For this analysis, the percentage was increased (doubled) to 2.7 percent of annual precipitation to account for potential increase in deep percolation from stormwater retention and detention structures.

2.2.2.5 Evapotranspiration from Undeveloped Urban Lands

ET from bare soil and from native vegetation is the residual term in the urban precipitation water budgets and is calculated as the difference between total inflows and the sum of all remaining outflows. Results indicate that ET from undeveloped urban lands decreases through time as a result of the decrease in undeveloped acres through time. Estimated annual ET from undeveloped urban lands is about 84 and 92 percent of annual precipitation in Rincon and Mesilla basins, respectively, during the 1940s and 1950s and then gradually decreases to about 77 and 74 percent, respectively, by 2016.

The portion of local precipitation that ultimately becomes ET has been estimated by surface water modeling studies of pre-development conditions in urbanized areas in the state of New Mexico by Tetra Tech (2015). The results of these studies indicate that the average annual ET in Las Cruces under pre-development conditions was 9.31 in/yr, or 97 percent of average annual precipitation. For this analysis, total urban ET is equal to effective precipitation on developed urban lands (previously described) plus ET on undeveloped urban lands (described in this section). Estimated total urban ET is about 90 and 94 percent of annual precipitation in Rincon and Mesilla basins, respectively, in the 1940s and 1950s and then gradually declines to about 85 percent in both basins by 2016 due principally due to expansion of developed areas.

2.2.3 Upland Watershed Water Budget

The upland watershed water budget is defined by the following equation:

$$P_{WS} = CU_{SW} + QSW_{Trib} + DP_{MFR} \tag{41}$$

Where,
P_{WS} is total precipitation falling on upland watershed areas (non-farm, non-urban lands);
CU_{SW} is consumptive use of P_{WS} by native plant transpiration (excluding riparian) and soil evaporation (ET);
QSW_{Trib} is surface water return flows to the Rio Grande from contributing tributaries; and
DP_{MFR} is deep percolation to groundwater from P_{WS} (mountain-front recharge).

Precipitation falling on the upland watershed surrounding the urban and farm areas (**Figure 2.2**) in the study area ultimately is lost to ET, runoff, and mountain front recharge. Precipitation falling on the non-farm, non-urban areas of the upland watershed is summarized in **Table 2.1**. The runoff outflow component of this water budget is the tributary inflow component in the Surface Water Budget. Methods used for estimating tributary inflows are described in Section 3.1.2 of this report. Mountain-front recharge is an inflow component to the Groundwater Budget, as described in Section 4.1.4.

Consumptive use of precipitation falling on the upland watershed areas in the basins is computed as the residual term in the upland watershed water budget. This term is computed as precipitation minus the sum of tributary return flows and mountain-front recharge. The vast majority of this precipitation is consumed by evapotranspiration processes. Areal recharge in the basins is assumed to be negligible; instead, recharge is represented as mountain-front recharge.

3 SURFACE WATER BUDGET

When applied to the surface water budget, Equation (1) becomes:

$$[Q_{SW\text{-}in}] - [Q_{SW\text{-}out}] = \Delta S_{SW} \qquad (42)$$

Where, $Q_{SW\text{-}in}$ is surface water inflows; $Q_{SW\text{-}out}$ is surface water outflows; and ΔS_{SW} is the change in storage within the surface water network.

Considering all components of the surface water budget, Equation (42) becomes:

$$[RG_{in}+TF+QSW_f+QSW_{nf}+WW+Q_{GW\text{-}in}] - [RG_{out}+SW_f+ID_f+EOC_{RG}+Q_{GW\text{-}out}] = \Delta S_{SW} \qquad (43)$$

Where,

RG_{in} is Rio Grande inflows;
TF is tributary inflows from upland arroyos;
QSW_f is surface water return flows from farm lands (farm tailwater);
QSW_{nf} is surface water return flows from non-farm lands (runoff);
WW is urban wastewater discharges to Rio Grande;
$Q_{GW\text{-}in}$ is groundwater inflows to the surface water network;
RG_{out} is Rio Grande outflows;
SW_f is applied surface water to farms (farm deliveries);
ID_f is farm incidental depletions;
EOC_{RG} is open channel evaporation along Rio Grande; and
$Q_{GW\text{-}out}$ is surface water outflows to groundwater.

Assuming that the storage changes within the surface water network are negligible each month, Equation (43) can be used to solve the net groundwater-surface water exchange as the following:

$$Q_{GW\text{-}SW} = Q_{GW\text{-}out} - Q_{GW\text{-}in} = (\text{sum of outflows}) - (\text{sum of inflows}) = RG_{out}+SW_f+ID_f+ EOC_{RG} -RG_{in}-TF-QSW_f-QSW_{nf}-WW \qquad (44)$$

Where, $Q_{GW\text{-}SW}$ is net groundwater-surface water exchange, which includes interactions along the river, canals, and drains. No direct measurements of the groundwater-surface water exchanges are available; however, all other components of the surface water budget can be derived from available data or the analysis of available data. The net groundwater-surface water exchange is estimated as the quantity required to close the surface water budget.

Figure 3.1 provides a graphical depiction of Equation (44).

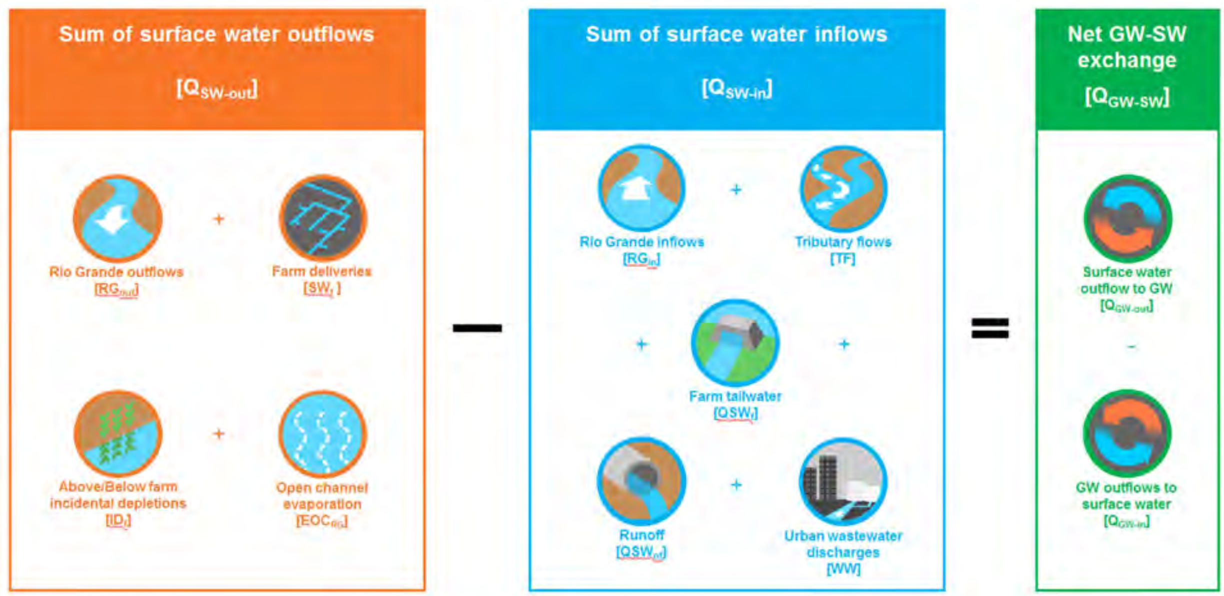

Figure 3.1. Graphical Depiction of Surface Water Budget Equation

The surface water budget and relationships with the land-water and groundwater budgets are shown on **Figure 1.2**. Farm deliveries are an input to the land-surface water budget. Net groundwater-surface water exchange is an input to the groundwater budget.

The monthly, basin-wide surface water budgets for Rincon and Mesilla basins are summarized in the accompanying dataset named *IntegratedWaterBudgets.xlsx*. Annual surface water budgets for Rincon Basin and Mesilla Basin are summarized in this chapter of the report and tabulated in **Appendices B1 and B2**.

3.1 Surface Water Inflows

3.1.1 Rio Grande Inflow

The Rio Grande enters Rincon Basin at a bedrock constriction at Caballo Dam and then flows generally southeastward to the bedrock constriction in Selden Canyon, which effectively separates Rincon Basin from Mesilla Basin. The Rio Grande enters Mesilla Basin at Selden Canyon, upstream from Leasburg Dam, and then flows southward through Mesilla Basin before exiting the southern end of the basin through the bedrock constriction at the Narrows in El Paso.

Main channel inflow to Rincon Basin is defined by streamflow in the Rio Grande below Caballo Dam. Daily mean streamflows below Caballo Dam were obtained from the International Boundary Water Commission (IBWC) for 1938 through 2006, the U.S. Geological Survey (USGS) from 2007 through 2013, and the Elephant Butte Irrigation District (EBID) for 2014.

US_MSJ_00001978

Monthly flow data for 2015 and 2016 were obtained from streamflow tables included in the respective Rio Grande Compact Commission Reports.

Main channel inflows to Mesilla Basin are defined by streamflow in the Rio Grande above Leasburg Dam. Daily mean streamflows above Leasburg Dam are reported by the United States Bureau of Reclamation (USBR) from 1938 through 1983. From 1984 through 2016, streamflow data are not reported for the Rio Grande above Leasburg Dam gage. For this period, streamflow above Leasburg Dam was computed as the sum of measured streamflow below Leasburg Dam and measured flow diverted into the Leasburg Canal, which has its head gate at the dam. Flow data for Leasburg Canal were obtained from the USBR and Elephant Butte Irrigation District (EBID). Flow data for below Leasburg Dam are not available for 2014 through 2016. Furthermore, flow data for 2011 and 2012 obtained from IBWC for below Leasburg Dam were determined to be anomalous when compared to historical measurements. A simple regression analysis was conducted to estimate flows in Rio Grande above Leasburg Dam to fill missing data for 2011, 2012, and 2014 through 2016. The regression equation (Flow above Leasburg = 0.9063*(Flow below Caballo) + 2044.8; r^2=0.98) is used to estimate monthly flows above Leasburg Dam using measured flows below Caballo Dam for the years with missing data.

Locations of streamflow gages used for defining the inflows and outflows of the surface water budgets are shown on **Figure 3.2**. Annual streamflows at the river inflow locations of the Rincon and Mesilla basins are shown on **Figure 3.3**.

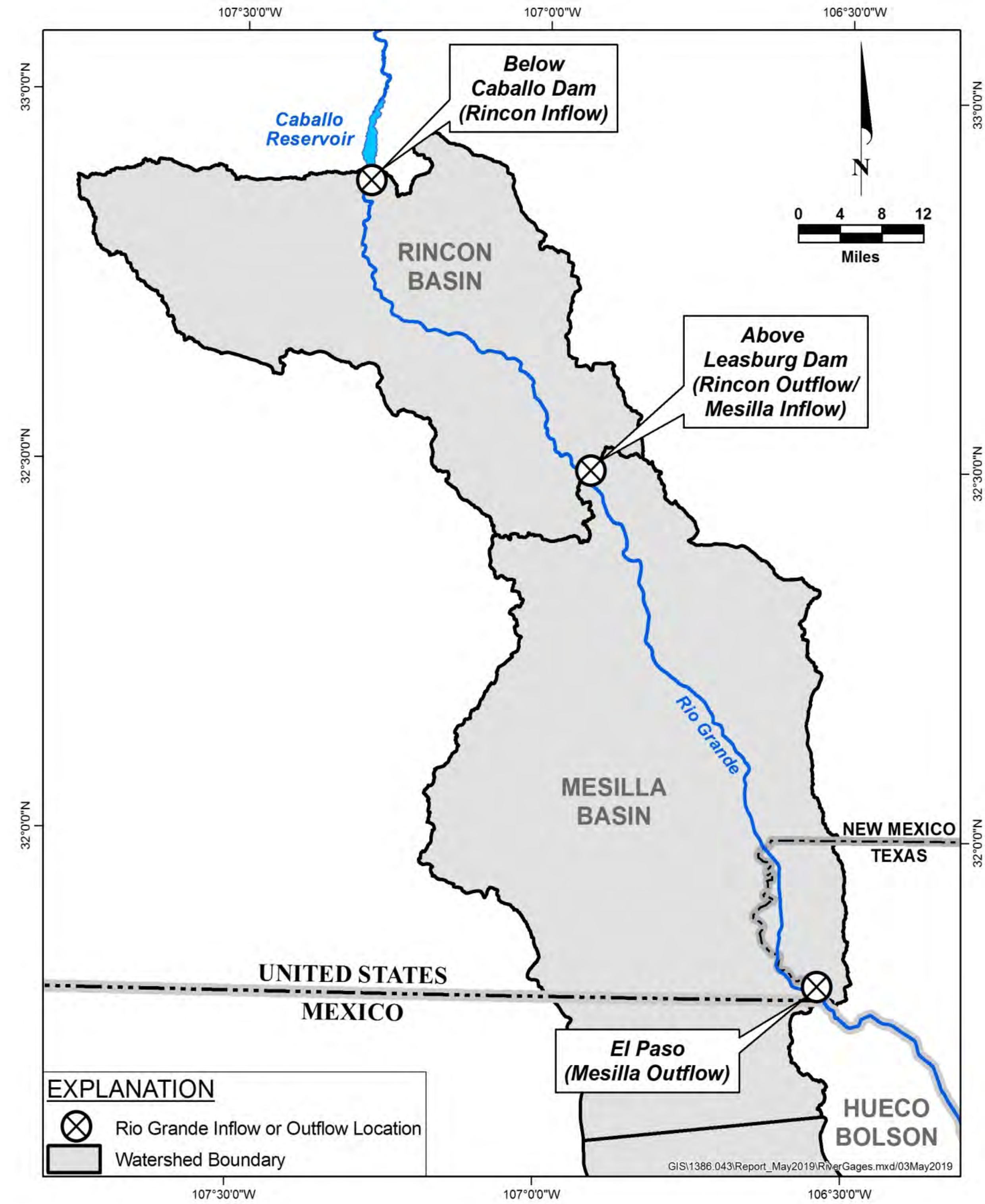

Figure 3.2. Locations of Rio Grande Inflows and Outflows in Rincon and Mesilla Basins

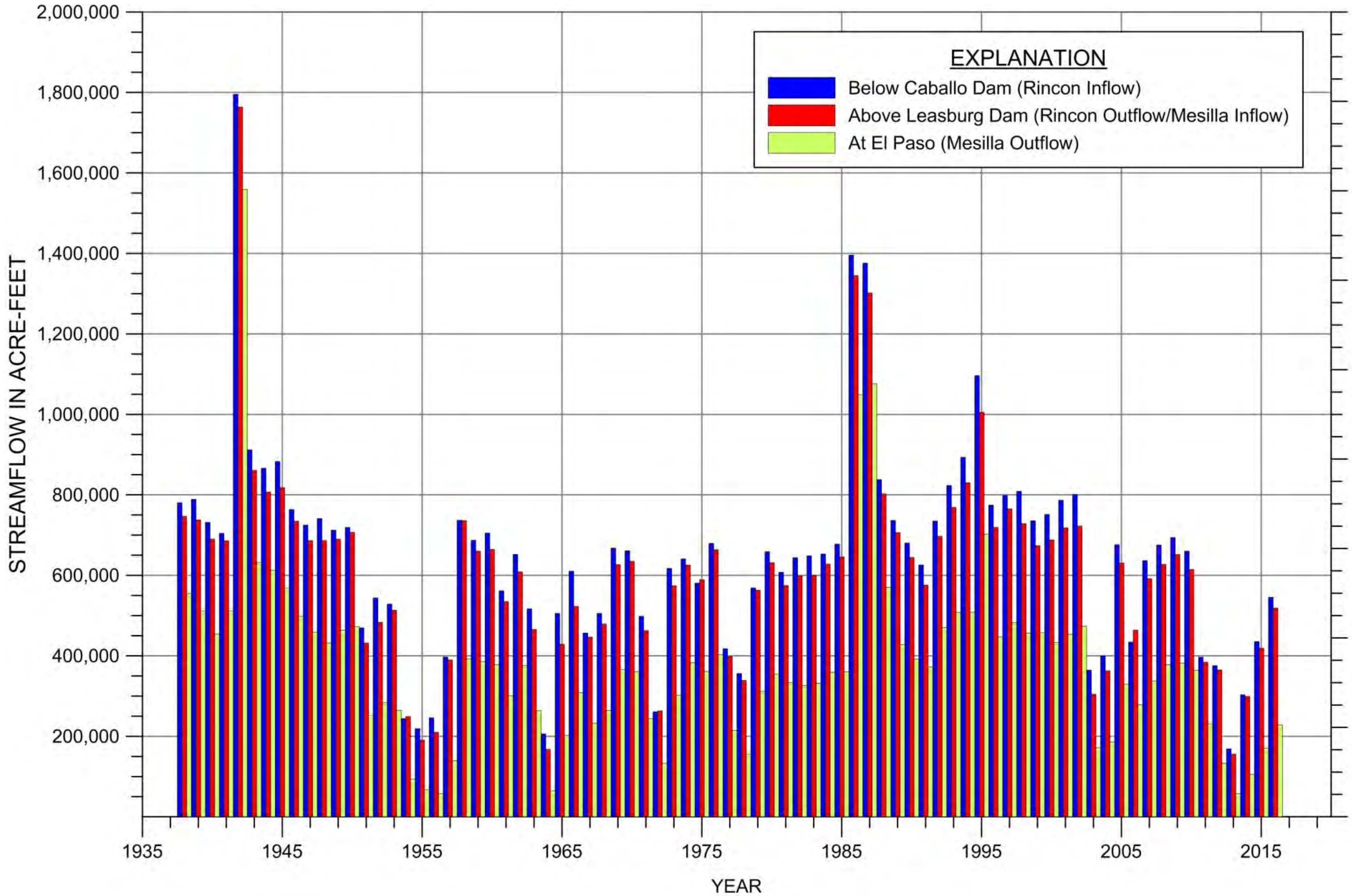

Figure 3.3. Annual Rio Grande Streamflows at Inflow and Outflow Locations in Rincon and Mesilla Basins

3.1.2 Tributary Inflow

Tributary inflows represent the volume of water that flows into the Rio Grande from ephemeral streams as a result of stormwater runoff in the upland areas of the study area. For this water budget analysis, runoff return flow volumes from urban and agricultural lands are estimated separately from runoff return flows from upland areas. Urban and farm lands were removed from the contributing watersheds considered for this tributary inflow analysis.

The U.S. Army Corps of Engineers (USACE) conducted hydrologic and hydraulic analyses for the Rincon and Mesilla basins for the Rio Grande Canalization Project (USACE and others, 1996). The USACE study delineated contributing and non-contributing sub-basins in the study area, and evaluated 100-year flood discharges at selected locations along the Rio Grande between Caballo Dam and American Diversion Dam. The contributing watersheds were digitized from the USACE report and used for this tributary inflow analysis. According to the USACE study, the Rincon Basin watershed (between Caballo Dam and Leasburg Diversion Dam) constitutes a major flood-producing area because of its steep-sloped arroyos that discharge directly to the Rio Grande. The Mesilla Basin (Between Leasburg Diversion Dam and American Diversion Dam) has less flood-producing potential because most arroyos discharge into the valley floor where flood waters pond in low-lying areas (USACE and others, 1996). Non-contributing sub-basins are associated with arroyos that do not have direct access through levees or railroad track embankments. The majority of tributary arroyos in Mesilla Basin do not contribute runoff discharges to the Rio Grande. Contributing watersheds in each basin are shown on **Figure 3.4**.

The watershed extent contributing to arroyo inflow was compared against watershed extent contributing to mountain-front recharge, and adjusted such that areas of overlap only contribute to mountain-front recharge. This ensures inflows to the surface water and groundwater system are consistent with estimated precipitation. Thus, for this analysis, tributary inflows to the river are generated only from precipitation falling within the alluvium basin.

Watershed runoff models require detailed streamflow data and information on physical characteristics for drainages and sub-watersheds. The lack of streamflow gages on the majority of drainages to the Rio Grande within the study area prevents the use of surface water modeling for determining tributary runoff for this water budget. Because of this limitation, we estimated runoff as a percentage of precipitation falling on the contributing watersheds.

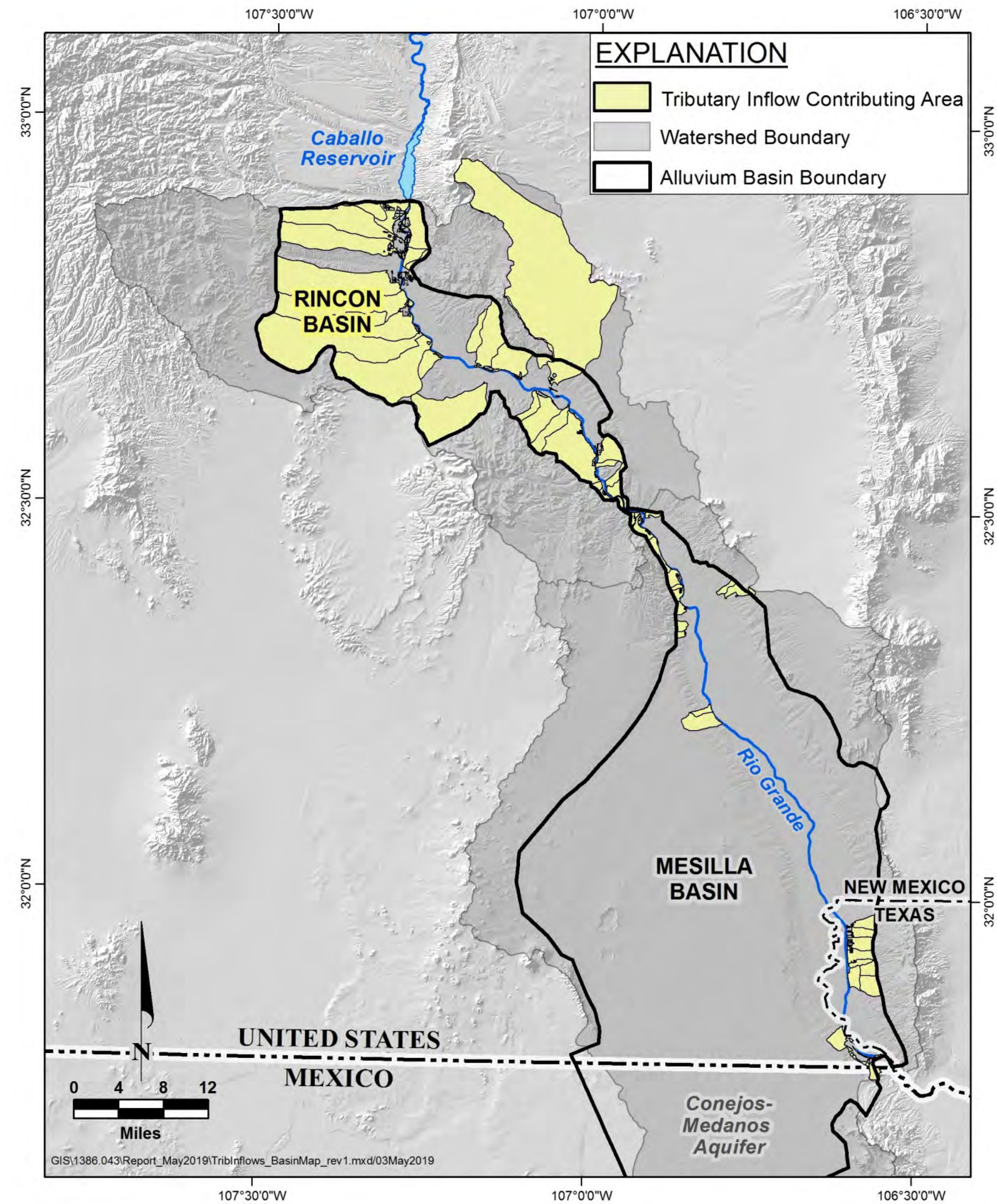

Figure 3.4. Sub-Watersheds Contributing to Tributary Inflows in Rincon and Mesilla Basins

Precipitation contributing to tributary inflows is based on monthly PRISM precipitation data. The PRISM dataset was previously described in Section 2.1.1 of this report. Basin precipitation is summarized in **Table 2.1**. Not all monthly precipitation becomes runoff and inflow to the Rio Grande. For this analysis, tributary inflows occur only during months when precipitation is greater than the average monthly precipitation based on PRISM data for 1938 through 2016. Average monthly precipitation is summarized on **Table 3.1**.

Table 3.1. Average Monthly Precipitation on Contributing Watersheds

Month	Rincon	Mesilla
January	0.47	0.52
February	0.41	0.44
March	0.25	0.30
April	0.29	0.26
May	0.30	0.39
June	0.59	0.63
July	1.68	2.07
August	1.85	2.23
September	1.43	1.66
October	0.83	0.99
November	0.48	0.53
December	0.62	0.75

Units in inches, based on monthly PRISM precipitation for 1938 through 2016.

Tributary inflow was assumed to be three percent of precipitation, based on results of a rainfall-runoff study conducted by Stone and Brown (1975) in a small semiarid watershed in the Jornada Basin in New Mexico. Annual tributary inflows in Rincon and Mesilla basins are shown on **Figure 3.5**. The estimated average annual tributary flows are about 5,500 AF in Rincon Basin and about 100 AF in Mesilla Basin.

As a comparison to the estimated tributary inflows described previously, stormflow volumes were quantified by a sequence of calculations using daily streamflow hydrographs compiled for stream gaging stations at the upstream and downstream ends of the Rincon Basin: Rio Grande below Caballo Dam, and Rio Grande above Leasburg Dam.

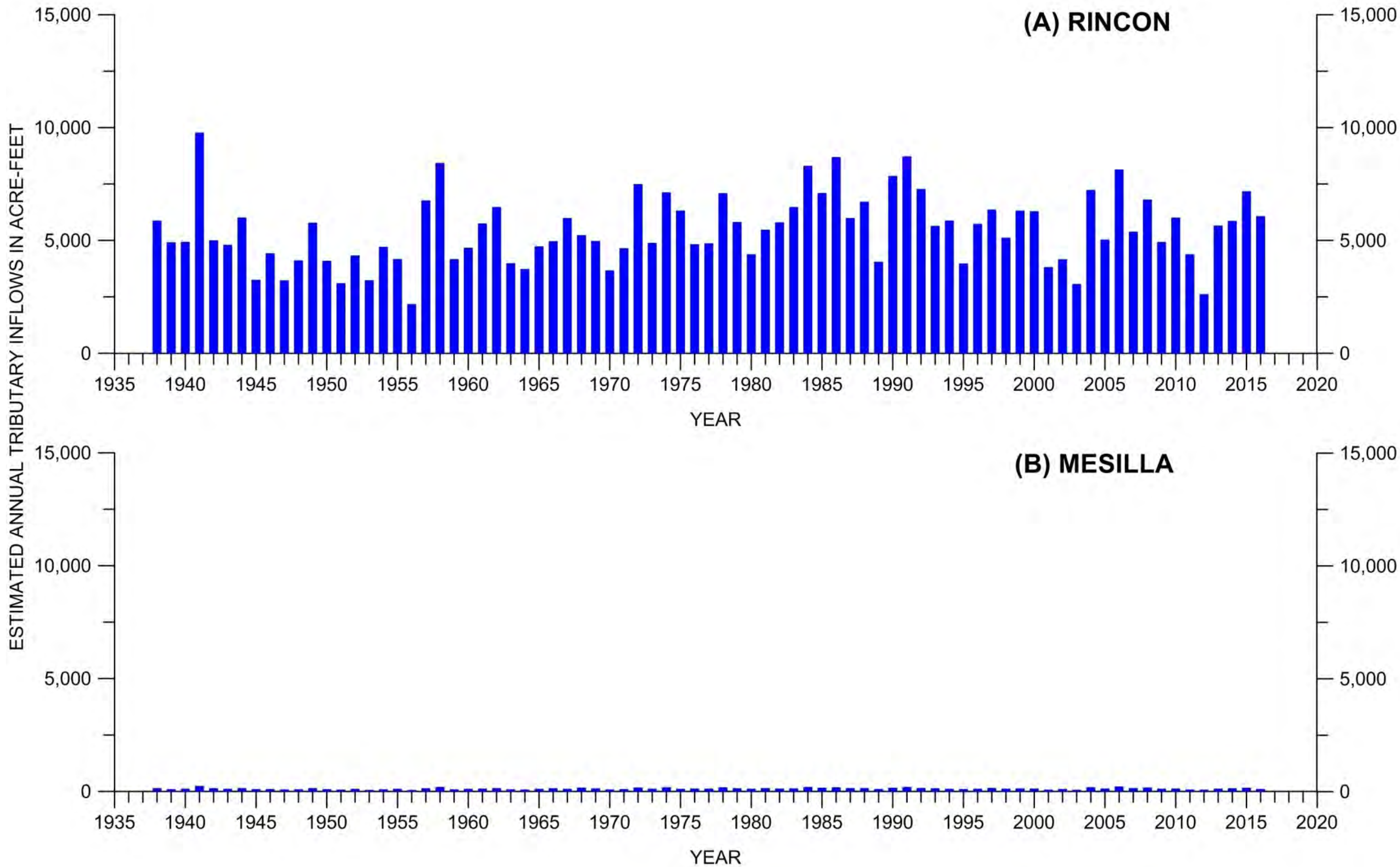

Figure 3.5. Estimated Annual Tributary Inflows for Rincon and Mesilla Basins

Periods of stormflow were identified over the period of record by days for which the mean daily streamflow recorded at Rio Grande above Leasburg Dam exceeds the previous day's mean daily discharge by a threshold streamflow change. An assumed threshold change of 250 cubic feet per second (cfs) was used for this analysis.

Each stormflow period is assumed to consist of four days. If the mean daily streamflow for a given day is at least 250 cfs greater than the mean daily streamflow from the previous day, then that day and the three subsequent days constitute the stormflow period.

For the stormflow period identified by the previous steps, the daily stormflow volume is calculated as the difference in mean daily discharge recorded at Rio Grande below Caballo Dam and Rio Grande above Leasburg Dam. The daily stormflow volumes are then summed for each month. Using this method, average annual tributary inflows in Rincon Basin are estimated to be about 3,530 AF.

Applying historic precipitation to the runoff curve for Rincon Basin specified in the Joint Investigation Report (JIR) resulted in runoff estimates that are appear to be vastly too large. Average annual runoff in Rincon Basin is estimated to be about 20,500 AF, using the JIR method. This magnitude of return flow to the river cannot be accounted for within the current water budgets. The JIR curve for Mesilla Basin resulted in average annual runoff of about 1,200 AF, which is generally consistent with estimates determined for this analysis.

3.1.3 Farm Surface Water Return Flow

Farm surface water return flow determined for the land-surface water budget described in Chapter 2 of this report are directly used as inflows to the surface water budgets for Rincon and Mesilla basins.

3.1.4 Urban Runoff Inflow

Urban runoff (returns to surface water system) determined for the land-surface water budget described in Chapter 2 of this report are directly used as inflows to the surface water budgets for Rincon and Mesilla basins.

3.1.5 Urban Wastewater discharges

Urban wastewater discharge is described in Section 2.2.1 of this report. Land-surface urban wastewater discharges are directly used as inflows to the surface water budgets for Rincon and Mesilla basins.

3.2 Surface Water Outflow

3.2.1 Rio Grande Outflow

Main channel outflows from the Rincon Basin are defined by streamflow in the Rio Grande above Leasburg, and are identical to Mesilla Basin main channel inflows as previously described. Main channel outflows from the Mesilla Basin are defined by streamflow in the Rio Grande at El Paso as reported by the International Boundary and Water Commission (IBWC) from 1938 through 2011. Additional data were obtained from streamflow table from the Rio Grande Compact Commission Report for 2012, from USBR for 2013, and from IBWC for 2014-2016. EBID also provided historic flow data for Rio Grande at El Paso; however, the values were redundant to the IBWC dataset. Annual streamflows at the outflow locations of the Rincon and Mesilla basins are shown on **Figure 3.3**. Annual streamflows at the outflow locations fluctuate from year to year and generally follow decadal-scale trends of relatively high and low flows.

3.2.2 Surface Water Deliveries to Farms

Water is diverted from the Rio Grande and delivered to farms for irrigation use in Rincon, Mesilla, and El Paso valleys via a conveyance network of canals and laterals. Based on an interview with Bert Cortez at USBR on April 26, 2019, canal system operators ("ditchriders") move diverted water through the distribution system by using a series of gates and turn outs. Ditchriders open the gates at turn outs to each farm and measures the amount delivered. The amount delivered is based on the farmers order for Project water.

Monthly deliveries to farms (farm deliveries) in the valleys are reported in U.S. Bureau of Reclamation crop reports and water distribution tables. The water distribution tables also summarize net project surface water supply, transportation losses, operational spills, and project surface water deliveries to non-farm users (municipal and industrial). However, a complete record of historical surface water deliveries to farms in the project area is not available from a single source, the period of record for reported farm deliveries is incomplete, and the reporting format changes through time. **Table 3.2** shows a summary of available farm delivery data by year.

Table 3.2. Availability of Surface Water Farm Delivery Data, 1938 through 2016

Year	RGP	RGP Leasburg Unit	RGP Mesilla Unit	RGP El Paso Unit	EBID	RGP/EBID: Rincon Unit/Division	EBID: Mesilla Division	EPCWID #1	HCCRD 1
1938	X	X	X	X		X			
1939	X	X	X	X		X			
1940	X	X	X	X		X			
1941	X	X	X	X		X			
1942	X	X	X	X		X			
1943	X	X	X	X		X			
1944	X	X	X	X		X			
1945	X	X	X	X		X			
1946	X	X	X	X		X			
1947	X	X	X	X		X			
1948	X	X	X	X		X			
1949	X	X	X	X		X			
1950	X	X	X	X		X			
1951	X	X	X	X		X			
1952	X	X	X	X		X			
1953	X	X	X	X		X			
1954	X	X	X	X		X			
1955	X	X	X	X		X			
1956	X								
1957	X	X	X	X		X			
1958	X	X	X	X		X			
1959	X	X	X	X		X			
1960	X	X	X	X		X			
1961	X	X	X	X		X			
1962	X	X	X	X		X			
1963	X	X	X	X		X			
1964	X	X	X	X		X			
1965	X	X	X	X		X			
1966	X	X	X	X		X			
1967	X	X	X	X		X			
1968	X	X	X	X		X			
1969	X	X	X	X		X			
1970	X	X	X	X		X			
1971	X								
1972	X								
1973	X								
1974	X	X	X	X		X			
1975	X								
1976	X	X	X	X		X			
1977	X	X	X	X		X			
1978	X	X	X	X		X			
1979	X				X			X	X
1980	X				X			X	X
1981	X				X			X	X
1982	X				X			X	X
1983	X				X			X	X

Year	RGP	RGP Leasburg Unit	RGP Mesilla Unit	RGP El Paso Unit	EBID	RGP/EBID: Rincon Unit/Division	EBID: Mesilla Division	EPCWID #1	HCCRD 1
1984	X				X			X	X
1985	X				X			X	X
1986	X				X			X	X
1987	X				X			X	X
1988	X				X			X	X
1989	X				X			X	X
1990	X							X	
1991	X				X	X	X	X	X
1992	X								
1993	X				X			X	X
1994	X				X			X	X
1995					X	X	X	X	X
1996					X	X	X	X	X
1997	X					X	X	X	X
1998					X	X	X	X	X
1999					X	X	X	X	X
2000					X	X	X	X	X
2001					X	X	X	X	X
2002					X	X	X	X	X
2003						X	X	X	X
2004					X	X	X	X	X
2005					X	X	X	X	X
2006					X	X	X	X	X
2007					X	X	X	X	
2008					X	X	X	X	
2009					X	X	X		
2010					X	X	X	X	
2011	X				X		X		
2012					X				
2013					X				
2014					X				
2015					X				
2016					X				

X = water distribution table is available
RGP = Rio Grande Project (full)
EBID = Elephant Butte Irrigation District
EPCWID#1 = El Paso County Water Improvement Distict #1
HCCRD1 = Hudspeth County Conservation and Reclamation District 1
Data Source:

Yellow	RGP annual history reports, scanned water distribution tables
Green	USBR: received as scanned water distribution tables for various years
Blue	EBID: received as annual totals in Excel file

Given these limitations, multiple sources of data and estimation methods are used to develop monthly datasets of surface water deliveries to farms in Rincon Valley, Mesilla Valley, and El Paso Valley for the entire study period from 1938 through 2016. Basinwide datasets are required for the farm soil water balance models developed for each valley, as previously described in Chapter 2 for Rincon and Mesilla basins. Annual deliveries to each valley, along with disaggregated deliveries to service areas and to districts, are summarized in **Table 3.3**.

Figure 3.6 shows irrigation district lands within each valley. EBID has lands in both Rincon and Mesilla valleys; EPCWID#1 has lands in both Mesilla and El Paso Valley; and Hudspeth County Conservation and Reclamation District 1 (HCCRD1) is located in the lower portions of El Paso Valley. Data sources and methods used to develop historic datasets for each valley are described in the following sections. Basinwide datasets were then disaggregated to summarize by district and by state.

3.2.2.1 Data Sources

Monthly values for deliveries were tabulated from scanned water distribution tables and imported into a database, which is described in a separate report. For each year, water distribution information is reported as aggregates for different project areas. The different reported project areas are shown in **Table 3.2**.

For 1938-1988, delivery data are reported in water distribution tables from Rio Grande Project History Annual Reports. Delivery data are not reported by district or subarea for 1956, 1971, 1972, 1973, and 1975; only Rio Grande Project total deliveries are reported for these years.

For 1989-2011, deliveries are reported in water distribution tables provided by the U.S. Bureau of Reclamation (USBR). Delivery data are not reported by district or subarea for 1992; only Rio Grande Project total deliveries are reported for this year. Water distribution tables from crop reports were also provided by EPCWID#1; however, the tables either were redundant of tables previously obtained by USBR or were blank.

Water distribution tables are not available for 2012 through 2016; however, total annual deliveries to EBID farms were provided by EBID for these years.

Water distribution tables for Hudspeth County Conservation and Reclamation District 1 (HCCRD1) are reported in the same RGP History Reports and USBR data as described above. Delivery data for the district are available for 1979 through 2006, except for 1990 and 1992.

Table 3.3 Summary of Annual Surface Water Deliveries to Farms in Rincon, Mesilla, and El Paso Valleys

			NEW MEXICO					TEXAS						
Year	**Farm Deliveries to Rincon Basin**	**Farm Deliveries to Mesilla Basin**	Farm Deliveries to Arrey/Rincon	Farm Deliveries to Leasburg	Farm Deliveries to Mesilla Eastside NM	Farm Deliveries to Mesilla Westside NM	Total Farm Deliveries to New Mexico (Arrey+Leasburg+ Eastside NM + Westside NM)	Farm Deliveries to Mesilla Eastside TX	Farm Deliveries to Mesilla Westside TX	Farm Deliveries to Texas (EPCWID#1) in Mesilla (Eastside TX+ Westside TX)	**Farm Deliveries to EPCWID#1 in El Paso Valley**	Total Farm Deliveries to EPCWID#1 (Mesilla+ El Paso Valley)	**Farm Deliveries to HCCRD1 in El Paso Valley**	Total Farm Deliveries to Texas (Mesilla+El Paso Valley)
1938	33,709	212,979	33,709	79,361	36,050	73,065	222,185	2,132	22,371	24,503	122,842	147,345	31,939	147,345
1939	39,911	248,066	39,911	92,436	41,989	85,102	259,437	2,484	26,056	28,540	149,887	178,427	38,971	178,427
1940	41,123	240,866	41,123	89,753	40,770	82,632	254,278	2,412	25,300	27,711	154,284	181,995	40,114	181,995
1941	35,145	203,205	35,145	75,719	34,395	69,712	214,971	2,035	21,344	23,379	117,414	140,793	30,528	140,793
1942	41,593	215,724	41,593	80,384	36,514	74,007	232,498	2,160	22,659	24,819	126,240	151,059	32,822	151,059
1943	49,339	264,134	49,339	98,423	44,708	90,614	283,085	2,645	27,744	30,388	169,683	200,071	44,118	200,071
1944	47,873	261,740	47,873	97,531	44,303	89,793	279,500	2,621	27,492	30,113	162,200	192,313	42,172	192,313
1945	50,820	297,580	50,820	110,886	50,369	102,089	314,164	2,980	31,257	34,236	186,850	221,086	48,581	221,086
1946	47,500	270,440	47,500	100,773	45,776	92,778	286,826	2,708	28,406	31,114	181,020	212,134	47,065	212,134
1947	43,493	253,040	43,493	94,289	42,830	86,809	267,421	2,534	26,578	29,112	170,370	199,482	44,296	199,482
1948	40,960	251,170	40,960	93,592	42,514	86,167	263,233	2,515	26,382	28,897	159,620	188,517	41,501	188,517
1949	44,960	258,580	44,960	96,353	43,768	88,709	273,791	2,589	27,160	29,749	176,050	205,799	45,773	205,799
1950	48,038	258,981	48,038	96,503	43,836	88,847	277,224	2,593	27,202	29,795	181,004	210,799	47,061	210,799
1951	24,702	137,209	24,702	51,128	23,224	47,071	146,125	1,374	14,412	15,786	125,707	141,493	32,684	141,493
1952	28,181	150,168	28,181	55,956	25,418	51,517	161,072	1,504	15,773	17,277	153,497	170,774	39,909	170,774
1953	26,638	146,073	26,638	54,430	24,725	50,112	155,905	1,463	15,343	16,806	137,729	154,535	35,810	154,535
1954	8,021	52,315	8,021	19,494	8,855	17,947	54,317	524	5,495	6,019	41,934	47,953	10,903	47,953
1955	5,563	40,121	5,563	14,950	6,791	13,764	41,068	402	4,214	4,616	34,779	39,395	9,043	39,395
1956	8,313	38,326	8,313	14,281	6,487	13,148	42,229	384	4,026	4,409	40,903	45,313	10,635	45,313
1957	12,041	82,375	12,041	30,695	13,943	28,260	84,939	825	8,652	9,477	75,568	85,045	19,648	85,045
1958	38,245	208,595	38,245	77,728	35,308	71,561	222,841	2,089	21,910	23,999	153,927	177,926	40,021	177,926
1959	36,595	196,411	36,595	73,188	33,245	67,381	210,409	1,967	20,630	22,597	173,983	196,580	45,236	196,580
1960	41,068	202,353	41,068	75,402	34,251	69,420	220,141	2,026	21,254	23,280	158,979	182,259	41,335	182,259
1961	26,833	161,788	26,833	60,286	27,385	55,503	170,007	1,620	16,994	18,614	137,360	155,974	35,714	155,974
1962	38,424	214,463	38,424	79,914	36,301	73,574	228,213	2,147	22,526	24,674	158,533	183,207	41,219	183,207
1963	27,886	160,206	27,886	59,697	27,117	54,961	169,660	1,604	16,827	18,432	124,914	143,346	32,478	143,346
1964	5,304	29,982	5,304	11,172	5,075	10,286	31,837	300	3,149	3,449	29,682	33,131	7,717	33,131
1965	22,328	120,676	22,328	44,967	20,426	41,399	129,120	1,208	12,675	13,884	91,596	105,480	23,815	105,480
1966	32,192	159,349	32,192	59,377	26,972	54,667	173,208	1,595	16,737	18,333	109,927	128,260	28,581	128,260
1967	20,788	113,693	20,788	42,365	19,244	39,004	121,401	1,138	11,942	13,080	90,788	103,868	23,605	103,868
1968	29,334	133,475	29,334	49,736	22,592	45,790	147,453	1,336	14,020	15,356	92,912	108,268	24,157	108,268
1969	37,184	190,570	37,184	71,011	32,257	65,377	205,829	1,908	20,017	21,925	136,314	158,239	35,442	158,239
1970	40,581	209,098	40,581	77,915	35,393	71,734	225,623	2,094	21,963	24,056	138,870	162,926	36,106	162,926
1971	27,222	129,538	27,222	48,269	21,926	44,440	141,857	1,297	13,606	14,903	96,589	111,492	25,113	111,492
1972	11,833	54,255	11,833	20,217	9,183	18,613	59,846	543	5,699	6,242	50,628	56,870	13,163	56,870
1973	31,669	166,656	31,669	62,100	28,209	57,173	179,151	1,669	17,505	19,174	119,249	138,423	31,005	138,423
1974	38,463	191,102	38,463	71,209	32,347	65,560	207,579	1,913	20,073	21,986	122,339	144,325	31,808	144,325
1975	36,078	170,406	36,078	63,498	28,844	58,460	186,879	1,706	17,899	19,605	121,538	141,143	31,600	141,143
1976	44,460	203,349	44,460	75,773	34,420	69,761	224,414	2,036	21,359	23,395	127,261	150,656	33,088	150,656
1977	19,969	100,973	19,969	37,625	17,091	34,640	109,325	1,011	10,606	11,617	72,279	83,896	18,793	83,896
1978	11,786	52,398	11,786	19,525	8,869	17,976	58,156	525	5,504	6,028	48,165	54,193	12,523	54,193
1979	35,197	150,728	35,197	56,165	25,513	51,709	168,584	1,509	15,832	17,341	103,668	121,010	30,300	151,310
1980	42,641	194,127	42,641	72,336	32,859	66,598	214,433	1,944	20,390	22,334	113,363	135,697	27,199	162,923
1981	38,464	171,079	38,464	63,748	28,958	58,691	189,861	1,713	17,970	19,682	112,406	132,089	43,038	175,151
1982	40,348	187,203	40,348	69,757	31,687	64,222	206,014	1,874	19,663	21,538	136,857	158,394	53,392	211,786
1983	39,421	194,663	39,421	72,536	32,949	66,782	211,688	1,949	20,447	22,396	110,748	133,144	47,978	181,122

			NEW MEXICO					TEXAS						
Year	**Farm Deliveries to Rincon Basin**	**Farm Deliveries to Mesilla Basin**	Farm Deliveries to Arrey/Rincon	Farm Deliveries to Leasburg	Farm Deliveries to Mesilla Eastside NM	Farm Deliveries to Mesilla Westside NM	Total Farm Deliveries to New Mexico (Arrey+Leasburg+ Eastside NM + Westside NM)	Farm Deliveries to Mesilla Eastside TX	Farm Deliveries to Mesilla Westside TX	Farm Deliveries to Texas (EPCWID#1) in Mesilla (Eastside TX+ Westside TX)	**Farm Deliveries to EPCWID#1 in El Paso Valley**	Total Farm Deliveries to EPCWID#1 (Mesilla+ El Paso Valley)	**Farm Deliveries to HCCRD1 in El Paso Valley**	Total Farm Deliveries to Texas (Mesilla+El Paso Valley)
1984	40,084	181,772	40,084	67,733	30,767	62,359	200,943	1,820	19,093	20,913	105,073	125,986	62,832	188,818
1985	46,725	187,819	46,725	69,986	31,791	64,434	212,936	1,881	19,728	21,608	108,927	130,536	70,370	200,906
1986	59,238	231,242	59,238	86,167	39,141	79,331	263,876	2,315	24,289	26,604	107,456	134,060	33,868	167,928
1987	63,131	255,280	63,131	95,124	43,210	87,577	289,041	2,556	26,814	29,370	108,531	137,900	63,688	201,588
1988	50,806	220,739	50,806	82,253	37,363	75,727	246,149	2,210	23,186	25,396	107,326	132,722	46,714	179,436
1989	53,981	220,656	53,981	82,222	37,349	75,699	249,250	2,209	23,177	25,386	108,635	134,022	48,406	182,428
1990	43,265	186,319	43,265	69,427	31,537	63,919	208,149	1,866	19,570	21,436	98,820	120,256	25,693	145,949
1991	48,575	205,524	48,575	76,583	34,788	70,507	230,453	2,058	21,587	23,645	131,079	154,725	45,252	199,977
1992	41,966	214,186	41,966	79,811	36,254	73,479	231,510	2,145	22,497	24,642	129,910	154,552	33,777	188,329
1993	48,618	232,650	48,618	86,691	39,379	79,814	254,502	2,329	24,437	26,766	109,961	136,727	55,071	191,798
1994	61,149	265,826	61,149	99,053	44,995	91,195	296,392	2,662	27,921	30,583	133,404	163,987	59,719	223,706
1995	60,533	222,298	60,533	82,834	37,627	76,262	257,256	2,226	23,349	25,575	132,269	157,844	62,302	220,146
1996	51,325	230,708	51,325	85,968	39,050	79,147	255,490	2,310	24,233	26,543	167,854	194,396	51,348	245,744
1997	51,852	231,352	51,852	86,207	39,159	79,368	256,587	2,316	24,300	26,617	108,441	135,058	34,010	169,068
1998	61,964	226,777	61,964	84,503	38,385	77,799	262,651	2,271	23,820	26,090	117,468	143,558	42,895	186,453
1999	51,695	208,008	51,695	77,509	35,208	71,360	235,772	2,083	21,848	23,931	185,564	209,495	48,942	258,437
2000	55,585	215,427	55,585	80,273	36,464	73,905	246,227	2,157	22,628	24,785	117,859	142,644	46,466	189,110
2001	57,194	217,608	57,194	81,086	36,833	74,653	249,767	2,179	22,857	25,036	148,571	173,607	42,378	215,985
2002	55,628	219,417	55,628	81,760	37,139	75,274	249,801	2,197	23,047	25,244	195,043	220,287	46,606	266,893
2003	12,342	61,735	12,342	23,004	10,450	21,179	66,975	618	6,484	7,103	88,803	95,906	23,089	118,995
2004	12,967	61,036	12,967	22,744	10,331	20,939	66,981	611	6,411	7,022	88,803	95,825	23,089	118,914
2005	41,213	157,602	41,213	58,726	26,676	54,067	180,683	1,578	16,554	18,132	89,306	107,438	21,336	128,774
2006	19,206	83,719	19,206	31,196	14,171	28,721	93,293	838	8,794	9,632	86,217	95,849	23,667	119,516
2007	35,117	132,367	35,117	49,323	22,405	45,410	152,255	1,325	13,903	15,229	94,327	109,556	24,525	134,081
2008	43,080	163,812	43,080	61,040	27,727	56,198	188,046	1,640	17,206	18,846	94,327	113,173	24,525	137,698
2009	43,798	143,897	43,798	53,620	24,357	49,366	171,140	1,441	15,114	16,555	83,781	100,336	21,783	122,120
2010	33,648	168,755	33,648	62,882	28,564	57,894	182,988	1,690	17,725	19,415	98,255	117,670	61,343	316,694
2011	4,734	19,010	4,734	7,084	3,218	6,522	21,557	190	1,997	2,187	11,068	13,255	2,878	16,133
2012	13,386	59,288	13,386	22,092	10,035	20,340	65,853	594	6,227	6,821	34,519	41,340	8,975	50,315
2013	4,592	19,273	4,592	7,182	3,262	6,612	21,648	193	2,024	2,217	11,221	13,439	2,918	16,356
2014	8,764	45,524	8,764	16,963	7,706	15,618	49,051	456	4,782	5,237	26,505	31,743	6,891	38,634
2015	17,400	62,170	17,400	23,166	10,523	21,328	72,418	622	6,530	7,153	36,197	43,350	9,411	52,761
2016	20,535	73,372	20,535	27,340	12,419	25,171	85,466	735	7,707	8,441	42,719	51,161	11,107	62,268

Units in acre-feet
Deliveries are based data reported in U.S. Bureau of Reclamation crop report water distribution tables.
Bolded headers indicate inputs to farm water budgets.
EPCWID#1 = El Paso County Water Improvement District #1
HCRRD1 = Hudspeth County Conservation and Reclamation District 1

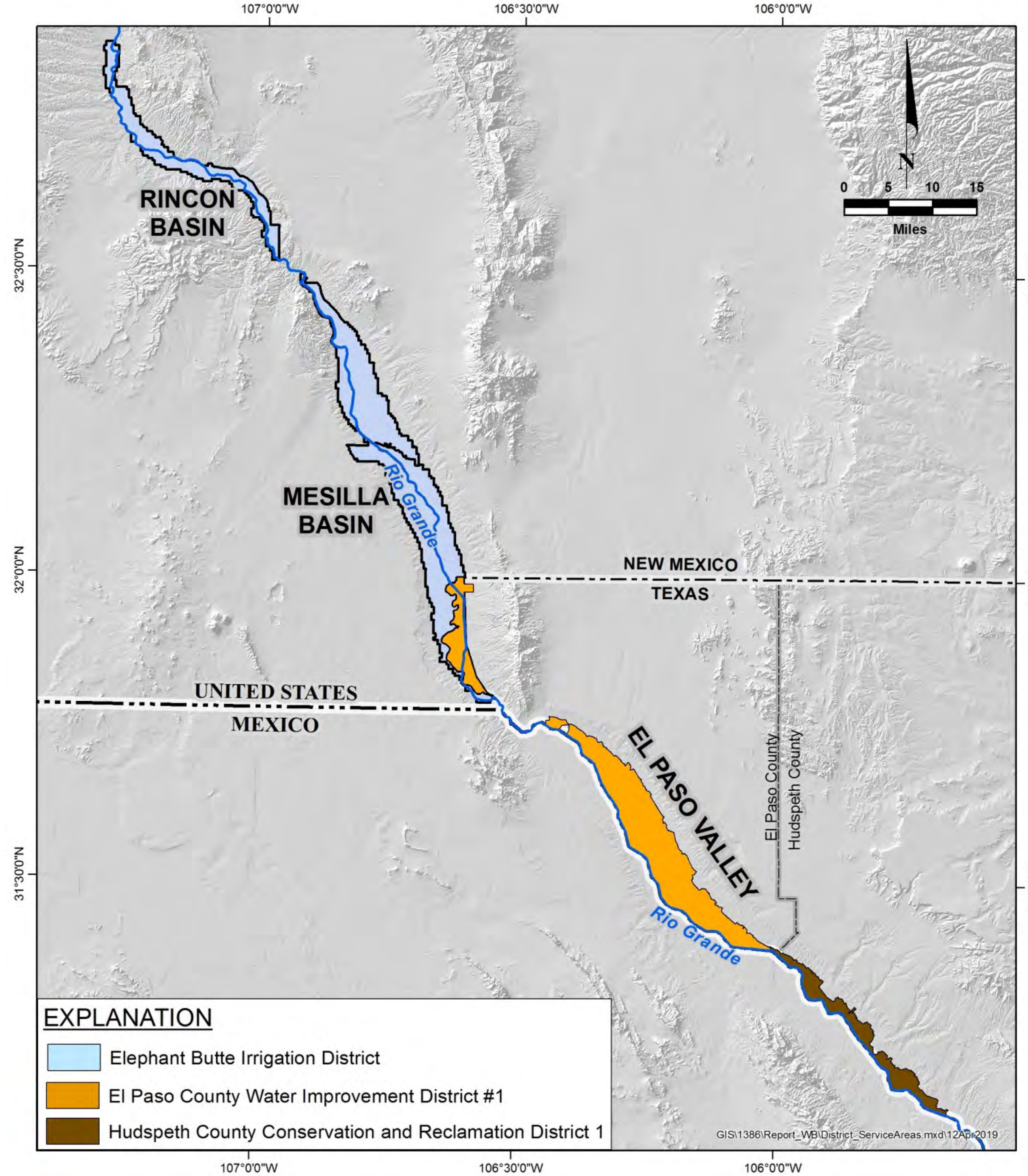

Figure 3.6. Irrigation District Lands in Project Area

3.2.2.2 Methods for Rincon and Mesilla Basins

From 1938 through 1978, water distribution tables summarize farm deliveries by Rio Grande Project subareas or basins (Rincon Unit, Mesilla Unit, El Paso/Ysleta Unit). After 1978, farm deliveries are reported by District (EBID, EPCWID#1, HCCRD) or EBID service area (Arrey, Leasburg, or Mesilla). For 1956, 1971, 1972, 1973, 1978 through 1990, 1992, 1993, 1994, and 2012 through 2016, farm delivery data are either missing or are reported in a manner that is inconsistent with other reporting periods (for example, deliveries reported for districts not by basin area). Basinwide deliveries are required for the water budget analyses described herein. For 1995 through 2011, total farm deliveries to Mesilla Basin is computed as the reported deliveries to EBID Mesilla service area plus estimated farm deliveries to Texas lands (EPCWID#1) in Mesilla Basin. Texas deliveries in Mesilla Basin are estimated as a portion of the total reported deliveries to EPCWID#1. Total reported deliveries to EPCWID#1 are disaggregated to Mesilla Basin and El Paso Valley based on district land acreages in each basin (83.5 percent in El Paso Valley and 16.5 percent in Mesilla Basin) (**Figure 3.6**). Monthly basinwide farm deliveries during the periods of missing or inconsistent data were estimated using regression models for Rincon and Mesilla basins that predict farm deliveries (Q_{fd}) as a function of several explanatory variables.

The regression model for the Rincon Basin takes the following form:

$$Q_{fd} = \beta_0 + \beta_1 \times Q_{rhg} + \beta_2 \times Q_{rhg}^2 + \beta_3 \times allot + \beta_4 \times Apr + \beta_5 \times Aug + \beta_6 \times Sep \qquad (45)$$

Explanatory variables used to estimate farm deliveries in Rincon Basin include monthly streamflow in the Arrey Canal (Q_{rhg}), the square of monthly streamflow in the Arrey Canal (Q_{rhg}), the annual surface water allotment (allot), and indicator variables for the months of April (Apr), August (Aug), and September (Sep). Indicator variables were added based on exploratory data analysis indicating that farm deliveries during those months tended to be under predicted in regression models considering only Arrey Canal flows and surface water allotment.

The regression coefficients in Equation (45) were estimated using monthly data during months for which farm deliveries were reported. Measured farm delivery data prior to 1950 were excluded from the regression to avoid potential influence of supplemental groundwater pumping on surface water delivery data. However, the regression equation is essentially the same with or without the pre-1950 data. **Table 3.4** summarizes the regression model used for Rincon farm deliveries, including the explanatory variables with associated coefficients and measures of statistical significance.

The final time series of farm deliveries in the Rincon Basin is based on reported farm deliveries, when available, and estimates from Equation (45) for months when farm deliveries were not reported.

Table 3.4. Summary of Explanatory Variables Used Iin Regression Model to Estimate Rincon Basin Farm Deliveries

Explanatory Variable	Coefficient (β)
Intercept (β_0)	-5.43×10^{2}
Monthly flow in Arrey Canal (β_1)	3.63×10^{-1}
Square of monthly flow in Arrey Canal (β_2)	5.81×10^{-6}
Annual RGP surface water allotment (β_3)	2.38×10^{2}
Indicator variable for April (β_4)	6.51×10^{2}
Indicator variable for August (β_5)	2.84×10^{2}
Indicator variable for September (β_6)	8.64×10^{2}

NOTE: Regression model estimated based on 492 reported monthly farm delivery values, with model R^2 = 0.89. Standard error of the regression is equal to 1,024.

The regression model for the Mesilla Basin takes the following form:

$$Q_{fd} = \beta_0 + \beta_1\times Q_{rhg} + \beta_2\times Q_{rhg}^{2} + \beta_3\times allot + \beta_4\times Apr + \beta_5\times Sep \quad (46)$$

The explanatory variables used to estimate farm deliveries in the Mesilla Basin are similar to those used for the Rincon Basin, with two exceptions. First, the term Qrhg in Equation (46) represents the sum of diversions in the Leasburg, Eastside, and Westside canals less El Paso Carriage. Second, the indicator variable for month of August was not included in the model. **Table 3.5** summarizes the regression model used for Mesilla farm deliveries, including the explanatory variables with associated coefficients and measures of statistical significance.

The final time series of farm deliveries for Mesilla Basin is based on reported farm deliveries, when available, and estimates from Equation (46) for months when farm deliveries were not reported.

Table 3.5. Summary of Explanatory Variables Used in Regression Model to Estimate Mesilla Basin Farm Deliveries

Explanatory Variable	Coefficient (β)
Intercept (β_0)	-1.44×10^{3}
Monthly flow in Leasburg, Eastside, and Westside Canals (β_1)	3.54×10^{-1}
Square of monthly flow in Leasburg, Eastside, and Westside Canals (β_2)	2.50×10^{-6}
Annual RGP surface water allotment (β_3)	5.39×10^{2}
Indicator variable for April (β_4)	3.74×10^{3}
Indicator variable for September (β_5)	3.51×10^{3}

NOTE: Regression model estimated based on 512 reported monthly farm delivery values, with model R^2 = 0.95. Standard error of the regression is equal to 3,167.

The regression equations were not used for 2015 and 2016 because data are unavailable for diversions for one of the major canals (Westside). For 2015 and 2016, reported total annual deliveries to EBID were disaggregated to EBID lands in Rincon and Mesilla basins based on proportional land acreages in each basin. According to geospatial datasets provided by the district, EBID lands extend across an area of 34,839 acres in Rincon Basin (25 percent of EBID lands) and 106,149 acres in Mesilla Basin (75 percent of EBID lands). Deliveries to EBID farms in Mesilla Basin are computed as 75 percent of reported total EBID deliveries, and deliveries to EBID farms in Rincon Basin are computed as 25 percent of reported total EBID deliveries. Deliveries to the Texas portion of Mesilla Basin (13,800 acres) were estimated as 13 percent of deliveries to EBID Mesilla, based on relative land acreages (acreage of Texas Mesilla is 13 percent of acreage of EBID Mesilla). Basinwide farm deliveries in Mesilla Basin are the sum of EBID Mesilla deliveries and Texas Mesilla deliveries. Annual deliveries were distributed to monthly deliveries based on the average monthly distribution from reported data.

Figures 3.7 and 3.8 shows the complete time series of annual farm deliveries including both original farm delivery data from RGP history reports and estimated farm deliveries based on the estimation methods previously described.

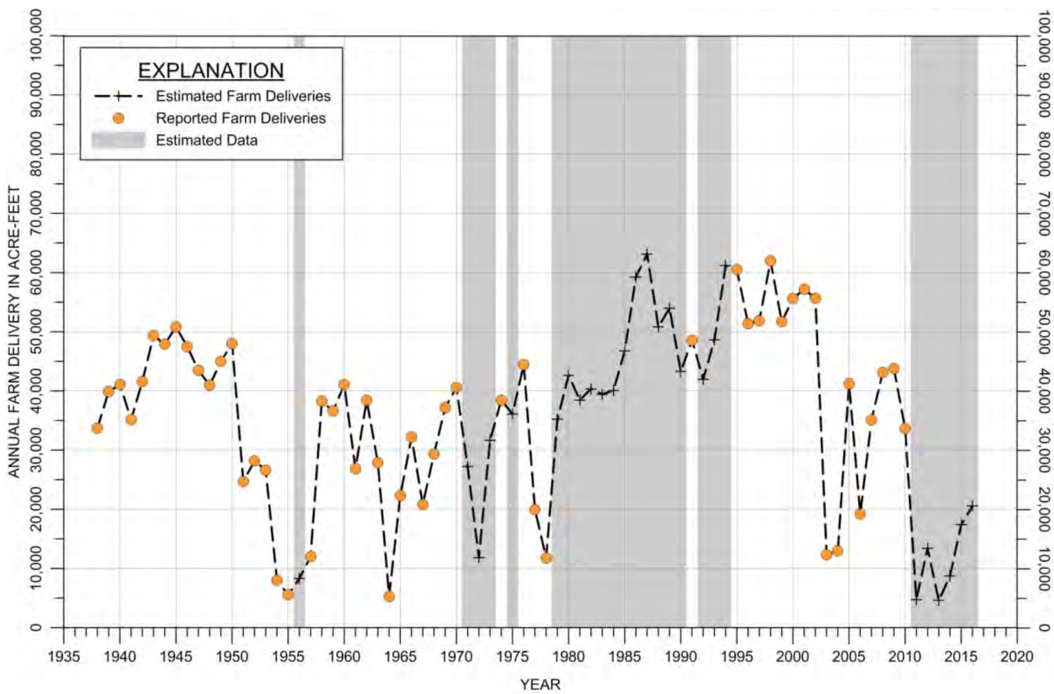

Figure 3.7. Summary of Surface Water Deliveries to Farms in Rincon Basin

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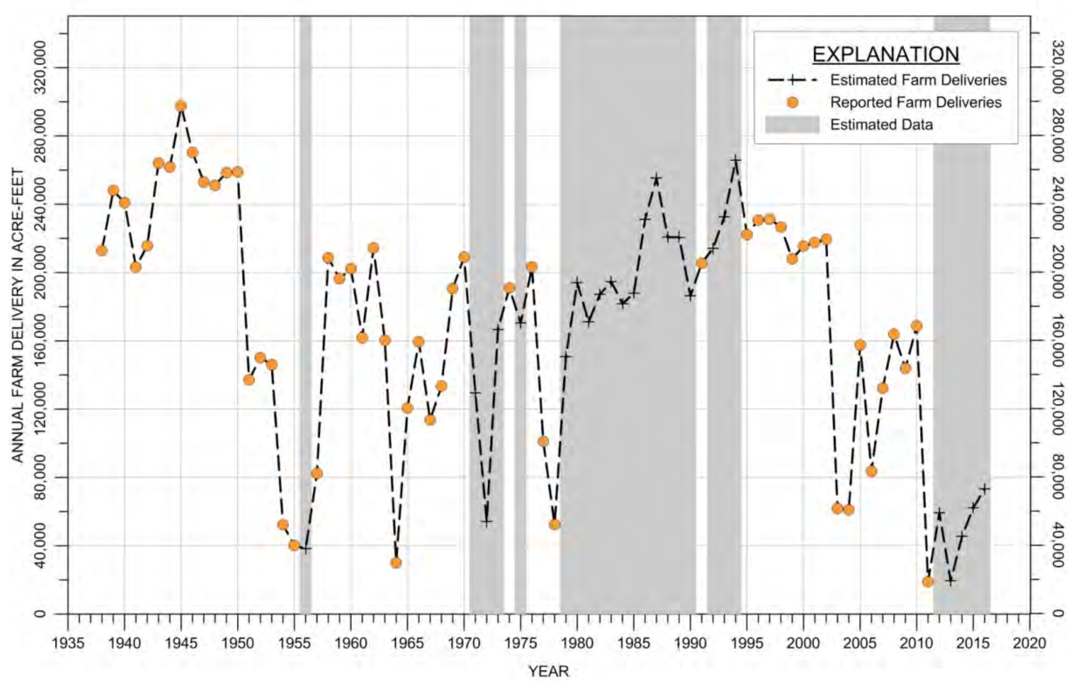

Figure 3.8. Summary of Surface Water Deliveries to Farms in Mesilla Basin

3.2.2.3 Methods for El Paso Valley

El Paso Valley is shown on **Figure 3.6**. The Rio Grande History Reports define El Paso Valley as lands from El Paso to the Hudspeth-El Paso County line. This definition includes only EPCWID#1 lands in El Paso Valley, not Hudspeth County Conservation and Reclamation District 1 (HCCRD1) lands. However, for this report, El Paso Valley includes both EPCWID#1 and HCCRD1 lands because HCCRD1 receives Project water as return flows from EPCWID#1.

For 1938 through 1978, project water deliveries are reported for El Paso Valley (El Paso/Ysleta unit). However, data are missing for 1956, 1971, 1972, 1973, and 1975. A simple regression analysis was conducted to estimate monthly deliveries for these years. The regression equation (Farm Deliveries to El Paso Valley = 0.6105*(Farm Deliveries to Mesilla) + 1458.8; r^2=.92), describes the relationship between reported farm deliveries in El Paso Valley and reported farm deliveries in Mesilla Basin for 1938 through 1978. The equation is used to estimate total monthly farm deliveries in El Paso Valley for the missing years (1956, 1971, 1972, 1973, and 1975) from reported farm deliveries in Mesilla Basin for those same years.

For 1979 through 2008 and 2010, El Paso Valley farm deliveries are estimated based on reported total deliveries to EPCWID#1. Total deliveries to EPCWID#1 are disaggregated based on proportions of total district acreage located in Mesilla Basin and El Paso Valley (**Figure 3.6**). Based on a geospatial dataset provided by EPCWID#1, the total area of the district is 86,929 acres, with 72,596 acres (or 83.5 percent) located in El Paso Valley and 14,343 acres (or 16.5 percent) located in Mesilla Basin. El Paso Valley farm deliveries are estimated as 83.5 percent of total deliveries to the district (farm and non-farm). Non-farm deliveries are reported in EPCWID#1 water distribution tables and presumably represent delivery of project water to the city of El Paso for municipal and industrial use. For this evaluation, non-farm deliveries are considered to be deliveries that would have gone to farms if the associated lands were not urbanized over time. Non-farm deliveries were assigned only to El Paso Valley; thus, for months when EPCWID#1 non-farm deliveries are equal to total district deliveries (no farm deliveries occurred), the entire total district amount is applied to El Paso Valley (no deliveries to Mesilla Basin).

For 2009 and 2011 through 2016, no data are available for deliveries to El Paso Valley or EPCWID#1. The only project delivery data available for this time period are for total annual deliveries to EBID. In the absence of measured data, farm deliveries to El Paso Valley are estimated based on Texas Mesilla estimates from (1) the Mesilla regression method for 2009 and 2011-through 2014, and from (2) reported annual EBID deliveries for 2015 and 2016.

For 2009 and 2011 through 2014, total EPCWID#1 deliveries were estimated by dividing Texas Mesilla deliveries from the Mesilla regression by the percentage of EPCWID#1 land located in Mesilla Basin (16.5 percent). El Paso Valley deliveries were then computed as 83.5 percent of the estimated total EPCWID#1 deliveries.

For 2015 and 2016, following the same methodology previous described for Rincon and Mesilla basins, total EBID deliveries were disaggregated to Rincon and Mesilla basins based on relative proportions of total district acreages. Texas Mesilla deliveries were then estimated to be 13 percent of EBID Mesilla deliveries, based on proportion of land acreage in Mesilla Basin. Total EPCWID#1 deliveries were subsequently estimated using the same proportion methods described above for 2009 and 2011 through 2014.

In addition, surface water is also delivered to Hudspeth County Conservation and Reclamation District 1 (HCCRD1), located in Hudspeth County immediately downstream from the RGP-defined extent of the valley. Surface water deliveries to HCCRD1 are equal to reported "supplemental" deliveries in Rio Grande Project History Report tables. The delivered water is comprised of irrigation return flows, wastewater, and operational spills from upstream water users (EPCWID#1 and City of El Paso). Farm deliveries to HCCRD1 are reported for 1979 through 2006, except for 1990 and 1992. Farm deliveries to HCCRD1 are on average 26 percent of farm deliveries to EPCWID#1 El Paso Valley, based on reported and estimated data for 1979 through 2006. This ratio was applied to the deliveries dataset to estimate HCCRD1 farm deliveries for missing years from 1938 through 2016.

3.2.3 Incidental Depletions

Above-farm incidental depletion is a component of total canal losses, and includes water loss to soil evaporation, and transpiration by vegetation in and surrounding canals. The mechanisms for water loss for below-farm incidental depletion are similar, but apply only to open drains. Above-farm incidental depletions represent water lost to the atmosphere from the surface-water network. Similarly, below-farm incidental depletions from drains consume a portion of groundwater discharge to drains that otherwise would have returned to the main channel Rio Grande. If below-farm incidental depletions are zero, then all groundwater discharge to drains returns to the main channel – if incidental depletions are not zero, then only a portion of groundwater discharge to drains ultimately returns to the main channel.

Above-farm incidental depletion is defined by the NMOSE (Wilson and others, 2003, p. 70) as "evaporation from canals and laterals that convey water from stream or reservoir to the farm headgate; transpiration by phreatophytes along canals and laterals; and evaporation of leakage from off-farm water supply pipelines." Below-farm incidental depletion is defined by the NMOSE as "evaporation of runoff and seepage from irrigated fields; evaporation from open drains and tailwater recovery pits; and transpiration by phreatophytes along drains and below irrigated fields."

A procedure described by the NMOSE was used to quantify above-farm and below-farm incidental depletion of surface water deliveries (Wilson and others, 2003). Monthly consumptive irrigation requirements (CIR) are multiplied by either an above-farm or below-farm incidental depletion factor (IDF). The consumptive irrigation requirement was computed as the portion of crop ET satisfied by surface water deliveries.

Above-farm incidental depletions occur only if water is flowing in the canals. The land-surface water budget assumes that prior to 1951, all crop consumptive use was satisfied by surface water deliveries, or precipitation. The land-surface water budget further assumes that beginning in 1951, crop consumptive use was principally satisfied by a combination of surface water deliveries and supplemental groundwater pumping (**Figures 2.9 and 2.10**). The fraction of crop consumptive use satisfied by surface water is calculated as the monthly farm delivery divided by the monthly crop consumptive water use. During and after 1951, only the portion of crop consumptive use satisfied by surface water (CIR_{SW}) is used to calculate above-farm incidental depletions. The source of irrigation water (groundwater vs. surface water) is not relevant to the magnitude of below-farm incidental depletion. Therefore, below-farm incidental depletion is calculated as the product of the total CIR and the below-farm incidental depletion factor. Above-farm and below-farm incidental depletions are shown on **Figures 3.9a, 3.9b, 3.10a, and 3.10b** for Rincon and Mesilla basins, respectively.

3.2.4 Open-Water Evaporation

A portion of the water conveyed along surface water features, including the main channel of the Rio Grande and agricultural canals and drains, is lost to evaporation. For this evaluation, open-water evaporation is estimated using monthly pan evaporation rates and estimated surface area of the river channel, canals, laterals, and drains.

Monthly pan evaporation from Caballo Reservoir was used for this analysis, with several exceptions. During 1938, monthly pan evaporation rates from Caballo Reservoir were not available, and instead monthly pan evaporation rates from Elephant Butte Reservoir were used. For isolated months with missing data, the average monthly rate over the period of record was substituted.

The evaporation rate, per unit area, was calculated by multiplying the pan evaporation rate by a pan-coefficient of 0.7, as recommended in the JIR. Evaporation volume was calculated by multiplying the monthly evaporation rate by the river surface area. The evaporative surface area was estimated based on stream channel geometry inputs to the OSE Administrative Model (SSPA, 2007) to be about 1,180 acres in the Rincon Basin, and 2,710 acres in the Mesilla Basin. **Figure 3.9c and 3.10c** show estimated open-water evaporation losses in Rincon and Mesilla basins, respectively.

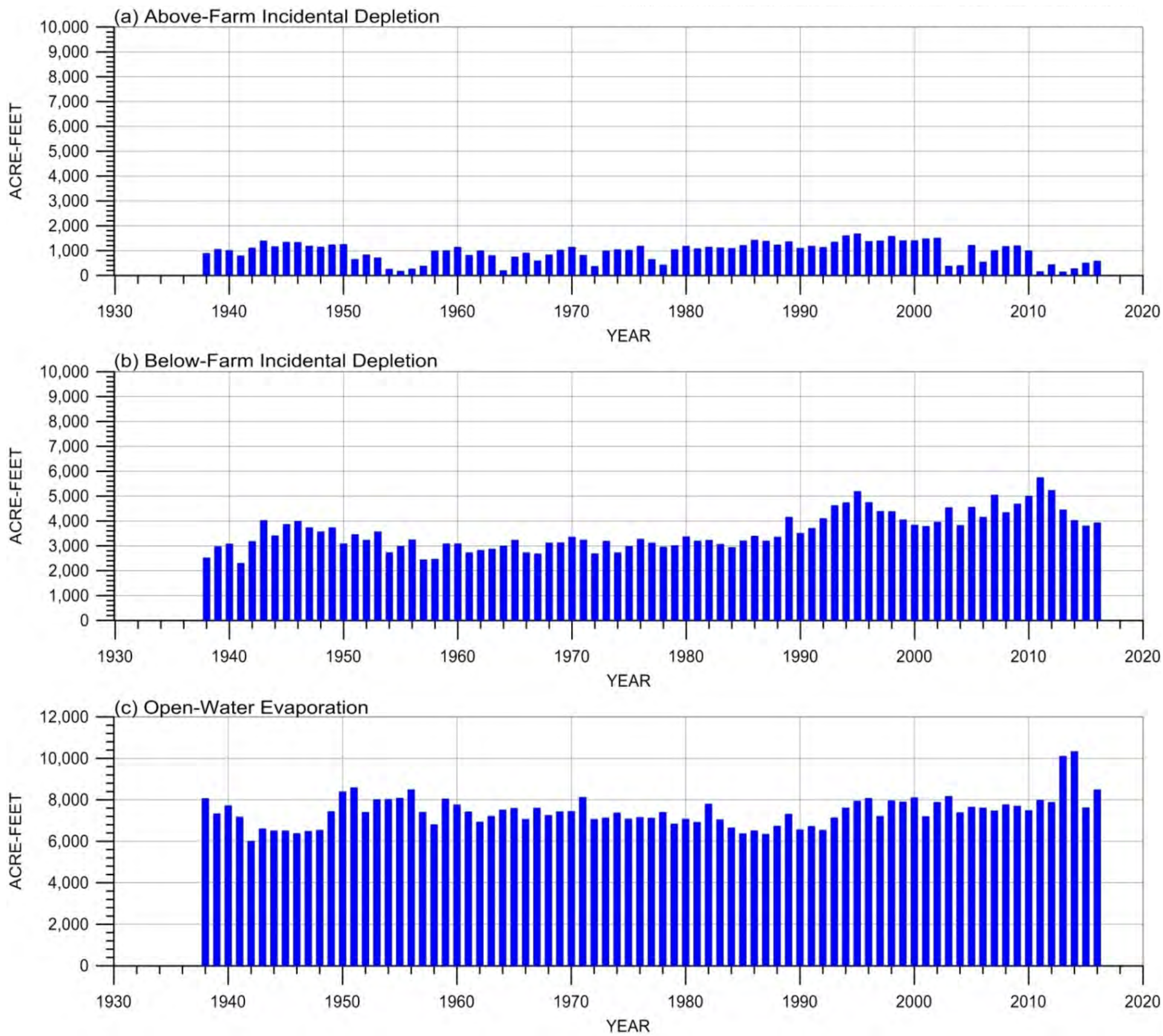

Figure 3.9. Estimated Annual Surface Water Losses in Rincon Valley

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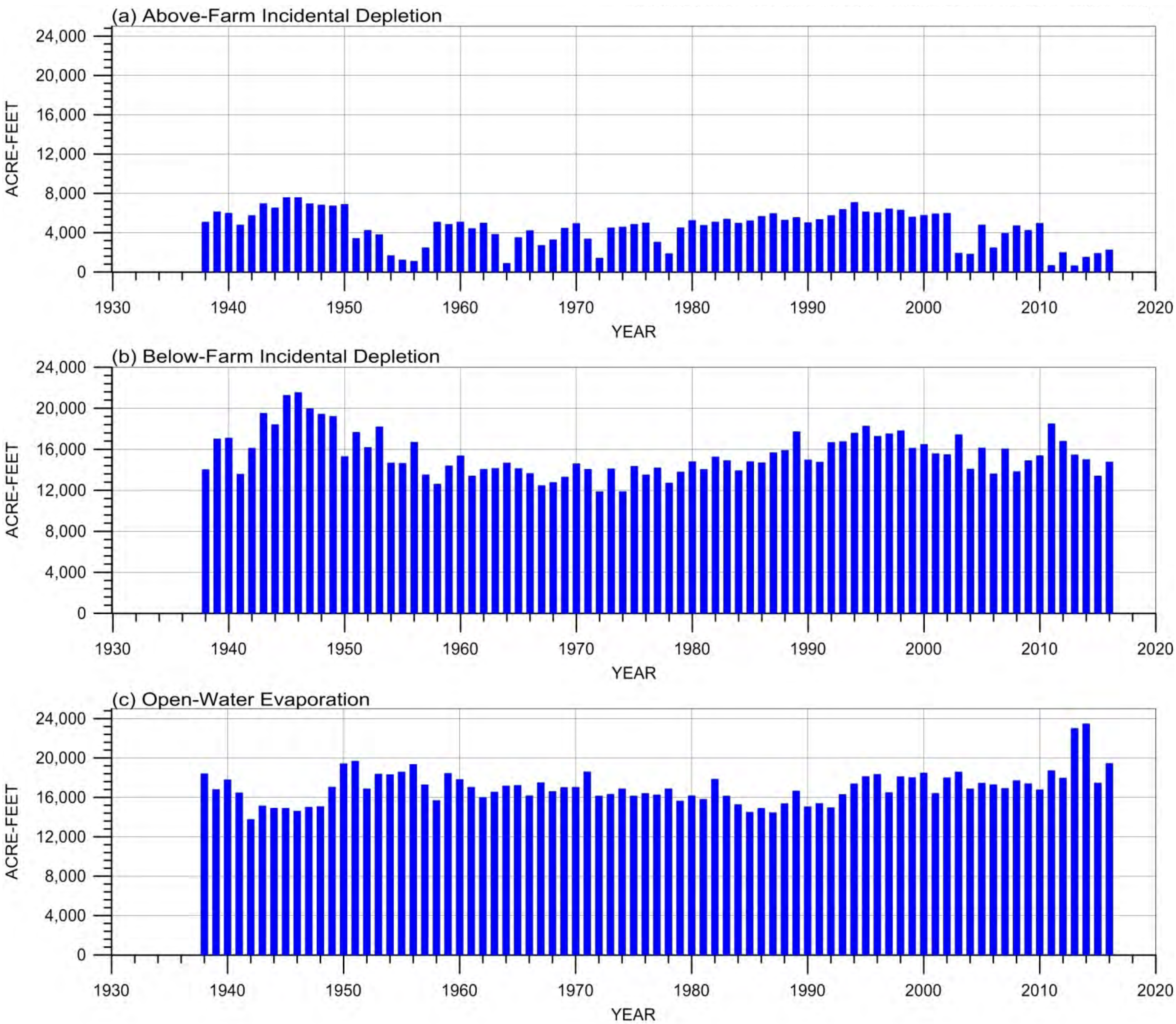

Figure 3.10. Estimated Annual Surface Water Losses in Mesilla Valley

3.3 Surface Water Network Interaction with Groundwater

Monthly exchanges between groundwater and surface water were calculated as the difference between outflows and inflows of the surface water budget, as stated in Equation 36. Estimated annual net groundwater-surface water exchange is shown on **Figure 3.11** for Rincon and Mesilla basins. A positive value of $Q_{GW\text{-}SW}$ reflects monthly net gain to the surface water network from groundwater, whereas a negative value reflects monthly net loss to groundwater from surface water. In Rincon Basin, $Q_{GW\text{-}SW}$ has fluctuated around zero over the study period. In Mesilla Basin, on the other hand, $Q_{GW\text{-}SW}$ has generally fluctuated around annual surface water losses of roughly 50,000 acre-feet per year (AF/year) for almost the entire study period since the 1950s. Prior to 1950, surface water gains occurred at an average rate of approximately 50,000 AF/year. The net loss of groundwater contributions to surface water flows after 1950 coincides with the timing of substantial increase in groundwater withdrawals throughout the study area.

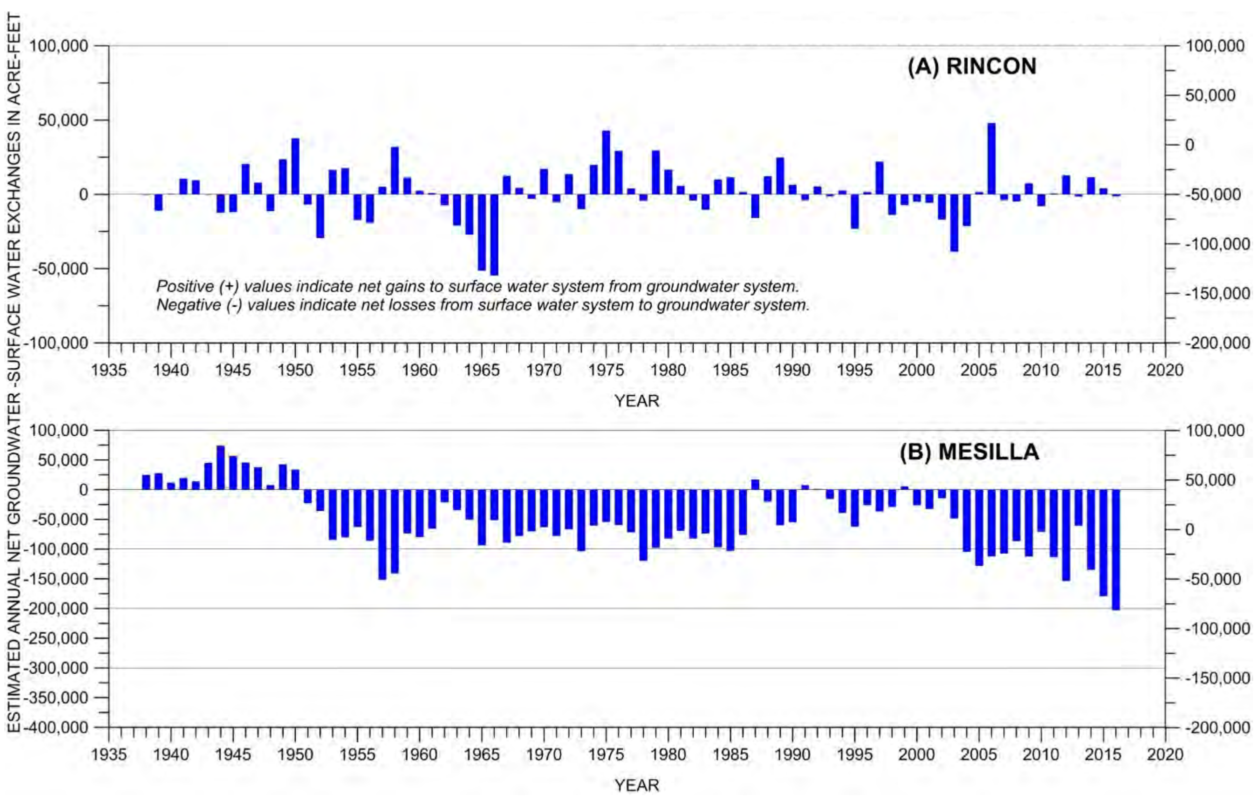

Figure 3.11 Estimated Annual Net Groundwater–Surface Water Exchanges in Rincon and Mesilla Basins

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4 GROUNDWATER BUDGET

When applied to the groundwater budget, Equation (1) becomes:

$$[Q_{GW\text{-}in}] - [Q_{GW\text{-}out}] = \Delta S_{GW} \quad (47)$$

Where,

$Q_{GW\text{-}in}$ is the sum of land-surface inflows;
$Q_{GW\text{-}out}$ is sum of land-surface outflows; and
ΔS_{GW} is change in soil moisture.

All components of the groundwater budget can be derived from available data or the analysis of available data.

Considering all components of the groundwater budget, Equation (47) becomes:

$$[GW_{IB\text{-}in}+MFR+DP_f+DP_{nf}+Q_{GW\text{-}out}] - [GW_{IB\text{-}out}+ET_{rip}+GW_{app\text{-}f}+GW_{app\text{-}nf}+Q_{GW\text{-}in}] = \Delta S_{GW} \quad (48)$$

Where,

$GW_{IB\text{-}in}$ is Interbasin groundwater inflow from adjacent basins;
MFR is natural recharge (mountain-front recharge);
DP_f is deep percolation to groundwater from farm lands (agricultural);
DP_{nf} is deep percolation to groundwater from non-farm lands;
$Q_{GW\text{-}out}$ is surface water outflow to groundwater;
$GW_{IB\text{-}out}$ is Interbasin groundwater outflow to adjacent basins;
ET_{rip} is riparian evapotranspiration (consumptive use by phreatophytes);
$GW_{app\text{-}f}$ is applied groundwater to farm lands (agricultural pumping);
$GW_{app\text{-}nf}$ is applied groundwater to non-farm lands (urban pumping); and
$Q_{GW\text{-}in}$ is groundwater outflows to the surface water network.

When groundwater inflows are not equal to outflows there is a resulting change in the amount of groundwater stored in the aquifer. The change in groundwater storage is evidenced by a change in groundwater surface levels in an unconfined aquifer or a change in piezometric heads in a confined aquifer. Spatial and temporal distribution of available groundwater level data are not adequate for estimating changes in groundwater storage throughout the basin over time; however, all other components of the groundwater budget can be derived from available data or the analysis of available data. Changes in groundwater storage are estimated as the quantity required to close the groundwater budget.

Figure 4.1 provides a graphical depiction of Equation (48).

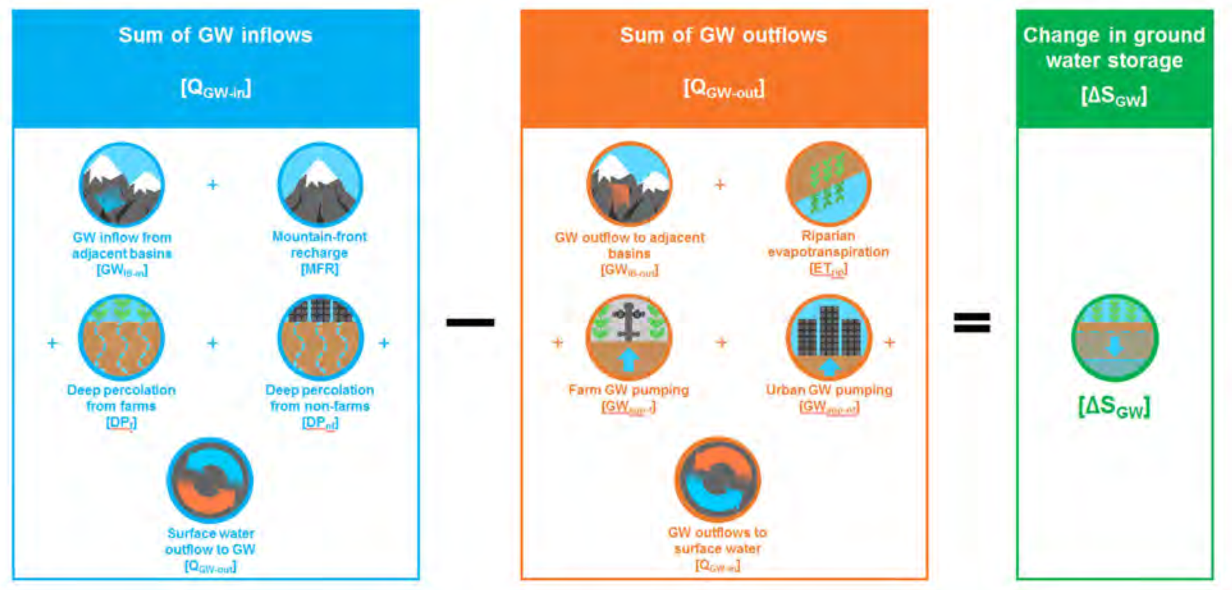

Figure 4.1. Graphical Depiction of Groundwater Budget Equation

The groundwater budget and relationships with the land-water and surface water budgets are shown on **Figure 1.2**. Groundwater pumping is an input to the land-surface water budget.

The monthly, basin-wide groundwater budgets for Rincon and Mesilla basins are summarized in the accompanying dataset named *IntegratedWaterBudgets.xlsx*. Annual groundwater budgets for Rincon Basin and Mesilla Basin are summarized in this chapter of the report and tabulated in **Appendices C1 and C2**.

4.1 Groundwater Inflows

Groundwater inflows to the Rincon and Mesilla groundwater basins include (1) subsurface flow from adjacent groundwater basins, (2) mountain-front recharge, (3) agricultural deep percolation, (4) urban deep percolation, and (5) infiltration from surface water bodies including canals, laterals, and the main-channel Rio Grande. The latter inflow is lumped under a single term representing net groundwater-surface water exchange, as previously described in Section 3.3 of this report, and is included as an outflow component described in Section 4.2. Each of these groundwater inflow components was calculated separately for the Rincon and Mesilla basins.

4.1.1 Interbasin Subsurface Inflows

Groundwater enters Rincon Basin from the adjacent Jornada del Muerto Basin (**Figure 4.2**) through buried basin-fill sediments in vicinity of Rincon Arroyo, located approximately 15 miles

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upriver from Leasburg Dam. Rincon Arroyo underflow is estimated to be 1,500 AF/year, based on groundwater modeling studies of the Jornada basin (Shomaker & Associates, 1996; Kambhammettu and others, 2007). This annual rate was converted to a constant rate of 125 AF/month for the entire Rincon Basin groundwater budget time period. Groundwater enters Rincon Basin as seepage from Caballo Reservoir and Dam at an estimated rate of 1 AF/year based on input files for the SSPA (2007) groundwater flow model.

Underflow to the Mesilla Valley consists of groundwater flow from the adjacent Jornada del Muerto Basin through buried basin-fill sediments and as flow through relatively shallow, saturated alluvium from Selden Canyon (**Figure 4.2**). Underflow from the Jornada Basin is estimated to be less than 850 AF/year by Hawley and Kennedy (2004), and underflow from Selden Canyon is estimated to be 10 AF/year based on simulation results from the NMOSE administrative groundwater model (SSPA, 2008). Total underflow into the Mesilla Basin is estimated to be 860 AF/year. This annual rate was converted to a constant rate of 72 AF/month for the entire Mesilla Basin groundwater budget time period.

Interbasin subsurface inflows are summarized in **Table 4.1**.

Table 4.1. Summary of Interbasin Flows in Rincon and Mesilla Basins

<table>
<tr><th colspan="7">INTERBASIN GROUNDWATER INFLOWS AND OUTFLOWS
(acre-feet)</th></tr>
<tr><th colspan="3">Rincon Basin</th><th colspan="4">Mesilla Basin</th></tr>
<tr><th colspan="2">Inflow</th><th>Outflow</th><th colspan="2">Inflow</th><th colspan="2">Outflow</th></tr>
<tr><th>From Jornada del Muerto Basin via Rincon Arroyo</th><th>From Caballo Reservoir</th><th>To Mesilla Basin via Seldon Canyon</th><th>From Jornada del Muerto Basin via East of Las Cruces</th><th>From Rincon Basin via Seldon Canyon</th><th>To Hueco Bolson via Fillmore Pass</th><th>To Hueco Bolson via The Narrows</th></tr>
<tr><td>1500</td><td>1</td><td>10</td><td>860</td><td>10</td><td>1000</td><td>50</td></tr>
</table>

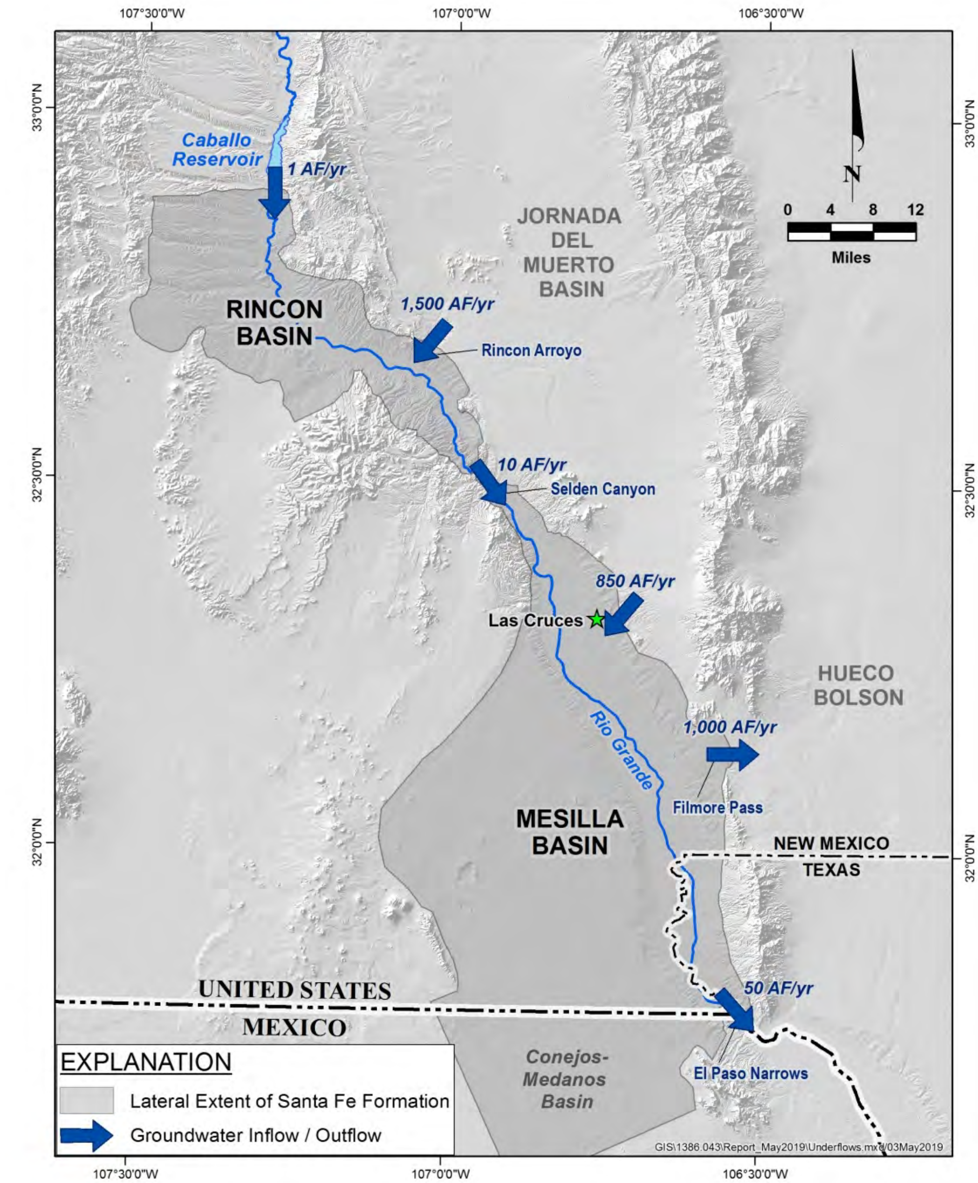


Figure 4.2. Locations of Interbasin Groundwater Flows in Rincon and Mesilla Basins

4.1.2 Agricultural Deep Percolation

Agricultural deep percolation inflows for Rincon and Mesilla basins were estimated as previously described in Section 2.1.3 of this report. Agricultural deep percolation outflows from the land-surface water budgets are inflows to the groundwater budgets.

4.1.3 Urban Deep Percolation

Urban (non-farm) deep percolation inflows for Rincon and Mesilla basins were estimated as previously described in Section 2.2.2 of this report. Urban deep percolation outflows from the land-surface water budgets are inflows to the groundwater budgets.

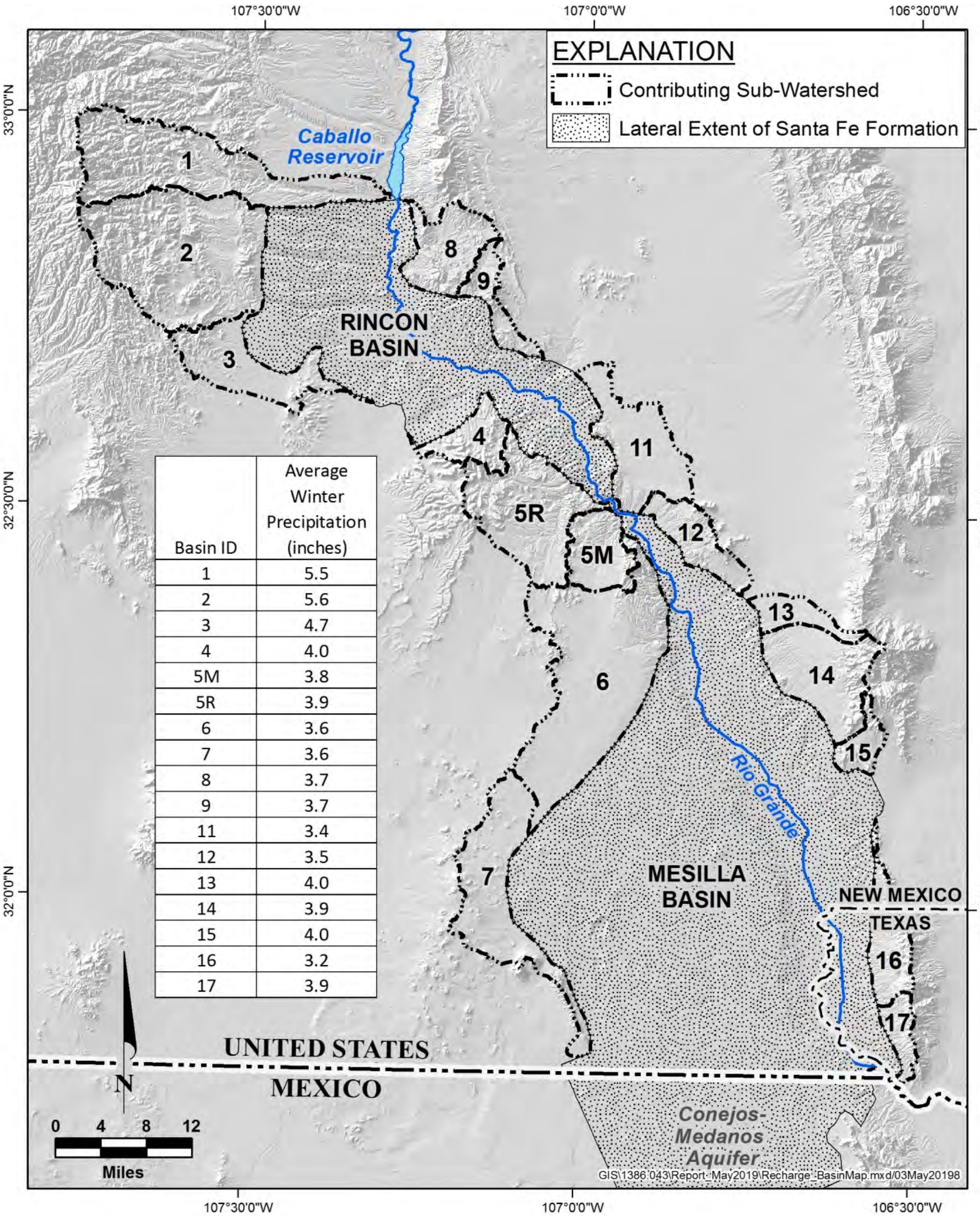
4.1.4 Natural Aquifer Recharge

Natural aquifer recharge in the Rincon and Mesilla Basins principally occurs as mountain-front recharge along the basin margins near the lateral extent of the Santa Fe Formation. Recharge occurs where runoff from precipitation in the upper portions of the watershed infiltrates into the basin alluvium deposits. Mountain-front recharge in the United States portions of the study area was evaluated using the Hearne-Dewey (1988) regression equation for mean annual recharge of a tributary basin. The Hearne-Dewey regression equation was developed, based on data for 16 basins in northern New Mexico, to estimate average annual basin water yield based on winter precipitation, basin slope, and basin area. The method assumes that recharge occurs solely along ephemeral streams in response to snow melt and local rainfall events. Recharge is estimated using the following equation:

$$Q = (1.074 \times 10^{-5})\, A^{1.216}\, P^{2.749}\, S^{0.535} \qquad (49)$$

Where,
Q is mean annual recharge;
A is area of drainage basin;
P is mean winter precipitation; and
S is slope of basin.

The inputs to the regression equation are mean winter precipitation, basin area, and basin slope. Tributary sub-watersheds that contribute to mountain-front recharge were defined based on the intersection of USGS Watershed Boundary Dataset HU-10 with the lateral extent of the Santa Fe formation. **Figure 4.3** shows the spatial extent of the contributing sub-watersheds for the Rincon and Mesilla basins.



Basin ID	Average Winter Precipitation (inches)
1	5.5
2	5.6
3	4.7
4	4.0
5M	3.8
5R	3.9
6	3.6
7	3.6
8	3.7
9	3.7
11	3.4
12	3.5
13	4.0
14	3.9
15	4.0
16	3.2
17	3.9

Figure 4.3. Sub-Watersheds Contributing to Mountain-Front Recharge in Rincon and Mesilla Basins North of the International Border with Mexico

Winter precipitation was determined on the basis of historical precipitation surfaces included in the PRISM dataset, previously described in Section 2.1.1 of this report. Winter precipitation was defined as the months October through April, as was done in the original study of Hearne and Dewey (1988). Precipitation data for each contributing sub-watershed were extracted from the nation-wide PRISM dataset. Winter precipitation data were compiled for each year from 1895 through 2010 and used to determine an average winter precipitation value for each contributing sub-watershed (**Figure 4.3**).

The original study of Hearne and Dewey (1988) defines the basin slope by two points along the main stream channel, 10 percent and 85 percent from the lowest point on the channel. A stream order analysis was undertaken within each contributing watershed to identify the main stream channel. Points along the main channel located 10 percent and 85 percent of the total channel length from the basin outlet were then calculated for each contributing watershed, and the channel slope between these two points was calculated.

The Hearne-Dewey (1988) regression analysis yielded mountain-front recharge rates of about 9,360 AF/year and 5,430 AF/year for the Rincon and Mesilla basins respectively. These estimates are compared against previously published estimates of mountain-front and mountain-slope recharge rates in the Rincon and Mesilla Basins in **Table 4.2**, and are generally comparable to those previously estimates. The annual rates determined in this analysis were converted to constant rates of 780 AF/month and about 450 AF/month for the groundwater budgets for the Rincon and Mesilla basins, respectively.

Table 4.2. Comparison of Mountain-Front and Mountain-Slope Recharge Estimates

Rincon Basin	Mesilla Basin	Rincon and Mesilla Basins, Total	Source
9,360	3,440	12,800	This study (M&A 2017)
9,880[a]	5,390[a]	15,270[a]	SSPA, 2008
4,540[a]	12,970[a]	17,510[a]	Weeden and Maddock (1999)
NR	NR	10,830[a]	Frenzel and Kahler (1992)
23,910	4,350	28,260	Wilkins (1996)

Mountain-front and mountain-slope recharge rates in acre-feet per year
NR: Not reported
[a] Rates used in groundwater flow model

Mountain-front recharge occurring in the Conejos-Medanos Basin, Mexico, is estimated to be 2,000 AF/year, based on a previous study by CH2MHILL (2013). This annual rate was converted to a constant rate of about 167 AF/month for the Mesilla Basin groundwater budget.

4.2 Groundwater Outflows

Discharge or outflow from the Rincon and Mesilla groundwater basins occurs via: (1) subsurface flow into adjacent groundwater basins (Interbasin outflows), (2) agricultural groundwater pumping, (3) urban groundwater pumping, (4) evapotranspiration (ET) from phreatophytes (riparian vegetation), and (5) groundwater flow into gaining reaches of streams and drains. Groundwater outflows to surface water are lumped under a single term representing net groundwater-surface water exchange. Each of these groundwater outflow components was determined separately for the Rincon and Mesilla basins.

4.2.1 Interbasin Subsurface Outflow

Groundwater underflow from the Rincon Basin occurs as discharge through relatively shallow, saturated river alluvium in Selden Canyon. Underflow through Selden Canyon from Rincon Basin into Mesilla Basin is estimated to be 10 AF/yr, based on simulation output from the NMOSE administrative groundwater model (SSPA, 2007). This annual rate was converted to a constant rate of 0.8 AF/month for the Mesilla Basin groundwater budget.

Groundwater underflow from the Mesilla Basin occurs as discharge to the adjacent Hueco Bolson at Fillmore Pass, and in the saturated river alluvium at the El Paso Narrows (**Figure 4.2**). Underflow at Fillmore Pass is estimated to be 1,000 AF/year, based on groundwater model simulations by Montgomery & Associates (M&A) (2016) for Hueco Bolson. Underflow at the ElPaso Narrows is estimated to be 50 AF/year, based on field studies reported by Slichter (1905). Total underflow from the Mesilla Basin into adjacent basins is estimated to be 1,050 AF/year. This annual rate was converted to a constant rate of about 88 AF/month for the Mesilla Basin groundwater budget.

Interbasin subsurface outflows are summarized in **Table 4.1**.

4.2.2 Agricultural Groundwater Pumping

Irrigation groundwater pumping rates in the Rincon and Mesilla basins were estimated as described in Section 2.1 of this report.

4.2.3 Urban Groundwater Pumping

Urban groundwater pumping in the basins includes three categories of water uses: (1) municipal and industrial (M&I), (2) domestic, and (3) stock. M&I pumping was further partitioned into pumping corresponding to large municipalities, including Las Cruces, Santa Teresa, El Paso (Canutillo wellfield), and the wellfield serving Ciudad Juarez located in the Conejos-Medanos aquifer in the southern portions of the Mesilla Basin. Annual groundwater withdrawals for M&I uses are summarized in **Table 4.3**.

Table 4.3. Summary of Estimated Annual Municipal and Industrial Groundwater Pumping in Rincon and Mesilla Basins

YEAR	M&I GROUNDWATER PUMPING[a] (acre-feet/year)								
	NEW MEXICO							TEXAS	CHIHUAHUA, MEXICO
	Mesilla Basin				Rincon Basin			Mesilla Basin	Mesilla Basin
	Las Cruces, NM	Anthony and La Tuna, NM	SunlandPark, Santa Teresa, and El Paso Electric, NM	Rural M&I (Mesilla)	Salem and Garfield, NM	Rural M&I (Rincon)	Total New Mexico M&I	El Paso, TX (Canutillo wellfield)	Ciudad Juarez (Conejos-Medanos wellfield)
1938	0	0	0	96	0	0	96	0	0
1939	0	0	0	96	0	0	96	0	0
1940	296	0	0	97	0	39	431	0	0
1941	525	0	0	101	0	39	665	0	0
1942	845	0	0	109	0	39	992	0	0
1943	876	0	0	109	0	39	1,023	0	0
1944	876	0	0	109	0	39	1,023	0	0
1945	876	257	0	109	0	39	1,280	0	0
1946	876	234	0	109	0	39	1,257	0	0
1947	884	209	0	109	0	39	1,240	0	0
1948	1,475	215	0	109	0	77	1,876	0	0
1949	1,989	194	0	110	0	77	2,370	0	0
1950	2,035	220	0	110	0	77	2,442	0	0
1951	2,107	309	19	110	0	77	2,621	0	0
1952	3,396	384	1,114	110	0	77	5,081	2,435	0
1953	3,545	384	1,151	110	0	77	5,267	5,826	0
1954	4,321	384	1,777	110	0	77	6,669	7,061	0
1955	5,211	507	2,426	110	0	77	8,331	3,648	0
1956	5,315	507	2,492	112	0	81	8,508	9,265	0
1957	5,315	507	2,831	112	0	81	8,846	10,162	0
1958	5,517	510	2,793	112	0	81	9,012	9,550	0
1959	6,791	537	2,525	311	0	81	10,246	13,988	0
1960	6,930	537	2,525	272	0	81	10,346	15,690	0
1961	7,168	534	2,436	363	0	81	10,583	16,133	0
1962	7,569	541	2,352	286	0	81	10,830	17,076	0
1963	7,689	595	2,346	466	0	81	11,178	22,782	0
1964	7,764	576	2,338	350	0	81	11,110	22,188	0
1965	8,583	2,342	2,151	557	0	81	13,716	20,530	0
1966	8,030	1,902	1,996	302	0	81	12,311	19,290	0
1967	7,863	2,887	2,027	319	0	81	13,178	24,276	0
1968	7,701	2,693	2,060	331	0	81	12,866	16,147	0
1969	8,302	2,214	2,095	358	0	81	13,050	14,197	0
1970	8,560	2,650	2,105	419	0	81	13,815	19,370	0
1971	8,558	2,412	2,105	624	0	120	13,818	25,291	0
1972	8,578	2,225	2,473	597	0	120	13,993	23,626	0
1973	8,852	2,223	4,646	641	0	120	16,483	19,940	0
1974	9,343	1,839	5,235	645	0	120	17,181	17,596	0
1975	9,432	1,579	5,273	734	0	120	17,138	19,132	0
1976	9,434	1,525	5,427	808	0	142	17,336	18,011	0
1977	11,494	2,764	5,281	1,115	0	153	20,806	25,258	0
1978	11,718	1,234	5,152	1,292	0	173	19,569	26,821	0
1979	11,732	1,067	4,970	1,229	0	180	19,178	22,276	0
1980	11,899	1,479	4,196	1,438	0	255	19,267	20,917	0
1981	11,690	1,170	4,206	1,652	0	251	18,969	18,221	0
1982	14,173	400	4,211	1,726	0	291	20,802	19,743	0

YEAR	M&I GROUNDWATER PUMPING[a] (acre-feet/year)								
	NEW MEXICO							TEXAS	CHIHUAHUA, MEXICO
	Mesilla Basin				Rincon Basin			Mesilla Basin	Mesilla Basin
	Las Cruces, NM	Anthony and La Tuna, NM	SunlandPark, Santa Teresa, and El Paso Electric, NM	Rural M&I (Mesilla)	Salem and Garfield, NM	Rural M&I (Rincon)	Total New Mexico M&I	El Paso, TX (Canutillo wellfield)	Ciudad Juarez (Conejos-Medanos wellfield)
1983	16,263	217	4,211	1,975	0	319	22,985	18,298	0
1984	15,480	230	3,041	2,291	0	352	21,394	17,979	0
1985	15,928	502	3,119	2,542	0	387	22,478	16,660	0
1986	19,333	467	2,800	2,871	0	350	25,821	15,822	0
1987	17,011	510	3,087	3,043	0	320	23,972	17,894	0
1988	16,702	499	3,307	3,169	0	313	23,988	18,338	0
1989	19,555	660	3,524	3,452	0	309	27,499	20,841	0
1990	19,243	616	4,160	5,783	173	646	30,621	16,920	0
1991	17,618	776	4,561	5,986	188	618	29,746	15,024	0
1992	18,535	1,211	4,721	6,444	182	644	31,738	12,956	0
1993	19,488	1,452	6,714	7,175	195	763	35,787	15,477	0
1994	19,770	1,659	6,813	7,734	215	746	36,938	20,526	0
1995	20,869	1,882	6,368	8,080	185	840	38,224	23,605	0
1996	21,203	1,799	6,584	8,649	235	952	39,423	26,019	0
1997	21,368	1,760	6,886	8,552	283	925	39,773	22,772	0
1998	21,528	1,783	8,666	8,658	248	841	41,725	24,509	0
1999	22,027	1,655	6,855	8,393	237	874	40,040	22,136	0
2000	24,375	2,239	7,442	10,148	256	1,042	45,503	24,683	0
2001	22,659	2,777	8,114	9,563	252	1,098	44,463	23,272	0
2002	22,301	2,896	7,567	9,911	266	1,241	44,183	22,592	0
2003	22,223	2,563	7,383	9,725	313	1,358	43,566	25,064	0
2004	26,318	2,642	6,421	9,521	314	471	45,688	22,224	0
2005	24,975	2,193	6,626	9,679	239	306	44,018	20,901	0
2006	25,147	2,475	5,050	10,934	205	323	44,134	24,490	0
2007	25,657	2,304	3,914	10,793	222	273	43,163	21,170	0
2008	26,135	2,158	5,599	11,101	142	216	45,352	22,461	0
2009	21,584	2,183	5,486	9,812	294	248	39,607	24,376	0
2010	22,516	2,278	6,975	9,724	290	431	42,214	22,593	12,979
2011	23,878	2,355	8,295	10,447	337	361	45,674	23,937	27,401
2012	22,124	2,210	8,122	10,136	324	378	43,294	23,035	27,401
2013	20,656	2,165	6,034	8,808	289	650	38,602	22,404	27,401
2014	20,855	2,260	6,831	8,288	282	775	39,291	22,573	27,401
2015	21,082	2,220	6,013	7,709	310	793	38,127	21,636	27,401
2016	21,022	2,153	6,166	7,863	324	751	38,279	20,009	27,401

[a] M&I = Municipal and Industrial water use

Information for water production wells located in New Mexico was obtained from records for points of diversion available from the online New Mexico Water Rights Reporting System (NMWRRS) (NMOSE, 2015), which links to New Mexico's Water Administration Technical Engineering Resource System (WATERS) database. The WATERS database includes information on well location, water use, well construction details, pump yield, metered pumping data, and water right information. Individual wells were considered and evaluated for this water budget analysis. Basin-wide pumping was determined by summing pumping rates for individual wells located within each basin and for each water use category. If location coordinates were not specifically reported for a well, then the well was assumed to be located at the center of its reported cadastral location. Wells without reported location coordinates or cadastral location were assumed to not exist and were not included in this analysis.

Information for water production wells in Texas was obtained from the Texas Water Development Board's (TWDB) online Groundwater Database (GWDB) (TWDB, 2015). The Groundwater Database contains information for well construction, water use, depth to water, and estimated pumping rates. Information for water production wells in Mexico includes location, approximate extraction rates, and water use, as reported by the IBWC (2011).

Reported well installation information indicates that relatively few wells existed in the study area prior to 1950 and most were registered as domestic wells. **Figures 4.4 and 4.5** show reported cumulative annual well installation histories by water use for registered water supply wells in New Mexico and Texas, respectively. Wells installations in New Mexico steadily increased from 1950 through the 1970s. After the 1970s, well installation rates increased again through about 2016. The majority of wells installed during the 1980s and 1990s were domestic wells; however, the number of M&I well installations increased as well. An increase in the rate of installation of irrigation wells occurred in the mid-2000's (**Figure 4.4**). M&I wells have been the dominant well type in the Texas portions of Mesilla Basin (**Figure 4.5**). However, irrigation well installations increased in the mid-2000. By 2015, more than 11,500 registered water supply wells (approximately 7,400 urban and 4,100 irrigation) were installed in both basins in the study area. However, these counts do not reflect the total number of potentially active water supply wells. Well installation dates are not reported in the state databases for more than 3,500 wells in New Mexico portions of the study area and 17 wells in Texas portions. Spatial distributions of production wells in 1938 (before Compact) and in 2014 are shown on **Figures 4.6 and 4.7**. The spatial locations of wells are not utilized for the water budgets; instead, well locations are used as inputs to the numerical groundwater flow model developed by William R. Hutchison.

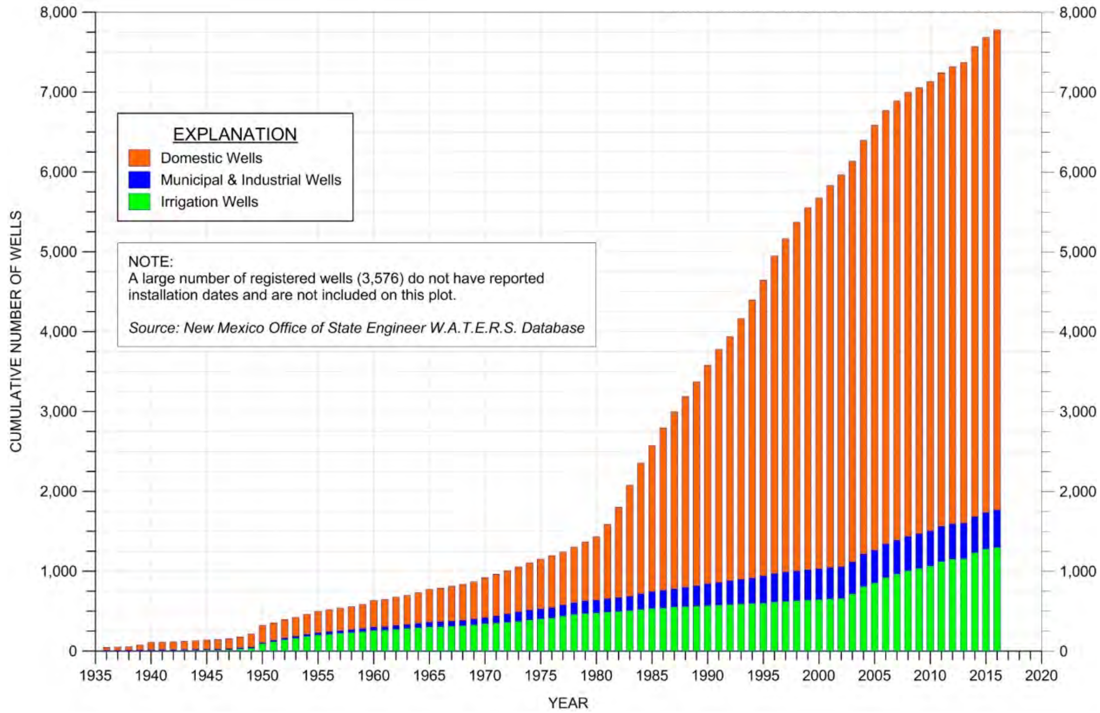


Figure 4.4 Cumulative Reported New Mexico Well Installation History in Rincon and Mesilla Basins

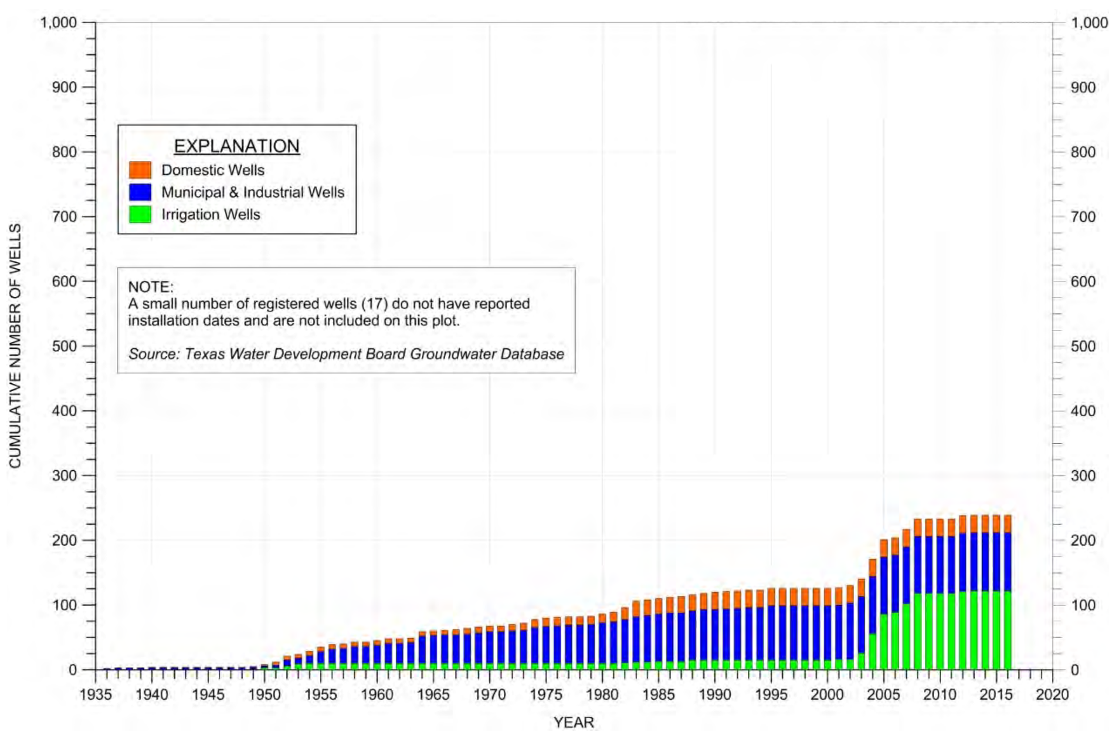


Figure 4.5. Cumulative Reported Texas Well Installation History in Mesilla Basin

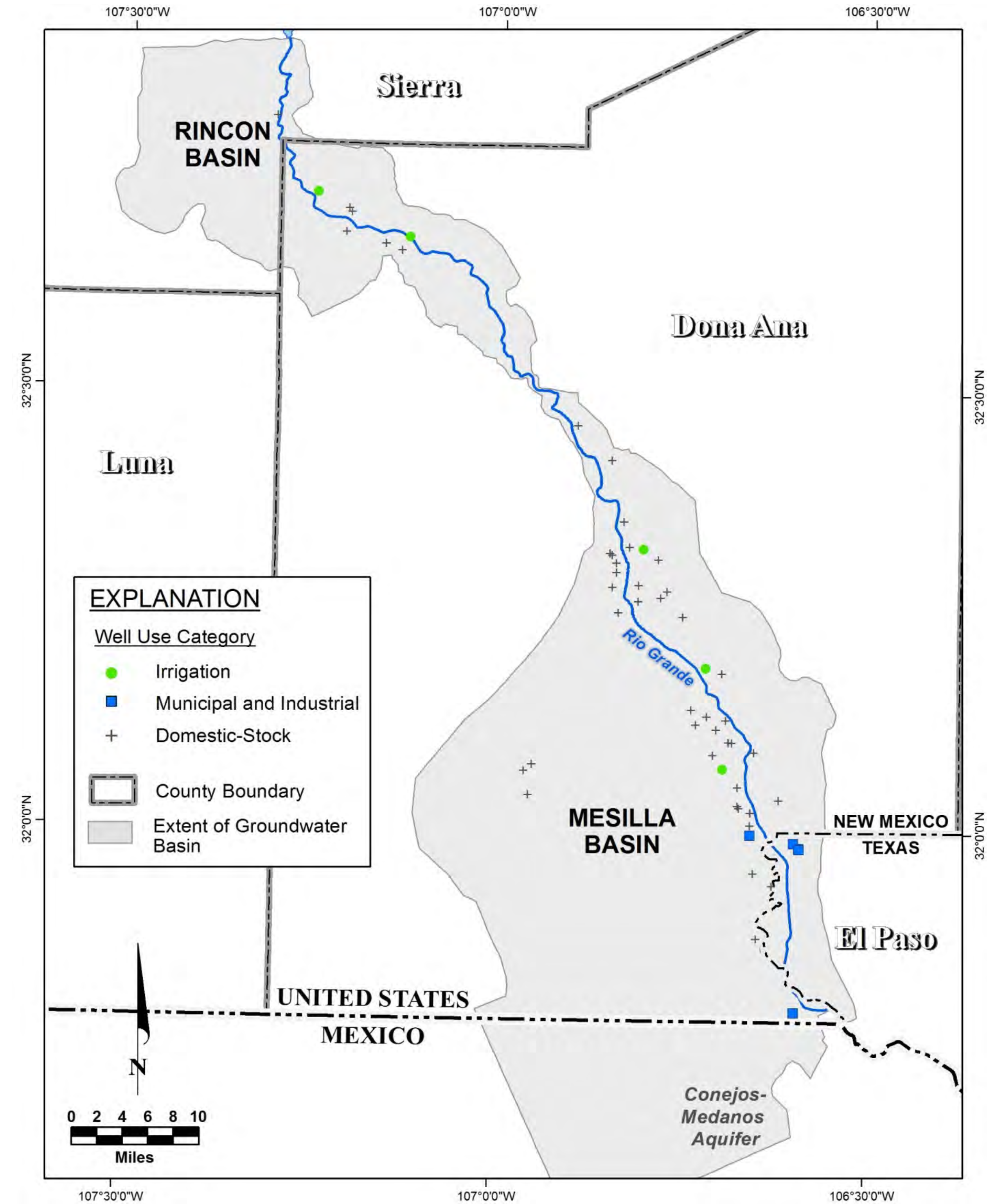


Figure 4.6. Location of Reported Wells in Rincon and Mesilla Basin: 1938

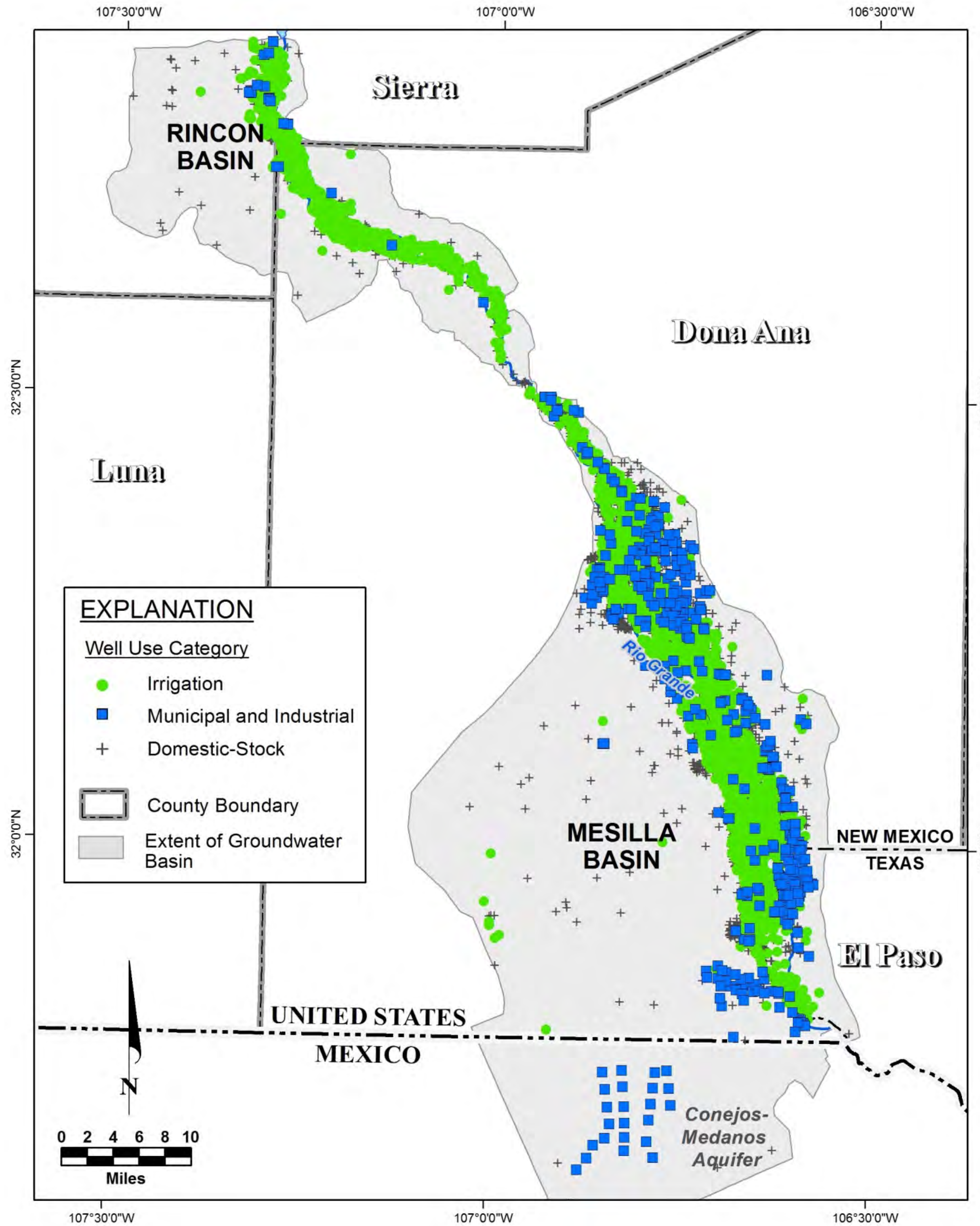


Figure 4.7. Location of Reported Wells in Rincon and Mesilla Basin: 2016

Estimated total historic annual urban groundwater pumping in the study area occurred predominantly in Mesilla Basin and has substantially increased through time since the 1950s. Pumping estimates for each urban water use category (M&I, domestic, and stock) is described in the following sections of this report. Cumulative annual estimated groundwater withdrawals by water use are shown on **Figure 4.8**. The majority of groundwater pumped from the basin aquifers is used for irrigation purposes. M&I groundwater use increased through time as urban areas grew in the basins. Although there are large numbers of domestic wells in the basins, collectively they account for a very small portion of overall estimated groundwater withdrawals. The well registries do not always record when wells are no longer active or were destroyed. It is possible that some wells, especially domestic wells, are no longer used because households connected to municipal water supplies.

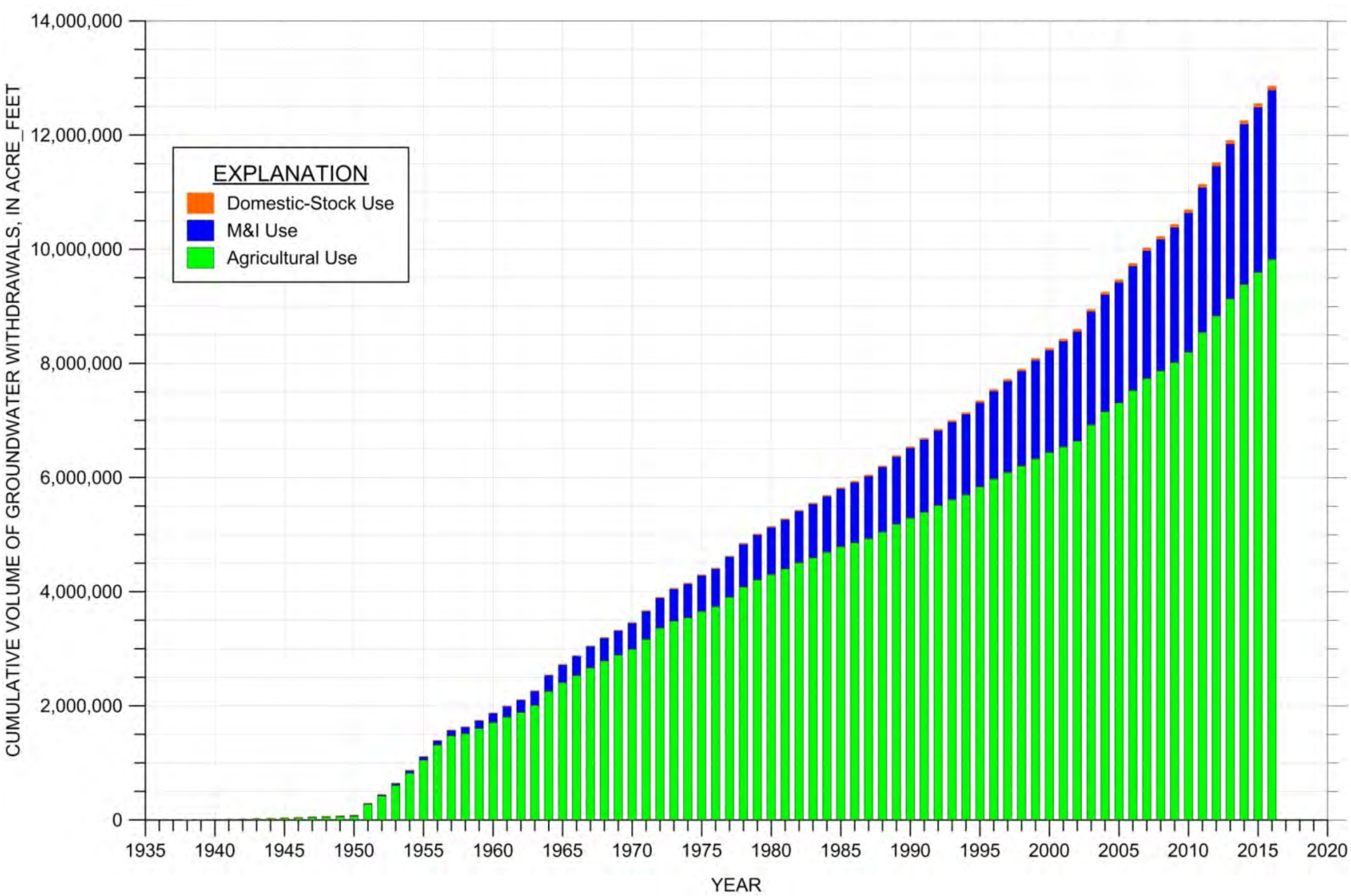


Figure 4.8. Cumulative Estimated groundwater Withdrawals in Rincon and Mesilla Basins in New Mexico, Texas, and Mexico

4.2.3.1 Municipal and Industrial Pumping

The principal sources of information used to develop basin-wide M&I pumping estimates for the water budgets are (1) metered pumping data obtained from the online New Mexico Water Rights Reporting System (NMWRRS), which links to New Mexico's Water Administration Technical Engineering Resource System (WATERS) database, (2) pumping datasets obtained from El Paso Water Utilities for the Canutillo wellfield, and (3) input datasets for the numerical groundwater flow model developed for the New Mexico Office of State Engineer (NMOSE) by S.S. Papadopulos & Associates (SSPA) (2007). For periods when primary source data were not available, pumping estimates were made using available data, as described in subsequent portions of this section.

Information on well location, drill date, and water use was obtained from well records available for active points of diversion from the online NMWRRS and TWDB GWDB. This information was used for (1) determining whether a well is located in Rincon or Mesilla basin, (2) assigning a well to a water use category, and (3) assigning a pumping start date to a well. Wells with no reported drill dates were assumed to be active and were evenly distributed over the study period. Basin-wide pumping was determined by summing pumping rates for individual wells located within each basin. **Figure 4.9** shows the locations of municipal and industrial water supply wells in the study area. The vast majority of M&I wells in the study area are located within Mesilla Basin along the Rio Grande corridor. Estimated historic groundwater pumping by water use sector in Rincon and Mesilla basins is shown on **Figures 4.10 and 4.11**, respectively.

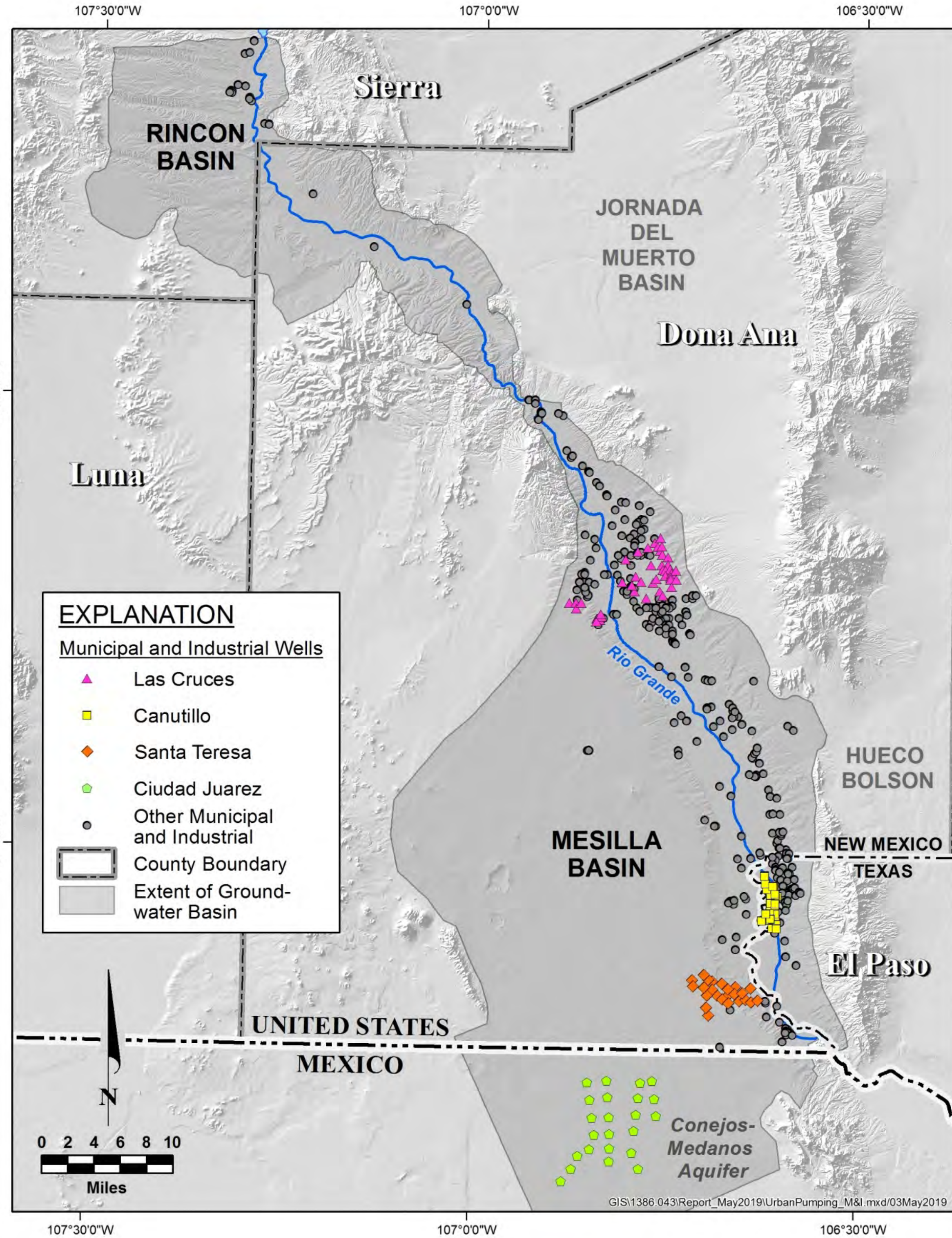


Figure 4.9. Locations of Municipal and Industrial Water Supply Wells In Rincon and Mesilla Basins

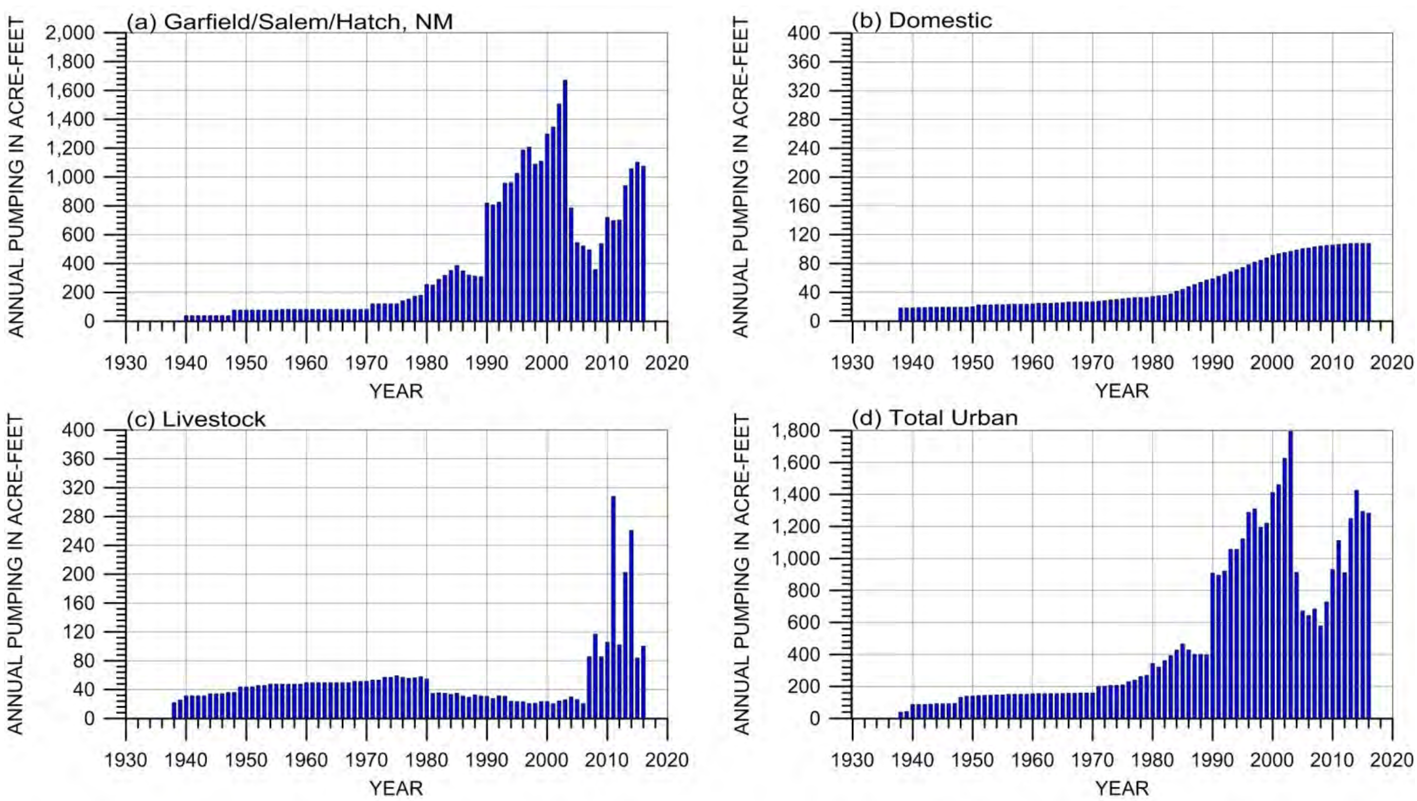


Figure 4.10. Estimated Historic Annual Urban Groundwater Withdrawals by Water Supply Wells in Rincon Basin

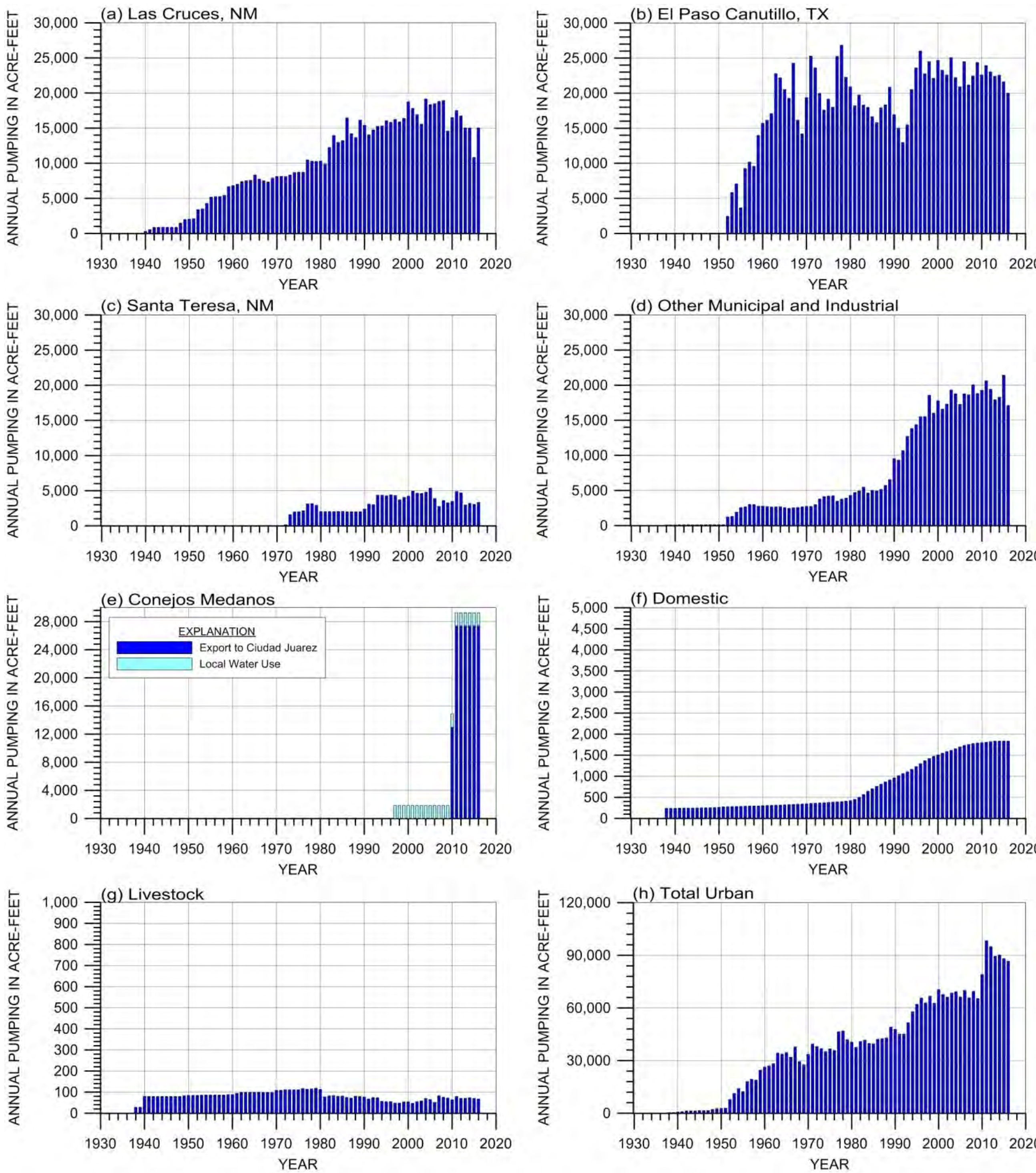


Figure 4.11. Estimated Historic Annual Urban Groundwater Withdrawals by Water Supply Wells in Mesilla Basin

The SSPA (2007) groundwater flow model of the Lower Rio Grande Basin is based on primary data sources on urban groundwater pumping that were unavailable for this investigation. The procedures for determining urban groundwater pumping rates for the SSPA model were reviewed and were determined to be satisfactory for the objective of this analysis. Furthermore, the well input datasets for the model are consistent with available water rights information, as well as regional trends and projections of water use in the basins reported by Terracon and others (2004) and Shomaker & Associates (2008). The SSPA model files for well pumping includes annotation that describes the owner and use of the simulated wells. The SSPA model urban pumping dataset is considered to be a reliable data source for this water budget analysis.

Groundwater pumping information is available for January 1940 through February 2004 from the SSPA (2007) model. It was therefore necessary to extend the period of record on groundwater pumping from 1938 through 2016 for this water budget analysis. This was done individually by well type using a variety of data sources to check estimated values. Non-irrigation well categories specified in the SSPA model include public supply (Las Cruces, Canutillo, and Santa Teresa), New Mexico Municipal and Industrial (NM M&I), Texas Municipal and Industrial (TX M&I), New Mexico Domestic, Sanitary, and Stock, as well as Texas Domestic, Sanitary and Stock. These well types, except domestic and stock, are grouped into the M&I pumping category. Public supply and NM M&I uses constitute the majority of urban groundwater pumping in the basins.

In 2004, the NMOSE imposed metering requirements on wells in the Lower Rio Grande (LRG) Water Master District, which includes the Rincon and Mesilla basins. Meters are required for all wells in the New Mexico portions of the basins, except single-family domestic wells and livestock wells. According to the 2007 LRG Water Master Report, by 2007, about 86 percent of wells were in compliance with the metering requirements (Dorman, 2008). The metering requirements also include reporting monthly data on a quarterly basis. The metered pumping datasets include dates and totalizer readings, which allows for monthly or annual pumping volumes to be estimated. Prior to 2004, if metered data were not available for a particular well, then an annual pumping rate was obtained from the SSPA model for the well. Monthly pumping rates were determined by applying a monthly distribution factor to annual rates. Monthly distribution factors were determined for each well based on available metered data associated with the well; or, if metered data were not available for a well, then an average distribution was applied based on metered data for other wells.

Las Cruces

Las Cruces, New Mexico municipal groundwater pumping data were compiled from a variety of sources. Monthly pumping data for January 1940 through February 2004 were obtained from pumping input datasets for the SSPA (2007) groundwater model. The SSPA model input files are annotated with well identifiers, which were used to match model wells to registered wells from the New Mexico and Texas well databases. Las Cruces production wells in the study area have state registration identifiers starting with “LRG 430”. The pumping time-series data in the model input files were compared to reported drill dates for the individual wells. In some cases, pumping in the SSPA model is assigned to wells before the reported drill dates. In these cases, any pumping rates that were specified before the reported drill date for a particular well were equally distributed and added to wells that had already been drilled.

Monthly Las Cruces well pumping for 2004 through 2016 were estimated following a series of steps using several data sources. First, medium-growth demand projections from the City of Las Cruces 40 year water development plan (Shomaker and Associates, 2008) were evaluated against historical pumping trends shown in model input files for the SSPA (2007) groundwater model, and were found to be in good agreement. Second, the demand projections were compared against available Las Cruces well metered pumping data for 2009 through 2013. The metered groundwater diversions are slightly lower than the projections; further investigation revealed that this is due to the absence of metered data for several public supply wells. Based on these comparisons, the demand projections were determined to be reliable.

Las Cruces water demand projections are available at 5-year intervals starting in 2005 (Shomaker and Associates, 2008). Annual demands between projected years were calculated by linear interpolation. Next, the water demand projections had to be adjusted to remove Las Cruces groundwater pumping from the Jornada del Muerto Basin (**Figure 4.9**) so the water budget considers only Las Cruces groundwater pumping in the Mesilla Basin. Las Cruces groundwater diversion metered data for 2010 through 2013 were examined to determine the average proportion of groundwater diversions that occur in the Jornada Basin. From 2010 through 2013, about 12 percent of total Las Cruces annual groundwater pumping occurred in the Jornada Basin. Annual water demand projections were accordingly multiplied by a factor of 0.88 to represent only water demand satisfied by groundwater diversions from the Mesilla Basin.

The final task for determining Las Cruces groundwater pumping was to down-sample from annual to monthly groundwater diversions. This is necessary because water demand varies seasonally in Las Cruces. Seasonal pumping variations specified in the SSPA (2007) groundwater model were investigated. From 1982 through 2004, the ratio of primary irrigation (PI) to secondary irrigation (SI) groundwater diversions was equal to 3.9. This indicates that 3.9 times as much groundwater was pumped during the PI season (March through October) compared to the SI season (November through February). For consistency with historical SSPA model data, this ratio was used to partition yearly pumping between PI and SI periods, with constant monthly pumping rates within the periods. The resulting calculated values were checked to ensure consistency with projected annual groundwater diversions and then used to complete the groundwater diversion record for the City of Las Cruces.

Historic annual groundwater pumping from Las Cruces water production wells is shown on **Figure 4.10a**. Annual groundwater pumping to supply Las Cruces has increased from less than 3,000 AF/year in the 1950s to nearly 20,000 AF/year by 2004. Annual pumping by Las Cruces decreased slightly after 2010.

El Paso Canutillo

The City of El Paso, Texas extends into the Mesilla Basin. El Paso Water Utilities operates the Canutillo wellfield for municipal supply for users in Mesilla Basin (**Figure 4.8**). Canutillo pumping data were obtained from El Paso Water Utilities for this analysis. Monthly pumping volumes were provided for 1967 through 2016 and annual pumping volumes were provided for 1952 through 1966. The annual volumes were disaggregated to monthly volumes using average monthly distribution fractions. The monthly fractions were estimated using the available post-1966 monthly data. The monthly volumes were directly used in this evaluation.

Reported historic annual pumping from El Paso Water Utilities supply wells in the Canutillo wellfield is shown on **Figure 4.9b**. Annual pumping from the wellfield increased through the 1970s before decreasing steadily during the 1980s and early 1990s. Since 1995, Canutillo pumping has been relatively stable with rates ranging from about 21,000 to 26,000 AF/year.

Santa Teresa

Pumping data for water supply wells that serve the city of Santa Teresa, New Mexico are reported in the SSPA (2007) groundwater model by primary and secondary irrigation stress periods from 1972 through 2004. Metered data for Santa Teresa wells are available from 2004 through 2016. Similar to the procedure used for Las Cruces wells, metered data were analyzed to determine the fraction of total annual pumping that occurs during each month. Those monthly fractions were then used to disaggregate pumping rates from the SSPA model from stress period values to monthly values. **Figure 4.11c** shows annual pumping rates summed over all Santa Teresa wells. Annual pumping rates were less than 3,000 AF/year during the 1970s and 1980s, which then increased to nearly 5,000 AF/year during the 1990s. Pumping rates have subsequently declined during recent years.

Other Municipal and Industrial

In addition to M&I groundwater pumping by specific municipal water providers, M&I pumping by other water users, referred herein as “other M&I” pumping, occurs throughout the Rincon and Mesilla basins (**Figure 4.9**). Other M&I wells are predominantly located in the New Mexico portion of the Mesilla basin, and were identified based on reported water right information associated with wells in this category located in New Mexico. Most of the nearly 400 other M&I wells shown on **Figure 4.9** are associated with municipal water use (55 wells) mobile home parks (53 wells), commercial uses (48 wells), community type uses (48 wells), dairy operations (39 wells), subdivisions (37 wells), and several other categories with smaller number of wells.

Pumping rates corresponding to New Mexico wells in this category have been tabulated as input data to the SSPA (2007) groundwater model for the period from 1940 through 2004. Metered data for some of these wells are available from 1990 through 2016. Metered pumping data for wells in this category were analyzed to determine the monthly distribution of total annual groundwater pumping, and the corresponding fractions were used to disaggregate pumping rates reported in SSPA model input data sets to monthly time series. For the period after 2004, metered pumping rates were assigned to each well, where available.

Groundwater pumping for the other M&I wells in Texas was determined based on records from the Texas Water Development Board (TWDB) database and the OSE-SSPA model (SSPA, 2008). For years 1945-1990, groundwater diversions from the NMOSE administrative groundwater flow model WEL package were used. For 1991-1999, 1990 rates were repeated. For years 2000-2012, TWDB groundwater diversion estimates are used, where available; otherwise, reported rates from the WEL package are used. TWDB records provide annual values for groundwater diversion by well; if monthly diversions were available from the WEL package data, then the annual values were used to rescale the average monthly diversion fractions. Otherwise, annual diversions were distributed equally among months of the year, for each well.

Annual pumping from the other M&I wells in Rincon and Mesilla basins is shown on **Figures 4.10a and 4.11d**. Pumping from these wells increased steadily through time before substantially increasing in the 1990s. Annual rates became more stable after the 1990s, with rates varying between about 16,000 and 20,000 AF/year.

Conejos-Medanos

The Conejos-Medanos Aquifer is located in Chihuahua, Mexico and is the southern portion of the Mesilla Basin aquifer system (**Figure 4.9**). Prior to 2010, groundwater withdrawals in the Conejos-Medanos Aquifer were less than 2,000 acre-feet per year, and were associated with relatively small-scale agriculture, small municipalities, livestock, and utilities water uses (SGM, 2011). Monthly groundwater pumping rates reported by SGM (2011) are used in this study. The earliest water right registry in the Mexican Public Registry of Water Rights (REPDA) occurred in 1997; it is therefore assumed that groundwater pumping prior to 1997 as negligible and is not considered in the water budget. **Figure 4.11e** shows annual groundwater pumping rates in the Conejos-Medanos aquifer. It should be noted that some of the groundwater uses depicted in **Figure 4.11e** correspond to agriculture; however, the pumped volumes are estimated differently from the procedure used to estimate irrigation pumping in the Rincon and Mesilla Basins, and therefore are reported as M&I pumping for this analysis.

In 2010, Ciudad Juarez began pumping groundwater from its constructed wellfield in the Conejos-Medanos aquifer for supplemental municipal water supply. Water is conveyed (exported) from the wellfield to Ciudad Juarez, located approximately 15 miles to the east, via the Conejos-Medanos Aqueduct. Municipal pumping rates in Conejos-Medanos was about 13,000 AF/yr in 2010 and approximately 27,400 AF/yr from 2011 through 2014 (SGM, 2011). Pumping rates for 2015 and 2016 are not available for this analysis; thus, pumping rates for these years were assigned to be the same as in 2014. These pumping rates are shown in **Figure 4.11e**. Groundwater pumping for export to Ciudad Juarez is substantially greater than groundwater pumping to supply local water demands.

Total Municipal and Industrial Pumping

The vast majority of M&I groundwater pumping in the study area occurs within Mesilla Basin, as shown on **Figure 4.9**. Annual M&I pumping in Mesilla Basin substantially increased after the early-1950s, and steadily increased through time to approximately 65,000 AF/year by 2000. In 2010, the Ciudad Juarez wellfield in the Conejos-Medanos aquifer in the southern portions of Mesilla Basin began pumping operations, which resulted in a sudden increase in total M&I pumping in Mesilla Basin (**Figure 4.11h**). From 2000 through 2016, M&I pumping rates in the United States portion of Mesilla Basin (not including Conejos Medanos) ranged from about 65,000 to 69,000 AF/year.

4.2.3.2 Domestic Pumping

Basin-wide groundwater withdrawals from domestic wells were calculated by multiplying the number of domestic wells located within the study area, for each month, by a constant pumping rate. Monthly records of domestic wells were developed based on reported drill date for active points of diversion with specified domestic use in the NMOSE WATERS database. Reported well drill dates were then used to determine the number of wells that existed in the study area each month. Total groundwater pumping by domestic wells was then calculated assuming a constant monthly pumping ("diversion") rate of 0.025 AF/month (0.3 AF/year), as was done in a previous study by the NMOSE regarding groundwater withdrawals for domestic use in New Mexico (NMOSE, 2000).

Records for a portion of domestic wells did not contain information on drill date or well casing information. Those wells were excluded from this water budget analysis.

Historic annual domestic pumping in the Rincon and Mesilla basins is shown on **Figures 4.10b and 4.9f**. Annual pumping rates have increased through time, most dramatically after 1980, to a maximum estimate of about 2,000 AF/year by 2013. However, domestic pumping is a relatively small component of the overall groundwater budget.

4.2.3.3 Livestock pumping

Groundwater pumping to supply livestock water consumption was estimated based on beef cattle livestock water consumption estimates from the National Agricultural Statistics Service (USDA, 2013) for years 1975 through 2013, and estimates of per capita (animal unit or head) water consumption by beef cattle published by the NMOSE (Longworth and others, 2008). Per capita water use by livestock prior to 1975 is assumed to be similar to stock water use in 1975. Annual groundwater diversion rate per stock well was calculated as the total stock water use in Doña Ana County, divided by the number of Doña Ana County stock wells recorded in the NMOSE WATERS database. Calculated values of groundwater diversion per well were then multiplied by the number of stock wells located within each basin to yield a monthly a time series of groundwater diversion for livestock. Annual pumping estimates for stock wells in the Rincon and Mesilla basins are shown on **Figures 4.10c and 4.11g**. Livestock pumping is a small component of the overall groundwater budget for the basins with total pumping rates smaller than 200 AF/year. The noticeable decrease in stock pumping in 1980 occurred as a result of a substantial decrease in the number of cattle in the basins at that time (USDA, 2013).

4.2.4 Riparian Consumptive Use

Consumptive use of groundwater by phreatophyte vegetation (riparian evapotranspiration) in the Rincon and Mesilla basins was analyzed by Land IQ for this water budget analysis. Annual riparian consumptive use was estimated for this analysis using evapotranspiration rates reported by Land IQ , annual acreages of riparian vegetation specified in the SSPA (2007) groundwater flow model prepared for the NMOSE for 1938 through 2009, and annual acreages reported by Land IQ from 2010 through 2016. Annual riparian vegetation consumptive use estimates are shown on **Figure 4.12**. Riparian vegetation acreages are shown in **Table 4.4**. The step-wise changes in total vegetation consumptive use rates through time is a result of limited availability of aerial imagery required for estimating riparian vegetation acreages; changes occur at the mid-point between two available images. Estimated annual rates were converted to monthly rates and equally distributed to each month of the respective year. For this analysis, riparian vegetation consumptive use is assumed to be constant throughout the year. Further refinements might account for seasonal differences in riparian consumptive use.

Bare soil evaporation along the Rio Grande is also included in total riparian evapotranspiration. Since riparian soil evaporation depends on a depth to water through time, this water budget relies on preliminary results from the groundwater flow model developed by William Hutchison.

Riparian evapotranspiration for each basin is summarized in Appendix C. Values represent total riparian evapotranspiration (vegetation and soil). Average annual total riparian evapotranspiration is about 10,200 AF in Rincon Basin and about 11,600 AF in Mesilla Basin. Net Groundwater-Surface Water Exchange

Net groundwater-surface water exchanges for Rincon and Mesilla basins were estimated as previously described in Section 3.3 of this report. Exchanges from the surface water budgets are input to the groundwater budgets. A positive value from the surface water budget reflects monthly net loss of groundwater to the surface water network, whereas a negative value reflects monthly net gain in groundwater from surface water.

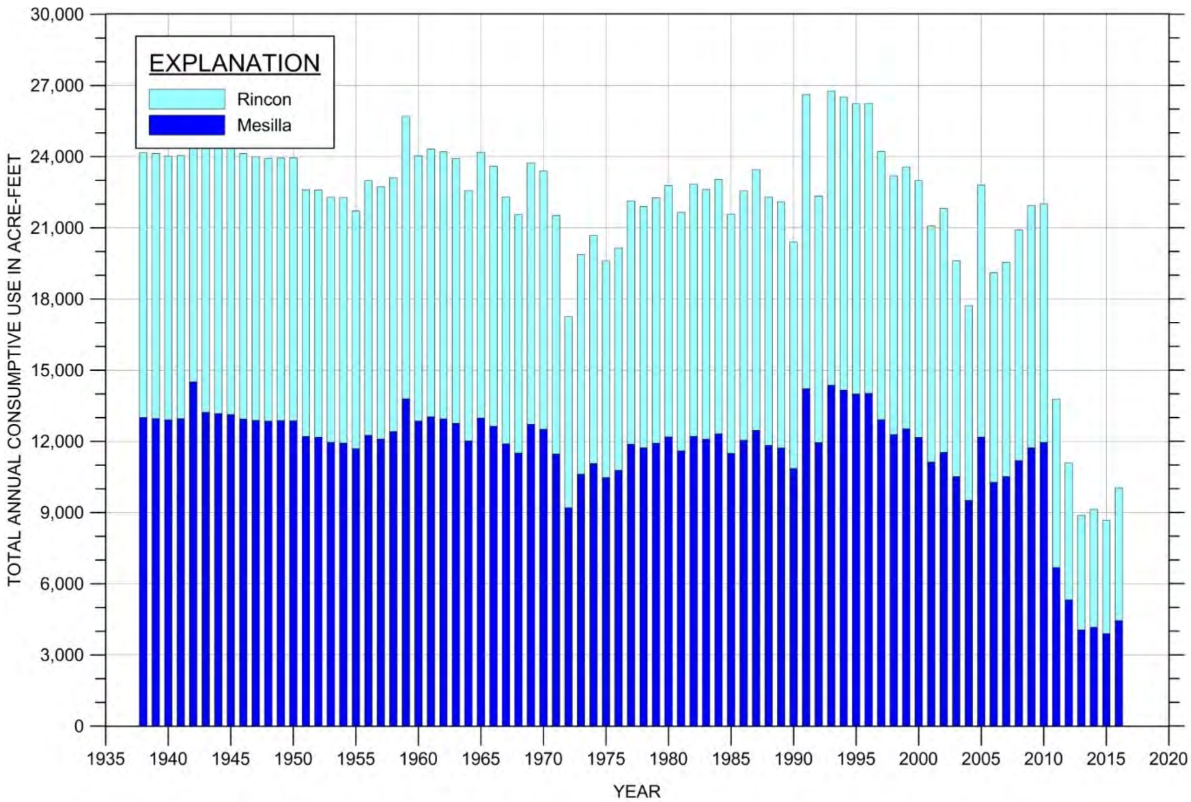


Figure 4.12. Estimated Annual Riparian Consumptive Use in Rincon and Mesilla Basins

Table 4.4. Summary of Riparian Vegetation Acreages in Rincon and Mesilla Basins

	Vegetation Acreage by Plant Group - Rincon (acres)			Vegetation Acreage by Plant Group - Mesilla (acres)										
Year	Riparian Tree	Riparian Shrub	Riparian Herb	Riparian Tree	Riparian Shrub	Riparian Herb	Riparian in Rincon (acres)	Riparian in Mesilla (acres)	Total Area (Acres)	Total Riparian Tree (Acres)	Total Riparian Shrub (Acres)	Total Riparian Herb (Acres)	Total Riparian Vegetation Area (Acres)	Acreage Source
1938	135	686	283	65	443	625	1,104	1,133	15,049	200	1,129	907	2,236	SSPA-1955
1939	135	686	283	65	443	625	1,104	1,133	15,049	200	1,129	907	2,236	SSPA-1955
1940	135	686	283	65	443	625	1,104	1,133	15,049	200	1,129	907	2,236	SSPA-1955
1941	135	686	283	65	443	625	1,104	1,133	15,049	200	1,129	907	2,236	SSPA-1955
1942	135	686	283	65	443	625	1,104	1,133	15,049	200	1,129	907	2,236	SSPA-1955
1943	135	686	283	65	443	625	1,104	1,133	15,049	200	1,129	907	2,236	SSPA-1955
1944	135	686	283	65	443	625	1,104	1,133	15,049	200	1,129	907	2,236	SSPA-1955
1945	135	686	283	65	443	625	1,104	1,133	15,049	200	1,129	907	2,236	SSPA-1955
1946	135	686	283	65	443	625	1,104	1,133	15,049	200	1,129	907	2,236	SSPA-1955
1947	135	686	283	65	443	625	1,104	1,133	15,049	200	1,129	907	2,236	SSPA-1955
1948	135	686	283	65	443	625	1,104	1,133	15,049	200	1,129	907	2,236	SSPA-1955
1949	135	686	283	65	443	625	1,104	1,133	15,049	200	1,129	907	2,236	SSPA-1955
1950	135	686	283	65	443	625	1,104	1,133	15,049	200	1,129	907	2,236	SSPA-1955
1951	135	686	283	65	443	625	1,104	1,133	15,049	200	1,129	907	2,236	SSPA-1955
1952	135	686	283	65	443	625	1,104	1,133	15,049	200	1,129	907	2,236	SSPA-1955
1953	135	686	283	65	443	625	1,104	1,133	15,049	200	1,129	907	2,236	SSPA-1955
1954	135	686	283	65	443	625	1,104	1,133	15,049	200	1,129	907	2,236	SSPA-1955
1955	135	686	283	65	443	625	1,104	1,133	15,049	200	1,129	907	2,236	SSPA-1955
1956	135	686	283	65	443	625	1,104	1,133	15,049	200	1,129	907	2,236	SSPA-1955
1957	135	686	283	65	443	625	1,104	1,133	15,049	200	1,129	907	2,236	SSPA-1955
1958	135	686	283	65	443	625	1,104	1,133	15,049	200	1,129	907	2,236	SSPA-1955
1959	135	686	283	65	443	625	1,104	1,133	15,049	200	1,129	907	2,236	SSPA-1955
1960	135	686	283	65	443	625	1,104	1,133	15,049	200	1,129	907	2,236	SSPA-1955
1961	211	583	86	159	481	119	881	759	15,020	370	1,064	206	1,640	SSPA-1967
1962	211	583	86	159	481	119	881	759	15,020	370	1,064	206	1,640	SSPA-1967
1963	211	583	86	159	481	119	881	759	15,020	370	1,064	206	1,640	SSPA-1967
1964	211	583	86	159	481	119	881	759	15,020	370	1,064	206	1,640	SSPA-1967
1965	211	583	86	159	481	119	881	759	15,020	370	1,064	206	1,640	SSPA-1967
1966	211	583	86	159	481	119	881	759	15,020	370	1,064	206	1,640	SSPA-1967
1967	211	583	86	159	481	119	881	759	15,020	370	1,064	206	1,640	SSPA-1967
1968	211	583	86	159	481	119	881	759	15,020	370	1,064	206	1,640	SSPA-1967
1969	211	583	86	159	481	119	881	759	15,020	370	1,064	206	1,640	SSPA-1967
1970	211	583	86	159	481	119	881	759	15,020	370	1,064	206	1,640	SSPA-1967
1971	139	338	56	112	470	30	533	612	13,585	251	808	86	1,145	SSPA-1974
1972	139	338	56	112	470	30	533	612	13,585	251	808	86	1,145	SSPA-1974
1973	139	338	56	112	470	30	533	612	13,585	251	808	86	1,145	SSPA-1974
1974	139	338	56	112	470	30	533	612	13,585	251	808	86	1,145	SSPA-1974
1975	139	338	56	112	470	30	533	612	13,585	251	808	86	1,145	SSPA-1974
1976	139	338	56	112	470	30	533	612	13,585	251	808	86	1,145	SSPA-1974
1977	139	338	56	112	470	30	533	612	13,585	251	808	86	1,145	SSPA-1974
1978	139	338	56	112	470	30	533	612	13,585	251	808	86	1,145	SSPA-1974
1979	139	338	56	112	470	30	533	612	13,585	251	808	86	1,145	SSPA-1974
1980	139	338	56	112	470	30	533	612	12,880	251	808	86	1,145	SSPA-1986
1981	622	417	1,011	179	200	566	2,050	945	14,730	801	617	1,578	2,995	SSPA-1986
1982	622	417	1,011	179	200	566	2,050	945	14,730	801	617	1,578	2,995	SSPA-1986
1983	622	417	1,011	179	200	566	2,050	945	14,730	801	617	1,578	2,995	SSPA-1986
1984	622	417	1,011	179	200	566	2,050	945	14,730	801	617	1,578	2,995	SSPA-1986
1985	622	417	1,011	179	200	566	2,050	945	14,730	801	617	1,578	2,995	SSPA-1986
1986	622	417	1,011	179	200	566	2,050	945	14,730	801	617	1,578	2,995	SSPA-1986
1987	622	417	1,011	179	200	566	2,050	945	14,730	801	617	1,578	2,995	SSPA-1986
1988	622	417	1,011	179	200	566	2,050	945	14,730	801	617	1,578	2,995	SSPA-1986
1989	622	417	1,011	179	200	566	2,050	945	14,730	801	617	1,578	2,995	SSPA-1986
1990	622	417	1,011	179	200	566	2,050	945	14,730	801	617	1,578	2,995	SSPA-1986
1991	323	612	883	41	455	1,237	1,817	1,733	15,285	363	1,067	2,120	3,550	SSPA-1986
1992	323	612	883	41	455	1,237	1,817	1,733	15,000	363	1,067	2,120	3,550	SSPA-1997
1993	323	612	883	41	455	1,237	1,817	1,733	15,000	363	1,067	2,120	3,550	SSPA-1997
1994	323	612	883	41	455	1,237	1,817	1,733	15,000	363	1,067	2,120	3,550	SSPA-1997
1995	323	612	883	41	455	1,237	1,817	1,733	15,000	363	1,067	2,120	3,550	SSPA-1997
1996	323	612	883	41	455	1,237	1,817	1,733	15,000	363	1,067	2,120	3,550	SSPA-1997
1997	323	612	883	41	455	1,237	1,817	1,733	15,000	363	1,067	2,120	3,550	SSPA-1997
1998	323	612	883	41	455	1,237	1,817	1,733	15,000	363	1,067	2,120	3,550	SSPA-1997
1999	323	612	883	41	455	1,237	1,817	1,733	15,000	363	1,067	2,120	3,550	SSPA-1997
2000	323	612	883	41	455	1,237	1,817	1,733	15,000	363	1,067	2,120	3,550	SSPA-1997
2001	323	612	883	41	455	1,237	1,817	1,733	14,994	363	1,067	2,120	3,550	SSPA-2004
2002	323	612	883	41	455	1,237	1,817	1,733	14,994	363	1,067	2,120	3,550	SSPA-2004
2003	323	612	883	41	455	1,237	1,817	1,733	14,994	363	1,067	2,120	3,550	SSPA-2004
2004	323	612	883	41	455	1,237	1,817	1,733	14,994	363	1,067	2,120	3,550	SSPA-2004
2005	323	612	883	41	455	1,237	1,817	1,733	14,994	363	1,067	2,120	3,550	SSPA-2004
2006	323	612	883	41	455	1,237	1,817	1,733	14,994	363	1,067	2,120	3,550	SSPA-2004
2007	323	612	883	41	455	1,237	1,817	1,733	14,994	363	1,067	2,120	3,550	SSPA-2004
2008	323	612	883	41	455	1,237	1,817	1,733	14,994	363	1,067	2,120	3,550	SSPA-2004
2009	323	612	883	41	455	1,237	1,817	1,733	14,994	363	1,067	2,120	3,550	SSPA-2004
2010	1,075	64	3	535	32	2	1,142	569	12,809	1,610	96	5	1,711	Land IQ-2014
2011	1,075	64	3	535	32	2	1,142	569	12,809	1,610	96	5	1,711	Land IQ-2014
2012	1,075	64	3	535	32	2	1,142	569	12,809	1,610	96	5	1,711	Land IQ-2014
2013	1,075	64	3	535	32	2	1,142	569	12,809	1,610	96	5	1,711	Land IQ-2014
2014	1,075	64	3	535	32	2	1,142	569	12,809	1,610	96	5	1,711	Land IQ-2014
2015	1,075	64	3	535	32	2	1,142	569	12,809	1,610	96	5	1,711	Land IQ-2014
2016	1,075	64	3	535	32	2	1,142	569	12,809	1,610	96	5	1,711	Land IQ-2014

NOTE: Highlighted years are surveyed values from the source indicated.

4.3 Change in Aquifer Storage

When groundwater inflows are not equal to outflows there is a resulting change in the amount of groundwater stored in the aquifer. The change in groundwater storage is evidenced by a change in groundwater surface levels in an unconfined aquifer or a change in piezometric heads in a confined aquifer. For this analysis, changes in groundwater storage are estimated as the quantity required to close the groundwater budget shown in Equation (40). Changes in groundwater storage are used as a calibration metric for this analysis. Calibration of the water budgets was accomplished by adjusting various components until the estimated changes in groundwater storage were in reasonable agreement with simulated changes in groundwater storage from the calibrated numerical groundwater flow model developed by William Hutchison for this litigation project.

Estimated annual changes in groundwater storage are shown on **Figure 4.13**. Annual gains and losses of groundwater storage have occurred in both basins through time. Storage gains are shown as positive values on the **Figure 4.13** and storage losses are shown as negative values. It is important to note that estimated changes groundwater storage from this water budget analysis represents total storage change throughout each entire basin. This analysis does not address or identify trends that could occur in localized areas, such as agricultural versus non-agricultural areas. Groundwater storage losses occurred periodically in Rincon Basin, particularly during the 1950s, 1970s, and after 2002. A loss of groundwater storage has occurred in Mesilla Basin during the 1950s and during almost every year between 1986 and 2016. The years with the largest losses in groundwater storage in Mesilla Basin generally coincide with time periods when surface water deliveries to farms were relatively small (**Figures 2.10 and 4.13**), such as in early to mid-1950s, 2003 to 2004, and after 2010. A similar correlation occurs for Rincon Basin, such as in the mid-1950s and after 2010; however, the trends are not as obvious, partly because the magnitude of storage changes is substantially smaller than in Mesilla Basin.

Cumulative estimated annual groundwater storage changes in Rincon and Mesilla basins are shown on **Figure 4.14**. To evaluate calibration results, the cumulative storage change curves from water budget results are plotted with the cumulative curves from numerical model simulation results. Combined cumulative storage changes (both basins combined) have fluctuated above the zero line for most years from 1938 through the mid-1990s. The curve dropped below zero (cumulative loss) during the 1956-1957 and then again after 2002. Periods of gains and losses have occurred in Rincon Basin; however, the general, long-term trend is cumulative loss of groundwater in storage through time after 1975. The cumulative storage change curve for Mesilla Basin shows a similar pattern as the combined curve. A relatively steep rise in cumulative storage occurred during the 1980s when surface water deliveries to farms were relatively high. Cumulative groundwater storage has generally declined since 1986. The dramatic decrease in cumulative storage in Mesilla after 2010 indicates the impacts on the water budgets from Ciudad Juarez pumping in Conejos-Medanos in the southern portions of the basin in Mexico.

Cumulative gains in groundwater storage occurred in both basins from 1938 to about 1950. During this time period, applied irrigation water (farm deliveries) exceeded crop consumptive use estimates and the excess water was routed to deep percolation in the land-surface water budget presented herein. The gain in groundwater storage indicates that an excessive amount of water was applied to crops prior to 1950.

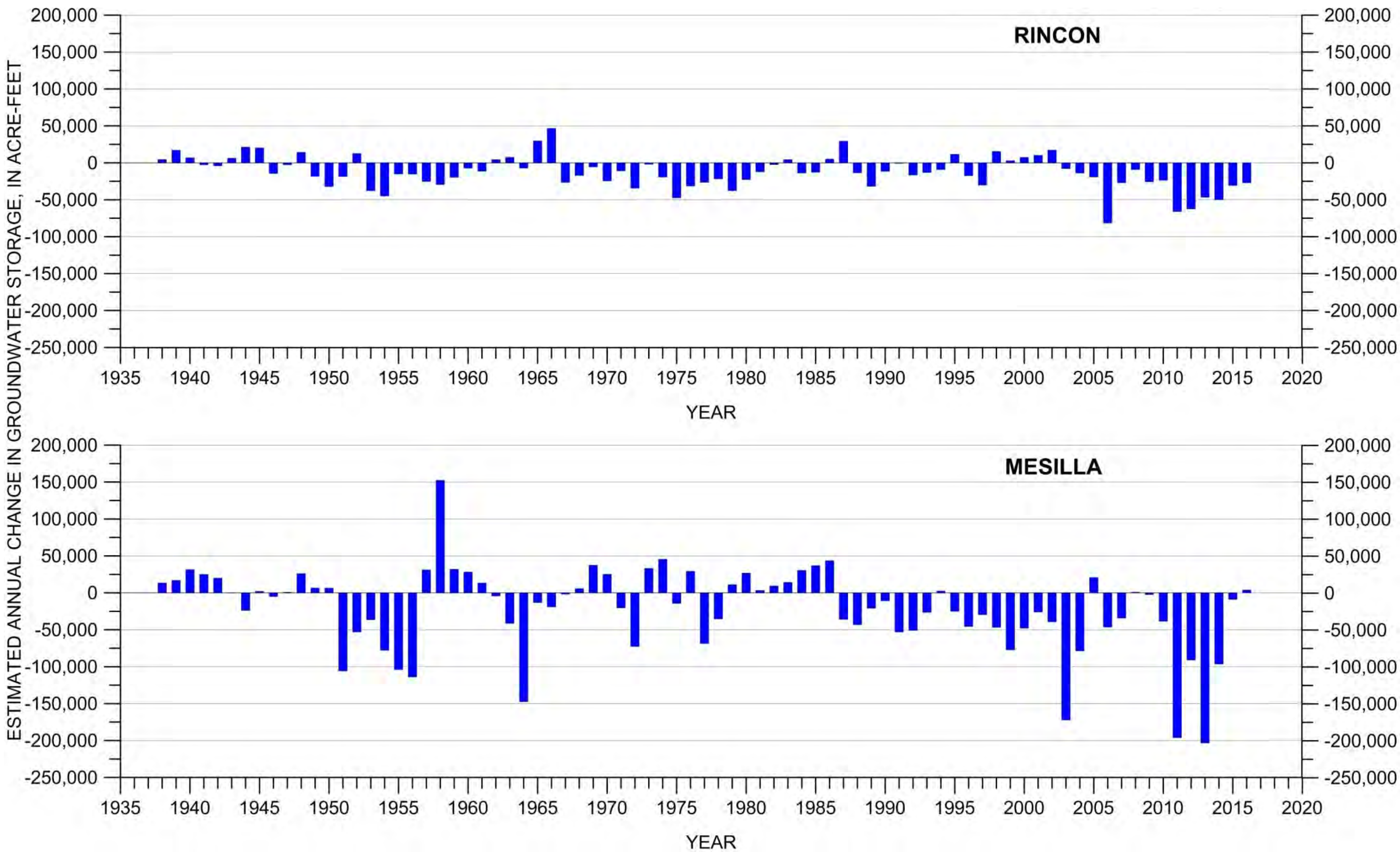


Figure 4.13. Estimated Annual Changes in Groundwater Storage for Rincon and Mesilla Basins

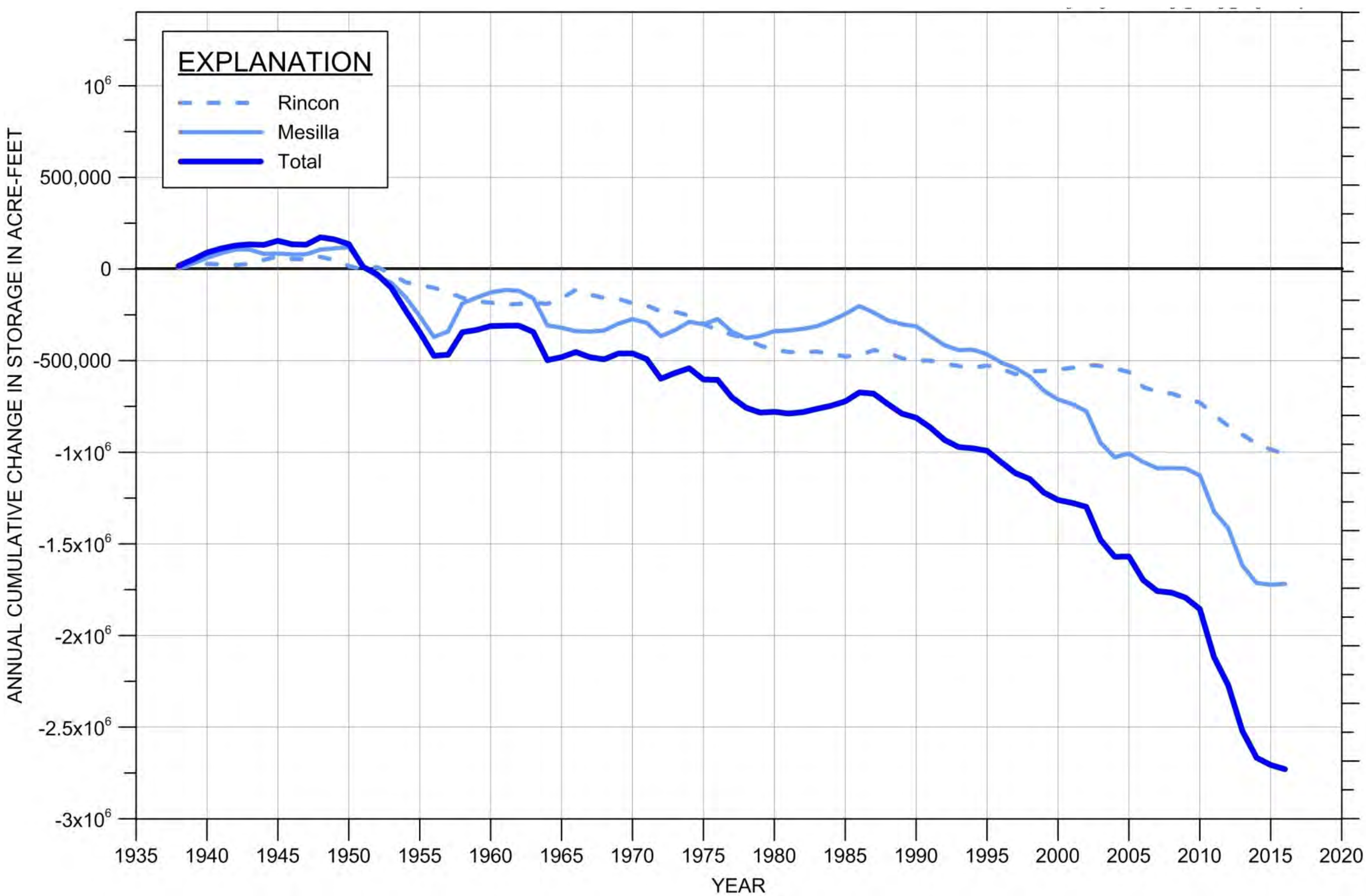


Figure 4.14. Estimated Annual Cumulative Change in Groundwater Storage in Rincon and Mesilla Basins

5 SUMMARY OF WATER BUDGET RESULTS

Monthly, basin-wide land-surface water, surface water, and groundwater budgets were developed for Rincon and Mesilla basins for 1938 through 2016. Water budgets were developed to provide conceptual inputs to other expert analyses, including a numerical groundwater flow model. These water budgets are integrated with multiple components linking to each other.

Water budget patterns were evaluated and compared for wet and dry years. Average annual values for water budget components during wet and dry periods are summarized in **Table 5.1**. Four time periods were selected for this evaluation based on climate and drought history descriptions reported by Terracon and others (2004). Wet periods contain years with above average precipitation. The selected wet periods are 1938 through 1943 and 1990 through 1999. The selected drought periods are 1945 through 1956 and 2009 through 2016. The period from 1945 through 1956 was further divided into two periods to evaluate potential impacts on the water budgets resulting from the advent of substantial groundwater pumping in 1950. The period from 1945 through 1949 represents drought conditions without supplemental irrigation pumping, and the period 1950 through 1956 represents drought conditions with supplemental pumping.

In both basins, agricultural consumptive use remained generally the same during wet or dry years. However, supplemental groundwater pumping substantially increased during drought periods when surface water deliveries were small. The ratio of supplemental groundwater pumping to agricultural consumptive use is used to evaluate irrigation practices during wet and drought years, except for pre-1950 when crop water demands within districts were fully satisfied by applied farm deliveries and precipitation. After 1950, crop water demands are satisfied by farm deliveries, precipitation, and supplemental groundwater pumping. After 1950, the ratios of supplemental pumping to agricultural consumptive use in both basins range from 0.6 to 0.85 during drought periods; the ratio ranges from 0.3 to 0.40 during wet periods. These results indicate that supplemental groundwater pumping is used to maintain agricultural production when surface water allotments are small. Without the availability of supplemental groundwater pumping, crop applied water demands could not be fully satisfied.

Urban consumptive use and urban groundwater pumping in the basins generally increase through time and do not appear to be substantially dependent on climate conditions. Urban applied water demands are met predominantly by groundwater pumping and are not dependent on surface water availability, which varies during dry and wet periods.

The volume of groundwater storage in the Rincon and Mesilla basins aquifers has generally declined since 1938 conditions. Annual gains and losses of groundwater storage have occurred in both basins through time. The years with the largest losses in groundwater storage generally coincide with time periods when surface water deliveries to farms were relatively small, such as in the early-1950s and after 2003. Groundwater storage in Mesilla Basin has declined during most years since 1986. This reduction in groundwater storage is principally attributed to an increase in groundwater withdrawals throughout the basins.

Table 5.1. Summary of Water Budgets for Selected Wet and Dry Periods

	RINCON BASIN					MESILLA BASIN				
	1938-1943	1945-1949	1950-1956	1990-1999	2009-2012	1938-1943	1945-1949	1950-1956	1990-1999	2009-2012
	Wet	*Dry*	*Dry*	*Wet*	*Dry*	*Wet*	*Dry*	*Dry*	*Wet*	*Dry*
LAND-SURFACE WATER BUDGET										
INFLOWS										
Total Precipitation	634,333	450,881	397,452	673,424	480,918	953,020	687,177	570,011	936,006	671,471
Total Urban Pumping	73	110	146	1,098	1,187	828	1,882	9,884	56,740	84,831
Surface Water Deliveries to Farms	40,137	45,547	21,351	52,094	23,892	230,829	266,162	117,599	222,365	97,738
Ag. Groundwater Pumping	1,115	2,288	28,109	25,611	61,649	2,092	4,857	151,371	72,270	167,343
OUTFLOWS										
Surface runoff from farms	6,032	5,475	3,208	3,488	1,641	34,224	31,115	16,431	12,722	5,509
Ag. Consumptive Use (crops)	36,599	41,770	46,672	64,684	72,147	194,494	219,373	230,814	243,385	222,992
Ag. Deep Percolation	7,821	8,263	6,152	19,135	18,583	51,634	57,397	48,712	64,343	45,666
Total Urban Consumptive Use	468	414	443	1,389	1,097	22,181	16,382	17,680	49,976	48,141
Native watershed Consumptive Use	600,528	424,519	372,843	637,441	452,234	846,514	611,410	505,649	829,744	592,778
Total Wastewater Discharge	0	0	0	120	295	152	459	3,159	16,771	19,322
Urban Runoff	37	30	31	75	73	705	563	517	2,851	2,625
Tributary Inflows	5,879	4,156	3,683	6,282	4,478	133	96	81	130	92
Total Urban Deep Percolation	21	22	26	205	291	600	800	2,268	11,546	15,635
Mountain Front Recharge	9,360	9,360	9,360	9,360	9,360	5,432	5,432	5,432	5,432	5,432
Exported Groundwater	0	0	0	0	0	0	0	0	0	16,945
Change in Ag. Soil Moisture Storage	417	-181	400	73	-60	1,945	-643	2,010	-81	-382
Ag. Pump/Crop CU	*0.03*	*0.05*	*0.60*	*0.40*	*0.85*	*0.01*	*0.02*	*0.66*	*0.30*	*0.75*
SURFACE WATER BUDGET										
INFLOWS										
Rio Grande Inflows	952,128	764,921	424,305	797,157	531,633	914,188	723,056	397,805	740,784	503,777
Tributary Inflows	5,879	4,156	3,683	6,282	4,478	133	96	81	130	92
Urban Runoff	37	30	31	75	73	705	563	517	2,851	2,625
Wastewater Discharges	0	0	0	120	295	152	459	1,842	9,973	12,259
Surface runoff from farms	6,032	5,475	3,208	3,488	1,641	34,224	31,115	16,431	12,722	5,509
OUTFLOWS										
Surface Water Deliveries to Farms	40,137	45,547	21,351	52,094	23,892	230,829	266,162	117,599	222,365	97,738
Incidental Depletions	4,052	5,029	3,779	5,723	5,862	22,010	27,415	19,380	22,775	19,358
Rio Grande Outflow	914,188	723,056	397,805	740,784	503,777	703,734	484,104	213,005	479,709	277,260
Net SW-GW Exchange	1,453	5,719	-148	-1,154	3,177	23,562	37,715	-48,038	-24,800	-112,196
GROUNDWATER BUDGET										
INFLOWS										
Interbasin Inflows	1,501	1,501	1,501	1,501	1,501	860	860	860	860	860
Mountain Front Recharge	9,360	9,360	9,360	9,360	9,360	5,432	5,432	5,432	5,432	5,432
Ag. Deep Percolation	7,821	8,263	6,152	19,135	18,583	51,634	57,397	48,712	64,343	45,666
Total Urban Deep Percolation	21	22	26	205	291	600	800	2,268	11,546	15,635
OUTFLOWS										
Ag. Groundwater Pumping	1,115	2,288	28,109	25,611	61,649	2,092	4,857	151,371	72,270	167,343
Urban Groundwater Pumping	73	110	146	1,098	922	828	1,882	9,884	56,740	84,415
Riparian ET	11,381	11,162	10,473	11,476	8,290	13,264	12,938	12,157	13,132	8,922
Interbasin Outflows	10	10	10	10	10	1,050	1,050	1,050	1,050	1,050
Net SW-GW Exchange	1,453	5,719	-148	-1,154	3,177	23,562	37,715	-48,038	-24,800	-112,196
Change in Storage	4,670	-143	-21,550	-6,840	-44,314	17,729	6,049	-69,152	-36,212	-81,940

Notes: Units in acre-feet

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APPENDIX A

ANNUAL LAND-SURFACE WATER BUDGETS
FOR RINCON AND MESILLA BASINS

APPENDIX A1. ANNUAL LAND-SURFACE WATER BUDGET FOR RINCON BASIN

	RINCON BASIN																																
	INFLOWS, in acre-feet												OUTFLOWS, in acre-feet																				
Year	Precipitation on Urban Lands			Precipitation on Agricultural Lands	Precipitation on Upland Watershed	Total Precipitation on Basin	Urban Applied Groundwater				Surface Water Deliveries to Farms	Agricultural Applied Groundwater	Agricultural Surface Runoff	Agricultural Crop Consumptive Use	Agricultural Non-crop Consumptive Use	Agricultural Deep Percolation	Urban Consumptive Use	Consumptive Use of Wastewater	Consumptive Use in Undeveloped, Non-Agricultural Lands	Consumptive Use in Upland Watershed Lands	Consumptive Use of Domestic Pumping	Urban Wastewater Discharge			Urban Runoff	Tributary Outflows to Surface Water	Urban Deep Percolation					Mountain Front Recharge	Change in Soil Moisture Storage
	Urban Excess Precipitation	Urban Effective Precipitation	Total Urban				M&I	Domestic	Imported	Total												To Surface Water	Exported	Total			Applied Water	Conveyance Loss	Septics	Precipitation	Total		
1938	464	23	487	18,896	607,694	627,076	0	40	0	40	33,709	830	5,903	31,410	7,683	5,440	0	0	417	592,461	32	0	0	0	37	5,873	0	0	9	10	18	9,360	2,998
1939	375	20	394	15,191	510,397	525,982	0	44	0	44	39,911	925	5,769	34,854	8,461	7,329	0	0	336	496,125	35	0	0	0	30	4,911	0	0	9	8	16	9,360	-386
1940	330	18	347	13,501	538,911	552,760	39	50	0	88	41,123	971	5,706	35,120	7,442	8,377	0	35	296	524,623	41	0	0	0	27	4,928	0	4	9	7	19	9,360	-1,050
1941	789	41	830	31,370	1,009,419	1,041,618	39	50	0	89	35,145	910	6,804	35,195	15,031	9,058	0	35	707	990,295	41	0	0	0	65	9,764	0	4	9	17	29	9,360	1,337
1942	393	21	414	15,293	521,844	537,551	39	50	0	89	41,593	1,400	6,134	37,056	7,230	8,381	0	35	352	507,485	41	0	0	0	33	4,998	0	4	9	8	21	9,360	-523
1943	370	20	390	14,284	506,339	521,013	39	51	0	89	49,339	1,656	5,874	45,960	4,981	8,339	0	35	332	492,180	42	0	0	0	31	4,799	0	4	9	8	21	9,360	125
1944	449	24	474	17,024	643,056	660,554	39	53	0	92	47,873	1,523	5,994	40,882	7,556	11,105	0	35	402	627,686	44	0	0	0	38	6,010	0	4	9	10	23	9,360	881
1945	263	14	277	9,933	344,854	355,064	39	53	0	92	50,820	1,889	5,990	41,207	4,673	10,871	0	35	235	332,248	44	0	0	0	22	3,247	0	4	9	6	19	9,360	-100
1946	370	21	391	12,863	469,445	482,699	39	53	0	92	47,500	2,206	5,582	44,481	5,151	8,666	0	35	331	455,664	44	0	0	0	31	4,421	0	4	9	8	21	9,360	-1,313
1947	278	15	293	9,896	343,287	353,476	39	55	0	94	43,493	2,325	5,176	40,617	3,124	7,807	0	35	248	330,708	46	0	0	0	24	3,219	0	4	9	6	19	9,360	-1,010
1948	362	20	382	12,255	428,373	441,010	77	55	0	133	40,960	2,532	4,799	37,837	6,010	5,894	0	69	323	414,900	46	0	0	0	31	4,113	0	8	9	8	25	9,360	1,208
1949	511	28	540	17,402	604,215	622,156	77	63	0	140	44,960	2,488	5,831	44,710	5,922	8,075	0	69	456	589,076	54	0	0	0	44	5,778	0	8	9	11	28	9,360	312
1950	399	20	419	12,641	421,583	434,643	77	64	0	141	48,038	2,904	6,723	46,975	2,244	8,712	0	69	356	408,137	54	0	0	0	34	4,086	0	8	9	9	26	9,360	-1,072
1951	258	15	272	8,536	332,828	341,636	77	66	0	143	24,702	32,669	3,449	47,959	3,281	7,199	0	69	230	320,370	55	0	0	0	22	3,098	0	8	11	6	24	9,360	4,019
1952	380	22	402	12,660	460,516	473,578	77	68	0	145	28,181	23,313	3,998	48,847	5,516	6,209	0	69	339	446,829	57	0	0	0	33	4,327	0	8	11	8	27	9,360	-416
1953	317	18	336	10,135	335,191	345,661	77	68	0	145	26,638	29,050	3,765	50,763	3,378	7,201	0	69	283	322,604	57	0	0	0	28	3,226	0	8	11	7	26	9,360	716
1954	487	28	515	15,233	484,124	499,871	77	70	0	148	8,021	32,231	1,825	44,074	5,266	4,343	0	69	434	470,058	59	0	0	0	43	4,706	0	8	11	11	29	9,360	-23
1955	417	23	441	12,542	436,504	449,486	77	70	0	148	5,563	37,308	1,472	44,671	5,004	4,426	0	69	371	422,979	59	0	0	0	37	4,165	0	8	11	9	28	9,360	-160
1956	217	13	230	6,603	230,459	237,291	81	71	0	152	8,313	39,286	1,220	43,416	4,851	4,978	0	73	193	218,927	59	0	0	0	19	2,172	0	8	11	5	24	9,360	-263
1957	723	40	763	21,493	692,346	714,602	81	71	0	152	12,041	24,320	3,082	43,167	8,304	3,976	0	73	643	676,224	60	0	0	0	64	6,762	0	8	11	16	35	9,360	-674
1958	851	47	898	25,662	876,213	902,773	81	71	0	152	38,245	6,284	6,973	45,181	8,189	8,754	0	73	756	858,432	60	0	0	0	76	8,421	0	8	11	19	38	9,360	1,095
1959	418	23	441	12,620	438,532	451,593	81	71	0	152	36,595	16,509	6,061	45,736	5,322	9,141	0	73	372	425,012	60	0	0	0	37	4,159	0	8	11	9	29	9,360	-536
1960	444	26	470	14,343	488,489	503,303	81	73	0	155	41,068	13,146	5,904	45,376	6,602	8,897	0	73	394	474,463	62	0	0	0	40	4,666	0	8	12	10	30	9,360	1,778
1961	604	35	639	18,508	593,343	612,490	81	74	0	155	26,833	17,726	4,393	44,408	7,637	7,726	0	73	536	578,239	62	0	0	0	54	5,744	0	8	12	13	34	9,360	-1,097
1962	655	38	693	20,651	665,993	687,336	81	74	0	155	38,424	13,640	6,543	45,412	10,067	11,249	0	73	582	650,161	62	0	0	0	59	6,472	0	8	12	14	35	9,360	-557
1963	365	22	387	11,157	425,329	436,873	81	74	0	155	27,886	21,197	4,093	42,631	5,109	8,237	0	73	324	411,988	62	0	0	0	33	3,981	0	8	12	8	28	9,360	169
1964	323	20	342	10,456	395,687	406,485	81	75	0	156	5,304	38,971	958	43,440	5,023	4,833	0	73	286	382,607	62	0	0	0	29	3,720	0	8	12	7	28	9,360	476
1965	439	26	465	13,520	507,082	521,067	81	75	0	156	22,328	28,588	3,423	47,655	6,319	7,440	0	73	389	492,996	63	0	0	0	40	4,725	0	8	12	10	30	9,360	-402
1966	498	30	528	15,111	521,077	536,716	81	76	0	157	32,192	17,255	5,020	42,500	7,348	9,569	0	73	441	506,759	63	0	0	0	46	4,959	0	8	13	11	32	9,360	121
1967	579	34	613	17,702	623,363	641,678	81	76	0	157	20,788	21,636	3,633	43,468	5,910	7,161	0	73	513	608,020	63	0	0	0	53	5,983	0	8	13	13	34	9,360	-46
1968	506	30	537	15,624	554,166	570,326	81	78	0	159	29,334	21,709	4,538	48,263	6,151	8,164	0	73	449	539,579	65	0	0	0	46	5,227	0	8	13	11	32	9,360	-450
1969	471	28	500	14,517	520,081	535,098	81	78	0	159	37,184	18,378	5,411	47,568	5,286	10,292	0	73	418	505,751	65	0	0	0	43	4,970	0	8	13	10	32	9,360	1,522
1970	361	22	383	11,244	387,872	399,499	81	78	0	160	40,581	18,465	5,726	48,450	5,048	11,232	0	73	320	374,849	65	0	0	0	33	3,663	0	8	13	8	29	9,360	-165
1971	454	27	481	14,057	484,145	498,683	120	81	0	201	27,222	27,130	4,126	48,771	5,623	10,581	0	108	403	470,136	67	0	0	0	41	4,649	0	12	14	10	36	9,360	-691
1972	737	42	778	22,730	782,851	806,359	120	82	0	202	11,833	31,267	3,304	47,365	7,768	7,775	0	108	654	766,005	68	0	0	0	66	7,486	0	12	14	16	42	9,360	-382
1973	553	32	585	16,075	501,516	518,176	120	87	0	206	31,669	22,929	4,949	47,451	7,544	9,836	0	108	491	487,272	72	0	0	0	50	4,884	0	12	15	12	39	9,360	887
1974	794	44	838	23,888	731,416	756,142	120	87	0	207	38,463	12,635	7,333	47,381	6,637	11,955	0	108	705	714,935	72	0	0	0	71	7,122	0	12	15	17	44	9,360	1,679
1975	660	37	697	19,989	650,905	671,591	120	90	0	210	36,078	16,663	6,505	47,685	10,241	10,527	0	108	587	635,226	75	0	0	0	59	6,319	0	12	15	14	41	9,360	-2,231
1976	488	29	517	14,332	511,334	526,183	142	89	0	230	44,460	18,106	6,305	49,813	6,280	14,620	0	127	433	497,149	73	0	0	0	44	4,824	0	14	16	11	41	9,360	-120
1977	488	29	517	14,460	510,211	525,188	153	88	0	241	19,969	31,443	3,146	46,727	6,957	8,391	0	137	433	495,987	72	0	0	0	44	4,863	0	15	16	11	42	9,360	651
1978	742	45	787	21,440	749,853	772,080	173	89	0	262	11,786	33,781	2,356	47,465	9,482	7,456	0	156	658	733,411	73	0	0	0	68	7,082	0	17	16	17	50	9,360	248
1979	642	39	681	18,789	598,958	618,429	180	91	0	270	35,197	19,732	5,477	47,254	9,263	11,104	0	162	568	583,792	75	0	0	0	59	5,806	0	18	16	14	48	9,360	606
1980	491	30	521	13,831	455,794	470,146	255	89	0	344	42,641	18,264	6,060	48,524	8,132	12,306	0	229	434	442,055	72	0	0	0	46	4,379	0	25	17	11	53	9,360	-287
1981	591	37	628	17,164	573,177	590,968	251	70	0	321	38,464	18,310	5,603	49,820	8,626	11,156	0	226	523	558,348	53	0	0	0	55	5,468	0	25	17	13	56	9,360	-1,265
1982	600	38	638	17,262	611,613	629,513	291	71	0	362	40,348	17,334	5,892	48,153	9,173	11,013	0	262	530	596,459	54	0	0	0	57	5,794	0	29	17	14	60	9,360	684
1983	658	42	699	18,464	687,374	706,538	319	73	0	392	39,421	15,543	5,771	47,380	11,313	9,605	0	287	580	671,544	54	0	0	0	62	6,470	0	32	18	15	65	9,360	-629
1984	941	57	997	26,612	859,561	887,170	352	75	0	427	40,084	14,160	7,651	48,742	10,025	10,521	0	317	830	841,902	55	0	0	0	89	8,300	0	35	20	21	77	9,360	3,910
1985	730	46	777	20,863	746,659	768,298	387	79	0	466	46,725	13,436	7,331	50,251	13,971	11,918	0	348	644	730,204	58	0	0	0	70	7,095	0	39	21	17	77	9,360	-2,444
1986	961	61	1,022	26,982	905,248	933,252	350	79	0	429	59,238	9,585	9,386	57,418	8,676	16,099	0	315	846	887,204	56	0	0	0	93	8,684	0	35	23	22	80	9,360	4,135
1987	690	45	735	19,045	624,011	643,791	320	80	0	401	63,131	6,724	9,369	48,372	13,758	20,657	0	288	606	608,669	55	0	0	0	68	5,982	0	32	25	16	73	9,360	-3,187
1988	715	46	761	20,006	702,517	723,285	313	87	0	399	50,806	16,391	8,246	51,183	11,416	14,970	0	281	628	686,447	60	0	0	0	71	6,710	0	31	26	17	74	9,360	1,388
1989	443	30	474	12,540	428,587	441,601	309	88	0	397	53,981	23,915	7,690	57,621	9,260	16,691	0	278	388	415,178	60	0	0	0	45	4,050	0	31	28	10	69	9,360	-813
1990	879	58	937	25,694	802,178	828,810	819	89	0	909	43,265	21,560	4,181	57,742	11,799	15,746	17	581	768	784,967	61	97	0	97	90	7,851	50	73	29	21	173	9,360	1,056
1991	1,054	69	1,123	28,603	894,175	923,902	806	90	0	896	48,575	23,557	4,963	58,605	12,577	21,327	19	556	920	876,099	59	105	0	105	109	8,716	55	71	31	25	182	9,360	3,262
1992	816	58	874	22,706	753,049	776,628	826	96	0	922	41,966	31,244	3,002	63,724	10,293	20,294	18	580	710	736,417	64	102	0	102	86	7,272	53	73	32	20	178	9,360	-1,398
1993	545	39	584	15,715	598,094	614,392	958	99	0	1,057	48,618	32,078	2,983	65,164	10,683	20,255	20	686	473	583,099	65	109	0	109	58	5,635	57	86	34	13	190	9,360	-2,674
1994	609	46	655	17,772	614,872	633,299	962	96	0	1,057	61,149	24,701	3,242	68,862	9,889	20,396	22	672	528	599,641	60	120	0	120	66	5,871	63	85	36	15	199	9,360	1,206
1995	420	32	452	12,158	418,410	431,021	1,025	98	0	1,122	60,533	27,631	3,128	71,031	7,441	18,548	19	756	364	405,079	60	103	0	103	46	3,972	54	93	37	10	195	9,360	191

RINCON BASIN

INFLOWS, in acre-feet

Year	Precipitation on Urban Lands			Precipitation on Agricultural Lands	Precipitation on Upland Watershed	Total Precipitation on Basin	Urban Applied Groundwater				Surface Water Deliveries to Farms	Agricultural Applied Groundwater
	Urban Excess Precipitation	Urban Effective Precipitation	Total Urban				M&I	Domestic	Imported	Total		
1996	628	48	676	17,862	598,414	616,952	1,187	101	0	1,288	51,325	31,916
1997	689	55	744	19,479	659,237	679,459	1,208	102	0	1,310	51,852	26,020
1998	549	43	592	15,425	536,733	552,750	1,089	106	0	1,195	61,964	18,416
1999	716	56	771	20,582	655,672	677,025	1,110	111	0	1,221	51,695	18,991
2000	725	58	783	20,188	655,746	676,717	1,298	115	55	1,468	55,585	15,361
2001	374	32	406	10,715	396,030	407,151	1,350	114	56	1,521	57,194	12,752
2002	460	39	499	12,369	432,915	445,784	1,507	120	476	2,102	55,628	15,456
2003	338	30	368	9,198	326,426	335,993	1,671	123	515	2,308	12,342	58,993
2004	876	76	953	22,658	754,636	778,246	785	129	513	1,427	12,967	49,563
2005	583	52	635	15,641	524,918	541,195	545	127	528	1,200	41,213	33,985
2006	1,025	80	1,104	26,481	845,698	873,283	528	122	535	1,185	19,206	52,099
2007	585	53	638	15,918	572,914	589,470	495	189	361	1,045	35,117	53,065
2008	874	66	941	22,158	698,006	721,106	358	221	262	841	43,080	35,653
2009	613	56	669	15,862	508,026	524,557	542	191	265	998	43,798	39,310
2010	729	64	793	18,432	631,882	651,107	721	211	262	1,194	33,648	51,110
2011	594	54	647	14,367	448,862	463,877	698	414	266	1,379	4,734	84,990
2012	338	31	370	8,243	275,517	284,130	702	209	265	1,176	13,386	71,186
2013	733	64	796	17,618	589,273	607,687	939	310	406	1,656	4,592	69,126
2014	755	66	821	18,832	616,489	636,142	1,057	369	476	1,902	8,764	58,994
2015	954	86	1,039	21,658	758,036	780,733	1,103	192	505	1,800	17,400	48,722
2016	771	70	841	19,229	646,414	666,484	1,075	208	156	1,439	20,535	49,129

OUTFLOWS, in acre-feet

Year	Agricultural Surface Runoff	Agricultural Crop Consumptive Use	Agricultural Non-crop Consumptive Use	Agricultural Deep Percolation	Urban Consumptive Use	Consumptive Use of Wastewater	Consumptive Use in Undeveloped, Non-Agricultural Lands	Consumptive Use in Upland Watershed Lands	Consumptive Use of Domestic Pumping	Urban Wastewater Discharge			Urban Runoff	Tributary Outflows to Surface Water	Urban Deep Percolation					Mountain Front Recharge	Change in Soil Moisture Storage
										To Surface Water	Exported	Total			Applied Water	Conveyance Loss	Septics	Precipitation	Total		
1996	3,025	71,266	8,262	18,481	24	856	542	583,331	62	132	0	132	70	5,723	68	107	40	16	230	9,360	70
1997	2,773	65,661	9,150	19,299	28	833	594	643,521	62	158	0	158	78	6,356	82	107	41	17	247	9,360	467
1998	3,665	62,670	10,440	21,201	25	757	472	522,261	63	138	0	138	63	5,112	72	97	42	14	225	9,360	-2,173
1999	3,922	62,118	8,709	15,799	24	786	615	640,000	67	132	0	132	83	6,312	69	99	44	18	230	9,360	719
2000	3,700	59,893	9,272	19,016	82	938	621	640,105	69	186	0	186	85	6,281	30	117	46	18	211	9,360	-748
2001	2,680	51,953	8,653	17,563	34	988	319	382,861	67	245	0	245	45	3,810	16	122	47	10	195	9,360	-189
2002	2,733	54,423	8,952	16,237	74	1,142	392	419,399	72	217	0	217	56	4,156	412	137	48	12	609	9,360	1,109
2003	687	60,488	8,121	12,151	83	1,259	288	314,004	74	254	0	254	41	3,062	439	151	48	9	648	9,360	-912
2004	1,345	60,975	9,332	12,267	83	459	745	738,046	79	271	0	271	108	7,229	423	63	50	23	559	9,360	1,268
2005	2,251	63,833	8,727	16,180	77	308	495	510,524	76	267	0	267	73	5,034	378	43	50	15	487	9,360	-152
2006	4,619	67,763	7,324	16,669	71	330	870	828,199	71	257	0	257	128	8,139	362	43	51	27	483	9,360	1,411
2007	1,880	71,602	8,980	20,921	58	286	495	558,179	137	263	0	263	74	5,376	211	38	52	16	316	9,360	716
2008	5,526	66,896	8,667	21,309	40	234	742	681,844	169	259	0	259	110	6,803	58	29	52	23	162	9,360	-1,508
2009	2,353	68,289	6,740	20,946	45	263	519	493,746	138	379	0	379	78	4,920	81	39	52	16	189	9,360	641
2010	2,730	72,653	8,269	19,574	55	427	617	616,522	159	266	0	266	93	6,000	177	58	53	19	306	9,360	-37
2011	770	78,431	7,041	16,705	60	366	502	435,124	361	248	0	248	76	4,379	237	53	53	16	359	9,360	1,144
2012	712	69,215	7,769	17,107	52	381	286	263,545	156	289	0	289	44	2,613	191	54	54	9	308	9,360	-1,988
2013	1,615	65,929	7,863	15,739	70	626	619	574,263	257	194	0	194	94	5,650	377	79	54	20	530	9,360	189
2014	1,995	61,288	7,964	15,625	76	747	638	601,271	315	218	0	218	97	5,858	401	92	54	20	567	9,360	-281
2015	1,727	59,135	11,034	16,432	81	769	805	741,503	136	222	0	222	123	7,173	442	95	55	26	618	9,360	-547
2016	1,777	59,820	10,157	16,659	48	716	650	630,987	153	224	0	224	100	6,068	151	91	55	21	318	9,360	479

APPENDIX A2. ANNUAL LAND-SURFACE WATER BUDGET FOR MESILLA BASIN

MESILLA BASIN

Year	INFLOWS, in acre-feet: Precipitation on Urban Lands: Urban Excess Precipitation	Precipitation on Urban Lands: Urban Effective Precipitation	Precipitation on Urban Lands: Total Urban	Precipitation on Agricultural Lands	Precipitation on Upland Watershed	Total Precipitation on Basin	Urban Applied Groundwater: M&I	Urban Applied Groundwater: Domestic	Urban Applied Groundwater: Imported	Urban Applied Groundwater: Total	Surface Water Deliveries to Farms	Agricultural Applied Groundwater	OUTFLOWS, in acre-feet: Agricultural Surface Runoff	Agricultural Crop Consumptive Use	Agricultural Non-crop Consumptive Use	Agricultural Deep Percolation	Urban Consumptive Use	Consumptive Use of Wastewater	Consumptive Use in Undeveloped, Non-Agricultural Lands	Consumptive Use in Upland Watershed Lands	Consumptive Use of Domestic Pumping	Urban Wastewater Discharge: To Surface Water	Urban Wastewater Discharge: Exported	Urban Wastewater Discharge: Total	Urban Runoff	Tributary Outflows to Surface Water	Urban Deep Percolation: Applied Water	Urban Deep Percolation: Conveyance Loss	Urban Deep Percolation: Septics	Urban Deep Percolation: Precipitation	Urban Deep Percolation: Total	Mountain Front Recharge	Exported Groundwater	Change in Soil Moisture Storage
1938	22,333	195	22,528	76,403	836,893	935,824	96	266	0	362	212,979	1,140	33,452	166,229	32,952	46,317	0	86	21,343	831,333	151	0	0	0	659	128	0	10	115	331	455	5,432	0	11,544
1939	15,384	148	15,532	52,677	613,121	681,330	96	266	0	362	248,066	1,689	34,084	185,391	26,884	53,603	0	86	14,693	607,599	151	0	0	0	463	90	0	10	115	229	354	5,432	0	2,463
1940	19,004	191	19,195	66,109	706,138	791,442	392	317	0	710	240,866	1,989	33,381	198,791	27,228	52,819	86	87	18,138	700,595	200	161	0	161	582	111	10	48	117	284	460	5,432	0	-3,260
1941	40,816	391	41,207	140,611	1,488,478	1,670,296	626	323	0	949	203,205	1,848	42,108	204,451	42,298	54,263	166	91	38,933	1,482,810	204	241	0	241	1,271	236	50	78	119	612	859	5,432	0	2,535
1942	21,775	234	22,009	73,149	807,262	902,420	953	324	0	1,277	215,724	2,642	31,662	194,266	23,208	45,946	286	98	20,757	801,700	204	255	0	255	690	129	194	121	120	328	763	5,432	0	-3,572
1943	17,548	200	17,748	58,477	660,582	736,807	984	325	0	1,309	264,134	3,247	30,654	217,838	18,549	56,853	309	98	16,717	655,046	205	256	0	256	566	104	197	125	120	266	707	5,432	0	1,958
1944	23,689	278	23,967	78,730	875,498	978,194	984	325	0	1,309	261,740	3,359	31,451	221,137	25,616	61,850	309	98	22,552	869,927	205	256	0	256	777	139	197	125	120	360	802	5,432	0	3,696
1945	14,655	178	14,833	47,795	544,996	607,624	1,241	326	0	1,568	297,580	4,269	34,920	230,365	12,885	71,599	502	98	13,943	539,476	206	256	0	256	488	88	248	138	121	224	730	5,432	0	-222
1946	15,838	203	16,041	51,381	627,861	695,283	1,219	329	0	1,548	270,440	4,827	31,128	230,100	16,590	53,748	485	98	15,059	622,335	207	256	0	256	537	93	244	136	122	243	745	5,432	0	-4,923
1947	13,789	182	13,971	45,212	510,258	569,441	1,201	330	0	1,531	253,040	4,933	29,182	212,539	13,423	51,617	431	98	13,102	504,745	207	304	0	304	475	81	231	136	122	212	702	5,432	0	-3,582
1948	14,437	198	14,635	48,250	543,431	606,316	1,799	332	0	2,131	251,170	5,164	28,821	200,626	21,300	47,447	618	98	13,709	537,915	208	716	0	716	505	83	154	213	123	223	714	5,432	0	6,386
1949	22,893	319	23,212	75,862	858,146	957,220	2,293	338	0	2,631	258,580	5,089	31,526	223,234	23,056	62,575	801	99	21,726	852,578	214	762	0	762	812	136	352	279	125	355	1,111	5,432	0	-872
1950	14,909	210	15,119	47,605	548,338	611,062	2,365	350	0	2,716	258,981	6,303	31,327	225,765	6,635	55,481	777	99	14,140	542,818	222	848	0	848	537	87	354	287	128	232	1,002	5,432	0	-6,324
1951	11,667	176	11,843	38,953	447,741	498,537	2,544	361	0	2,905	137,209	172,095	18,834	243,121	12,698	53,053	667	99	11,057	442,238	228	1,414	0	1,414	427	71	62	302	133	183	680	5,432	0	20,548
1952	17,101	265	17,366	55,837	658,101	731,304	7,439	364	0	7,802	150,168	123,832	20,965	241,969	21,776	48,364	3,645	99	16,197	652,567	229	1,460	796	2,255	635	102	685	755	135	269	1,844	5,432	0	-3,236
1953	9,899	158	10,057	32,687	386,340	429,085	11,016	371	0	11,386	146,073	158,111	20,058	246,860	12,141	53,247	4,977	99	9,370	380,849	235	1,643	1,903	3,546	373	60	1,375	1,018	136	156	2,685	5,432	0	4,566
1954	14,729	239	14,967	47,891	544,981	607,839	13,653	373	0	14,026	52,315	181,427	8,375	215,350	18,807	41,440	6,022	99	13,933	539,464	236	2,449	2,307	4,755	562	85	1,507	1,269	137	233	3,147	5,432	0	-2,339
1955	18,044	285	18,328	59,521	647,229	725,078	11,902	376	0	12,278	40,121	190,992	9,970	220,391	18,277	40,978	5,922	153	17,059	641,696	238	2,522	1,188	3,710	698	102	896	1,221	139	287	2,543	5,432	0	1,017
1956	9,836	175	10,011	31,761	345,399	387,170	17,691	381	0	18,072	38,326	226,835	5,485	222,245	20,931	48,424	8,281	155	9,286	339,909	240	2,555	3,025	5,580	392	57	2,037	1,638	141	158	3,974	5,432	0	-163
1957	21,891	403	22,294	71,523	838,545	932,362	18,927	384	0	19,311	82,375	137,793	13,379	213,265	29,541	39,108	8,856	155	20,640	832,985	242	2,650	3,360	6,010	896	128	2,169	1,736	142	354	4,401	5,432	0	-3,602
1958	32,441	607	33,047	106,370	1,218,377	1,357,794	18,481	385	0	18,866	208,595	31,550	34,735	216,417	29,571	64,937	8,229	156	30,548	1,212,755	243	3,242	3,229	6,471	1,364	190	1,909	1,715	143	529	4,296	5,432	0	844
1959	13,978	278	14,255	45,875	553,709	613,840	24,153	389	0	24,541	196,411	73,616	29,024	206,050	21,987	60,054	10,760	347	13,145	548,195	245	3,279	4,724	8,003	603	82	2,852	2,191	143	230	5,416	5,432	0	-1,216
1960	18,799	399	19,198	60,749	670,788	750,735	25,955	395	0	26,350	202,353	92,191	29,127	219,480	29,795	68,721	11,504	313	17,655	665,250	250	3,336	5,295	8,631	833	106	3,182	2,325	145	312	5,964	5,432	0	8,170
1961	20,222	451	20,673	67,921	740,911	829,506	26,635	412	0	27,047	161,788	76,919	23,507	204,422	31,762	53,625	11,686	394	18,966	735,366	264	3,412	5,448	8,860	918	113	3,308	2,387	148	338	6,182	5,432	0	-6,688
1962	23,466	528	23,994	75,884	873,586	973,463	27,825	423	0	28,248	214,463	68,457	33,018	215,743	37,695	72,756	12,019	327	21,980	868,020	274	3,831	5,749	9,580	1,090	134	3,407	2,491	149	395	6,443	5,432	0	-412
1963	13,794	333	14,127	44,904	557,877	616,909	33,878	426	0	34,304	160,206	103,000	22,628	205,647	18,557	61,402	14,342	500	12,903	552,364	275	3,912	7,629	11,540	657	81	4,565	2,931	151	234	7,881	5,432	0	-126
1964	12,570	316	12,886	39,406	495,526	547,817	33,217	437	0	33,654	29,982	203,742	4,672	206,029	19,388	38,887	13,827	387	11,743	490,019	284	4,283	7,424	11,707	612	75	4,412	2,885	153	215	7,664	5,432	0	4,154
1965	17,918	466	18,384	57,767	647,145	723,296	34,164	456	0	34,620	120,676	125,351	17,467	205,271	31,250	53,379	15,089	574	16,716	641,610	301	4,089	6,880	10,969	892	104	4,568	2,964	155	309	7,996	5,432	0	-3,576
1966	22,817	597	23,415	73,396	800,031	896,841	31,519	463	0	31,982	159,349	106,376	25,041	218,703	24,957	68,453	13,794	352	21,261	794,470	305	4,047	6,489	10,537	1,160	129	4,094	2,743	158	396	7,391	5,432	0	1,961
1967	18,360	532	18,892	59,640	697,997	776,530	37,372	465	0	37,837	113,693	112,664	16,452	188,824	24,713	57,609	16,565	384	17,056	692,460	306	3,838	8,276	12,114	979	105	5,180	3,130	159	325	8,793	5,432	0	-1,601
1968	28,122	844	28,966	92,548	993,950	1,115,464	28,932	471	0	29,403	133,475	98,875	23,317	212,470	33,689	55,626	12,999	388	26,050	988,359	309	3,925	5,456	9,381	1,567	158	3,637	2,527	162	505	6,831	5,432	0	-206
1969	22,554	738	23,292	74,645	774,231	872,167	27,166	478	0	27,644	190,570	84,987	28,271	207,241	28,638	81,624	12,010	433	20,830	768,676	315	4,341	4,846	9,186	1,313	123	3,085	2,452	163	412	6,112	5,432	0	4,422
1970	14,282	504	14,786	44,017	542,187	600,990	33,103	507	0	33,610	209,098	85,621	28,815	206,644	22,887	81,094	14,615	492	13,151	536,675	341	4,349	6,423	10,772	866	80	4,343	2,881	166	265	7,656	5,432	0	-708
1971	17,000	629	17,629	54,171	627,624	699,425	38,989	515	0	39,503	129,538	138,975	18,730	206,114	24,800	77,872	16,762	679	15,608	622,098	345	4,391	8,521	12,912	1,072	94	5,327	3,309	170	320	9,126	5,432	0	-4,832
1972	29,815	1,118	30,934	94,820	1,081,125	1,206,879	37,499	525	0	38,024	54,255	164,378	13,523	206,639	34,476	58,477	15,608	1,089	27,298	1,075,528	352	4,667	7,900	12,567	1,948	165	5,019	3,215	173	570	8,977	5,432	0	337
1973	20,242	815	21,057	65,403	695,773	782,232	36,303	530	0	36,833	166,656	93,594	25,370	205,663	33,184	57,522	15,618	1,112	18,478	690,230	355	5,368	6,631	11,999	1,371	111	4,359	3,215	175	393	8,142	5,432	0	3,913
1974	32,762	1,333	34,095	103,933	1,134,599	1,272,627	34,658	536	0	35,194	191,102	44,650	33,738	209,422	29,130	63,180	15,103	1,072	29,824	1,128,989	359	5,581	5,819	11,400	2,294	178	3,936	3,147	177	644	7,904	5,432	0	4,213
1975	18,769	840	19,609	59,748	708,249	787,605	36,151	545	0	36,696	170,406	87,056	24,475	212,683	35,575	52,820	15,597	1,149	17,033	702,713	364	5,617	6,283	11,900	1,361	103	4,238	3,266	181	375	8,061	5,432	0	-8,345
1976	21,298	1,002	22,300	67,443	768,887	858,630	35,205	557	0	35,762	203,349	64,465	28,917	209,446	30,127	68,324	15,196	1,223	19,269	763,336	371	5,661	6,160	11,821	1,597	119	3,759	3,208	185	432	7,584	5,432	0	-1,558
1977	18,941	930	19,871	59,892	670,353	750,116	45,911	584	0	46,496	100,973	136,166	14,953	211,009	27,410	38,947	19,643	2,417	17,084	664,813	397	5,670	8,453	14,123	1,467	108	5,661	4,068	188	390	10,306	5,432	0	4,713
1978	32,363	1,628	33,991	102,886	1,104,359	1,241,237	46,217	599	0	46,816	52,398	145,150	11,340	212,891	42,602	33,215	19,116	2,227	29,104	1,098,751	409	6,008	8,881	14,888	2,583	176	5,849	4,137	190	675	10,851	5,432	0	387
1979	23,557	1,210	24,767	75,146	835,891	935,804	41,274	615	0	41,889	150,728	95,799	24,713	206,691	36,866	47,877	17,535	2,114	21,123	830,330	421	4,829	7,538	12,366	1,936	129	5,474	3,785	195	498	9,951	5,432	0	5,524
1980	19,817	1,087	20,904	61,829	673,793	756,527	39,929	621	0	40,551	194,127	67,957	27,872	215,523	36,099	51,017	16,931	2,312	17,713	668,253	420	5,459	6,933	12,392	1,678	108	4,619	3,675	201	425	8,921	5,432	0	-6,600
1981	24,823	1,416	26,239	76,553	839,256	942,048	36,939	599	0	37,539	171,079	73,292	24,903	220,626	35,763	43,264	15,026	2,484	22,121	833,689	385	5,999	6,202	12,200	2,162	135	3,763	3,466	214	540	7,983	5,432	0	-3,635
1982	21,747	1,291	23,038	65,705	758,057	846,801	40,254	637	0	40,892	187,203	82,133	26,440	218,272	36,178	48,595	16,513	2,532	19,321	752,508	401	6,481	6,714	13,195	1,947	117	4,151	3,864	237	479	8,730	5,432	0	5,556
1983	22,277	1,371	23,648	68,096	821,301	913,045	40,963	704	0	41,667	194,663	62,823	27,353	219,224	42,384	43,681	16,919	2,990	19,732	815,747	435	7,062	6,199	13,261	2,048	122	3,745	4,049	269	498	8,561	5,432	0	-7,062
1984	35,117	2,059	37,175	107,732	1,222,565	1,367,472	39,021	777	0	39,798	181,772	73,625	34,056	224,520	36,152	45,180	15,553	3,113	31,031	1,216,946	466	6,511	6,142	12,653	3,295	187	3,862	3,841	311	791	8,804	5,432	0	23,219
1985	29,075	1,858	30,932	91,893	1,034,452	1,157,277	38,751	839	0	39,590	187,819	75,081	29,542	233,550	57,980	46,235	15,301	3,546	25,605	1,028,863	498	6,690	5,658	12,348	2,805	156	3,690	3,866	341	665	8,562	5,432	0	-12,514
1986	33,617	2,222	35,840	103,136	1,161,970	1,300,946	41,293	897	0	42,190	231,242	52,628	35,044	237,370	39,434	60,323	16,038	4,182	29,516	1,156,362	526	7,740	5,474	13,215	3,322	176	3,611	4,246	371	779	9,007	5,432	0	14,836
1987	24,745	1,658	26,403	75,163	857,199	958,765	41,546	939	0	42,485	255,280	56,676	38,486	230,005	47,971	78,397	15,663	3,947	21,667	851,635	541	8,002	6,064	14,066	2,498	132	3,728	4,142	399	579	8,848	5,432	0	-7,742
1988	26,176	1,782	27,958	80,285	896,983	1,005,226	42,014	991	0	43,005	220,739	92,200	34,160	239,110	44,081	69,485	16,293	3,977	22,858	891,410	564	7,279	6,231	13,510	2,698	141	4,067	4,166	428	619	9,280	5,432	0	6,387
1989	19,334	1,385	20,719	58,548	635,826	715,094	48,032	1,036	0	49,068	220,656	105,566	31,923	247,641	41,733	69,303	19,049	4,436	16,832	630,294	585	7,982	5,982	13,964	2,039	100	5,803	4,780	451	463	11,497	5,432	0	-5,830
1990	28,201	2,063	30,264	86,298	1,008,656	1,125,218	46,722	1,110	0	47,832	186,319	77,190	11,528	232,420	53,249	54,981	17,383	6,393	24,483	1,003,069	634	8,619	5,052	13,672	3,035	155	4,520	4,755	476	683	10,434	5,432	0	-2,370
1991	35,632	2,591	38,223	110,337	1,200,435	1,348,996	43,965	1,146	0	45,110	205,524	62,325	17,154	228,936	57,952	61,515	15,573	6,562	30,856	1,194,815	642	8,835	5,362	14,197	3,905	188	3,147	4,486	504	871	9,007	5,432	0	12,627
1992	26,824	2,085	28,909	81,827	941,045	1,051,780	43,868	1,201	0	45,070	214,186	77,369	11,809	241,976	51,659	71,214	15,333	6,906	23,152	935,469	672	9,214	5,735	14,950	3,008	144	2,116	4,564	530	664	7,874	5,432	0	-3,279
1993	24,158	1,903	26,061	73,869	835,576	935,506	50,306	1,249	0	51,555	232,650	59,789	13,336	238,436	55,836	69,546	18,324	7,492	20,794	830,014	696	9,981	6,307	16,288	2,760	130	3,039	5,163	553	604	9,358	5,432	0	-10,851
1994	19,114	1,580	20,693	59,621	676,035	756,349	56,502	1,288	0	57,790	265,826	50,743	12,716	245,642	49,233	69,022	20,947	8,305	16,400	670,498	705	9,915	6,225	16,140	2,229	105	5,467	5,643	583	484	12,176	5,432	0	-425
1995	17,289	1,433	18,722	51,379	599,169	669,270	60,804	1,349	0	62,153	222,298	91,041	11,663	249,144	38,632	61,226	22,406	8,615	14,796	593,645	733	10,308	6,835	17,144	2,051	92	6,624	6,016	617	442	13,698	5,432	0	4,053
1996	21,203	1,798	23,001	62,750	749,886	835,637	64,255	1,420	0	65,675	230,708	78,808	12,173	249,950	43,949	67,108	23,588	8,714	18,094	744,343	767	10,529	7,329	17,858	2,562	111	7,794	6,301	654	547	15,296	5,432	0	-915

APPENDIX A2. ANNUAL LAND-SURFACE WATER BUDGET FOR MESILLA BASIN

MESILLA BASIN

INFLOWS, in acre-feet

Year	Precipitation on Urban Lands			Precipitation on Agricultural Lands	Precipitation on Upland Watershed	Total Precipitation on Basin	Urban Applied Groundwater				Surface Water Deliveries to Farms	Agricultural Applied Groundwater
	Urban Excess Precipitation	Urban Effective Precipitation	Total Urban				M&I	Domestic	Imported	Total		
1997	27,244	2,385	29,629	82,778	880,206	992,613	61,358	1,480	0	62,838	231,352	71,149
1998	20,131	1,761	21,892	60,263	672,028	754,183	65,164	1,537	0	66,702	226,777	77,343
1999	24,242	2,164	26,406	74,069	790,029	890,504	61,085	1,593	0	62,679	208,008	76,942
2000	22,930	2,069	25,000	71,899	775,486	872,385	68,907	1,631	0	70,539	215,427	75,361
2001	12,722	1,217	13,939	37,888	425,815	477,641	66,404	1,665	0	68,070	217,608	58,764
2002	18,374	1,774	20,148	55,019	623,415	698,582	65,288	1,713	0	67,001	219,417	57,492
2003	12,738	1,260	13,998	38,927	422,779	475,704	66,978	1,752	18	68,748	61,735	207,412
2004	34,058	3,379	37,437	103,470	1,117,969	1,258,876	67,147	1,806	263	69,216	61,036	168,696
2005	23,569	2,389	25,958	71,286	753,992	851,236	64,394	1,847	241	66,482	157,602	102,868
2006	40,023	3,265	43,289	115,517	1,274,103	1,432,909	68,116	1,863	281	70,260	83,719	150,020
2007	25,111	2,624	27,734	75,386	845,437	948,558	63,859	1,912	356	66,126	132,367	138,030
2008	30,836	2,704	33,539	88,165	989,926	1,111,630	67,474	1,918	277	69,669	163,812	81,432
2009	21,554	2,300	23,854	63,446	727,081	814,380	63,461	1,919	234	65,614	143,897	109,563
2010	22,543	2,392	24,935	66,649	789,900	881,484	77,086	1,913	413	79,412	168,755	91,478
2011	14,204	1,541	15,745	44,835	455,763	516,343	96,334	1,944	484	98,763	19,010	261,492
2012	13,052	1,434	14,486	38,726	420,463	473,675	93,049	1,954	533	95,535	59,288	206,837
2013	22,847	2,378	25,225	67,019	718,193	810,438	87,488	1,971	476	89,935	19,273	228,191
2014	26,536	2,698	29,234	80,673	896,751	1,006,658	88,228	1,977	651	90,856	45,524	197,582
2015	31,186	3,346	34,531	99,242	1,039,937	1,173,710	86,081	1,974	689	88,745	62,170	159,351
2016	21,381	2,326	23,707	66,685	728,425	818,818	84,635	1,972	768	87,375	73,372	169,796

OUTFLOWS, in acre-feet

Year	Agricultural Surface Runoff	Agricultural Crop Consumptive Use	Agricultural Non-crop Consumptive Use	Agricultural Deep Percolation	Urban Consumptive Use	Consumptive Use of Wastewater	Consumptive Use in Undeveloped, Non-Agricultural Lands	Consumptive Use in Upland Watershed Lands	Consumptive Use of Domestic Pumping	Urban Wastewater Discharge			Urban Runoff	Tributary Outflows to Surface Water	Urban Deep Percolation					Mountain Front Recharge	Exported Groundwater	Change in Soil Moisture Storage
										To Surface Water	Exported	Total			Applied Water	Conveyance Loss	Septics	Precipitation	Total			
1997	11,878	257,369	45,787	62,695	22,352	8,653	23,178	874,632	814	10,892	7,735	18,627	3,355	142	5,597	6,109	686	711	13,104	5,432	0	7,551
1998	12,736	251,392	48,451	63,023	25,658	8,528	17,082	666,488	844	10,724	8,875	19,599	2,519	108	4,915	6,443	713	530	12,602	5,432	0	-11,221
1999	12,231	238,587	41,079	63,096	22,522	8,781	20,512	784,471	876	10,710	8,526	19,236	3,086	125	4,407	6,120	737	645	11,908	5,432	0	4,024
2000	13,576	245,554	40,431	66,014	25,736	11,051	19,349	769,936	894	10,737	9,662	20,398	2,967	118	4,819	6,883	757	615	13,075	5,432	0	-2,888
2001	10,066	209,861	36,361	59,345	22,617	10,548	10,697	420,315	911	11,120	7,860	18,980	1,679	67	7,617	6,622	774	346	15,359	5,432	0	-1,373
2002	10,929	211,083	42,180	61,430	21,979	10,744	15,408	617,886	940	10,199	7,374	17,573	2,463	97	8,437	6,534	793	504	16,268	5,432	0	6,305
2003	3,295	229,826	38,635	43,086	22,338	10,758	10,650	417,281	963	10,419	6,438	16,857	1,735	66	10,395	6,627	810	353	18,185	5,432	0	-6,768
2004	6,053	226,734	54,615	41,311	22,317	11,357	28,401	1,112,358	994	11,301	6,515	17,816	4,707	179	9,049	6,850	832	951	17,682	5,432	0	4,489
2005	9,051	225,790	47,357	51,755	20,799	11,481	19,596	748,439	1,017	10,687	6,273	16,960	3,309	121	8,823	6,552	850	664	16,888	5,432	0	-2,197
2006	26,242	219,990	52,118	48,997	21,343	12,737	33,316	1,268,462	1,016	11,513	6,885	18,398	5,592	209	9,073	6,825	867	1,116	17,881	5,432	0	1,909
2007	7,375	230,116	55,644	52,547	19,712	12,257	20,786	839,868	1,054	11,536	7,191	18,726	3,607	138	6,986	6,512	878	718	15,094	5,432	0	100
2008	20,526	210,227	51,841	54,415	21,015	12,871	25,574	984,332	1,048	11,922	6,677	18,598	4,391	162	8,397	6,850	890	871	17,009	5,432	0	-3,599
2009	7,544	211,418	45,501	50,554	18,866	11,415	17,788	721,538	1,046	12,213	6,153	18,365	3,144	111	8,769	6,260	893	622	16,544	5,432	0	1,890
2010	9,634	214,812	54,014	52,843	20,484	11,324	18,583	784,351	1,035	12,243	6,340	18,583	3,308	117	7,701	6,408	898	652	15,659	5,432	12,979	-4,421
2011	1,705	243,080	37,539	37,241	22,282	12,262	11,688	450,259	1,061	12,510	9,084	21,594	2,102	72	6,368	6,892	904	413	14,577	5,432	27,401	5,772
2012	3,155	222,656	41,780	42,028	20,977	11,970	10,723	414,963	1,061	12,070	6,675	18,745	1,947	68	7,929	6,539	913	382	15,762	5,432	27,401	-4,768
2013	5,363	222,223	47,397	38,792	18,757	10,323	18,767	712,650	1,074	11,580	7,349	18,929	3,412	112	6,576	5,957	917	667	14,118	5,432	27,401	708
2014	10,134	223,345	39,619	42,492	20,023	9,818	21,780	891,188	1,080	11,864	8,048	19,912	3,980	131	5,672	6,032	917	776	13,397	5,432	27,401	8,189
2015	8,828	207,956	64,295	43,229	19,163	9,234	25,568	1,034,350	1,057	11,615	6,321	17,937	4,701	155	7,164	5,852	938	917	14,871	5,432	27,401	-3,545
2016	6,389	210,790	53,356	43,573	18,318	9,540	17,525	722,897	1,054	12,162	6,306	18,468	3,227	97	5,902	5,753	938	629	13,223	5,432	27,401	-4,255

APPENDIX B

ANNUAL SURFACE WATER BUDGETS
FOR RINCON AND MESILLA BASINS

APPENDIX B1. ANNUAL SURFACE WATER BUDGET FOR RINCON BASIN

	RINCON BASIN										
	INFLOWS, in acre-feet					OUTFLOWS, in acre-feet					
Year	Rio Grande Inflow	Tributary Inflows	Urban Return Flows	Wastewater Discharges	Agricultural Surface Runoff	Farm Deliveries	Above-Farm Incidental Depletion	Below-Farm Incidental Depletion	Rio Grande Outflow	Open Channel Evapotranspiration	Net GW-SW Exchange [a]
1938	780,377	5,873	37	0	5,903	33,709	890	2,519	746,809	8,064	-200
1939	788,971	4,911	30	0	5,769	39,911	1,051	2,968	737,503	7,336	-10,913
1940	731,833	4,928	27	0	5,706	41,123	1,009	3,079	689,756	7,719	192
1941	704,194	9,764	65	0	6,804	35,145	794	2,302	685,870	7,172	10,457
1942	1,795,525	4,998	33	0	6,134	41,593	1,106	3,180	1,764,125	6,010	9,324
1943	911,865	4,799	31	0	5,874	49,339	1,393	4,022	861,064	6,610	-140
1944	866,176	6,010	38	0	5,994	47,873	1,161	3,411	807,029	6,505	-12,238
1945	882,811	3,247	22	0	5,990	50,820	1,342	3,863	817,741	6,500	-11,804
1946	763,668	4,421	31	0	5,582	47,500	1,338	3,991	734,811	6,378	20,315
1947	724,903	3,219	24	0	5,176	43,493	1,186	3,736	686,122	6,491	7,706
1948	741,064	4,113	31	0	4,799	40,960	1,151	3,568	686,642	6,542	-11,144
1949	712,157	5,778	44	0	5,831	44,960	1,237	3,734	689,964	7,438	23,522
1950	719,270	4,086	34	0	6,723	48,038	1,253	3,091	706,889	8,393	37,551
1951	469,345	3,098	22	0	3,449	24,702	651	3,454	431,714	8,587	-6,807
1952	543,854	4,327	33	0	3,998	28,181	830	3,232	483,261	7,401	-29,306
1953	528,551	3,226	28	0	3,765	26,638	715	3,566	512,961	8,014	16,324
1954	244,019	4,706	43	0	1,825	8,021	259	2,734	248,983	8,028	17,433
1955	219,074	4,165	37	0	1,472	5,563	178	2,982	190,774	8,086	-17,165
1956	246,022	2,172	19	0	1,220	8,313	265	3,245	210,054	8,490	-19,066
1957	397,012	6,762	64	0	3,082	12,041	377	2,443	389,665	7,409	5,015
1958	737,111	8,421	76	0	6,973	38,245	991	2,465	735,901	6,805	31,827
1959	687,398	4,159	37	0	6,061	36,595	1,006	3,090	660,028	8,046	11,109
1960	705,076	4,666	40	0	5,904	41,068	1,140	3,086	664,889	7,760	2,257
1961	561,574	5,744	54	0	4,393	26,833	812	2,729	534,678	7,426	712
1962	651,892	6,472	59	0	6,543	38,424	996	2,825	608,601	6,938	-7,183
1963	517,010	3,981	33	0	4,093	27,886	804	2,875	465,457	7,217	-20,878
1964	205,997	3,720	29	0	958	5,304	196	2,993	167,632	7,510	-27,069
1965	505,587	4,725	40	0	3,423	22,328	746	3,231	428,652	7,593	-51,226
1966	610,257	4,959	46	0	5,020	32,192	907	2,725	522,835	7,068	-54,553
1967	456,434	5,983	53	0	3,633	20,788	589	2,681	446,738	7,606	12,299
1968	505,638	5,227	46	0	4,538	29,334	830	3,121	479,136	7,252	4,224
1969	667,577	4,970	43	0	5,411	37,184	1,025	3,130	626,314	7,430	-2,918
1970	661,119	3,663	33	0	5,726	40,581	1,141	3,355	635,026	7,442	17,006
1971	498,401	4,649	41	0	4,126	27,222	816	3,237	462,793	8,129	-5,019
1972	260,832	7,486	66	0	3,304	11,833	366	2,686	263,173	7,065	13,435
1973	617,215	4,884	50	0	4,949	31,669	991	3,194	574,290	7,137	-9,816
1974	640,897	7,122	71	0	7,333	38,463	1,042	2,728	625,535	7,379	19,725
1975	580,590	6,319	59	0	6,505	36,078	1,024	2,979	589,097	7,072	42,777
1976	679,573	4,824	44	0	6,305	44,460	1,179	3,270	663,705	7,159	29,028
1977	417,384	4,863	44	0	3,146	19,969	646	3,120	398,321	7,123	3,742
1978	356,091	7,082	68	0	2,356	11,786	423	2,954	338,836	7,404	-4,193
1979	568,590	5,806	59	0	5,477	35,197	1,039	3,011	563,274	6,841	29,429
1980	658,608	4,379	46	0	6,060	42,641	1,181	3,366	631,371	7,073	16,540
1981	607,918	5,468	55	0	5,603	38,464	1,075	3,197	574,867	6,926	5,485
1982	643,904	5,794	57	0	5,892	40,348	1,145	3,230	599,006	7,801	-4,116
1983	648,270	6,470	62	0	5,771	39,421	1,115	3,067	599,712	7,044	-10,214
1984	653,002	8,300	89	0	7,651	40,084	1,093	2,936	628,117	6,648	9,836
1985	677,457	7,095	70	0	7,331	46,725	1,211	3,200	645,911	6,373	11,468
1986	1,395,913	8,684	93	0	9,386	59,238	1,426	3,394	1,344,964	6,512	1,457
1987	1,376,079	5,982	68	0	9,369	63,131	1,383	3,198	1,301,724	6,349	-15,712
1988	837,802	6,710	71	0	8,246	50,806	1,230	3,357	802,721	6,736	12,021
1989	736,518	4,050	45	0	7,690	53,981	1,364	4,152	706,116	7,317	24,627
1990	680,366	7,851	90	97	4,181	43,265	1,100	3,506	644,394	6,567	6,247
1991	626,003	8,716	109	105	4,963	48,575	1,180	3,711	575,897	6,722	-3,812
1992	734,987	7,272	86	102	3,002	41,966	1,134	4,100	696,883	6,542	5,176
1993	823,263	5,635	58	109	2,983	48,618	1,345	4,622	769,008	7,138	-1,318
1994	893,482	5,871	66	120	3,242	61,149	1,603	4,738	830,120	7,615	2,443
1995	1,096,181	3,972	46	103	3,128	60,533	1,680	5,186	1,005,213	7,938	-22,881

APPENDIX B1. ANNUAL SURFACE WATER BUDGET FOR RINCON BASIN

	RINCON BASIN										
	INFLOWS, in acre-feet					OUTFLOWS, in acre-feet					
Year	Rio Grande Inflow	Tributary Inflows	Urban Return Flows	Wastewater Discharges	Agricultural Surface Runoff	Farm Deliveries	Above-Farm Incidental Depletion	Below-Farm Incidental Depletion	Rio Grande Outflow	Open Channel Evapotranspiration	Net GW-SW Exchange [a]
1996	774,430	5,723	70	132	3,025	51,325	1,370	4,750	719,290	8,077	1,431
1997	798,609	6,356	78	158	2,773	51,852	1,394	4,391	764,961	7,214	21,839
1998	808,758	5,112	63	138	3,665	61,964	1,581	4,380	728,287	7,960	-13,564
1999	735,493	6,312	83	132	3,922	51,695	1,404	4,051	673,783	7,903	-7,105
2000	751,474	6,281	85	186	3,700	55,585	1,405	3,838	688,048	8,106	-4,743
2001	786,631	3,810	45	245	2,680	57,194	1,482	3,784	718,086	7,195	-5,669
2002	801,219	4,156	56	217	2,733	55,628	1,505	3,954	722,580	7,882	-16,831
2003	364,532	3,062	41	254	687	12,342	378	4,537	304,568	8,169	-38,583
2004	399,598	7,229	108	271	1,345	12,967	400	3,821	362,755	7,390	-21,218
2005	676,086	5,034	73	267	2,251	41,213	1,219	4,554	630,504	7,647	1,425
2006	434,348	8,139	128	257	4,619	19,206	545	4,152	463,853	7,612	47,876
2007	636,609	5,376	74	263	1,880	35,117	1,011	5,043	591,802	7,470	-3,758
2008	675,412	6,803	110	259	5,526	43,080	1,169	4,342	627,150	7,766	-4,604
2009	693,836	4,920	78	379	2,353	43,798	1,199	4,687	651,492	7,703	7,312
2010	660,420	6,000	93	266	2,730	33,648	992	4,998	614,628	7,491	-7,753
2011	396,756	4,379	76	248	770	4,734	158	5,745	384,117	7,989	515
2012	375,521	2,613	44	289	712	13,386	434	5,236	364,872	7,882	12,632
2013	168,827	5,650	94	194	1,615	4,592	148	4,452	155,623	10,106	-1,458
2014	302,987	5,858	97	218	1,995	8,764	277	4,025	299,135	10,334	11,380
2015	435,512	7,173	123	222	1,727	17,400	503	3,799	419,242	7,617	3,804
2016	545,506	6,068	100	224	1,777	20,535	581	3,927	518,930	8,484	-1,218

[a] Positive values indicate gains to the surface water system; negative values indicate losses from the surface water system.

APPENDIX B2. ANNUAL SURFACE WATER BUDGET FOR MESILLA BASIN

	MESILLA BASIN										
	INFLOWS, in acre-feet					OUTFLOWS, in acre-feet					
Year	Rio Grande Inflow	Tributary Inflows	Urban Return Flows	Wastewater Discharges	Agricultural Surface Runoff	Farm Deliveries	Above-Farm Incidental Depletion	Below-Farm Incidental Depletion	Rio Grande Outflow	Open Channel Evapotranspiration	Net GW-SW Exchange [a]
1938	746,809	128	659	0	33,452	212,979	5,070	14,028	554,916	18,397	24,342
1939	737,503	90	463	0	34,084	248,066	6,139	17,016	511,468	16,802	27,351
1940	689,756	111	582	161	33,381	240,866	5,998	17,098	453,769	17,778	11,517
1941	685,870	236	1,271	241	42,108	203,205	4,789	13,580	511,311	16,471	19,630
1942	1,764,125	129	690	255	31,662	215,724	5,753	16,108	1,559,193	13,764	13,680
1943	861,064	104	566	256	30,654	264,134	6,967	19,517	631,745	15,130	44,849
1944	807,029	139	777	256	31,451	261,740	6,524	18,405	611,863	14,898	73,778
1945	817,741	88	488	256	34,920	297,580	7,571	21,268	568,748	14,886	56,560
1946	734,811	93	537	256	31,128	270,440	7,578	21,537	497,968	14,606	45,306
1947	686,122	81	475	304	29,182	253,040	6,950	19,964	458,696	15,007	37,492
1948	686,642	83	505	716	28,821	251,170	6,824	19,436	431,576	15,064	7,302
1949	689,964	136	812	762	31,526	258,580	6,734	19,215	463,531	17,052	41,912
1950	706,889	87	537	848	31,327	258,981	6,890	15,300	472,598	19,417	33,496
1951	431,714	71	427	1,414	18,834	137,209	3,416	17,662	251,986	19,684	-22,503
1952	483,261	102	635	1,460	20,965	150,168	4,243	16,179	283,617	16,868	-35,348
1953	512,961	60	373	1,643	20,058	146,073	3,806	18,188	264,603	18,371	-84,053
1954	248,983	85	562	2,449	8,375	52,315	1,669	14,669	93,705	18,313	-79,782
1955	190,774	102	698	2,522	9,970	40,121	1,225	14,627	67,083	18,581	-62,429
1956	210,054	57	392	2,555	5,485	38,326	1,103	16,688	57,441	19,343	-85,643
1957	389,665	128	896	2,650	13,379	82,375	2,477	13,512	139,565	17,284	-151,505
1958	735,901	190	1,364	3,242	34,735	208,595	5,079	12,607	392,805	15,688	-140,659
1959	660,028	82	603	3,279	29,024	196,411	4,859	14,379	385,809	18,444	-73,114
1960	664,889	106	833	3,336	29,127	202,353	5,107	15,363	378,119	17,816	-79,532
1961	534,678	113	918	3,412	23,507	161,788	4,425	13,402	300,795	17,036	-65,182
1962	608,601	134	1,090	3,831	33,018	214,463	4,983	14,056	376,153	16,005	-21,014
1963	465,457	81	657	3,912	22,628	160,206	3,835	14,142	263,708	16,545	-34,298
1964	167,632	75	612	4,283	4,672	29,982	886	14,668	64,320	17,160	-50,258
1965	428,652	104	892	4,089	17,467	120,676	3,504	14,124	202,376	17,218	-93,306
1966	522,835	129	1,160	4,047	25,041	159,349	4,221	13,639	308,771	16,174	-51,059
1967	446,738	105	979	3,838	16,452	113,693	2,708	12,469	232,707	17,492	-89,043
1968	479,136	158	1,567	3,925	23,317	133,475	3,289	12,776	264,375	16,600	-77,589
1969	626,314	123	1,313	4,341	28,271	190,570	4,468	13,297	365,373	17,009	-69,643
1970	635,026	80	866	4,349	28,815	209,098	4,951	14,599	360,682	17,031	-62,776
1971	462,793	94	1,072	4,391	18,730	129,538	3,360	14,052	244,134	18,590	-77,406
1972	263,173	165	1,948	4,667	13,523	54,255	1,415	11,865	133,553	16,146	-66,242
1973	574,290	111	1,371	5,368	25,370	166,656	4,488	14,103	301,775	16,325	-103,163
1974	625,535	178	2,294	5,581	33,738	191,102	4,582	11,878	382,879	16,873	-60,012
1975	589,097	103	1,361	5,617	24,475	170,406	4,859	14,349	360,954	16,142	-53,943
1976	663,705	119	1,597	5,661	28,917	203,349	5,003	13,503	402,770	16,406	-58,968
1977	398,321	108	1,467	5,670	14,953	100,973	3,038	14,188	214,578	16,259	-71,482
1978	338,836	176	2,583	6,008	11,340	52,398	1,865	12,714	155,992	16,880	-119,095
1979	563,274	129	1,936	4,829	24,713	150,728	4,507	13,787	312,557	15,638	-97,663
1980	631,371	108	1,678	5,459	27,872	194,127	5,254	14,797	353,990	16,167	-82,153
1981	574,867	135	2,162	5,999	24,903	171,079	4,754	14,040	333,336	15,811	-69,046
1982	599,006	117	1,947	6,481	26,440	187,203	5,100	15,262	326,586	17,844	-81,996
1983	599,712	122	2,048	7,062	27,353	194,663	5,381	14,905	331,936	16,140	-73,272
1984	628,117	187	3,295	6,511	34,056	181,772	4,976	13,927	359,326	15,276	-96,890
1985	645,911	156	2,805	6,690	29,542	187,819	5,216	14,805	359,891	14,501	-102,873
1986	1,344,964	176	3,322	7,740	35,044	231,242	5,666	14,690	1,048,877	14,886	-75,885
1987	1,301,724	132	2,498	8,002	38,486	255,280	5,952	15,671	1,076,156	14,450	16,667
1988	802,721	141	2,698	7,279	34,160	220,739	5,278	15,904	569,919	15,362	-19,798
1989	706,116	100	2,039	7,982	31,923	220,656	5,552	17,726	428,136	16,640	-59,449
1990	644,394	155	3,035	8,619	11,528	186,319	5,024	14,969	391,874	15,043	-54,503
1991	575,897	188	3,905	8,835	17,154	205,524	5,348	14,759	372,060	15,376	7,087
1992	696,883	144	3,008	9,214	11,809	214,186	5,750	16,669	470,358	14,955	860
1993	769,008	130	2,760	9,981	13,336	232,650	6,370	16,757	508,007	16,297	-15,134
1994	830,120	105	2,229	9,915	12,716	265,826	7,076	17,584	508,576	17,377	-38,648
1995	1,005,213	92	2,051	10,308	11,663	222,298	6,120	18,263	702,391	18,120	-62,136

APPENDIX B2. ANNUAL SURFACE WATER BUDGET FOR MESILLA BASIN

	MESILLA BASIN										
	INFLOWS, in acre-feet					OUTFLOWS, in acre-feet					
Year	Rio Grande Inflow	Tributary Inflows	Urban Return Flows	Wastewater Discharges	Agricultural Surface Runoff	Farm Deliveries	Above-Farm Incidental Depletion	Below-Farm Incidental Depletion	Rio Grande Outflow	Open Channel Evapotranspiration	Net GW-SW Exchange [a]
1996	719,290	111	2,562	10,529	12,173	230,708	6,046	17,270	446,822	18,342	-25,476
1997	764,961	142	3,355	10,892	11,878	231,352	6,425	17,509	483,088	16,490	-36,364
1998	728,287	108	2,519	10,724	12,736	226,777	6,299	17,807	456,553	18,105	-28,831
1999	673,783	125	3,086	10,710	12,231	208,008	5,592	16,111	457,361	18,010	5,147
2000	688,048	118	2,967	10,737	13,576	215,427	5,778	16,483	433,238	18,476	-26,044
2001	718,086	67	1,679	11,120	10,066	217,608	5,931	15,580	453,477	16,410	-32,012
2002	722,580	97	2,463	10,199	10,929	219,417	5,978	15,485	473,488	17,994	-13,907
2003	304,568	66	1,735	10,419	3,295	61,735	1,911	17,434	172,336	18,581	-48,086
2004	362,755	179	4,707	11,301	6,053	61,036	1,833	14,070	186,891	16,860	-104,306
2005	630,504	121	3,309	10,687	9,051	157,602	4,793	16,120	329,784	17,441	-127,932
2006	463,853	209	5,592	11,513	26,242	83,719	2,479	13,613	278,495	17,291	-111,812
2007	591,802	138	3,607	11,536	7,375	132,367	3,940	16,047	337,831	16,921	-107,352
2008	627,150	162	4,391	11,922	20,526	163,812	4,712	13,829	377,831	17,710	-86,256
2009	651,492	111	3,144	12,213	7,544	143,897	4,249	14,897	382,003	17,394	-112,063
2010	614,628	117	3,308	12,243	9,634	168,755	4,955	15,374	363,798	16,780	-70,268
2011	384,117	72	2,102	12,510	1,705	19,010	671	18,491	230,397	18,709	-113,230
2012	364,872	68	1,947	12,070	3,155	59,288	2,000	16,795	132,844	17,959	-153,225
2013	155,623	112	3,412	11,580	5,363	19,273	655	15,469	57,451	23,004	-60,238
2014	299,135	131	3,980	11,864	10,134	45,524	1,521	15,010	105,267	23,461	-134,462
2015	419,242	155	4,701	11,615	8,828	62,170	1,900	13,409	170,502	17,464	-179,098
2016	518,930	97	3,227	12,162	6,389	73,372	2,251	14,771	228,350	19,452	-202,610

[a] Positive values indicate gains to the surface water system; negative values indicate losses from the surface water system.

APPENDIX C

ANNUAL GROUNDWATER BUDGETS
FOR RINCON AND MESILLA BASINS

APPENDIX C1. ANNUAL GROUNDWATER BUDGET FOR RINCON BASIN

	RINCON BASIN										
	INFLOWS, in acre-feet				OUTFLOWS, in acre-feet						
Year	Transbasin Inflow	Mountain-Front Recharge	Agricultural Deep Percolation	Urban Deep Percolation	Agricultural Groundwater Pumping	Urban Groundwater Pumping	Riparian Consumptive Use	Transbasin Outflow	Net Exchange with Surface Water Network [a]	Change in Storage (residual)	Cum. Storage Change
1938	1,501	9,360	5,440	18	830	40	11,152	10	-200	4,488	4,488
1939	1,501	9,360	7,329	16	925	44	11,170	10	-10,913	16,970	21,459
1940	1,501	9,360	8,377	19	971	88	11,107	10	192	6,890	28,348
1941	1,501	9,360	9,058	29	910	89	11,086	10	10,457	-2,604	25,745
1942	1,501	9,360	8,381	21	1,400	89	12,336	10	9,324	-3,897	21,848
1943	1,501	9,360	8,339	21	1,656	89	11,437	10	-140	6,169	28,017
1944	1,501	9,360	11,105	23	1,523	92	11,366	10	-12,238	21,235	49,253
1945	1,501	9,360	10,871	19	1,889	92	11,378	10	-11,804	20,185	69,437
1946	1,501	9,360	8,666	21	2,206	92	11,191	10	20,315	-14,265	55,172
1947	1,501	9,360	7,807	19	2,325	94	11,107	10	7,706	-2,554	52,618
1948	1,501	9,360	5,894	25	2,532	133	11,077	10	-11,144	14,172	66,790
1949	1,501	9,360	8,075	28	2,488	140	11,056	10	23,522	-18,252	48,538
1950	1,501	9,360	8,712	26	2,904	141	11,069	10	37,551	-32,075	16,462
1951	1,501	9,360	7,199	24	32,669	143	10,398	10	-6,807	-18,330	-1,868
1952	1,501	9,360	6,209	27	23,313	145	10,412	10	-29,306	12,523	10,655
1953	1,501	9,360	7,201	26	29,050	145	10,325	10	16,324	-37,767	-27,112
1954	1,501	9,360	4,343	29	32,231	148	10,351	10	17,433	-44,939	-72,051
1955	1,501	9,360	4,426	28	37,308	148	10,020	10	-17,165	-15,006	-87,057
1956	1,501	9,360	4,978	24	39,286	152	10,733	10	-19,066	-15,252	-102,309
1957	1,501	9,360	3,976	35	24,320	152	10,634	10	5,015	-25,260	-127,569
1958	1,501	9,360	8,754	38	6,284	152	10,701	10	31,827	-29,321	-156,890
1959	1,501	9,360	9,141	29	16,509	152	11,898	10	11,109	-19,649	-176,538
1960	1,501	9,360	8,897	30	13,146	155	11,176	10	2,257	-6,956	-183,494
1961	1,501	9,360	7,726	34	17,726	155	11,278	10	712	-11,262	-194,756
1962	1,501	9,360	11,249	35	13,640	155	11,254	10	-7,183	4,268	-190,488
1963	1,501	9,360	8,237	28	21,197	155	11,164	10	-20,878	7,477	-183,011
1964	1,501	9,360	4,833	28	38,971	156	10,551	10	-27,069	-6,896	-189,907
1965	1,501	9,360	7,440	30	28,588	156	11,200	10	-51,226	29,604	-160,303
1966	1,501	9,360	9,569	32	17,255	157	10,957	10	-54,553	46,636	-113,668
1967	1,501	9,360	7,161	34	21,636	157	10,408	10	12,299	-26,455	-140,122
1968	1,501	9,360	8,164	32	21,709	159	10,048	10	4,224	-17,093	-157,215
1969	1,501	9,360	10,292	32	18,378	159	11,027	10	-2,918	-5,471	-162,686
1970	1,501	9,360	11,232	29	18,465	160	10,885	10	17,006	-24,403	-187,090
1971	1,501	9,360	10,581	36	27,130	201	10,055	10	-5,019	-10,900	-197,989
1972	1,501	9,360	7,775	42	31,267	202	8,047	10	13,435	-34,283	-232,272
1973	1,501	9,360	9,836	39	22,929	206	9,260	10	-9,816	-1,853	-234,126
1974	1,501	9,360	11,955	44	12,635	207	9,622	10	19,725	-19,338	-253,464
1975	1,501	9,360	10,527	41	16,663	210	9,126	10	42,777	-47,356	-300,820
1976	1,501	9,360	14,620	41	18,106	230	9,374	10	29,028	-31,227	-332,047
1977	1,501	9,360	8,391	42	31,443	241	10,261	10	3,742	-26,402	-358,449
1978	1,501	9,360	7,456	50	33,781	262	10,159	10	-4,193	-21,653	-380,102
1979	1,501	9,360	11,104	48	19,732	270	10,334	10	29,429	-37,763	-417,866
1980	1,501	9,360	12,306	53	18,264	344	10,591	10	16,540	-22,527	-440,392
1981	1,501	9,360	11,156	56	18,310	321	10,047	10	5,485	-12,101	-452,493
1982	1,501	9,360	11,013	60	17,334	362	10,629	10	-4,116	-2,285	-454,778
1983	1,501	9,360	9,605	65	15,543	392	10,522	10	-10,214	4,279	-450,499
1984	1,501	9,360	10,521	77	14,160	427	10,721	10	9,836	-13,696	-464,195
1985	1,501	9,360	11,918	77	13,436	466	10,080	10	11,468	-12,604	-476,799
1986	1,501	9,360	16,099	80	9,585	429	10,511	10	1,457	5,048	-471,751
1987	1,501	9,360	20,657	73	6,724	401	10,987	10	-15,712	29,181	-442,570
1988	1,501	9,360	14,970	74	16,391	399	10,465	10	12,021	-13,382	-455,952
1989	1,501	9,360	16,691	69	23,915	397	10,366	10	24,627	-31,694	-487,646
1990	1,501	9,360	15,746	173	21,560	909	9,550	10	6,247	-11,495	-499,141
1991	1,501	9,360	21,327	182	23,557	896	12,399	10	-3,812	-681	-499,822
1992	1,501	9,360	20,294	178	31,244	922	10,388	10	5,176	-16,407	-516,229
1993	1,501	9,360	20,255	190	32,078	1,057	12,393	10	-1,318	-12,914	-529,143
1994	1,501	9,360	20,396	199	24,701	1,057	12,339	10	2,443	-9,095	-538,237

	RINCON BASIN										
	INFLOWS, in acre-feet				OUTFLOWS, in acre-feet						
Year	Transbasin Inflow	Mountain-Front Recharge	Agricultural Deep Percolation	Urban Deep Percolation	Agricultural Groundwater Pumping	Urban Groundwater Pumping	Riparian Consumptive Use	Transbasin Outflow	Net Exchange with Surface Water Network [a]	Change in Storage (residual)	Cum. Storage Change
1995	1,501	9,360	18,548	195	27,631	1,122	12,230	10	-22,881	11,490	-526,748
1996	1,501	9,360	18,481	230	31,916	1,288	12,216	10	1,431	-17,289	-544,037
1997	1,501	9,360	19,299	247	26,020	1,310	11,297	10	21,839	-30,069	-574,106
1998	1,501	9,360	21,201	225	18,416	1,195	10,905	10	-13,564	15,326	-558,780
1999	1,501	9,360	15,799	230	18,991	1,221	11,039	10	-7,105	2,735	-556,046
2000	1,501	9,360	19,016	211	15,361	1,413	10,826	10	-4,743	7,221	-548,825
2001	1,501	9,360	17,563	195	12,752	1,465	9,948	10	-5,669	10,114	-538,711
2002	1,501	9,360	16,237	609	15,456	1,626	10,269	10	-16,831	17,177	-521,534
2003	1,501	9,360	12,151	648	58,993	1,794	9,107	10	-38,583	-7,660	-529,194
2004	1,501	9,360	12,267	559	49,563	914	8,210	10	-21,218	-13,793	-542,987
2005	1,501	9,360	16,180	487	33,985	672	10,613	10	1,425	-19,178	-562,165
2006	1,501	9,360	16,669	483	52,099	650	8,832	10	47,876	-81,455	-643,619
2007	1,501	9,360	20,921	316	53,065	684	9,032	10	-3,758	-26,935	-670,554
2008	1,501	9,360	21,309	162	35,653	579	9,726	10	-4,604	-9,033	-679,587
2009	1,501	9,360	20,946	189	39,310	733	10,207	10	7,312	-25,575	-705,161
2010	1,501	9,360	19,574	306	51,110	932	10,065	10	-7,753	-23,623	-728,785
2011	1,501	9,360	16,705	359	84,990	1,113	7,116	10	515	-65,818	-794,603
2012	1,501	9,360	17,107	308	71,186	911	5,774	10	12,632	-62,238	-856,841
2013	1,501	9,360	15,739	530	69,126	1,249	4,826	10	-1,458	-46,623	-903,464
2014	1,501	9,360	15,625	567	58,994	1,426	4,970	10	11,380	-49,727	-953,191
2015	1,501	9,360	16,432	618	48,722	1,295	4,788	10	3,804	-30,708	-983,900
2016	1,501	9,360	16,659	318	49,129	1,283	5,600	10	-1,218	-26,965	########

[a] Positive values indicate gains to the surface water system; negative values indicate losses from the surface water system.

APPENDIX C2. ANNUAL GROUNDWATER BUDGET FOR MESILLA BASIN

	MESILLA BASIN										
	INFLOWS, in acre-feet				OUTFLOWS, in acre-feet						
Year	Transbasin Inflow	Mountain-Front Recharge	Agricultural Deep Percolation	Urban Deep Percolation	Agricultural Groundwater Pumping	Urban Groundwater Pumping	Riparian Consumptive Use	Transbasin Outflow	Net Exchange with Surface Water Network [a]	Change in Storage (residual)	Cum. Storage Change
1938	860	5,432	46,317	455	1,140	362	13,007	1,050	24,342	13,164	13,164
1939	860	5,432	53,603	354	1,689	362	12,968	1,050	27,351	16,830	29,993
1940	860	5,432	52,819	460	1,989	710	12,914	1,050	11,517	31,391	61,384
1941	860	5,432	54,263	859	1,848	949	12,957	1,050	19,630	24,981	86,365
1942	860	5,432	45,946	763	2,642	1,277	14,511	1,050	13,680	19,841	106,206
1943	860	5,432	56,853	707	3,247	1,309	13,229	1,050	44,849	168	106,375
1944	860	5,432	61,850	802	3,359	1,309	13,177	1,050	73,778	-23,730	82,645
1945	860	5,432	71,599	730	4,269	1,568	13,129	1,050	56,560	2,045	84,691
1946	860	5,432	53,748	745	4,827	1,548	12,942	1,050	45,306	-4,889	79,802
1947	860	5,432	51,617	702	4,933	1,531	12,887	1,050	37,492	718	80,520
1948	860	5,432	47,447	714	5,164	2,131	12,852	1,050	7,302	25,953	106,473
1949	860	5,432	62,575	1,111	5,089	2,631	12,881	1,050	41,912	6,415	112,888
1950	860	5,432	55,481	1,002	6,303	2,716	12,874	1,050	33,496	6,336	119,224
1951	860	5,432	53,053	680	172,095	2,905	12,207	1,050	-22,503	-105,729	13,494
1952	860	5,432	48,364	1,844	123,832	7,802	12,182	1,050	-35,348	-53,018	-39,524
1953	860	5,432	53,247	2,685	158,111	11,386	11,960	1,050	-84,053	-36,230	-75,754
1954	860	5,432	41,440	3,147	181,427	14,026	11,928	1,050	-79,782	-77,771	-153,525
1955	860	5,432	40,978	2,543	190,992	12,278	11,692	1,050	-62,429	-103,769	-257,294
1956	860	5,432	48,424	3,974	226,835	18,072	12,255	1,050	-85,643	-113,880	-371,174
1957	860	5,432	39,108	4,401	137,793	19,311	12,099	1,050	-151,505	31,054	-340,120
1958	860	5,432	64,937	4,296	31,550	18,866	12,414	1,050	-140,659	152,304	-187,815
1959	860	5,432	60,054	5,416	73,616	24,541	13,799	1,050	-73,114	31,869	-155,946
1960	860	5,432	68,721	5,964	92,191	26,350	12,858	1,050	-79,532	28,060	-127,886
1961	860	5,432	53,625	6,182	76,919	27,047	13,039	1,050	-65,182	13,226	-114,660
1962	860	5,432	72,756	6,443	68,457	28,248	12,948	1,050	-21,014	-4,198	-118,858
1963	860	5,432	61,402	7,881	103,000	34,304	12,759	1,050	-34,298	-41,239	-160,097
1964	860	5,432	38,887	7,664	203,742	33,654	12,022	1,050	-50,258	-147,366	-307,463
1965	860	5,432	53,379	7,996	125,351	34,620	12,989	1,050	-93,306	-13,036	-320,499
1966	860	5,432	68,453	7,391	106,376	31,982	12,637	1,050	-51,059	-18,850	-339,349
1967	860	5,432	57,609	8,793	112,664	37,837	11,902	1,050	-89,043	-1,716	-341,065
1968	860	5,432	55,626	6,831	98,875	29,403	11,511	1,050	-77,589	5,499	-335,565
1969	860	5,432	81,624	6,112	84,987	27,644	12,722	1,050	-69,643	37,269	-298,296
1970	860	5,432	81,094	7,656	85,621	33,610	12,508	1,050	-62,776	25,029	-273,267
1971	860	5,432	77,872	9,126	138,975	39,503	11,465	1,050	-77,406	-20,297	-293,564
1972	860	5,432	58,477	8,977	164,378	38,024	9,206	1,050	-66,242	-72,670	-366,234
1973	860	5,432	57,522	8,142	93,594	36,833	10,613	1,050	-103,163	33,029	-333,205
1974	860	5,432	63,180	7,904	44,650	35,194	11,066	1,050	-60,012	45,429	-287,777
1975	860	5,432	52,820	8,061	87,056	36,696	10,475	1,050	-53,943	-14,161	-301,938
1976	860	5,432	68,324	7,584	64,465	35,762	10,780	1,050	-58,968	29,111	-272,827
1977	860	5,432	38,947	10,306	136,166	46,496	11,877	1,050	-71,482	-68,562	-341,389
1978	860	5,432	33,215	10,851	145,150	46,816	11,736	1,050	-119,095	-35,299	-376,688
1979	860	5,432	47,877	9,951	95,799	41,889	11,925	1,050	-97,663	11,121	-365,568
1980	860	5,432	51,017	8,921	67,957	40,551	12,191	1,050	-82,153	26,635	-338,933
1981	860	5,432	43,264	7,983	73,292	37,539	11,600	1,050	-69,046	3,105	-335,828
1982	860	5,432	48,595	8,730	82,133	40,892	12,208	1,050	-81,996	9,330	-326,498
1983	860	5,432	43,681	8,561	62,823	41,667	12,095	1,050	-73,272	14,170	-312,327
1984	860	5,432	45,180	8,804	73,625	39,798	12,319	1,050	-96,890	30,374	-281,953
1985	860	5,432	46,235	8,562	75,081	39,590	11,498	1,050	-102,873	36,743	-245,210
1986	860	5,432	60,323	9,007	52,628	42,190	12,049	1,050	-75,885	43,589	-201,621
1987	860	5,432	78,397	8,848	56,676	42,485	12,464	1,050	16,667	-35,805	-237,426
1988	860	5,432	69,485	9,280	92,200	43,005	11,834	1,050	-19,798	-43,233	-280,659
1989	860	5,432	69,303	11,497	105,566	49,068	11,727	1,050	-59,449	-20,870	-301,529
1990	860	5,432	54,981	10,434	77,190	47,832	10,858	1,050	-54,503	-10,721	-312,250
1991	860	5,432	61,515	9,007	62,325	45,110	14,220	1,050	7,087	-52,978	-365,228
1992	860	5,432	71,214	7,874	77,369	45,070	11,947	1,050	860	-50,916	-416,144
1993	860	5,432	69,546	9,358	59,789	51,555	14,367	1,050	-15,134	-26,430	-442,574
1994	860	5,432	69,022	12,176	50,743	57,790	14,168	1,050	-38,648	2,387	-440,187
1995	860	5,432	61,226	13,698	91,041	62,153	14,000	1,050	-62,136	-24,893	-465,080

APPENDIX C2. ANNUAL GROUNDWATER BUDGET FOR MESILLA BASIN

	MESILLA BASIN										
	INFLOWS, in acre-feet				OUTFLOWS, in acre-feet						
Year	Transbasin Inflow	Mountain-Front Recharge	Agricultural Deep Percolation	Urban Deep Percolation	Agricultural Groundwater Pumping	Urban Groundwater Pumping	Riparian Consumptive Use	Transbasin Outflow	Net Exchange with Surface Water Network [a]	Change in Storage (residual)	Cum. Storage Change
1996	860	5,432	67,108	15,296	78,808	65,675	14,021	1,050	-25,476	-45,381	-510,461
1997	860	5,432	62,695	13,104	71,149	62,838	12,919	1,050	-36,364	-29,502	-539,963
1998	860	5,432	63,023	12,602	77,343	66,702	12,292	1,050	-28,831	-46,638	-586,600
1999	860	5,432	63,096	11,908	76,942	62,679	12,532	1,050	5,147	-77,053	-663,653
2000	860	5,432	66,014	13,075	75,361	70,539	12,170	1,050	-26,044	-47,696	-711,349
2001	860	5,432	59,345	15,359	58,764	68,070	11,127	1,050	-32,012	-26,003	-737,352
2002	860	5,432	61,430	16,268	57,492	67,001	11,545	1,050	-13,907	-39,192	-776,543
2003	860	5,432	43,086	18,185	207,412	68,731	10,512	1,050	-48,086	-172,056	-948,599
2004	860	5,432	41,311	17,682	168,696	68,952	9,513	1,050	-104,306	-78,621	-1,027,220
2005	860	5,432	51,755	16,888	102,868	66,241	12,183	1,050	-127,932	20,525	-1,006,695
2006	860	5,432	48,997	17,881	150,020	69,978	10,278	1,050	-111,812	-46,345	-1,053,039
2007	860	5,432	52,547	15,094	138,030	65,771	10,516	1,050	-107,352	-34,082	-1,087,122
2008	860	5,432	54,415	17,009	81,432	69,392	11,190	1,050	-86,256	907	-1,086,215
2009	860	5,432	50,554	16,544	109,563	65,380	11,735	1,050	-112,063	-2,277	-1,088,492
2010	860	5,432	52,843	15,659	91,478	78,999	11,953	1,050	-70,268	-38,419	-1,126,911
2011	860	5,432	37,241	14,577	261,492	98,279	6,680	1,050	-113,230	-196,160	-1,323,071
2012	860	5,432	42,028	15,762	206,837	95,002	5,321	1,050	-153,225	-90,902	-1,413,973
2013	860	5,432	38,792	14,118	228,191	89,459	4,054	1,050	-60,238	-203,314	-1,617,287
2014	860	5,432	42,492	13,397	197,582	90,206	4,168	1,050	-134,462	-96,362	-1,713,649
2015	860	5,432	43,229	14,871	159,351	88,056	3,896	1,050	-179,098	-8,862	-1,722,511
2016	860	5,432	43,573	13,223	169,796	86,606	4,447	1,050	-202,610	3,798	-1,718,713

[a] Positive values indicate gains to the surface water system; negative values indicate losses from the surface water system.

APPENDIX D

SUMMARY OF WEB-BASED HYDROLOGIC DATABASE
FOR RIO GRANDE PROJECT DATA ANALYSIS

TECHNICAL MEMORANDUM

DATE:	May 31, 2019
TO:	SOMMACH SIMMONS & DUNN
FROM:	STAFFAN SCHORR Montgomery & Associates
SUBJECT:	SUMMARY OF WEB-BASED HYDROLOGIC DATABASE FOR RIO GRANDE PROJECT DATA ANALYSIS

This technical memorandum summarizes the web-based hydrologic database developed in support of data analysis for the Rio Grande Project litigation. The objective of the database is to store and provide access to public data available for analyses by experts on the project team. The RGP database comprises three components: a database, a website, and a Microsoft Access data management tool. This memorandum describes the database design and provides information on data sources for each data table contained within the database. All source data used to populate the database are included in the primary source data provided to counsel.

1.1 Web-Based Database Design

Project hydrologic data are housed in a secured Microsoft SQL server database hosted by Montgomery & Associates (M&A). The database is accessed using Windows Active Directory Domain User Accounts either via a secure website, or via in-office or remote access by designated M&A project personnel. Programming within the database is responsible for exciting searches and exports. Access to the data is granted based on login credentials.

1.1.1 Database

The SQL server database contains tables for surface water, monthly surface water flows, climate, agricultural water distribution, and metered groundwater withdrawals. Database queries interact with search criteria specified by the user via the website. Solely public-available source data are included in the database. Further processing and manipulation of data could be required for expert analysis; however, those derivative data are not included in this database.

1.1.2 Website

The website is accessed using Secure Sockets Layer (SSL) encryption and requires user authentication. Members of the project team were provided with individual usernames and randomly-generated passwords.

The website is composed of a Common Gateway Interface (CGI) executable (programmed with Delphi), supporting html files, Cascading Style Sheets (CSS) files, and JavaScript files. Through the website, the database is accessed via Microsoft's ActiveX Data Objects (ADO) technology. Links to all the datasets that can be accessed in the database are displayed upon website login, and also across the top of the screen in a menu bar format on the web page. The user can adjust search criteria settings for each dataset, choose the number of resulting rows to display on the screen, and export data to an external file.

1.1.3 Microsoft Access data management user interface

Database updates and modifications are made through a Microsoft Access user interface (UI) created for the database. The interface connects to the database using Open Database Connectivity (ODBC) and Windows accounts. Designated M&A project personnel have access to this interface.

1.2 Database Table Descriptions

The database comprises multiple tables of information related to expert analyses, including:

- Monthly Surface Water Flows
- Daily Surface Water Flows and Reservoirs
- Climate
- Agricultural Water Distribution
- Metered Groundwater Pumping
- Annual Allotments
- Water Quality: Historical (USGS Data Series 499)

This database contains source data accessible to experts for their respective analyses. Additional processing and manipulation of data might be required for analysis; however, those derivative data are not included in this database. Each data table contained in the database is described in the following section.

Table: Monthly Surface Water Flows

Flows along the agricultural water distribution network in the project area, including at the major river diversion head gates, are monitored at many locations. Flows are monitored along numerous canals, laterals, wasteways/spillways, and drains. In cooperation with this data compilation effort, the Elephant Butte Irrigation District (EBID) provided the principal monthly flow dataset included in the database for canals, laterals, wasteways/spillways, and drains in Rincon and Mesilla valleys. The EBID provided data directories compiled by the New Mexico State University (NMSU) containing historic flow data and metadata for individual EBID monitoring stations from the early-1900s through 2003 (2003 dataset). NMSU compiled the data from the U.S. Bureau of Reclamation (USBR), International Boundary and Water Commission (IBWC), U.S. Geological Survey (USGS), EBID, El Paso County Water Improvement District

#1, and "Parson's Data". The EBID also provided a separate data directory containing historical flow data updated from 1975 through 2006 (2006 dataset); however the original source of these data was not documented in the deliverable. Monthly flow data from both the 2003 and 2006 datasets were loaded into the database; however, most data were duplicates of each other. Where duplicate data existed between the 2003 and 2006 datasets, values from the 2006 dataset were kept because that dataset contained a longer period of record. Some stations were included in the 2003 dataset and not included in the 2006 dataset, and vice versa. Collectively, these data are sourced from EBID.

A secondary source of monthly data for flows along the agricultural water distribution networks are historic data files and tables obtained from the irrigation districts and the U.S. Bureau of Reclamation (USBR). These data augment the EBID-provided data (described previously) to construct a comprehensive dataset for monthly flows for the entire study period. Most of the flow data included in this table was extracted from old data files as daily or monthly values. Values included in the database reflect the data received. Monthly flow data at the major diversion canal head gates, at Rio Grande below Caballo Dam, and Rio Grande at El Paso were obtained from the EBID and IBWC to update this table through 2016. Data for 2015 and 2016 were downloaded from the EBID website for the major diversions and were obtained from Rio Grande Compact Commission annual reports for Rio Grande below Caballo Dam.

Flows along the Rio Grande are monitored at numerous locations in the Rio Grande Project area from Elephant Butte Reservoir through El Paso Valley. Historic flow data were downloaded from the International Boundary and Water Commission (IBWC) website for Rio Grande streamflow gages below Elephant Butte Reservoir, below Caballo Reservoir, at El Paso, at Acequia Madre (flows to Mexico), and below American Dam. Historic flow data were downloaded from the U.S. Geological Survey's (USGS) online National Water Information System for three streamflow gages at San Marcial, located upstream from Elephant Butte Reservoir. Data requests to the USBR and IBWC provided data for Rio Grande at El Paso from 2013 through 2016, which were not available from the online sources. Monthly flow data for Rio Grande below Caballo Dam for 2014 through 2016 were obtained from the EBID.

Monitoring stations with monthly flow data are summarized on **Table 1**.

Table: Daily Surface Water Flows and Reservoirs

Daily surface flow data were obtained from a variety of sources and were used as a secondary source of monthly flow data. In many instances, flow data are missing for days during the non-irrigation season when the distribution system was not active. Although flows were likely zero during these times, the database reflects missing or blank values as received in the source data. Daily data were not available for all stations for all time during the study period.

Reservoir information is also included in this daily surface water table. The Reservoir data can be queried separately from flow stations on the web-based interface. Daily water elevations and storage volumes, as well as monthly surface area and total evaporation, for Elephant Butte and Caballo reservoirs were obtained from the USBR for 1938 through 2014. Monthly pan evaporation and precipitation at both reservoirs, and monthly inflows to Elephant Butte Reservoir, were obtained from tables included in annual reports by the Rio Grande Compact Commission (RGCC) for 1940 through 2012. The monthly values are included in the database on the last day of each month with zeroes entered for all other days of that particular month.

Table: Climate

Daily climate data for weather stations in the region are included in the database for the period 1900 through 2013. The data were downloaded from the National Oceanic and Atmospheric Administration's (NOAA) National Centers for Environmental Information website [https://www.ncdc.noaa.gov/]. Twelve weather stations are included in the database. These stations were selected because they (1) are located within or adjacent to the project area and (2) have a long period of record for climate data. The weather stations included in the database are summarized in **Table 2**.

Each weather station monitors for numerous parameters on a daily basis, including: average cloudiness, average wind speed, pan evaporation, maximum temperature in evaporation pan, precipitation, percent possible sunshine, minimum and maximum soil temperature, snowfall, snow depth, minimum and maximum temperature, temperature at time of measurement, daily total sunshine, and 24-hour wind movement. These datasets use codes for parameter names and flags for measurement notes, causes for failure to record data, and sources for raw data. A separate file containing descriptions of these codes and station information can be downloaded along with the climate data.

Table: Agricultural Water Distribution

Data for monthly agricultural water distribution within irrigation district boundaries in Rincon and Mesilla basins were obtained from summary tables from annual Rio Grande Project history reports, the U.S. Bureau of Reclamation (USBR), and the irrigation districts in the basins. Water distribution data include diversions, canal losses, canal wastes, farm deliveries, deliveries to non-agricultural entities, and other reported quantities. Farm deliveries were the principal component of interest from these summary tables. Monthly data were tabulated from annual Rio Grande history reports for 1938 through 1980. Data were generally reported as project totals and inconsistently aggregated for a variety of subarea-groupings in the Rio Grande Project area. The project history reports are not available after 1988. Data for after 1988 were obtained from the USBR and El Paso County Water Improvement District #1 (EPWCID#1).

Availability of water distribution data, including surface water deliveries to farms, is summarized in **Table 3**.

Table: Metered Groundwater Pumping

New Mexico Office of the State Engineer (NMOSE) records groundwater pumping (withdrawal) data for metered water production wells in the state. Well information, including measured groundwater withdrawals, are available from the NMOSE's online New Mexico Water Rights Reporting System (NMWRRS) [*http://nmwrrs.ose.state.nm.us/index.html*], which links to the Water Administration Technical Engineering Resource System (WATERS) for well reports and well permit information. Well information and pumping records were obtained from the NMWRRS for wells listed as being located in the Lower Rio Grande ("LRG") basin, which includes areas outside the basins of interest for this project. Wells are referred to as "points of diversion" (POD) in the NMWRRS. A Point of Diversion Summary was downloaded in html format for each well in the basin. The Point of Diversion Summary provides POD number, location coordinates, drill date, basic well constriction information, and metered pumping data. Pumping data include a "meter reading" and a "meter amount" for each well. The meter reading is the total volume of water that has flowed through the meter since installation. This is often called the totalizer reading. The meter reading value gradually increases during pumping and resets (or flips) when the meter reading reaches the maximum value on the gage, similar to a car odometer. The meter amount value is the volume pumped since the previous reading. The totalizer meter readings are reported as gallons with a reported multiplier of 10, 100, or 1000; multipliers are reported for each well and flow meter. The meter amount values are reported in acre-feet units. The information from each html file was extracted and compiled into a database for this project.

Groundwater withdrawals are reported to the NMOSE periodically by well owners. Withdrawal data are available from 1987 through 2016. The number of wells with reported pumping data increased through time as the NMOSE implemented its well metering program.

Reported pumping records obtained from the NMOSE Point of Diversion Summary sheets were evaluated to identify any issues with the data that could result in inaccurate estimates of total pumping. The majority of reported pumping data appeared to be adequately formatted and organized. However, several instances of duplicate or suspect data suggest that there are uncertainties inherent in the dataset. Apparent discrepancies could be a result of erroneous reporting by the well owner or errors in data management by the NMOSE.

Table: Annual Allotments

Annual allotments for Project water were provided by the EBID in cooperation with this data compilation effort. Allotments (in feet) were provided for 1950 through 2015.

Table: Water Quality (USGS Data Series 499)

Water quality data contained in this database table are from USGS Data Series 499, Design and Compilation of a Geodatabase of Existing Salinity Information for the Rio Grande Basin, from the Rio Arriba-Sandoval County Line, New Mexico, to Presidio, Texas, 2010 (Shah and Maltby, 2010). The data are shown as received from John Walton. Definitions for fields or flag codes were not received with the dataset.

Table 1. Summary of Stations and Years with Available Monthly Flow Data

Station Name	Data Availability (source)
Acequia Madre	1938-2006, 2008-2010 (IBWC)
Alamo Alto Drain	1938-1976, 1980-1983 (USBR)
Angostura Drain	1930-1982 (EBID), 1983 (USBR)
Anthony Drain	1930-1983, 1998, 2001-2003
Arrey Canal	1918-2006 (EBID), 2007-2013 (USBR), 2014-2016 (EBID)
Ascarate Wasteway	1955-1984 (USBR)
Bonita Lateral	1938-2002 (USBR)
Border Drain	1938-1976, 1980-1983 (USBR)
Caballo Inflow	2002-2012 (USBR)
Caballo Release	2002-2012 (USBR)
Canutillo Lateral	1979-1982 (EBID)
Chamberino Drain	1930-1983 (EBID)
Cuadrilla Drain	1938-1969, 1971-1976, 1980-1983 (USBR)
Del Rio Drain	1930-2006 (EBID)
Del Rio Lateral	1955-1972, 1974-1992, 1994-2006 (EBID), 2007-2010 (USBR)
East Drain	1930-1992, 1994-2003 (EBID)
Eastside Canal	1916-1918, 1920-2006 (EBID), 2007-2013 (USBR), 2014-2016 (EBID)
Elephant Butte Inflow	2002-2012 (USBR)
Elephant Butte Release	2002-2012 (USBR)
Fabens Drain	1938-1976, 1980-1983 (USBR)
Fabens Intercepting Drain	1938-1976, 1980-1983 (USBR)
Fabens Waste Channel	1939-1983 (USBR)
Franklin Canal	1914-2010 (USBR)
Franklin Drain	1938-1976, 1980-1983 (USBR)
Garfield Drain	1930-2006 (EBID)
Hatch Drain	1930-2006 (EBID)
Hudspeth Feeder Canal	1947-1972, 1974-1983 (USBR)
Island Drain	1938-1976, 1980-1983 (USBR)
Island Siphon Drain	1938-1976, 1980-1983 (USBR)
La Mesa Drain	1930-2006 (EBID)
La Union East Canal	1979-1992, 1997-2003 (EBID), 2004 (USBR), 2006-2011 (EPCWID,USBR)
La Union West Canal	1979-2002 (EBID), 2006-2011 (EPCWID)
Leasburg Canal	1908-2006 (EBID), 2007-2013 (USBR), 2014-2016 (EBID)
Leasburg Canal at First Check	1996-2006 (EBID)
Leasburg Canal at HDG	1993-1995, 1997-2004 (EBID)
Leasburg Canal Below 1st Check	1996-1999, 2001-2002 (EBID)
Leasburg Drain	1930-1983 (EBID)
Leasburg Unit Waste	1938-1947, 1952, 1954-1982 (USBR)
Mesa Drain	1930-1983 (EBID)
Mesilla Drain	1938-1969, 1972-1976, 1980-1983 (USBR)
Mesilla Unit Waste	1938-1947, 1952, 1954-1982 (USBR)

Station Name	Data Availability (source)
Middle Drain	1938-1976, 1980-1983 (USBR)
Montoya Drain	1930-1995, 1997-2002 (EBID)
Montoya Intercepting Drain	1985-1990 (EBID)
Nemexas Drain	1930-1984, 1997-1999, 2001-2003 (EBID)
Percha Lateral	1953-2006 (EBID)
Picacho Drain	1930-2006 (EBID)
Playa Drain	1938-1976, 1980-1983 (USBR)
Rincon Drain	1930-2006 (EBID)
Rincon Unit Waste	1938-1943, 1946, 1952, 1954-1983 (USBR)
Rio Grande Above Leasburg Dam	1924-1972, 1974-1983 (EBID)
Rio Grande at Anthony Bridge	1986-1989, 2001-2003 (EBID)
Rio Grande at Courchesne Bridge	1940-2008 (USBR)
Rio Grande at El Paso	1889-2011 (IBWC), 2012 (RGCC report), 2013 (USBR), 2014-2016 (IBWC)
Rio Grande at Haynor Bridge	2001-2006 (EBID), 2008 (USBR)
Rio Grande at Leasburg Cable	1994-2006 (EBID)
Rio Grande at San Marcial	1899-1963 (USGS)
Rio Grande at Vado Bridge	1985-1992 (USBR)
Rio Grande at Vinton Bridge	1985-1990 (EBID)
Rio Grande Below Caballo Reservoir	1938-2006 (IBWC), 2007-2013 (USGS), 2014-2016 (RGCC)
Rio Grande Below Elephant Butte Reservoir	1915-2011 (IBWC)
Rio Grande Below Leasburg Dam	1914-1915, 1919-1928, 1930-1999, 2001-2003 (EBID), 2004-2010 (USBR)
Rio Grande Below Mesilla Dam	1980-2006 (EBID), 2007-2010 (USBR)
Rio Grande Below Percha Dam	1922-1937 (EBID)
Rio Grande Conveyance Channel at San Marcial	1952-2013 (USGS)
Rio Grande Floodway at San Marcial	1950-2013 (USGS)
Rio Grande Over Leasburg Dam	1938 (USBR)
River Drain	1938-1976, 1983-1983 (USBR)
Riverside Canal	1938-2010 (USBR)
Rio Grande Below American Dam	1938-2011 (IBWC)
Santo Tomas Drain	1985-1990 (EBID)
Santo Tomas River Drain	1986-1990 (Parsons)
Selden Drain	1930-1983 (EBID)
Spillway/Wasteway # 23a	1985-1992, 1997-2006 (EBID)
Spillway/Wasteway # 32	1979-1992, 1997-1999, 2000-2002 (EBID)
Spillway/Wasteway # 34	1983, 1985-1992, 1997-1998, 2000-2002 (EBID)
Spillway/Wasteway # 35	1980-1992, 1997-2002 (EBID)
Spillway/Wasteway # 36	1985-1992, 1997-2002 (EBID)
Spillway/Wasteway # 38	1985-1992, 1997-2002 (EBID)

Station Name	Data Availability (source)
Three Saints East Lateral	1987-1988, 1990 (USBR), 2006-2012 (EPCWID)
Three Saints Lateral	1979-1982, 1984-1994, 1996-2003 (EBID), 2006 (USBR)
Tornillo Canal	1924-1983 (USBR)
Tornillo Canal at Alamo Alto	1925-1943, 1945-1983 (USBR)
Tornillo Drain	1938-1945, 1947-1983 (USBR)
Wasteway # 19	1982-2004, 2006 (EBID), 2007-2013 (USBR), 2014-2016 (EBID
Wasteway # 21	1985-1993, 1997-2003 (EBID)
Wasteway # 25	1985-2001 (EBID)
Wasteway # 30	1985-2005 (EBID)
Wasteway # 40	1991-1999 (EBID)
Wasteway # 1	1992, 1997-2001 (EBID)
Wasteway # 15	1985-2004, 2006 (EBID)
Wasteway # 16 Hatch Canal	1979-1999, 2001-2003 (EBID)
Wasteway # 16 Rincon Siphon	1993-2006 (EBID)
Wasteway # 16b	1985-1990 (EBID)
Wasteway # 18 Eastside Canal	1985-2002 (EBID)
Wasteway # 18 Rincon Lateral	1979-2006 (EBID)
Wasteway # 1a	1989-1992, 1994-1998, 2000-2002 (EBID)
Wasteway # 20	1979-1988 (EBID)
Wasteway # 3	2001-2003 (EBID)
Wasteway # 31	1981-2004 (EBID)
Wasteway # 31b	1985-1988, 2002-2003 (EBID)
Wasteway # 32a	1985-1988 (EBID)
Wasteway # 32b	1985-1992, 1997-2002 (EBID)
Wasteway # 34a	1985-1988 (EBID)
Wasteway # 35c	1985-1988 (EBID)
Wasteway # 5 Leasburg Canal	1979-2006 (EBID)
Wasteway # 8	1979-2006 (EBID)
West Drain	1930-1985, 1997-1999, 2001-2003 (EBID)
Westside Canal	1916-1918, 1920-2006 (EBID), 2007-2013 (USBR), 2014-2016 (EBID)

EBID = Elephant Butte Irrigation District
EPCWID = El Paso County Water Improvement District #1
IBWC = International Boundary and Water Commission
RGCC = Rio Grande Compact Commission
USBR = U.S. Bureau of Reclamation
USGS = U.S. Geological Survey

Table 2. Summary of Selected NOAA Weather Stations in Project Area

Station ID	Station Name	Latitude	Longitude	Period of Record
GHCND:USC00291672	CHAMBERINO NM US	32.06667	-106.66667	08/01/1911 - 06/30/1932
GHCND:USW00023044	EL PASO INTERNATIONAL AIRPORT TX US	31.81111	-106.37583	07/01/1947 - 12/31/2013
GHCND:USW00023080	EL PASO TX US	31.78333	-106.5	01/01/1921 - 12/31/1947
GHCND:USC00292848	ELEPHANT BUTTE DAM NM US	33.146	-107.1843	08/01/1908 - 11/30/2012
GHCND:US1NMDA0040	HATCH 6.9 ESE NM US	32.6275	-107.0467	03/23/2004 - 12/31/2013
GHCND:US1NMDA0041	HATCH 7.2 ESE NM US	32.6242	-107.0418	03/12/2005 - 12/31/2013
GHCND:USC00293855	HATCH NM US	32.6775	-107.19583	04/01/1900 - 04/30/2008
GHCND:USC00414931	LA TUNA 1 S TX US	31.98	-106.5975	03/01/1943 - 09/30/2012
GHCND:USC00294799	LAS CRUCES NM US	32.31667	-106.8	10/27/1944 - 12/31/2013
GHCND:USC00298535	STATE UNIVERSITY NM US	32.2823	-106.7598	04/01/1959 - 12/31/2013
GHCND:USC00290131	STATE UNIVERSITY NM US	32.28333	-106.75	01/01/1900 - 03/31/1959
GHCND:USC00419966	YSLETA TX US	31.69528	-106.32167	02/01/1939 - 09/30/2009

Table 3. Summary of Available Data for Surface Water Deliveries to Farms

Year	RGP	RGP Leasburg Unit	RGP Mesilla Unit	RGP El Paso Unit	EBID	RGP/EBID: Rincon Unit/Division	EBID: Mesilla Division	EPCWID#1	HCCRD1
1938	X	X	X	X		X			
1939	X	X	X	X		X			
1940	X	X	X	X		X			
1941	X	X	X	X		X			
1942	X	X	X	X		X			
1943	X	X	X	X		X			
1944	X	X	X	X		X			
1945	X	X	X	X		X			
1946	X	X	X	X		X			
1947	X	X	X	X		X			
1948	X	X	X	X		X			
1949	X	X	X	X		X			
1950	X	X	X	X		X			
1951	X	X	X	X		X			
1952	X	X	X	X		X			
1953	X	X	X	X		X			
1954	X	X	X	X		X			
1955	X	X	X	X		X			
1956	X								
1957	X	X	X	X		X			
1958	X	X	X	X		X			
1959	X	X	X	X		X			
1960	X	X	X	X		X			
1961	X	X	X	X		X			
1962	X	X	X	X		X			
1963	X	X	X	X		X			
1964	X	X	X	X		X			
1965	X	X	X	X		X			
1966	X	X	X	X		X			
1967	X	X	X	X		X			
1968	X	X	X	X		X			
1969	X	X	X	X		X			
1970	X	X	X	X		X			
1971	X								
1972	X								
1973	X								
1974	X	X	X	X		X			
1975	X								
1976	X	X	X	X		X			
1977	X	X	X	X		X			
1978	X	X	X	X		X			
1979	X				X			X	X
1980	X				X			X	X
1981	X				X			X	X
1982	X				X			X	X
1983	X				X			X	X
1984	X				X			X	X
1985	X				X			X	X
1986	X				X			X	X
1987	X				X			X	X
1988	X				X			X	X
1989	X				X			X	X
1990	X							X	
1991	X				X	X	X	X	X
1992	X								
1993	X				X			X	X
1994	X				X			X	X
1995					X	X	X	X	X

Year	RGP	RGP Leasburg Unit	RGP Mesilla Unit	RGP El Paso Unit	EBID	RGP/EBID: Rincon Unit/Division	EBID: Mesilla Division	EPCWID#1	HCCRD1
1996					X	X	X	X	X
1997	X					X	X	X	X
1998					X	X	X	X	X
1999					X	X	X	X	X
2000					X	X	X	X	X
2001					X	X	X	X	X
2002					X	X	X	X	X
2003						X	X	X	X
2004					X	X	X	X	X
2005					X	X	X	X	X
2006					X	X	X	X	X
2007					X	X	X	X	
2008					X	X	X	X	
2009					X	X	X		
2010					X	X	X	X	
2011	X				X		X		
2012					X				
2013					X				
2014					X				
2015					X				
2016					X				

X = water distribution table is available

RGP = Rio Grande Project (full)
EBID = Elephant Butte Irrigation District

EPCWID#1 = El Paso County Water Improvement Distict #1
HCCRD1 = Hudspeth County Conservation and Reclamation District 1

Data Source:

Yellow	RGP annual history reports, scanned water distribution tables
Green	USBR: received as scanned water distribution tables for varoius years
Blue	EBID: received as annual totals in Excel file

APPENDIX E

SUMMARY OF MODEL INPUT DATASETS
PREPARED IN SUPPORT OF
NUMERICAL GROUNDWATER FLOW MODEL DEVELOPMENT

TECHNICAL MEMORANDUM

DATE:	May 31, 2019
TO:	SOMMACH SIMMONS & DUNN
FROM:	STAFFAN SCHORR Montgomery & Associates
SUBJECT:	SUMMARY OF MODEL INPUT DATASETS PREPARED IN SUPPORT OF NUMERICAL GROUNDWATER FLOW MODEL DEVELOPMENT

This technical memorandum summarizes the conversion of water budget information to model input datasets in support of the numerical groundwater flow model for the Rincon and Mesilla basins being developed by William R. Hutchison. Source data and methods used to estimate water budgets for the basins are described in detail in the water budgets report for Rincon and Mesilla basins. The information herein summarizes the datasets provided to Mr. Hutchison for model development. For this task, Montgomery & Associates assigned model boundary condition values to grid cells based on the spatial distribution of the various water budget components for each basin.

1.1 Model Grid

The model grid was generated using AlgoMesh software. The grid design was developed by Montgomery & Associates with oversight from Mr. Hutchison. The model grid was vertically discretized into four model layers as described in a separate memorandum prepared by Montgomery & Associates. Each grid grid was then populated with unique identifiers (cell IDs), model layer elevations, preliminary values for aquifer properties, and initial water levels. Aquifer property values from the SSPA (2007) groundwater model were assigned to the AlgoMesh grid as preliminary values for starting model calibration.

Initial water levels assigned to the grid are based on water level contours prepared by M&A using USGS water level data from the National Water Information System (NWIS). No measurement data are available for the start of the model simulation period, 1938. 81 measurements were selected from available USGS data to represent initial water level conditions in the basins: 35 measurements for 1945 through 1949, 39 measurements for 1950 through 1959, and 8 measurements for 1960 through 1969. The data for the 1960s were used for areas at the margins of the basin where no other data exist and water levels likely had not substantially changed over time. The vast majority of measurement data are from wells located along the Rio Grande corridor. In addition to measurement data, control points were used to guide contouring in areas missing actual measurement data and to maintain interpolated water levels at or below land surface along the river. Initial groundwater level elevation contours are shown on **Figure 1**.

Deliverables:

- *AlgoMesh.zip* containing numerous text files, shapefiles, and tables related to the properties of the model grid.

1.2 Groundwater Pumping

Groundwater pumping data sources and methods for estimating historical withdrawals are described in detail in the water budgets report. Information for active water production wells in the Rincon and Mesilla basins were compiled from websites for the New Mexico Office of the State Engineer and the Texas Water Development Board. Relevant information preserved from the state well databases for each well include well identifier, spatial location coordinates, installation date, well use, well depth, and screened casing depths. Each well was assigned the cell identifier of the grid cell it is located within. Model layers were assigned to each well based on well construction information and the model layer elevations at the respective grid cell. Adjustments were made to grid cell and layer assignments based on feedback from Mr. Hutchison during model construction, principally to avoid assigning a well to inactive grid cells.

For this model, urban wells include all water production wells not categorized as irrigation use. Urban wells are as Municipal and Industrial (M&I) or domestic-stock wells. There are 7,181 urban wells included in the model dataset. Monthly urban pumping rates for individual wells were assigned based on (1) model inputs prepared by SSPA (2007) for a previous groundwater flow model for the Lower Rio Grande Basin, (2) measured pumping data, and (3) estimates from published hydrologic reports. Estimated monthly groundwater pumping for water user groups defined in the water budgets report were distributed to individual well locations based on reported well owner information and well use. A monthly pumping rate was assigned to each well from January 1938 through December 2016. A pumping value of zero is assigned to a well for months prior to when the well started pumping groundwater, as well as for months after pumping stopped at the well.

Total estimated agricultural pumping in the basins is summarized in the water budgets report. The model input dataset for irrigation wells was not populated with monthly agricultural pumping rates because pumping data are largely unknown for irrigation wells in the basins. There are 3,951 irrigation wells reported as being located in the model area. Monthly agricultural pumping estimates from the farm water budget will be distributed to individual irrigation wells by Mr. Hutchison during model construction and calibration.

Deliverables:

- *Urban_Pumping_ft3_for_WEL.xlsx*
- *WEL_global_ID_list.xlsx*
- *WEL_IRR_global_ID_list.xlsx*

1.3 Streamflow Routing

Datasets were prepared to conform to the MODFLOW Streamflow-Routing package (SFR2), which is designed to route flow through a network of channels representing a variety of rivers, streams, canals, laterals, and farm drains. The SFR package uses two components to define the stream network: reaches and segments. A reach defines (1) the routing order from upstream to downstream within a segment, (2) the model cell location of the reach, and (3) the length of the channel reach contained in each model grid cell. A segment is a group of reaches that defines (1) the tributary and diversion flows, (2) the streambed hydraulic properties, and (3) the channel geometry (streambed elevation and slope, streambed thickness, and channel depth and width).

A streamflow-routing dataset was developed for this model using two principal sources of information for locations and geometry of the network: (1) a geospatial dataset for the agricultural water conveyance network provided by the Elephant Butte Irrigation District (*EBID_Conveyances*, dated 4/28/2014), and (2) the streamflow-routing model input file (LRG_2007.sfr) prepared by SSPA (2007) for a previous groundwater flow model for the Lower Rio Grande Basin. A database was prepared to facilitate the management of the SFR data from the SSPA (2007) model and the development of the current SFR dataset.

The same streamflow-routing network (segment numbers, divisions, connections, and geometry) that was simulated in the SSPA (2007) model is included in the input datasets for the current model. The main conveyance features are included in the model dataset; some smaller conveyance features are not included. Conveyance features were selected from the EBID conveyance dataset, divided into reaches and segments as defined by the SSPA (2007) model, and attributed with the respective segment information from the SSPA (2007) model files. The network was then overlain by the current model grid to assign reach numbers, model grid cell identifier, and reach length within each grid cell representing the streamflow-routing network in the model. A generalized diagram of the streamflow-routing network for the current model is included in **Figure 2**.

Locations of segment inflows, diversions, and farm deliveries were assigned based on the SSPA (2007) model files. Monthly flow values for each inflow and diversion were assigned from the project's online database, which was developed by Montgomery & Associates and described in a separate memorandum.

Historical flows at Rio Grande below the Caballo Reservoir Dam provide the primary inflow of water to the simulated stream network. These flows are specified at the beginning of the first segment (segment 1) of the streamflow-routing network. Flow data were obtained from the project's online database, as described in a separate memorandum.

Diversions from the Rio Grande principally occur at five locations: Arrey Canal (segment 2), Percha Lateral (segment 3), Leasburg Canal (segment 76), Eastside Canal (segment 143), and Westside Canal (segment 195). Diversion flows at these locations are specified as monthly rates. Diversion flows were measured as flows near the main diversion headgate in the respective canal.

Surface water deliveries to farms (farm deliveries) are specified in the SFR datasets as a percentage of available flow from the upstream segment. The flow percentages are initially specified to be equal to the values included in the SSPA (2007) model input files. The percentages specified for these farm delivery outflows could change during model calibration to match measured water levels, flows, and farm deliveries.

Tributary inflows to the river are specified in the SFR network. These are flows from ephemeral streams to the river in response to runoff from rainfall events in the watershed. Contributing watersheds were assigned to a SFR river segment based on location. For each basin, the amount of inflows received by each selected river segment was computed by dividing the total contributing watershed area for each segment by the total contributing watershed area for the entire basin. **Table 1** summarizes the relative proportions of contributing watersheds to SFR river segments for each basin. The basin-wide monthly tributary inflows will be distributed during model construction based on these relative proportions.

Table 1. Summary of contributing watersheds for distributing tributary inflows

SFR River Segment	Basin	Contributing Watershed Area (acres)	Proportion of Basin Area
17	Rincon	72625	0.303
35	Rincon	78311	0.326
18	Rincon	43579	0.182
26	Rincon	26246	0.109
58	Rincon	2859	0.012
75	Rincon	16343	0.068
84	Mesilla	2759	0.119
90	Mesilla	2229	0.096
102	Mesilla	2531	0.109
116	Mesilla	565	0.024
142	Mesilla	2588	0.112
372	Mesilla	9773	0.422
373	Mesilla	1938	0.083
430	Mesilla	797	0.034

In addition to natural surface water flows in the stream network, discharges from major wastewater treatment facilities and urban return flows are included in the streamflow-routing dataset. Locations of wastewater discharges were selected based on the approximate location of the respective facility. Each facility discharges treated wastewater to the Rio Grande. Wastewater discharges are specified at four locations: Hatch/Salem (segment 26), Las Cruces (segment 102), Anthony (segment 326), and Sunland Park/El Paso Electric (segment 430). Wastewater discharges from the City of El Paso's Hickerson treatment facility into Rio Grande occur downstream from the outlet of the groundwater model and, thus, are considered as exported groundwater in the water budgets and are not included in the model inputs dataset. Historical discharges from the main wastewater treatment facilities in the model area are described in the water budgets report. Monthly discharge rates were assigned to the respective segment of the streamflow-routing network.

Monthly urban return flows will be distributed to SFR river segments that intersect or are nearest to mapped urban areas in each basin. The discharge points for urban return flows to the surface water network are unknown for this analysis. For simplicity, all monthly urban return flows are assigned to river segments associated with Hatch, Las Cruces, Anthony, or El Paso. Estimated urban return flows for Rincon Basin will be assigned to the river segment at Hatch. Estimated urban return flows for Mesilla Basin will be assigned to river segments at Las Cruces, Anthony, and El Paso. Mapped urban areas in vicinity of each of these municipalities are grouped and assigned to a specific SFR river segment. Small urban areas located between Las Cruces and Anthony and between Anthony and El Paso were assigned to one of these groups based on their relative locations. **Table 2** summarizes the relative proportions of urban areas contributing urban return flows to SFR river segments. The basin-wide monthly urban return flows will be distributed during model construction based on these relative proportions.

Table 2. Summary of grouped urban areas for distributing urban return flows

SFR River Segment	Basin	Grouped Urban Area	Contributing Urban Area (acres)	Proportion of Basin Area
26	Rincon	Hatch	1020.76	1
116	Mesilla	Las Cruces	27966.86	0.501
371	Mesilla	Anthony	2618.992	0.0470
373	Mesilla	El Paso	25195.53	0.452

Deliverables:

- *SFR_AM600.accdb*
- *SFR_diagram.pdf*
- *AM600_monthly.sfr* (preliminary)
- *AM600_yearly.sfr* (preliminary)
- *TribInflows_UrbRetFlows.xlsx*

1.4 Riparian Evapotranspiration

Model input data for riparian vegetation was prepared using information prepared by Land IQ, as summarized in the water budgets report. Land IQ mapped the extents of riparian vegetation for 1955, 2005, and 2014 and determined plant distributions for each mapped year. Model input datasets were prepared by selecting the model grid cells that intersect the mapped vegetation polygons. Vegetation distributions within each grid cell for each mapped year were determined from the Land IQ datasets. The model input dataset for each mapped year comprises a cell identifier, cell area, percent bare ground in the cell, percent tree-shrub in the cell, and basin identifier. Evapotranspiration rates for riparian vegetation will be assigned by Mr. Hutchison during model construction.

Deliverables:

- *ET_GridCells_RipExtents_1955_2005_2014.xlsx*

1.5 Mountain-Front Recharge and Transbasin Boundary Flows

Methods for estimating mountain-front recharge and transbasin boundary flows are described in the water budgets report. The volume of estimated mountain-front recharge from a contributing watershed was evenly distributed to model grid cells along the active model boundary at the interface with the respective watershed. The volume assigned to each grid cell was divided by the cell area to determine a recharge flux for each cell. The sum of recharge at the designated recharge cells is equal to the total recharge estimate reported in the water budgets report.

Similarly, transbasin inflows and outflows were evenly distributed to model grid cells along the model boundary at the location of the boundary flow. The boundary flow volume assigned to each grid cell was divided by the cell area to determine a flux for each cell. The sum of flow at the designated boundary flow cells is equal to the total estimated boundary flow reported in the water budgets report.

Recharge and boundary flow grid cells were attributed with model grid cell identifier, model layer, flux rate, and initial water level elevation.

Deliverables:

- *MntF_Underflow_Recharge.accdb*
- *MntFront_Recharge.xlsx*
- *Underflow.xlsx*

1.6 Urban Recharge

Urban recharge is specified at model grid cells that intersect mapped urban areas within the basins. Urban areas are represented as the maximum extent of high-density urban lands as mapped by Land IQ and described in the water budgets report. Model cells that intersect mapped urban lands were selected to represent urban recharge. Monthly estimates of urban recharge for each basin were distributed evenly among the selected urban recharge cells in the respective basin. The estimated monthly basinwide urban recharge volumes from the water budgets were divided by the total urban gridded acreage in each basin, as represented by the sum of grid cell acreages that represent urban lands, to determine a total recharge rate in acre-foot per acre units. This rate was multiplied by the acreage (acres) of each grid cell to determine a volumetric monthly recharge rate for each cell through time.

Deliverables:

- *Recharge_Urban_gridcentroids.xlsx*

1.7 Model Calibration Data

The groundwater flow model will be calibrated to measured surface water flows and groundwater levels at locations throughout the model area. Each flow or groundwater monitoring station was assigned to a model grid cell based on the spatial location of the station. Monthly flow data were obtained from the project's online database, which was developed by Montgomery & Associates and described in a separate memorandum.

Groundwater level measurements for the study area were obtained from the United States Geological Survey's (USGS) online National Water Information System (NWIS). Groundwater level measurements were assigned to representative model layers based on reported well construction and layer elevations at the assigned grid cell.

Deliverables:

- *CalibrationData_CanalDrainsWasteways.xlsx*
- *USGS_WLs.accdb*

1.8 Farm Budget Summary

A farm water budget dataset was prepared for each basin to facilitate model development. The farm budget simplifies the overall integrated water budget for the basin into components that are most important for the groundwater flow model. Farm water budget inflows include farm deliveries, effective precipitation, infiltration of excess precipitation, and applied groundwater. Farm water budget outflows include potential crop consumptive use, actual consumptive use by soil evaporation on non-cropped lands, deep percolation at agricultural fields, and deep percolation of agricultural conveyance losses. The residual of the water budget is net change in soil moisture. Results of the farm budget are consistent with the integrated water budgets for the basins, as reported in the water budgets report. Like the water budgets, the farm water budget comprises lands inside irrigation district boundaries and lands outside irrigation district boundaries. Crop lands outside the districts are assumed to receive only groundwater for irrigation.

Deliverables:

- *FarmBudget_RinMes.xlsx*
- *FarmBudget_RinMes _in.xlsx*
- *FarmBudget_RinMes_out.xlsx*

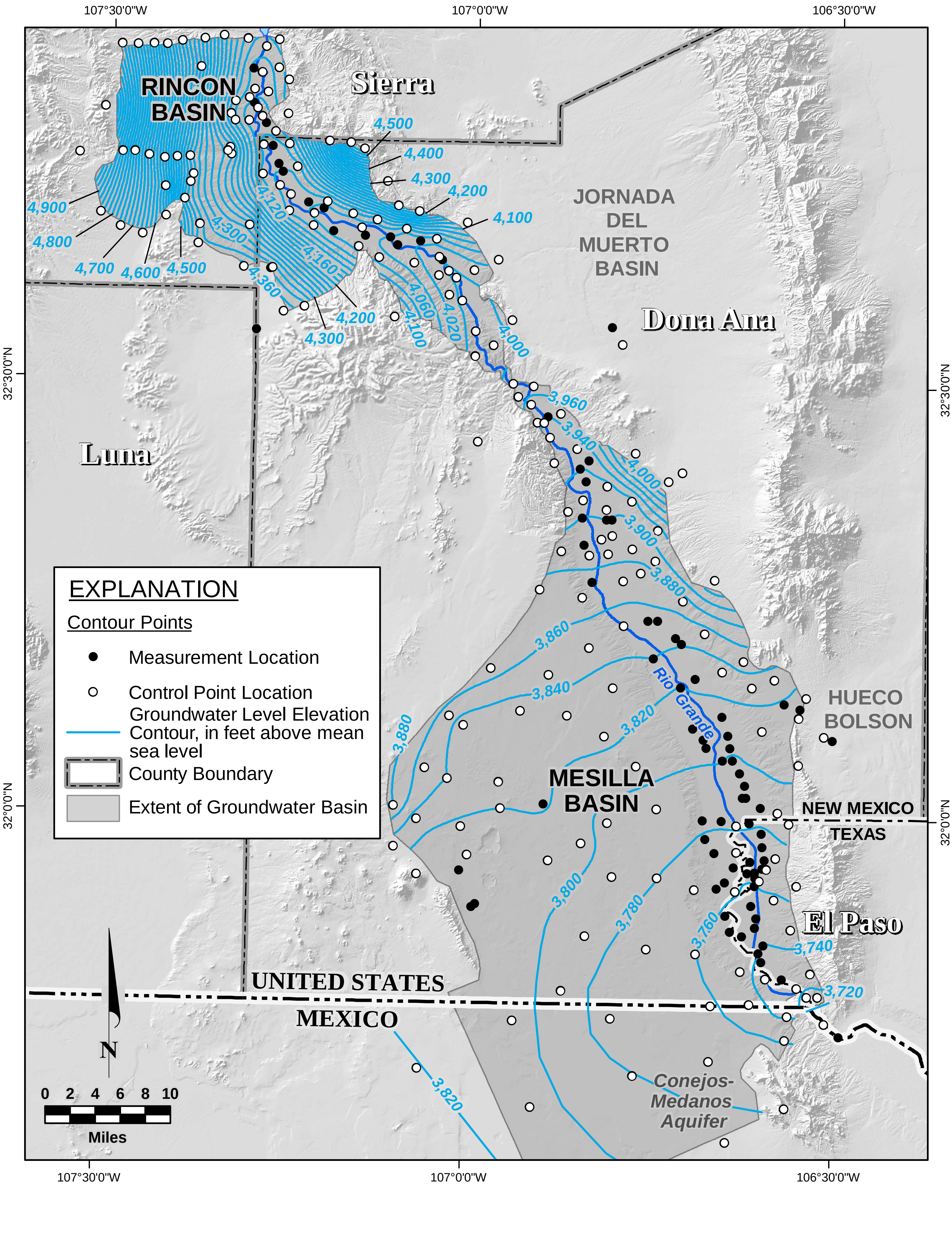

FIGURE 1. CONTOURS OF INITIAL GROUNDWATER LEVEL ELEVATIONS FOR MODEL INPUT

US_MSJ_00002079

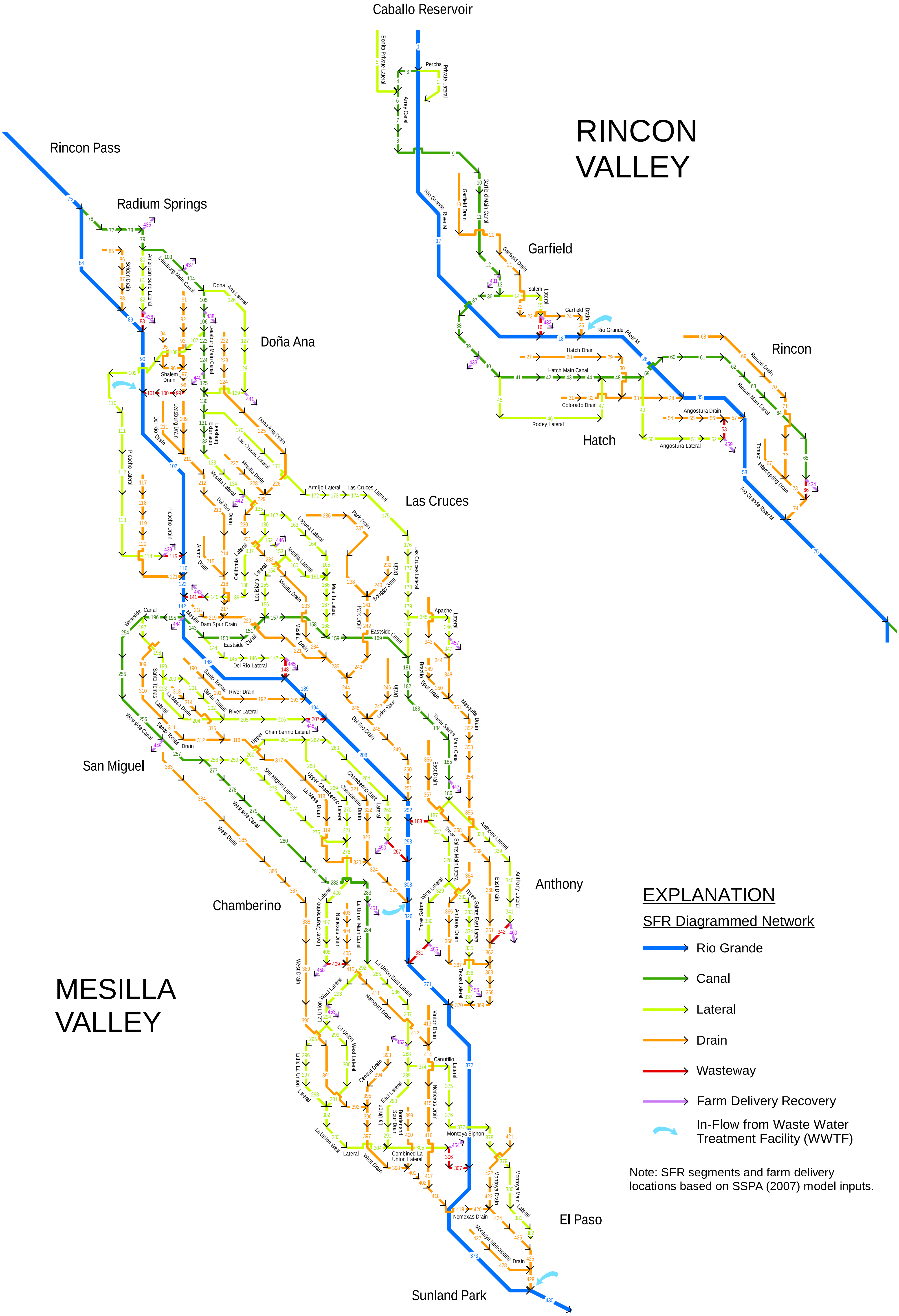

FIGURE 2. DIAGRAM OF STREAMFLOW-ROUTING NETWORK

US_MSJ_00002080

APPENDIX F

SUMMARY OF HYDROGEOLOGIC FRAMEWORK
FOR NUMERICAL GROUNDWATER FLOW MODEL DEVELOPMENT

TECHNICAL MEMORANDUM

DATE:	May 31, 2019
TO:	SOMMACH SIMMONS & DUNN
FROM:	STAFFAN SCHORR Montgomery & Associates
SUBJECT:	SUMMARY OF HYDROGEOLOGIC FRAMEWORK FOR NUMERICAL GROUNDWATER FLOW MODEL GRID DEVELOPMENT

This technical memorandum summarizes the geologic framework developed for the numerical groundwater flow model for the Rincon and Mesilla basins being developed by William R. Hutchison. Information provided herein includes data sources, methodology for developing a three-dimensional geologic model, and the hydrostratigraphic framework used for developing the layers for the groundwater model.

BACKGROUND

The numerical model will incorporate two groundwater basins: Rincon Basin and Mesilla Basin. Rincon Basin is the southern portion of the larger Palomas Basin. The Rincon and Mesilla basins are topographic depressions in the regional bedrock surface that are generally bounded by high-angle faults and physically separated by intervening bedrock highs. These geologic faults and uplifted areas are important controls on the groundwater flow of the basin aquifer systems. As is typical in the Basin and Range Province, the principal aquifers in the basins comprise the non-consolidated to weakly consolidated sediments that have been deposited within the structural basin areas. These "basin-fill" deposits are chiefly of alluvial origin. The bedrock complex is the principal source of the sediments that comprise the basin-fill deposits. In general, the bedrock units are crystalline to strongly lithified, resulting in low permeability and limited aquifer potential. The basin-fill deposits and valley-fill alluvium (along the Rio Grande corridor) comprise the principal aquifer systems in the basins and provide the vast majority of groundwater supplies to wells in the region.

GEOLOGIC HISTORY AND SETTING

The geologic history of the project area summarized herein is based chiefly on information provided in reports by the New Mexico Water Resources Research Institute (Hawley and Kennedy, 2004; Hawley and others, 2005; and Hawley and others, 2017), which has conducted extensive research on the geology and aquifer systems in the region.

The hydrostratigraphic layering scheme used for this analysis is based on interpretations from these studies.

The project area lies within the southern reach of the Rio Grande rift tectonic province which is a north-trending continental feature that separates the regional Colorado Plateau physiographic region on the west from the Great Plains region on the east. The Rio Grande rift feature extends from central Colorado through central New Mexico to the northern part of Chihuahua, Mexico. The basins in the project area are part of a series of basins and adjacent mountain uplifts within this rift zone. The rift zone, including the basin and uplift areas, began forming 25 to 30 million years ago (Ma). During the rifting process, the Earth's crust was stretched and pulled apart by extensional forces, resulting in the formation of large fault blocks that were rotated, uplifted and/or down-dropped. The movement and rotation of the fault blocks resulted in the formation of north-trending intermontane half-graben to full-graben structures within the rift zone. The upper surfaces of the fault blocks were chiefly volcanic-tectonic features, and it is on these surfaces that basin-fill deposits accumulated. The basin-fill deposits are chiefly of alluvial origin, although some facies are of lacustrine, eolian, and colluvial origin. In addition, some basaltic flows, pyroclastic deposits, and other volcanic rocks are interbedded with the basin-fill at some locations in the project area. These volcanic rocks are associated with features such as feeder dikes, sills, and breccia pipes (Hawley and Kennedy, 2004).

During and after the formation of the basins, sediments eroded from the adjacent uplifted areas were deposited in the half-graben basins. This basin-filling continued until approximately 670,000 to 700,000 years ago (0.67 to 0.70 Ma), as indicated by the subsequent entrenchment of the Rio Grande channel. These basin-fill deposits are the lower and middle hydrostratigraphic units of what is presently known as the Santa Fe Group.

The basin-fill deposits in the Rincon and Mesilla basins are comprised of Santa Fe Group hydrostratigraphic units which have been informally subdivided into lower, middle, and upper units on the basis of their lithologic properties, depositional origin, and post-depositional lithification. These units range in age from 23 to 0.7 Ma. They are chiefly alluvial in origin. Generalized geology of the study area is shown on **Figure 1**.

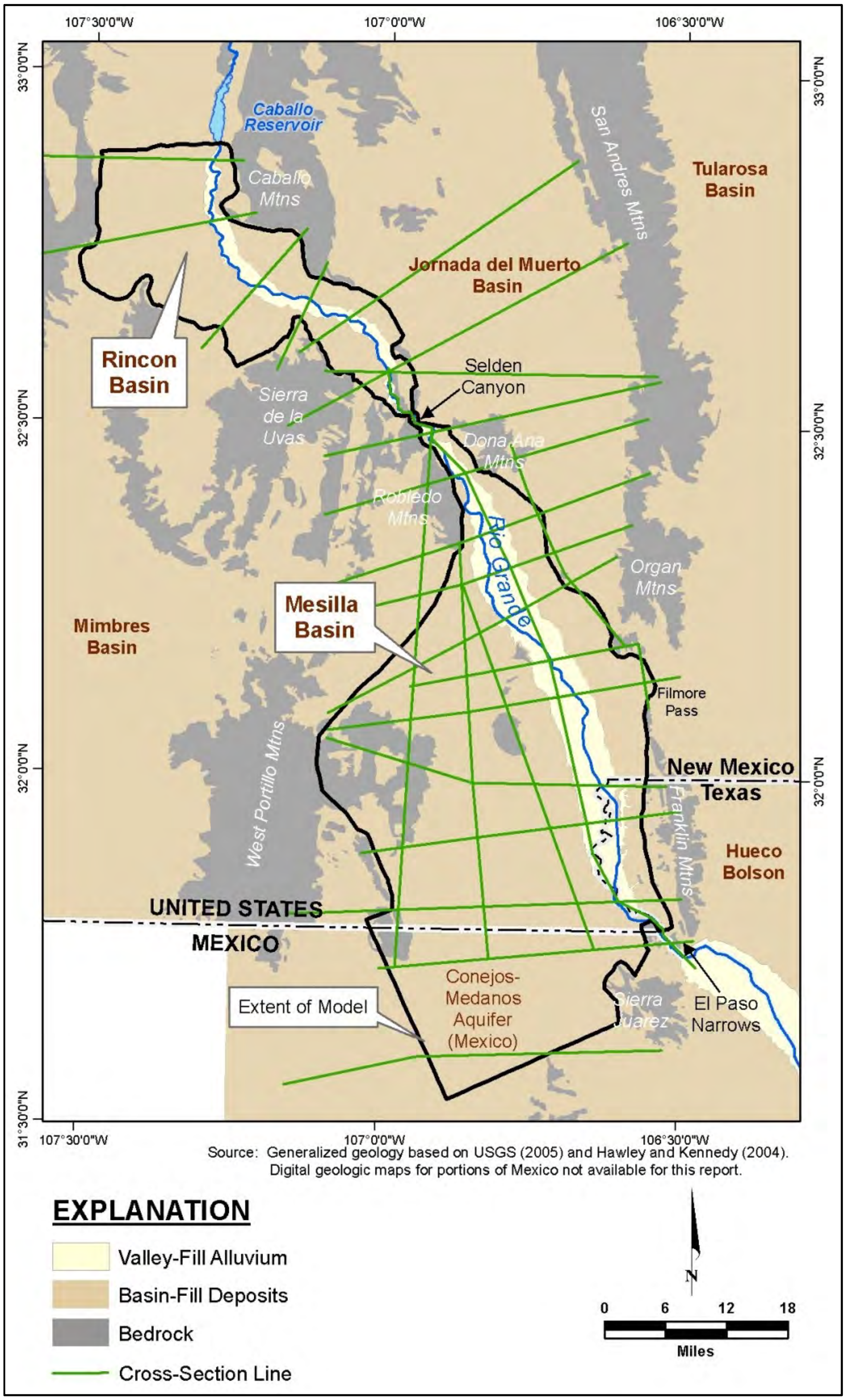

Figure 1. Generalized geology in Rincon and Mesilla Basins, with locations of cross-sections from New Mexico Water Resources Research Institute reports used to develop the aquifer framework.

Hydrostratigraphy and Layering Framework

Geologic units in the project area are listed below in order of increasing depth and age.

- Rio Grande valley-fill/river alluvium deposits
- Santa Fe Group basin-fill deposits
    - Upper Santa Fe Unit (USF) – Camp Rice & Palomas Formations
    - Middle Santa Fe Unit (MSF) – Fort Hancock & Rincon Valley Formations
    - Lower Santa Fe Unit (LSF) – Hayner Ranch Formation
- Bedrock Complex
    - Volcanic, sedimentary, igneous, and metamorphic rocks

The groundwater aquifer(s) in the basins consist of the lower, saturated intervals of the valley-fill alluvium, along with the underlying Santa Fe Group basin-fill units.

Valley-Fill/River Alluvium Deposits

The valley-fill (or river) alluvium occurs in and beneath the Rio Grande river channel and floodplain along the valley floors in the Rincon and Mesilla basins. It also occurs along the river channel in the intra-basin areas including Selden Canyon (between Rincon and Mesilla basins) and El Paso Narrows (between Mesilla Basin and Hueco Bolson) (**Figure 1**). Valley-fill alluvium is also present in the channels and floodplains of the major tributary arroyos of the Rio Grande, although they tend to be unsaturated and therefore do not comprise a substantial aquifer. For this model, the valley-fill unit solely comprises deposits along the Rio Grande and its floodplain. The valley-fill sediments are generally coarse-grained, but range from sand and gravel to silt and clay in texture. The deposits range in width from about 1 to 2 miles in Rincon Valley, and 2 to 5 miles in Mesilla Valley. Along the river channel in the shallow, intra-basin areas (e.g. Selden Canyon and El Paso Narrows), the width of the valley-fill deposits are approximately equivalent to the width of the river channel itself, which ranges from about 50 to 200 feet.

The average thickness of the valley-fill alluvium deposits is on the order of 60 to 80 feet.

Santa Fe Group Basin-Fill Deposits

The basin-fill deposits of the Santa Fe Group collectively comprise the vast majority of the groundwater flow system in the study area. The Santa Fe Group has been subdivided into five separate geologic units based on their relative ages and lithologies. From youngest to oldest, these units are the Camp Rice, Palomas, Fort Hancock, Rincon Valley, and Hayner Ranch Formations (Hawley and Kennedy, 2004). Overall thickness of the basin-fill deposits varies substantially throughout each basin. Maximum thickness of basin-fill is about 500 feet in Rincon Basin and about 2,500 to 3,000 feet in Mesilla Basin.

Hawley and Kennedy (2004) grouped these geologic units of the Santa Fe Group into three hydrostratigraphic units. The groups were determined based on age, lithology, and hydraulic properties of the deposits. The upper Santa Fe Group unit (USF) consists of the Camp Rice and Palomas Formations which are comprised chiefly of unconsolidated sand and gravel with minor lenses of silt and clay. Locally, it can include basalt flows. The USF is the most productive aquifer zone, but only the lower portions of the unit are saturated. The middle Santa Fe Group unit (MSF) consists of the Rincon Valley Formations which tend to be more fine-grained than the USF and consist of floodplain, alluvial flat, and playa deposits, but also includes extensive clean sand layers interbedded with silt and clay. Because the MSF is up to 2,000 feet thick, it is considered the principal aquifer zone. The lower Santa Fe Group unit (LSF) consists of the Hayner Ranch Formation which is chiefly comprised of fine-grained sediments similar to the MSF but locally more cemented. The LSF is an important aquifer zone in the lower Mesilla Basin from near Mesquite to Canutillo and La Union where a substantial thickness of eolian sand occurs (Hawley and Kennedy, 2004).

Bedrock Complex

The bedrock complex includes all intrusive and extrusive consolidated rock units. In the basin areas, the bedrock complex generally occurs beneath the alluvial and basin-fill deposits, except those which intruded and/or are interbedded with the basin-fill deposits. Surface exposures of bedrock are chiefly in the mountain and highland areas. However, bedrock outcrops do occur in isolated areas within the alluvium basin boundaries, such as north of Selden Canyon and west of Vado, New Mexico (**Figure 1**). These outcrops are based on mapping by Hawley and Kenney (2004) and USGS (2005). The various rock units that comprise the bedrock complex include, from youngest to oldest in age:

- Basalt flows, maar deposits (breccias and airfall units), and cinder cones
- Basalt and andesite flows, silicic volcanic flows (rhyolite, latite, and dacite), andesitic to dacitic flows, ash flow tuffs, sandstone, mudstone, conglomerate, and undifferentiated sedimentary rocks
- Quartzite, limestone and other carbonate rocks
- Limestone and other carbonate rocks, sandstone, shale, gypsite, and other undifferentiated sedimentary rocks
- Granitic and undifferentiated metamorphic rocks

STRUCTURAL FEATURES AND CONTROLS

Bedrock configuration and geologic structural features that affect groundwater movement in the project area include mountains and other geologic uplift areas, configuration of bedrock surface, fault zones and flexures within and adjacent to basin boundaries, and intrusive and extrusive rocks that penetrate or interbed with the basin-fill deposits. Impacts on groundwater flows from faults in the non-consolidated to weakly consolidated Santa Fe units are unknown.

MODEL LAYERING

Layering in the numerical model will be based on the principle hydrostratigraphic units. Hydrostratigraphy refers to the layering of aquifers and associated confining units of a study area. Hydrostratigraphic units are geologic sub-units with similar hydrogeologic properties or geologic units with distinct hydrogeologic properties. The hydrostratigraphic framework of an aquifer system is the elevation surfaces of the top and bottom of each hydrostratigraphic unit.

The hydrostratigraphic framework for the aquifer systems in the Rincon and Mesilla basins is based on geologic interpretations by Dr. John Hawley and the New Mexico Water Resources Research Institute. The aquifer framework for the basins was originally developed based on geologic information and cross-sections reported by Hawley and Kennedy (2004) and Hawley and others (2005). The framework was subsequently updated with new geologic interpretations delineated in cross-sections reported by Hawley and others (2017).

A continuous three-dimensional (3D), volumetric representation of the hydrostratigraphic framework for the aquifer system in Rincon and Mesilla basins was prepared using the geologic modeling software Leapfrog® Geo, developed by Seequent. The Leapfrog geologic model was prepared by importing a series of 23 cross-sections prepared by Hawley and Kennedy (2004) and Hawley and others (2005, 2017) into the Leapfrog 3D model space and digitizing (or drawing lines in digital format) the contacts between adjacent hydrostratigraphic units as delineated on the cross-sections. Mapped faults on the cross-sections are represented as offsets along the contacts or changes in thickness in layers. The software interpolates elevation surfaces, with a specified resolution of 500 feet, for the top and bottom of each hydrostratigraphic unit using the digitized contact lines along the length of each cross-section, coupled with control features to guide interpolations between cross-sections or in areas not included in the cross-sections. The cross-sections cover the entire model area from below Caballo Dam in northern Rincon Basin to the southern portions of Mesilla Basin in northern Chihuahua, Mexico, as shown on **Figure 1**. The framework is bounded on the top by the land surface and on the bottom by the bedrock surface. An example cross-section used to construct the 3D geologic model is shown on **Figure 2**.

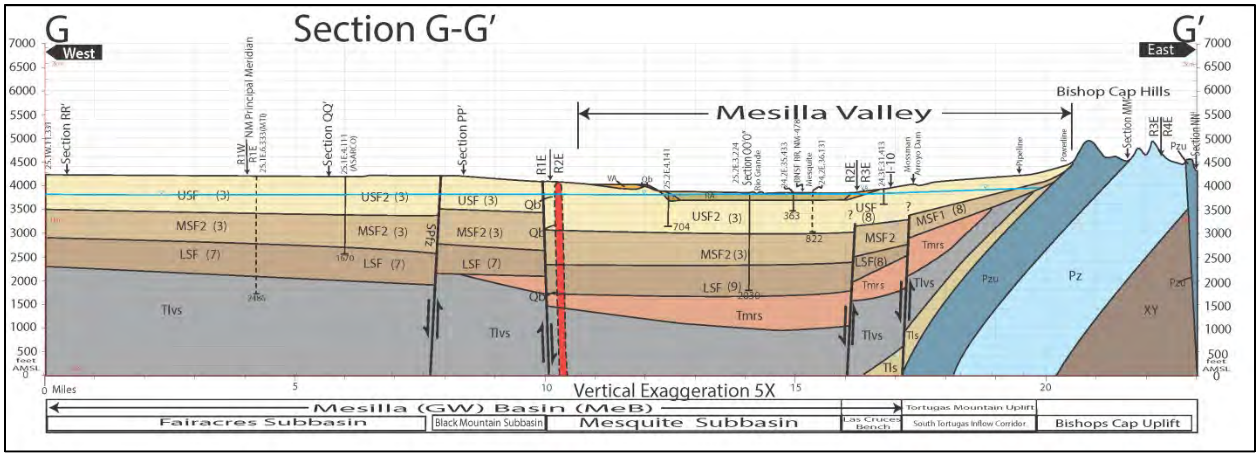

Figure 2. Example geologic cross-section for the Mesilla Basin from Hawley and others (2017). RA is valley-fill/river alluvium (greenish-tan); USF is upper Santa Fe unit (light tan); MSF is middle Santa Fe unit (tan); LSF is lower Santa Fe unit (brown); and bedrock units (various other colors).

The groundwater system in the Rincon and Mesilla basins groundwater model is represented as a four-layer aquifer system. The active portions of the model layers are bounded by the bedrock units that are assumed to be impermeable. Model layers are delineated as follows:

- Model layer 1 comprises the valley-fill/river alluvium deposits
- Model layer 2 comprises the upper Santa Fe unit
- Model layer 3 comprises the middle Santa Fe unit
- Model layer 4 comprises the lower Santa Fe unit

Thicknesses of each aquifer layer were determined from the 3D geologic model. The average thickness of model layer 1 (river alluvium) is about 85 feet, with a maximum thickness of about 150 feet. Average thickness of model layer 2 (upper Santa Fe) is about 500 feet, with a maximum thickness of about 1,100 feet. Average thickness of model layer 3 (middle Santa Fe) is about 640 feet, with a maximum thickness of about 1,985 feet. The average thickness of model layer 4 (lower Santa Fe) is about 560 feet, with a maximum thickness of about 2,240 feet.

Model grid layers were generated by importing elevation surfaces from the 3D geologic model into the MODFLOW grid generating software AlgoMesh. Model layer top and bottom elevations are consistent with the corresponding layers of the geologic model (hydrostratigraphic framework). Model grid datasets were then provided to William H. Hutchison for model development.

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APPENDIX G

FARM WATER BUDGETS FOR IRRIGATION DISTRICTS IN EL PASO VALLEY, TEXAS
1938 THROUGH 2016

TECHNICAL MEMORANDUM

DATE:	May 31, 2019
TO:	SOMMACH SIMMONS & DUNN
FROM:	STAFFAN SCHORR Montgomery & Associates
SUBJECT:	FARM WATER BUDGETS FOR IRRIGATION DISTRICTS IN EL PASO VALLEY, TEXAS: 1985 THROUGH 2016

1.1 Objective and Scope

I was asked by counsel to develop farm water budget for two agricultural districts located in El Paso Valley, Texas to support economic analyses by Dr. David Sunding and Dr. Lydia Dorrance. The two districts are El Paso County Water Improvement District #1 (EPCWID#1) and Hudspeth County Conservation and Reclamation District 1 (HCRRD1). EPCWID#1 has lands in both Mesilla Basin and El Paso Valley; this farm budget considers only the portion of EPCWID#1 located in El Paso Valley. For the analysis, a farm water budget was developed for agricultural lands in EPCWID#1 and HCRRD1 with the principal goals of estimating (1) agricultural groundwater pumping for irrigation and (2) deep percolation beneath agricultural fields. Due to the lack of historic direct measurements of agricultural applied groundwater (pumping) and agricultural deep percolation, soil water balance models were used to estimate these components, along with surface runoff and soil moisture changes on agricultural lands. The soil water balance models were developed and implemented using GoldSim simulation software. Model results were used to prepare the farm water budgets for EPCWID#1 and HCRRD1.

El Paso Valley is an alluvial valley along the Rio Grande, extending from the El Paso Narrows to Fort Quitman (**Figure 1**). The valley extends across the Hueco Bolson groundwater basin. The river flows from Mesilla Basin into El Paso Valley at the Narrows. Farm lands across the river in Mexico are not included in this analysis. Urban lands, including the City of El Paso and Ciudad Juarez, and their associated water budgets are also not included in this analysis.

A soil water balance model was developed for each district to estimate agricultural groundwater pumping and deep percolation over the time period of interest, 1985 through 2016. The models tracks soil moisture within the maximum extent of cropped areas of EPCWID#1 and HCRRD1 on a monthly time step. The farm soil water balance models for El Paso Valley follow the same governing equations and framework as the models previously developed for the Rincon and Mesilla basins. The farm soil water balance model framework, design, and implementation are described in detail in the separate water budget report submitted for Rincon and Mesilla basins.

1.2 Model Inputs

Crop lands in EPCWID#1 and HCRRD1 were mapped by Land IQ for several years during the study period. The EPCWID#1 and HCRRD1 farm budgets encompasses a maximum crop area of 68,704 acres (about 107 square miles) and 17,752 acres (about 28 square miles), respectively. All crop lands are located within the districts' boundaries and irrigation demand is supplied by both surface water deliveries and supplemental groundwater pumping.

Tabular crop distribution and evapotranspiration (ET) (crop consumptive use) datasets for EPCWID#1 and HCRRD1 prepared by Land IQ were used in this farm water budget analysis. The Land IQ datasets contain annual acreages and monthly ET data for nineteen crop categories, along with annual ET adjustment factors computed based on analysis of historic crop yield. Theoretical crop ET rates were computed by dividing adjusted crop ET by the corresponding crop ET adjustment factor. The adjusted Land IQ adjusted ET (AET) rates are referred to herein as target AET rates, meaning that they reflect the best available estimates, and should be reproduced by the soil water balance model to the extent possible. This analysis assumes that irrigation practices and irrigation non-uniformity are the same as in Mesilla Basin; however, double-cropping is not incorporated into the El Paso Valley models due to lack of data. The soil water balance model simulates total ET from all the crops, and so target AET was calculated as an area-weighted average over the different crop types over the study period. Crop acreages for EPCWID#1 were adjusted for pre-irrigation of cotton and pecans by one month, consistent with the Rincon and Mesilla models; However, HCRRD1 was modified to have pre-irrigation of all crops by two months to also represent leaching of salts from the fields prior to planting. The application of water for leaching is seen in available data when surface water deliveries are reported during winter months when crop ET values are zero. EPCWID#1 personnel verified in an interview on April 23, 2019 that more salt leaching is required in HCCRD1 than in EPCWID#1 due to the higher salinity of the available irrigation water in HCCRD1.

The soil water balance model for each district tracks all root zone soil moisture, including in cropped and non-cropped areas. For non-cropped area, this requires the computation of bare soil evaporation. The method for estimating bare soil evaporation is described in the water budget report for Rincon and Mesilla basins. For this analysis, precipitation is specified to be the same as in Mesilla Basin.

Soil properties required for the soil water balance model include the residual moisture content, permanent wilting point, critical soil moisture, field capacity, total porosity, pore size distribution index, and saturated hydraulic conductivity (K_{sat}). Because soil types are similar in Mesilla and the two El Paso Valley districts, soil properties specified in the EPCWID#1 and HCRRD1 models are the same as in the Mesilla Basin model.

The soil water balance model simulates total ET from all the crops, and so effective root zone depth was calculated as an area-weighted average over the different crop types over the study period. Crop rooting depths are described in the water budget report for Rincon and Mesilla basins.

The applied water demand by crops is satisfied by surface water deliveries and supplemental groundwater pumping. The farm soil balance model provides an estimate for total applied water to meet the target crop ET. Applied surface water deliveries are reported for most years; however, supplemental agricultural groundwater pumping is not reported. Supplemental pumping is estimated as the quantity of applied water required to achieve the target crop ET estimated by Land IQ in addition to surface water deliveries.

Data for surface water deliveries to farms are available from USBR crop report water distribution tables for 1985 through 2008 for EPCWID#1 and for 1985 through 2006 for HCCRD1. Data sources and methods used for estimating deliveries to farms when data are missing are described in the water budget report for Rincon and Mesilla basins.

1.3 Results

The annual farm budgets for EPCWID#1 lands in El Paso Valley and for HCRRD are summarized in **Tables 1 and 2, respectively**. Estimates for total applied agricultural water, farm deliveries, and supplemental groundwater pumping for the two districts are shown on **Figures 2 and 3**.

Surface water deliveries to farms in EPCWID#1 in El Paso Valley were generally larger than 100,000 acre-feet per year (AF/yr) from 1985 through 2002, with an average of about 129,000 AF/yr. A substantial reduction in deliveries to EPCWID#1 in El Paso Valley occurred in 2003 and again in 2011, when average deliveries were about 95,000 AF/yr and 27,000 AF/yr, respectively, during these time periods. Surface water deliveries to HCCRD1 farms were generally larger than 40,000 AF/yr from 1985 through 2002, with an average of about 48,000 AF/yr. Similar to EPCWID#1, a substantial reduction in deliveries to HCCRD1 farms occurred in 2003 and again in 2011, when average deliveries were about 28,000 AF/yr and 7,000 AF/yr, respectively, during these time periods.

Crop acreage within both EPCWID#1 farms in El Paso Valley and HCRRD1 farms has declined since 1985, based on data provided by Land IQ. In EPCWID#1 in El Paso Valley, for example, average cropped acreage from 1985-2002 was about 50,000 acres, whereas average cropped acreage from 2003-2016 was about 34,000 acres. In HCRRD1, average cropped acreage from

1985-2002 was about 15,000 acres, whereas average copped acreage from 2003-2016 was about 8,000 acres.

According to model results, supplemental groundwater pumping occurred in EPCWID#1 and HCRRD1 each year during the study period. As expected, groundwater pumping has an inverse relationship with farm deliveries, where pumping increases as farm deliveries decrease. In years with reduced surface water availability, groundwater is required to satisfy crop demand. Average annual supplemental groundwater pumping for EPCWID#1 farms in El Paso Valley from 1985 through 2016was about 79,000 AF/yr. Average annual supplemental groundwater pumping for HCCRD1 farms from 1985 through 2016 was about 19,000 AF/yr.

In contrast to similar analyses conducted for the Rincon and Mesilla Valleys, agricultural groundwater pumping data are not available to validate simulated results from the EPCWID#1 and HCRRD1 soil water balance models.

Within the soil water balance model, monthly deep percolation is calculated as the sum of on-farm conveyance losses and field losses. Estimated annual agricultural deep percolation for EPCWID#1 farms in El Paso Valley and HCRRD1 farms is shown on **Figure 4a** and **Figure 5a**. Field losses account for soil moisture derived from both applied irrigation water and precipitation; however, the contribution from applied irrigation water is substantially greater than contributions from precipitation. Similar to the Mesilla farm soil water model, 10 percent of reported farm deliveries are assigned to deep percolation from infiltration along on-farm water conveyance features. Average annual estimated deep percolation is approximately 42,000 AF in EPCWID#1 farms in El paso Valley and 18,000 AF in HCRRD1 farms.

The soil water balance model computes evapotranspiration rates based on theoretical crop evapotranspiration rates and simulated soil moisture conditions. For this analysis, the monthly theoretical evapotranspiration rates are from crop consumptive use datasets prepared by Land IQ. Estimates of crop consumptive use for El Paso Valley are shown on **Figures 4b and 5b** for EPCWID#1 and HCRRD1 respectively. For reference, **Figures 4b and 5b** also show target adjusted crop consumptive use, or AET, developed by Land IQ for EPCWID#1 and HCRRD. AET simulated by the EPCWID#1 and HCRRD1 soil water balance models closely follows the target AET values from Land IQ.

Mean annual crop AET for 1985 through 2016 is about 155,000 AF for EPCWID#1 as simulated by the model, compared to about 154,000 AF as estimated by Land IQ. Mean annual crop AET for 1985 through 2016 is about 43,000 AF for HCRRD1 as simulated by the model, compared to about 42,000 AF as estimated by Land IQ.

TABLE 1. ANNUAL FARM WATER BUDGET FOR EL PASO COUNTY WATER IMPROVEMENT DISTRICT #1 LANDS IN EL PASO VALLEY: 1985 THROUGH 2016

	INFLOWS, in acre-feet				OUTFLOWS, in acre-feet										
Year	Total Precipitation on Agricultural Lands (Crop)	Total Precipitation on Agricultural Lands (Non-Crop)	Farm Deliveries	Ag. Applied Groundwater Pumping	Ag. Consumptive Use of Precipitation (Effective Precipitation) (Crop)	Ag. Consumptive Use of Precipitation (Effective Precipitation) (Non-Crop)	Ag. Consumptive Use of Applied Water (Crop)	Ag. Consumptive Use (Soil Evaporation) (Non-crop)	Ag Surface Runoff (Crop)	Ag Surface Runoff (Non-Crop)	Ag. Field Deep Percolation (Crop)	Ag. Field Deep Percolation (Non Crop)	Ag Conveyance Deep Percolation (Crop)	Change in Ag Soil Moisture Storage (Crop)	Change in Ag Soil Moisture Storage (Non-Crop)
1985	37,923	30,221	108,927	62,372	34,805	27,941	119,334	3,069	2,854	1,231	19,895	5	10,893	9,101	10,830
1986	41,964	34,518	107,456	43,636	38,497	25,489	111,974	11,147	2,543	1,262	18,721	86	10,746	-1,617	8,727
1987	30,873	24,865	108,531	66,305	27,891	18,936	132,076	15,728	2,834	1,126	22,911	115	10,853	-2,480	581
1988	34,062	25,475	107,326	92,316	30,762	21,471	133,988	14,389	3,075	1,125	39,415	147	10,733	-1,424	5,495
1989	23,678	19,739	108,635	96,138	21,859	18,423	145,752	13,598	1,999	562	38,121	225	10,864	-875	-2,339
1990	38,648	25,347	98,820	77,663	35,740	21,565	123,212	18,142	2,406	815	29,773	82	9,882	283	-1,420
1991	45,575	36,247	131,079	75,211	40,004	26,425	139,105	11,936	4,496	2,546	37,874	614	13,108	1,433	10,570
1992	34,654	26,026	129,910	91,559	32,300	19,140	157,310	16,370	2,184	595	42,597	1,257	12,991	887	-3,485
1993	30,526	24,252	109,961	106,407	28,136	20,082	158,466	18,025	2,311	805	39,094	825	10,996	2,045	-9,643
1994	27,553	16,659	133,404	101,841	26,070	15,750	171,917	18,302	1,546	214	33,018	78	13,340	-958	180
1995	21,918	16,183	132,269	98,373	20,267	13,252	166,968	14,471	2,033	388	34,636	155	13,227	-110	3,455
1996	32,225	14,308	167,854	59,120	30,072	13,324	158,052	18,421	2,464	375	34,905	121	16,785	-417	-597
1997	35,805	25,580	108,441	101,519	33,734	20,397	153,191	12,277	1,579	485	33,432	366	10,844	1,192	3,849
1998	28,985	15,704	117,468	98,383	26,701	12,755	158,911	20,880	2,371	563	33,971	212	11,747	-1,209	-6,363
1999	35,481	19,446	185,564	33,669	32,716	18,028	141,993	10,212	3,130	669	45,486	186	18,556	-1,124	4,295
2000	36,489	16,829	117,859	77,918	33,158	15,360	140,619	14,644	3,091	849	33,610	198	11,786	-2,751	-1,469
2001	16,945	11,151	148,571	77,855	16,058	10,576	162,153	14,476	1,475	65	33,257	101	14,857	-250	1,752
2002	19,963	20,837	195,043	49,421	18,272	19,205	172,396	11,076	2,157	381	38,026	219	19,504	1,089	2,934
2003	12,465	16,402	88,803	94,780	10,841	15,447	136,806	18,010	913	270	30,634	201	8,880	-1,980	-7,573
2004	39,190	37,539	88,803	76,333	36,451	31,232	117,945	12,339	2,126	1,125	27,131	80	8,880	350	4,206
2005	21,611	31,252	89,306	76,902	18,955	23,419	127,937	15,230	1,360	896	24,583	318	8,931	-564	-1,993
2006	44,832	40,831	86,217	52,812	34,354	31,589	96,550	13,255	9,668	7,774	23,734	66	8,622	-556	-365
2007	22,277	33,627	94,327	79,425	20,946	31,629	127,983	14,358	1,280	621	23,837	45	9,433	1,263	-1,740
2008	29,388	35,992	94,327	51,805	23,782	23,468	94,415	20,243	5,348	5,255	30,683	56	9,433	1,063	-2,240
2009	20,502	26,547	83,781	78,946	19,331	23,439	119,409	12,660	1,091	455	22,984	41	8,378	620	1,367
2010	20,647	28,777	235,935	25,205	18,761	26,866	115,103	14,423	2,832	804	108,649	43	23,594	1,181	-1,705
2011	13,902	19,346	11,068	163,391	12,903	17,013	136,355	11,563	310	420	25,093	68	1,107	-2,332	5,207
2012	8,471	20,247	34,519	69,910	8,004	19,156	78,361	19,300	431	241	15,361	37	3,452	-812	-10,384
2013	17,609	32,090	11,221	96,564	15,800	28,925	79,932	11,945	1,344	2,091	16,143	5	1,122	-397	575
2014	22,881	36,944	26,505	85,486	19,829	18,235	81,085	16,036	2,584	3,650	17,831	131	2,651	-396	10,181
2015	26,636	46,959	36,197	76,710	23,877	37,187	82,989	19,135	2,179	2,619	18,528	64	3,620	-408	-3,287
2016	19,701	29,750	42,719	88,138	18,023	27,461	95,416	14,673	1,423	1,251	20,018	19	4,272	-432	-1,816

TABLE 2. ANNUAL FARM WATER BUDGET FOR HUDSPETH COUNTY CONSERVATION AND RECLAMATION DISTRICT 1: 1985 THROUGH 2016

	INFLOWS, in acre-feet				OUTFLOWS, in acre-feet											
Year	Total Precipitation on Agricultural Lands (Crop)	Total Precipitation on Agricultural Lands (Non-Crop)	Farm Deliveries	Ag. Applied Groundwater Pumping	Ag. Consumptive Use of Precipitation (Effective Precipitation) (Crop)	Ag. Consumptive Use of Precipitation (Effective Precipitation) (Non-Crop)	Ag. Consumptive Use of Applied Water (Crop)	Ag. Consumptive Use (Soil Evaporation) (Non-crop)	Ag Surface Runoff (Crop)	Ag Surface Runoff (Non-Crop)	Ag. Field Deep Percolation (Crop)	Ag. Field Deep Percolation (Non Crop)	Ag Conveyance Deep Percolation (Crop)	Change in Ag Soil Moisture Storage (Crop)	Change in Ag Soil Moisture Storage (Non-Crop)
1985	13,748	3,859	70,370	3,955	12,626	3,587	39,622	3,772	1,302	134	33,873	3,752	7,037	-904	6,800
1986	14,557	5,204	33,868	23,113	13,439	2,972	34,871	1,341	833	205	17,289	109	3,387	-41	2,337
1987	10,384	4,018	63,688	12,787	9,388	3,199	40,748	2,572	1,188	156	28,357	86	6,369	-415	-774
1988	13,486	1,898	46,714	39,169	12,221	1,302	46,000	1,582	1,207	49	30,923	403	4,671	108	2,799
1989	9,622	1,597	48,406	32,711	8,899	1,510	51,424	1,554	827	17	23,661	418	4,841	-372	-443
1990	12,728	3,808	25,693	30,713	11,774	3,294	36,685	3,812	724	110	15,504	135	2,569	319	-1,984
1991	14,035	7,106	45,252	19,168	12,506	4,648	39,376	2,342	1,382	540	17,375	391	4,525	92	2,383
1992	11,227	4,452	33,777	33,154	10,475	2,696	47,188	685	618	102	16,572	788	3,378	-123	230
1993	8,300	5,854	55,071	10,701	7,655	4,808	37,773	3,537	847	198	22,684	543	5,507	10	-3,641
1994	7,339	4,084	59,719	9,986	6,948	3,857	41,911	3,160	623	59	18,276	40	5,972	-90	369
1995	7,483	2,361	62,302	14,516	6,934	1,997	47,198	2,639	831	47	19,718	85	6,230	104	876
1996	10,998	1,025	51,348	24,263	10,266	958	48,846	2,980	783	22	17,765	123	5,135	1,684	-931
1997	10,967	4,894	34,010	25,828	10,338	3,563	41,928	2,129	482	105	12,621	301	3,401	-1,434	2,266
1998	9,374	2,173	42,895	26,059	8,639	1,814	45,425	4,406	805	66	17,437	108	4,290	518	-3,008
1999	11,504	2,689	48,942	15,799	10,605	2,506	41,904	1,301	916	74	14,940	141	4,894	-222	1,870
2000	10,105	3,671	46,466	11,098	9,186	3,350	36,690	3,485	976	186	14,631	112	4,647	39	-1,964
2001	5,236	2,024	42,378	21,110	4,962	1,920	43,285	2,686	422	12	12,594	51	4,238	-77	652
2002	6,808	3,734	46,606	22,919	5,842	3,401	49,064	1,702	549	72	13,469	127	4,661	84	1,092
2003	2,717	4,742	23,089	9,376	2,069	4,477	22,048	5,878	243	64	7,609	101	2,309	-439	-4,435
2004	6,734	13,092	23,089	7,002	6,265	10,791	18,654	2,781	433	408	6,942	6	2,309	54	1,273
2005	5,723	7,936	21,336	14,599	4,468	6,451	26,232	3,818	358	210	6,296	20	2,134	104	-498
2006	11,029	11,105	23,667	10,738	8,472	8,567	21,835	2,738	2,378	2,141	7,753	7	2,367	111	169
2007	6,545	7,900	24,525	21,484	6,155	7,430	33,070	2,573	345	147	7,774	8	2,452	625	-126
2008	10,260	6,633	24,525	15,994	8,311	4,344	27,163	4,211	1,782	959	7,962	14	2,452	-322	533
2009	7,161	4,996	21,783	29,545	6,751	4,423	37,501	2,451	314	87	8,604	25	2,178	491	659
2010	8,258	4,512	61,343	10,338	7,312	4,214	37,582	2,802	819	124	25,109	33	6,134	592	-275
2011	3,537	5,054	2,878	36,891	3,260	4,459	31,211	3,428	80	109	6,807	28	288	-624	-685
2012	2,183	5,237	8,975	14,407	2,063	4,955	17,384	4,376	111	63	3,843	5	898	-620	-2,274
2013	4,465	8,377	2,918	22,538	4,009	7,547	18,110	2,490	337	551	4,710	1	292	457	-207
2014	5,834	9,623	6,891	20,264	5,058	4,737	19,203	3,689	657	954	5,039	28	689	304	2,255
2015	6,354	12,661	9,411	14,734	5,733	9,830	16,716	4,954	486	754	4,939	9	941	416	-1,618
2016	4,142	8,635	11,107	14,425	3,806	7,947	17,294	3,590	297	395	4,835	1	1,111	407	-1,372

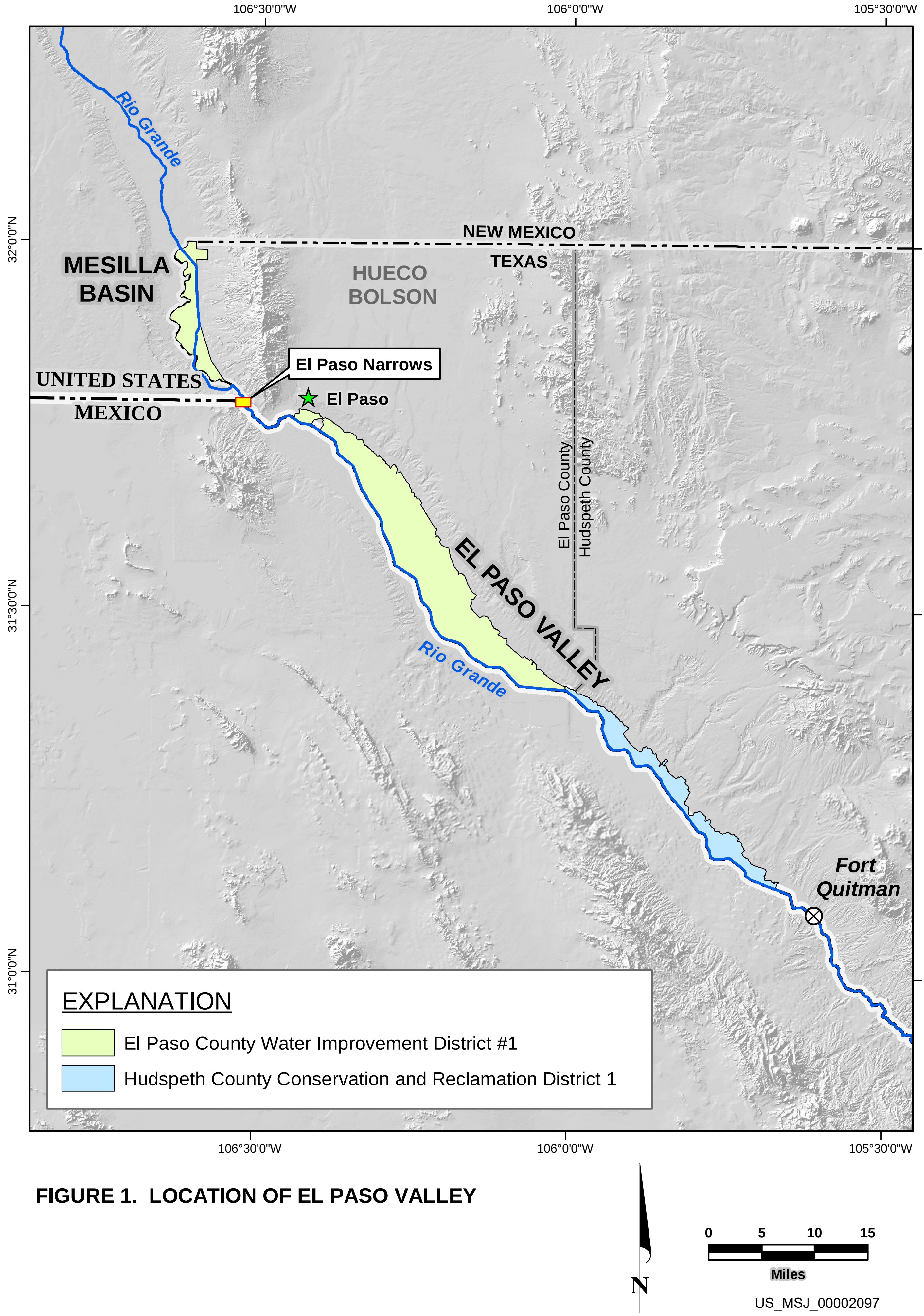

FIGURE 1. LOCATION OF EL PASO VALLEY

US_MSJ_00002097

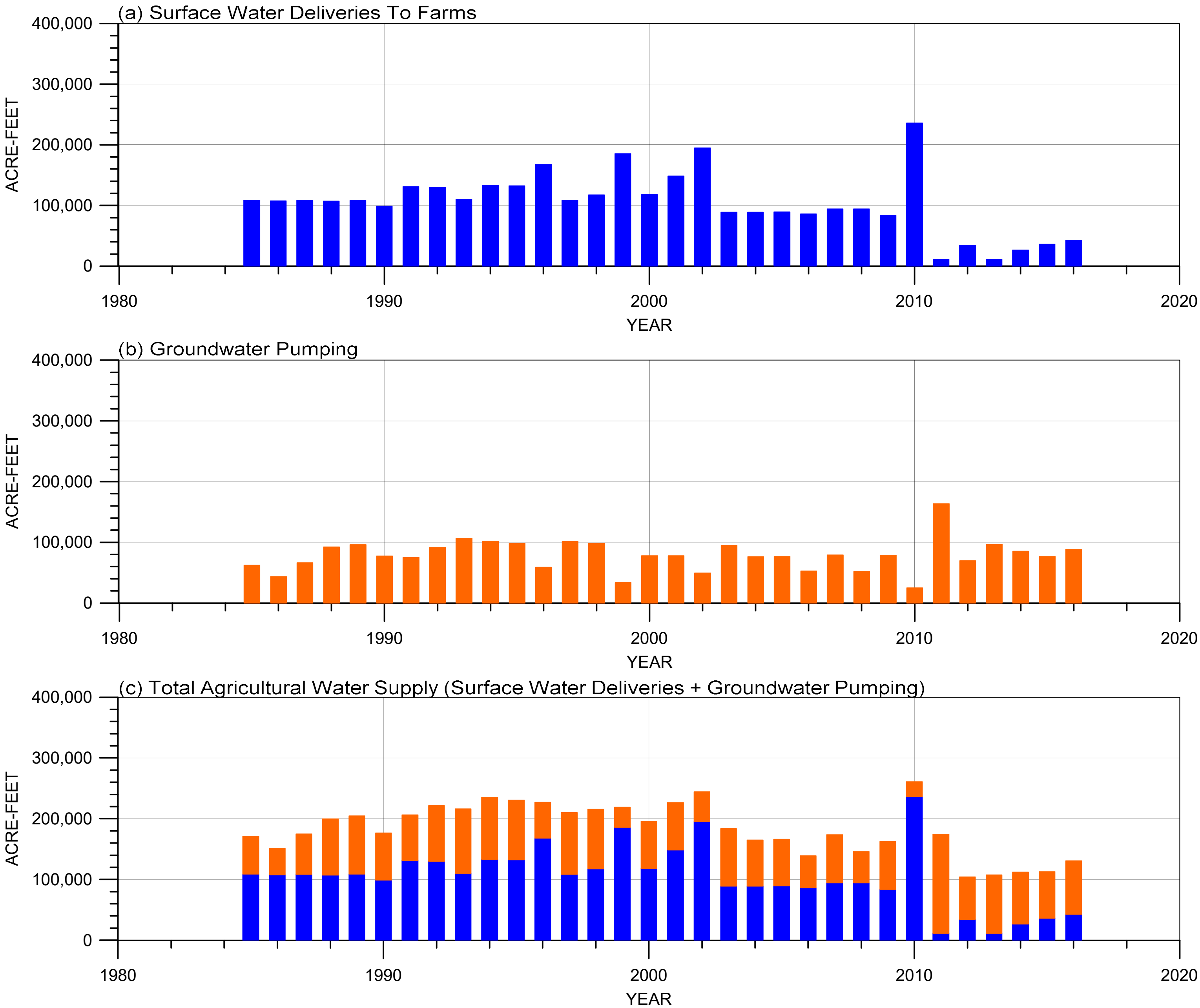

FIGURE 2. ESTIMATED ANNUAL IRRIGATION APPLIED WATER SUPPLY EL PASO COUNTY WATER IMPROVEMENT DISTRICT #1 IN EL PASO VALLEY: 1985 THROUGH 2016

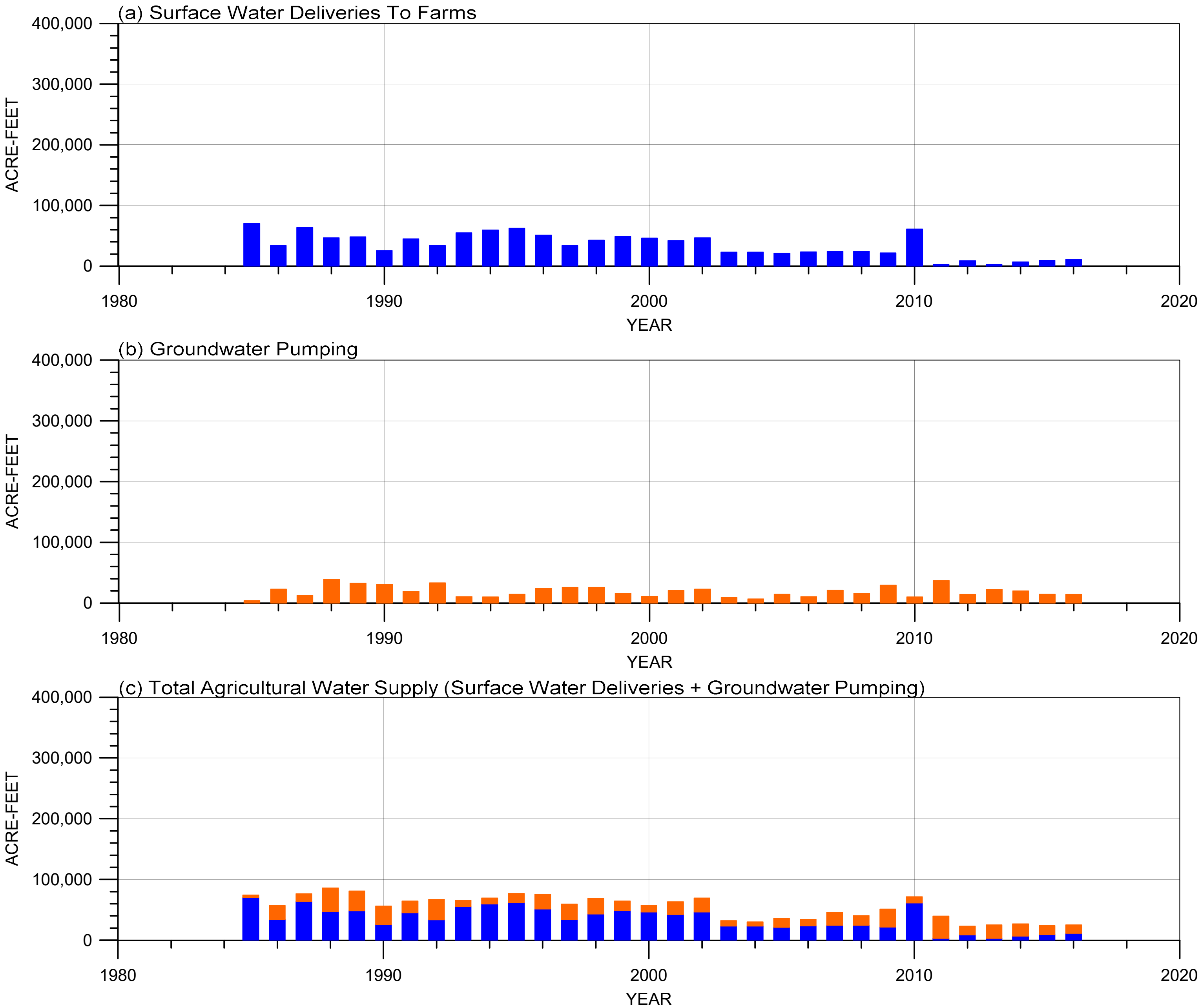

FIGURE 3. ESTIMATED ANNUAL IRRIGATION APPLIED WATER SUPPLY HUDSPETH COUNTY CONSERVATION AND RECLAMATION DISTRICT 1 IN EL PASO VALLEY: 1985 THROUGH 2016

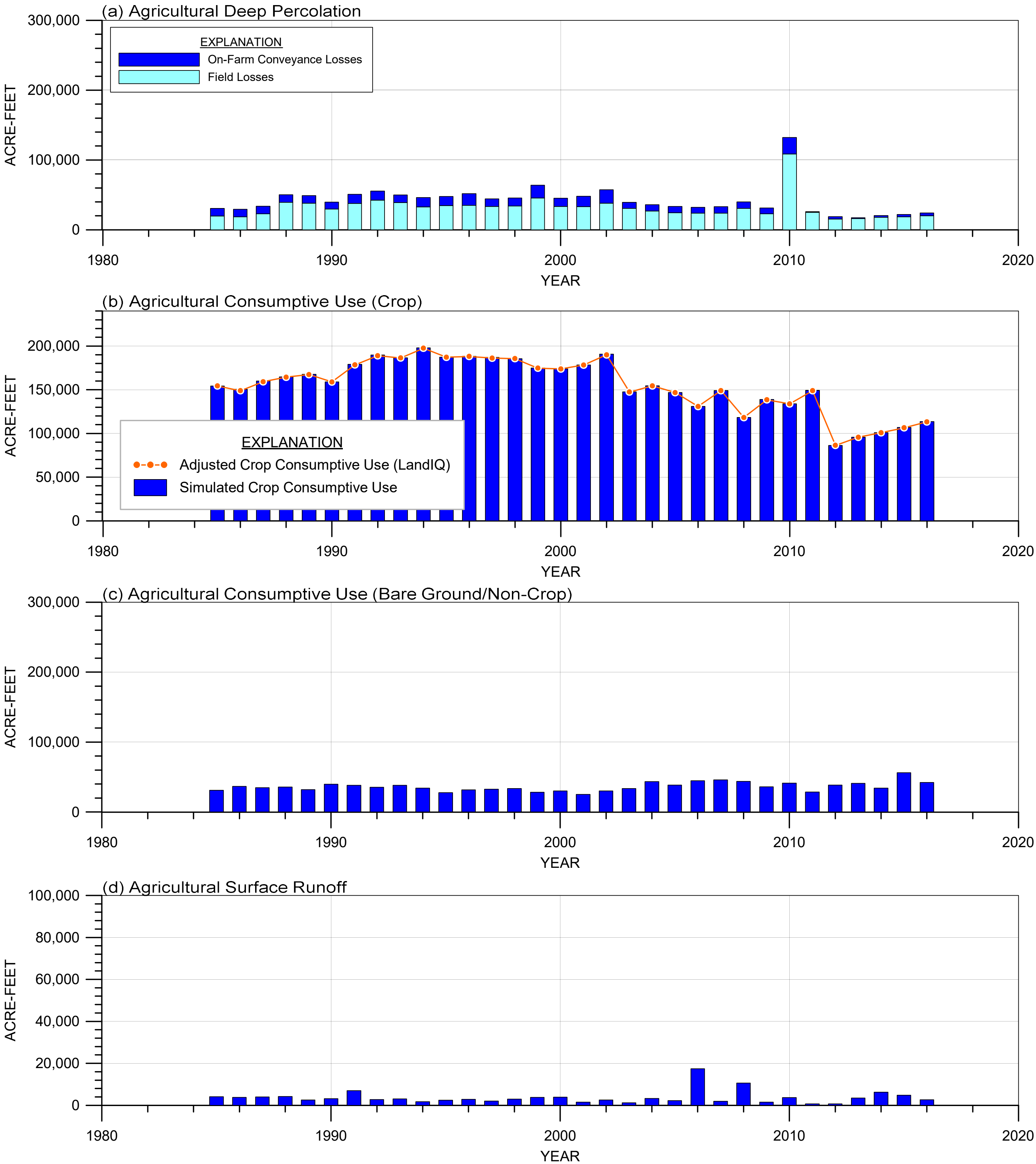

FIGURE 4. ESTIMATED ANNUAL FARM WATER BUDGET OUTFLOWS EL PASO COUNTY WATER IMPROVEMENT DISTRICT #1 IN EL PASO VALLEY: 1985 THROUGH 2016

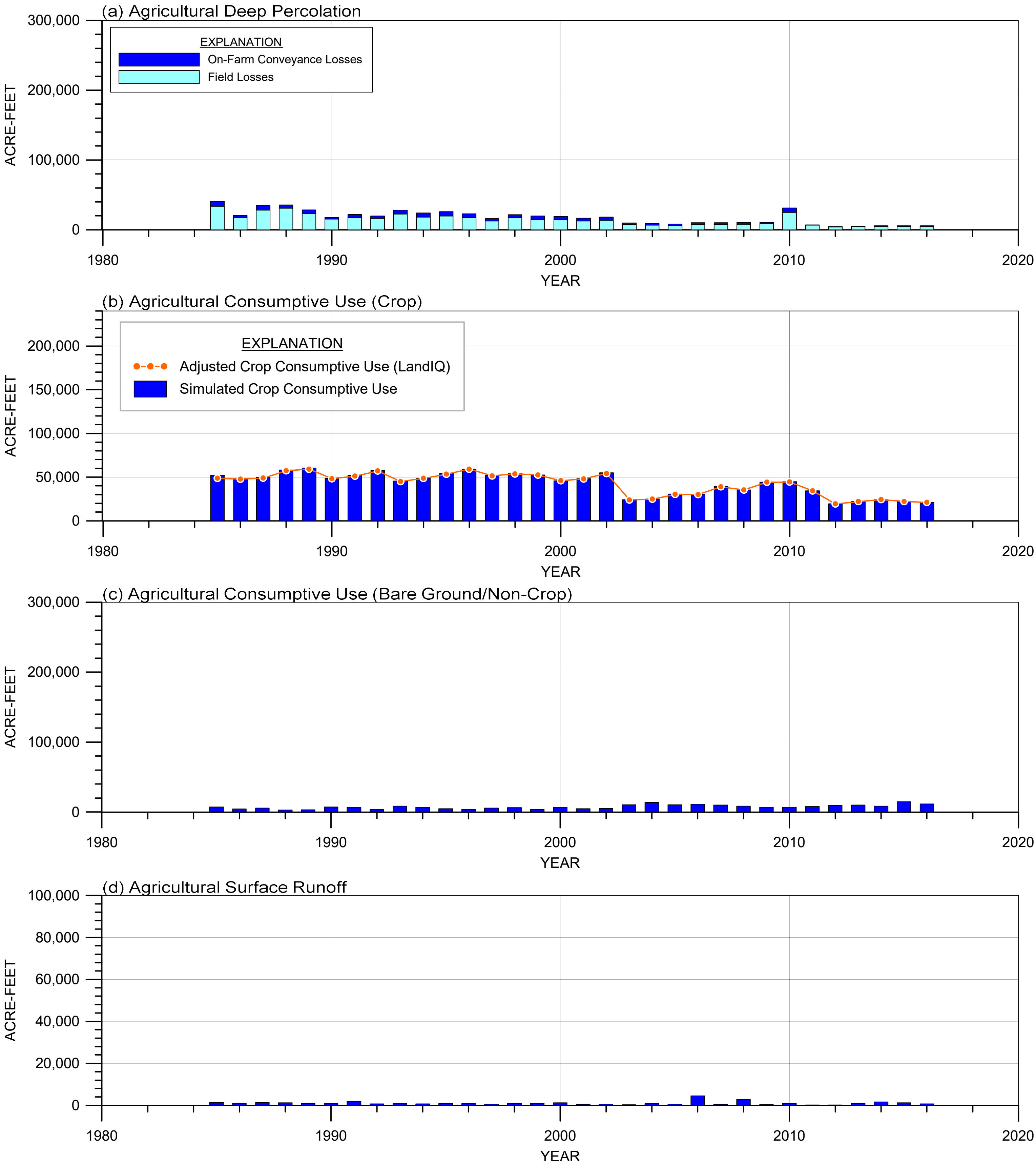

FIGURE 5. ESTIMATED ANNUAL FARM WATER BUDGET OUTFLOWS HUDSPETH COUNTY CONSERVATION AND RECLAMATION DISTRICT 1 IN EL PASO VALLEY: 1985 THROUGH 2016

APPENDIX H

PROFESSIONAL RESUMES

Staffan W. Schorr, Hydrogeologist / Principal

Office: TUCSON

Years Experience

Total: 20 | M&A: 12

Education

M.S., Hydrology, University of Arizona (2005)

B.S., Geology, University of Arizona (1997)

Key Areas of Expertise

Regional hydrogeologic characterization

Flow and transport modeling

Development of geologic models

Integration of GIS and conceptual models for numerical model construction

Database development and management

Aquifer test design, implementation, and data analysis

Staffan Schorr specializes in regional hydrogeologic characterization in support of groundwater modeling. He applies his background in numerical and analytical groundwater flow modeling to a variety of M&A projects to simulate the effects of long-term pumping, mine dewatering, and managed aquifer recharge and recovery. He has extensive experience using GIS methods to develop numerical model inputs, display model results, and develop geospatial databases for conceptual hydrogeologic models. He also manages M&A's GIS and 3D modeling services, and specializes in the use of Leapfrog software to develop volumetric geologic and geochemical interpolation models. His other interests include characterizing the interactions between groundwater and surface water along riparian corridors. Prior to joining M&A, Staffan worked for 8 years in watershed planning at Pima Association of Governments, a regional agency that facilitates coordination among local jurisdictions.

Representative Projects

Groundwater Modeling | Groundwater Resource Development

Groundwater Flow Model • Hueco Bolson • El Paso Water Utility
Updated hydrogeologic sections with new borehole data and geophysical logs, evaluated data from the Texas Water Development Board's groundwater database, developed a 3D geologic model, and constructed and calibrated a numerical groundwater flow-and-transport model to support the management of brackish groundwater resources and wellfields [EL PASO COUNTY, TX]

Groundwater Flow Model • Lower Rio Grande Valley • Texas Water Development Board
Developed a conceptual hydrogeologic model, relational database, and geodatabase to provide input for a groundwater flow-and-transport model used to evaluate future desalination operations [SOUTHERN TX]

Groundwater Flow Model • Northern Portions of Queen City, Sparta, and Carrizo Wilcox • Texas Water Development Board
Developed a conceptual hydrogeologic model, relational database, and geodatabase to provide input for a groundwater flow model used to evaluate regional groundwater availability. [NORTHEASTERN TX]

Groundwater Flow Model • Kinney County • William R. Hutchison, Independent Groundwater Consultant
Supervised development of MODFLOW USG model grid using AlgoMesh software [KINNEY COUNTY, TX]

Groundwater Flow Model • Bluebonnet Groundwater Conservation District • William R. Hutchison, Independent Groundwater Consultant
Provided support for numerical model development: evaluated previous aquifer layer interpolations, updated aquifer layering using available well borehole geophysical logs, and supervised development of a geologic model that

Modeling Codes & Software

MODFLOW
FEFLOW
PEST
MODFLOW-SURFACT
MT3D
HEC-RAS
WINFLOW
THWELLS
Leapfrog Hydro
Leapfrog Geo
Groundwater Vistas
ArcView
ArcGIS
Spatial Analyst
3D Analyst

Additional Training

2017: Fundamental and Advanced Techniques of Leapfrog Geo

2015: Introduction to MineSight

2013: MODFLOW-USG workshop

2012: Fundamental and Advanced Techniques of Leapfrog Hydro

2010: Advanced Techniques for Aquifer Test Analysis Featuring AQTESOLV

2010: Fundamentals of Leapfrog Hydro

2009: HEC-RAS 3-Day Short Course

2008: Advanced Techniques for Aquifer Test Analysis Featuring AQTESOLV

2008: Calibration, Uncertainty Analysis, and Optimization — A Seminar

combines all aquifer layers from existing Groundwater Availability Models in vicinity of the District [NORTH-CENTRAL, TX]

Groundwater Modeling | Hydrologic Impact Analysis

Environmental Impact Analysis • Arivaca Groundwater Flow Model • Pima County Regional Flood Control District
Projected changes in groundwater levels and potential impacts to environmentally sensitive areas related to pumping in a hydrologically isolated basin [PIMA COUNTY, AZ]

Groundwater Modeling | Tailings Water Management

Water Balance • Sierrita Mine • Freeport-McMoRan Corporation
Developed and updated spreadsheet water budget models for tailings impoundments at the Sierrita open-pit copper mine [PIMA COUNTY, AZ]

Groundwater Modeling | Mine Dewatering

Dewatering & Impacts Modeling • Collahuasi Mine / Rosario Pit • Compañía Minera Doña Inés de Collahuasi SMC
Designed and constructed a groundwater flow model to support dewatering operations and predict the environmental impacts associated with a large, open-pit mine in a complex mountain aquifer system [NORTHERN CHILE]

Groundwater Modeling | Managed Aquifer Recharge

Water Level / Quality Projections • Tonopah Desert Recharge Project • Central Arizona Water Conservation District
Developed flow and solute-transport models to project changes in nitrate concentrations and groundwater levels associated with recharge and future recovery operations [WESTERN AZ]

Water Level / Quality Projections • Central Avra Valley Storage & Recovery Project • Central Arizona Water Conservation District
Updated flow and solute-transport models to project groundwater level rise and changes in concentrations of total dissolved solids resulting from recharge operations [PIMA COUNTY, AZ]

Water Level Projections • Superstition Mountains Recharge Project • Central Arizona Water Conservation District
Updated a groundwater flow model to evaluate recharge rates and predict the rise in groundwater levels associated with recharge operations [MARICOPA COUNTY, AZ]

Permit Support • Willow Springs South Ranch Village Project • ANAM, Inc.
Developed an analytical model to support regulatory permitting requirements for recharging treated effluent [PINAL COUNTY, AZ]

GIS & 3D Geologic Modeling

Geospatial Model Development • Various Sites • Various Clients
Developed or supervised the development of dozens of 3D geospatial models for hard-rock and basin-fill groundwater systems using Leapfrog® software [U.S., PERÚ, CHILE]

GIS Development & Application • Various Sites • Various Clients
Developed GIS inventories of wells, infrastructure, water use, land use, and other related features; prepared cartographically correct maps, figures, and 3D geologic models for many investigations and modeling projects [U.S., CHILE, PERÚ, ARGENTINA, BOLIVIA]

Managed Aquifer Recharge

Hydrogeologic Characterization • Recovery Wellfield Siting Study (Phase 1) • Central Arizona Water Conservation District
Conducted a hydrogeologic assessment, well inventory, and wellfield analysis for recovering stored CAP water [PINAL COUNTY, AZ]

Groundwater Modeling | Mine Water Supply

Groundwater Flow Model • Confidential Site • Confidential Client
As part of due diligence efforts, designed and implemented a model to project groundwater level impacts associated with potential future pumping for a new water supply; constructed a 3D geospatial model of an alluvial groundwater system using Leapfrog Hydro [WESTERN AZ]

Mine Water Supply

Aquifer Testing & Analysis • Proposed Copper Mine Reopening • Freeport-McMoRan Corporation
Planned and implemented an aquifer testing program; analyzed test data to evaluate groundwater resources [PIMA COUNTY, AZ]

Aquifer Testing & Analysis • Big Sandy Valley • Freeport-McMoRan Corporation
Analyzed long-term test data from a confined aquifer to evaluate potential groundwater resources, impacts to environmentally sensitive areas, and hydraulic connectivity between aquifers [MOHAVE COUNTY, AZ]

Water Policy & Planning

Hydrogeologic Characterization • Regional Water Plan • Confidential Client
Evaluated hydrogeologic data and supervised the development of a 3D data model to support the initial phases of a regional water plan [PIMA COUNTY, AZ]

Hydrogeologic Characterization • Various Sites • Pima County Regional Flood Control District
Conducted basic hydrogeologic investigations using publicly available data sources for Aguirre Valley, Altar Valley, and the Ajo-Why area to support an amendment to Pima County's Water Resources Comprehensive Plan [PIMA COUNTY, AZ]

Publications & Presentations

Development of conceptual plan for direct recovery of Central Arizona Project water stored at Tonopah Desert Recharge Project, Maricopa County, Arizona
Meyer, J.J., Cross, M.M., Schorr, S.W., Shipman, T.D., and Fuerst, D., 2009, National Groundwater Association 2009 Groundwater Summit, Tucson, AZ, April 19–23

Hydrogeologic conceptual model for the Collahuasi Mine area, Chile
Thomasson, M.J., Schorr, S.W., Davis, L.A., Rosko, M.J., Acosta, O.J., 2010, Water in Mining, Second International Congress on Water Management in the Mining Industry, Santiago, Chile, June 9–11

Conceptual model report: Lower Rio Grande Valley Groundwater Transport Model
Schorr, S., Hutchison, W.R., Panday, S., and Rumbaugh, J., 2017, prepared for Texas Water Development Board, June 30, 2017.

Conceptual model report: Groundwater Availability Model for northern portion of the Queen City, Sparta, and Carrizo-Wilcox Aquifers
Schorr, S., Hutchison, W.R., Panday, S., and Rumbaugh, J., 2018, prepared for Texas Water Development Board, draft report June 28, 2018.

Colin P. Kikuchi, Ph.D., Groundwater Hydrologist

Office: TUCSON

Years of Experience

Total: 10 | M&A: 5

Education

Ph.D., Hydrology & Water Resources, Minor in Agricultural and Resource Economics, University of Arizona (2015)

M.S., Hydrology & Water Resources, University of Arizona (2011)

B.A., Environmental Studies and Geography, Middlebury College (2005)

Key Areas of Expertise

Groundwater flow modeling

Quantitative uncertainty prediction for hydrologic simulations

Analysis of groundwater / surface water interactions

Agricultural water balance

Design of hydrologic monitoring networks

Colin Kikuchi joined M&A in 2014, bringing a background in quantitative hydrology and groundwater-surface water interaction. He has developed conceptual hydrogeologic models in a variety of environments for M&A clients, and routinely uses analytical and numerical modeling tools to evaluate groundwater systems. Prior to joining M&A, Colin worked on projects evaluating groundwater and groundwater-surface water interactions for the USGS Alaska Science Center. From 2012–2013, he served as the lead instructor for the Alaska Section of American Water Resources Association's workshop series on groundwater and surface-water interactions.

Representative Projects

Recharge Analysis

Recharge Analysis • Salar de Lagunillas • Compañía Minera Cerro Colorado
Designed and installed a streambed and borehole temperature monitoring network; analyzed the statistical uncertainty of natural groundwater recharge [CHILE]

Recharge Analysis • Salar de Punta Negra • Compañía Minera Escondida Ltda.
Analyzed the statistical uncertainty of natural groundwater recharge [CHILE]

Recharge Uncertainty Analysis • San Pedro – Inacaliri Basin • CODELCO
Evaluated hydrogeologic and geochemical data to develop alternate conceptual models; quantified the uncertainty of groundwater budget components, including natural recharge and underflow in and out of basin. Provided technical guidance to monitoring station design and installation, analyzed streambed and borehole temperature data to estimate natural recharge [CHILE]

Groundwater Modeling

Agricultural and Surface Water Budgets • Paso Robles Sub-Basin • City of Paso Robles
Prepared historical agricultural and surface water budget components using daily soil-water balance and surface water models; conducted numerical model simulations to evaluate streamflow depletion; developed future projected water budgets incorporating climate change impacts [SAN LUIS OBISPO COUNTY, CALIFORNIA]

Mine Dewatering Feasibility • Cove Project • Au-Reka Gold Corporation
Evaluated hydrogeologic data and existing numerical models to support underground mine dewatering estimates; led preparation of a new groundwater model [LANDER COUNTY, NEVADA]

Groundwater-surface water interactions • Upper Verde Watershed • The Nature Conservancy
Developed summary narrative of hydrogeologic and surface water studies and data on the Verde River; conducted numerical simulations to evaluate streamflow depletion; analyzed historical data to develop conceptual model of future streamflow under climate and watershed management scenarios [YAVAPAI COUNTY, ARIZONA]

Groundwater Flow Model Simulation • Bingham Canyon Mine • Rio Tinto / Kennecott Utah Copper
Conducted numerical simulations of perched groundwater flow; developed refined grid model using MODFLOW-USG to facilitate use of regional groundwater flow model to evaluate pressure heads along geotechnical sections [SALT LAKE COUNTY, UT]

Scenario Analysis • Santa Margarita Basin • Hydrometrics, WRI
Conducted numerical simulations and analyzed results to evaluate hydrogeologic impacts of managed aquifer recharge projects in a sedimentary rock aquifer; prepared water budgets to support Groundwater Sustainability Plan development [SANTA CRUZ COUNTY, CALIFORNIA]

Numerical Groundwater Flow Simulation • Salares de Centenario & Ratones • ERAMET SA
Conducted probabilistic lithium reserve estimate using numerical flow and transport model [ARGENTINA]

Water Quality Data Compilation • Hueco Bolson • El Paso Utilities
Organized water quality data and prepared maps and time-series plots of chloride concentrations as data inputs for a groundwater flow and transport model [EL PASO COUNTY, TX]

Contaminant Investigation

Capture Analysis • Inactive Rancho Cordova Test Site • The Boeing Company
Conducted probabilistic numerical modeling analysis of capture/hydraulic containment of extraction wells downgradient of plume, evaluated impact of extraction wells on migration of contaminants originating off-site [SACRAMENTO COUNTY, CA]

Analysis of Aquifer Test Data • Inactive Rancho Cordova Test Site • The Boeing Company
Compiled data on groundwater pumping rates and water levels; developed a conceptual model of an unconsolidated, multiple-aquifer system; used analytical and numerical solutions to infer aquifer hydraulic properties based on aquifer test data [SACRAMENTO COUNTY, CA]

Statistical Analysis of Water Quality Data • Former Lisbon Mine & Mill • Rio Algom Mining LLC
Analyzed groundwater quality data to assess the suitability of multiple sampling methods to characterize long-term trends [SAN JUAN COUNTY, UT]

Codes & Software

MODFLOW, MODFLOW-USG
PEST

AQTESOLV

GoldSim

MAxSym (Axisymmetric Numerical Simulator)

IDC (Irrigation Demand Calculator)

SURFER/KT3D

HSPF

Additional Training

2018: MODFLOW Solvers: Speed, Convergence, and Robustness

2017: (FEFLOW) Groundwater modeling for open-cast mining

2015: Fundamentals of MODFLOW-USG, an unstructured grid version of MODFLOW

2015: Model Calibration and Uncertainty Analysis with PEST

2011: Practical Statistics for Environmental Applications

2010: Introduction to Distributed Temperature Sensing (DTS) Systems for Water Resource Applications

Feasibility Studies

Aquifer Testing & Hydrologic Analysis • Apache Leap Tuff Aquifer & Queen Creek Corridor • Resolution Copper Mining
Analyzed aquifer test data to infer the saturated and unsaturated hydraulic properties of intact rock mass; analyzed streamflow and surface water quality data to support a baseflow characterization and develop hydrographs [PINAL COUNTY, AZ]

Adjudication & Water Rights

Litigation Support • Confidential Site • Confidential Client
Evaluated numerical model and conducted predictive simulations to evaluate drawdowns due to well-field operation [NM]

Litigation Support • Confidential Site • Confidential Client
Evaluated methodology and proof-of-concept study developed by Arizona Department of Water Resources for quantifying subflow capture and prepared recommendations for improvements to modeling approach [AZ]

Other Experience

USGS Experience

Conducted hydrologic/hydrodynamic simulations of groundwater–surface water interactions in riparian wetlands

Served as a technical review team member for aquatic and riparian instream flow studies, Susitna–Watana Hydroelectric Project, as part of the FERC licensing process

Performed field investigations and hydrologic simulations for a permafrost-affected boreal catchment

Worked as lead scientist for regional-scale groundwater availability study

Developed conceptual hydrogeologic model and a numerical groundwater flow model for the Matanuska-Susitna Valley

Used a land-surface modeling code to estimate spatially distributed groundwater recharge

Investigated groundwater–surface water interactions using temperature data

Performed routine groundwater and surface water measurements

Collaborated with state agency personnel to conduct a 2-week synoptic measurement of groundwater levels

Publications & Presentations

Journal Articles

Towards Increased Use of Data Worth Analyses in Groundwater Studies, Kikuchi, C.P., in Groundwater, volume 55, issue 5

On the optimal design of experiments for conceptual and predictive discrimination of hydrologic system models
Kikuchi, C.P., Ferré, T.P.A., and Vrugt, J.A., 2015, in Water Resources Research, volume 51

Runoff sources and flow paths in a partially burned, upland boreal catchment underlain by permafrost
Koch, J.C., Kikuchi, C.P., Wickland, K.P., and Schuster, P., 2014, in Water Resources Research, volume 50 issue 10

Review: Groundwater in Alaska
Callegary, J.B., Kikuchi, C.P., Koch, J.C., Lilly, M.R., and Leake, S.A., 2013, in Hydrogeology Journal, volume 21

Spatially telescoping measurements for improved characterization of groundwater-surface water interactions
Kikuchi, C.P., Ferré, T.P.A., and Welker, J.M., 2012, in Journal of Hydrology, volume 446–447

USGS Reports

Shallow groundwater in the Matanuska-Susitna Valley, Alaska – Conceptualization and simulation of flow
Kikuchi, C.P., 2013, USGS Scientific Investigations Report 2013-5049

Recent Conference Papers

Practical Uncertainty Analyses in Mining Hydrogeology
Kikuchi, C.P., 2019, Nevada Water Resources Association Mine Water Management Symposium, Reno, NV, January 28-29.

Global sensitivity analysis of a land surface model: An applied case study
Kikuchi, C.P., Kimmelshue, J., and Heilman, M., 2016, Concord, CA, September 28-29.

What / Where / When to Measure? Systematic Planning and Design for Groundwater Sampling and Monitoring Networks
Kikuchi, C.P., Ferré, T.P.A., and Bayley, T.W., 2016, NGWA Annual Summit, Denver, CO, April 25-27

Chance-constrained optimization in sustainable groundwater management
Kikuchi, C.P., and Ferré, T.P.A., 2016, GRA Workshop on the "Role of Models and Data in Implementing SGMA", Davis, CA, February 8-9

Quantifying groundwater recharge uncertainty: A multiple-model framework and case study
Kikuchi, C.P., and Ferré, T.P.A., 2014, American Geophysical Union 2014 Fall Meeting, San Francisco, CA, December 15–19

No. 141, Original

IN THE

SUPREME COURT OF THE UNITED STATES

TEXAS v. NEW MEXICO AND COLORADO

EXPERT REPORT OF
GREGORY K. SULLIVAN, P.E.
AND
HEIDI M. WELSH

Prepared for:

STATE OF NEW MEXICO

Prepared by:

Gregory K. Sullivan, P.E.

Adelheid M. Welsh

October 31, 2019

Spronk Water Engineers, Inc.

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FIGURES

TABLES

APPENDICES

LIST OF ABBREVIATIONS

2008 OA	2008 Operating Agreement
ACE	American Canal Extension
AF	Acre-feet
Reclamation	Bureau of Reclamation
CFB Model	Canal and Farm Budget Model
cfs	Cubic feet per second
CIR	Crop irrigation requirement
cms	Cubic meters per second
Compact	Rio Grande Compact
DCMI	Domestic, commercial, municipal, and industrial
DE	David's Engineering
DP	Deep percolation
EBID	Elephant Butte Irrigation District
EPA	Environmental Protection Agency
EPCWID	El Paso County Water Improvement District No. 1
EPW	El Paso Water
ET	Evapotranspiration
FHG	Farm headgate
Ft. Quitman	Fort Quitman, Texas
gpm	Gallons per minute
GPS	Global positioning system
HCCRD	Hudspeth County Conservation and Reclamation District No. 1
Hueco Model	Hueco Ground Water Model
Hydros	Hydros Consulting
IBWC	International Boundary and Water Commission
ILRG Model	Integrated Lower Rio Grande Model
JID	Juarez Irrigation District
JMAS	Junta Municipal de Aqua y Saneamiento (water utility for Ciudad Juarez)
LRG	Lower Rio Grande
LRG Area	Area of irrigation and non-irrigation water use in the Rincon, Mesilla, El Paso, and Juarez Valleys between Caballo Reservoir and Ft. Quitman Texas
M&A	Montgomery & Associates
MAD	Management allowable depletion
MFE	Maximum farm irrigation efficiency
MMA	McDonald-Morrisey Associates, LLC
MX-IBWC	Mexican section of the International Boundary and Water Commission
NMAGO	New Mexico Office of the Attorney General
NMISC	New Mexico Interstate Stream Commission
NMOSE	New Mexico Office of the State Engineer
NMR-M Model	New Mexico Rincon-Mesilla Ground Water Model
NPDES	National Pollutant Discharge Elimination System

PET	Potential evapotranspiration
QA/QC	Quality assurance and quality control
RGCC	Rio Grande Compact Commission
RGJI	Rio Grande Joint Investigation
RiverWare	RiverWare simulation model
RHG	River headgate
SSPA	S.S. Papadopulos & Associates
SWDataSet	Surface Water Dataset prepared by SWE
SWE	Spronk Water Engineers, Inc.
URGWOM	Upper Rio Grande Water Operations Model
USGS	United States Geological Survey
US-IBWC	United States section of the International Boundary and Water Commission
WDR	Water Distribution Report
WTP	Water Treatment Plant
WWTP	Wastewater Treatment Plant

1.0 QUALIFICATIONS AND SUMMARY OF OPINIONS

1.1 Overview of Qualifications of Gregory K. Sullivan, P.E.

My name is Gregory K. Sullivan, and I am a principal and senior water resources engineer at Spronk Water Engineers, Inc. ("SWE") in Denver, Colorado. I have Bachelors of Science degree in Civil Engineering from Colorado State University (1985) and a Master of Science Degree in Civil Engineering from the University of Colorado (1990). I am a registered professional engineer in Colorado, New Mexico, Idaho, and Nevada.

After receiving my undergraduate degree in 1985, I took a job with J.W. Patterson & Associates in Denver where I performed work in water supply planning, water rights analysis, surface water and ground water analysis and modeling, and hydrology. In 1990, I accepted a position at SWE as a staff engineer, became a shareholder in 1992, and am currently one of two majority shareholders. SWE is a consulting firm in areas of water resources engineering and water rights. We work for federal, state, and local governments and other water providers; commercial and industrial water users; and farmers, ranchers and other individuals. Most of our work is in the areas of water supply planning, municipal water supply modeling, surface water and ground water modeling, water rights engineering, and conjunctive management of ground water and surface water.

During my 35-year career in water resources and water rights engineering I have worked on numerous projects involving analyses of historical irrigation water use, municipal water use, and surface water and ground water modeling, primarily in Colorado, Idaho, and New Mexico. Among these efforts was my work in the use and modification of the H-I Model of the Arkansas River in Colorado that was used in the original jurisdiction lawsuit filed in 1985 by the State of Kansas against the State of Colorado in the U.S. Supreme Court. The model simulates daily operation of irrigation water uses under approximately two dozen canal systems along the Arkansas River in Colorado between the City of Pueblo and the Colorado-Kansas state line from 1950 to the present. I testified as expert in the case on several occasions before Special Master Littleworth.

My work on the Rio Grande in New Mexico began in the 1990s when I assisted in the development of the original farm budget model of the Rincon and Mesilla basins that was later used in development of the 2007 S.S. Papadopulos & Associates ("SSPA") ground water model of those basins. Since that time, I have worked on various Rio Grande matters leading up to the development and application of the models described in this report.

My professional resume is provided in **Appendix 1A** to this report along with a list of cases in which I have testified as an expert during the past four years. SWE is being compensated at a rate of $200 per hour for my work on this case, and this compensation is not dependent on the outcome of the case.

1.2 Overview of Qualifications of Adelheid M. Welsh

My name is Adelheid (Heidi) M. Welsh. I am a senior watershed scientist and partner at Spronk Water Engineers, Inc. ("SWE") in Denver, Colorado. I have Bachelors of Science degree in Watershed Science from Colorado State University (2007). I am a registered professional hydrologist through the American Institute of Hydrology.

During college, I took a hydrology internship at the Teton Science School (summer 2006) and worked for the U.S. Forest Service Arapahoe-Roosevelt National Forest (Fall 2006 - Spring 2007) in Fort Collins. After receiving my undergraduate degree in 2007, I worked for the U.S. Forest Service Back Hills National Forest in Sundance, WY. In Fall 2007, I took a job with AATA, Inc. in Denver, where I conducted work in environmental consulting which included data analysis, report writing, and GIS applications.

In 2009, I took a job at SWE as a watershed scientist and became a shareholder in 2017. During my 10-year career in water resources and water rights engineering I have worked on numerous projects involving analyses of historical water use, surface water and ground water modeling, and water accounting. I have extensive experience in compilation and analysis of hydrologic and spatial data.

My work on the Rio Grande in New Mexico began in the 2012 when I assisted in the development of the surface water and accounting dataset and the updated farm budget model of the Lower Rio Grande basin, including the Rio Grande Project, Juarez Valley, and Hudspeth.

My professional resume is provided in **Appendix 1B** to this report. SWE is being compensated at a rate of $150 per hour for my work on this case, and this compensation is not dependent on the outcome of the case.

1.3 Assignments

SWE has contracted for its consulting work on this case through the New Mexico Interstate Stream Commission ("NMISC") and the New Mexico Office of the Attorney General ("NMAGO"). Our assignments on this case were developed in discussions with legal counsel for the State of New Mexico. We were asked by legal counsel to develop analyses and expert opinions in the following areas:

- Compilation and analysis of historical records on the hydrology and use of water under the Rio Grande Project ("Project") and nearby areas.
- Development of Canal and Farm Budget Models ("CFB Models") of the major irrigation users between Elephant Butte Reservoir and Fort Quitman Texas, including the Elephant Butte Irrigation District ("EBID"), the El Paso County Water Improvement District No. 1 ("EPCWID"), the Hudspeth County Conservation and Reclamation District No. 1 ("HCCRD"), and the Juarez Irrigation District ("JID").
- Coordination of development of integrated surface water and ground water models of the area along the Rio Grande from San Marcial, New Mexico ("San Marcial") to Fort Quitman, Texas ("Ft. Quitman").
- Analysis of historical Project operations.
- Analysis of the impacts of ground water pumping in New Mexico, Texas, and Mexico on streamflows and water deliveries to the major irrigation water users and El Paso Water ("EPW" a.k.a. "EPWU") in the study area.
- Analysis of the impacts of the 2008 Operating Agreement ("2008 OA") on deliveries of water to the major irrigation water users.
- Review of expert reports and supporting data, analyses, and modeling submitted by experts for the State of Texas and the United States.

Summaries of the opinions that were developed by Ms. Welsh and Mr. Sullivan for this case follow.

1.4 Summary of Opinions of Adelheid M. Welsh

Ms. Welsh prepared and is responsible for the opinions in Section 3 and Section 4 which are summarized below. In addition, she was also involved in compiling the data used in the CFB Models described in Section 6, disseminating data for use in the New Mexico models, and in post-processing the model output files into summary tables and graphs.

<u>Section 3 – Lower Rio Grande Hydrologic Data</u>

1. Data from various sources were reviewed and compiled into an Excel database identified as the SWDataSet. The data in the SWDataSet are organized by flow type and annotated with site information such as the location information, period of record, and metadata reference.

2. The data in the SWDataSet are well documented. Detailed metadata has been prepared and is provided with each data entry and includes contact names, originator

information, supporting files, descriptions, processing notes, spatial domain, data quality, time period of content, and other information.

3. The SWDataSet is the best available compilation of surface water and other data for the Lower Rio Grande Area ("LRG Area"), and the information contained in the database is suitable for use in hydrologic modeling and analyses.

4. The data in the SWDataSet have undergone extensive review and quality assurance and quality control ("QA/QC") consistent with industry standards. This includes double checking all data entry against the source information and preparation of tabular, graphical, and statistical summaries that were prepared for each data site to assess the data for consistency.

5. Despite extensive efforts over several years to obtain all available flow records in the Lower Rio Grande basin, there remained missing data that needed to be estimated for technical analysis and modeling purposes. Over a relevant time period, correlations were derived from two sets of available data. The missing data were estimated using the correlation equation and available data. The estimates of these missing data in the SWDataSet are reasonable and suitable for use in modeling and analysis.

Section 4 – Rio Grande Project Accounting Data

6. The Project records, including Water Distribution Reports, Bureau of Reclamation ("Reclamation") tables, accounting reports, and allocation records, were compiled. Information from these reports was added into two Excel spreadsheets that comprise the Accounting DataSet.

7. The Accounting DataSet is comprehensive and is comprised of the best available Project data. In addition to our review, these data have been reviewed by employees in the New Mexico Office of the State Engineer ("NMOSE") and/or the NMISC for consistency and accuracy. All the data in the Accounting DataSet have undergone QA/QC by two or more water resources professionals.

1.5 Summary of Opinions of Gregory K. Sullivan

Mr. Sullivan prepared Section 2 and Sections 5 through 15, and is responsible for the opinions presented in those sections, which are summarized below.

Section 5 – Historical Water Supply and Water Use

8. Most of the water supply for the Lower Rio Grande below Caballo Reservoir originates as Rio Grande flow passing the San Marcial gage and entering Elephant Butte Reservoir. Annual San Marcial gage flows averaged approximately 890,000 AF during the 1890 - 2017 period of record. The flows have been cyclical, with 10-year average flows generally above average through the 1940s, below average during the 1950s - 1970s, above average in the 1980s and 1990s, and below average thereafter. (Figure 5-1).

9. The average annual inflow available to the Project at San Marcial was estimated in the Rio Grande Joint Investigation ("RGJI") as 1,031,000 AF based on flows for the period from 1890 - 1935 adjusted for upstream development. Annual San Marcial flow since that time has averaged 754,000 AF. (Table 5-1).

10. The annual reservoir release necessary to supply the Project was estimated in the RGJI as 773,000 AF. This was increased to the "normal annual release" of 790,000 AF described in Rio Grande Compact ("Compact"). In the generally wet period following the RGJI analysis (1936 - 1950) annual reservoir releases averaged 845,000 AF. Since then annual reservoir releases have averaged only 607,000 AF (1951-2017). (Table 5-1).

11. Average annual depletions of Rio Grande flow between the Caballo Reservoir outlet and the El Paso gage are at approximately the same level now as they were at the time of the Compact (250,000 AF/y). (Figure 5-2).

12. The total annual Project irrigated area contemplated in the RGJI totaled 145,000 acres, while acres that were actually authorized to be irrigated totaled 159,650 acres (155,000 acres plus an additional 3%). The reported actual irrigated area peaked at approximately 160,000 acres in the early 1950s. Since then, the irrigated area has declined, largely due to urbanization, and currently stands at approximately 105,000 acres. (Figure 5-4)

13. Average annual farm headgate deliveries ("FHG deliveries") of Project water were relatively steady from the 1950s - 1970s, increased during the 1980s and 1990s, and have declined since then due to the recent drought. (Figure 5-10, Figure 5-12, Figure 5-14).

14. The total applied water in EBID, including deliveries of Project water and supplemental pumping, has declined slightly since the 1980s. Conversely, the total

applied water in EPCWID, including deliveries to EPW, has remained steady through time. (Figure 5-15 and Figure 5-19).

15. Project operational waste in EBID typically comprised roughly 10% of canal heading diversions from the 1940s and 1950s and thereafter declined to less than 10% in most years. Operational waste in EPCWID followed a similar pattern in the early years with the waste exceeding 10% in the 1940s, and then declining to roughly 10% or less during the 1950s - 1970s. However, when EPCWID took over water distribution within the district in 1980, operational waste increased substantially to an average of approximately 25% of canal diversions until the recent drought. The increased EPWID waste has resulted in a substantial increase in flows to HCCRD. The excess waste in EPCWID has impacted Project water allocations and deliveries to EBID. (Figure 5-20 through Figure 5-23).

16. The NMOSE has required all well users in the LRG basin within New Mexico to measure and report ground water pumping since 2009. During the relatively dry decade that the measuring requirement has been in effect (2009-2018), annual LRG irrigation pumping in New Mexico has averaged 219,000 AF. New Mexico pumping during this period has been affected by the reduction in Project water allocations to EBID as a result of the 2008 OA. Unlike in New Mexico, there reportedly are no requirements in Texas or Mexico to measure and report pumping, and no records of LRG irrigation pumping are available for those areas. (Figure 5-25).

17. Non-irrigation pumping, primarily for municipal uses, has increased substantially throughout the LRG Area, most notably in the El Paso and Juarez areas. Annual non-irrigation pumping in New Mexico increased to an average of approximately 38,000 AF during the last ten years. This is much less than the non-irrigation pumping that has averaged approximately 82,000 AF in Texas and 144,000 AF in Mexico during the last ten years. (Figure 5-26 through Figure 5-28).

Section 6 – Lower Rio Grande Canal and Farm Budget Models

18. Monthly CFB Models were prepared to simulate irrigation water use in LRG Area during the period from 1938 - 2017. The models were developed to assess the historical use of surface water and ground water in the LRG Area, and specifically to compute:

    - Crop-weighted consumptive use of applied water for the irrigation units in the LRG Area;
    - FHG deliveries for periods when records were not available; and

- Supplemental pumping for all areas, and the primary (ground water only) pumping in New Mexico.

Separate models were developed for four subareas in EBID (Rincon, Leasburg, Mesilla Westside, and Mesilla Eastside), three subareas in Texas (Mesilla Westside, Mesilla Eastside, and El Paso Valley), three subareas in Mexico (JID Units 1, 2, and 3), and the HCCRD.

19. Annual CFB Models were prepared for the portions of the Texas and Mexico irrigation districts that overlie the Hueco Bolson during 1903 - 1939 for the purpose of developing certain input data used in the Hueco Ground Water Model ("Hueco Model") developed by McDonald-Morrisey Associates, LLC ("MMA").

20. The monthly and annual CFB Models that were developed to simulate irrigation water use in the LRG Area are based on commonly used water budget analysis techniques and procedures. Similar water budget analyses are routinely used in the analysis of historical use for changes of irrigation water rights before the Colorado Water Courts.

21. The monthly CFB Models for the LRG Area irrigation units are reasonable representations of the historical irrigation operations during the 1938 - 2017 study period. The simulated consumptive use of applied surface water and ground water, conveyance losses, and on-farm losses are reasonable and representative of the variable water supply and hydrologic conditions that occurred over the 80-year study period.

22. The monthly supplemental ground water pumping and primary ground water pumping computed in the CFB Models are reasonable estimates of the amounts of pumping that were historically required to meet the unmet irrigation demands considering the historical surface water supplies. The simulated pumping for EBID during 2009 - 2017 was within 1% of the reported values. (Figure 6-5).

Section 7 – Need for Modeling Analysis of Claims and Counterclaims

23. Due to the complex effects that Project operations and LRG Area irrigation operations have on the amount and timing of surface water flow, ground water flows and their interaction, a simulation model is useful and necessary to understand and quantify these effects. The model should be reasonably calibrated over a representative historical period and be capable of simulating appropriate dynamic responses of Project and irrigation operations to variations in water supply in historical and alternative scenarios.

24. A simulation model of the LRG Area should reasonably simulate important physical processes and management processes that affect the occurrence, movement, and use of ground water and surface water. Important physical processes include surface water flow, ground water flow, surface water and ground water interactions, evaporation, and evapotranspiration. Important management processes include Project water allocation, reservoir operations, canal operations, and on-farm irrigation operations. (Table 7-1).

Section 8 – Overview and Assessment of Integrated LRG Model

25. The Integrated LRG Model ("ILRG Model") consists of a RiverWare Model that simulates the LRG Area from the Rio Grande at San Marcial gage upstream of Elephant Butte Reservoir to the Rio Grande at Ft. Quitman Gage in Texas. The RiverWare Model is linked to two ground water models - the New Mexico Rincon-Mesilla Ground Water Model ("NMR-M Model") that simulates ground water flow in the Rincon and Mesilla basins between the Caballo Reservoir outlet and the El Paso Narrows, and the Hueco Model that simulates ground water flow in the El Paso and Juarez Valleys from the El Paso Narrows to Ft. Quitman. The ILRG Model simulates the period from 1940 - 2017 and operates using monthly stress periods.

26. The RiverWare Model component of the ILRG Model simulates the surface water and shallow ground water systems of the LRG Area and is the principal vehicle for computing the impacts of pumping and the effects of operational changes on surface water flows. It employs rule-based processes that simulate the essential functions of the Project and operations of the LRG Area irrigation systems. It is through these rule-based processes that the simulated systems are re-operated in alternative scenarios in a manner that reflects the real-world response to changes in conditions.

27. The NMR-M Model and the Hueco Model simulate the hydraulic effect of ground water pumping on surface flows and the effect of drains on ground water flows. The ground water models are linked to the RiverWare Model through certain data that are passed between the models in successive iterations.

28. The RiverWare Model and the ground water models of the ILRG Model have been calibrated to simulate historical surface water and ground water flows during the 1940 - 2017 study period using historical data for reservoir releases, canal operations, and FHG deliveries. The calibrated models reasonably replicate the seasonal, annual, and inter-annual variations in surface water and ground water flows.

29. In order to simulate the human-influenced management processes of the Project and LRG Area irrigation systems, the ILRG Model employs rule-based simulation processes

to simulate reservoir operations, canal diversions, FHG deliveries, and other processes. These rules were tuned in a calibration-like process to reasonably match historical records of reservoir releases, canal diversions, FHG deliveries, streamflows, and the simulated pumping in the calibration run.

30. The calibrated and tuned ILRG Model is the best available tool for evaluating claims, counterclaims, and answering questions about the effects of certain actions on Project operations and deliveries of water to LRG water users. The ILRG Model is superior to the ground water model of the Rincon and Mesilla basins developed by the Texas experts ("Texas Model") for use in the litigation because (a) it simulates the entire LRG Area between the El Paso Gage and Fort Quitman, (b) it employs monthly stress periods that allow it to simulate the important seasonal variations in ground water and surface water flows, and (c) it is capable of simulating the dynamic response of Project operations to changes in flow through rule-based simulation processes.

31. Post-processing spreadsheets were prepared to summarize outputs from the ILRG Model to illustrate the model results and to verify the models are correctly functioning. Tables and charts depicting the model results are presented in Section 9 for the Historical Base Run, in Section 10 for the Alternate Scenario Runs, in Section 13 in responses to the Hutchison Report, and in Section 14 in the responses to the Dorrance Report.

Section 9 – Historical Base Run of Integrated LRG Model

32. The tuned version of the ILRG Model was used to simulate the historical period from 1940 - 2017, including Project operations, to develop the Historical Base Run. The Historical Base Run was compared to alternative runs of the tuned model that simulated various no-pumping and alternative operating scenarios. Project water allocations were simulated using the D1/D2 allocation procedure from 1940 - 2005, the D3 allocation procedure without carryover in 2006 and 2007, and the D3+Carryover procedure in the 2008 OA from 2008 - 2017. Irrigation pumping coverage in EBID, EPCWID, and HCCRD was specified to increase linearly from 0% in 1947 to 100% in 1955, and in JID from 0% in 1939 to 100% in 1954. Non-irrigation pumping and return flows were specified and simulated based on historical records and estimates.

33. The simulated outputs for the Historical Base Run reasonably match the results from the historical records and the historical calibration run of the ILRG Model. Based on this match and the dynamic functionality of the ILRG Model, the Historical Base Run represents a reasonable baseline for comparison to alternative scenarios with reduced pumping, or other changes in model inputs.

Section 10 – Alternative Runs of Integrated LRG Model

34. Thirteen runs were made of the ILRG Model including the Historical Base Run (Run 1), nine no-pumping runs (Runs 2 - 10), and three alternative operations runs (Runs 11 - 13). All runs were made with the tuned version of the ILRG Model in which rules are used to compute Project water allocations, reservoir releases, canal diversions, and FHG deliveries. Changes in model inputs cause dynamic responses of all simulated processes as the changed conditions ripple spatially and temporally through the model, just as they would in the real world. Model outputs from the alternative scenarios were compared to the outputs from the Historical Base Run or another scenario and the differences were computed and summarized in tables and charts.

35. In the no-pumping runs, all pumping or just non-irrigation pumping was turned off in all areas (Run 2) or in certain geographic areas (Runs 3 - 10). When non-irrigation pumping was turned off, so were the associated wastewater treatment plant discharges and urban deep percolation. Because the Project is operated as a single system, any effects of pumping on surface water supplies that are upstream of points of delivery affect Project operations. The model results show that pumping in Texas and Mexico affects Project water deliveries to EBID water users in New Mexico.

36. A run of the ILRG Model was made in which all irrigation and non-irrigation pumping in the Rincon and Mesilla basins in New Mexico was turned off (Run 3). Comparison of the results from this run against the Historical Base Run show that without New Mexico pumping, annual FHG deliveries during the period from 1985 - 2016 would increase by an average of 26,200 AF to EBID and 8,200 AF to EPCWID. (Table 10A-3a).

37. A run of the ILRG Model was made in which all irrigation and non-irrigation pumping in Texas was turned off (Run 4). Comparison of the results from this run against the Historical Base Run show that without Texas pumping, annual FHG deliveries to EBID during the period from 1985 - 2016 would increase by an average of 5,100 AF, with a maximum annual increase of 32,500 AF. (Table 10A-4a and Table 10A-4b).

38. A run of the ILRG Model was made in which all irrigation and non-irrigation pumping in Mexico was turned off (Run 5). Comparison of the results from this run against the Historical Base Run show that without Mexico pumping, annual FHG deliveries during the period from 1985 - 2016 would increase by a maximum of 3,900 AF to EBID, 3,400 AF to EPCWID, and 9,400 AF to HCCRD. (Table 10A-5b).

39. In addition to the simulated effects on FHG deliveries in the no-pumping runs, turning off pumping in the ILRG Model results in simulated impacts to Project storage (including releases, evaporation, and spills), riparian evapotranspiration, river and

canal evaporation, incidental canal losses, and ground water storage. These impacts are reasonable and consistent with the interconnected nature of the Project and the LRG Area irrigation systems.

40. Two runs of the ILRG Model were made to evaluate the effect of the 2008 OA on Project operations. In Run 11, the D1/D2 allocation procedure was simulated to allocate Project water during the period from 1948 - 2017, and in Run 12 the D3+Carryover accounting was simulated during this 70-year period. Comparison of the results showed that the 2008 OA caused annual EBID FHG deliveries to be (a) reduced by an average of approximately 69,100 AF during periods with low diversion ratios (55 years) and (b) increased by an average of 56,900 AF during periods with high diversion ratios (15 years), for an overall decrease in annual EBID FHG deliveries over the 70-year period averaging 42,100 AF. The results also showed that the 2008 OA increased FHG deliveries to EPCWID in most years with an overall average annual increase of 14,700 AF. (Table 10A-12b).

41. A run of the ILRG Model was made to evaluate the effects of reducing Project operational waste. Run 13 limits waste in EBID and in EPCWID to the lesser of the historical amounts or 10% of diversions. The results show that reducing excess operational waste would have resulted in increases in annual Project water deliveries during 1985 - 2016 averaging 28,600 AF to EBID and 12,700 AF to EPCWID. (Table 10A-13).

Section 11 – Response to Brandes Report

42. Based on review of the expert report by Dr. Robert Brandes, his backup files and references, and attending his deposition, I developed the responses to his report that are presented in Section 11. The following is a summary of certain of the responses:

    a. Dr. Brandes attributed all changes in flows after 1950 to pumping in the Rincon basin and Mesilla basin based on single- and double-mass curve analyses. These simple graphical techniques can be useful in identifying changes in flows, but they are not useful or reliable in determining what caused the changes in flows. For complex interconnected systems like the Rio Grande Project and LRG Area, a robust simulation model capable of simulating the dynamic responses of the simulated systems to changes in condition is needed to reasonably determine the effects of certain actions, like the effects of pumping, on Project operations and deliveries to LRG Area water users; and to distinguish these effects from other factors that may have contributed to changes in flows or deliveries.

b. The annual changes in El Paso gage flows and deliveries to Texas and New Mexico water users that are computed by Dr. Brandes occur in virtually all years, including years of full Project water allocations. This does not make sense considering how the Project operates in years with full allocations. In these years, if there was an increase in supply because pumping was reduced, then Reclamation would adjust reservoir releases in order to deliver the same amounts of water to the Project water users, and therefore no significant changes in irrigation season flows and deliveries would be expected to occur in these years.

c. Dr. Brandes' analyses of changes in the flow of the Rio Grande at El Paso are not relevant to this litigation because this is neither a point of compliance for the Compact, nor a point of delivery for the Project.

d. Dr. Brandes incorrectly states that the available Project supply is solely determined by the volume of water either in or projected to be in Project storage each year. In reality, Project releases are affected by (i) the amount of water available in storage at the beginning of the irrigation season, (ii) the inflows to storage during the irrigation season, (iii) the gains and losses between the Caballo outlet and the downstream delivery points, and (iv) the demands of the Project water users.

Section 12 – Response to Montgomery and Associates Report

43. Based on review of the expert report by Mr. Staffan Schorr and Dr. Colin Kikuchi of Montgomery and Associates ("M&A"), their backup files and references, and attending their depositions, I developed the responses to their report that are presented in Section 12. The following is a summary of certain of the responses:

a. While M&A developed comprehensive surface water and ground water budgets for the LRG Area, only a few of the outputs from those analyses were used in the Texas Model and in the Texas analyses of impacts from pumping.

b. M&A performed monthly historical farm budget analyses to (i) estimate supplemental pumping and deep percolation in the Rincon and Mesilla basins for use in the Texas Model, and (ii) to estimate pumping in the El Paso Valley and HCCRD for Texas' analysis of damages from New Mexico pumping. The results from these analyses are unreliable because the soil-water balance model that is central to the farm budget analyses is deeply flawed and produces nonsensical results that are physically impossible and contrary to conditions that would be expected to exist in productive and generally well-managed irrigation districts.

c. Notwithstanding the flaws in M&A's farm budget analysis procedures, the estimates of pumping computed by the M&A analysis in New Mexico and Texas appear to be overstated, largely because of because of differences in irrigated area, crop ET, and FHG deliveries compared to the data used in in SWE's CFB Models

Section 13 – Response to Hutchison Report

44. Based on review of the expert report by Dr. William Hutchison, his backup files and references, and review of portions of his deposition transcript, I developed the responses to his report that are presented in Section 13. The following is a summary of certain of the responses:

   a. New Mexico's legal counsel have advised that Dr. Hutchison's definition of a 1938 condition is not appropriate for characterizing the water entitlements of the states. Moreover, it would be inappropriate to define a 1938 condition on the basis of historical operations in a single year as Dr. Hutchison did in his analyses.

   b. The Texas Model developed by Dr. Hutchison is inappropriate for use in analyzing the effects of pumping on Project operations and deliveries of water to LRG water users because:

      i. The model does not employ rule-based simulation processes that allow the model to appropriately respond to changes in surface water flows when pumping is reduced.

      ii. The model does not simulate Project operations and uses of water between the El Paso gage and Ft. Quitman.

      iii. The annual stress periods in the model do not allow distinction of the significant differences in Project operations and river conditions between the irrigation season and non-irrigation season.

   c. The lack of re-operation in the Texas Model is evident in the relatively steady computed annual impacts of Rincon-Mesilla pumping on Rio Grande at El Paso flows, including in years of full Project water allocations. In years with full Project water allocations, it is expected that the irrigation season flow at El Paso would not be appreciably different without pumping because

Reclamation would adjust Project releases to deliver the same amount of water to Project water users.

d. Dr. Hutchison's modeling analyses of Alternative Consumptive Use scenarios and Conjunctive Use scenarios are of little use because the Texas Model lacks any capability to simulate the Project re-operation that would occur in these scenarios.

Section 14 – Response to Dorrance Report

45. Based on review of the expert report by Dr. Lydia Dorrance, and her backup files and references, I developed the responses to her report that are presented in Section 14. The following is a summary of certain of the responses:

a. Dr. Dorrance's analysis to disaggregate the changes in El Paso gage flow simulated by the Texas Model is oversimplified and not a substitute for a fully functional dynamic simulation model of the area between the El Paso gage and Ft. Quitman.

b. Dr. Dorrance's disaggregation analysis is flawed and inappropriate because (i) it relies on results from a flawed model, (ii) it assumes the increased flows would occur in historical monthly proportions, and (iii) all of the increased flow is assumed available for allocation to Texas water users without diminishment by transit losses or operational inefficiencies.

c. Dr. Dorrance's flawed disaggregation analysis resulted in incorrect and inflated estimates of the effects of New Mexico pumping on deliveries to Texas water users.

Section 15 – Response to Sunding Report

46. Based on review of the expert report by Dr. David Sunding, and his backup files and references, I developed the responses to his report that are presented in Section 15. The following is a summary of certain of the responses:

a. Dr. Sunding's analyses are flawed because they rely on unreasonable and unreliable analyses by Dr. Hutchison and Dr. Dorrance of the effects of New Mexico pumping on Texas water users.

b. Dr. Sunding unreasonably assumes that shortages in EPW surface water supply were caused solely by New Mexico pumping and not by other factors, including drought.

c. The damages analysis by Dr. Sunding is based on simulated impacts on El Paso gage flows from all pumping throughout the Rincon and Mesilla basins and therefore implicitly includes impacts of pumping in the Texas portion of the Mesilla basin.

2.0 BACKGROUND

2.1 Study Area

The Rio Grande begins in headwaters in the San Juan Mountains in Colorado that flow east and join other tributaries in the broad and agriculturally productive San Luis Valley of Colorado. The river flows south out of the San Luis Valley and into New Mexico where it picks up considerable flow from the mountains of northern New Mexico and continues in a generally southerly direction through mostly incised canyons past Taos and Santa Fe before reaching the Middle Rio Grande Valley that extends from Cochiti Lake to San Marcial, about 25 miles south of Socorro.

San Marcial is situated at the northern end of Elephant Butte Reservoir, the primary source of water for the Project that serves lands in the Rincon, Mesilla, and El Paso Valleys in southern New Mexico and western Texas. Additional lands are irrigated west of the Rio Grande in the Juarez Irrigation District in Mexico and further to the southwest in Hudspeth County, Texas down to Ft. Quitman.

The study area for this report is primarily the areas tributary to or hydraulically connected to the Rio Grande between San Marcial and Ft. Quitman. This includes the ground and surface water irrigated lands that are part of the Project, the JID, the HCCRD, and the non-irrigation water uses for the towns and cities in the study area. A map depicting the study area is included as **Figure 2-1**.

2.2 Rio Grande Compact

This section provides a brief overview of certain aspects of the Rio Grande Compact ("Compact"). More detailed information on the Compact is provided in the report of Estevan Lopez (2019). The States of Colorado, New Mexico, and Texas agreed to the Compact in March 1938 to equitably apportion the Rio Grande upstream of Ft. Quitman. The Compact was ratified by Congress and became effective on May 31, 1939.

The annual delivery obligations for Colorado are provided in Article III and New Mexico's delivery obligations are provided under Article IV. In 1948, the Rio Grande Compact Commission ("RGCC") changed New Mexico's Article IV delivery obligation from a nine-month schedule of delivery at San Marcial to an annual delivery determined based on the computed annual inflow to Elephant Butte Reservoir. The RGCC also adopted a new Otowi Gage index table for computing New Mexico's delivery obligation.

Article VI sets out long-term average delivery requirements through a system of debits and credits that allow the states to deviate from the annual obligations based on certain criteria. Annual compact accounting, including these debits and credits, commenced in 1940. The Compact is administered by the RGCC, which is comprised of one voting representative from each of the three States, and a non-voting representative from the United States acting as chair of the Commission.

2.3 Rio Grande Project

The remainder of this section provides an overview of the Rio Grande Project and its operation. More detailed descriptions of the historical operation of the Project and its water allocation and accounting mechanisms is provided in the Barroll Report (2019).

The Rio Grande Project is one of the first large-scale irrigation project developed by Reclamation. It was authorized by Congress in 1905 and construction commenced in 1907 (USNRC, 1938). The Project was developed to improve and expand the existing irrigation systems in the Rincon, Mesilla, and El Paso Valleys, as well as deliver water to Mexico. Elephant Butte Reservoir began storing water in 1915 and was completed in 1916. The major diversion dams and canals for the Project were completed by 1919, and most of the lateral distribution systems and irrigated lands were developed by 1929. High water table conditions caused by irrigation necessitated construction of drainage systems that were largely completed by 1925 (USNRC, 1938). Caballo Reservoir was constructed downstream of Elephant Butte Reservoir for flood control and to conserve winter hydropower releases from Elephant Butte Reservoir for subsequent irrigation use, and the reservoir began operation in 1938. This work, as well as construction of the American Diversion Dam and American Canal, was done as part of the International Boundary and Water Commission's ("IBWC") Canalization Project, which, along with the IBWC's Rectification Project, also realigned the river and adjacent irrigation infrastructure in many areas between Caballo Dam to Fort Quitman (IBWC, 1938; Reclamation, 1938; and IBWC, 1943).

The total irrigated area under the Project was originally planned to total 155,000 acres with 88,000 acres (57%) within EBID in New Mexico and 67,000 acres (43%) within EPCWID in Texas (USNRC, 1938). Of these amounts, about 16,000 acres were in the Rincon Valley, 82,000 acres were in the Mesilla Valley (10,000 acres in Texas), and 57,000 acres were in the El Paso Valley. A 1938 contract between EBID and EPCWID approved by the United States increased the original acreage allotted to the two districts by 3% resulting in a total area authorized to be irrigated of 90,640 acres in EBID and 69,010 acres in EPCWID (EBID, 1938).

The reported actual irrigated area varied through the years as lands were brought in and out of production. The reported actual irrigated area peaked at approximately 160,000 acres in the early 1950s and has generally declined since that time due mainly to urbanization, largely in and around Las Cruces and El Paso. The normal annual release from Project storage to satisfy Project irrigation demands was specified in the Compact as 790,000 AF, including 60,000 AF delivered to the Republic of Mexico at Juarez to satisfy a 1906 Treaty obligation (Reclamation, 1985).

Prior to construction of Elephant Butte Reservoir, the Rio Grande flow available for irrigation in southern New Mexico and western Texas was characterized by highly variable annual and seasonal flows depending mostly on the snowpack accumulation and subsequent snowmelt runoff from the upper portions of the Rio Grande watershed in southern Colorado and northern New Mexico. The original storage capacity in Elephant Butte Reservoir was about 2,274,000 AF, which was sufficient to store almost three years of the normal annual Project release and was essential for controlling and regulating the large fluctuations in Rio Grande flow (USNRC, 1938).

Completion of Caballo Reservoir in 1938 added 346,000 AF of Project storage, however the total Project storage capacity has declined through time due to silt accumulation in the reservoirs. The total combined storage capacity in Elephant Butte Reservoir and Caballo Reservoir declined from 2,570,000 AF in 1940 (Reclamation, 1940) to about 2,000,000 AF in the late 2000's (RGCC, 2017).

The current major diversion structures for the Project include the following:

Diversions Structures
Rio Grande Project

<table>
<tr><th>Region</th><th>Dam</th><th>Canal(s)</th></tr>
<tr><td>Rincon Basin</td><td>Percha Dam</td><td>Arrey Canal</td></tr>
<tr><td rowspan="2">Mesilla Basin
(NM & TX)</td><td>Leasburg Dam</td><td>Leasburg Canal</td></tr>
<tr><td>Mesilla Dam</td><td>Eastside Canal
Westside Canal</td></tr>
<tr><td>El Paso Valley</td><td>American Dam</td><td>Franklin Canal
Riverside Canal
Tornillo Canal</td></tr>
<tr><td>Juarez Valley</td><td>International Dam</td><td>Acequia Madre</td></tr>
</table>

Portions of the southern Mesilla basin extend into Texas, and diversions at the Mesilla Dam into the Eastside Canal and Westside Canal are delivered to Project lands in both New Mexico and Texas.

At present, all Project water deliveries to Project lands in the El Paso Valley originate as diversions from the Rio Grande at the American Dam into the American Canal which delivers water to the Franklin Canal and Riverside Canal headings. Prior to 1999, there was a separate diversion from the Rio Grande at the Riverside Canal heading. In 1999, the American Canal Extension ("ACE") was completed so that all diversions at American Dam could be delivered through a concrete-lined channel to the Franklin Canal and Riverside Canal headings. Until 1938, there was another diversion from the Rio Grande further downstream that supplied the Tornillo Canal. Reconfiguration of the river alignment in the Fabens area and adjacent irrigation infrastructure as part of the Rio Grande Rectification Project eliminated the river diversion for the Tornillo Canal, and since that time the supply for the Tornillo Canal has been derived from water tailing out of the Franklin Canal and Riverside Canal. Periodically, water has been diverted at times from drains to supply water to the Tornillo Canal.

Deliveries of treaty water to Mexico are made at the International Dam located downstream of the American Dam. Following completion of the American Dam in the 1930s, all of the Rio Grande flow has typically been diverted into the American Canal, except for the water that is left in the river to meet the delivery obligation to Mexico at the Acequia Madre. Prior to construction of the ACE, Project water that was destined for the Riverside Canal was diverted into the American Canal and then released back to the Rio Grande downstream of the International Dam through the Leon Street Wasteway or the Ascarate Wasteway where it flowed down the river channel to the Riverside Dam.

The HCCRD is located in Hudspeth County and receives its supply as waste and irrigation return flows from the Project. The Project is not supposed to be operated to intentionally or directly deliver water to the HCCRD.

2.4 Rio Grande Project Operating Procedures

Project lands are distributed along the Rio Grande in the relatively narrow Rincon, Mesilla, and El Paso Valleys. The first Project diversion occurs at Percha Dam approximately two miles below the Caballo Reservoir outlet and the last river diversion is at the International Dam approximately 110 miles downstream. As described above, other Project diversions from the river existed further downstream at Riverside Dam until 1999 and at the Tornillo Canal until 1938.

Due to the long and narrow configuration of the Project lands along with Rio Grande, irrigation return flows to the river from each canal service area as well as any other inflows are available as part of the supply for downstream Project diversions. This can result in efficient Project operation with full reuse of most or all of the irrigation return flows and other flows except those that accrue to the drains or river below the last Project diversion point. Originally, reuse of return flows within the Project occurred downstream of American Dam by means of major diversions from the Rio Grande at the canal headings for Riverside Canal and Tornillo Canal. When these canal headings were removed in 1938 (Tornillo Canal) and the 1999 (Riverside Canal) the opportunity to reuse return flows within EPCWID become more limited. However, reuse of return flows was still possible by diversion and use of drain flows for irrigation of the lower portions of the EPCWID service area. This use of drain flows within EPCWID is reflected in the Project records in many years from 1945 - 1982 (USBR, 1992 and NMSU, 2004). Additional details and discussion of the use of drain water is provided in both the Barroll Report (2019) and the MMA Report (2019).

The normal annual Project release of 790,000 AF described in the Compact appears to be largely based on an analysis in the RGJI that showed that the total supply diverted at the Project canal headings was comprised of varying amounts of storage releases, returns flows and seepage, and a small amount of tributary inflows. The RGJI describes a required annual storage release of 773,000 AF. This figure appears to have been increased to 790,000 AF during the Compact negotiations.

Historical descriptions of the day-to-day Project operations reinforce how the drain flows, wasteway flows, and other river gains or losses are considered in determining the reservoir releases necessary to meet orders for Project water. The following description from the 1936 Project History report is typical:

> *Water releases at the reservoir are changed twice a week to meet the irrigation requirements. The amount to be released is determined by advance orders to ditchriders by water users. These orders are summed for the different divisions and an allowance made for drain and waste return to arrive at the amount to be released. Under normal conditions this can be done very accurately with a small waste below the project limits. (Reclamation, 1936)*

More detailed descriptions of how the reservoir releases were determined are contained in certain versions of the annual Project History reports. A particularly detailed description is provided in the 1943 Project History report (Reclamation, 1943). It describes how the amount of flow needed in the Rio Grande at El Paso is computed by first tabulating the water orders for users in the El Paso Valley and Juarez with allowances for drain returns, waste returns and transmission losses. This figure is then used as a starting point for computations that systematically proceed upstream adding diversion demands and transmission losses and subtracting returns to arrive at the reservoir release that, when combined with the available return flows, is sufficient to meet the Project water demands.

While there have been changes in water allocation procedures through the years (e.g., the D1/D2 operation and the 2008 OA), the process for determining reservoir releases is similar today as it was at the time of the Compact. This is reflected in the following statement contained in the September 16, 2019 Supplemental Disclosure of Dr. Ian Ferguson:

> *Under the Operating Agreement, Reclamation releases Project water from Caballo Dam in accordance with water orders from EBID, EPCWID, and the United States section of the International Boundary and Water Commission ("US-IBWC") on behalf of Mexico. Water orders for Mexico are determined by the Mexican Section of IBWC ("MX-IBWC") and provided to Reclamation by US-IBWC. Water orders for EBID and EPCWID are determined and provided by each district, respectively. Water orders are limited by the allocation balance remaining on each entity's respective Project water account. The quantity of water released from Caballo Dam to satisfy Project water orders is determined by EBID and EPCWID, in consultation with Reclamation, based on the total amount of water ordered and anticipated gains and losses to the Rio Grande between Caballo Dam and Project diversion points. Project diversion dams and canal headings are subsequently operated to execute diversions and deliveries in accordance with water orders placed by EBID, EPCWID, and by US-IBWC for delivery to Mexico.*

The foregoing descriptions show how the amount of irrigation return flows and other flows entering the river are carefully considered in determining how much water to release from Project storage. For a particular aggregate demand, the more return flows that are entering the river, the less water that needs to be released from storage to meet that demand.

The term "diversion ratio" is used in characterizing the relative amount of reservoir release that is needed to meet downstream water demands. The diversion ratio may be computed as the sum of the river heading diversions divided by the reservoir release[1]. The lower the diversion ratio, the higher the reservoir release needs to be to meet downstream water demands. On an annual basis, the diversion ratio can range from 0.6 or less in dry years to over 1.0 in full supply years. The diversion ratio also varies throughout the year depending on river conditions. It is typically low at the beginning of the season when drain flows are low and river seepage losses are high. Drain flows and

[1] In the accounting under the 2008 Operating Agreement, the diversion ratio is computed as the sum of charged diversions divided by the reservoir release.

river seepage fluctuate through the irrigation season in response to surface water irrigation and pumping and this impacts the diversion ratio throughout the year.

2.5 Rio Grande Project Water Allocation

The allocation of Project water to Project water users has consistently been based on equal delivery of water per acre until the 2008 OA, as discussed below.

2.5.1 Equal Allotment Per Acre (Inception - 1978)

Reclamation operated all Project facilities through 1978 including the canals and laterals that delivered water to the Project water users. During this time Reclamation attempted to make available to all Project water users an equal amount of water per acre irrigated. There were no significant shortages during the first several decades of the Project operation and Reclamation did not impose any full-season Project water allotments until 1951 when the first significant drought following the completion of Elephant Butte Reservoir in 1915 occurred. Prior to 1951, there were often years when the releases from Project storage exceeded the normal annual release of 790,000 AF described in the Compact.

2.5.2 D1/D2 Allocation Procedure (1979 - 2007)

When the Project water users completed payments under their repayment contracts, Reclamation contracted with EBID (1979) and EPCWID (1980) to take over operation of the canal facilities and deliveries to the water users under each canal. This necessitated accounting for Project deliveries at canal headings rather than at the farm headgates. After this accounting adjustment, there still was equal delivery of water per acre to the Project water users, however, the districts became responsible for these deliveries rather than Reclamation.

To facilitate the delivery change to canal headings, Reclamation analyzed records of historical Project operations from 1951 - 1978 and developed relationships between Project releases and Project diversions and deliveries based on linear regression. The D1 Curve defined the relationship between Project releases and the sum of deliveries to U.S. farms and deliveries to Mexico at the head of the Acequia Madre. The D2 Curve defined the relationship between Project releases and the sum of diversions at all U.S. canal headings and at the Acequia Madre heading.

From 1979 - 2005, the D1 Curve was used to compute the allocation to Mexico based on the usable water available in Project storage and the D2 Curve was used to compute the diversion allocation to EBID and EPCWID. The districts were responsible for distributing water from their canal headings to the water users in their respective service areas.

An accounting system was established by Reclamation to track diversions by each district against their annual allocations. In general, the districts are charged against their allocations for the water they divert and use, but receive credits for certain operations. These credits are described in detail in the Barroll Report (2019).

2.5.3 2008 Operating Agreement (2006 - Present)

Reclamation, EBID, and EPCWID entered into an Operating Agreement for the Rio Grande Project on March 10, 2008 ("2008 OA"). Under the 2008 OA, the annual allocation to Mexico and EPCWID continued to be computed using the D1/D2 Procedure, while the allocation to EBID was modified to be based on the diversion ratio. In years when the diversion ratio is low, the EBID allocation is lower than the D1/D2 allocation that it previously received. In years when the diversion ratio is high, EBID could potentially receive an allocation greater than a D1/D2 allocation, although this has not happened since 2008 OA has been in effect. The revised allocation procedure, referred to as the D3 Procedure, was implemented informally beginning in 2006.

The other significant change in the 2008 OA was that each district was allowed to carry over any unused allocation that remained at the end of the year to add to the allocation it received in the subsequent year. Prior to the 2008 OA, the Project was operated on an annual basis and any unused allocation at the end of the year became part of the supply that was reallocated in the next year 57%/43% to EBID and EPCWID after determining the Mexico allocation under the D1 curve.

3.0 LOWER RIO GRANDE HYDROLOGIC DATA

Surface water data in the Lower Rio Grande have been collected by various agencies since the late 1880s. SWE compiled much of the available data into the Rio Grande Project Surface Water Dataset ("SWDataSet"). The SWDataSet is a compilation of flow and reservoir storage data that are used in various analyses and models by New Mexico representatives and consultants. The purpose of the SWDataSet is to provide a central data repository to ensure data integrity and consistency in the data that are used in the various analyses and models developed on behalf of New Mexico for this case. As more data become available through discovery or other means, these additional data will be added to the SWDataSet collection. The SWDataSet spreadsheet, original data, and metadata are being disclosed along with this report.

Most of the data in the SWDataSet fall into the following data categories:

- Streamflows
- Reservoir storage
- Diversions
- Drain flows
- Wasteway flows
- Municipal flows
- Metered ground water pumping

A list of all the flow data compiled in the SWDataSet is shown in **Table 3-1**. The measurement sites are listed by flow data type and location. The available period of record is also provided in the table. The earliest flow data are from 1889 and all available flow data have been compiled through 2017. All measurements sites with location information are shown in **Figure 3-1** through **Figure 3-5**.

3.1 SWDataSet Description

3.1.1 Organization of SWDataSet

The flow data have been imported into a single Excel spreadsheet and are organized by type, including river flows, canal flows, wasteway flows, drain flows, municipal flows, reservoir data, and metered irrigation pumping data.

3.1.2 Data Sources

The following is a summary of the major data sources used in the SWDataSet. A list of the data sources is provided in **Table 3-2.**

- EBID
- EPCWID
- Environmental Protection Agency ("EPA")
- IBWC
- RGCC
- Reclamation
- United States Geological Survey ("USGS")

3.1.3 Time-step

Most of the data in the SWDataSet are monthly data consistent with the monthly stress periods or time-steps used in the modeling and other analyses. Certain of the data that originated as daily data were aggregated and converted to monthly volumes, and these aggregation operations are contained in separate worksheets in the data backup folders.

Annual totals and monthly averages are generally provided below the monthly data. In cases where there are only annual data available, these values are shown in the annual total section and noted in the comments under the period of record. As needed for input into modeling or analysis, these annual data were converted to monthly volumes.

3.1.4 Period of Record

The SWDataSet includes all available flow data for the measurement sites from the earliest record available through 2017. The earliest compiled river flow records are for the Rio Grande at El Paso which date back to 1889. The earliest canal diversion records are for the Leasburg Canal which date back to 1908.

For certain data, there are missing months or years within the period of record. These data gaps are shown in two data matrices provided in the SWDataSet - one showing the monthly data availability and the other showing annual data availability. The monthly and annual data availability matrices are included in **Appendix 3A**.

3.1.5 Data Column Heading

The heading of the column for each measurement site contains the following information:

- District
  - EPCWID, EBID, HCCRD, and JID.
- Region
  - The region refers to the irrigation basin or main canal system (Rincon, Leasburg, Mesilla (NM), Mesilla (TX), El Paso, Hudspeth, and Mexico).
- Location
  - The location information is sourced to a worksheet (“Loc_info”). The location information is an export from an ArcGIS shapefile and in decimal degrees (1983 datum).
- Units
  - Data are in units of monthly AF and are typically rounded to the nearest AF.
- Site Code or other codes/gages numbers
  - The site code is from NMOSE.
    - The site code is based on the basin, type of gage, and miles downstream from Elephant Butte Dam. For example, the site code Westside Canal is 4C95.8A, the “4” is for the Mesilla basin below Leasburg, the “C” is for canal, the “95.8” is the miles downstream of Elephant Butte Dam, and the “A” is needed since there are three canal diversions from the Mesilla Dam (note that Eastside Canal is “B” and Del Rio Lateral is “C”).
  - The other site codes include USGS gage numbers, Reclamation 2008 Operating agreement codes, and EPA National Pollutant Discharge Elimination System (“NPDES”) permit numbers.

- Period of record
  - The period of record contains the year of the earliest record to the year of the latest record. Missing data are documented in the "Data_List" worksheet and are shown in the data matrices. As described above, some the records may be annual only and are noted in a comment.
  - Any estimated data are also noted in a comment.
- Name of measurement site/structure.

3.1.6 Backup Data Folders

The SWDataSet contains a series of backup folders that include the original data and metadata. The backup folders are named based on a source code (i.e., LRG.Doc.SWXXX). Each monthly data entry has a corresponding source code that references the source of the data/backup folder. The source code for each monthly data entry is located in the same worksheet as the monthly data in a parallel table labeled "Source Files." The table of source codes is located to the right of the data table. A summary of the backup data folders and various data sources is provided in **Table 3-2**.

Certain records in the SWDataSet are sourced to LRG.Doc.SW025. The source LRG.Doc.SW025 refers to a compilation of monthly data and not the original source data. Therefore, when data are sourced to the LRG.Doc.SW025, there is an additional source column adjacent to the LRG.Doc.SW025 column that lists the original source. An example of this is shown in the table below.

		DATA	SOURCE FILES	
District:		EBID	EBID	
Region:		Rincon	Rincon	
Location Lat (dd):		32.869	32.86912627	32.86912627
Location Long (dd):		-107.305	-107.305247	-107.305247
Units:		(af)	(af)	(af)
BOR 2008 OA Code:		R2	R2	R2
Site Code:		2C29.5A	2C29.5A	2C29.5A
Extent of Record:		1918-2017	1918-2017	1918-2017
Year	Month	Arrey Canal	Data Source - Arrey Canal	SW25 Source - Arrey Canal
1938	1	0	LRG.Doc.SW025	LRG.Doc.SW016
1938	2	1,698	LRG.Doc.SW025	LRG.Doc.SW016
1938	3	7,234	LRG.Doc.SW025	LRG.Doc.SW007
1938	4	12,294	LRG.Doc.SW025	LRG.Doc.SW007

In the above example, the data can be found in both source folders (SW025 and SW016 or SW007), but the original data are in the SW016 or SW007 folders.

3.1.7 Metadata

Metadata documentation for each data source is contained in the backup data folders in a Word document. The metadata documents native units, conversion factors, data quality, period of record, contacts for the data, compilation notes, links to online data, etc.

3.1.8 Conversion Units

The following conversion factors wereused to convert the measurement units of certain data in the SWDataSet:

- 1 cubic meter per second = 35.31467 cubic feet per second
- 1 cubic foot per second = 1.98345 acre-feet per day
- 1 million gallons = 3.0689 acre-feet

3.1.9 Gage Location Information

Reasonable efforts have been made to compile the geographic coordinates of all measurement sites. Location data include confirmed gage locations and approximate gage locations. Confirmed gage locations are those in which the publishing entity (USGS, EBID, IBWC, etc.) provides coordinates, there are ArcGIS shapefiles associated with the measurement site, or the site has been field verified using a Global Positioning System ("GPS") device. Approximate locations include sites in which the location of the feature (i.e., wasteway) is generally known, but the exact location of the gage is unknown. Schematic diagrams from Reclamation and IBWC and high-resolution imagery from Google Earth were used to approximate gage locations. The source of the location information is described in the "Loc_info" worksheet in the SWDataSet.

3.1.10 Quality Assurance and Quality Control ("QA/QC")

The general QA/QC process of data entry into the SWDataSet is double-checking the data after they are entered into a spreadsheet. For example, after data are copied in, the data are totaled and checked against the totals of the corresponding data in the original source files. Details of the QA/QC process for each data source are included in the metadata.

3.1.11 Data Summaries

For each type of data, there are data summary tabs that include a table generator and a generator for a several summary charts. The summary table and charts show monthly and annual data from 1889 or 1903 through 2017. Example summary tables and charts for each data type is provided in **Appendix 3B.**

Worksheets "ToFarmBudget" and "ToRiverWare" were added to the SWDataSet to facilitate export of certain data for use in modeling.

3.2 Missing Data

Certain of the missing surface water data were estimated to provide complete datasets for modeling or other analyses. Procedures were developed to estimate missing data based on averages, correlations, and other statistical approaches involving comparison to other measured data such as Rio Grande flow data. Municipal wastewater discharges were largely estimated using correlations of annual wastewater discharge and total municipal pumping. Details for how the missing data were estimated are in shown in **Table 3-3**.

The SWDataSet has two worksheet tabs for certain data types that have missing data that were estimated. One worksheet tab contains the raw data and is indicated with an "X" (i.e, "CanalsX"). The other worksheet contains estimates of the missing data and is named without the "X" (i.e., "Canals"). In the worksheets with missing data estimates, the estimated data are noted with a comment in the "Period of Record," and a note in the data source referencing the backup folder with the missing data calculations.

3.2.1 Rincon and Mesilla Basin Data Gaps

The datasets for the Rincon and Mesilla basins are mostly complete. Estimates of wastewater treatment plant ("WWTP") discharges prior to the late 1990s were made and are summarized in **Table 3-3**.

Missing months of data within a year were estimated using an average for that month from the prior and subsequent year. For years with no data, the WWTP was estimated using an average annual percentage of pumping. Ground water pumping from municipalities contributing to the WWTPs were obtained from SSPA. The annual estimated WWTP discharge was distributed evenly into each month (divided by 12). There are two exceptions to this method described below.

For El Paso Electric, a wastewater discharge of 53% was used based on a report from NREL (2004). This reported percentage is comparable to the average percentage computed from the records.

The Village of Hatch receives water supplies from outside of the Lower Rio Grande area for which records are not available. For this town, a relationship between WWTP discharge and population was developed to estimate the WWTP discharge back in time.

3.2.2 Hueco Basin Data Gaps

NMOSE/ISC staff, MMA, and SWE coordinated to identify missing data needed for the Hueco Model back to 1903 when the simulation period commences. A majority of the missing data that needed to be estimated for the Hueco Model was for Mexico from 1903 - 1939. A summary of the missing data for the Hueco Model area and data estimation techniques are summarized in **Table 3-3**.

For Ciudad Juarez, there are no data available for sewage/WWTP production. Estimates made by IBWC (1989) were used for 1950 - 1984. For the rest of the years, the sewage/WWTP production was estimated as 49 percent of the total Ciudad pumping based on an average derived from the IBWC estimates.

For EPW, discharge from the Northwest WWTP, Socorro WWTP, and Bustamante WWTP were estimated back in time. Northwest WWTP estimates from 1987 to August 2002 were based on data used in the Upper Rio Grande Water Operations Model ("URGWOM") model and these data were provided by the NMOSE.

There are EPA discharge data for Socorro WWTP available from 1989 - 1993. The annual Socorro WWTP discharge decreased from 28,000 AF in 1990 to 500 AF in 1993 (zero by 1994). The Bustamante WWTP discharge first began in 1991 and the first record of Bustamante WWTP discharge is 31,000 AF in 1995. It was assumed that the Bustamante WWTP increased from 1991 - 1993 as the Socorro WWTP discharge decreased. To estimate the annual total Socorro/Bustamante WWTP discharge, the unit waste flows from Bustamante WWTP (gallons per day per capita) were multiplied by the percentage of the total City of El Paso population served by the Bustamante WWTP (Brown and Caldwell, 1997). The City of El Paso population was obtained from the El Paso County website (El Paso County, 2016).

The Socorro WWTP had several treatment ponds known as the Socorro Ponds located south of the current location of Bustamante WWTP. Based on appearance of these ponds in a 1967 aerial photo, it was assumed that the Socorro WWTP began operating in 1967. The Socorro WWTP discharge was estimated from 1967 - 1988. From 1991 - 1994, the Bustamante WWTP discharge was estimated as the total Socorro/Bustamante WWTP minus the reported Socorro WWTP discharge.

There are no data for the JID diversions downstream of Acequia Madre. However, there are estimates from various sources from USNRC (1938), Carreno (1957), and IBWC (1989) for 1930 - 1936, 1938 - 1947, and 1950 - 1984, respectively. The IBWC estimates of lower river diversions by JID were based on analysis of gaged river flows. This procedure was used to estimate diversions before 1984 in the years that estimates from others were not available. The lower river gages were discontinued in 1984, and no estimates of lower river JID diversions were made after that time.

3.3 Urban Deep Percolation

Urban deep percolation represents the ground water returns from municipal water use and includes systems losses and deep percolation from lawn irrigation. No records of urban deep percolation volumes were available and therefore values were estimated as described below.

System losses represent leakage from municipal water conveyance systems. Estimates of total system losses for Las Cruces and El Paso are published in various reports. Based on these reports, the system loss to ground water was estimated as the lower end of the reported range of the total system loss, which may include measurement and billing errors. The system loss for EPW was estimated as 7% of the total water use (EPW, 2014 and EPW, 2019). For Las Cruces and all other municipalities, as system loss of 10% was assumed (Shoemaker, 2008).

Lawn irrigation deep percolation was estimated as a percentage of the computed outdoor use of municipal water. The outdoor use was computed as the total monthly water use (total diversion less system loss) minus the monthly indoor use which was estimated as the average monthly water use during December through February. Monthly lawn irrigation deep percolation was computed as 15% of the total monthly outdoor use. This assumes an average irrigation efficiency of 80% (Barta, 2004 and Rogers, 1997) and a spray loss of 5% (Kincaid, 1987).

Urban deep percolation was computed for the following municipal areas:

- Mesilla Basin
  - Las Cruces
  - Santa Teresa
  - Anthony
  - Mesquite
  - Berino
  - Garfield
  - Radium Springs
- El Paso Valley
  - El Paso

The total monthly municipal water use was based on reported total pumping and use of Project water by EPW. Pumping data for the municipal users in the Rincon and Mesilla basins were provided by SSPA and pumping data for EPW were provided by MMA.

Surface water use data were obtained from the SWDataSet. The resulting urban deep percolation volumes are summarized in Section 5.9.

4.0 RIO GRANDE PROJECT ACCOUNTING DATA

4.1 Introduction

Project accounting is comprised of flow data to track the delivery of water to Project lands and to Mexico. The Project accounting data includes the following three types of data.

- Water Distribution Reports
- Project Water Allocation
- Accounting Records

The accounting dataset is comprised of two Excel spreadsheets. The Project Water Allocation and Accounting Reports data are in one spreadsheet (2019-10-25 Draft RGP Accounting Data – Confidential.xlsx) and the Water Distribution Report data are in the other spreadsheet (2019-10-25 Draft WDR Data – Confidential.xlsx). The following sections describe and summarize the different types of Project accounting data.

4.2 Water Distribution Reports (1918 - 2011)

The Water Distribution Reports ("WDRs") are part of the Rio Grande Project Histories and date back to 1918. The Rio Grande Project Histories are annual published reports from Reclamation that are available from 1912 - 1988. These documents include information on the operation and maintenance of the Project and contain data on crop, irrigation, weather, surface flows, operational costs, etc.

From 1918 - 1978[2], the WDRs report the monthly deliveries of Project water to the farms by unit or major canal system. The units include Rincon, Leasburg, Mesilla, and El Paso (a.k.a. Yselta). There are also total Rio Grande Project WDRs which are a sum of the data for individual units. After the Project operations were transferred to the districts in 1979, the WDRs are reported by district (EBID and EPCWID) and there are records for HCCRD as well. A summary of the available and compiled WDR data is shown in **Figure 4-1**. Examples of the WDRs are shown in **Appendix 4A**.

[2] For the first couple of years, only the river headgate diversions and irrigated acreages were reported.

The following is a list of the WDR data types:

- Irrigated acres,
- River headgate (“RHG”) or canal heading diversions,
- Canal loss,
- Canal waste,
- El Paso Valley carriage,
- Non-agriculture diversions, and
- Farm headgate (“FHG”) deliveries.

The RHG diversions or canal heading diversions are measured flows for the major canals. Most of the canals divert from the river, but some canal headings are off other canals. These include the Franklin Canal that diverts from the American Canal, the Riverside Canal that diverts from the ACE (after 1999), and the Mesilla Texas diversions that divert from the Eastside and Westside Canals.

The WDRs include the reported total FHG deliveries to Project water users. Between the canal heading diversion and the farm headgates, a portion of the water seeps into the ground water or is consumed by vegetation in and around the canal (“Canal Loss”). Water is also spilled through various wasteways and returned to the river (“Canal Waste” or “Operational Spill”). To improve the conveyance of water downstream, some water is carried through EBID canals to the El Paso Valley (“El Paso Valley Carriage”). The non-agricultural diversions by EPW in the El Paso Valley are also reported.

The calculations for the reported canal heading diversions and Canal Waste in the WDRs for the El Paso Valley vary from year-to-year. Some of the El Paso Valley WDRs have notes indicating how these values were calculated, and these have been compiled and are shown in **Appendix 4B.**

4.2.1 FHG Deliveries (1920 - 2016)

FHG delivery records reported by unit are available from 1920 - 1978 and include Rincon, Leasburg, Mesilla, and El Paso Valley. Since 1979, the FHG deliveries are reported by district. Some EBID records from 1991 - 2010 are reported separately for the Rincon and Mesilla Valleys (including Leasburg). In 2011, there is a separate WDR for the Mesilla Valley only.

In addition to the WDR data, there are annual total EBID FHG deliveries available for 2011 - 2016 reported by the EBID. These records were compiled into the accounting dataset in the WDR spreadsheet.

Within the WDR accounting dataset, the FHG deliveries were disaggregated into units as necessary to have a continuous record of deliveries by unit over time. This was done by pro-rating the monthly district total values using the reported RHG diversions for each unit. For example, the Rincon FHG delivery was computed as the total EBID FHG delivery multiplied by the Rincon diversions (Arrey Canal plus Percha Lateral) divided by the total EBID diversions (Rincon, Leasburg, Mesilla Eastside NM, and Mesilla Westside NM). The diversions to each unit were obtained from the SWDataSet.

Prior to 1979, the total FHG deliveries for the Mesilla Unit were disaggregated into Mesilla Eastside and Mesilla Westside using the canal diversions for the Eastside Canal and Westside Canal. Then, the computed Mesilla Eastside and Mesilla Westside FHG deliveries were further disaggregated into New Mexico and Texas portions using reported irrigated area data.

After 1979, the total district-wide FHG deliveries for EBID and EPCWID were distributed by unit based on reported monthly diversions.

The compiled FHG deliveries by unit and by district from 1938 - 2016 are shown in **Table 4-1.** The values in black are from the records and the values in blue are computed and include the disaggregated values and the totals by district.

The FHG deliveries from the records were used as input into the CFB Models described in Section 6. Some additional adjustments and estimates of missing data were made to the records as needed and as described in that section.

4.3 Allocation Data (1951 - Present)

Prior to the development of the D1/D2 allocation procedures in 1979, Reclamation operated the Project to make available for delivery an equal amount to the farm headgates of all Project lands (Reclamation, 2015). The allocation of Project water beginning in 1951 was reported in the Rio Grande Project Histories as an allotment in AF per acre. An initial allotment was made in the beginning of the irrigation season. This allotment was occasionally increased over the runoff season (May - July) based on the amount of runoff accrued in the Project storage. During the 1940s, with ample available Project storage, there were no full season allotments reported in the Project Histories. The initial and final Project allotments from 1951 - 1978 are summarized in **Table 4-2** based on a summary table prepared by Reclamation (2012).

The D1/D2 allocation procedures started in 1979, and the annual allocations were computed as annual diversion volumes for EBID and EPCWID. Distribution of water from the canal headings to the farms was handled by the districts (Reclamation, 2015). Initial and final allocations to the districts are shown in **Table 4-3**. The values from 1979 - 2018 were obtained from Reclamation and district accounting and allocation reports provided by Dr. Peggy Barroll**.** There are some missing allocation data for EBID (1979 - 1983) and EPCWID (1980 - 1982). Also, except for 1984 - 1985, there are no data for the Mexico allocation from 1979 - 2002. Annual allocations for these years were estimated by Dr. Barroll. Examples of the allocation records are shown in **Appendix 4C**.

As described above, the 1940s were wet years with plentiful reservoir supply and the first full-season Project water allotment did not occur until 1951. Therefore, 1940 - 1950 were assumed to be full supply years[3]. From 1951 - 1978, there were a mix of full supply and less than full supply years. Full supply years were assumed to be years with final allotments to the farms of 3.0 AF/acre or more (Reclamation, 1985). From 1979 - 2005, full supply years were assumed to be years with Mexico being allocated 60,000 AF or diverting roughly 60,000 AF or more. After 2005, full supply years were assumed to be years with an annual allocation to EPCWID (not including carryover) of at least 360,000 AF. The 360,000 AF figure was determined in consultation with Dr. Barroll based on review of deliveries and allocations during full supply years from 1984 - 2005.

4.4 Accounting Records (1979 - present)

Accounting records for EBID and EPCWID from 1979 - 2018 have been compiled into the Accounting Dataset. The accounting records track the allocation, diversion charges, credits, and allocation balance for each district. The first available accounting records are reported as irrigation season totals. Monthly accounting records are available beginning in the mid-1980s. The accounting records are in a mostly consistent format throughout the D1/D2 allocation time period (1979 - 2005). Credits to EPCWID were added after the construction of the ACE, and the accounting reports changed after the 2008 OA to reflect changes in the allocation procedures. Below is a list of the type of data in the accounting records:

[3] The term "full supply" as used herein is synonymous with "full allotment" or "full allocation."

- Allocation of Project water,
- Delivery charges,
- Credits, and
- Allocation balance/carryover.

Project water is delivered to the districts at canal headings in New Mexico and Texas. Texas lands in the southern Mesilla basin receive Project water that has been diverted by EBID at canal headings in New Mexico. Project water is delivered to the following structures, listed generally in upstream to downstream order. Maps of the accounting points for EBID and EPCWID are shown in **Figure 4-2** and **Figure 4-3.**

Examples of the accounting reports are provided in **Appendix 4D**.

New Mexico Delivery Points	**Texas Delivery Points**
• Arrey Canal	• La Union West Canal
• Percha Canal	• La Union East Canal
• Leasburg Canal	• Three Saints Lateral
• Westside Canal	• Robertson- Umbenhauer WTP
• Eastside Canal	• Franklin Canal
• Del Rio Lateral	• Jonathan Rogers WTP
• California Lateral	• Riverside Canal
• Various river pumps	

Delivery charges to EBID include the total diversions to EBID at the canal headings listed above minus deliveries to Texas in the Mesilla basin. Credits to EBID include credits for bypass water diverted at Arrey Canal or Leasburg Canal, and credit for flood waters diverted. In addition, there is an adjustment to the EBID delivery charges for diversions that are less than 95 percent of orders. EBID is charged the maximum of 95 percent of its order or the actual diversions.

Delivery charges to EPCWID include the total diversions to EPCWID at the canal headings listed in the above table. In recent years, EPCWID has also been charged for diversions to others including Tigua Pueblo, IBWC, and Yselta del Sur. The largest credits to EPCWID consist of water discharged though the Ascarate Wasteway prior to completion of the ACE in 1999, Haskell WWTP effluent discharges to the ACE, and a credit to the district for unordered and unused water. Since 2003, EPCWID has also received an ACE Conservation Credit that is added to EPCWID's total allocation and not included in the delivery charge.

For both EBID and EPCWID, if one district is ordering water and the other is not, the delivery charge to the district ordering water is equal to the total Caballo Dam release.

Figure 4-4 shows the total allocations to each district, JID, and the total delivery charges to each district from 1979 - 2018. Since 1979, EBID tended to take delivery of most of its allocation. Since 1979, EPCWID took delivery of less than its full allocation in most years. The total EPCWID annual deliveries have decreased since 2005.

5.0 HISTORICAL WATER SUPPLY AND WATER USES

5.1 Introduction

The Rio Grande, like many rivers of the southwestern United States, is characterized by wide swings in annual flow, owing largely to the significant variability in the annual snowpack accumulation and runoff from the headwaters in southern Colorado and northern New Mexico from which most of the Rio Grande flow is derived. Irrigation development in the San Luis Valley of Colorado and later the Middle Rio Grande of New Mexico have long affected the flow of the Rio Grande at San Marcial that is the source of most of the water for the Project. Regulation of upstream water uses in Colorado and New Mexico to meet the annual delivery obligations of Colorado (at the State line) and New Mexico (at San Marcial until 1949 and at Elephant Butte Reservoir thereafter) also have affected the flow available to Lower Rio Grande water users.

Construction of Elephant Butte Reservoir in 1915 and Caballo Reservoir in 1938 were instrumental in regulating the variable supply from upstream for delivery of a more dependable irrigation supply to Project water users. The Project water supply is described in the RGJI as comprised of storage releases, irrigation returns, and, to a minor degree, sporadic tributary inflows.

The average annual demand for irrigation water for the Project and for delivery to Mexico was estimated in the RGJI based on diversion records for the period from 1930 - 1936 and estimates of reuse of return flows and reservoir evaporation losses as follows:

Table 95 – Required Annual diversion demand upon Rio Grande at San Marcial for Rio Grande project and Mexican treaty obligation (USNRC, 1938)

Item	*Annual Demand (acre-feet)*
Net diversions for Rio Grande Project irrigated acreages of 145,000	*600,000*
Rio Grande Project wastes	*65,000*
Riverbed losses above Tornillo Heading	*64,000*
Salinity control in area under Tornillo Canal	*7,000*
Fulfillment of Mexican Treaty obligation	*37,000*
Total reservoir releases	*773,000*
Reservoir evaporation	*120,000*
Reservoir seepage	*60,000*
Total demand on San Marcial	*953,000*

The total release requirement of 773,000 AF/y was increased slightly during the Compact negotiations to the normal annual release of 790,000 AF/y described in the Compact.

The RGJI also included analysis of the flow available at San Marcial. Based on analysis of historical gage records from 1890 - 1935, corrected to account for upstream development that had occurred by the mid-1930s, the average annual flow available at San Marcial for downstream use was estimated at 1,031,000 AF/y. Records of water availability and water use since the mid-1930s indicate that the average available supply has been less than what was estimated in the RGJI and the use of water has been slightly more than what was estimated.

This section summarizes various historical records of water supply and water uses from before the Compact to the present.

5.2 Rio Grande Flows

Rio Grande flow records for the period of available record were compiled for gages between San Marcial and El Paso as follows:

- San Marcial (1890-2017),
- Elephant Butte Reservoir Outlet (1915-2017),
- Caballo Reservoir Outlet (1922-2017, Rio Grande above Percha Dam used for 1922-1937), and
- El Paso (Courchesne) (1895-2017).

Since completion of Caballo Reservoir in 1938, releases from Project storage have been measured below the Caballo Reservoir outlet. Prior to that time Project releases were measured below Elephant Butte Reservoir. From 1922 - 1937 there was a Rio Grande gage upstream of Percha Dam, the first Project diversion located approximately two miles downstream of the Caballo Reservoir outlet. Comparison of the annual releases from Elephant Butte Reservoir to the annual flows in the Rio Grande above Percha Dam during the period of concurrent record shows there was an average annual gain of about 20,000 AF in the 29-mile reach between the Elephant Butte Reservoir outlet and Percha Dam. Therefore, the records for the Rio Grande above Percha Dam are a better representation of the flow available at the upstream end of the Project prior to the time that Caballo Reservoir was constructed.

The upper graph in **Figure 5-1** plots the annual Rio Grande flows at San Marcial since 1890 as well as the 10-year average flow. Annual San Marcial flows averaged approximately 890,000 AF/y during the period of record. The 10-year average line clearly shows the cyclical nature of the flows in the Lower Rio Grande basin during the last almost 130 years. By decade, the flows were above average through the 1940s, below average from the 1950s through the 1970s, above average in the 1980s and 1990s, and below average thereafter.

The middle chart in **Figure 5-1** compares the annual San Marcial flows to the Project releases below Caballo Reservoir since 1922 (Rio Grande at Percha Dam flows used before 1938). The regulating and dampening effect of Project storage is seen by comparing the two lines in this chart.

Another illustration of the cyclical nature of the Rio Grande flows is presented in the lower chart in **Figure 5-1** that depicts the cumulative departure from average for the San Marcial gage and the Caballo Reservoir releases during the period from 1922 - 2017. The cumulative departure line for the San Marcial gage flows generally increases through

1945, then decreases until 1978, then increases again until 1999, and decreases thereafter. The cumulative departure line for the Caballo Reservoir releases follows a similar pattern, except it is dampened and shifted forward in time by 3-5 years reflecting the storage regulation of the reservoir inflows.

Table 5-1 provides a comparison of the average annual San Marcial inflows and Caballo Reservoir releases for various historical periods and against the comparable planning estimates presented in the RGJI. These comparisons show that the San Marcial flows have been substantially less than were estimated in the RGJI. During the generally wet period until 1950, actual reservoir releases were greater than the estimated releases needed to supply the Project. This was due in part to the Project irrigated area that grew to about 160,000 acres by the early 1950s and well in excess of the 145,000 acres analyzed in the RGJI. The early 1950s also marked the end of the prolonged wet period that had existed for several decades and, as a result, reservoir releases were less than projected in the RGJI due to the drier conditions.

The upper chart in **Figure 5-2** compares the annual Caballo Reservoir releases and El Paso gage flows from 1920 - 2017. The decreases in flow from Caballo Reservoir to El Paso generally reflect the consumptive use of surface water and ground water for irrigation and non-irrigation uses as well as the consumptive use by native vegetation.

The net Rio Grande depletion between the Caballo Reservoir release and El Paso gage, computed as the difference between the lines in the upper chart is plotted as the blue bars in the lower chart in **Figure 5-2**. The 10-year average depletion, plotted as a black line, shows the annual depletions remained relatively steady around 250,000 AF until the wet period of the early 1980s when the average annual depletions increased to over 300,000 AF during the 1990s. With the commencement of the recent dry period in the early 2000s, the average annual depletions have declined back down to around 250,000 AF. **Table 5-1** includes a summary of the average annual Caballo to El Paso depletions for various historical periods.

Figure 5-3 summarizes the annual Rio Grande flows at the Ft. Quitman gage that is located downstream of the HCCRD. Until the mid-1940s, the annual flows often exceeded 200,000 AF. In the following three decades, which were characterized by drier conditions and more careful Project operation to minimize waste, the Ft. Quitman flows averaged less than 40,000 AF. A return of wetter conditions and less efficient Project operation resulted in a significant increase in Ft. Quitman flows that persisted through 2010. Additional discussion of the Project waste is provided in Section 5.6.

5.3 Irrigated Area

The authorized irrigated area for the Project is described in the 1938 contract between EBID and EPCWID and consists of 90,640 acres in New Mexico (57%) and 69,010 acres in Texas (43%). The actual irrigated area in the Project varied through time as new lands were brought into irrigation during the early years of the Project and as lands were taken out of production due to urbanization. In addition, the actual irrigated area fluctuated from year to year as a result of planting and fallowing decisions by farmers in response to forecast water supplies.

The preparers of the RGJI assumed that not all irrigable acres would be irrigated in any one year because of fallowing and other decisions, and they estimated the water requirements for the Project based on a total combined actual irrigated area of 145,000 acres.

The reported annual Project irrigated areas for EBID, EPCWID, and the combined total are plotted in the upper chart in **Figure 5-4** for 1920 - 2017. The Project irrigated area increased rapidly to approximately 140,000 acres in the mid-1920s at which time it leveled out for about 10 years. The irrigated area slowly increased through the 1940s and reached a peak of approximately 160,000 acres in the early 1950s. This is about 15,000 acres greater than the acreage figure used in the RGJI for estimating the average annual reservoir release of 773,000 AF/y.

Since the peak in the early 1950s, the irrigated area steadily declined to the current (2017) value of approximately 105,000 acres. This represents a decline of 55,000 acres or 34% from the peak. The irrigated area in EBID has decreased by 23,000 acres (25%) from a peak of about 93,000 acres to the current 70,000 acres. The decrease in irrigated area in EPCWID has been greater at 32,000 acres (48%), declining from 67,000 acres to 35,000 acres.

As shown in the lower chart in **Figure 5-4**, the reported irrigated area in the HCCRD also increased rapidly during the 1920s reaching almost 15,000 acres in 1930. After declining to about 11,000 acres in 1938, it rose to a peak of 18,000 acres in the early 1950s. As a consequence of the severe drought that affected the Project in the mid-1950s, the irrigated area in the HCCRD, which relies on waste from the Project for its supply, declined precipitously to about 4,000 acres in the late 1950s. Since then, the irrigated area has fluctuated up and down and peaked again in the late 1980s at 17,000 acres, and then declined to the current (2017) 8,000 acres.

The reported irrigated area for the JID is also plotted in the lower chart in **Figure 5-4**. The area increased from about 19,000 acres in 1920 to about 58,000 acres in the mid-1930s and then declined to about 24,000 acres in the mid-1950s. Since then, the JID irrigated area has fluctuated between about 30,000 acres and 45,000 acres, and currently stands at about 32,000 acres (2017).

The decline in irrigated area in the Project and in the JID has been due in part to urbanization, mostly in and around Las Cruces, El Paso, and Juarez. It appears that the fluctuation in the HCCRD irrigated area may have been due to the variability in the water supply for the area.

EPW has reportedly contracted for use of the Project water associated with some of the EPCWID lands that have gone out of production, and this reportedly is the basis for the deliveries of Project water they began receiving in the mid-1940s.

5.4 Diversions

Annual irrigation season (Mar - Oct) diversions at or near the canal headings are plotted in **Figure 5-5** for EBID and EPCWID and **Figure 5-6** for HCCRD and JID during the period from 1920 - 2017. EBID diversions include diversions at the Arrey Canal in the Rincon basin, and the Leasburg Canal, Westside Canal, and Eastside Canal in the Mesilla basin. The Westside Canal and Eastside Canal deliver water to EBID lands in New Mexico and to EPCWID lands in Texas, and the diversions for these canals were pro-rated to EBID and EPCWID based on reported annual irrigated area in each district.

EBID diversions were highest during the wet period that lasted until about 1950. Diversions fluctuated during the 1950s - 1970s as the Project supply cycled through dry and wet periods. Diversions generally increased during the full supply years of the 1980s and 1990s with the 10-year average diversions returning to the level that occurred in the 1940s. Since 2002, diversions have declined dramatically as a result of the drought and enactment of the 2008 OA that has substantially reduced Project water allocations to EBID.

EPCWID diversions include diversions at the Franklin Canal, Riverside Canal (starting in 1928), Tornillo Canal (until 1937), the EPCWID portions of the Westside Canal and Eastside Canal in the Mesilla basin, and EPW diversions. The EPCWID diversions increased rapidly through the 1920s as additional lands were brought into irrigation. Similar to EBID, the EPCWID diversions were at a high level throughout the wet period of the 1930s and 1940s. Diversions plummeted during the early and mid-1950s and then varied up and down through the wet and dry years of the 1960s and 1970s. Diversions during the full supply years of the 1980s and 1990s almost reached the pre-1950 levels with increasing amounts of water delivered to EPW (orange bars in **Figure 5-5**). Commencement of the drought in

2002 resulted in a decline in EPCWID diversions, but because of the 2008 OA diversions did not decline as much as in EBID.

Irrigation season canal heading diversions for the HCCRD are plotted in the upper chart in **Figure 5-6** and include measured or estimated flows in the Tornillo Canal at Alamo Alto, the Hudspeth Feeder Canal, and the Tornillo Drain. Because the HCCRD supply is derived entirely of EPCWID waste and return flows, the HCCRD diversions generally follow the pattern of the EPCWID supply. HCCRD diversions were high in the 1930s and 1940s, and even higher in the 1980s and 1990s. Flows were more variable in the 1950s, 1960s, 1970s and after 2002.

Irrigation season diversions to the JID are plotted in the lower chart in **Figure 5-6**. These include reported diversions at the International Dam to the Acequia Madre and reported and estimated diversions from the Rio Grande downstream of International Dam until 1984. Completion of the American Dam in 1938 allowed the United States to better regulate deliveries to Mexico under the 1906 Treaty. After that time, the United States could divert all flow in the Rio Grande except for the amount being passed a short distance downstream to Mexico for diversion into the Acequia Madre. Diversions into the American Canal could then be delivered to the Franklin Canal heading or returned to the river downstream of the International Dam for delivery to the Riverside Canal heading. Before construction of the American Dam, delivery of flows to the Riverside Canal and the Tornillo Canal had to be delivered in the river past the Acequia Madre and there was no physical way to keep Mexico from diverting in excess of its treaty allotment. This accounts for the large diversions by Mexico until 1938. Since that time, JID diversions have fluctuated in concert with the diversions by the U.S. districts. Reported annual diversions often exceeded the 1906 Treaty limit of 60,000 AF because of the unregulated diversions from the river downstream of the International Dam.

Computed irrigation season canal heading diversions for irrigation in <u>AF per acre</u> are shown in **Figure 5-7** for EBID and EPCWID and in **Figure 5-8** for HCCRD and JID. These figures are based on the actual reported irrigated area in each district. Because of the generally declining acreages in both EBID and EPCWID average per acre diversions for both districts have increased since 1950s. This is especially the case for EPCWID which saw its 10-year average per acre diversions increase from about 3 AF/ac in the early 1960s to about 7 AF/ac in the 1990s. Per acre diversion have declined in recent years due to the prolonged drought.

Average per acre diversions for the HCCRD also increased markedly from about 3 AF/ac in the 1960s to about 8 AF/ac in the 1990s. In the JID, per acre diversions have remained relatively steady since completion of the American Canal in 1938. The per acre diversions are relatively low compared to EBID, EPCWID, and HCCRD because JID has significant additional supply from sewage/WWTP returns and drain flows that are not included in the per acre diversions shown in **Figure 5-8**.

Irrigation season canal heading diversions per <u>authorized acre</u> for EBID and EPCWID are summarized in **Figure 5-9**. The EPCWID diversions include diversions by EPW for municipal use. The authorized Project acres total 90,640 acres in EBID and 69,010 (EBID 1938). The per authorized acre diversions in EBID increased from approximately 4 AF/y in the 1960s to over 5 AF/y in the 1990s before declining in recent years due to the effects of drought and the 2008 OA. Similarly, the per authorized acre diversions in EPCWID increased from about 3 AF/y in the 1960s to about 5 AF/y in the 1990s before declining in recent years. The per authorized acre diversions in EPCWID are generally lower than in EBID because there has been more urbanization in EPCWID resulting in less overall water demand.

5.5 Farm Headgate Deliveries of Surface Water

Similar charts to the canal heading diversion charts were prepared to summarize the reported and estimated FHG deliveries of surface water. Summaries of the annual FHG delivery volumes are shown in **Figure 5-10** for EBID and EPCWID and **Figure 5-11** for HCCRD and JID. The FHG delivery volumes vary widely depending on the Project supply.

EBID FHG deliveries during full supply years of the 1980s and 1990s are slightly greater than during the full supply years of the 1960s and 1970s. EBID FHG deliveries have declined sharply since 2002 due to effects of drought and the 2008 OA.

FHG deliveries for EPCWID are shown as stacked bars for irrigation deliveries (red) and EPW deliveries (yellow). There are 10-year average lines in the EPCWID chart for the irrigation deliveries only and the total deliveries. The EPCWID FHG deliveries during full supply increased from approximately 150,000 AF during the 1960s - 1980s to over 200,000 AF in many years during the 1990s and 2000s.

FHG deliveries to HHCRD varied widely from 1940 to the present but increased from an average of 20,000 AF/y - 30,000 AF/y during the 1960s and 1970s to approximately 50,000 AF/y in the 1990s and early 2000s.

There are no records of FHG deliveries for JID and the values in **Figure 5-11** were estimated based on total diversions minus an estimated total canal loss. The estimated JID FHG deliveries have increased through time due to reported increases in WWTP discharges to the canal system and lining of the JID canals and laterals.

Computed irrigation season farm headgate diversions for irrigation in AF per acre are shown in **Figure 5-12** for EBID and EPCWID and in **Figure 5-13** for HCCRD and JID. These figures are based on the actual reported irrigated area in each district. Because of the generally declining acreages in both EBID and EPCWID average per acre FHG deliveries for both districts have remained steady or slightly increased since the 1950s. Per acre FHG deliveries have declined in recent years due to the prolonged drought. The declines are greater in EBID due to effects of the 2008 OA. Per acre farm deliveries in HCCRD increased from an average of 2 AF/ac in the 1960s to an average of 3.5 AF/ac in the 1990s and 2000s. In JID, FHG deliveries increased from an average of 1 AF/ac in the 1960s almost 2 AF/ac in recent years.

5.6 Farm Headgate Deliveries of Surface Water Plus Pumping

Charts summarizing FHG deliveries of surface water plus supplemental ground water pumping are shown in **Figure 5-15** through **Figure 5-18**. These charts are identical to the charts in **Figure 5-10** through **Figure 5-13** except that the estimated supplemental ground water pumping was added to the FHG deliveries to compute the total applied water. The estimated supplemental ground water pumping was computed as part of the CFB Model analyses that are described in Section 6.

The stabilizing effect of the supplemental pumping is obvious in the total applied volumes for EBID and EPCWID summarized in **Figure 5-15**. The applied water volumes for HCCRD in **Figure 5-16** are more variable due to the large variations in surface water supply and large variations in irrigated area. The total applied water volumes for JID increase substantially through the 1950s and 1960s due to the development of supplemental ground water supplies and increased supply from Ciudad Juarez sewage/WWTP returns.

The computed annual total applied water per actual irrigated acre shown in **Figure 5-17** are relatively stable for EBID and EPCIWD throughout the study period with the averages fluctuating between approximately 3 AF/ac and 3.5 AF/ac in both districts.

The annual total applied water for HCCRD shown in **Figure 5-18** has more variability than the EBID and EPCWID values, but the 10-year average also fluctuates in the range of 3 to 3.5 AF/ac. The JID total applied water values also shown in **Figure 5-18** increased from approximately 2 AF/ac in the early 1950s to an average that varies between 3 and 3.5 AF/ac from about 1970 to the present.

The annual total applied water for EBID and EPCWID are shown per authorized acre in **Figure 5-19**. The EBID amounts varied above and below 3 AF/ac throughout the study period. The EPCIWD amounts were slightly less averaging about 2.5 AF/ac. The lower average for EPCWID is likely due to greater urbanization in the EPCWID service area and resulting in lower irrigation water demands.

5.7 Waste and Deliveries to HCCRD

Historical data were reviewed to assess how Project operational waste has changed over time. Operational waste is a generally unavoidable part of operating a large irrigation Project. In order to operate without waste, it would be necessary to release the water from storage in the amounts and with the timing that, when combined with the gains and losses between the reservoir outlet and the delivery points, would result in delivery of exactly what was ordered. Such operational perfection is generally not achievable due to the time it takes for releases to reach the farms, the day-to-day variations in gains and losses between the Caballo Reservoir outlet and the delivery points, changes in water orders after releases have been made, and variations in efforts to control and manage the Project supply. Operational waste appears as discharges from canals back to the river or drains through wasteways, and as water tailing out the end of the canals.

Operational waste is not lost to the Project if it can be diverted downstream and used within the Project. Indeed, this is what happens with much of the waste from the EBID canals that returns to the river and is part of the supply that is diverted and used in the EPCWID or the JID. The operational waste that is lost to the Project is the waste that leaves the Project area below the Tornillo Division of the EPCWID.

Reported annual volumes of operational waste for EBID are plotted in **Figure 5-20** along with annual canal heading diversions. The annual EBID operational waste was relatively consistent and trending downward from the 1940s through the 1970s. The operational waste spiked upward during a few years in the late-1980s and early-1990s before declining to the lower levels in the mid-1990s and thereafter. Note that portions of the reported EBID operational waste may have been intentional because water that was destined for downstream delivery below El Paso was reportedly sometimes delivered through EBID canals and wasted back to the river downstream because the conveyance efficiency of the canals was often better than the river during dry conditions.

Figure 5-21 shows the annual waste and FHG deliveries as a percentage of annual canal diversions. The operational waste fluctuated above and below 10% through the mid-1960s and then declined to around 5% from the mid-1960s through 2001 except during the wet periods in the mid-1980s and mid-1990s. As described above, much of the EBID operational waste would have been diverted and used in the EPCWID and therefore was not lost to the Project.

Similar charts for reported operational waste in the El Paso Valley portion of the EPCWID are provided in **Figure 5-22** and **Figure 5-23**. The reported annual waste volumes in **Figure 5-22** exhibit a somewhat similar pattern to the EBID waste volumes in that the annual volumes were relatively high in the 1930s and 1940s and then lower through the 1970s.

However, beginning in the 1980s, the reported El Paso Valley waste increased substantially over what it was prior to that time, and not just during a few years in the 1980s and 1990s like it did in EBID. It is noteworthy that that increase in waste generally coincided with the EPCWID taking over the water distribution within the district from Reclamation.

Records of operational waste for the El Paso Valley are not available after 2002, so the annual waste volumes after 2002 were estimated based on a linear regression with the reported total annual canal flow to HCCRD (Tornillo Canal at Alamo Alto + Hudspeth Feeder Canal) that is also plotted in **Figure 5-22** and seems to generally follow the pattern of the reported El Paso Valley waste prior to 2002.

Figure 5-23 shows the annual El Paso Valley waste as a percentage of total El Paso Valley diversions (computed as Franklin Canal diversions minus Ascarate Wasteway flows [before completion of the ACE in 2000] plus Riverside Canal diversions plus EPW diversions). When Reclamation tightened up Project operations in the early 1950s, the waste declined from over 20% of diversions to generally less than 10% of diversions where it remained through the late-1970s. Then, inexplicably, the waste increased to an average of approximately 25% of diversions where it remained until the recent drought.

Assuming 10% represents a reasonable upper limit for El Paso Valley operational waste, **Figure 5-24** was prepared to summarize the annual waste volumes that exceeded this threshold. As shown in the table embedded in **Figure 5-24**, the annual El Paso Valley operational waste since 1980 during non-spill years averaged 51,200 AF, and annual operational waste in excess of 10% averaged 28,000 AF. Assuming this operational waste represents water that could have been saved, EBID and EPCWID would have shared in this savings 57%/43%. EBID’s share of the savings would have averaged approximately 16,000 AF/y and this represents a reasonable approximation of the impact that the increase in El Paso Valley waste had on EBID during the period from 1980 - 2017.

5.8 Irrigation Pumping

Since 2009, all wells in the New Mexico part of the LRG basin have been required to be metered by order of the New Mexico State Engineer (with the exception of single-family domestic wells and small stock wells). Many non-irrigation wells were metered long before 2009 under State Engineer permit conditions. All metered ground water uses are reported annually in the LRG Water Master Reports. The total annual metered irrigation pumping volumes in the Rincon basin and Mesilla basin in New Mexico from 2009 - 2018 are shown in **Figure 5-25**. Since 2016, the irrigation pumping has also been reported by subarea (Rincon, Mesilla North/Leasburg, and Mesilla South) and outlying areas. The stacked bars in **Figure 5-25** depict the annual irrigation pumping by subarea starting in 2016.

5.9 Non-Irrigation Water Uses and Return Flows

Water used for non-irrigation purposes in the LRG Area includes domestic, municipal, commercial, and industrial ("DCMI") uses. Most of the non-irrigation water uses are supplied by in-basin ground water pumping with the exception of EPW use of Project water, and ground water imported by Las Cruces from the Jornada basin.

A portion of the non-irrigation water use returns to the Rio Grande, canals, and drains through WWTP discharges and to the ground water system through urban deep percolation. These return flows were tabulated and estimated as described in Section 3.

Summaries of the combined annual non-irrigation water uses and measured and estimated return flows in New Mexico, Texas, and Mexico are shown in **Figure 5-26** through **Figure 5-28**. Annual pumping and return flows have averaged the following volumes during the past five years:

Average Annual Non-Irrigation Pumping and Return Flows
LRG Study Area
2013-2017
(acre-feet)

Region	Pumping	WWTP Discharges	Urban Deep Percolation	Total Returns
New Mexico	36,500	12,900	4,100	16,900
Texas	86,700	52,100*	11,900	64,000
Mexico	150,900	71,400	0	71,400

* NW WWTP (7,100 AF/y), Haskell WWTP (15,500 AF/y), and Bustamante WWTP (29,500 AF/y)

6.0 LOWER RIO GRANDE CANAL AND FARM BUDGET MODELS

Canal and Farm Budget Models ("CFB Models") were prepared to simulate historical irrigation water use in the major irrigation units in New Mexico, Texas, and Mexico between Elephant Butte Reservoir and Ft. Quitman. The models employ typical water balance calculations based on the simple formula:

- Inflows - Outflows = Change in Storage.

The CFB Models simulate use of surface water and ground water to meet the irrigation requirements for the crops that were historically grown in the study areas. The models simulate delivery of water from the canal headings to the farms including conveyance losses to seepage, incidental consumptive losses, wasteway flows, and carriage water operations. Simulated deliveries of surface water to the farms are used to meet crop irrigation water requirements limited by reasonable maximum farm irrigation efficiencies, and the deliveries that are not consumed return as deep percolation or surface runoff. A soil moisture reservoir is simulated in the root zone of the crop to carry over excess surface water applications from one stress period to the next. After development of irrigation wells in the late-1940s and early 1950s, unmet crop water demands are assumed to be met by ground water pumping.

The CFB Models were developed to assess the historical use of surface water and ground water in the LRG Area, and specifically to compute:

- Crop-weighted consumptive use ("CU") of applied water for the irrigation units in the LRG Area;
- FHG deliveries for periods when records were not available;
- Supplemental pumping for all irrigation units, and the primary (ground water only) pumping in New Mexico; and,
- Annual inputs for the Hueco Model simulation of period from 1903 - 1939).

In addition, the CFB Models were used to verify the canal and farm budget simulation process that was implemented in the RiverWare Model.

6.1 Simulated Irrigation Units

Separate CFB Models were developed for distinct irrigation units within the four irrigation districts in the LRG Area (EBID, EPCWID, HCCRD, and JID) based on the geography and availability of input data (e.g., diversion data, irrigated area data, cropping data, etc.). The following tables lists the separate CFB Models that were prepared, and the geographic area for each model is mapped in **Figure 6-1**.

Identification of CFB Models by Irrigation Unit

Irrigation Unit	District	Location
Rincon	EBID	Rincon Valley in Sierra and Dona Ana Counties, New Mexico
Leasburg	EBID	Leasburg Canal service area in the Mesilla Valley in Dona Ana County, New Mexico
Mesilla Westside (NM)	EBID	Westside Mesilla Canal service area in the Mesilla Valley in Dona Ana County, New Mexico
Mesilla Eastside (NM)	EBID	Eastside Mesilla Canal service area in the Mesilla Valley in Dona Ana County, New Mexico
Mesilla Westside (TX)	EPCWID	Westside Mesilla Canal service area in the Mesilla Valley in El Paso County, Texas
Mesilla Eastside (TX)	EPCWID	Eastside Mesilla Canal service area in the Mesilla Valley in El Paso County, Texas
El Paso Valley	EPCWID	El Paso Valley in El Paso County, Texas
HCCRD	HCCRD	Hudspeth County, Texas
JID Unit 1	JID	Northern portion of the JID Irrigation District in Chihuahua, Mexico
JID Unit 2	JID	Middle portion of the JID Irrigation District in Chihuahua, Mexico
JID Unit 3	JID	Southern portion of the JID Irrigation District in Chihuahua, Mexico

6.2 Study Period

The primary CFB Models simulate historical irrigation operations using available historical data from 1938 - 2017 using a monthly time-step. CFB Model simulations for the irrigation units in the El Paso Valley area of the EPCIWD, HCCRD, and JID were also prepared for the period from 1903 - 1937 using an annual time-step to compute certain data that were used in the Hueco Model developed by MMA.

6.3 CFB Model Simulation Processes

The equations used in the CFB Models for lands with supplemental ground water are shown on **Table 6-1** and a schematic flow diagram of the computations is shown in **Figure 6-2**. In each time-step, the irrigation demand volume is computed based on the weighted crop irrigation requirement ("CIR") multiplied by irrigated area. Water supplies are simulated to meet the monthly irrigation demand in the following order:

1. Farm headgate deliveries of surface water,
2. Soil moisture carryover from the prior month, and
3. Ground water pumping.

The surface water available to the crop is computed as FHG delivery multiplied by the estimated maximum farm irrigation efficiency ("MFE").

If the available surface water is not sufficient to meet the irrigation demand, stored soil moisture carried over from the prior time-step is used next to meet any unmet irrigation demand. The simulated capacity of the soil moisture reservoir for each irrigation unit is based on the management allowable depletion ("MAD") portion of water holding capacity of the crop root zone.

Ground water pumping is computed as the unmet irrigation demand that remains after simulating the use of surface water and stored soil moisture, and is computed as the unmet CIR demand divided by the MFE and limited by the available ground water pumping capacity. The available ground water pumping capacity is specified by (a) the pumping season, (b) the pumping development, (c) the pumping capacity, and (d) the portion of the unmet demand met by pumping.

If the available surface water supply exceeds the crop irrigation demand, the excess surface water supply is stored in the available capacity in the soil moisture reservoir. Water stored in the soil moisture is available for crop water consumption in subsequent months. If the water available for soil moisture carryover plus the beginning of month soil moisture exceeds the soil moisture reservoir capacity, then the excess supply adds to the on-farm losses.

On-farm losses are computed as the total water delivery to farm (surface water and ground water pumping) multiplied by the on-farm irrigation inefficiency (100% minus MFE) plus the portion of the delivery that exceeds the CIR and the excess soil moisture reservoir capacity. The on-farm losses are divided between surface runoff and deep percolation. Surface runoff is computed as the on-farm loss multiplied by a user-specified surface runoff percentage. Deep percolation is computed as the total on-farm loss minus the surface runoff.

Lands irrigated solely by ground water ("primary ground water lands") have been identified within or near the EBID area and are simulated in the EBID CFB Models. There currently is no simulation of primary ground water lands in the Texas and Mexico CFB Models because there is no available information on lands that may be irrigated solely by ground water in these areas.

The simulation of primary ground water lands in the EBID CFB Models is similar to the CFB Models of the areas with supplemental pumping except there is no simulation of a soil moisture reservoir. Ground water is pumped to meet the weighted irrigation water demand limited by the available pumping capacity as described above. The well development for primary ground water lands is implicit in the specified annual primary ground water acres. The primary ground water pumping is computed as the consumptive use of primary ground water pumping divided by the specified MFE. The total on-farm loss is computed as the primary ground water pumping minus the crop consumptive use. The on-farm losses are split between surface runoff and deep percolation as described above.

The annual CFB Models for the irrigation units in the Hueco Model area for 1903 - 1937 employ the same logic as the monthly CFB Models except they use an annual time-step.

Descriptions of the input data that were used in preparing the monthly CFB Models for the 1938 - 2017 study period are provided below. The input data for the annual CFB Models for the Hueco Model area from 1903 - 1937 are described in **Appendix 6A**.

6.4 CFB Model Inputs

The following is a list of the input data and input parameters that are required for the monthly CFB Models:

- Monthly surface water diversions (AF)
- Irrigated area (acres)
    - Lands that receive both surface water and ground water ("supplemental acres")
    - Lands that receive only ground water ("primary acres")
- Monthly crop irrigation requirement (feet)
- Excess effective precipitation (feet)
- Farm headgate deliveries (AF)
- Conveyance loss, wasteway flows, and carriage water percentages (% of diversions)
- Maximum farm irrigation efficiency (percent)
- Surface runoff percent (% of total on-farm loss)

- Available soil moisture reservoir capacity within the crop root zone of the irrigated crops (feet)
- Supplemental ground water pumping capacity (pumping coverage %, maximum pumping rate, % unmet demand met by pumping, pumping season)
- Primary ground water pumping capacity (maximum pumping rate [gpm], % unmet demand met by pumping, pumping season)

Detailed descriptions of the input data and parameters used in the monthly CFB Models are provided below.

6.4.1 Surface Water Supplies

Monthly surface water diversions for the CFB Models were obtained from the SWDataSet described in Section 3. The following table summarizes the surface water diversions from 1938 - 2017 simulated in each CFB Model.

Surface Water Diversions for Monthly CFB Models

Irrigation Unit	Surface Water Diversions (1938 - 2017)
Rincon	Arrey Canal (1938 - 2017) + Percha Lateral (1953 - 2017)
Leasburg	Leasburg Canal (1938 - 2017) + California Extension (1986 - 2017) + Pumped from River (1985 - 2017)
Mesilla Westside (NM)	Westside Canal (1938 - 2017); pro-rated to NM Mesilla lands and TX Mesilla lands based on irrigated area
Mesilla Westside (TX)	
Mesilla Eastside (NM)	Eastside Canal (1938 - 2017) + Del Rio Lateral (1955 - 2017); pro-rated to NM Mesilla lands and TX Mesilla lands based on irrigated area
Mesilla Eastside (TX)	
El Paso Valley	Franklin Canal (1938 - 2017) – Ascarate Wasteway (1938 - 1999) + Riverside Canal (1938 - 2017) + Bustamante WWTP outfall to Riverside Canal (1991 - 2017 in Feb - Nov) + 50% x Socorro WWTP (1967 - 1993 in Feb - Nov) + Drain Water Diverted at Fabens (1945 - 1982)
HCCRD	1938 - 4/1947: Hudspeth Canal (Tornillo End) + Tornillo Drain 5/1947 - 2017: Tornillo Canal (at Alamo Alto) + Tornillo Drain + Hudspeth Feeder Canal
JID Unit 1	2/3 x Acequia Madre (1938 - 2017)
JID Unit 2	1/3 x Acequia Madre (1938 - 2017) + 3/4 x Ciudad Juarez Sewage (1938 - 2017 in Feb - Nov) + 1/2 x River Diversions (1938 - 1984)
JID Unit 3	1/4 x Ciudad Juarez Sewage (1938 - 2017 in Feb - Nov) + 1/2 x River Diversions

There is evidence of reuse of drain water for irrigation in El Paso Valley, HCCRD, and JID (IBWC, 1989; USBR, 1992; NMSU, 2004). There are some limited records of these drain returns to canals in the El Paso Valley from 1945 - 1982 and these are used in the CFB Model for that area (Reclamation, 1992 and NMSU, 2004). There are no records of drain flow use in HCCRD and JID and no drain flow use is simulated for these areas in the CFB Models.

Monthly diversions records for the primary surface water sources used in the Rincon, Leasburg, and Mesilla units are complete for the 1938 - 2017 study period. The diversion data for several small diversion facilities that were developed after 1938 (Percha Lateral, California Extension, Del Rio Lateral, and Pumped from River) are also complete.

Monthly diversion records for the surface water sources used in the El Paso Valley, HCCRD, and JID units are largely complete for the 1938 - 2017 period, but include some estimates as described in Section 3. Additional details regarding the irrigation water supplies for the El Paso Valley, HCCRD, and JID are provided below.

El Paso Valley Surface Water Supplies

A simplified schematic diagram of the El Paso Valley diversion works is shown in **Figure 6-3**. There are two main canals, Franklin Canal and Riverside Canal, that supply the El Paso Valley. All water for the El Paso Valley is diverted at American Dam into the American Canal that conveys water to the Franklin Canal heading. Water is diverted from the American Canal upstream of the Franklin Canal heading to supply EPW's Robertson/Umbenhauer Water Treatment Plant ("WTP"), and a portion of American Canal flow can be wasted back to the Rio Grande through the Leon Street Wasteway. Until 1999, water was returned from the Franklin Canal to the Rio Grande through the Ascarate Wasteway. The discharges from the Leon Street and Ascarate Wasteways were conveyed down the Rio Grande for diversion at Riverside Dam into the Riverside Canal.

The Riverside Dam failed in the late 1980s and a coffer dam was used to continue diverting water into the Riverside Canal until the completion of the ACE in 1999. The ACE extended the American Canal south past the Franklin Canal heading to the Riverside Canal heading. EPW diverts from the Riverside Canal to supply the Jonathan Rogers WTP that was constructed in 1993. The measuring structure of the Riverside Canal is reportedly located downstream of the intake for Jonathan Rogers WTP.

EPW currently has two WWTPs in the El Paso Valley - the Haskell WWTP constructed in 1923 and the Bustamante WWTP constructed in 1991. Prior to the completion of the ACE, the Haskell WWTP discharged to the river upstream of Riverside Dam. Since 1999, the Haskell WWTP has discharged either to the river or to the ACE. Haskell WWTP discharges are included in the measured diversions for the Riverside Canal. The Bustamante WWTP typically discharges into the Riverside Canal downstream of the Riverside Canal heading, and while these discharges are not included in the measured Riverside Canal diversions, they are available for irrigation use by EPCWID farmers. The Bustamante WWTP can also discharge to the Rio Grande or to the Rio Bosque Wetlands Park through the Riverside Drain.

Prior to construction of the Bustamante WWTP, the Socorro WWTP treated wastewater in the area, and reportedly discharged to the Socorro Ponds and canals located downstream of the Bustamante WWTP. There are limited discharge records for the Socorro WWTP and most of the monthly discharges were estimated as described in Section 3. While there is little information available regarding the Socorro WWTP operations, it appears that water was discharged to the ponds and canals in the vicinity, but the outfall locations and portion of discharges to the canals is unknown. Given the absence of information, it was assumed 50% of the Socorro WWTP discharges were discharged to canals and available for irrigation of EPCWID farms in the El Paso Valley. Simulated irrigation use of WWTP discharges in the EPCWID was limited to the months of February - November.

HCCRD Surface Water Supplies

HCCRD primarily receives its water as waste and return flows from EPCWID at the El Paso-Hudspeth County Line. The HCCRD diversion works are shown in **Figure 6-4**. From 1938 to April 1947, water was conveyed to HCCRD through the Hudspeth Canal (Tornillo End) and the Tornillo Drain. In May 1947, the Hudspeth County Regulating Reservoir No. 1 was completed at the El Paso-Hudspeth County Line, and the HCCRD inflow system was reconfigured and thereafter, the surface water supply available to HCCRD is represented by the measured flows in the Tornillo Canal at Alamo Alto, the Hudspeth Feeder Canal, and the Tornillo Drain.

JID Surface Water Supplies

The surface water supplies used in the JID vary among the three JID irrigation units (Units 1, 2 and 3). The following is a summary of how the reported and estimated JID surface water supplies were distributed among the three JID units:

JID Surface Water Supplies (% Source)

Source	Unit 1	Unit 2	Unit 3
Acequia Madre	67%	33%	0%
Sewage/WWTP Flow	0%	75%	25%
River Diversions	0%	50%	50%

Unit 1 is allocated two-thirds of the Acequia Madre diversion and Unit 2 is allocated the remaining one-third (IBWC, 1989). Based on location, the Juarez sewage/WWTP discharges are available to Units 2 and 3, and it was assumed that the Unit 2 receives 75% and Unit 3 receives the remaining 25%. There are two diversions from the Rio Grande downstream of the Acequia Madre heading at the International Dam. One is located near the El Paso-Hudspeth County Line and can supply water to Unit 2 and the other is located near the Alamo Arroyo in Hudspeth County and can supply water to Unit 3. The total river diversions were assumed split equally between Unit 2 and Unit 3.

The diversion records of Acequia Madre are mostly complete during the 1938-2017 study period, and missing records were estimated as described in Section 3. The estimates of JID river diversions downstream of the Acequia Madre, and Juarez sewage/WWTP discharges described in Section 3 were used.

6.4.2 Irrigated Area

The CFB Models require input of annual values for the irrigated area that receives surface water and supplemental ground water (supplemental acres), and the irrigated area that receives only ground water (primary acres).

The annual irrigated areas values used in the monthly CFB Models for 1938 - 2017 were provided by David's Engineering ("DE") for each irrigation unit, with the exception of the Mexico irrigated area from 1938 - 1949 which are from Carreno (1957). The following is a summary of the irrigated area data from 1938 - 2017.

Irrigated Area Data for CFB Models

District	**Supplemental Acres 1938 - 2017**	**Primary Acres 1938 - 2017**
EBID	1938 - 1975: Reclamation reports 1976 - 2017: Intera Normalized Difference Vegetation Index ("NDVI") analysis	New Mexico Hydrographic Survey
EPCWID		There are no data on primary ground water acres in EPCWID, HCCRD, and JID and therefore the primary ground water acres were set to zero.
HCCRD	1938 - 1975: Reclamation reports and Intera NDVI analysis 1976 - 2017: Intera NDVI analysis	
JID	1938 - 1949: Carreno (1957) 1950 - 1975: IBWC (1989) 1976 - 2017: Intera NDVI analysis	

6.4.3 Crop Irrigation Requirements

The CFB Models require the monthly crop-weighted CIR in feet (AF/ac) for each irrigation unit (including during the winter months). The CIR is the total crop evapotranspiration less effective precipitation. Monthly crop-weighted CIR values for each irrigation unit were developed by DE (2019). Separate CIR values were provided for the primary ground water lands in the EBID irrigation units based on determination that these areas had slightly different cropping patterns than the lands with surface water and supplemental ground water.

The crop-weighted CIR values provided by DE were adjusted downward in the CFB Models from 1938 - 1970 at the direction of DE. The crop weighted CIR values were reduced by 5% from 1938 - 1953, followed by a linear reduction in the adjustment each year until it reached 0% in 1970.

6.4.4 Excess Effective Precipitation

Excess effective precipitation is the monthly effective precipitation in excess of the monthly crop evapotranspiration that is available for storage in the soil moisture reservoir. The monthly excess effective precipitation was computed by DE for each irrigation unit as the effective precipitation minus surface runoff minus CIR (DE, 2019). The monthly excess effective precipitation was added to the soil moisture reservoir in the CFB Models.

6.4.5 Farm Headgate Deliveries

Monthly records of FHG deliveries are published by Reclamation in the WDRs. These records were disaggregated as necessary to the irrigation units simulated in the CFB Models as described in Section 4.2. There were limited adjustments made to the reported FHG deliveries when the reported values were greater than the reported RHG diversions or when the reported canal loss was negative. For example, in 2010 there are several months that the reported El Paso Valley RHG diversion is less than the reported El Paso Valley FHG deliveries. In months such as these, the FHG delivery was computed as the minimum of the reported FHG delivery or the RHG diversion minus the estimated canal loss, and the waste was set to zero.

When FHG delivery records were not available, they were estimated as the monthly surface water diversions minus the reported or estimated monthly canal loss, waste, and carriage water. Descriptions of the methods used to make these estimates are provided in the following section. Annual summaries of the reported and estimated FHG deliveries that were used in the CFB Models are provided in **Table 6-2**.

6.4.6 Canal Loss, Operational Waste, and Carriage Water

The CFB Models simulate the losses and bypasses (carriage deliveries) that historically occurred in delivering water from the canal headings to the farms. There are records of monthly conveyances losses and carriage deliveries published by Reclamation in the WDRs for EBID and EPCWID. The following is a summary of the different types of losses and carriage water that are contained in the WDRs.

- Canal Loss – Canal diversions lost to seepage and incidental consumptive use.
- Waste / Operational Spills – Canal diversions returned to the river via wasteways.
- El Paso Valley Carriage – Canal diversions conveyed to El Paso Valley in the EBID canals instead of the river to reduce transit losses.
- To Eastside Canal – Leasburg Canal diversions delivered to Eastside Canal.

Monthly average canal loss and waste percentages were computed from the 1951 - 1978 WDR records for EBID and EPCWID from as a percentage of the monthly canal heading diversions for the months of March - October. Seasonal average loss percentages were computed for the winter months (November - February). These monthly and seasonal percentages were used to compute the canal loss and waste when records were not available. While there reportedly has been some canal lining in EPCWID during recent decades, there were no adjustments made to the percentages for estimated canal loss in recent years.

There are no records of El Paso Valley Carriage after 1978, and it was assumed there was no El Paso Valley carriage thereafter.

There are no records of Leasburg diversions delivered to the Eastside Canal after 1978, however it was assumed these operations continued and the To Eastside Canal flow was estimated as 1.5% of the total Leasburg diversion.

The canal loss for HCCRD was based on reported values when available and estimated as 50% of diversions when records were not available based on the historical data. There are no records of waste for HCCRD and it was assumed to be zero.

There are no data for the JID waste and canal loss, and the waste was assumed to be zero. JID canal losses were estimated as 40% of diversions before canal lining that reportedly began in 1970. This is based on the approximate average of conveyance losses in the El Paso Valley.

Based on reports regarding JID operations obtained and translated by MMA, significant canal lining occurred in the JID between about 1970 and 1987. MMA provided information on lengths and widths of the primary and secondary JID canals that were lined between 1970 and 1987. Assuming that fully unlined canals would lose 40% of diversions and fully lined canals would lose 5% of diversions, weighted average annual conveyance losses were estimated based on the proportion of the total canal area in each unit that was lined. The resulting adjusted canal losses ranged from 40% in 1970 to 33% for Unit 1, 20% for Unit 2, and 21% for Unit 3 in 1987.

6.4.7 Incidental Canal Loss and Canal Seepage

The incidental canal loss is the portion of the total canal loss that is lost to evaporation and evapotranspiration from vegetation along the canals. The incidental canal loss was computed as 6% of the total reported or estimated canal loss (LRGGWMCC, 2005). The canal seepage is computed as the total canal loss minus the incidental canal loss.

6.4.8 Maximum Farm Irrigation Efficiency

The CFB Models require input of an MFE that limits the percentage of the farm water supply (FHG deliveries surface water plus ground water pumping) that is available for crop consumptive use. The MFE functions as an upper limit on the portion of the applied water that is either consumed within the current time-step or stored in the soil moisture reservoir for later use.

The MFE values used in the CFB Models were provided by DE and were developed based on the estimated achievable unit-wide average efficiencies that would occur under water short conditions given the soil types, field configurations and slopes, irrigation practices, and assuming a reasonably high level of management. The MFE values provided by DE started at 65% for 1938-1950 and transitioned upward to 75% for 1984-2017. The same time varying MFE values were used for all CFB Models.

6.4.9 On-Farm Surface Runoff

The simulated on-farm losses were split between deep percolation and surface runoff.

DE provided annual surface runoff percentages that decrease through time due to improved irrigation and water management practices, laser land leveling, and increased use of border irrigation. The surface runoff percentages provided by DE varied from approximately 6% of the on-farm loss for 1938-1950 to approximately 1% of the on-farm loss for 1984-2017. The same time-varying surface runoff percentages were used in all CFB Models.

6.4.10 Soil Moisture Reservoir

The CFB Models simulate a soil moisture reservoir that can be used to store excess irrigation water in the current month for carryover and use in subsequent month(s). The simulated soil moisture reservoir is limited to the soil moisture reservoir capacity within the crop root zone. The following equation was used to compute the capacity of the soil moisture reservoir

SM Cap = AWC x Root Depth x MAD% x Irr Area

where

SM Cap =	Soil Moisture Reservoir Capacity in (AF)
AWC =	Weighted available soil moisture holding capacity of the soils (field capacity minus wilting point) in inches/foot of soil depth. (feet/feet)
Root Depth =	Crop weighted average maximum rooting depth (feet)
MAD%=	Crop-weighted MAD that defines the portion of the AWC in which irrigated fields are maintained to avoid significant moisture stress to the crop (%)
Irr Area =	Irrigated area (acres)

All of the soil moisture reservoir input parameters were provided by DE. A value of 1.74 inches per foot was specified as the AWC for all irrigation units. Separate crop weighted average Root Depth and MAD values were provided for EBID, EPCWID, HCCRD, and JID.

6.4.11 Supplemental Pumping

Supplemental ground water pumping was computed in the CFB Model based on all or a specified percentage of the unmet crop demand on the supplemental acres after consideration of the available surface water supplies as follows:

SupplCU = min (UnmetCIR x %SupplCIR, SupplMax x %PumpDevelop) x Pump Season Flag

where

SupplCU =	CU of supplemental ground water (AF)
UnmetCIR =	Unmet CIR after surface water supplies (AF)
%SupplCIR =	% of unmet CIR met by pumping (%)
%PumpDevelop =	% irrigated area with wells (%)
SupplMax =	Maximum monthly supplemental pumping rate (AF/month)
PumpFlag =	Start and end month flag for pumping

The UnmetCIR is computed as the total CIR minus the CIR met from surface water deliveries in the current month and the available soil moisture carryover from prior the month.

The %SupplCIR provides the ability to limit pumping to less than the amount needed to meet the full unmet demand, after applying the surface water supply. The % Suppl CIR is currently assumed to be 100%

The %PumpDevelop describes the portion of the study area served by wells. Well development proceeded rapidly during the early 1950s into the mid-1950s in response to the multi-year drought that resulted in the first significant water shortages in the history of the Project. The specified pumping development is based on a well development timeline developed by Dr. Barroll (NMOSE 2015) for New Mexico and Texas. MMA provided information on well development in JID. For all units except JID Unit 1, the %PumpDevelop is specified to increase linearly from 0% in 1947 to 100% in 1955. For JID Unit 1, the %PumpDevelop is specified to increase linearly from 0% in 1939 to 100% 1954.

The SupplMax is the upper limit on the maximum available well pumping capacity in AF/month that would limit pumping in peak demand months. There were no SupplMax limits imposed in the CFB Models.

The PumpFlag specifies the months in which pumping is allowed to occur to meet unmet irrigation demands. The pumping season in all CFB Models was set as February - November.

6.4.12 Primary Pumping

Primary ground pumping occurs on irrigated lands that have no access to surface water. The irrigated area data for the primary ground water lands are available for New Mexico based on Hydrographic Survey information, and these data were provided by DE and used in the CFB Models of irrigation units in New Mexico.

There are placeholders for primary ground water acres in the Texas and Mexico CFB Models, but no information is presently available to specify the primary ground water acres in these areas.

The primary ground water pumping is computed in the CFB Models based on the crop irrigation demand on the primary acres as follows:

PrimaryCU = min (PrimaryCIR x %PrimaryCIR, PrimMax)

where

PrimaryCU = CU of primary ground water (AF)

PrimaryCIR =CIR on primary acres (AF)

%PrimaryCIR = % of CIR that can be met by pumping

PrimMax = Maximum monthly primary pumping rate (AF/month)

The PrimaryCIR is the weighted average CIR for the crops grown on the lands irrigated solely by ground water. DE developed different cropping patterns from the primary acres compared to the supplemental acres, and therefore the weight average CIR is different between the primary and supplemental lands. There is no soil moisture simulated on the primary acres because it is assumed that pumping occurs to meet the crop CIR and not to carryover additional water in the soil moisture reservoir for later use.

The %PrimaryCIR can be specified to limit the percent of demand met by pumping on primary ground water lands. This input parameter is set at 100% in the current CFB Models.

The PrimMax parameter can be set to limit primary ground water pumping based on the available pumping capacity of the well. There is no upper limit on the well pumping capacity specified in CFB Models.

There is no pumping development percentage for the primary ground water acres like there is for the supplemental ground water pumping. It is assumed sufficient pumping capacity exists to irrigate the specified primary ground water acres.

6.5 Simulation of Historical Irrigation Operations

6.5.1 EBID CFB Models

There are four EBID CFB Models, including the Rincon, Leasburg, Mesilla East (EBID), and Mesilla West (EBID). The Rincon CFB Model simulates all lands irrigated in the Rincon basin. The Leasburg CFB Model simulates lands irrigated in the northern portion of the Mesilla basin from the Leasburg Canal. A portion of the Leasburg Canal diversions are conveyed to the Mesilla East CFB Model. Mesilla East (EBID) Model simulates lands in the southern portion of the Mesilla basin under the Eastside Canal, and the Mesilla West (EBID) Model simulates lands under the Eastside Canal. The surface water supplies for the Eastside Canal and Westside Canal are distributed between EBID and EPCWID proportionally based on irrigated acreage. The boundaries of the CFB Models for EBID are illustrated in **Figure 6-1**.

6.5.2 EPCWID CFB Models

There are three EPCWID CFB Models, including Mesilla East (EPCWID), Mesilla West (EPCWID), and El Paso Valley. As described above, the surface water supplies for the Eastside Canal and Westside Canal are distributed proportionally between EBID and EPCWID based on irrigated area. The lands in the El Paso Valley Model consist of all areas served by the Franklin, Riverside, and Tornillo Canals simulated as a single unit. This is reasonable because the Project is reported operated to make available water on an equal per acre basis. The boundaries of the CFB Models for EPCWID are shown in **Figures 6-1.**

6.5.3 HCCRD CFB Models

There is little information available on the historical operation of HCCRD, and the area is simulated with a single CFB Model assuming that the HCCRD operates to equalize the supply made available to all district lands. The boundaries of the HCCRD CFB Model are shown in **Figure 6-1.**

Based on review of aerial photographs, it was determined that HCCRD Regulating Reservoir No. 1 and HCCRD Regulating Reservoir No. 2 (aka Clayton Reservoir) were constructed in 1947, and HCCRD Regulating Reservoir No. 3 (aka McKinney Reservoir) was constructed in 1996. The HCCRD CFB Model includes the capability to simulate the operation of the three HCCRD reservoirs as a single reservoir to regulate the sometimes erratic HCCRD supply.

There is little data on the HCCRD reservoirs and operations. The composite reservoir capacity was set at 2,600 AF (estimated capacity for HCCRD Reservoir Nos. 1 and 2) until

1995 and was increased by 1,000 AF (estimated capacity for HCCRD Reservoir No. 3) to 3,600 AF in 1996. Reservoir evaporation is computed in the HCCRD CFB Model as the net monthly evaporation provided by DE multiplied by the surface area of the reservoirs. The surface area was assumed to be 257 acres from 1947 - 1955 and 541 acres from 1996 - 2019 based on delineation of the reservoir surface areas from aerial photos. The simulated operation of the HCCRD reservoirs was disabled in the runs of the CFB Model that are provided with this report. This was determined to have less than 5% impact on the simulated historical HCCRD pumping.

6.5.4 JID CFB Models

The surface water supplies and other information for the JID CFB Models are based on limited information that is available for the JID operation. There are three CFB Models for JID that simulate the operations in JID Units 1, 2, and 3. The boundaries of the JID CFB Models are shown in **Figure 6-1**.

The JID surface water supplies were distributed to the JID irrigation units as described above in Section 6.5.1. It is assumed that all JID irrigation units supplement the available surface supplies with ground water pumping. It is suspected based on review of aerial images that drain water is used for irrigation in Unit 2 and Unit 3, but such use is not simulated in the CFB Models, except to the extent that the drain flows are present in the simulated River Diversions.

6.6 Results

The Excel spreadsheet for the CFB Models contains numerous tables and charts to present monthly and annual results. District-wide summaries of the CFB Model results are provided in **Appendix 6B** and include the following tables and charts:

- Monthly charts of on-farm CU (1938 - 2017),
- Annual charts of farm deliveries, CU, losses, irrigated acres, and loss and efficiency percentages (1938 - 2017),
- Annual and average monthly charts of pumping and deep percolation (1938 - 2017),
- Average monthly tables of the inflows, outflows, and changes in storage (1938 - 2017), and
- Annual tables of the inflows, outflows, and changes in storage (1938 - 2017).

Annual tables and charts summarizing the simulated 1903 - 1937 results for the annual CFB Models developed to provide inputs to the Hueco Model are also available in the CFB Model spreadsheet.

Among the results provided in the CFB Model spreadsheet are the computed supplemental pumping and primary pumping (EBID only) volumes. Records of annual ground water pumping are available for EBID from 2009 - 2017. Comparisons of computed vs. actual annual ground water pumping for the EBID CFB Models are shown in **Figure 6-5**. In general, there is good agreement between the computed and actual pumping from 2009 - 2017.

The results from the CFB Models are referenced in Section 12 in the responses to the M&A expert report.

7.0 NEED FOR MODELING ANALYSIS OF CLAIMS AND COUNTERCLAIMS

The Rio Grande between Elephant Butte Reservoir and Fort Quitman is a highly developed working river system that is the life blood to the region in sustaining local economies and natural ecosystems. The historical time-series data in Section 5 show there have been changes and/or fluctuations in Rio Grande flows and Project diversions and deliveries prior to and since the Rio Compact was entered in 1938. The Rio Grande flow and water supply available for use is affected by numerous natural and man-caused factors including the following:

- Precipitation runoff,
- Water surface evaporation,
- Evapotranspiration of native vegetation,
- Project operations,
- Irrigation operations,
- Municipal water supply operations,
- Ground water pumping, and
- Surface and ground water interaction.

The claims and counterclaims filed in the pending lawsuit assert that certain actions such as pumping and changes in Project operating procedures have impacted Rio Grande flows and deliveries of Project water. Due to the complex interactions between the above factors and surface and ground water flows, it is not possible to reliably quantify and differentiate the effect of a certain action (e.g., pumping) on a certain outcome (e.g. changes in El Paso flow) using historical data alone. The mere presence of a correlation between two quantities does not mean there is a cause-and-effect relationship between them. The correlation may be spurious, or there may be multiple factors causing a change in some quantity.

Texas has claimed that changes in the Rio Grande flow at El Paso are due to the development of upstream ground water pumping. The double-mass curve analysis presented in the Texas expert report by Robert J. Brandes is based on an alleged cause and effect relationship evidenced by a correlation.

While pumping has certainly impacted Rio Grande flows, there are likely other factors that have contributed to the changes in flow including the following:

- Reduction in inflows to Project storage,
- Changes in irrigated area and crop selection,
- Changes in irrigation practices,
- Increases in downstream pumping, and
- Changes in Project operations.

While changes in the flow of the Rio Grande at El Paso may be of historical interest, flow changes at any single river gage are irrelevant to this case, to the Compact, and to the operation of the Project. Of more relevance are changes in the deliveries of Project water for beneficial use.

For complex water systems like the Lower Rio Grande, it is necessary to develop simulation model(s) to better understand and quantify the interrelationships among natural and man-influenced processes, and to isolate and compute the effects of actions relevant to the claims and counterclaims in this case. The reliability of predictions from a simulation model is enhanced if (a) the model is reasonably calibrated over a representative historical period, and (b) the simulated processes reflect reasonable and appropriate dynamic responses to simulated changes to historical conditions.

The modeling requirements in this case are more complex than in a typical ground water modeling project that might, for example, involve determining the amount, timing, and location of impacts on ground water levels and surface water flows resulting from ground water pumping. In typical ground water pumping evaluations, the objective in constructing the model is to reasonably simulate the relevant physical process so that the model produces reasonable estimates of stream depletions and changes in ground water levels given the simulated pumping volumes. Model calibration in this instance would be focused on adjusting aquifer characteristics, boundary conditions, and other physical parameters so that the simulated historical conditions (e.g., water levels and streamflows) reasonably match historical values.

The Lower Rio Grande system is more complicated because of the need to simulate the operations of the Project and the LRG irrigation systems. The Project facilities and irrigation systems are operated and managed to respond to changes in the available water supply, and this introduces a human element that needs to be incorporated in the model processes. Not only do the physical processes need to reasonably respond to changes in inflows and modeled stresses, but so do the Project operations. For example, simulating a reduction in pumping within the Project area would be expected to cause the following responses:

- Reduced on-farm consumptive use, deep percolation, and surface runoff from pumping.
- Increased ground water levels and drain flows.
- Increased riparian evapotranspiration due to shallower ground water levels.
- Increased ground water flow to the Rio Grande and/or reduced Rio Grande flows to the ground water system.
- The above responses would generally increase Rio Grande flows which in turn would affect Project operations depending on the Project supply at the time.
  - During full supply periods, the increased river flows would prompt reductions in reservoir releases to deliver the same amounts to Project water users. This in turn would accumulate additional water in storage that would be carried forward and used in subsequent non-full supply periods.
  - During non-full supply periods, the additional flow in the river and additional water carried over in reservoir storage would increase the supply available for delivery to New Mexico, Texas, and Mexico water users.
- Increased deliveries for irrigation would increase surface water consumptive use, deep percolation, and surface runoff. If pumping in only certain areas was reduced or turned off, then the changes in surface water supplies to other areas would result in corresponding changes in pumping to meet unmet demands in those areas.
- Increased reservoir storage would increase reservoir evaporation and increase reservoir spills.
- During the non-irrigation season, much of the additional river flow would exit from the downstream end of the system unconsumed.

The foregoing list of expected responses to simulated changes in pumping are the same types of responses that historically occurred when the surface water supplies and pumping varied between historical wet and dry periods.

7.1 Required Model Features

In order to fully evaluate the claims and counterclaims in this case, a robust model of the hydrologic and water use systems between San Marcial and Fort Quitman is needed. The model should generally simulate the following features:

- Inflows
- Reservoir operations

- River routing
- Irrigation operations and pumping
- Non-irrigation operations and pumping
- Non-beneficial ET
- Ground water flow
- Ground water/surface water interaction

The model features listed above should not be simulated based on fixed inputs that cannot change in alternative scenarios. A model based on fixed inputs rather than dynamic processes has little or no ability to dynamically respond to changes in the modeled stresses. For example, if reservoir releases and canal diversions are fixed at historical levels in simulation of alternative scenarios (e.g., reduced pumping), then the model has no functionality to adjust to changes in river flow, and most or all of the changes in river flow will unreasonably accumulate as changes in Rio Grande outflows from the study area.

The manner of dynamic simulation of model processes depends on whether the processes are physically-based or management-based as described below. **Table 7-1** contains a list of the required simulation processes, including whether they are physical or management processes.

7.2 Physical Processes

Physical processes move water based on physical relationships or mass balance calculations that are not dependent on human decisions or management. For example, reservoir evaporation is a physical process that depends on evaporation rates and reservoir surface area. It may be dynamically simulated in a model using a time-series input of evaporation rates and reservoir surface area computed based on the simulated reservoir storage contents and the surface area-volume relationship for the reservoir. Another example of a physical process is river seepage computed based on the simulated head difference between the river surface and the connected ground water system, and the conductance of the riverbed materials through which the seepage travels. In the foregoing examples, there obviously are human decisions that affect the reservoir contents or river flows, but the physical processes involved in evaporating water from the reservoir surface or seeping water from a river are independent of those human decisions.

Physical processes may be calibrated by adjusting input parameters in the simulation equations within reasonable bounds to match simulated values to observed values. In the calibration process, reservoir releases, diversions, and FHG deliveries are set at historical values and the model parameters are adjusted to match streamflows, drain flows, and ground water levels.

7.3 Management Processes

Project and irrigation operations involve management decisions that need to be translated into rule-based simulation processes appropriate for the spatial and temporal scales of the model. For example, rules can be developed to simulate farm headgate demands as a function of irrigated area and crop irrigation requirements. Farm headgate deliveries can then be simulated as the lesser of the demand or the available supply. Such rules allow the model simulation to dynamically adjust farm headgate deliveries in alternative scenarios in response to changes in the available water supply.

Simulation of management processes can also be adjusted to reasonably match simulated and observed values. The process of adjusting the simulated management processes is described in this report as "tuning" to distinguish it from "calibrating" the physical processes. In the tuning process, the simulation rules are adjusted to reasonably match historical reservoir operations, canal diversions, farm headgate deliveries, and other historical data.

8.0 OVERVIEW AND ASSESSMENT OF INTEGRATED LRG MODEL

8.1 Introduction

Three simulation models were developed and integrated for use in assessing certain of the claims and counterclaims in this case. These models consist of a RiverWare Model of the surface water and alluvial ground water systems from San Marcial to Ft. Quitman ("RiverWare Model"), a MODFLOW ground water model of Rincon and Mesilla Valleys located between the Caballo Reservoir outlet and the Rio Grande at El Paso gage, and another MODFLOW ground water model of the El Paso Valley and Juarez Valley located between the El Paso gage and Ft. Quitman. Together, the three models are referred to as the "Integrated LRG Model" or "ILRG Model." A map showing the spatial domains of the three models is provided **Figure 8-1**.

The RiverWare Model is the principal vehicle for computing the impacts of pumping and the effects of operational changes on the surface water system. The ground water models play a supporting role in computing certain inputs to the RiverWare Model including canal seepage, evapotranspiration of native/riparian vegetation, and flux between the shallow Rio Grande alluvial aquifer and the Upper Santa Fe Group and/or Middle Santa Fe Group.

The ILRG Model simulates irrigation and non-irrigation water uses over a study period that extends from January 1940 to December 2017 using monthly stress periods. Integration of the three models occurs through passing of certain information between the RiverWare Model and the ground water models as they are run iteratively until closure.

This section provides on overview of the three models, their suitability for assessing claims and counterclaims in this case, and development of post-processing tools for summarizing and assessing alternative model scenarios. Details regarding the development, calibration, and operation of the three models are provided in the reports of other New Mexico experts.

8.2 RiverWare Model

The RiverWare Model was developed by Hydros Consulting ("Hydros") in Boulder, Colorado. The model simulates the operations of EBID and EPCWID that comprise the Project, the HCCRD system located south of the EPCWID in Hudspeth County, and the JID system located west of Rio Grande in Mexico. A simplified schematic diagram of the flow linkages in the RiverWare Model is shown in **Figure 8-2**.

RiverWare is a full-featured customizable river system modeling package that is well-suited for modeling a river system like the Rio Grande between San Marcial and Fort Quitman. The modeling software is equipped with a rich menu of functions to simulate various flow process and can be customized to simulate other flow processes through development of scripted rule sets.

The RiverWare Model performs the following water budget calculations during each monthly stress period to simulate Project and other irrigation operations within the study area.

- Reservoir Budget,
- River Budget,
- Canal and Farm Budget, and
- Shallow Ground Water Budget.

Schematic diagrams of the RiverWare water budgets are shown in **Figure 8-3** through **Figure 8-7**.

8.2.1 Reservoir Budget

The Reservoir Budget in the RiverWare Model simulates operation of Project storage in Elephant Butte Reservoir and Caballo Reservoir. Inflows to the reservoirs consist of historical Rio Grande at San Marcial gage flows, precipitation, and unmeasured gains/losses derived from water balance analysis of historical reservoir operations data. Releases from storage are simulated to meet Project water demands, a small pre-Project diversion, and to spill water when the reservoir is full.

The simulated usable water in Project storage available for allocation is computed each month from February through July as the usable water in storage plus the reservoir releases to date. The usable Project supply is allocated to EBID, EPCWID, and Mexico in the Historical Base Run using three sets of allocation rules. D1/D2 Rules are used to simulate historical operations from 1948 - 2005. While the D1/D2 Rules did not actually go into operation until 1980, they were judged to reasonably simulate the equal allocation per acre procedure that functioned before that time. The D3+Carryover Rules from the 2008 OA are used to simulate allocation of Project water from 2008 - 2017. The D3 Rules without carryover accounting are used in 2006 and 2007.

During the wet period from 1940 - 1947 when Reclamation did not set any annual Project water allotments, historical records show that the Project water users generally called for and were delivered whatever water they needed and sometimes more. Therefore, the

RiverWare rules during the 1940 - 1947 period were developed to generally match historical operations without the restriction of an annual allocation.

Storage releases to Mexico are made on a set monthly schedule for delivery to the International Dam and diversion into the Acequia Madre. Storage releases to EBID and EPCWID are made based on rules that deliver water to meet the demands of EBID and the combined irrigation and EPW demand of EPCWID, as limited by the computed annual allocations. Water available to HCCRD is comprised of simulated waste and return flows from EPCWID.

8.2.2 River Budget

The River Budget in the RiverWare Model simulates the routing of flows down the Rio Grande. Inflows consist of reservoir releases, drain and wasteway flows, wastewater treatment plant discharges, and on-farm surface runoff. Outflows include canal diversions, river evaporation, and flow past Ft. Quitman. Seepage between the river and alluvial aquifer is computed based on the difference in head between the river water surface and the simulated ground water level and is calibrated using specified riverbed conductance values.

8.2.3 Farm Budget

Irrigation operations within EBID, EPCWID, HCCRD, and JID are simulated in RiverWare Model using a farm budget simulation algorithm similar to one used in the CFB Models described in Section 6. The farm budget calculations in the RiverWare Model are performed using monthly stress periods for the following geographic areas.

Geographic Units for RiverWare Model Farm Budget Calculations[4]

EBID	EPCWID	HCCRD	JID
Rincon	Mesilla Eastside	Unit 1	Unit 1
Leasburg	Mesilla Westside	Unit 2	Unit 2
Mesilla Eastside	El Paso Valley	Unit 3	Unit 3
Mesilla Westside			

[4] Calculations for the above geographic units are disaggregated to a sub-area level in Riverware to spatially distribute the pumping, and irrigation return flows along the Rio Grande.

Simulated deliveries to the various major canal headings on the Rio Grande are conveyed to farms after being reduced by wasteway discharges back to the river and by canal and lateral conveyance losses. The conveyance loss includes a seepage component computed by the ground water models. The total conveyance loss is computed in the RiverWare Model as the seepage loss from the ground water models divided by 0.94 reflecting an assumed incidental consumptive conveyance loss of 6%.

The monthly crop water demands for each unit are computed as the irrigated area multiplied by the crop-weighted average CIR. The CIR for each crop is computed outside of the RiverWare Model as the potential evapotranspiration ("PET") less the effective precipitation.

The water supply available to meet the crop water demand is computed in the RiverWare Model as the farm headgate delivery multiplied by a specified MFE that increases through time. Available supply in excess of the crop demand may be stored in the root zone of the crop for subsequent use. Until 1948, if the simulated monthly available water supply, including the soil moisture carryover from the prior month, was insufficient to meet the crop water demand, then a shortage was computed. Significant use of ground water for irrigation commenced in 1948 and was fully implemented by 1955, and shortages in crop water demand were assumed alleviated in part by ground water pumping beginning in 1948 and in full by 1955 and beyond.

On-farm losses and excess farm deliveries become surface runoff to the Rio Grande and deep percolation to the alluvial aquifer. Additional irrigation return flows include wasteway discharges to drains or to the river and canal seepage accruals to the alluvial aquifer.

8.2.4 Ground Water Budget

The RiverWare Model includes a ground water object under each water user object that functions like a large cell in a MODFLOW ground water model. Inflows to the ground water object include canal seepage computed in the ground water models, flow between the alluvial aquifer and other aquifers in the ground water model (inflows or outflows to the ground water object), and on-farm deep percolation losses computed in the Farm Budget. Outflows from the ground water object include alluvial ground water pumping and riparian ET computed in the ground water models. Other inflows/outflows are computed based on head differences between the ground water object and surrounding objects including river seepage, drain flows, and lateral flows to other ground water objects.

8.3 New Mexico Rincon-Mesilla Ground Water Model

The New Mexico Rincon-Mesilla Ground Water Model ("NMR-M Model") was developed by SSPA using the USGS MODFLOW software to simulate ground water use in the Rincon Valley and Mesilla Valley between the Caballo Reservoir outlet and the Rio Grande at El Paso. The modelled area includes all of the EBID service area in New Mexico and the Mesilla Valley portion of the EPCWID service area in Texas. The model simulates ground water flow in the Rio Grande alluvium and the deeper and more laterally extensive aquifers of the Upper, Middle, and Lower Santa Fe Groups. Lying over the upper model layers is a surface flow network constructed using the MODFLOW SFR Package that simulates head dependent interaction between the ground water system and the Rio Grande and the Project canals, laterals, and drains. Most of the irrigation pumping is simulated in the alluvial aquifer and most of the non-irrigation pumping is simulated in the aquifers of the Santa Fe Group.

Water budget diagrams illustrating the simulation processes of the NMR-M Model are shown in **Figure 8-8**. Specified time-series inputs to the NMR-M Model are pumping from non-alluvial wells and mountain front recharge. Other inputs to the NMR-M Model are passed from the RiverWare Model and consist of reservoir releases, canal diversions, farm headgate deliveries, wasteway flows, deep percolation, and pumping from the alluvial aquifer for irrigation. Data passed from NMR-M Model to the RiverWare Model include canal seepage, riparian ET, non-irrigation pumping from the alluvial aquifer, flow between alluvial aquifer and Santa Fe Group.

Simulated monthly farm headgate deliveries are removed from NMR-M Model and the corresponding deep percolation and surface runoff from the RiverWare Model are added to the NMR-M Model. The difference between the removed farm headgate deliveries and the added irrigation return flows represents the on-farm consumptive use of applied water in the RiverWare Model.

8.4 Hueco Ground Water Model

The Hueco Model was developed by MMA using USGS MODFLOW software to simulate ground water use in the alluvial aquifer and the Santa Fe Group aquifers of the Hueco Bolson that underlie the El Paso Valley from the Rio Grande at El Paso gage to near Ft. Quitman. The modeled area includes a large portion of El Paso County in Texas including the City of El Paso, Hudspeth County, and the Juarez Valley, including Ciudad Juarez.

The model simulates Irrigation and ground water pumping of EPCWID in the El Paso Valley, the HCRRD, and the JID. Non-irrigation pumping is simulated for EPW, which serves the City of El Paso, other significant M&I water users in the El Paso area, and the water and sanitation utility for Ciudad Juarez, Junta Municipal de Aqua y Saneamiento ("JMAS"). Like the NMR-M Model, surface water features and their interaction with the underlying ground water system are simulating using the MODFLOW SFR Package.

The ground water model water budget diagrams in **Figure 8-8** also apply to the Hueco Model. Specified inflows and information passed between the RiverWare Model and the Hueco Model are the same as for the NMR-M Model.

8.5 Integration of LRG Models

A manual iteration procedure is used to execute runs of the ILRG Model, and a diagram illustrating the procedure is shown in **Figure 8-9**. The major simulation processes are shown on the right side of the diagram in blue for the RiverWare Model and the left side in brown for the ground water models. Information passed between the models is listed in the center with the information passed from the RiverWare Model to the ground water models shown in blue and the information passed from the RiverWare Model to the ground water models shown in brown.

An illustration of the model execution process is provided at the bottom of **Figure 8-9**. The procedure for making an iterated model run starts by running the RiverWare Model with an initial time-series of input data from the ground water model from a prior run. After running the RiverWare Model, the required RiverWare Model outputs are passed to the two ground water models and they are both run. Required outputs from the ground water model are then passed to the RiverWare Model and it is executed again. This iterative process is repeated until the differences in the simulated flows from one iteration to the next is relatively small. Closure typically occurs within several iterations.

8.6 Calibration of LRG Models

As described previously, calibration of the LRG Models is specific to adjustment of the simulation of the physical processes in the model. The models were calibrated by simulating the historical study period using historical data for the following model inputs:

- Reservoir releases,
- River diversions,
- Farm headgate deliveries,
- EPW deliveries,
- Non-irrigation pumping, and
- Non-irrigation return flows.

Selected model input parameters were varied during the calibration process to improve matching of the following simulated outputs to the historical observed values:

- River flows,
- Drain flows,
- Ground water levels in the alluvial aquifer, and
- Ground water levels in the Santa Fe Group (ground water models).

A diagram illustrating the calibration process for the RiverWare Model is shown in **Figure 8-10**. The fixed historical time series inputs are shown in black, the values computed in the RiverWare Model are shown in blue, the values computed in the ground water models and passed to the RiverWare Model are shown in green, and the calibration targets are shown in red.

Summaries of the RiverWare Model calibration results for the Rio Grande at El Paso and the Rio Grande at Ft. Quitman are provided in **Figure 8-11** and **Figure 8-12**, respectively. Each figure contains three charts and several calibration statistics at the bottom of the page.

El Paso Gage

The measured and modeled monthly flows for the Rio Grande at El Paso gage are plotted in the upper graph in **Figure 8-11**. All model error[5] or imperfections in simulating consumptive use, return flows, well pumping depletions, drain flows, and other processes upstream of the El Paso gage accumulate as differences between the modeled and measured flows at the gage. Visual comparison of the two lines in the upper chart indicates generally excellent agreement between the modeled and measured streamflows. The other charts in **Figure 8-11** compare the modeled and measured annual flows (lower left) and the modeled vs. measured flows in a scatter plot (lower right). The mean monthly flow during the calibration run was 31,698 AF compared to a mean measured flow of 31,191 AF. The mean residual or mean error is +506 AF or approximately +1.6% of the measured mean monthly flow. Depictions of modeled and measured flows at El Paso gage were evaluated for model calibration purposes only, and contrary to Texas's position in this case, the El Paso gage is not a Compact delivery point.

Ft. Quitman Gage

The measured and modeled flows at the Rio Grande at Ft. Quitman gage at the downstream end of the ILRG Model are plotted in **Figure 8-12**. Comparison of the measured and modeled flows in the upper chart shows the model performs well in matching the trends and fluctuations in flows, but also shows accumulation of some additional model error in simulating conditions downstream of the El Paso gage in the El Paso Valley and Juarez Valley. This is due in part to the general lack of data regarding water use and water distribution in these areas. The mean monthly modeled flow during the calibration run was 11,030 AF compared to a mean measured flow of 10,345 AF. The mean residual or mean error is +685 AF or approximately +6.6% of the measured mean monthly flow.

8.7 Tuning of LRG Models

After calibrating the physical processes in the RiverWare Model, the historical time series data for reservoir releases, diversions, and farm headgate deliveries were replaced with rules to simulate major management processes of the Project operations and water uses. Tuning of the RiverWare Model refers to adjustment of the rules for these management processes to reasonably match historical operations, specifically the following:

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[5] In modeling parlance, "error" refers to differences between simulated values and observed values. It does not mean or imply a mistake in the model.

- Allocations,
- Reservoir releases,
- River diversions,
- Wasteway flows,
- Farm headgate deliveries, and
- River flows.

A diagram illustrating the tuning process for the RiverWare Model is shown in **Figure 8-13**. The diagram is the same as the calibration diagram in **Figure 8-12** except the tuning targets are highlighted in yellow.

Simulation of Project operations with rules rather than using historical data results in some decline in the agreement between modeled and historical streamflows because of the challenge in developing fixed rules to simulate operations that may include to varying degrees uncertain and ad hoc decision processes. Some decline in agreement between simulated and observed flows is an unavoidable consequence associated with development of a model that appropriately responds to simulated changes in historical conditions.

Further, the errors that are present in the tuned model simulation of historical conditions (i.e., in the historical operations run) are also largely present in alternative simulations using the tuned model (e.g., in no-pumping runs). Therefore, when differences are computed between the output of two runs of the tuned models (e.g., simulated streamflows or farm deliveries), these errors tend to cancel each other out, resulting in changes in outputs that reasonably represent the effects of changes in the simulated model inputs.

Figure 8-14 through **Figure 8-18** provide comparisons of various model outputs from the tuned ILRG Model simulation of historical operations during 1940 - 2017 against the results from the calibration run in which reservoir releases, diversions, and farm headgate deliveries were set at historical values. As described further in Section 9, the tuned model simulation of historical conditions is designated as the Historical Base Run against which simulations of alternative scenarios were compared. Consistent with this, the tuned model results are identified as the Historical Base Run (black line) and compared to the Calibration Run (orange line). The following is a list of the comparisons between the Historical Base Run and the Calibration Run shown in **Figure 8-14** through **Figure 8-18.**

- **Figure 8-14** – Annual Summary of Project Storage and Rio Grande Flows
- **Figure 8-15** – Annual Summary of Irrigation Operations – EBID
- **Figure 8-16** – Annual Summary of Irrigation Operations – EPCWID
- **Figure 8-17** – Annual Summary of Irrigation Operations – HCCRD
- **Figure 8-18** – Annual Summary of Irrigation Operations – JID

The graphical comparisons in the above figures show that the simulated values in Historical Base Run of the tuned ILRG Model reasonably matches the values from the historical Calibration Run. Of particular note is how well the simulated irrigation pumping in the Historical Base Run matches the magnitude and trends in the simulated pumping in the Calibration Run. Differences in the simulated pumping reflect the accumulated differences in all simulated processes that occur between the Project storage and farm headgate deliveries of surface water. Given this, the general agreement between the simulated pumping in the Historical Base Run and the Calibration Run is considered excellent.

The matches between the simulated reservoir storage contents, Caballo Reservoir releases, El Paso flows and Ft. Quitman flows in the Historical Operations Run and the Calibration Run are also excellent.

Additional discussion of the results of the Historical Base Run is found in Section 9 below.

8.8 Model Output and Post-Processing of Results

Post-processing spreadsheets were prepared to summarize output from the ILRG Model. The purpose of the spreadsheets is to help illustrate and explain the model results and to help verify the models are correctly functioning. Post-processing spreadsheets were developed to summarize the following model results:

- Calibration and tuning results,
- Water budgets and balances,
- River point flow diagrams and flow maps, and
- Changes in modeled outputs for alternative scenarios.

Tables and charts from the post-processing spreadsheets are presented in the foregoing subsections on model calibration (Section 8.6) and model tuning (Section 8.7), in Section 9 in the discussion of the Historical Base Run, and in Section 10 in the discussion of the model runs that were made in support of New Mexico's counterclaims.

8.9 Suitability of ILRG Model for Assessment of Claims and Counterclaims

The ILRG Model was successfully calibrated and tuned over a 78-year study period comprised of a wide variety of hydrologic conditions ranging from the wet periods of the 1940s, 1980s, and 1990s with little or no pumping, to the dry periods of the 1950s and 2010s with substantial pumping. The calibration and tuning results demonstrate that the model reasonably simulates surface and ground water use between Elephant Butte Reservoir and Ft. Quitman as well as the physical interaction between the surface and ground water systems.

In addition, the ILRG Model complies with the objectives described in Section 7 for developing calibrated rule-based models that are capable of reasonably simulating appropriate responses to simulated changes in historical input data and/or operating conditions. This includes dynamic simulation of the substantive real-world processes of allocating Project supplies to the U.S. districts and Mexico, releasing those allocations to meet the Project water demands and the 1906 Treaty obligation to Mexico in combination with the simulated downstream return flows to the river from irrigation and non-irrigation uses.

It is my opinion that the ILRG Model is the best available scientific tool for evaluating the effects of hydrological and institutional changes within the LRG Area on surface water supplies, streamflows, and ground water storage in the Rio Grande basin between Elephant Butte Reservoir and Ft. Quitman.

9.0 HISTORICAL BASE RUN OF INTEGRATED LRG MODEL

9.1 Introduction

The ILRG Model was used to simulate historical conditions over the 1940 - 2017 study period for purposes of calibrating and tuning the model as described above. In addition, the tuned version of the model was used to develop the Historical Base Run that was compared to the results of alternative scenarios that were also simulated with the tuned version of the ILRG Model. This section of the report provides an overview of the operational specifications for the Historical Base Run as well as summaries of the simulated results.

9.2 Key Operational Specifications for Historical Base Run

The following is a summary of the key specifications and rules for simulating Project operations and irrigation and non-irrigation water uses in the Historical Base Run of the ILRG Model:

- Project Water Allocation – The D1/D2 allocation procedure developed by Reclamation and implemented starting in 1979 is used to allocate Project water from 1940 - 2005. While the D1/D2 Procedure was not officially implemented until 1979, it was determined to reasonably approximate the somewhat ad-hoc equal allocation per acre procedure that existed prior to 1979. Annual full supply allocations prior to 1979 were estimated based on maximum allocations reported during that time. The D3 allocation procedure without carryover is simulated in 2006 and 2007. The D3+Carryover allocation procedure is simulated starting in 2008 through the end of the study period. While certain details of the 2008 OA allocation procedure were modified from time to time after 2008, the allocation procedure simulated in the ILRG Model is consistent with the 2017 version of the 2008 OA allocation worksheet.
- Project Accounting – The Project accounting includes tracking the Project diversions to EBID, EPCWID, and JID. Reservoir releases are made from the Project storage to deliver water to the districts and the diversions are limited to the Project water allocations. The EBID diversion charges include Arrey Canal, Leasburg Canal, Eastside Canal, and Westside Canal flows to New Mexico. The EPCWID diversion charges include Eastside Canal and Westside Canal flows to Texas, Franklin Canal minus Ascarate Wasteway (pre-1999), Riverside Canal, and EPW diversions of Project water. Credits against diversion charges are simulated for the ACE credit and the Haskell WWTP credit.

- FHG Demands – Irrigation demands at the farm headgate are computed based on historical irrigated area, historical monthly crop-weighted average CIR values, and specified maximum farm irrigation efficiency values that increase through time.
- Conveyance Losses – Canal conveyance losses are computed in the SFR packages of the NMR-M Model and the Hueco Model. An incidental loss of 6% is added to the computed conveyance loss to represent consumptive use by evaporation and vegetation along the canals and laterals.
- Canal Diversion Demands – Diversion demands at the canal headings are computed as the FHG demands divided by the conveyance efficiency (1.0 minus the conveyance loss factor) multiplied by factors developed during the model tuning to match historical diversions.
- Irrigation Pumping – Irrigation pumping coverage is specified to increase linearly from 0% in 1947 to 100% in 1955 and remain at that level for the rest of the study period. Upon reaching full coverage in 1955, it is conservatively assumed that irrigation pumping meets 100% of the unmet irrigation demand after Project water deliveries to Project lands. Pumping on the simulated non-Project lands in EBID that are served only by wells is also conservatively assumed to meet 100% of the simulated irrigation demand.
- Non-irrigation Pumping and Return Flows – Municipal pumping, wastewater treatment plant return flows, and urban deep percolation are based on historical records and estimates. Domestic pumping is set at historical estimated levels.

9.3 Historical Base Run Results

The Historical Base Run simulates historical Project operations and water uses between Elephant Butte Reservoir and Ft. Quitman from 1940 - 2017. The simulated Project operations and water uses generally track the historical records that are summarized in Section 5. However, simulation of the Historical Base Run provides additional information and insight on the hydrologic and water use processes for which comprehensive measurements and records are not available. For example, the model results show estimated historical ground water pumping that was needed to meet the unmet irrigation demands after Project water deliveries, and the various components that contribute to the gains and losses of selected river reaches. The following are selected results and observations from review of the Historical Base Run.

9.3.1 Reservoir Operations

Figure 9-1 summarizes the simulated annual inflows, outflows, and end-of-year storage contents of Elephant Butte Reservoir, Caballo Reservoir, and the two reservoirs combined. Inflows are represented as stacked positive bars and include Rio Grande inflows, local inflows, and precipitation. Outflows are shown as stacked negative bars and consist of releases, evaporation, and storage adjustments (for periodic adjustments to the reservoir stage-capacity table due to siltation). The end-of-year storage contents is plotted as a black line in the figures and the annual changes in the end-of-year storage correspond to differences between the total reservoir inflows and outflows.

Review of the combined reservoir storage chart shows how the reservoir inflows varied through times affecting the reservoir contents and the reservoir releases. Two years of high inflows in the early 1940s caused the reservoirs to spill in 1942. This followed by a mix of average and below average inflows during the 1940s that resulted in a decline in the simulated reservoir contents. This was followed by six out of seven years with very low inflow that resulted in five consecutive years from 1953 - 1957 with reservoir releases of less than 500,000 AF. Inflow conditions improved in late 1950s resulting in some increases in reservoir contents and Project supply. The 1960s and 1970s were characterized by inflows typically ranging between 400,000 AF and 1,000,000 AF, and reservoir releases fluctuated accordingly between full and partial. The late 1970s ushered in prolonged period of above normal inflows and full water supply conditions for the Project that lasted until the early 2000s when drought again returned to the Rio Grande basin and Project deliveries plummeted. Since that time, Project storage has remained low and reservoir releases have been less than average.

The simulated annual allocations and charges to EBID and EPCWID during the 1940 - 2017 study period are summarized in **Figure 9-2.** These reflect allocations under the D1/D2 Procedure until 2005, the D3 Procedure without carryover in 2006 and 2007, and the D3 + Carryover Procedure thereafter. The full supply conditions during the 1940s and 1980s and 1990s are reflected in the full allocations to the districts during these years. The fluctuations in allocations during the 1950s - 1970s are also evident.

When the recent extended drought commenced in the early 2000s, the allocations to EBID and EPCWID declined together as provided for under the D1/D2 procedure. This changed when the D3 accounting was implemented with the allocations to EBID generally dropping in comparison to the EPCWID allocations which continued to be determined under the D1/D2 methodology. The carryover accounting under the 2008 OA is evident in the simulated EPCWID allocations during the late 2000s that were greater than any time prior.

9.3.2 EBID Operations

Figure 9-3 summarizes the simulated historical diversions, FHG deliveries, pumping, and conveyance losses for EBID. The simulated EBID diversions and FHG deliveries were greatest during the full supply periods of the 1940s, 1980s, and 1990s. Diversions were low during the multi-year droughts of the mid-1950s and 2010s, and during shorter term dry periods in the 1960s, 1970s, and 2000s. Adoption of the 2008 OA also contributed to the relatively low diversions after 2007.

The simulated pumping was generally inversely proportional to the FHG deliveries with low pumping in full supply years and high pumping in low supply years. Simulated annual pumping during recent dry years has ranged between about 200,000 AF and 300,000 AF, which is similar to the simulated annual pumping during the dry years of the 1950s, 1960s, and 1970s.

9.3.3 EPCWID Operations

Figure 9-4 summarizes the simulated historical diversions, FHG deliveries, pumping, and conveyance losses for EPCWID. Similar to EBID, the EPCWID diversions were high during the full supply years of the 1940, 1980s, and 1990s, and low during the non-full supply years of the 1950s, 1960s, 1970s, and during the recent extended drought that began in the early 2000s. The simulated EPCWID diversions did not decline as much as the EBID diversions after 2007 because the 2008 OA allocates water first to EPCWID at the expense of the allocations to EBID.

The simulated annual pumping by EPCWID was greatest during dry years between 1950 and 1980 reaching as much as 154,000 AF. Because of the reduction in irrigated area and enactment of the 2008 OA, simulated annual irrigation pumping in EPCWID during the recent drought topped out at about 70,000 AF. The modeling shows little unmet irrigation water demand after considering the available surface water supply during the 1980s and 1990s and therefore little simulated supplemental pumping.

9.3.4 Hudspeth Operations

Figure 9-5 summarizes the simulated historical diversions, FHG deliveries, pumping, and conveyance losses for HCCRD. Because HCCRD relies on waste from EPCWID, the pattern of its supply generally mirrors the supply of EPCWID, rising in wet years and falling in dry years. Most of the simulated supplemental pumping to meet unmet demand occurred prior to 1980, with the simulated maximum annual pumping of 32,000 AF in 1954. The simulated surface water supply after 1980 was generally adequate to meet irrigation demands without supplemental pumping.

9.3.5 Juarez Operations

Figure 9-6 summarizes the simulated historical diversions, FHG deliveries, pumping, and conveyance losses for Juarez. Pursuant to the 1906 Treaty, 60,000 AF are delivered to the headgate of the Acequia Madre in full supply years. Deliveries to Juarez are reduced in non-full supply years in proportion to the reduction in deliveries to the districts. The simulated farm headgate deliveries have steadily increased since 1980 due to simulated increases in wastewater discharges to the Acequia Madre and increased use of irrigation return flows. However, because of gradual increases in irrigated area through time, the annual supplemental pumping has generally fluctuated between 50,000 AF and 100,000 AF during most years since ground water use became widespread in the early 1950s.

9.3.6 River Flows

Annual water budget summaries of river inflows and outflows are shown in **Figure 9-7** for Rincon and Mesilla basins upstream of El Paso and in **Figure 9-8** for the El Paso Valley down to Ft. Quitman. The stacked positive bars represent inflows to the river and the stacked negative bars represent outflows from the river. The black line represents the net difference between the sum of the inflow bars and the sum of the outflow bars. The black line also is equal the difference between the Rio Grande inflows entering the top of the reach and the Rio Grande outflows existing the bottom of the reach, which are not shown on the graph.

In the Caballo to El Paso reach, the largest inflows are wastewater and drain returns. The primary outflows are canal diversion. The simulated annual river seepage is positive during the wet periods of the 1940s and 1990s indicating that the river is gaining flow from the ground water system. During most of the remainder of the simulation period the river seepage is negative indicating the river is losing water to the ground water system. Within each year, the river gains and losses vary monthly and seasonally.

In the El Paso to Ft. Quitman reach, the largest inflows are wasteway returns (mostly discharges from the American Canal below International Dam that are rediverted at the Riverside Canal prior to construction of the American Canal Extension in 1999). The next largest inflows are the canal returns at the lower end of the HCCRD. Other relatively minor inflows are drain returns and wastewater treatment plant discharges. The largest outflows are the canal diversions at American Dam and at the Riverside Dam when it was in operation. The other outflow is the net river seepage from the river to the ground water system.

Figure 9-9 summarizes the annual flow at different points between Caballo Reservoir and Ft. Quitman. The difference in reservoir releases between wet years and dry years is evident in the point flow charts. The point flows generally decrease in the downstream direction as water is diverted for irrigation. There is a characteristic increase in flows downstream of the Mesilla Dam that represent the simulated flows of the La Mesa Drain and other drains in the area. River flows are typically depleted to at or near zero below International Dam followed by an increase in flow as water was discharged from American Dam back to the Rio Grande to deliver water for diversion at Riverside Dam until completion of the American Canal Extension in 1999. Some increase in flow at the County Line and at Ft. Quitman is also evident in many years as the river is replenished by irrigation return flows.

A different depiction of the historical river flows is provided in the monthly flow maps **Figure 9-10** that show the simulated monthly average flow in cubic feet per second at various locations between Caballo Reservoir and Ft. Quitman. The flows are color coded in ranges to aid in interpretation ranging from dark blue for flows greater than 500 cfs through lighter shades of blue then green and finally white flow flows less than 10 cfs. The characteristic pattern of flows is for large releases from Caballo during the irrigation season and these flows are gradually depleted to zero at some point downstream, typically at American Dam and/or International Dam. The flows are modestly restored in the downstream reaches down to Ft. Quitman. During the non-irrigation season, there are no simulated releases from Caballo, the simulated flows increase through return flows in varying amounts depending on whether conditions are relatively wet or relatively dry.

10.0 ALTERNATIVE RUNS OF INTEGRATED LRG MODEL

10.1 Introduction

The ILRG Model was used to simulate alternative scenarios in response to certain of the Texas claims and to support certain of the New Mexico counterclaims. All alternative scenarios were simulated with the tuned version of the ILRG Model that was used to produce the Historical Base Run described in Section 9. The simulated alternative scenarios fall into two categories as follows:

- No-Pumping Scenarios – Most of the alternative scenarios involved turning off pumping in certain geographic areas or turning off certain types of pumping.
- Operations Scenarios – Other alternative scenarios involved simulation of changes in certain rules for Project operations or irrigation operations.

A list of the model runs that were performed for this report is provided in **Table 10-1**. The no-pumping scenario runs are described in Section 10.2 and the operations scenario runs are described in Section 10.3.

10.2 No-Pumping Scenarios

The purpose of simulating no-pumping scenarios was to evaluate the effects that pumping in New Mexico, Texas, and Mexico has on Project operations and deliveries of Project water. The no-pumping scenarios were simulated by running the ILRG Model with changes in rules or input data depending on the type of pumping that was turned off. For irrigation pumping, the RiverWare Model rule that computes pumping based on the unmet crop irrigation demand is switched off. Reductions in surface runoff and deep percolation return flows that result from turning off the irrigation pumping are simulated as part of the farm budget algorithm in the RiverWare Model.

As previously described, non-irrigation pumping and the corresponding WWTP returns and urban deep percolation returns are simulated in the ILRG Model based on external input of data to the model. Therefore, turning off non-irrigation pumping requires modifying these model inputs to set the pumping and corresponding return flows to zero.

After modifying the irrigation pumping switch and/or the non-irrigation pumping and return flow input data sets, the ILRG Model is executed using the same iterative procedure involving alternating runs of the RiverWare Model and the ground water models until closure is reached (typically 3 to 4 iterations). Turning off pumping results in increased in ground water levels, increased drain flows, and reduced river seepage. This in turn causes the RiverWare Model to adjust Project water allocations, reservoir releases, canal diversions, and FHG deliveries to adjust to the change in water supply. The simulated changes in water supply and system responses ripple spatially and temporally through the model linkages.

Output data from the alternative scenario run are tabulated and compared to the results from the Historical Base Run or another run to quantify what changed between the runs.

Appendix 10A contains two tables and one figure that compare results from each no-pumping run to the Historical Base Run for the period from 1985 - 2016. This period was selected for summarizing the results of the no-pumping runs because it is the period for which Texas is claiming damages from New Mexico pumping. The following is an explanation the summary tables and figure in **Appendix 10A** for the All Pumping Off run (Run 2) (**Table 10A-2a**, **Table 10-A2b**, and **Figure 10A-2**). These explanations are also applicable to the summary tables and figure for the other no-pumping runs summarized in **Appendix 10A**.

Table 10A-2a tabulates average annual differences in certain model inputs and outputs during the 1985 - 2016 period. The first several rows tabulate the "Change in Pumping Stress" which summarizes the differences in model inputs between the no-pumping run and the Historical Base Run. The change in pumping stress consists of the irrigation pumping and/or net non-irrigation pumping (total non-irrigation pumping minus corresponding WWTP returns and urban deep percolation returns) that are turned off.

The remaining rows in **Table 10A-2a** under "Effects of Change in Pumping Stress" show the simulated effects of the changes in input stresses on the following model outputs:

- Farm Headgate Deliveries (Mar-Oct)
- Farm Headgate Deliveries (Nov-Feb)
- Irrigation Pumping
- Reservoir Evaporation
- Riparian ET
- River Evaporation and Incidental Canal Loss
- Rio Grande at Ft. Quitman Flows

- Changes in Storage (Reservoir, Ground Water, Soil Moisture)
- Sum of the above effects.

The first two columns in **Table 10A-2a** summarize annual averages for the Historical Base Run and the All Pumping Off Run, respectively. The third column presents the annual average differences between the two runs. The last two columns show percentage changes computed in two different ways; the first computes the differences between the model runs as a percentage of the simulated change in stress, and the second computes the percentage change of each quantity from the average in the Historical Base Run. The sum of the annual changes does not equal the total change in the simulated stress because certain of the model outputs are not independent quantities (e.g., pumping and FHG deliveries).

The results summarized in **Table 10A-2a** generally illustrate how the model simulates the real-world response of the Project operation and LRG Area irrigation systems to the changes in water supply that would have resulted if the historical pumping had not occurred. These responses are described in more detail below for certain of the no-pumping runs.

Note that for discussion purposes, the results of the no-pumping runs are described in terms of the effect of turning off pumping and the resulting increases in various simulated quantities (e.g., Project water deliveries, reservoir storage, ground water storage, Rio Grande flows, etc.) However, by changing the algebraic sign, the results can also be interpreted as the effects of pumping on the simulated results.

Table 10A-2b presents the change in each year from 1985 - 2016 for certain of the model outputs that are summarized in **Table 10A-2**. Specifically, the annual outputs summarized in **Table 10A-2** include changes in farm headgate deliveries, reservoir evaporation, riparian ET, river evaporation plus incidental canal loss, Rio Grande flows at El Paso and Ft. Quitman.

Figure 10A-2 contains bar charts showing the simulated change in FHG deliveries to EBID, EPCWID (including deliveries to EPW), and HCCRD. The blue bars illustrate the change in FHG deliveries during March - October and the orange bars show the change in FHG deliveries during November - February.

10.2.1 No New Mexico Pumping Scenario (Run 3)

In response to the analyses of impacts of New Mexico pumping described in the Texas expert reports, the No New Mexico Pumping Scenario was simulated with the ILRG Model to analyze the Project operations that would occur in the absence of New Mexico pumping, including the re-operation of the Project that would occur with the changes in drain flows, and river gains and losses without pumping. The results described in this section show that the simulated effects of New Mexico pumping on deliveries to Texas water users are far less than the impacts computed by the Texas experts.

In the No New Mexico Pumping Scenario, the RiverWare Model rule that simulates irrigation pumping to meet the unmet monthly irrigation demand that remains after the simulated use of surface water and soil moisture is switched off. This results in simulated irrigation shortages in EBID during all years. The magnitude of the shortage varies depending on the Project supply. In wet years with full allocations, the shortages to Project lands are relatively small, while in dry years with low allocations, the shortages are substantial.

The simulated effects of turning off New Mexico pumping in the ILRG Model during the 1985 - 2016 study period are summarized in in **Table 10A-3a**, **Table 10A-3b**, and **Figure 10A-3** in **Appendix 10A**.

The average annual effects of turning off New Mexico pumping on river flows, diversions, storage, and other simulated processes are summarized in **Table 10A-3** for 1985 - 2016 period. The simulated effect of turning off irrigation and non-irrigation pumping in New Mexico results in year-round increases in drain flows, and reductions in river losses and/or increases in river gains. These changes in flow in turn result in changes in reservoir operations and deliveries of Project water depending largely on the simulated allocation of Project water. In full allocation years there is relatively little change in FHG deliveries while in non-full allocation years there are much larger changes. The simulated effects on reservoir operations from pumping include (a) increases in reservoir evaporation, (b) increases in allocations in non-full supply years, and (c) increases in spills.

The increased river flows without New Mexico pumping that would either increase Project water deliveries in the current year or would be carried over in Project storage and allocated and delivered in subsequent years both show up in the simulations as impacts to the Project supply delivered to both New Mexico and Texas. This is reflected in the results in **Table 10A-3a** that show that New Mexico pumping impacts on March - October FHG deliveries average 26,200 AF/y to EBID and 8,200 AF/y to EPCWID.

Without New Mexico pumping, there would be increased reservoir evaporation due to the reduction in reservoir releases necessary to make deliveries to Project water users, increased river and canal evaporation due to the general increase in the surface water supply, and more riparian evapotranspiration due to increased ground water levels. Together, these effects would have averaged 11,600 AF/y during 1985 - 2016, or approximately 8% percent of the net pumping stress. This can be characterized as the salvage effect of New Mexico pumping.

Turning off pumping in New Mexico would also increase the flow of the Rio Grande at Ft. Quitman. The simulated increase in annual Ft. Quitman flows averaged 66,600 AF during the 1985 - 2016 period and is comprised of increased spills from Project storage, increased winter flows, and return flows from the additional Project water deliveries to EPCWID, HCCRD, and JID.

Finally, the ILRG Model shows that if there had been no New Mexico pumping then alluvial ground water storage would have increased by an average of 10,500 AF/y and non-alluvial ground water storage would have increased by an average of 12,100 AF/y over the 1985 - 2016 period.

The annual volumes of impacts from New Mexico pumping that correspond to the averages in **Table 10A-3a** are presented in **Table 10A-3b**. The impacts on seasonal and annual FHG deliveries to EBID, EPCWID, and HCCRD are summarized in **Figure 10A-3**.

Additional comparisons of the model outputs for the Historical Base Run and the No New Mexico Pumping Scenario are provided in **Appendix 10B** for the entire 1940 - 2017 study period to illustrate the ILRG Model responses to turning off New Mexico pumping. Comparisons of annual storage and Rio Grande flows are shown in **Figure 10B-1**. Comparisons of annual diversions, FHG deliveries, pumping, and conveyance losses are presented in **Figure 10B-2** for EBID, **Figure 10B-3** for EPCWID, and **Figure 10B-5** for HCCRD. The results in these figures illustrate that diversions by EBID and EPCWID are not appreciably different with or without pumping in full supply years. The impacts of pumping are concentrated in the non-full supply years with additional diversions and deliveries of water in the no-pumping run to EBID, EPCWID, and HCCRD.

More detailed depictions of the simulated Project storage, river flows, and deliveries or Project water are presented in **Figure 10B-5** through **Figure 10B-17**. These figures compare the simulated monthly volumes from the Historical Base Run (black line) and No New Mexico Pumping Scenario (orange line). In these figures, the differences in Project operations during full supply years and non-full supply years are evident. In addition, the differences in flows during the irrigation and non-irrigation seasons are also evident.

The results of the No New Mexico Pumping Scenario show that the effects of New Mexico pumping on deliveries to Texas water users are much smaller than computed in the analyses performed by the Texas experts. The summary results in **Appendix 10A** and more detailed results in **Appendix 10B** show that the ILRG Model simulates reasonable and appropriate responses that would result from turning off New Mexico pumping that reflect the real-world response of Project operations to changes in water supply.

Additional comparisons of the ILRG Model results for the No New Mexico Pumping run to the results in the Texas expert reports are provided in Section 13 and Section 14.

10.2.2 No Texas Pumping Scenarios (Runs 4, 7, 8)

Several runs were made of the ILRG Model to evaluate the effect of pumping in Texas on Project operation and the surface water supplies of the LRG water users. The results from these simulations show that pumping in Texas also impacts Project operations and deliveries of Project water to EBID and EPCWID, particularly in non-full supply years.

The No Texas Pumping Scenarios were simulated in the same manner as the No New Mexico Pumping Scenario. Turned off in the No Texas Pumping Scenarios were all or a portion of the supplemental irrigation pumping, and all or a portion of the non-irrigation pumping and the associated WWTP and urban deep percolation return flows. The following are specifications and summaries of the results of the No Texas Pumping Scenarios.

All Texas Pumping Off (Run 4) – In this scenario, all supplemental irrigation pumping and non-irrigation pumping in the Texas portion of the Mesilla basin and the El Paso Valley was turned off. In addition, the urban return flows from the non-irrigation pumping were also turned off, including WWTP discharges and urban deep percolation. On average over the period from 1985 - 2016, 20,500 AF/y of irrigation pumping, 88,900 AF/y of non-irrigation pumping, and 45,600 AF/y of urban return flows were turned off. This was a net change in pumping stress of 63,800 AF/y. The results from the All Texas Pumping Off run are summarized in **Table 10A-4a**, **Table 10A-4b**, and **Figure 10A-4** in **Appendix 10A**. If Texas had not pumped ground water, the EBID farm deliveries during 1985 - 2016 would have increased by an average of 5,100 AF/y with a maximum annual increase of 32,500 AF in 2009. Without Texas pumping, EPCWID and Hudspeth diversions and FHG deliveries would increase in some years and decrease in other years. The reason for the decreases is due to the impacts of pumping on surface flows sometimes being less than the changes in irrigation and non-irrigation return flows. On average, the greatest effect of no Texas pumping would be an increase in ground water storage averaging 49,300 AF/y over the 1985 - 2016 period.

- Texas Mesilla Pumping Off (Run 7) – In this run, all supplemental irrigation pumping and non-irrigation pumping in the Texas portion of the Mesilla basin (including EPW's Canutillo wells) was turned off. On average over the period from 1985 - 2016, the net change in pumping stress averaged 13,800 AF/y and was comprised of an average of 2,800 AF/y of irrigation pumping, 24,100 AF/y of non-irrigation pumping less 13,200 AF/y of urban return flows. The results of this run are summarized in **Table 10A-7a**, **Table 10-7b**, and **Figure 10-7** in **Appendix 10A**.

- Texas Non-irrigation Pumping Off (Run 8) – In this run, all Texas non-irrigation pumping and associated urban return flows were turned off. On average over the period from 1985 - 2016, the net change in pumping stress totaled 43,300 AF/y and was comprised of an average of 88,900 AF/y of non-irrigation pumping less 45,600 AF/y of urban return flows. The results of this run are summarized in **Table 10A-8a**, **Table 10A-8b**, and **Figure 10A-8** in **Appendix 10A**.

10.2.3 No Mexico Pumping Scenario (Runs 5)

In this scenario, all supplemental pumping in JID and all municipal pumping and associated WWTP discharges in Ciudad Juarez were turned off. On average over the period from 1985 - 2016, 59,200 AF/y of irrigation pumping, 115,000 AF/y of municipal pumping, and 57,300 AF/y of WWTP discharges were turned off. The results of these runs are summarized in **Table 10A-5a**, **Table 10A-5b**, and **Figure 10A-5** in **Appendix 10A**. The maximum annual impacts of Mexico pumping on FHG deliveries were 3,900 AF to EBID, 3,400 AF to EPCWID, and 9,400 AF to HCCRD. Mexico pumping had an average annual impact on ground water storage of 89,200 AF/y during 1985 - 2016.

10.2.4 No Rincon-Mesilla Pumping Scenario (Runs 6)

A run of the ILRG Model was made to evaluate the effect of turning off all irrigation and non-irrigation pumping in the Rincon basin and Mesilla basin in New Mexico and in the Texas portion of the Mesilla basin. The purpose of this run was to simulate a scenario that was directly comparable to 100% reduced pumping run of Texas Model described in the Hutchison Report. In this scenario, all irrigation pumping and all non-irrigation pumping and urban return flows in the Rincon and Mesilla basins were turned off. This included pumping of the Canutillo wellfield (EPW) and the Conejos-Medanos wellfield (Juarez). On average over the period from 1985 - 2016, 125,800 AF/y of irrigation pumping, 64,900 AF/y of non-irrigation pumping, and 28,100 AF/y of urban return flows were turned off. The results of these runs are summarized in **Table 10A-6a**, **Table 10A-6b**, and **Figure 10-6** in **Appendix 10A**. Without pumping in the Rincon and Mesilla basins, EBID farm deliveries during 1985-2017 would have increased by an average of 30,400 AF/y with the greatest increases being 109,400 AF in 2010. Additional discussion of the No Rincon-Mesilla Pumping scenario is provided in Section 14.

10.3 Operational Scenarios

Three alternative operating scenarios were simulated using the ILRG Model. Two runs were made to evaluate the impacts of the 2008 OA on Project operations. The other run was made to assess the effects on the Project from excess operational waste.

10.3.1 2008 Operating Agreement Scenarios (Runs 11 and 12)

Two runs of the ILRG Model were made to evaluate the effect of the D3+Carryover accounting in the 2008 OA on Project operations and LRG water supplies. In Run 11, the D1/D2 allocation procedure was simulated to allocate Project water during the entire period from 1948 - 2017 period, and in Run 12 the D3+Carryover accounting was simulated during this 70-year period[6]. Otherwise, both runs utilized the same RiverWare Model simulation rules as in the Historical Base Run. Irrigation pumping was simulated based on the unmet irrigation demand and the non-irrigation pumping and associated return flows were set at historical levels.

The simulated effects of the D3+Carryover accounting from the 2008 OA are illustrated by the simulated differences in the ILRG Model outputs computed as the Run 12 minus Run 11 during the 1948 - 2017 period. The differences between these runs are summarized in **Table 10A-12** in **Appendix 10A** and in **Table 10B-12** in **Appendix 10B**. The impact of the simulated impact of the 2008 OA was to reduce EBID farm deliveries by an average of 42,100 AF/y during 1948 - 2017 and increase EPCWID deliveries by an average of 16,100 AF/y during the same period. The annual results summarized in **Table 10B-12** show that the effect of the 2008 OA on EBID FHG deliveries varies significantly depending on the hydrologic state of the basin. The following is a summary of the average annual effect on EBID and EPCWID FHG deliveries in three intervals of the 1948-2017 period.

Average Effect of 2008 Operating Agreement on March - October FHG Deliveries In Wet and Dry Periods

Period	Wet/Dry	EBID	EPCWID
1948 - 1985	Dry	-68,700	13,400
1986 - 2000	Wet	56,900	23,300
2001 - 2017	Dry	-70,000	15,600
1948 - 2017	All Years	-42,100	16,100

In the two historical dry periods with a relatively low diversion ratios (55 years), annual EBID FHG deliveries are substantially reduced by an average of approximately 68,700 AF while in the wet period from 1986-2000 (15 years) with a relatively high diversion ratios, annual EBID FHG deliveries increased by an average 56,900 AF. The effect of the 2008 OA

[6] As described in Section 8.2.1, the RiverWare rules do not simulate annual allocations during the wet period from 1940 – 1947.

on EPCWID is more consistent with increased FHG deliveries in most years with an average annual increase of 16,100 AF.

10.3.2 Reduced Waste Scenario (Run 13)

As discussed in Section 5, beginning with the 1950s drought and continuing through the 1970s, Reclamation was able to operate the Project with operational waste below 10% during most years. In a few years during the wet periods of the mid-1980s and mid-1990s, the EBID waste increased to approximately 20%. The situation in EPCWID was markedly different than in EBID from the 1980s through the 2000s (after EPCWID took over operations) with the operational waste consistently in the range of 20% to 30%.

A run of the ILRG Model was made to evaluate the benefit to the Project from reducing the operational waste. The RiverWare operational rules were modified so that the operational waste was limited to the lesser of the historical amounts or 10% of the simulated diversions. The differences between this run and the Historical Base Run are summarized in **Table 10A-13** in **Appendix 10A** The results show that reducing excess operational waste would have resulted in increases in annual Project water deliveries during 1985 - 2016 averaging 28,600 AF to EBID and 12,700 AF to EPCWID.

11.0 RESPONSE TO BRANDES REPORT

Robert J. Brandes, Ph.D., P.E. prepared a May 31, 2019 expert report on behalf of the State of Texas ("Brandes Report"). The subjects of the Brandes Report generally included the following:

- New Mexico Ground Water Development
- Historical Changes in Rio Grande Flows
- Project Operations
- Effect of Ground Water Pumping on Project Deliveries

SWE was asked by legal counsel for New Mexico to review the Brandes Report to identify information or opinions with which we disagreed, and to prepare expert opinions to respond to these issues. We attempted to identify and respond to all substantive issues in which there appeared to be differences of opinion, however a lack of response to a particular issue should not be interpreted as tacit agreement with Dr. Brandes' opinion(s).

Brandes Opinion 1 – *Extensive ground water development in the Rincon and Mesilla basins of New Mexico that began in the 1950s has depleted drain flows and river flows, and this has altered the Project water budget by reducing flows in the Rio Grande that would reach water users in Texas. (Page 10 paragraph 1).*

Response:

The conceptual discussion of the impacts of pumping on Texas water users in Section 4 implies that New Mexico pumping has caused continuous and unrelenting impacts on Texas water users since the early 1950s. The discussion exaggerates the impacts for the following reasons:

1. Pumping in New Mexico varied substantially since it developed in the early 1950s with higher pumping amounts in low Project supply years and lower pumping amounts in full supply years.
2. In full supply years, Reclamation delivered all water ordered by EPCWID and EBID up to their total allocations. To the extent there were varying Project delivery efficiencies (i.e., diversion ratio), Reclamation could adjust releases from storage to deliver the water that was ordered. Therefore, there would not be shortages of delivered water to EPCWID as a result of New Mexico (or Texas) pumping on Project water deliveries in full supply years.

3. There were full supply years from 1979 through 2002, and Dr. Brandes ignores the full deliveries to Texas during all of these years.
4. Additionally, if ground water pumping caused any reductions in the diversion ratio within the Project areas, this would apply to New Mexico, Texas, and Mexico pumping. Dr. Brandes ignores the impacts of Texas and Mexico pumping on Project operations.
5. Dr. Brandes also ignores that Reclamation operated the Project releases and deliveries, encouraged conjunctive use of ground water by all Project participants to meet the full irrigation demands from 1951 - 1978, and then formalized the needed conjunctive use of surface water and ground water by implementing the D1/D2 allocation procedure in 1980 and operating thereunder until major changes in the operating procedures were initiated in 2006 and then adopted in the 2008 OA. Instead, Dr. Brandes blames all changes in Project water deliveries and Rio Grande flows on New Mexico pumping.
6. The foregoing criticisms apply to all of the analyses of historical river flows, drain flows, and Project water deliveries that are presented in the Brandes Report.

Brandes Opinion 2 – *The estimated annual withdrawals for irrigation in the Rincon and Mesilla basins since 1940 are presented on the bar chart in Figure 4.3. As shown by the bars on the chart in Figure 4.3, annual groundwater withdrawals for irrigation has varied considerably, likely in response to wet/dry conditions, and the annual volume of groundwater pumpage for irrigation was substantial even in the early 1950s, indicating that the groundwater well pumping capacity, and likely the total number of irrigation wells, at that time were significant. The demands for additional supplies of irrigation water during the severe drought of the 1950s and during other dry periods, particularly in the mid-2000s and after 2010, are illustrated by the higher levels of groundwater withdrawals on the chart. (Page 11 paragraph 2).*

Response:

The ground water withdrawals for irrigation in Figure 4.3 in the Brandes Report include a significant amount of pumping in the Texas portion of the Mesilla basin. Since roughly 10% of the total Project irrigated area in the Mesilla basin is in Texas, it is reasonable to assume that roughly 10% of the estimated Mesilla basin irrigation pumping in Figure 4.3 would also be in Texas.

The high pumping in the early 1950s is unrealistic given that significant irrigation well development began in New Mexico in the late 1940s and was not complete until about 1955. The pumping estimates shown in Figure 4.3 indicate that almost all of the pumping capacity developed in a single year, with pumping increased from about 10,000 AF in 1950 to about 200,000 AF in 1951. It is unrealistic to assume that all of the irrigation wells would have been constructed in a single year.

As described in the responses to the M&A Report, the total irrigation water demands are overstated because the crop irrigation water requirements are too high beginning in the mid-1980s. Since the irrigation pumping is estimated based on the unmet irrigation demand, this leads to the irrigation pumping also being overstated.

The estimated irrigation pumping during the full supply years of the 1980s and early 1990s averaging nearly 100,000 AF/y is unrealistically high given the full allocation of surface water during those years.

Brandes Opinion 3 *–The plot in Figure 4.5 shows the total combined groundwater withdrawals for both irrigation and urban uses in the Rincon and Mesilla basins [5]. As indicated, since 1950, the total annual groundwater withdrawals consistently have been above 100,000 AF per year, with peak pumpage in recent dry years in the range of 300,000 to over 400,000 AF. (Page 12 paragraph 2).*

Response:

A substantial portion the annual pumping in Figure 4.5 of the Brandes Report is from irrigation wells in the Texas portion of the Mesilla Valley, from EPW's Canutillo wellfield, and from the Juarez Conejos-Medanos wellfield. Pumping from these non-New Mexico wells contributes to the depletions of Rio Grande flow for which Texas is claiming damages. **Figure 11-1** disaggregates the Texas estimates of the total annual pumping in the Rincon and Mesilla basins between the amounts from wells in New Mexico, Texas, and Mexico.

Brandes Opinion 4 *– A report by an unknown author reportedly prepared in 1982 is cited as evidence of the following impacts from ground water development in the Rincon and Mesilla basins:*

> *This groundwater development has changed the flow regime established prior to 1951 such that a greater release is required from Elephant Butte Reservoir to achieve the same flow at El Paso. This new trend, which was established after the end of the drought of the 1950's, has continued to the present (1982).*
>
> *In conclusion, all four figures used in this analysis show that the effects of the groundwater development below Elephant Butte Dam induced by the drought of the 1950's have significantly affected the amount of water reaching El Paso. The*

new relationship is well defined and has been continuous to the present (1982). (Page 14 paragraph 2 and 4).

Response:

The reliability of conclusions from a 1982 report by an unknown author with unknown affiliation using unsourced data is questionable. Dr. Brandes presents analyses similar to those in his report, and my responses are therefore focused on review of his analyses.

Brandes Opinion 5 *– A 1986 report by Tipton and Kalmbach prepared for the IBWC is described and the following conclusions are cited from the report*

1) Depletions of the Rio Grande upstream of the El Paso Narrows have increased. The annual depletions from 1922 through 1950 averaged 237,000 acre-feet per year, from 1951 through 1984 averaged 260,000 acre-feet per year, and from 1980 through 1984 averaged 305,000 acre-feet per year.

5) The use of wells in the Rincon Valley and Mesilla Basin for supplemental irrigation water and for municipal, industrial, and domestic uses since 1951 is the principal cause for the increased depletion upstream of the El Paso Narrows. (Page 15 paragraph 1 and 2).

Response:

The Rio Grande depletions upstream of the El Paso Narrows were reportedly computed as the annual flow at El Paso minus the releases from Project storage. Based on this calculation, the 1986 report concluded that annual Rio Grande depletions increased by an average of 23,000 AF/y after 1950 based on comparison of average depletions during 1922 - 1950 (237,000 AF/y) to average depletions during 1951 - 1984 (260,000 AF)/y).

The 1986 report does not describe the specific sources for the data that were used in the analyses described in the report. Also, the attachments to the report that are the basis for some of the conclusions in the report were not provided. This makes it difficult to review and assess the validity of the report analyses and conclusions.

The report text indicates that the releases from Project storage were a combination of releases from Elephant Reservoir and releases from Caballo Reservoir. Since Caballo Reservoir began operating in 1938, it is assumed that Elephant Butte Reservoir releases were used before 1938. As described previously in Section 5, on average, there was an average gain of about 20,000 AF/y between the Elephant Butte Reservoir outlet and the approximately location of the Caballo Reservoir outlet between 1930 and 1938. Therefore, depletions computed from Elephant Butte Reservoir releases would be expected to be lower than depletions computed from Caballo Reservoir releases before 1938. Using Elephant Butte Reservoir releases for more than half of the 1922 - 1950 period would have depressed the average computed depletions during this period. Comparison of this figure to average depletions after 1950 that are computed entirely based on Caballo Reservoir releases would result in misleading conclusion about differences in average depletions before and after 1950.

As described in Section 5, average depletions from the Caballo Reservoir outlet (or Percha Dam prior to 1938) to El Paso remained relatively steady from the 1930s through the 1970s at about 250,000 AF, increased to around 300,000 AF during the 1990s, and fell back to around 250,000 during the last decade. Therefore, any conclusions about long term persistent trends in depletions are not supported by the available data.

Brandes Opinion 6 *– A 1997 report by a hydrologic task committee appointed by a New Mexico District Court is described and the following conclusion from the report is cited as evidence that ground water pumping causes depletions to Rio Grande flows.*

> *Well withdrawals in the LRGB have been derived partly from stored groundwater, partly from surface-water depletion and partly from capture of evapotranspiration. The fraction derived from the surface water grows through time. The historical portion of well withdrawal from surface-water depletion is estimated to be between 80 and 90 percent. Specific wells may derive water from appreciable different proportions of each source. (Page 15 paragraph 6).*

Response:

The 1997 report describes a ground water model that was developed and used for analysis of basic effects of ground water pumping.

> *Various pumping scenarios were examined using a ground water model to illustrate basic hydrologic relationships. The ground water modeling results are dependent on a number of simplifying assumptions and do not simulate the historical development within the LRGB.*

The 1997 report indicates that the model was used to simulate the effect of pumping of a hypothetical well at a rate of 500 gallons per minute ("gpm") at various locations in the basin and distances from the river and at various depths to assess the effect that well location had pumping impacts to (a) ground water storage, (b) river flow, and (c) capture of evapotranspiration (of native vegetation). The report concluded that the location and depth of the well had a significant impact on how much the simulated pumping depleted the river.

Support for the reported conclusion that between 80% and 90% of historical well withdrawals come from surface water depletions was not found in the 1997 report. The results of various model runs in Appendix A of the 1997 report show substantially more variability in the amount of pumping that is derived from the stream after 100 years of pumping (42% - 93%).

Details about the ground water model construction were not provided in the 1997 report and it is unclear whether the model was calibrated. The report includes the following caveats regarding the model results:

> *Although the work presented in this report is based on the most recent technical information available, it should not be considered as a definitive description of the hydrogeologic system or its response to stresses.*
>
> *A cautionary note is in order. Model simulations quantify the impacts of pumping in the LRGB, but are affected by the way that a model is constructed. The simulations are also affected by the assumptions made regarding hydrologic relationships. If an accurate quantification of the effects of ground-water withdrawals is desirable, the key hydrogeologic relationships that are assumed in any model should be subjected to scrutiny and verification.*

Based on stated purpose of the 1997 modeling work, the simplified nature of the model runs, and the caveats regarding the model results, the report conclusions should be interpreted as preliminary, approximate, and conceptual. The NMR-M Model is far more sophisticated and evolved than the relatively simple model described in the 1997 Report. There is no point in relying on results from a model developed over 20 years ago when more capable tools, like the NMR-M Model and the ILRG Model, are available today.

Brandes Opinion 7 *– Dr. Brandes summarizes a 2008 presentation by Gary Esslinger, manager of the EBID concerning the 2008 Operating Agreement. Esslinger explained the development of the D1/D2 Curves that were used to allocate Project water from 1979 - 2007, and which continue to be used to allocate water to Texas and Mexico under the 2008 Operating Agreement, allowed groundwater pumping in New Mexico to be grandfathered at the 1951-1978 levels that are embedded in the D1/D2 Curves. (Page 16 paragraph 5)*

Response:

Figure 4.6 in the Brandes Report illustrates the annual reservoir release and diversion data for 1951 - 1978 (red dots) that were used to develop the D2 Curve (red line). The D2 line is the best fit straight line through the 1951 - 1978 data that are generally scattered above and below the line. More recent data are shown in the plot for two periods from 2003 - 2007 (before full implementation of the 2008 OA) and for 2008 - 2017 (after the 2008 OA). The recent data in Figure 4.6 are charged diversions during Project releases from storage as compared to the 1951 - 1978 data used to develop the D2 Curve which are total annual diversions and include diversions outside of the Project release period. As a result, recent data are biased low compared to the 1951-1978 data.

Additionally, as to the 2003 - 2007 data, all years except 2005 are within the scatter range of the D2 Curve data and therefore do not exhibit unusually low deliveries. Lastly, during the 2008 - 2017 period, Texas received annual allocations based on the 2008 OA procedure, and therefore any deviation in Project performance below the D2 line was fully shouldered by New Mexico under the D3 allocation procedure. During the 2008 - 2017 period, Texas was also able to carry over significant amounts of water, resulting in Texas's annual allocation far exceeding its historical 43% share, and forcing more ground water pumping New Mexico, for which Brandes seeks to blame New Mexico.

Brandes Opinion 8 *– Figure 5.2 is a plot of cumulative releases from Caballo Reservoir (or from Elephant Butte before 1938) and cumulative Rio Grande flows at El Paso beginning in 1930 and extending through 2015. As shown, the cumulative curves for both the Caballo releases (red circles) and the El Paso Rio Grande flows (green squares) exhibit steeper segments reflecting higher flow conditions and also flatter segments indicating lower flow conditions. The effects of the high flows during the early 1940s and mid-1980s and the low flows of the early to mid-1950s are readily apparent in the two curves. Lower flow conditions also are indicated beginning around 2010, which is consistent with observed climatic and hydrologic conditions. Overall, the cumulative curve for the Rio Grande flows at El Paso generally shows a somewhat flatter trend after the 1950s, indicating less river water reached El Paso relative to what was released from Caballo. The early 1950s, of course, is when significant groundwater pumping for irrigation began in New Mexico. Flattening of the slope of the cumulative curve for the Rio Grande flows at El Paso beginning in the early 1950s is more likely than not indicative of the effects of lowered groundwater levels and increased losses from the Rio Grande and drainage ways that resulted from the development of significant groundwater pumping in the Rincon and Mesilla basins. (Page 19 paragraph 1).*

Response:

The historical flow of the Rio Grande at the El Paso gage is not relevant to this litigation because (a) it is not a point of compliance for the Compact, and (b) it is not a point of delivery for the Project. The Project was conceived and has been operated to provide equal delivery of water per acre of irrigated land. Until 1979, Reclamation was responsible for making water available for delivery to the users on an equal per acre basis. After the districts took over the internal distribution of water to the Project water users, Reclamation's obligation to deliver water was changed to the major canal headings with the idea that the district would perform the remainder of the water distribution that would continue equal delivery of water per acre. Since 1979, Reclamation has accounted for deliveries to EBID and EPCWID at canal headings and other points upstream and downstream the El Paso gage, but there continues to be no Project accounting at the El Paso gage.

The relative steep slopes of the reservoir releases (red circles) and El Paso flows (green squares) during the 1930s and 1940s reflects the generally above average water supply conditions that resulted in full Project supplies through that period and relatively high releases from storage. There were no annual water allocations set by Reclamation during the 1940s and 1950s and farmers ordered whatever water they thought they needed.

The general flattening of both curves after 1950 reflects the decline in average annual releases that occurred because the average water supply after 1950 was much lower than before 1950, despite the wet periods of the 1980s and 1990s. The following are comparison of the average reservoir releases before and after 1950:

Comparison of Average Annual Storage Releases (acre-feet)

Years	All Years	Excluding Spill Years
1930-1950	829,000	781,000
1951-2017	607,000	575,000

In addition, as shown in Figure 5.1 of the Brandes Report, the Project is generally more efficient in conveying flows released from the reservoir downstream to El Paso at higher flows. The flattening and slight divergence of the cumulative reservoir release and El Paso flow curves in Figure 5.2 after 1950 are consistent with reduced river efficiency that exists at lower flows.

Brandes Opinion 9 *– Dr. Brandes presents a plot of the cumulated annual flows of the Montoya Drain from 1938 - 1995 in Figure 5.3. As shown on the graph, the historical data exhibit a drastic change of slope beginning during the early 1950s and then continuing with a flatter slope through 1995. This flattening of the slope of the historical data compared to the straight-line extension of the pre-1950 data trend (red dashed line) indicates that the flow discharging from the drain was significantly reduced – by an average of approximately 39,000 acre-feet per year from 1951 through 1995. While some of this flow reduction may be attributed to improved irrigation efficiency, it more likely than not was due to the loss of groundwater inflows to the drain that resulted from the lowering of groundwater levels caused by irrigation pumping that began in the early 1950s. (Page 21 paragraph 2).*

Response:

It appears that the Montoya Drain data plotted by Dr. Brandes in Figure 5.3 were taken directly from the USBR reports. Detailed review of these reports showed that Reclamation was inconsistent in how it aggregated and reported the drain data. Beginning in 1934 (except for 1937) the flows of the West Drain and NeMexas Drain are included in the Montoya Drain records. Prior to 1934 and in 1937, these flows are not included in the Montoya Drain records, and the recorded flows for these two drains need to be added to the Montoya Drain records during these years to create a consistent historical record.

The reported flows of the Montoya Drain were much greater during the wet period before 1950 than during comparable wet and low pumping periods after 1950. As described above, projecting conditions during the wet period of 1938-1950 forward for comparison to conditions that existed during the drier period after 1950 may exaggerate the apparent deviation in flows. As to the pumping impacts, it should be noted that most of the Montoya Drain is located in Texas and therefore most of the pumping impacts to Montoya Drain flows are likely from Texas wells.

Further, as recognized by Dr. Brandes, there likely are other factors that contributed to the reduction in drain flows other than irrigation pumping. Dr. Brandes specifically mentions improvements in irrigation efficiency as one cause. Other potential causes are listed in the response to Brandes Opinion 10 below.

Brandes Opinion 10 *– A double-mass plot of the cumulative annual Rio Grande at El Paso flow versus the cumulative annual releases from Caballo Reservoir from 1930 - 2017 is presented in Figure 5.4 of the Brandes Report. The deviation of the historical flows curve after 1950 (blue triangles) from the extension of the curve before the 1950s (dashed red line) averages 78,667 acre-feet per year, which is equivalent to a total reduction in the flow of the Rio Grande at El Paso of about 5,000,000 acre-feet for the period from 1951 through 2017, excluding the flood years of 1986-1987 and 1995. Based on this demonstration, it is more likely than not that groundwater pumping in New Mexico within the Rincon and Mesilla basins that began in the early 1950s and continues today played a major role in reducing flows in the Rio Grande at El Paso from what they were prior to the 1950s without groundwater pumping for the same annual quantities of water released from Caballo Reservoir. In essence, the extension of the 1930-1950 curve represents the "no compact violation" condition.*

In essence, the extension of the 1930-1950 cumulative flow curve beyond 1950 to 2017 on the plot in Figure 5.4 (red dashed line) can be considered to represent the cumulative flows of the Rio Grande at El Paso that would have occurred if substantial groundwater pumping had not developed in the Rincon and Mesilla basins. (Page 22 paragraph 2).

Response:

Dr. Brandes initially observes that ground water pumping in New Mexico played a major role in reducing flows in the Rio Grande at El Paso. However, he goes much further in later statements without additional evidence to conclude that extension of the 1930 - 1950 cumulative flow line represents the "no compact violation" condition and that any post-1950 deviations from the 1930 - 1950 projection were caused by pumping in the Rincon and Mesilla basins.

As previously described, Dr. Brandes used reservoir releases for Elephant Butte Reservoir prior to 1938, and this affects the 1930 - 1950 projection line. If Dr. Brandes had instead used the Rio Grande at Percha Dam flow for 1930-1938, the average deviation between the 1930-1950 projection line and the cumulative Rio Grande at El Paso flow would be less than 78,667 AF/y.

Further, it is unreasonable to attribute all deviations from the 1930 - 1950 projection line to New Mexico pumping. There are many other factors that may have contributed to the change in the slope of the double-mass curve in Figure 5.4, including the following:

- Pumping in Texas Mesilla – Well pumping in the Texas portion of the Mesilla basin including Irrigation well pumping, municipal well pumping by EPW at the Canutillo wellfield, and other non-irrigation pumping.
- Pumping in El Paso Valley and Juarez Valley – Well pumping in the El Paso Valley and the Juarez Valley that depleted deliveries of Project water and caused additional water to have to be released from Project storage to deliver water to EPCWID farms.
- Reduction in Reservoir Releases – Generally lower reservoir releases after 1950 coupled with the reduced Project delivery efficiency that exists at lower flows as shown in Figure 5.1 of the Brandes Report.
- Reduction in Diversions and FHG Deliveries – Reductions in surface water diversions and farm headgate deliveries as a result of the reduced reservoir releases that occurred after 1950.
- Increased Project Operating Efficiency – Increases in Project operating efficiency (enactment of annual water allotments, reduced waste, etc.) that occurred after the first Project water shortages in the early 1950s.
- Increased On-Farm Irrigation Efficiency – Increases in on-farm irrigation efficiency resulting from land-leveling, lateral lining, increased use of level basin irrigation, soil moisture monitoring, education, and other factors that led to reduced irrigation return flows.
- Reduced Irrigated Area – Reduction in irrigated area in New Mexico and especially in Texas that led to reduced water demands. Increasingly, the EPCWID did not take delivery of its full annual allocation.
- Changes in Crops – Changes to crops that consume more water and return less water to the stream.
- Implementation of 2008 OA – Implementation of the 2008 OA accounting starting in 2006 that reduced the overall delivery efficiency of the Project through reduced deliveries to EBID and reduced drain flow returns to the Rio Grande.

It is also important to note that the cumulative Rio Grande at El Paso flows plotted in Figure 5.4 of the Brandes Report are year-round flows, including flows during the winter period that are not considered a part of the Project water supply. Review of the Brandes analysis indicates that an average of about 16,000 AF/y of the deviation in El Paso flows from the pre-1950 line is represented by changes in flows during the non-irrigation season. Since there are no Project releases during the non-irrigation season, changes in flows during that time are not considered Project water. Further, since the flows at El Paso during the winter are reportedly comprised primarily of poor-quality drain flows, they are less usable for irrigation than Project supplies during the irrigation season.

For the reasons listed above, it is improper to conclude that pumping in New Mexico was the sole cause of reduced flows in the Rio Grande at El Paso after 1950. While the double-mass curve analysis presented as Figure 5.4 in the Brandes Report does show there was a reduction in flow relative to the releases from Project storage, it provides no information or evidence for what caused the reduction in flow.

In addition, as described above, changes in flow at the El Paso gage are irrelevant to this case, to the Compact, and to the Project operations. What is relevant is that the Project has always operated as a unit, and prior to the 2008 OA, operated to allocate and deliver equal amounts of water to each farm acre based on the D1/D2 procedure, which allowed for conjunctive use of ground water to meet irrigation demands (Lopez, 2019) In order to understand whether pumping anywhere within the Project area has impacted the historical Project deliveries, it is necessary to develop and apply a robust simulation model of the entire Project. As described previously, the simulation model must be capable of simulating the full dynamic response of the Project operations to changes in supply. The simple double-mass curve analyses presented in the Brandes Report are not useful for determining the impact of New Mexico pumping on Texas water deliveries.

Brandes Opinion 11 *– The corresponding annual river flows in the absence of groundwater pumping after 1950 (no compact violation condition) can be estimated by calculating the incremental annual increases in the extended cumulative flow curve (red dashed line). These estimated annual flows of the Rio Grande at El Paso without the effects of groundwater pumping for the 1951-2017 period are plotted on the bar chart in Figure 5.5 along with the corresponding historical annual flows. As expected, the annual flows without the effects of groundwater pumping are higher than the actual historical annual flows which were influenced by groundwater pumping. (Page 23 paragraph 2).*

Response:

Figure 5.5 in the Brandes Report is presented as evidence for the annual effects of ground water pumping on Rio Grande at El Paso flows. The differences between the historical flows and the flows without the effects of ground water pumping in Figure 5.5 of the Brandes Report are plotted in **Figure 11-2.** The green shading in the chart indicates whether there was a full allocation of Project water in each year. The estimates of substantial impacts on El Paso flows during every non-spill year of the study period except 1988 do not make sense given how the Project operates. In full allocation years, it is reasonable to assume that the Project water users took delivery of all of the Project water they were allocated or needed. Therefore, assuming there would be more water in the river without pumping, Reclamation would reduce reservoir releases so that the same amount of water would be delivered to the Project water users in full allocation years, including EPCWID. As a result, in full allocation years without pumping, there should be little if any additional flow at El Paso compared to the historical condition, except for some additional flows during the winter resulting from the increase in drain flows that would occur without pumping.

Because the year-in and year-out effects of pumping shown in Figure 5.5 of the Brandes Report are not consistent with the expected response of the Project to changes in supply, the annual differences in the bars in Figure 5.5 are not reliable indicators of the impact of pumping in the Rincon basin and Mesilla basin on El Paso flows.

Brandes Opinion 12 – *The counterpart to the analysis of the change in the Rio Grande flows at El Paso caused by the development of groundwater pumping in the Rincon and Mesilla basins is a similar analysis of streamflow depletions. For purposes of this analysis, streamflow depletions are defined as the difference between the annual releases from Caballo Reservoir and the corresponding annual flows in the Rio Grande at El Paso. Streamflow depletions in this case are the result of diversions from the river into the main canals for irrigation in the Rincon and Mesilla basins, river channel losses due to evaporation and seepage, and evapotranspiration by vegetation along the river, offset by arroyo inflows to the Rio Grande between Caballo Reservoir and El Paso and discharges into the Rio Grande from irrigation drains and canal wasteways. Figure 5.6 presents the double-mass graph of these cumulative streamflow depletions for the 1930 through 2017 period. Here again, the distinct change in slope after groundwater pumping began in the early 1950s and the increasing deviation of the historical data after the 1950s (brown diamonds) from the projection of the pre-1950 historical data (green dashed line) are indicative of the expected effects of groundwater pumping on streamflow depletions. (Page 23 paragraph 3).*

Response:

The results shown in Figure 5.6 of the Brandes Report are skewed due to the use of Elephant Butte Reservoir releases before 1938. This affects the slope of the green line and inflates the differences between the projected 1930 - 1950 line and the cumulative depletions after 1950.

As described in Section 5, the average annual depletions between Caballo Reservoir and El Paso are about the same today as they were in the late-1930s at approximately 250,000 AF/y.

The criticisms of the double-mass curve analysis of El Paso flows described above also apply to the double-mass curve analysis of Rio Grande depletions in Figure 5.6 of the Brandes Report. The double-mass curve can show there was a change in depletions relative to reservoir releases, but does not inform as to the causes for any changes in depletions. Dr. Brandes provided no evidence to support an opinion that all increases in depletions after 1950 are due to pumping. A robust model capable of dynamic response to changes in flow is necessary to compute the portion of the changes in depletions to Rio Grande flow above El Paso caused by pumping in New Mexico and Texas.

Brandes Opinion 13 *– The various graphical illustrations presented in this section all exhibit the common theme that hydrologic conditions along the Rio Grande in the Rincon and Mesilla basins changed noticeably beginning after the 1950s. While this coincides with the onset of the severe drought of the 1950s that affected much of the southwestern United States, it also is when significant groundwater pumping began to develop and accelerate along the Rio Grande in the Rincon and Mesilla basins to provide a supplemental water supply for irrigation in New Mexico. Based on the significant changes that occurred in the observed Rio Grande flows, streamflow depletions, and drain discharges that began with the substantial increase in groundwater pumping, there is strong empirical evidence that groundwater pumping was a primary cause of these changes, which, in turn, lead to reductions in the availability of surface water supplies from the Rio Grande for Project users in Texas. (Page 24 paragraph 3).*

Response:

While I agree with Dr. Brandes that the graphical illustrations presented in Section 5 show that there were changes in drain flows, Rio Grande flows, and streamflow depletions after 1950 relative to releases from Project storage, his quantification of these changes is affected by his use of Elephant Butte Reservoir releases before 1938 in developing the 1930 - 1950 projection lines in the various figures.

In addition, for the many reasons described above, I also disagree that the empirical evidence presented by Dr. Brandes shows that the post-1950 changes are due solely to New Mexico pumping. A robust model capable of simulating the dynamic response of the Project to changes in historical conditions is necessary to assess the effects of New Mexico pumping, Texas pumping, or other operations on El Paso flows and deliveries to Project water users.

***Brandes Opinion 14** – A fundamental premise of Rio Grande Project operations is that the annual supply of water available for Project users each year is determined by the volume of water either in storage or anticipated to be in storage in Elephant Butte and Caballo Reservoirs, and changes in downstream water demands or streamflow depletions do not affect the amount of the available supply. (Page 30 paragraph 5).*

Response:

It is incorrect to state that the available Project supply is solely determined by the volume of water either in or projected to be in Project storage each year. Review of the RGJI report and the record of the deliberations of the engineer representatives of Colorado, New Mexico, and Texas indicates they were very aware of the many factors that cause variations in Project water supply. The amount of water in storage at the beginning of the season and the reservoir inflows during the irrigation season are obviously important in determining the available water supply. However, the drain flows and other return flows from irrigation downstream of the reservoirs contribute substantially to the Project supply and therefore are of significant importance to the Project operation.

The amount of water that is actually released from storage and delivered for use also depends on the demands of the Project water users. In some years, the districts request delivery of most or all of their allocation and in other years they request less. As shown in **Figure 4-5**, EBID has historically requested delivery of most or all of its allocation more often than has EPCWID.

In summary, Project releases are affected by (a) the amount of water available in storage at the beginning of the irrigation season, (b) the inflows to storage during the irrigation season, (c) the gains and losses between the Caballo outlet and the downstream delivery points, and (d) the demands of the Project water users.

The effects on Project operations resulting from variations in downstream operations is evident in comparisons of historical canal heading diversions to historical reservoir releases and historical Project supplies. **Figure 11-3** contains scatter plots of the canal heading diversions versus reservoir releases during the typical March – October irrigation season. Separate graphs are presented for the canal heading diversions of EBID, EPCWID, JID, and the total. Each plot shows a range of diversions for similar reservoir releases. This is consistent with the descriptions of Project operations in the RGJI (NRC 1938), Project histories (Reclamation, 1992), operating manuals, and other information (Reclamation, undated) that indicate reservoir releases are set to deliver the amounts ordered by the Project water uses in combination with the drain flows and other gains and losses between the reservoir and the delivery points. For example, the graph of total Project diversions in the lower right of **Figure 11-3** shows that for approximately the same reservoir release, the annual diversions varied by 200,000 AF or more. Conversely, for approximately the same annual diversion, the annual reservoir releases varied by 150,000 AF to 200,000 AF.

Similar charts are presented in **Figure 11-4** showing the same irrigation season diversions plotted against the total available Project supply computed as the end of February Project storage plus the March - July reservoir inflows. There is even more scatter in the data in the graphs in **Figure 11-3** than in the graphs in **Figure 11-4**.

Another set of charts is presented in **Figure 11-5** to illustrate the year-to-year variability in Project operations. The upper left chart plots the irrigation season diversion ratio vs. the irrigation season releases and the upper right chart plots the diversion ratio vs. the annual available Project supply (end of February storage plus March-July inflows). There is substantial variability in the diversion ratio for similar annual reservoir releases and for similar annual Project supply. The diversion ratio will be higher when there are more drain flows and other return flows available to help meet diversion demands, and the diversion ratio will be lower when the return flows are lower and more reservoir water has to be released to meet demands.

Finally, the lower left chart in **Figure 11-5** shows the irrigation season reservoir releases versus the annual available Project supply. This chart shows substantial variation in annual reservoir releases for the same annual available Project supply. This variability reflects the wide range of downstream conditions that affect how much reservoir water is needed to be released to meet Project water demands.

Brandes Opinion 15 – *It is significant to note, however, that the operation of Elephant Butte and Caballo Reservoirs and the annual allocation of Project water and the associated releases from Caballo do not appear to have noticeably changed as a result of the groundwater pumping. The graph in Figure 6.4 presents a plot of annual reservoir releases from Caballo Reservoir versus the corresponding maximum combined storage in Caballo and Elephant Butte Reservoirs prior to and during the irrigation season. The storage data on this plot are limited to years when the total storage was less than 1,500,000 acre-feet because with storage amounts greater than this, annual releases have been somewhat erratic due to high river flows and releases of flood water. Data plotted on the graph are segregated into two time periods; one for 1940-1955 before the effects of groundwater pumping had fully evolved and the other for 1956-2014 after significant groundwater development had occurred. (Page 38 paragraph 4).*

Response:

The combined maximum storage in Figure 6.4 of the Brandes Report is not an accurate measure of the available annual Project water supply. Dr. Brandes computed the maximum storage separately for Elephant Butte Reservoir and Caballo Reservoir for each year based on the historical maximum end-of-month storage in each reservoir in each month from December - July. The maximum amounts for each reservoir were added together to determine the annual values plotted on the x-axis in Figure 6.4.

One problem with the Brandes methodology is that the maximum monthly storage values for each reservoir may come from different months within the December - July period, and in this instance the sum of those maximum values will exceed the maximum combined end-of-month reservoir storage for that year.

A larger problem is that the maximum monthly reservoir contents is not an accurate representation of the available supply because it does not reflect the reservoir releases before the maximum storage month, nor does it reflect the reservoir inflows after the maximum month. A better indication of the available Project supply is the end-of-February storage contents plus the sum of the reservoir inflows during March - July. These totals have appeared in prior Reclamation summaries of the Project water supply (Reclamation, 2012). This preferred indication of Project supply was used in the graphs in **Figure 11-4** and **Figure 11-5**.

Notwithstanding the inaccurate measure of Project supply plotted on the x-axis, the data plotted in Figure 6.4 of the Brandes Report do not show what Dr. Brandes claims they show. First, he states that the 1940 - 1955 data points shown as blue dots represent conditions before the effects of pumping had fully evolved. This is contrary to analyses presented in other portions of Dr. Brandes report where he describes the effects of pumping that began substantially affecting flows in 1951. Second, for similar maximum storage contents, the data in Figure 6.4 show releases from Caballo that range approximately between 100,000 AF to 200,000 AF. The reason for variations in the annual releases for similar reservoir contents is the annual variation in conditions downstream of the reservoir. This is similar to the scatter shown in the data in **Figure 11-3** through **Figure 11-5** and explained in more detail in the accompanying narrative.

Brandes Opinion 16 – *Notwithstanding the process embedded in the Operating Agreement for attempting to mitigate for the effects of groundwater pumping in New Mexico on deliveries to Texas, the fact remains that groundwater pumping along the Rio Grande in the Rincon and Mesilla basins of New Mexico is not limited and continues at significant levels, adversely affecting flows in the river and diversions for Project water users in Texas. This is evident by the data presented on the graphs in Figures 4.7, 5.4 and*

5.6 where the post-2007 data exhibit little change from conditions prior to adoption of the Agreement. (Page 38 paragraph 3).

Response:

The 2008 OA continued to allocate water to Texas and Mexico based on the D1 and D2 Curves and therefore these two entities generally receive the same allocation of water for a given amount of water in Project storage that they received under the original D1/D2 allocation procedure. To the extent that Project does not perform at the level implicit in the D1 and D2 Curves, the entire amount of the underperformance is born by a reduced allocation to New Mexico water users.

As described above, the D1 and D2 Curves implicitly grandfathered in the effects of pumping during 1951 - 1979 by New Mexico, Texas, and Mexico on Project performance and Project deliveries. To the extent that the annual flow at El Paso has declined further relative to releases from the Project storage since the 2008 OA was enacted, this may be caused in part by EPCWID taking less delivery of its allocation since the agreement was enacted. Prior to 2008 under the D1/D2 accounting in years that EPCWID had an allocation of more than 350,000 AF, the Project water deliveries to EPCWID averaged about 319,000 AF/y. Since 2008 under the 2008 OA EPCWID has taken delivery of an average of 288,000 AF/y in years with an annual allocation exceeding 350,000 AF, or about 30,000 AF/y less than before the 2008 OA was enacted.

Further, the bargain of the 2008 OA was that the percentage of surface water allocated to EPCWID would be increased, the percentage of surface water allocated to EBID would be decreased, and individual carryover accounts would be created in Elephant Butte Reservoir; and in exchange, EBID could pump additional ground water to make up for the reduction in its surface water deliveries. This forced reliance on ground water for EBID under the 2008 OA, would have reduced non-irrigation season return flows that reached the El Paso gage, and this would have contributed to further deviations in the double-mass curve lines after 2008. This impact of the 2008 OA was ignored by Dr. Brandes.

Brandes Opinion 17 – *The graph in Figure 7.2 presents an application of [the double-mass curve methodology] to the New Mexico deliveries to farms data for the 1938-2016 period. As shown, the curve represented by the historical data on this graph exhibits the same break in slope around the early 1950s as the curve for the Rio Grande flows at El Paso shown in Figure 5.4. Again, this supports the conclusion that groundwater pumping in the Rincon and Mesilla basins for irrigation of farms in New Mexico, which began to develop during the early 1950s, more likely than not impacted the deliveries of Project water to farms in New Mexico. The total reduction in farm deliveries for the 1951-2016 period is* *about 2,100,000 acre-feet, which translates to an average annual reduction of 33,547 acre-feet. (Page 41 paragraph 4).*

Response:

As for the other double-mass curves in the Brandes Report, the projection of the 1930 - 1950 line in the Figure 7.2 is skewed by the use of Elephant Butte Reservoir releases during 1930 - 1937. As described above, there are likely many other reasons that annual Project deliveries decreased relative to Project releases after 1950, and these would have also affected deliveries to New Mexico farms. To the extent that ground water pumping did affect deliveries to New Mexico farms, this obviously means that New Mexico pumping does not somehow only affect El Paso flows. In fact, because New Mexico nominally was allocated 57 percent of the Project supply (until 2008) and tended to use more of its allocation than did Texas, any changes in Project performance, regardless of the cause, would generally tend to impact deliveries to New Mexico users more than deliveries to Texas water users.

In addition to the change in slope of the New Mexico deliveries in Figure 7.2 in the early 1950s, there is another break in slope around the time that the 2008 OA went into effect. This would be consistent with the significant reduction in Project water allocations to New Mexico that resulted from the provision of the 2008 OA that causes New Mexico to bear the effect of any and all negative deviations of Project performance from the performance that is implicit in the D1 and D2 Curves.

A robust model capable of simulating the dynamic response of the Project to changes in historical conditions is necessary to assess the effects of New Mexico pumping, Texas pumping, or other operations on deliveries to New Mexico farms.

Brandes Opinion 18 *– The estimated annual values of the New Mexico farm deliveries without the reductions caused by groundwater pumping can be determined by calculating the annual incremental increases in the 1951-2016 extension of the 1938-1950 data curve (red dashed line). These values are plotted on the bar chart in Figure 7.3 along with the corresponding historical deliveries to farms in New Mexico for the 1951-2016 period. (Page 43 paragraph 1).*

Response:

Figure 7.3 in the Brandes Report compares the historical annual deliveries to New Mexico farms to the estimated annual deliveries without the effects of pumping derived from the double-mass curves presented in Figure 7.2. The estimates of substantial impacts on deliveries to New Mexico farms in all years of the study period do not make sense given how the Project operates. In full allocation years, it is reasonable to assume that the Project water users took delivery of all of the Project water they were allocated or needed. Therefore, assuming there would be more water in the river without pumping, Reclamation would reduce reservoir releases so that similar amounts of water would be delivered to the Project water users in full allocation years, including EBID. Because the year-in and year-out effects of pumping shown in Figure 7.3 of the Brandes Report are not consistent with the expected response of the Project to changes in supply, the annual differences in the bars in Figure 7.3 are not reliable indicators of the impact of pumping in the Rincon basin and Mesilla basin on deliveries to EBID farms.

Brandes Opinion 19 *– Estimates of the total annual deliveries to Texas in the El Paso Valley have been derived by subtracting from the irrigation-season Rio Grande flow at El Paso the amount of water diverted into the Acequia Madre for Mexico and adding the annual quantities of the City of El Paso's Canutillo well field pumping. These annual values are plotted on the bar chart in Figure 7.4 along with the corresponding annual deliveries to Texas farms in the Mesilla basin as developed by Montgomery. (Page 43 paragraph 2).*

Response:

The estimates of annual Texas deliveries in Figure 7.4 of the Brandes report are not reasonable estimates of deliveries to water users in Texas. The estimates of annual Texas deliveries generally represent the flow at El Paso adjusted to include Canutillo wellfield pumping and exclude Acequia Madre diversions. As such, these estimates overstate Texas deliveries because they are not reduced for the substantial conveyance losses between the El Paso gage and the Texas farm headgates and the EPW diversion points.

Brandes Opinion 20 *– The double-mass analysis approach has been applied to the historical total Project water deliveries to Texas to assess apparent changes in historical delivery patterns relative to releases from Caballo Reservoir. As shown in Figure 7.5, the curve represented by the historical data on the graph exhibits the same downward change in slope during the early 1950s as depicted on the double-mass graph for deliveries to farms in New Mexico in Figure 7.2. Again, more likely than not this is indicative of the effects of groundwater pumping that began about this same time in the Rincon and Mesilla basins for irrigation of farms in New Mexico. The deviation of the curve represented by the Texas total historical deliveries data (green squares) after 1950 from the extension of the 1938-1950 data curve out to 2016 (red dashed line) demonstrates that there was less water delivered to Texas relative to the releases from Caballo Reservoir. The total reduction in the total deliveries for the 1951-2016 period is about 2,400,000 acre-feet, which translates to an average annual reduction in deliveries of 39,689 acre-feet per year. Whether these reductions in deliveries to Texas are directly attributable to the effects of groundwater pumping in the Rincon and Mesilla basins of*

New Mexico may not be clearly established with this demonstration; however, the trend of reduced deliveries after groundwater pumping began in the late 1950s certainly is consistent with the reductions in the Rio Grande flows at El Paso. Based on these trends, one would conclude more likely than not that groundwater pumping in the Rincon and Mesilla basins played a major role in adversely affecting deliveries of Project water to Texas. (Page 45 paragraph 2).

Response:

The alleged reduction in Texas deliveries of 39,689 AF/y described in the report text does not match the 37,689 AF/y reduction shown on Figure 7.5.

The previously described issue with use of Elephant Butte Reservoir releases during 1930 - 1937 affects the projection of the 1930 - 1950 data in Figure 7.5 (dashed red line). As previously stated, a double-mass curve can illustrate a change in the relationship between two variables (in this case reservoir releases and Texas diversions); however, it does not provide information on the cause(s) of the change. Dr. Brandes admits that the curve in Figure 7.5 does not clearly establish that the reductions in Texas diversions are caused by New Mexico pumping. As described above, there are many factors other than New Mexico pumping that may have affected downstream water supplies relative to Caballo releases, and these factors would have also affected Texas diversions.

A robust model capable of simulating the dynamic response of the Project to changes in historical conditions is necessary to assess the effects of New Mexico pumping, Texas pumping, or other operations on diversions by Texas and deliveries to Texas farms.

Brandes Opinion 21 – *The deliveries of Project water to Texas that would have occurred in the absence of these apparent effects of groundwater pumping can be derived from the incremental annual increases in the projected extension of the 1938-1950 data curve from 1950 out to 2016 (red dashed line) in Figure 7.5. The resulting annual Texas deliveries without the effects of groundwater pumping are plotted on the bar chart in Figure 7.6 along with the corresponding historical Texas deliveries. As shown, the total deliveries to Texas without the effects of groundwater pumping generally are greater than the historical deliveries, thus demonstrating the adverse impacts of groundwater pumping. As discussed above, the average reduction in Texas deliveries from the projected deliveries without the effects of groundwater pumping in the Rincon and Mesilla basins is about 40,000 acre-feet per year. Since both the historical delivery values and the projected delivery values without groundwater pumping reflect the underlying calculation approach for estimating the historical deliveries of Project water in the El Paso Valley, any inherent uncertainties in this approach are embedded in both sets of total deliveries, which* *suggests that the calculated annual differences between the two sets of total delivery values are likely unaffected by these uncertainties. (Page 45 paragraph 3).*

Response:

Similar to the above criticisms of Figure 5.5 in the Brandes Report, the annual differences between the historical Texas deliveries (actually diversions as described above) and the estimated deliveries without pumping do not make sense in the context of the Project supply conditions. For example, there are significant differences between the green bars and orange bars in each year from 1979 - 1985 and yet these were full supply years under the Project, and Texas would have received the same full allocation with or without the effects of pumping. Further, during 1979 - 1985 EPCWID's Project water deliveries averaged approximately 58,000 AF/y less than its average annual allocation (see **Table 4-3**). During these full supply years that EPCWID left substantial portions of its annual allocations unordered and unused, it is unreasonable to claim that Texas deliveries were being impacted by New Mexico pumping. The annual effects of pumping on Texas deliveries allegedly shown in in Figure 7.6 of the Brandes Report are not consistent with the expected response of the Project to changes in supply, and therefore the annual differences in the bars in Figure 7.6 are not reasonable or reliable indicators of the impact of New Mexico pumping on Texas deliveries or diversions.

I disagree that cancelling of errors in the method used to compute the Texas deliveries causes the results to be unaffected by the errors. Cancelling of errors does not relieve the method of its deficiency in not considering the conveyance losses in delivering water to Texas farmers. There is also the problem of the 1930 - 1950 projection line being skewed by the use of Elephant Butte Reservoir releases. Finally, the 1930 - 1950 projection line inherently assumes there is no variability in the straight-line accumulation of annual values in the dashed red line in the double-mass plot in Figure 7.5. The lack of variation in the dashed red line compared to the inherent annual variability in the green squares likely introduces significant error when deriving annual values from the differences between the projected 1930-1950 line and the accumulation of actual values in the green squares.

12.0 RESPONSE TO MONTGOMERY AND ASSOCIATES REPORT

Staffan W. Schorr and Colin P. Kikuchi, Ph. D. of Montgomery & Associates ("M&A") prepared a May 31, 2019 expert report on behalf of the State of Texas entitled, *Water Budget Estimates in Support of Groundwater Model Development: Rincon and Mesilla Basins, New Mexico, Texas, and Northern Mexico, 1938 Through 2016* ("M&A Report"). Information in the M&A Report was used for three primary purposes. First, M&A compiled much of the hydrologic and water use data for the study area into a database for use by the other Texas experts. Second, M&A prepared water budgets for the Rincon and Mesilla basins for the period from 1938 - 2016 period for the purpose of estimating certain inputs for the Texas Model, including irrigation pumping, and return flows from irrigation and non-irrigation uses. Finally, M&A prepared a water budget analysis of irrigation operations in the El Paso Valley in Texas that was used in analysis of alleged damages to Texas from water quality impacts caused by New Mexico pumping during the period from 1985 - 2016.

SWE was asked by legal counsel for New Mexico to review the water budget analyses and data compilations presented in the M&A Report to identify information or opinions that we disagreed with, and to prepare expert opinions to respond these issues. We attempted to identify and respond to all substantive issues in which there appeared to be differences of opinion, however a lack of response to a particular issue should not be interpreted as tacit agreement with the opinions in the M&A Report.

M&A Opinion 1 *– I prepared separate water budgets for Rincon Basin and Mesilla Basin because the basins are separated by a bedrock constriction, which limits the hydrologic connection between the basins. The overall water budget for each basin comprises three types of budgets: Land-Surface Water Budget, Surface Water Budget, and Groundwater Budget. I used this approach to facilitate budget development by compartmentalizing common components. (Page 3 paragraph 2 and 3).*

Response:

The Montgomery water budget analyses provide comprehensive and detailed accounting of the inflows and outflows of (a) the Land Surface system, (b) the Surface Water system, and (c) the Groundwater system using actual data, estimated data, and water balances, and other calculation and modeling techniques. Certain of the computed water budget terms were used as inputs to the Texas Model and these were the focus of our review of the M&A analyses.

In all water budget analyses the sum of the inflows minus the sum of the outflows equals the change in storage. For the Land Surface Budget, this would be the change in soil moisture storage. For the Ground Water Budget this would be the change in ground water storage in the subsurface aquifers. In the Surface Water Budget, there are no changes in storage at the monthly time scale the budgets were prepared, and there are no reservoirs simulated (Elephant Butte Reservoir and Caballo Reservoirs are upstream of the geographical areas included in the water budget analyses).

Figure 12-1 through **Figure 12-3** summarize that computed average annual values for each of the water budget terms in the M&A Land-Surface Budget, Surface Water Budget, and Groundwater Budget, respectively. Positive values (bars to the right) represent inflows to the system and negative values (bars to the left) indicate outflows from the system. Changes in storage are shown as positive or negative as appropriate.

The bars in **Figure 12-1** through **Figure 12-3** are color-coded in relation to whether and how each of the water budget terms are used in the Texas Model.

- Blue bars – Model inputs that do not change in the reduced pumping model runs.
- Red bars – Model inputs that change in the reduced pumping model runs.
- Yellow bars – Quantities that are simulated in the model.
- Black bars – Quantities that are neither input to or simulated in the model.

For the water budget values that are inputs to the model, the abbreviations at the end of the bars indicate the whether the values are input through the MODFLOW WEL Package as cell-by-cell inputs or through the MODFLOW SFR Package as stream segment inputs.

The size of the bars gives an indication of the relative significance of the water budget terms to the three water budgets and to the modeling. The colors of the bars reflect the importance of the terms to the modeling of alternative scenarios. Model inputs that are changed between model runs (red bars) or are simulated in the model (yellow bars) are most significant. Model inputs that do not change between runs are less significant because they have little effect on the simulated differences between model runs. Obviously, the quantities that are not input or simulated in the model (black bars) are of least importance in the modeling. Note that while the on-farm consumptive use is not simulated in the model, the specified amount of consumptive use in the Land Surface Budget affects the computed pumping and irrigation returns flows (deep percolation and surface runoff) that are inputs to the Texas Model.

M&A Opinion 2 *– A farm water budget analysis was conducted to estimate monthly farm deep percolation and agricultural applied groundwater pumping in each basin (Rincon* *basin and Mesilla basin). In addition, estimates for change in agricultural soil moisture storage and agricultural surface water return flows were also determined by the farm water budget analysis. (Page 16 paragraph 1).*

Response:

The M&A Farm Budget Model was used to compute inputs to the Texas Model for applied ground water pumping for irrigation, and on-farm deep percolation and surface runoff from irrigation in the Rincon and Mesilla basins. The Farm Budget analysis was performed for the period from 1938 - 2016 using a monthly timestep. The monthly results were aggregated to annual values for input to the Texas Model which has annual stress periods.

The M&A Farm Budget Model is similar to the SWE CFB Model (and to the almost identical RiverWare farm budget algorithm) in that both models use a mass balance water budget approach to simulate the on-farm water deliveries, consumptive use, soil moisture storage, and irrigation return flows. In addition, supplemental pumping is assumed to meet unmet irrigation demands after commencement of widespread irrigation pumping in the Rincon basin and Mesilla basin. While there are similarities in the farm budget simulations, there are also some significant differences in model inputs and processes that result in material differences in the farm budget model outputs for irrigation pumping and on-farm irrigation losses due to deep percolation and surface runoff.

M&A Opinion 3 *– A soil water balance model was developed to estimate agricultural groundwater pumping and deep percolation over the time period of interest, 1938 through 2016. The model tracks soil moisture within the maximum extent of irrigated agricultural lands of the Rincon and Mesilla basins on a monthly time step. Four separate models were developed for this analysis: lands inside District boundaries in Rincon Basin, lands outside District boundaries in Rincon Basin, lands inside District boundaries in Mesilla Basin, and lands outside District boundaries in Mesilla Basin. The models follow identical governing equations and differ only in their respective data inputs. (Page 19 paragraph 1).*

Response:

The soil water balance model developed by M&A is a complex, non-linear iterative model. Inputs to the model include precipitation, applied surface water, and ground water pumping; and outputs consist of crop evapotranspiration (“ET”), deep percolation (“DP”), and soil moisture storage. The crop evapotranspiration and deep percolation are computed as functions of the soil moisture storage, and the soil moisture storage depends on the computed ET and DP. Because of these interdependencies, an iterative simulation process is performed in the model to simultaneously solve for the ET, DP, and soil moisture in each monthly stress period.

The soil water balance model simulates "virtual fields" for the Rincon basin and the Mesilla basin (including the Texas portion of the Mesilla basin) that are intended to represent aggregations of all the fields in each basin. Each virtual field is simulated as if it was a gravity-irrigated field as illustrated in Figure 2.3 of the M&A Report. Applied irrigation water (surface water and pumped ground water) is assumed to be introduced at the top of the field (left side in Figure 2.3) and assumed to flow across the virtual field to the bottom of the field (right side in Figure 2.3). Because irrigation water is present at the top of the field longer than at the bottom of the field, the soil water balance model simulates more infiltration of surface water at the top of the field than at the bottom of the field. Thus, the top of the virtual field can be adequately irrigated to bring the soil moisture to a level sufficient to avoid crop stress and meet the full ET demand of the crop, while the lower portion of the field can be insufficiently irrigated resulting in crop stress and a reduction in crop ET.

There are two time-series ET inputs to the soil water balance model that come from Land IQ. The first is the crop-weighted average theoretical ET computed as the reference ET multiplied by crop coefficients obtained from various references. The crop coefficients used by Land IQ were not locally calibrated. The second is an adjusted ET that is roughly 30% less than the theoretical ET until about 1970, with the adjustment transitioning to no adjustment by about 1990.

The parameterization of the soil moisture distribution under each virtual field is adjusted in the M&A soil water balance model during each month of the study period so that the simulated soil moisture across the virtual field is at the levels necessary for the computed aggregate ET to match the adjusted ET from Land IQ. Before 1970, when the target ET for most crops is 30% lower than the theoretical ET, the soil water balance model is calibrated to simulate substantial soil moisture stress in order for the simulated ET to match the target ET. The simulated soil moisture stress is gradually reduced during 1970 - 1990 as the adjusted ET from Land IQ transitions to the full theoretical ET. After that time, there is little or no simulated soil moisture stress and therefore the ET computed in the soil water balance model reaches the full theoretical ET across the entire virtual field.

There are five soil moisture states that represent important soil moisture thresholds in the root zone of an irrigated crop. These soil moisture thresholds are listed below in order from low to high soil moisture levels:

- Residual Moisture – Lowest soil moisture level.
- Wilting Point – Soil moisture level below which the crop is incapable of extracting water through the roots.
- Critical Moisture – Soil moisture level below which the crop will begin to experience stress and a reduction in ET.
- Field Capacity – Approximately maximum soil moisture content that can be retained in the soil against gravity. This typically occurs within a few days after a thorough irrigation or heavy precipitation event after gravity drainage of moisture stored temporarily above the field capacity level.
- Porosity – Maximum soil moisture content in which the soil is saturated and virtually all of the pore spaces between the soil particles are filled.

As described above, the soil water balance model simulates a continuous range of soil moisture across each virtual field creating sufficient stress (or no stress) so that the simulated aggregate ET matched the adjusted ET values from Land IQ. The model generally simulates less soil moisture stress through time as the adjusted ET values become closer to the theoretical ET values.

Figure 12-4 and **Figure 12-5** contain graphs that show the simulated monthly soil moisture in the Rincon and Mesilla virtual fields during the 1938 - 2016 study period. Each graph contains five dotted horizontal lines that represent the five soil moisture states referenced above. The solid black line represents the simulated maximum soil moisture level (θmax) at the top of the virtual field where infiltration would be greatest. The solid grey line represents the simulated minimum soil moisture level (θmin) at the bottom of the virtual field where infiltration would be least. The solid red line is the simulated average soil moisture across the virtual field (θavg).

The graphs for the simulated virtual fields representing the Rincon basin and Mesilla basin are generally similar. The following observations regarding the soil water balance model simulation of the Mesilla virtual field illustrated in **Figure 12-5** are also generally applicable to the simulation of the Rincon virtual field.

1. Maximum Soil Moisture – The simulated maximum soil moisture at the top of the field (black line) fluctuates from month to month, but remains well above the field capacity of the soil, and often reaches the total porosity of the soil. This result is nonsensical as the soil moisture in the root zone of a crop cannot physically remain above field capacity for more than a few days after an irrigation. The soil water balance model simulates the soil moisture at the top of the virtual field well above field capacity for the entire 1938 - 2016 simulation period.

2. Minimum Soil Moisture – The simulated minimum soil moisture at the bottom of the field (grey line) fluctuates from month to month, but remains below the wilting point through the mid-1980s. This is also nonsensical as it indicates that prior to the mid-1980s, significant portions of the fields in the Mesilla basin never had sufficient soil moisture to produce any ET. In other words, the crops were dead in those portions of the fields.
3. Average Soil Moisture – The average soil moisture fluctuates between field capacity and the critical level until around 1970. After that time, the average soil moisture begins fluctuating above field capacity for months at time through about 1985 and then generally remains continuously above field capacity through the remainder of the study period. As described above, this result in nonsensical.

The soil moisture conditions simulated in the M&A soil water balance model are illustrated in another form in the graphs presented in **Figure 12-6**. These figures show the simulated soil moisture conditions across the virtual field from top to bottom for an entire year at 10-year intervals from 1945 - 2015. There are four charts on each page and each chart shows the conditions for a three-month period – Jan-Mar, Apr-Jun, Jul-Sep, and Oct-Dec. The solid lines in each chart display the simulated soil moisture, which is highest at the top of the field and lowest at the bottom of the field. Note that the vertical axis for the soil moisture is reversed so as to intuitively mirror the infiltration of water below the ground surface. For reference, each chart includes horizontal dashed black and grey lines that depict the five key soil moisture states described above.

Also shown in each chart is the simulated crop stress coefficient (Ks) for each month across each virtual field, represented as dotted lines that are read on the right axis. The soil moisture water balance model simulates soil moisture stress when the simulated soil moisture falls below the critical level. The stress coefficient increases linearly from 0% at the critical soil moisture to 100% at wilting point. When the stress coefficient is at 0.0, the ET simulated in the soil water balance model is at the full theoretical value, and when the stress coefficient is at 1.0 the simulated ET is zero.

The following are observations of the conditions during the principal growing season (April - September) in decadal interval charts presented in **Figure 12-6**.

- 1945 - 1965: 40% of the field is above field capacity, 60%-70% of the field is above critical soil moisture with no stress and full theoretical ET. 10%-20% of the field is in a stressed condition with reduced ET. 20% of the field is at or below wilting point, indicating the crop is dead.
- 1975: 40%-50% of the field is above field capacity, 65%-75% of the field is above critical soil moisture with no stress and full theoretical ET. 10%-20% of the field is

in a stressed condition with reduced ET. 20% of the field is at or below wilting point, indicating the crop is dead.

- 1985: 60% of the field is above field capacity, 85% of the field is above critical soil moisture with no stress and full theoretical ET. 10%-15% of the field is in a stressed condition with reduced ET. 5% or less of the field is at or below wilting point, indicating the crop is dead.
- 1995 - 2015: 70% of the field is above field capacity, 95% or more of the field is above critical soil moisture with no stress and full theoretical ET. 5% or less of the field is in a stressed condition with reduced ET. None of the field is at or below wilting point.

The results from the M&A soil water balance model are nonsensical because they depict simulated conditions that are physically impossible and contrary to the conditions that would be expected to exist in a productive and well-managed irrigation district like EBID in the Rincon and Mesilla basins. As described above, it is physically impossible for the moisture content in the crop root zone of a well-drained soil to be above field capacity for more than a few days after an irrigation. It is also wholly unreasonable for 20% of the virtual field representing all fields in the Mesilla basin to be under soil moisture stress and another 20% of the virtual field to be dead during all simulated years through about 1970. This would reflect a level of irrigation incompetence that is not consistent with (a) farmers whose livelihood depends on their work, and (b) the adequate water supply that existed between the available Project supply and the supplemental ground water available to most farmers.

***M&A Opinion 4** – Annual surface water deliveries to farms (farm deliveries) and agricultural groundwater pumping in Rincon and Mesilla basins are shown on Figures 2.9 and 2.10, respectively. Agricultural groundwater pumping in Rincon and Mesilla basins varied through time depending principally on surface water availability. Groundwater pumping generally increased during years when surface water deliveries were low, and vice versa. The largest groundwater withdrawals occurred during the early to mid-1950s, and from 2003 through 2016, when surface water deliveries to farms were small for many consecutive years. The smallest amount of groundwater pumping occurred during the period of full Project allotment from 1979 through 2002. (Page 45 paragraph 2 and 5).*

Response:

Figure 12-7 through **Figure 12-9** summarize and compare various annual values from the M&A Farm Budget Model and the SWE CFB Model. One of the key outputs from the models is the simulated pumping, as the effects of ground water pumping are a primary focus of the case. The differences in the simulated annual pumping in large part reflect the aggregation of all differences in input data and computational methods into a single result. This is because pumping to compute the unmet demand after applied surface water is one of the last steps in both the M&A Farm Budget Model and the SWE CFB Model.

The simulated annual pumping volumes from the M&A Farm Budget Model and the SWE CFB Model for the Rincon and Mesilla basins combined are shown in **Figure 12-7**. The simulated annual pumping in the SWE CFB Model exceeds the pumping in the M&A Farm Budget Model in most years until the early 1980s when the results flip and the M&A Farm Budget Model pumping exceeds the SWE CFB Model pumping in most years through the remainder of the study period.

Most of the differences in the outputs from the M&A Farm Budget Model and the SWE CFB Model, including the differences in pumping, are due to differences in the following:

- Irrigated area,
- Crop evapotranspiration,
- Farm headgate deliveries,
- On-farm seepage losses, and
- Soil moisture simulation procedure.

The M&A Farm Budget Model includes two soil water balance models for each simulated region (e.g., two models for the Mesilla basin Project lands). One model simulates irrigation and evapotranspiration for the cropped area that is being actively irrigated, and another model simulates bare soil evaporation in the non-cropped or fallowed area.

The simulated cropped area varies from month to month depending on the monthly ET for each crop. If there is no ET demand (i.e., during the early spring before the crop has been planted or during the fall and winter after the crop has been harvested) M&A assumed the crop was not irrigated (with some exceptions for simulated pre-irrigation). The land associated with a crop is in the crop model if it is being irrigated and in the non-crop model if it is not being irrigated. As a result, the simulated area in the crop model is highest in the middle of the irrigation season and lowest or zero in the winter. As the simulated irrigated area changes through the year, the simulated soil moisture is transferred between the two soil water balance models based on changes in the overlying areas. When the cropped area increases from one month to the next, a portion of the non-cropped soil moisture is moved to the irrigated model, and when the cropped area decreases, a portion of the cropped area soil moisture is moved to the non-irrigated model.

The upper right chart in **Figure 12-8** compares the sum of the maximum monthly cropped areas in each year in the Rincon and Mesilla basins in the M&A Farm Budget Model to the comparable annual irrigated areas in the SWE CFB Model. The total crop area for the Rincon and Mesilla basins is generally higher in the M&A Farm Budget Model than in the SWE CFB Model until about 1977, when the comparison flips and the area in SWE CFB Model is higher than the M&A Farm Budget Model through the end of the study period.

The upper left chart in **Figure 12-8** compares the simulated annual ET of applied water in M&A Farm Budget Model against the annual values from the SWE CFB Model. There are two lines for the M&A Farm Budget Model values shown in **Figure 12-8**. The solid line reflects the ET of applied water during the growing season for each crop and the dotted line reflects the addition of computed ET on bare ground outside of the growing season within the annual irrigated acreage for each year. This adjustment was made to make the M&A figures more comparable to the SWE values obtained from DE that also included bare ground ET outside of the growing season.

The difference between the M&A and SWE lines in **Figure 12-8** reflect differences in irrigated area, cropping pattern, unit crop ET values, and other factors. The annual ET of applied water in the M&A Farm Budget Model is generally greater than the annual values in the SWE CFB Model through 1984. From 1985 through the end of the study period, the ET of applied water is greater in the M&A Farm Budget Model during most years and this is the primary reason that the pumping in the M&A Farm Budget Model is also greater during this period.

The lower left chart in **Figure 12-8** compares the area-weighted annual unit crop ET for the Rincon and Mesilla basins for the M&A Farm Budget Model and the SWE CFB Model. The unit ET for the M&A Farm Budget Model was computed as the simulated annual ET volume (shown in the upper left chart in **Figure 12-8**) divided by the simulated maximum monthly irrigated area in that year (upper right chart in **Figure 12-8**). As for the upper left chart, there are two lines for the M&A values. The solid line is the computed weighted average ET for the crop ET and the dotted line adds the additional ET on bare ground within the annual irrigated area. The differences in the annual unit ET values reflect the combination of differences in the unit ET values for the individual crops and differences in the annual crop mix. The unit ET values in the M&A Farm Budget Model are less than in the SWE CFB Model until the mid-1980s, and more than in the SWE CFB Model thereafter.

The lower right chart in **Figure 12-8** summarizes the annual FHG delivery inputs to the M&A Farm Budget Model and the annual totals for the SWE CFB Model. The FHG deliveries are very similar between the two models through 1979, after which there are some differences. The post-1979 differences in FHG deliveries are due to differences in how the EPCWID delivery totals were disaggregated between the El Paso Valley and the Texas Mesilla areas. M&A disaggregated the EPCWID deliveries based on irrigated area, and SWE disaggregated the deliveries based on diversions. On average, the M&A farm headgate deliveries are 4% greater than the SWE farm headgate deliveries during the 1985 - 2016 period.

Another difference between the M&A Farm Budget Model and the SWE CFB Model involves an assumption regarding on-farm conveyance losses. M&A assumed a 10% on-farm conveyance loss, and so the surface water applied to the fields was specified as 90% of the FHG deliveries. The SWE CFB Model does not explicitly simulate on-farm seepage losses, but rather any such losses are incorporated in the specified MFE that is part of the irrigation simulation procedure in the SWE CFB Model. Note that the M&A FHG deliveries shown in the lower right chart in **Figure 12-8** are before the 10% on-farm conveyance loss.

The SWE CFB Model and the RiverWare Model both employ a widely used water balance process that simulates the process of delivering irrigation water to the field, limiting the amount of water made available for crop water consumption based on a specified maximum farm irrigation efficiency, and simulating storage of irrigation water in the soil moisture reservoir underlying the field for later use when the surface water supply is inadequate. The simulation algorithm in the SWE CFB Model is described in more detail in Section 6.

Figure 12-9 compares the simulated deep percolation and surface runoff from irrigation in the Rincon and Mesilla Valleys The deep percolation is less in the M&A Farm Budget Model than in the SWE CFB Model before the mid-1980s, and then becomes roughly comparable thereafter. Conversely, the surface runoff in the M&A Farm Budget Model is much greater than in the SWE CFB Model.

M&A Opinion 5 *– A non-farm water budget analysis was conducted to estimate consumptive use, runoff, and deep percolation for urban and non-urban (upland watershed) areas in the Rincon and Mesilla basins, based on measured or estimated water supply and wastewater discharges. Non-farm lands in the study area include urban areas and undeveloped areas consisting primarily of native vegetation. The non-farm water budget is subdivided into urban lands and upland areas that are not classified as farm (agricultural) or urban (i.e., watershed area minus farm and urban areas) (Figure 2.1). The urban water budget is evaluated by water source: applied water and precipitation water. The applied water budget analysis is based on measured or estimated groundwater withdrawals (pumping), measured or estimated wastewater discharges, and estimates for consumptive use and deep percolation. The precipitation water budget analysis uses monthly precipitation and estimates for consumptive use (i.e., effective urban precipitation) and runoff to estimate urban deep percolation of precipitation. Use of* *surface water deliveries for non-farm purposes is minor compared to groundwater use and considered negligible for this analysis. (Page 16 paragraph 1 and Page 52 paragraph 1).*

Response:

The M&A Non-Farm Water Budget analyses were also performed for the period from 1938 - 2016 using a monthly timestep with certain results aggregated to annual values for input to the Texas Model.

The M&A Urban Applied Water Budget was used to prepare inputs to the Texas Model for applied ground water pumping for urban and domestic uses, wastewater treatment plant discharges, and urban deep percolation from applied water. While SWE did not prepare a full urban applied water budget, data were compiled or estimated for urban and domestic pumping, WWTP discharges, and urban deep percolation for the entire LRG Area, including the Rincon and Mesilla basins. Several charts were prepared to compare the values used in New Mexico's ILRG Model to the comparable values developed by M&A for the Texas Model as shown in **Figure 12-10**.

The upper left chart in **Figure 12-10** compares the urban and domestic pumping in the Rincon basin and Mesilla basin that were input to the ILRG Model against the values used in the Texas Model. The urban and domestic pumping volumes in the Rincon and Mesilla basins are similar between the Texas Model and the ILRG Model, with slight variations throughout the study period.

The upper right chart in **Figure 12-10** compares the WWTP discharges input to the ILRG Model in the Rincon basin and Mesilla basin against the values used in the Texas Model. The annual WWTP discharges simulated in the ILRG Model average approximately 1,300 AF more than the values used in the Texas Model. The reason for the difference is that (a) the ILRG Model includes estimates of El Paso Electric WWTP discharges prior to the records that begin in 2004 while the Texas Model does not and (b) the ILRG Model uses actual records of Las Cruces WWTP discharges while the Texas Model uses estimates.

The lower left chart in **Figure 12-10** compares the estimated urban deep percolation inputs for the ILRG Model in the Rincon and Mesilla Valleys against the values input to the Texas Model. On average, the urban deep percolation in the Rincon and Mesilla basins is approximately 5,300 AF/y greater in the Texas Model than the ILRG Model, and the Texas Model shows more variability than the ILRG Model throughout the study period. Reasons for differences between the urban deep percolation estimates are generally two-fold. First, the Texas Model estimates reflect an assumption that all pumping from the Canutillo wellfield is used locally in the Texas portion of the Mesilla basin compared to the values for the ILRG Model that are based on estimates of urban deep percolation from all the EPW supplies distributed evenly across all of the EPW service area. Second, the values for the Texas Model were computed as a residual in an urban water budget calculation compared to the values for the ILRG Model that were computed based on percentages of non-irrigation water use.

The M&A Urban Precipitation Water Budget was used to estimate the urban precipitation runoff and urban deep percolation of precipitation that were input to the Texas Model. The lower right chart in **Figure 12-10** shows the annual urban precipitation runoff and deep percolation values that were input to the Texas Model. While the ILRG Model does not simulate urban precipitation runoff and deep percolation, this not a substantive deficiency for two reasons. First, the combined urban precipitation runoff and deep percolation represents only 0.1% of the total input to the Texas Model. Second, these inputs are not varied in the alternative model runs involving changes in pumping. As a result, the presence or absence of simulated urban precipitation runoff and deep percolation will have very little or no effect on the computed differences between the alternative model runs.

M&A Opinion 6 – *Tributary inflows represent the volume of water that flows into the Rio Grande from ephemeral streams as a result of stormwater runoff in the upland areas of the study area. The watersheds that contribute flow to the Rio Grande were taken from a 1996 study by the U.S. Army Corps of Engineers. The majority of tributary arroyos in Mesilla Basin do not contribute runoff discharges to the Rio Grande. Contributing watersheds in each basin are shown on Figure 3.4. Watershed runoff models require detailed streamflow data and information on physical characteristics for drainages and sub-watersheds. The lack of streamflow gages on the majority of drainages to the Rio Grande within the study area prevents the use of surface water modeling for determining tributary runoff for this water budget. Because of this limitation, we estimated runoff as a percentage of the precipitation falling on the contributing watersheds. Tributary inflow was assumed to be three percent of precipitation, based on results of a rainfall-runoff study conducted by Stone and Brown (1975) in a small semiarid watershed in the Jornada Basin in New Mexico. Annual tributary inflows in Rincon and Mesilla basins are shown on Figure 3.5. The estimated average annual tributary flows are about 5,500 AF in Rincon Basin and about 100 AF in Mesilla Basin. (Page 72 paragraph 1, 2, 4 and Page 74 paragraph 2).*

Response:

Precipitation runoff from undeveloped areas as a percentage precipitation can vary widely depending on slope, soils, vegetation cover, precipitation intensity and other factors. The estimate of 3% runoff from the PRISM precipitation data, while not unreasonable, should be considered approximate and having substantial uncertainty.

The estimated average annual tributary inflows from upland areas totaling 5,600 AF/y for the Rincon and Mesilla basins represents only 0.2% of the simulated average annual inflows to the Texas Model. Also, similar to the urban precipitation runoff and deep percolation, the tributary inflows from upland areas do not vary in the alternative runs of the Texas Model and therefore have little or no difference on the computed differences between the model runs.

M&A Opinion 7 – *Natural aquifer recharge in the Rincon and Mesilla Basins principally occurs as mountain-front recharge along the basin margins near the lateral extent of the Santa Fe Formation. Recharge occurs where runoff from precipitation in the upper portions of the watershed infiltrates into the basin alluvium deposits. Mountain-front recharge in the United States portions of the study area was evaluated using the Hearne-Dewey (1988) regression equation for mean annual recharge of a tributary basin. The Hearne-Dewey regression equation was developed, based on data for 16 basins in northern New Mexico, to estimate average annual basin water yield based on winter precipitation, basin slope, and basin area. The Hearne-Dewey (1988) regression analysis yielded mountain-front recharge rates of about 9,360 AF/year and 5,430 AF/year for the Rincon and Mesilla basins respectively. (Page 97 paragraph 3 and Page 99 paragraph 3).*

Response:

The M&A estimates of mountain front recharge are input as specified inflows around the lateral boundaries of the Texas Model. A comparison of the annual M&A mountain front recharge estimates against the annual mountain front recharge in the Rincon and Mesilla basins in the ILRG Model is provided in **Figure 12-11**.

The annual combined mountain-front recharge for the Rincon and Mesilla basins in the ILRG Model averages 15,700 AF during 1951 - 2016 compared to 14,800 AF in the Texas Model. Given that the average difference of 900 AF/y is only 0.03 % of the total inflows to the Texas Model and the mountain front recharge is not varied in alternative model runs, the differences in mountain front recharge between the Texas Model and the ILRG Model is not significant.

M&A Opinion 8 – *I was asked by counsel to develop farm water budget for two agricultural districts located in El Paso Valley, Texas to support economic analyses by Dr. David Sunding and Dr. Lydia Dorrance. The two districts are El Paso County Water Improvement District #1 (EPCWID#1) and Hudspeth County Conservation and Reclamation District 1 (HCRRD1). EPCWID#1 has lands in both Mesilla Basin and El Paso Valley; this* *farm budget considers only the portion of EPCWID#1 located in El Paso Valley. For the analysis, a farm water budget was developed for agricultural lands in EPCWID#1 and HCRRD1 with the principal goals of estimating (1) agricultural groundwater pumping for irrigation and (2) deep percolation beneath agricultural fields. Due to the lack of historic direct measurements of agricultural applied groundwater (pumping) and agricultural deep percolation, soil water balance models were used to estimate these components, along with surface runoff and soil moisture changes on agricultural lands. The soil water balance models were developed and implemented using GoldSim simulation software. Model results were used to prepare the farm water budgets for EPCWID#1 and HCRRD1. (Appendix G, Page 1, Paragraph 1).*

Response:

The monthly farm budget analyses prepared by M&A for the EPCWID (El Paso Valley) and the HCRRD (a.k.a. HDDRD1) for the period from 1985 - 2016 utilized the same soil water balance model as was used for the farm budget analyses of the Rincon and Mesilla basins. These farm budget analyses were compared to the SWE CFB Model analyses for the same areas to assess differences between the input data and results. The farm budget inputs and outputs during the 1985 - 2016 study period are compared in **Figure 12-12** through **Figure 12-14** for the El Paso Valley and **Figure 12-15** and **Figure 12-16** for the HCCRD.

<u>**El Paso Valley**</u>

Figure 12-12 compares the computed annual supplemental pumping in the M&A Farm Budget Model to the comparable values from the SWE CFB Model during the 1985 - 2016 period. The annual pumping in the M&A Farm Budget Model averages about 78,900 AF compared to an average of 14,300 AF in the SWE CFB Model, a difference of about 64,700 AF. The differences in supplemental pumping are due largely to differences in the ET of applied water between the models.

The simulated pumping in the M&A Farm Budget during the full supply years from 1985 - 2002 is unrealistically high considering the following:

- Full Project water allocations made by Reclamation (see **Table 4-3**),
- Unused EP1 allocations (see **Table 4-3**),
- High FHG deliveries per acre (see **Figure 5-12**), and
- High operational waste through this period (see **Figure 5-23**).

The upper right chart in **Figure 12-13** compares the maximum annual cropped area in the El Paso Valley in the M&A Farm Budget Model to the annual irrigated area in the SWE CFB

Model. The M&A Farm Budget Model simulates much greater irrigated area than the SWE CFB Model until the last ten years when the values are similar. On average, the M&A Farm Budget Model acres for the El Paso Valley are about 14% greater than SWE CFB Model acres.

The irrigated area figures used in the M&A Farm Budget Model were provided by Land IQ. Based on review of the Land IQ data files, it seems possible that the irrigated area data that M&A used for the El Paso Valley portion of EPCWID may also include the EPCWID irrigated area in the Texas portion of the Mesilla Valley. This would explain most of the difference in irrigated area between the models in the El Paso Valley.

The upper left chart in **Figure 12-13** compares the annual ET of applied water in the El Paso Valley. The annual ET of applied water in M&A Farm Budget Model is much larger than the SWE CFB Model values throughout the 1985 - 2016 period, averaging about 47% more. In some years, the ET of applied water in the M&A Farm Budget Model is almost double the SWE CFB Model values. The differences are due largely to differences in irrigated area, unit crop ET, and cropping pattern.

The lower left chart in **Figure 12-13** compares the area-weighted annual unit crop ET in the El Paso Valley for the M&A Farm Budget Model and the SWE CFB Model. The differences in the unit crop ET reflect the combined differences in cropping pattern and the unit irrigation requirements of the individual crops. The unit ET for the M&A Farm Budget Model was computed as the annual ET of applied water volume (shown in the upper left chart in **Figure 12-13**) divided by the maximum monthly irrigated area in that year (upper right chart in **Figure 12-13**). The unit ET values in the M&A Farm Budget Model average almost 30% greater than the SWE CFB Model values during 1985 - 2016.

The lower right chart in **Figure 12-13** compares the annual FHG delivery volumes that are simulated in the M&A Farm Budget Model of the El Paso Valley to the SWE CFB Model values. On average, the FHG deliveries in the M&A Farm Budget Model are about 11% less than the values in the SWE CFB Model. It appears that the reported 2010 FHG deliveries for the El Paso Valley may be in error. If these are corrected, the average difference will be larger than 11%.

A closer look at the differences in the annual FHG deliveries is shown in **Figure 12-14**. The small differences in FHG deliveries that are present from 1985 - 2008 are due to differences in how the records of total Eastside Canal and Westside Canal FHG deliveries were disaggregated between EBID and EPCWID. SWE disaggregated the FHG deliveries based on relative diversions and M&A disaggregated the deliveries based on relative irrigated area.

After 2008, the differences in FHG deliveries are more substantial, and except for 2010, in which the data used by M&A appear to be in error[7], the M&A FHG deliveries are much less than the SWE FHG deliveries. During this time (except for 2010), there are no FHG delivery data for the El Paso Valley or for EPCWID. SWE estimated the FHG deliveries after 2008 for the El Paso Valley based on the reported monthly El Paso Valley diversions reduced by monthly average conveyance loss percentages derived from historical records. M&A estimated the missing data by first estimating the Texas Mesilla FHG deliveries from data and estimates of EBID FHG deliveries, then extrapolating the estimated Texas Mesilla FHG deliveries to total EPCWID FHG deliveries, and finally pro-rating those values to estimates of the El Paso Valley FHG deliveries. The convoluted M&A procedure did not consider that EBID and EPCIWD FHG deliveries were no longer comparable on a per acre basis after the 2008 OA went into effect. As shown in the lower chart in **Figure 12-14**, the M&A procedure results in unrealistically low estimates of El Paso Valley FHG deliveries as a percentage of El Paso Valley canal heading diversions.

HCCRD

Figure 12-15 compares the computed annual supplemental pumping in the M&A Farm Budget Model to the comparable values from the SWE CFB Model during the 1985 - 2016 period. The annual pumping in the M&A Farm Budget Model averages about 19,400 AF compared to an average of 2,100 AF in the SWE CFB Model, a difference of about 17,300 AF. The differences in supplemental pumping are due largely to differences in the ET of applied water and differences in FHG deliveries between the models.

The simulated pumping in the M&A Farm Budget Model during the full supply years from 1985 - 2002 is unrealistically high considering the following:

- High FHG deliveries per acre (see **Figure 5-13**),
- High Ft. Quitman flows (see **Figure 5-3**), and
- High operational waste through this period (see **Figure 5-23**).

The upper right chart in **Figure 12-16** compares the maximum annual cropped area in the HCCRD in the M&A Farm Budget Model to the annual irrigated area in the SWE CFB Model. The irrigated figures are relatively comparable with the M&A Farm Budget Model acres averaging about 3% less than the SWE CFB Model acres.

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[7] As described in Section 6.4.5, Reclamation records of EPCWID FHG deliveries exceed canal heading diversions in many months and are assumed to be in error.

The upper left chart in **Figure 12-16** compares the annual ET of applied water in the HCCRD. The annual ET of applied water in M&A Farm Budget Model is larger than the SWE CFB Model values throughout the 1985 - 2016 period, averaging about 30% more. The differences are due largely to differences in unit crop ET and cropping pattern.

The lower left chart in **Figure 12-16** compares the area-weighted annual unit crop ET in the HCCRD for the M&A Farm Budget Model and the SWE CFB Model. The differences in the unit crop ET reflect the combined differences in cropping pattern and the unit irrigation requirements of the individual crops. The unit ET for the M&A Farm Budget Model was computed as the annual ET of applied water volume (shown in the upper left chart in **Figure 12-16**) divided by the maximum monthly irrigated area in that year (upper right chart in **Figure 12-16**). The unit ET values in the M&A Farm Budget Model average over 30% more than the SWE CFB Model values.

The lower right chart in **Figure 12-16** compares the annual farm headgate delivery volumes that are simulated in the M&A Farm Budget Model of the HCCRD to the SWE CFB Model values. On average, the farm headgate deliveries in the M&A Farm Budget Model are about 26% less than the values in the SWE CFB Model.

13.0 RESPONSE TO HUTCHISON REPORT

William R. Hutchison, Ph.D., P.E., P.G. prepared a May 31, 2019 expert report on behalf of the State of Texas ("Hutchison Report"). The subjects of the Hutchison Report are generally twofold. First, the report describes the development of a MODFLOW ground water model of the Rincon and Mesilla basins in New Mexico and small portions of Texas and Mexico ("Texas Model") over a study period from 1938 - 2016. Second, the report describes use of the Texas Model to simulate reduced pumping and other scenarios during all or portions of the historical study period. The Hutchison Report includes a main summary report, 17 technical memoranda detailing the development and calibration of the Texas Model, and 4 technical memoranda describing use of the model to simulate reduced pumping and other scenarios.

SWE was asked by legal counsel for New Mexico to review the input data sets for the Texas Model and the model simulations of the reduced pumping scenarios to identify information or opinions with which we disagreed, and to prepare expert opinions to respond these issues. We attempted to identify and respond to all substantive issues in which there appeared to be differences of opinion, however a lack of response to a particular issue should not be interpreted as tacit agreement with Dr. Hutchison's opinion(s).

Hutchison Opinion 1 *– The 1938 condition can be viewed as a combination of three elements: 1) minimal groundwater pumping, 2) a specific number of irrigated acres and a specific distribution of irrigated crops, and 3) a specific amount of irrigation water that was applied (expressed in terms of acre-feet of water per irrigated acre). Simulations with the Texas Model demonstrate that increases in groundwater pumping have had a larger impact to Rio Grande at El Paso flows than increases in agricultural consumptive use. (Page 12 paragraph 1).*

Response:

New Mexico's legal counsel have advised that a 1938 condition is not appropriate for characterizing the water entitlements of the states. Moreover, it would be inappropriate to define a 1938 condition based on historical operations in a single year as Dr. Hutchison does in his analyses.

Hutchison Opinion 2 *– Simulations with the 2007 OSE Model and the Texas Model demonstrate that groundwater pumping resulted in decreased flows in the Rio Grande. Brandes (2019) developed an estimate of hypothetical Rio Grande at El Paso flows that would have occurred under a "without the effects of groundwater pumping" condition.*

Brandes (2019) concluded that the average increase in flow as compared with historic flows from 1951 to 2017 is about 79,000 AF/yr. (Page 12 paragraph 2).

Response:

As described in the response to Brandes Opinion 10 in Section 11, the analyses of historical data by Dr. Brandes unreasonably attributed all changes in Rio Grande at El Paso flow that occurred after 1950 to the effects of New Mexico pumping and did not consider other factors that may have contributed to reductions in flow at El Paso. Likewise, the modeling by Dr. Hutchison does not consider these other factors.

Hutchison Opinion 3 *– Simulations with the Texas Model demonstrate that an overall 60 percent reduction in all pumping would result in a hypothetical increase in Rio Grande at El Paso flow of about 73,000 AF/yr from 1951 to 2016. About 81 percent of the increase (59,000 AF/yr) is attributable to New Mexico pumping, and about 19 percent of the increase is attributable to Texas pumping (13,000 AF/yr). (Page 12 paragraph 2).*

Response:

The reduced pumping simulations performed by Dr. Hutchison are unreasonable and unreliable because the Texas Model does not simulate the dynamic operational responses of the Project and the LRG Area irrigation systems that would occur if pumping was reduced or turned off.

The following is a summary of the changes in inputs that are specified to occur in each of Dr. Hutchison's reduced pumping simulations:

- Irrigation pumping is reduced by a specified percentage (10% to 100%),
- Non-irrigation pumping and the corresponding urban infiltration are reduced by the same percentage, and
- On-farm deep percolation is reduced proportionately based in the reduction in total irrigation supply (SW+GW).

The following are inputs that are not changed in the reduced pumping simulations:

- Releases from Project storage,
- Canal diversions of Project water, and
- Wastewater treatment plant discharges.

The following are the simulated responses in Texas Model resulting from the foregoing changes in model inputs:

- Increased ground water levels and ground water storage,
- Increased riparian ET,
- Increased drain flows,
- Reduced canal seepage and river seepage,
- Increased Rio Grande flow from increased drain flows and reduced river seepage.

Because the reservoir releases and canal diversions are fixed at the historical amounts in the alternative runs, all increases in Rio Grande flow accumulate as increased flow at the downstream end of the model at El Paso. This simple process of the additional river flow running out the bottom of the model is not what happens during the irrigation season in the real world when the supply changes. In the real world, reservoir releases are continually adjusted in response to changing conditions downstream so as to deliver the ordered amounts of water.

The system response to the additional flow that would be in the river with a reduction in pumping would vary depending on whether it occurred in a year with a full allocation of Project water or a year with less than a full allocation. In a year with a full allocation, deliveries of Project water are limited by either the allocated amount or the water demand. In either case, it is reasonable to assume that Project water deliveries in a full allocation year would be about the same in a reduced pumping scenario as they were in the historical operation. Therefore, during a full allocation year in a reduced pumping scenario, the additional flow in the river would allow Reclamation to reduce reservoir releases and still deliver the same amounts to the Project water users. The reduction in reservoir releases would accumulate additional water in storage that would be carried over and allocated to EBID and EPCWID in subsequent years. The additional reservoir storage would also result in increased evaporation due to the greater surface area in the reservoir and would also result in increased spills when the Project storage filled to capacity.

During non-full supply years, the additional water in the river and additional accumulated reservoir storage during prior full allocation years would lead to increased allocations and increased deliveries to Project water users.

Because the Texas Model does not include simulation of reservoir and Project operations, it has no capability to simulate the real-world responses of the Project including changes in allocations, reservoir releases, diversions, and farm headgate deliveries. As a result, the increased river flow that occurs in the reduced pumping scenarios simply runs downstream to El Paso. This causes the Texas Model to overstate the effects of pumping in the Rincon and Mesilla basins on the flow of the Rio Grande at El Paso. The lack of simulation mechanisms in the Texas Model for reasonable dynamic responses to the changes in supply that would occur under conditions that are different from historical conditions renders the results from the Texas Model simulation of alternative scenarios meaningless and not helpful in assessing the effects of reduced pumping or changed conditions on Project operations and deliveries to LRG water users.

Figure 13-1 and **Figure 13-2** were prepared to compare the simulated changes in El Paso flow from the Texas Model and the ILRG Model for the scenario in which all pumping in the Rincon and Mesilla basins is turned off. In each figure the simulated changes in flows in the ILRG Model are summarized to show the changes during March - October (blue bars) and the changes during November - February and during months that the Project storage is spilling (grey bars). The results from the Texas Model are shown as a colored line representing the annual change in El Paso flow (purple line for simulation of no pumping during 1951-2016 and orange line for simulation of no pumping during 1985-2016).

Figure 13-1 compares the simulated change in El Paso flow in the ILRG Model for the a scenario in which all pumping in the Rincon and Mesilla basins is curtailed to the Texas Model simulation of the comparable scenario The average annual change in El Paso flow in the Texas Model during 1985 - 2016 is 124,700 AF compared to 93,900 AF in the ILRG Model (of which 25,100 AF occurs during reservoir release periods and 68,800 AF occurs during the non-release season or during spills). The simulated change in flow in the Texas Model is substantially greater because most of the increased river flow in the no-pumping scenario flows downstream to El Paso. In the ILRG Model with a simulated dynamic response to the changes in river flow, the reservoir releases are reduced in full allocation years and some of the increased flow in non-full supply years is allocated to EBID and as a result, much less of the additional flow makes it to El Paso. The simulated annual changes in El Paso flow in the ILRG Model reflect the expected response of the Project operation with little increased irrigation season flow during full allocation years (e.g., during the much of the 1980s and 1990s). Conversely, in the Texas Model the simulated changes in annual El Paso flow are relatively steady as they represent increases in river flow without the re-operation of the Project.

Figure 13-2 is similar to **Figure 13-1** with the results from the ILRG Model shown for the scenario with no New Mexico pumping (i.e., the pumping in the Texas Mesilla area was left on). The simulated average annual change in El Paso flow in the ILRG Model during 1985 - 2016 of 74,400 AF is about 19,500 AF less than when all pumping in the Rincon and

Mesilla basins is turned off, and only 17,600 AF of the average annual change in flow occurs during periods when reservoir releases are occurring (excluding spills).

Hutchison Opinion 4 *– One of the components of the "1938 condition" is the irrigated acreage and associated consumptive use expressed as acre-foot per acre in 1938. As documented in Technical Memorandum 3, agricultural consumptive use in New Mexico has increased since 1938 as shown in Figure 1. This technical memorandum documents the results of five scenarios where agricultural consumptive use is limited to that of 1938. The simulations were run from 1938 to 2016, but the modifications were applied only after 1950 to provide a means of comparison with other scenarios.*

The agricultural pumping, agricultural deep infiltration, and surface water diversion components of the hypothetical consumptive use scenarios were developed by summing the consumptive use of 1938 (149,005 AF/yr) and the associated canal losses and farm-level infiltration associated with irrigation. For each year, this sum was viewed as a demand and was compared with the annual historic surface water diversions for agricultural use. If the historic surface water deliveries were higher than the new demand, the excess remained in the surface water system (i.e. surface water flow diversions were reduced as compared with historic levels). If the historic surface water deliveries were less than the new demand, groundwater pumping for irrigation was set equal to the deficit. The five scenarios involve alternative urban and domestic groundwater pumping:

- *Scenario 1: limit of 10,000 AF/yr*
- *Scenario 2: limit of 20,000 AF/yr*
- *Scenario 3: limit of 30,000 AF/yr*
- *Scenario 4: limit of 40,000 AF/yr*
- *Scenario 5: limit of 50,000 AF/yr*

(Technical Memo 20 - Page 1 paragraphs 1 and 2; and page 4 paragraph 2).

Response:

Dr. Hutchison's Technical Memo 20 describes simulations under a presumption that New Mexico is entitled to consume for irrigation the same amount of water that it was consuming in 1938, which he estimates was 149,005 AF. When the historical annual surface water diversions during the simulation period were insufficient produce 149,005 AF of irrigation consumptive use, it was assumed that New Mexico water users could pump water to eliminate the deficit. Conversely, if the surface historical water supply was more than needed to produce 149,005 AF of consumptive use, then the diversions were reduced by the excess amount.

New Mexico's legal counsel have advised that a 1938 condition is not appropriate for characterizing the water entitlements of the states. Moreover, it would be inappropriate to define a 1938 condition based on historical operations in a single year.

The Alternative Consumptive Use scenarios imply that New Mexico should be limited to the irrigation consumptive use that allegedly existed in 1938 (149,005 AF), even if that means that New Mexico would have to reduce its use of Project water. However, Texas has provided no technical support for the notion that New Mexico's Project deliveries should be limited to the 1938 level.

Further, the simulations of reductions in New Mexico diversions of surface water in the Texas Model are nonsensical because there is not a corresponding reduction in simulated reservoir releases. Therefore, when the New Mexico diversions are reduced, the volume of the reduced diversion is left in the Rio Grande to run downstream to El Paso. In reality, if New Mexico's irrigation consumptive use was somehow limited under a 1938 condition, the reservoir releases would be reduced as necessary to limit the consumptive use of surface water and there would be no increase in El Paso flow during such years.

In addition, as described in the response to the reduced pumping scenarios, any change in pumping from what occurred historically would result in a dynamic response of the Project operation that would change the available surface water supply resulting in changed Project water allocations, diversions, and deliveries to Project water users. The Texas Model is not capable to simulating this dynamic response.

Because of the limitations of the Texas Model, the results of the simulations described in in Technical Memorandum 20 are of little value in assessing any alternative consumptive use scenarios based on a 1938 condition or otherwise.

It is unclear if the Alternative Consumptive Use scenarios are presented to illustrate Dr. Hutchison's analysis of how to achieve potential Compact compliance for New Mexico. It is also unclear whether Dr. Hutchison is proposing an analogous consumptive use cap for all Texas Project lands based on his 1938 condition.

***Hutchison Opinion 5** – The preferential use of surface water and the use of groundwater to meet demand deficits is the definition of conjunctive use. The simulations documented in this technical memorandum evaluated alternative hypothetical conjunctive use scenarios where historic groundwater pumping only occurred in years with less than specified amounts of surface water availability (i.e. pumping only in dry years to meet* *demand deficits). For purposes of these simulations, five scenarios were developed as follows:*

- *Scenario 1 assumed that groundwater pumping is zero when annual releases from Caballo are above 790,000 AF/yr (i.e. no pumping in 13 years, historic pumping in 66 years)*
- *Scenario 2 assumed that groundwater pumping is zero when annual releases from Caballo are above 700,000 AF/yr (i.e. no pumping in 30 years, historic pumping in 49 years)*
- *Scenario 3 assumed that groundwater pumping is zero when annual releases from Caballo are above 600,000 AF/yr (i.e. no pumping in 52 years, historic pumping in 27 years)*
- *Scenario 4 assumed that groundwater pumping is zero when annual releases from Caballo are above 500,000 AF/yr (i.e. no pumping in 60 years, historic pumping in 19 years)*
- *Scenario 5 assumed that groundwater pumping is zero when annual releases from Caballo are above 400,000 AF/yr (i.e. no pumping in 66 years, historic pumping in 13 years)*

(Technical Memo 21 - Page 2 paragraphs 1 and 5).

Response:

The Conjunctive Use scenarios described in Technical Memorandum 21 are similar to the 100% reduced pumping scenario described in Technical Memorandum 18 except that the pumping is only turned off in selected years rather than every year. Therefore, the same criticisms of the reduced pumping scenarios described above also apply to the Conjunctive Use scenario simulations. The lack of a mechanism in the Texas Model to simulate a dynamic response in the Texas Model to changing water supply renders the results of the Conjunctive Use scenarios as unreasonable.

It is also unclear if the Conjunctive Use scenarios are presented to illustrate Dr. Hutchison's analysis of how to achieve potential Compact compliance. It is also unclear whether Dr. Hutchison is proposing the same type of conjunctive use limits for Texas.

14.0 RESPONSE TO DORRANCE REPORT

Lydia R. Dorrance, Ph. D. prepared a May 31, 2019 expert report on behalf of the State of Texas ("Dorrance Report"). There were two primary subjects covered in the Dorrance Report. First, the report described analyses to translate simulated changes in the annual flows of the Rio Grande at El Paso flow computed by the Texas Model into changes in monthly surface water deliveries to EPCWID farmers in the El Paso Valley, farmers in the HCCRD, and municipal water users in the EPW service area. Second, the report described the effect that changes in the monthly surface water deliveries would have on the salinity of the mixed surface water and ground water supplies of farmers and municipal water users.

SWE was asked by legal counsel for New Mexico to review the analysis by Dorrance to translate modeled annual changes in El Paso flows into changes in deliveries of surface water to irrigation and municipal water users in the El Paso Valley to identify information or opinions with which we disagreed, and to prepare expert opinions to respond these issues. We attempted to identify and respond to all substantive issues in which there appeared to be differences of opinion, however a lack of response to a particular issue should not be interpreted as tacit agreement with Dr. Dorrance's opinion(s).

Dorrance Opinion 1 – *Modeling results provided by Dr. Bill Hutchinson demonstrate that in an alternative scenario in which pumping in the Rincon and Mesilla Valleys is reduced every year between 1985 and 2016 by 60% relative to that which was historically recorded, surface flow at El Paso increases. I evaluated how this increase in flow would impact the salinity of water applied for agriculture in EP1 and HCCRD1 under the alternative scenario. (Page 19 paragraph 3).*

Response:

The modeling results provided by Dr. Hutchison and used by Dr. Dorrance in her analysis were from a scenario in which 60% of all pumping in the Rincon and Mesilla basins was reduced, including irrigation and municipal pumping in the Texas portion of the Mesilla basin (including the Canutillo wellfield pumping). Therefore, the analyses by Dr. Dorrance of the effects of increased El Paso flows on deliveries to Texas users do not represent the effects of New Mexico pumping because they also include the effects of Texas Mesilla pumping. This results in inflated impacts attributed to New Mexico pumping that also inappropriately inflate the subsequent damage analyses by Dr. Sunding that are based on the results from the Dorrance analysis.

In addition, because of the absence of re-operation of the Project in Dr. Hutchison's modeling of the reduced pumping scenarios, the additional annual flows from simulation of the 60% reduced pumping scenario that Dr. Dorrance used in her analysis are unreliable and unusable for estimating the impacts of New Mexico pumping on irrigation and municipal water users in Texas.

In addition to the improper attribution of effects of pumping in the Texas portion of the Mesilla basin to New Mexico ground water pumping and the lack of re-operation of the Project in the Texas modeling results, the following additional responses are presented to the analyses by Dr. Dorrance.

Dorrance Opinion 2 *– The additional Rio Grande at El Paso flow in any given month would be delivered to EP1 under the Rio Grande Project. The delivery of additional water to EP1 would also result in additional surface water being made available for HCCRD1, and the historical ratio of surface water use between EP1 and HCCRD1 would remain unchanged in the alternative scenario. This assumption is supported by the clear positive correlation between discharge at El Paso and surface water use by to both EP1 and HCCRD1, such that both districts receive more surface water in years with greater flow at El Paso (See Figure 4). (Page 19 paragraph 4).*

Response:

Because the Texas Model operates with annual stress periods, Dr. Dorrance had to disaggregate the additional annual flows at El Paso from the Texas Model into monthly values introducing further error and uncertainty in her analysis. This disaggregation was based on percentages computed as historical monthly El Paso flows divided by the annual El Paso flow in each year. This presumes that the additional Rio Grande flow at El Paso that may result from a reduction in pumping in the Rincon and Mesilla basins would accrue in the same monthly proportions as the historical flows. However, Dr. Dorrance did not present any evidence to support this assumption.

It is possible that the additional flows with a reduction in upstream pumping would arrive with significantly different monthly timing. For example, the additional flow might allow the districts to begin reservoir releases earlier in the year, or to save water in storage for an additional release of water later in the irrigation season. In a full supply year, there may be no additional flow in any months because no additional deliveries would be appropriate in such a year. This is an example of why a model capable of simulating the dynamic response of the system to changes in supply is needed.

Further, the analysis by Dr. Dorrance presumes that nearly all of the simulated additional flow at El Paso in the reduced pumping scenario would be available for use by EPW, EPCWID, and HCCRD. This is contrary to the historical records that show on average only 64% of the monthly flow, after delivery of water to Mexico at the Acequia Madre, was delivered for use by EPW, EPCWID, and HCCRD during the March - October period in non-spill years.

Historical records of the monthly and annual flows of the Rio Grande at El Paso (less deliveries to Mexico) are shown in the black line in **Figure 14-1**. The monthly and annual deliveries to EPW, EPCWID, and HCCRD are shown in the stacked bars in **Figure 14-1**. The reason that an average of only 64% of the adjusted flow at El Paso was delivered to the Texas water users is because of the conveyance losses and other inefficiencies in the EPCWID and HCCRD delivery systems. Note that the 2010 historical farm delivery amounts in the Dorrance analysis are suspect as the sum of the deliveries significantly exceeds the total flow at the El Paso gage.

Figure 14-2 contains similar graphs showing the monthly and annual increased El Paso flows simulated in the Texas Model as a result of a 60% reduction in the Rincon-Mesilla pumping from 1985 - 2016 (black line) and the portions of that flow that Dr. Dorrance computed to be available for delivery to EPW, EPCWID, and HCCRD (stacked bars). The graphs show that Dr. Dorrance made available almost all of the additional flow at El Paso for delivery to the Texas water users. On average, 97% of the increased El Paso flow was determined by Dr. Dorrance to be available for delivery to Texas water users during the March - October period compared to the historical average of 64% of the El Paso flows that were actually delivered to Texas water users. Note that Dr. Dorrance also did not make any of the simulated increases in El Paso flow available for delivery to Mexico.

Finally, **Figure 14-3** compares the simulated increased monthly and annual El Paso flows (black line) and the amount of the increased flow that Dr. Dorrance estimated would actually be delivered for use by EPW, EPCWID, and HCCRD (stacked bars). The amount of the increased El Paso flow available to EPW in **Figure 14-3** that would have been delivered for use by EPW was limited so that the sum of the historical delivery plus the increased delivery did not exceed the historical maximum monthly EPW deliveries. The amounts of the increased El Paso flow delivered to EPCWID and HCCRD were limited to the simulated historical pumping by each district. In other words, it was assumed that each district would use the same amount of water that they did historically (surface water plus estimated pumping) and the additional surface water deliveries would only replace the portion of their supply that was historically pumped. As indicated in **Figure 14-3**, during many years most or all of the increased El Paso flow is assumed by Dr. Dorrance to be delivered for use during many or all months of the irrigation season. The full amount of the increased flow at El Paso (100%) was assumed delivered to the Texas water users in 37% of the March - October study period months. The full amount of the additional El Paso flow is assumed by Dr. Dorrance to be delivered to Texas users when there is sufficient historical unmet demand (i.e., historical pumping that can be replaced by surface water deliveries). In months that the simulated increased El Paso flow is greater than the total historical unmet demand, the excess El Paso flow goes undelivered in the Dorrance analysis, apparently as an increase in operational waste.

It is unreasonable for Dr. Dorrance to assume that most or all of the increase in El Paso flow that would occur by reducing pumping in the Rincon and Mesilla basins could be delivered for use by Texas water users undiminished by conveyance loss (i.e., as indicated in **Figure 14-3** when the stacked bars reach or nearly reach the black line). As a result, Dr. Dorrance's analysis overstates the effect that a reduction in pumping in the Rincon and Mesilla basins would have on increasing the supply of surface water to Texas users that they could use to replace what they historically pumped. Because the increase in deliveries to Texas water users from a reduction in Rincon-Mesilla pumping is overstated, so too are the computed damages from that pumping on Texas water users computed by Dr. Sunding.

Dorrance Opinion 3 *– In a given month and year, applied agricultural water in EP1 and HCCRD1 consists of a combination of surface water and groundwater (and can consist of exclusively surface water or groundwater) and groundwater is pumped to compensate for the shortfall between surface water agricultural application and total agricultural water application. In other words, groundwater is only pumped when there is not enough surface water delivered. (Page 19 paragraph 5).*

Response:

Figure 14-4 compares the annual changes in El Paso flow that Dr. Dorrance obtained from the Texas Model simulation of a 60% reduction in pumping in the Rincon and Mesilla basins during 1985 - 2016 to the simulated annual changes in El Paso flow from the ILRG Model simulation of the No New Mexico Pumping scenario. The average annual changes in El Paso flow during 1985 - 2016 are similar, with the Texas Model average being approximately 4% less than the ILRG Model average. While changes in flow are similar, the amounts of pumping turned off to produce the changes in flow were substantially greater in the ILRG Model than in the Texas Model. Because of the re-operation of the Project in the ILRG Model, a significant portion of the increased river flow in the no-pumping run was allocated to and used by EBID water users. The simulated change in flow at El Paso in the ILRG Model reflects increased allocations and deliveries to EPCWID and JID, increased winter flows and increased spills. Conversely when pumping is turned off in the Texas Model, most of the increase in river flow runs downstream to El Paso because there is no re-operation. Therefore, turning off a smaller amount of pumping in the Texas Model can produce a similar increased in average flows at El Paso as turning off a larger amount of pumping in the ILRG Model.

Figure 14-5 through **Figure 14-7** compare the increased deliveries to Texas users (EPCWID for irrigation, EPW, and HCCRD) computed by Dr. Dorrance from the Texas Model simulated increased El Paso flows against the comparable changes in Texas deliveries from the ILRG Model simulation of the No New Mexico Pumping scenario. In each figure, the annual changes from the Texas analyses during 1985 - 2016 are shown as an orange line and the annual results from the ILRG Model are shown as blue bars.

Figure 14-5 compares the estimates by Dr. Dorrance of changes in deliveries to EPCWID irrigation users in the El Paso Valley to the simulated changes in deliveries from the ILRG Model. The average annual change in deliveries from the ILRG Model (4,100 AF) is much less than the Dorrance estimate (28,000 AF). The reasons for the differences are primarily three-fold. First, as described previously, Dr. Dorrance makes virtually all of the simulated increase in El Paso flow available for delivery to the Texas users without conveyance losses. Second, contrary to the ILRG Model, the M&A farm budget analysis shows substantial unmet demand in all years during the historical period and so the additional flow in the reduced pumping scenario is used to meet the unmet demand. Third, much of the simulated increase in flows in the ILRG Model occurs during the non-release season and during spills, and so these supplies are not usable to meet unmet irrigation demands that may exist.

Figure 14-6 compares the changes in simulated deliveries to EPW between the Dorrance analysis and the ILRG Model. The Dorrance analysis shows much greater changes in EPW deliveries because she assumed EPW would receive certain percentages of the simulated additional El Paso flow. Conversely, the ILRG Model delivers additional flow to EPW only in years when there is an increase in the EPCWID Project water allocation. Because there were full allocations during 1985 - 2002, there are no simulated increases in allocations in these years and therefore no simulated increases in deliveries to EPW.

Figure 14-7 compares the changes in simulated deliveries to HCCRD between the Dorrance analysis and the ILRG Model. The Dorrance analysis shows much greater changes in HCCRD deliveries because she assumed HCCRD would receive certain percentages of the simulated additional El Paso flow to replace the M&A estimates of historical pumping. Conversely, the ILRG Model delivers additional flow to HCCRD only when there is unmet demand which is rare during most years during the 1985 - 2016 period.

Dorrance Opinion 4 – *The ratio of surface water supplied to the City of El Paso and the El Paso Valley irrigation districts (EP1 and HCCRD1) for a given month would be the same in the alternative scenario as was historically observed. This ratio can therefore be used to allocate excess surface water in the alternative scenario between the City of El Paso and the El Paso Valley irrigation districts. However, if, based on this partitioning, the City of El*

Paso's surface water delivery would exceed its maximum recorded delivery for a given month (as described below), the surplus would be allocated to the El Paso Valley irrigation districts. (Page 20 paragraph 2).

Response:

It is unreasonable to assume that the historical proportions between monthly El Paso flows and monthly EPCWID deliveries, EPW deliveries, and HCCRD deliveries would be preserved as to any increased El Paso flows. For example, HCCRD receives as its supply waste and drain flows leaving the EPCWID service area. The flows to the HCCRD can be significantly variable in response to the amount of water leaving the EPCWD service area. It is unreasonable to assume that a large historical spike in the historical supply reaching the HCCRD would be proportionally increased by any additional flow that the EPCWID would have available. It is more likely that the EPCWID would not waste more water, but rather would take delivery of that water at times it could be more beneficially used.

In addition, it is our understanding that EPW has been selling water to HCCRD since at least 2001 (Lopez, 2019). The historical records of deliveries to HCCRD likely reflect these deliveries, and therefore the proportioning method used by Dr. Dorrance would improperly allocate a proportion of the increased El Paso flow to HCCRD because of these sales.

In summary, the methodology applied by Dr. Dorrance over-allocates and improperly distributes the increased annual El Paso flows from the Texas Model (that have already been shown to be unreliable) among EPW, EPCWID, and HCCRD1. Therefore, the results from the Dorrance analysis are unreliable and unsuited for use in the analyses of economic damages that were conducted by Dr. Sunding.

In order to reasonably estimate the timing and amount of increased surface water deliveries to the Texas water users that would occur in a reduced pumping scenario, it is necessary to simulate this scenario using a robust model like the ILRG Model that is capable of simulating the dynamic response of the Project and the LRG irrigation systems to changes in flow. It is essential that such modeling include simulation of the El Paso Valley downstream of El Paso rather than using simple historical proportions.

15.0 RESPONSE TO SUNDING REPORT

David L. Sunding, Ph.D. prepared a May 31, 2019 expert report on behalf of the State of Texas ("Sunding Report") that describes his analysis of economic damages to Texas resulting from excessive pumping in New Mexico during the years 1985 - 2016. Damages were computed to agricultural water users, customers of the EPW, and to the broader West Texas regional economy.

SWE was asked by legal counsel for New Mexico to review Dr. Sunding's description of El Paso municipal water use and his characterization of the effects of excessive New Mexico pumping on Texas water users to identify information or opinions with which we disagreed, and to prepare expert opinions to respond these issues. We attempted to identify and respond to all substantive issues in which there appeared to be differences of opinion, however a lack of response to a particular issue should not be interpreted as tacit agreement with Dr. Sunding's opinion(s).

Sunding Opinion 1 *– Because of the seasonal nature of surface water deliveries, the configuration of El Paso's conveyance system differs between the summer irrigation season and the rest of the year. Figure 7 shows the typical distribution of water supply in El Paso during summer and winter, respectively. The map on the left side of Figure 7 shows how the city delivers water when surface water is available. The southern parts of the city are delivered surface water from the Jonathan Rogers Water Treatment Plant as shown in grey, and the central parts of the city are delivered surface water from the Robertson/Umbenhauer Surface water treatment plant as shown in Orange. The northwestern parts of the city are delivered shallow groundwater from the Upper Valley Water Treatment Plant supplied by the Canutillo Wellfield. However, the righthand panel shows the distribution pattern that is typical in winter, and also during periods of summer when surface water is unavailable. (Page 24 paragraph 2)*

Response:

The map in Figure 7 of the Sunding Report gives the impression that there are distinct areas where Project water is delivered when it is available. In reality, the delivery of water to various portions of the City varies continuously depending on the relative amounts of water available from the City's sources and fluctuations in water demand. In addition, there are not bright lines between where surface water is delivered and ground water is delivered. According to John Balliew (EPW president and CEO), different water sources can mix in the distribution system and a blend of surface water and ground water is delivered to many areas when surface water is available (Balliew, 2019 p. 21).

Sunding Opinion 2 *– Figure 8 shows the average production of water in El Paso for each month of the year. Water use in El Paso is highest during summer, when high temperatures cause demand for irrigation and cooling to peak. During summer EPWU can cover this peak demand with surface-water from the Rio Grande during years that it receives its full allocation of project water. During winter, demand is significantly lower, less than half of peak summer demand. The city has to rely entirely on groundwater during the winter when there are no surface water deliveries. However, because the peak in summer demand often outstrips available supply from the Rio Grande, groundwater demand also peaks during the summer. As a result, any shortfalls in Rio Grande supply during summer require additional capital investments in groundwater capacity to make up the difference. (Page 25 paragraph 1)*

Response:

Project water supplies can be very low during extended drought periods with or without the effects of New Mexico pumping. EPW's drought planning is based on a conservative assumption that no project water would be available to meet the peak summer demand (Balliew, 2019; pp. 210-211, 276). This condition could exist with or without pumping impacts on Project supplies. In very dry years with low Project water allocations, the typical operational practice is to aggregate the Project releases into two or three short releases during the irrigation season to minimize river conveyance losses. During such years, the reservoir gates can be shut for weeks at a time with no Project water deliveries. During these periods of no Project water deliveries, which can occur during times of peak summer demand, the EPW would have to meet its water demands solely from ground water pumping. Therefore, the City's ground water infrastructure would be necessary without or with the effects of New Mexico pumping.

Sunding Opinion 3 *– To evaluate the economic impacts on Texas from New Mexico's excessive groundwater pumping, I compare the historical deliveries of Rio Grande water above El Paso to a hypothetical scenario that assumes New Mexico significantly reduced groundwater pumping. The hypothetical water supply scenario was provided to me by Dr. Bill Hutchison and it assumes a 60 percent reduction in New Mexico groundwater pumping between 1938 and 2016. Figure 9 shows the historical and hypothetical Rio Grande flows at the border and is taken directly from Dr. Hutchison's calibrated model. The difference between water supply scenarios is most pronounced during dry years. Dr. Hutchison's model shows that under this hypothetical scenario, between 1985 and 2016, an additional 71,000 acre-feet of water would flow across the Texas-New Mexico border on average each year. (Page 27 paragraph 2)*

Response:

The historical and simulated annual Rio Grande at El Paso flows are from Dr. Hutchison's simulation of 60% reduction of all pumping in the Rincon and Mesilla basins, including irrigation pumping in the Texas portion of the Mesilla basin, and the municipal pumping from the Canutillo wellfield. As a result, Dr. Sunding's analyses of Texas damages in the El Paso Valley inappropriately includes damages from pumping by Texas farmers in the Mesilla basin and by City of El Paso pumping from the Canutillo wellfield.

Note that the 71,000 AF/y of average additional El Paso flow is an annual figure comprised of flows in both the irrigation season and non-irrigation season. The simulated increased flows at El Paso from the Texas Model and the disaggregation of these flows by Dr. Dorrance to increased deliveries to EPW, EPCWID, and HCCRD are unreliable and overstated for the reasons described in Sections 13 and 14 above.

Sunding Opinion 4 *– Excessive groundwater pumping in New Mexico caused EPCWID and HCCRD to receive reduced deliveries from the Rio Grande; consequently, they must deliver less surface water to their agricultural customers. In her expert report, Dr. Dorrance estimates that every additional 100 acre-feet of water delivered to the Texas-New Mexico border results in EPCWID and HCCRD delivering 58 and 20 additional acre-feet respectively to each of their districts. Dr. Dorrance's numbers indicate that had New Mexico reduced its excessive groundwater pumping, EPCWID and HCCRD would have delivered an average of around 45,000 and 14,000 additional acre-feet of water, respectively, every year between 1985 and 2016. (Page 30 paragraph 1 and 2)*

Response:

As described in Section 14, the portion of Hutchison's modeled increase in flow at El Paso that would be delivered to EPCWID, HCCRD, and EPW is overstated because Dr. Dorrance assumed that virtually all of the increased El Paso flow would be available for delivery to Texas water users without loss. This compares to the historical deliveries that averaged 64% of the flow at El Paso using the historical flow data presented in the Dorrance report.

Dr. Sunding misstates the results of the Dorrance analysis when he asserts the analysis showed that deliveries to EPCWID would increase by 45,000 AF/y and deliveries to HCCRD would increase by 14,000 AF/y in every year between 1985 – 2016. These are average annual increases in deliveries from the analysis by Dr. Dorrance. Further, as described previously, the Dorrance results are unreliable because they are based on results from Dr. Hutchison's Texas Model that lack the capability to re-operate the Project and LRG irrigation systems in response to changes in water supply.

Sunding Opinion 5 *– EPWU conjunctively uses groundwater and surface water to meet its demands. There is seasonality in EPWU's water supply portfolio. The share of customers supplied by surface and groundwater changes throughout the year, as previously shown in Figure 8, and also between wet and dry years. During the irrigation season, EPWU delivers the available surface water supply to its customers, and then pumps groundwater to meet remaining demand. (Page 45 paragraph 2)*

Response:

The chart in Figure 8 of the Sunding Report shows the monthly average EPW production of surface water and ground water. **Figure 15-1** shows the same information for each month of each year of the period from 1985 - 2016. As shown in this closer look of EPW production, monthly surface water deliveries vary significantly from month to month and year to year. During the full supply years of the 1980s, EPW's peak monthly Hueco pumping approached 10,000 AF per month. During the recent dry years, there was only one month with Hueco pumping in excess of 10,000 AF. Based on these comparisons there seems to be little connection between the peak monthly Hueco pumping and EPW's use of Project water.

The characterization that EWPU delivers surface water supply to customers and then pumps ground water to meet remaining demand may be true for portions of the EPW operations. However, based on EPW's current infrastructure, certain areas of the city are supplied only by ground water and many areas receive a blend of ground water and surface water when surface water is available (Balliew, 2019 p 21).

Sunding Opinion 6 *– Since the shallow wells in the Upper Valley in the Mesilla Aquifer are hydraulically connected to flow in the Rio Grande, my estimates assume that all additional groundwater comes out of wells in the Lower Valley wells, connected to the Hueco aquifer. (Page 47 paragraph 2)*

Response:

EPW operates its water supply sources to meet demands that vary throughout its service area. Because of the interconnected distribution system, many areas of the City receive a blend of water from different sources depending on the available supply, particularly the available surface water supply. As to the Canutillo wellfield, pumping from this source is generally used in the northwest portion of the City, but is also delivered into the downtown area when surface water supplies are limited. (Balliew, 1999 p. 189)

Sunding Opinion 7 *– In 2007, El Paso Water in partnership with the Fort Bliss military base, opened a state of the art desalination plant, which uses reverse osmosis to remove salts* *from brackish groundwater. The plant uses five reverse osmosis skids, which give it a maximum capacity of 27.5 MGD. The construction of the Kay Bailey Hutchison desalination plant cost $91 million, which I have omitted from my analysis because the plant was partially built for strategic military purposes. However, the economic case for continued operation of the plant is not, and instead is a result of unreliable supply of the Rio Grande water during peak summer months. In my discussions with EPWU's President and CEO John Balliew, he stated that the decision to operate Kay Bailey Hutchison was marginal, and that if EPWU had received a more reliable supply of water, then the plant would have been removed from active use and put into a condition of long-term preservation. (Page 48 paragraph 2)*

Response:

The Kay Bailey Hutchison Desalination Plant ("KBH Plant") was built for a variety of reasons, not solely because of low surface water supply in drought years. Importantly, the KBH Plant prevents brackish water intrusion into freshwater portions of the Hueco Bolson. John Balliew testified that it would be necessary to operate the KBH Plant even if EPW had more surface water because of the function of the KBH Plant to manage the brackish water intrusion problem (Balliew, 2019 p. 277).

Deliveries of surface water from the Project to EPW will never be reliable with or without New Mexico pumping due to the unreliable nature of snowmelt and rainfall runoff upstream of Elephant Butte Reservoir. Further, the records of EPW water production indicate that the KBH Plant operates in years of high and low deliveries of Project water to EPW. Since 2008 (the first full year of operation of the plant), the plant delivered an average of about 4,200 AF/y in the 5 years with surface water deliveries greater than 50,000 AF/y and an average of 5,900 AF/y in the 4 years of surface water deliveries less than 50,000 AF/y. While this shows some increased use of the plant in years of low surface water deliveries, it also shows that it would be unreasonable to attribute the continued use of the plant solely due to the effects of New Mexico pumping.

Sunding Opinion 8*– Prior to 2003, El Paso had many groundwater wells in the lower valley which had fallen into disuse, either because they required maintenance and rehabilitation in excess of their costs or because they produced water with levels of arsenic and salt above Safe Drinking Water Act standards. As a result of increasingly unreliable Rio Grande deliveries during months of peak summer demand, the city decided to rehabilitate many of these wells, even going so far as to begin a program of installing reverse osmosis wellheads at 11 previously productive wells which had suffered brackish water intrusion. (Page 50 paragraph 1).*

Response:

The reduction in Project water deliveries that commenced in 2003 was due in large part to a severe multi-year drought that affected the Lower Rio Grande Basin. As shown in **Figure 5-1**, the inflows to Elephant Butte Reservoir at the San Marcial Gage have been below average during most years since 2003. Further EPW's drought planning assumes that there will be no surface water available to meet peak summer demands. As a result, it is unreasonable to attribute the cost to rehabilitate wells when the drought commenced to the effects of New Mexico pumping. The EPW wells would have needed to be rehabilitated with or without the effects of New Mexico pumping.

Sunding Opinion 9 *– As discussed in Section III.E, the Franklin Mountains, lying between the northwest parts of El Paso and the rest of the city, present a major geographical barrier to water distribution in the area. To bridge this divide the city undertook a series of investments to improve conveyance of water between groundwater wells in the Mesilla Aquifer and downtown El Paso, which is typically served in summer by surface water. The Paisano Water Line brings water from the Upper Valley Water Treatment Plant along Paisano Drive to be distributed in Downtown and East El Paso. The old Paisano line had reliability issues, which led El Paso Water to decide to replace it in 2013. During droughts, when there was peak demand and no surface water available to supply downtown El Paso, the line was a bottleneck for transmitting water from the Upper Valley WTP to downtown El Paso. Consequently, El Paso Water decided to replace the line with a 48" pipe rather than the 36" pipe that previously existed. The incremental cost of installing the larger pipe was $1.54 million in 2016 dollars. There was an additional bottleneck in distributing water that supplied the Upper Valley Treatment Plant from the Canutillo wells. Building a water transmission line to break this bottleneck and supply additional water to the city during drought periods cost the city $14.56 million in 2016 dollars. El Paso Water also drilled two wells supplying Upper Valley Water Treatment Plant in 2011, near the peak of a major drought. Wells 208 and 312 were drilled and installed at a cost of $1.77 million in 2016 dollars. (Page 51 paragraph 3-5).*

Response:

The deposition testimony of John Balliew directly contradicts the Dr. Sunding opinion about why the capacity of the Paisano Water Line was increased. Balliew testified that the capacity of the original 36-inch pipeline was sufficient to deliver water from the Canutillo wellfield south and into the downtown El Paso area. The reason that the pipeline capacity was enlarged was to be able to deliver additional surface water from the Robertson/Umbenhauer WTP to areas further north that are currently supplied by the Canutillo wellfield. (Balliew, 2019 p. 320-321).

Sunding Opinion 10 *– Surface water that EPWU delivers to its customers is less salty than groundwater. According to data provided by EPWU, the average salinity of its delivered surface water is 675 mg/L TDS and the average salinity of its delivered groundwater is 862 mg/L TDS. This difference of 187 mg/L TDS in salinity over a prolonged period of time imposes a cost on customers. Based on data from Dr. Dorrance, under the hypothetical scenario, the share of surface water delivered to customers would increase by 7.6 percent. As seen in Figure 7, these additional surface water deliveries would be localized to specific parts of the city. Based on these observations, I assume that 7.6 percent of EPWU's customers would experience a reduction in salinity in the hypothetical scenario from 862 to 675 mg/L TDS. This share of the customer base corresponds to 13,890 residential accounts, 1,453 commercial and municipal accounts and 11 industrial accounts. (Page 53 paragraph 2)*

Response:

Dr. Sunding appears to assume that an average 7.6% increase in EPW's surface water supply without New Mexico pumping would result in 7.6% of EPW customers experiencing a reduction in salinity because their supplies would be converted from ground water to surface water. Assuming EPW did receive an increase in surface water without New Mexico pumping it seems unlikely that particular customers would see their supply switch from ground water to surface water. Instead, any increases in surface water would affect the blend of surface water and ground water that many customers receive.

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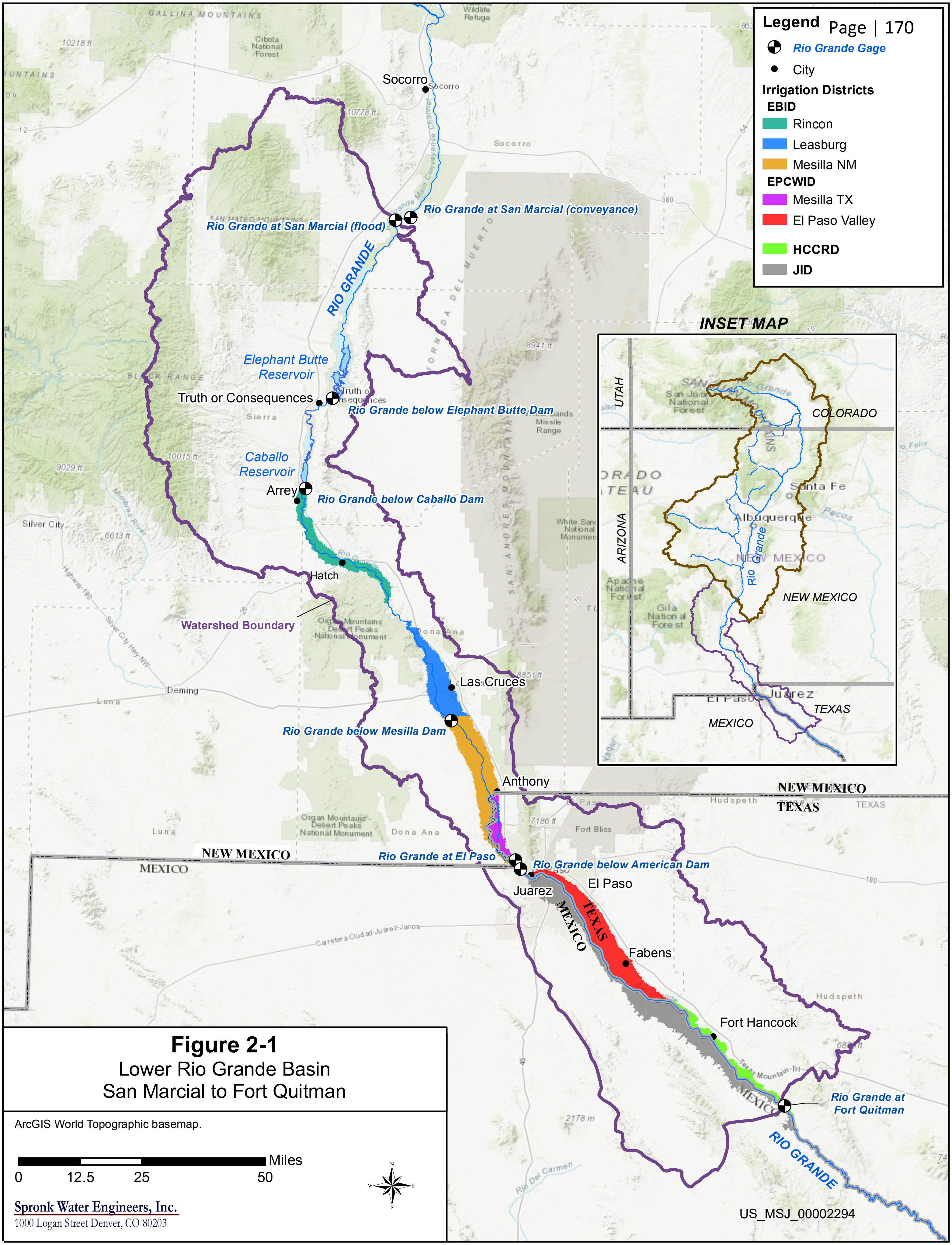
FIGURES



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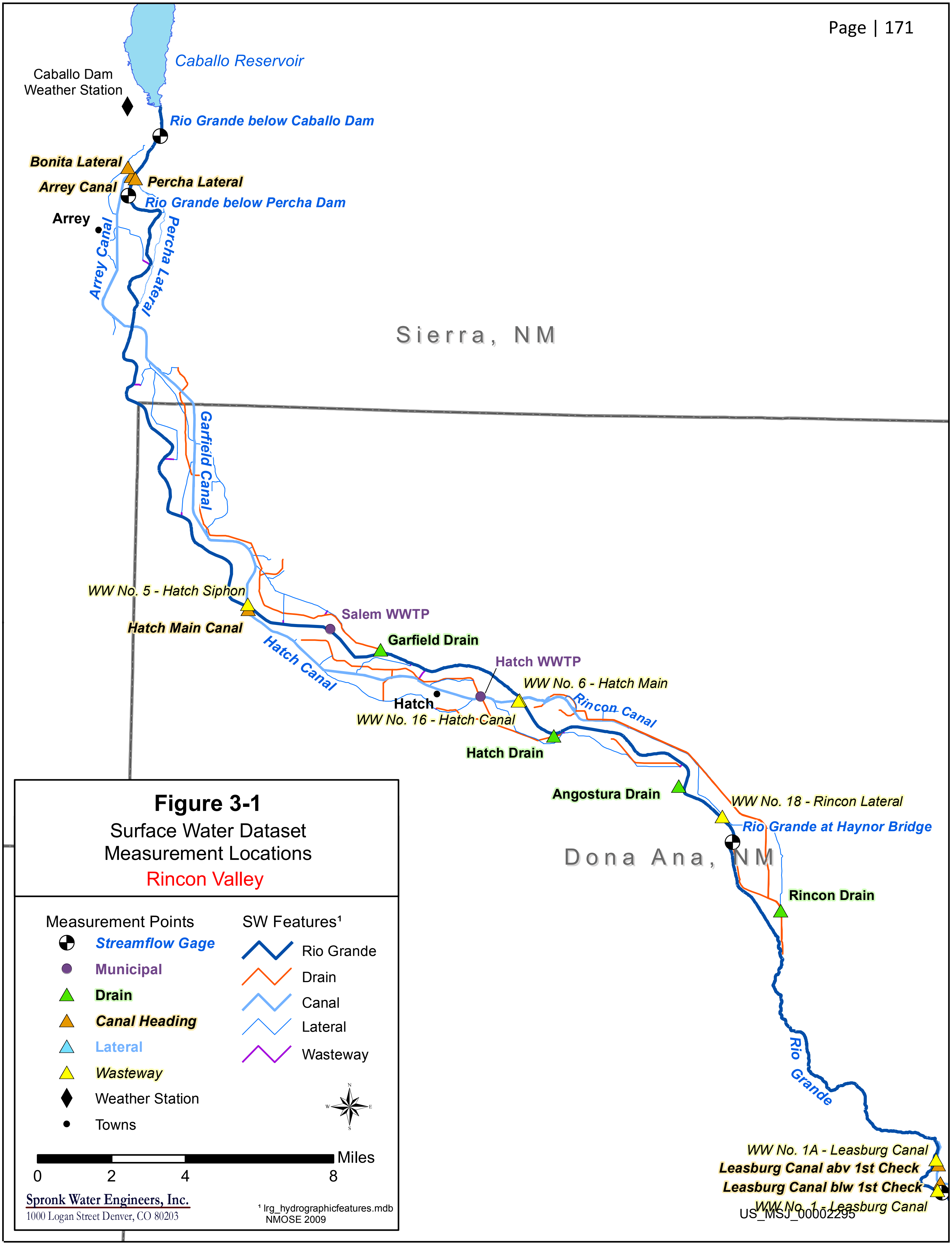
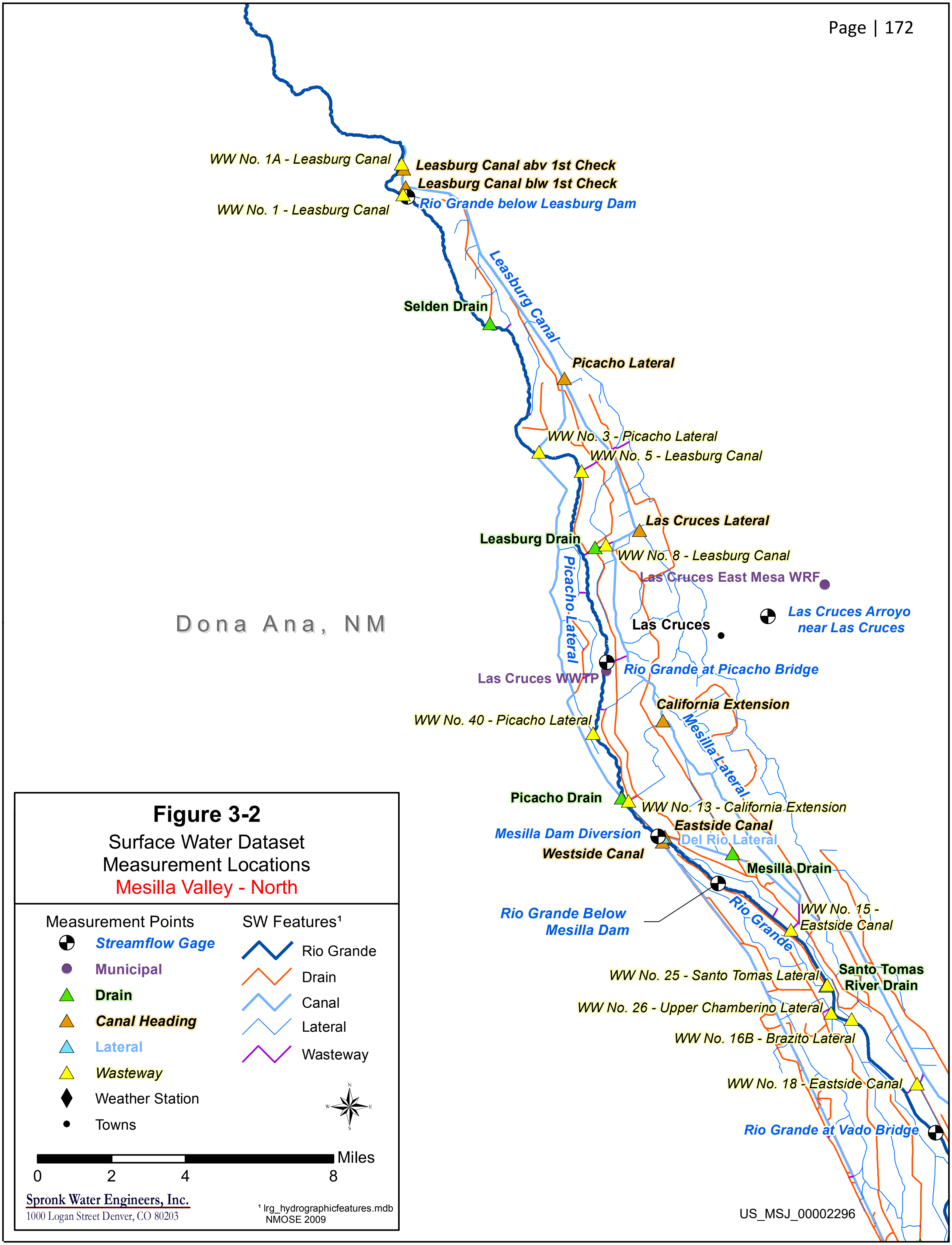


Figure 3-1
Surface Water Dataset
Measurement Locations
Rincon Valley


WW No. 1A - Leasburg Canal
Leasburg Canal abv 1st Check
Leasburg Canal blw 1st Check
WW No. 1 - Leasburg Canal
Rio Grande below Leasburg Dam
Leasburg Canal
Selden Drain
Picacho Lateral
WW No. 3 - Picacho Lateral
WW No. 5 - Leasburg Canal
Las Cruces Lateral
Leasburg Drain
WW No. 8 - Leasburg Canal
Las Cruces East Mesa WRF
Dona Ana, NM
Picacho Lateral
Las Cruces
Las Cruces Arroyo
near Las Cruces
Rio Grande at Picacho Bridge
Las Cruces WWTP
California Extension
WW No. 40 - Picacho Lateral
Mesilla Lateral
Picacho Drain
WW No. 13 - California Extension
Eastside Canal
Mesilla Dam Diversion
Del Rio Lateral
Westside Canal
Mesilla Drain
Rio Grande Below
Mesilla Dam
Rio Grande
WW No. 15 -
Eastside Canal
Santo Tomas
River Drain
WW No. 25 - Santo Tomas Lateral
WW No. 26 - Upper Chamberino Lateral
WW No. 16B - Brazito Lateral
WW No. 18 - Eastside Canal
Rio Grande at Vado Bridge
Figure 3-2
Surface Water Dataset
Measurement Locations
Mesilla Valley - North
Measurement Points
Streamflow Gage
Municipal
Drain
Canal Heading
Lateral
Wasteway
Weather Station
Towns
SW Features¹
Rio Grande
Drain
Canal
Lateral
Wasteway
N
W
E
S
Miles
0
2
4
8
Spronk Water Engineers, Inc.
1000 Logan Street Denver, CO 80203
¹ lrg_hydrographicfeatures.mdb
NMOSE 2009

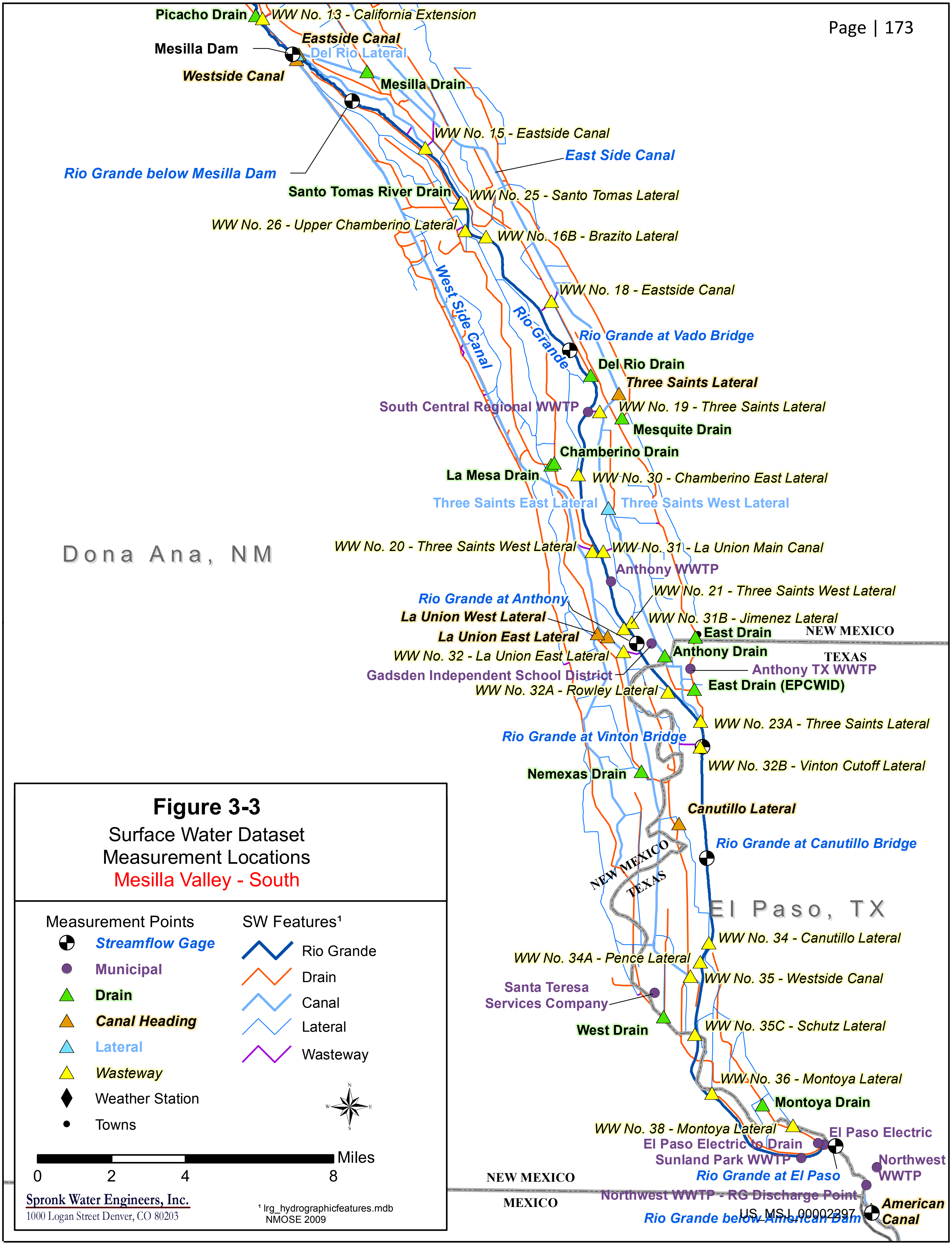
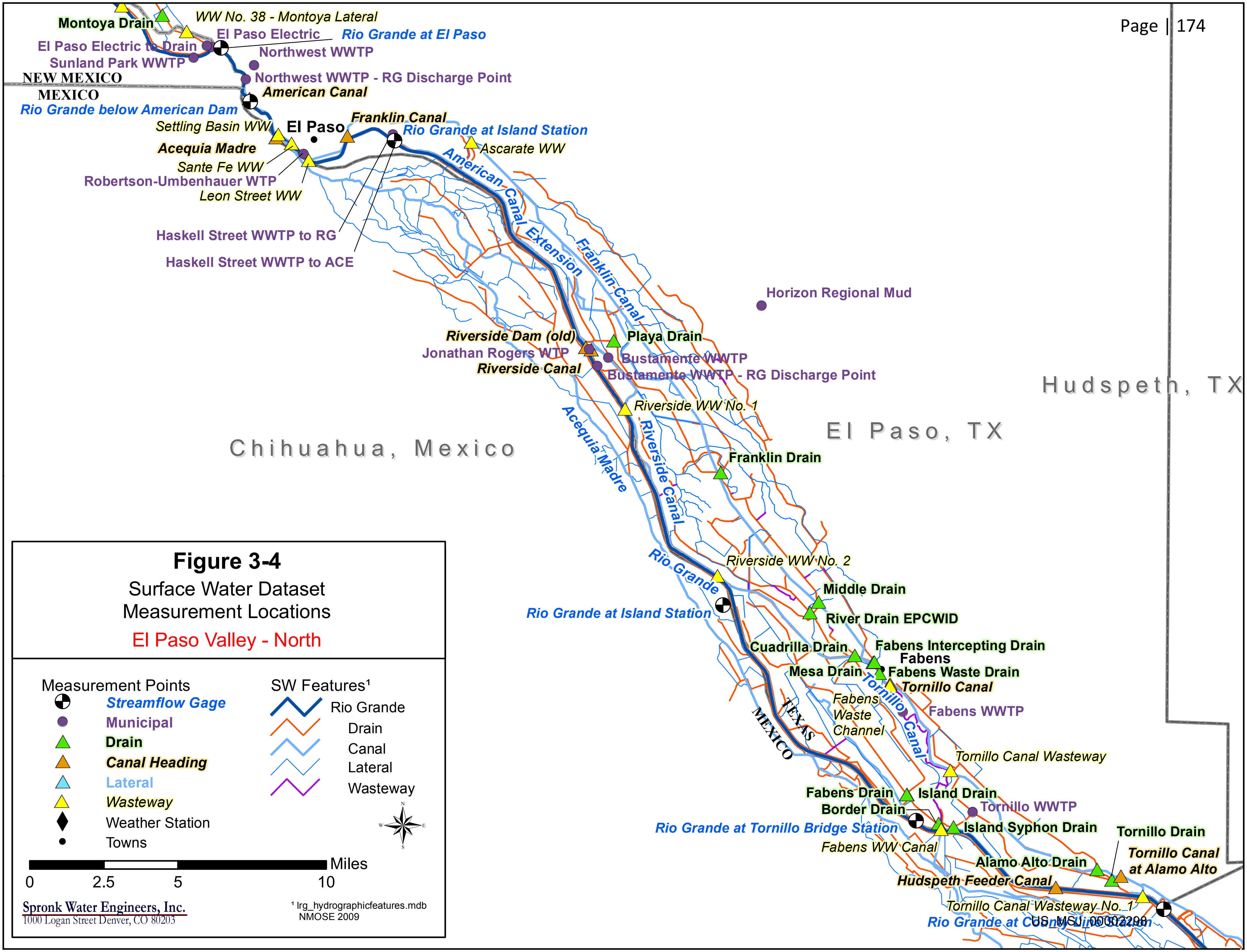


Figure 3-3
Surface Water Dataset
Measurement Locations
Mesilla Valley - South


Montoya Drain
WW No. 38 - Montoya Lateral
El Paso Electric
Rio Grande at El Paso
El Paso Electric to Drain
Northwest WWTP
Sunland Park WWTP
NEW MEXICO
MEXICO
Northwest WWTP - RG Discharge Point
American Canal
Rio Grande below American Dam
Settling Basin WW
El Paso
Franklin Canal
Rio Grande at Island Station
Ascarate WW
Acequia Madre
Sante Fe WW
Robertson-Umbenhauer WTP
Leon Street WW
Haskell Street WWTP to RG
Haskell Street WWTP to ACE
American Canal Extension
Franklin Canal
Horizon Regional Mud
Riverside Dam (old)
Playa Drain
Jonathan Rogers WTP
Bustamente WWTP
Riverside Canal
Bustamente WWTP - RG Discharge Point
Hudspeth, TX
Riverside WW No. 1
El Paso, TX
Chihuahua, Mexico
Acequia Madre
Riverside Canal
Franklin Drain
Rio Grande
Riverside WW No. 2
Middle Drain
Rio Grande at Island Station
River Drain EPCWID
Cuadrilla Drain
Fabens Intercepting Drain
Fabens
Mesa Drain
Fabens Waste Drain
Tornillo Canal
Fabens Waste Channel
Tornillo Canal
Fabens WWTP
TEXAS
MEXICO
Tornillo Canal Wasteway
Fabens Drain
Island Drain
Border Drain
Tornillo WWTP
Rio Grande at Tornillo Bridge Station
Island Syphon Drain
Tornillo Drain
Fabens WW Canal
Tornillo Canal at Alamo Alto
Alamo Alto Drain
Hudspeth Feeder Canal
Tornillo Canal Wasteway No. 1
Figure 3-4
Surface Water Dataset
Measurement Locations
El Paso Valley - North
Measurement Points
Streamflow Gage
Municipal
Drain
Canal Heading
Lateral
Wasteway
Weather Station
Towns
SW Features¹
Rio Grande
Drain
Canal
Lateral
Wasteway
Miles
0
2.5
5
10
Spronk Water Engineers, Inc.
1000 Logan Street Denver, CO 80203
¹ lrg_hydrographicfeatures.mdb
NMOSE 2009

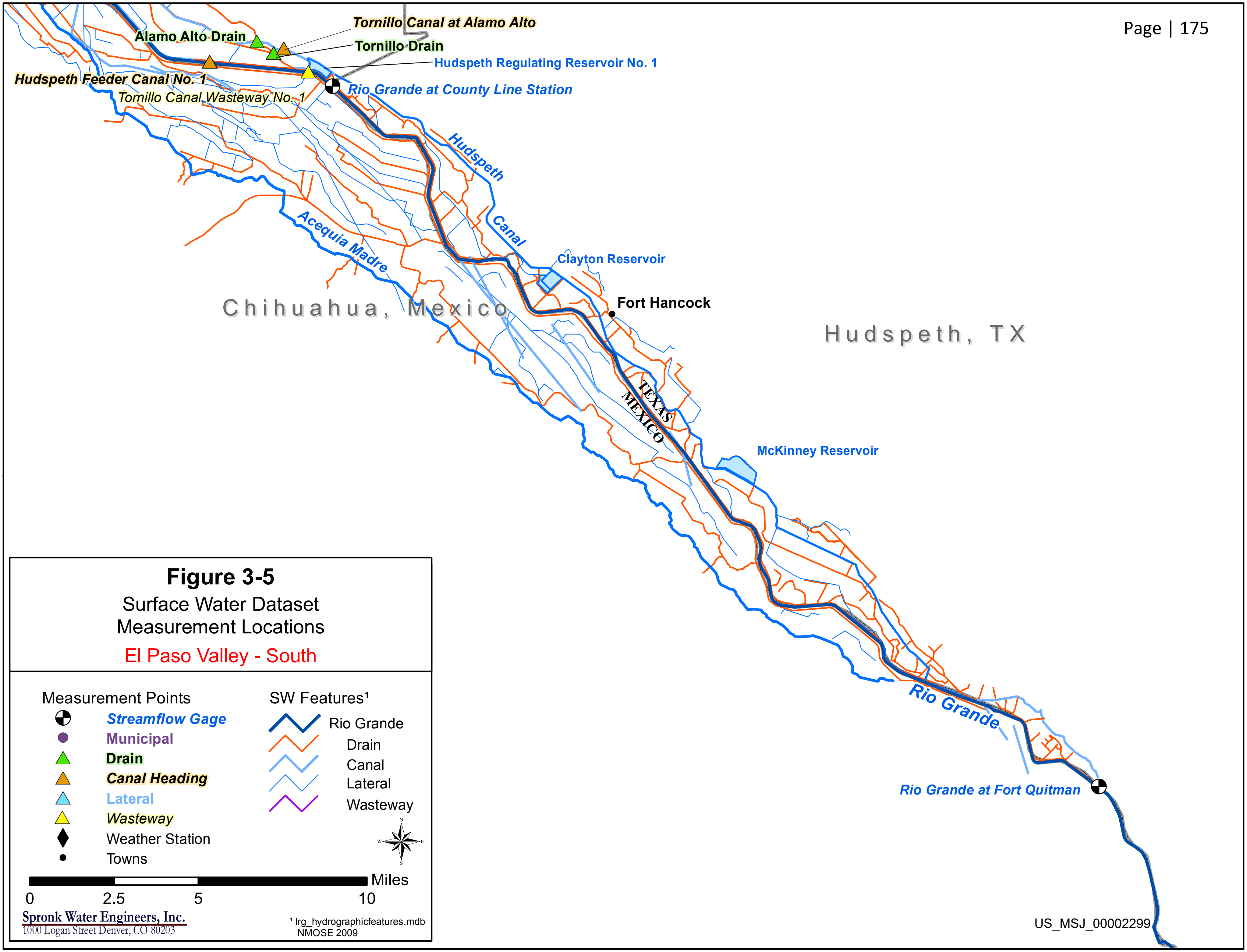
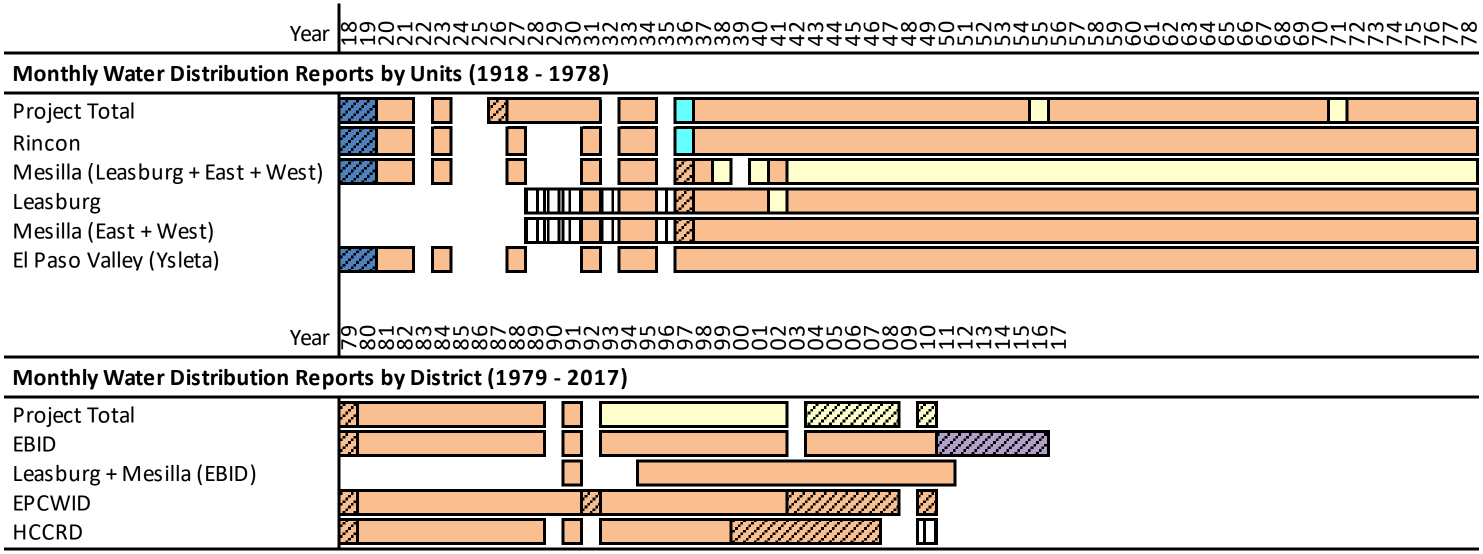


Figure 3-5
Surface Water Dataset Measurement Locations
El Paso Valley - South

Figure 4-1

Water Distribution Report Data (1918 - 2017)



Key:

- Water Distribution Report is available and monthly data for year are compiled.
- Annual farm delivery data only.
- Annual acreage and river headgate diversion data only.
- Water Distribution Report is available but values are illegible.
- Water Distribution Report is not available but values are estimated using reports for other units.
- Hashed where only annual data are available or only part of the records are available (e.g., only river headgate diversions are available).
- Acreage data only.

Notes: There may be some missing months within certain years.
Project totals include total for Rincon, Leasburg, Mesilla, and El Paso Valley (pre-1979), and EBID plus EPCWID (post-1979).
Pre-1979, Mesilla (East + West) includes lands in New Mexico and Texas under the Eastside and Westside canal systems.
Mesilla (East + West) includes lands in New Mexico and Texas under the Eastside and Westside canal systems.

Source: LRG.Doc.SW109: Water Distribution Reports.

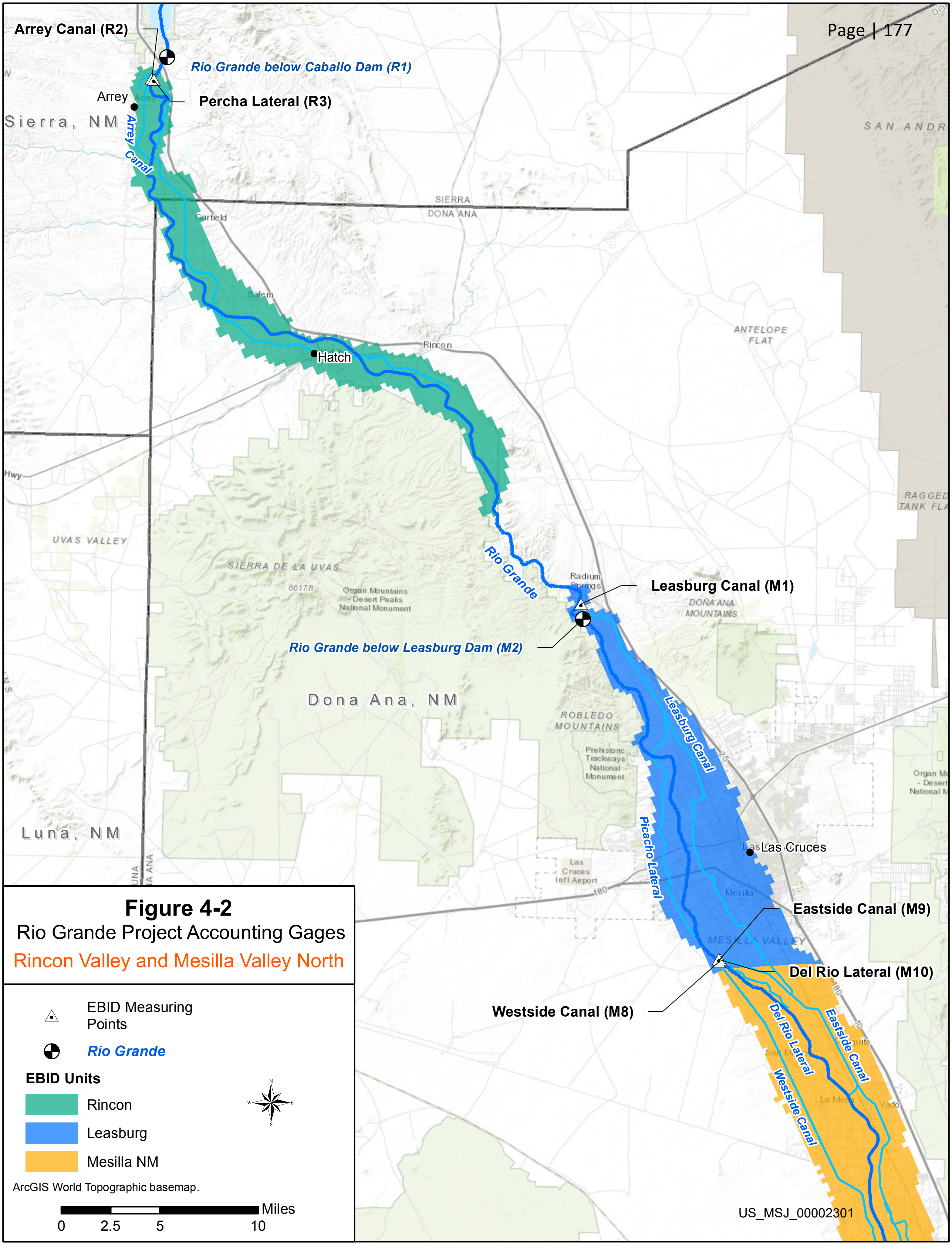


Figure 4-2
Rio Grande Project Accounting Gages
Rincon Valley and Mesilla Valley North

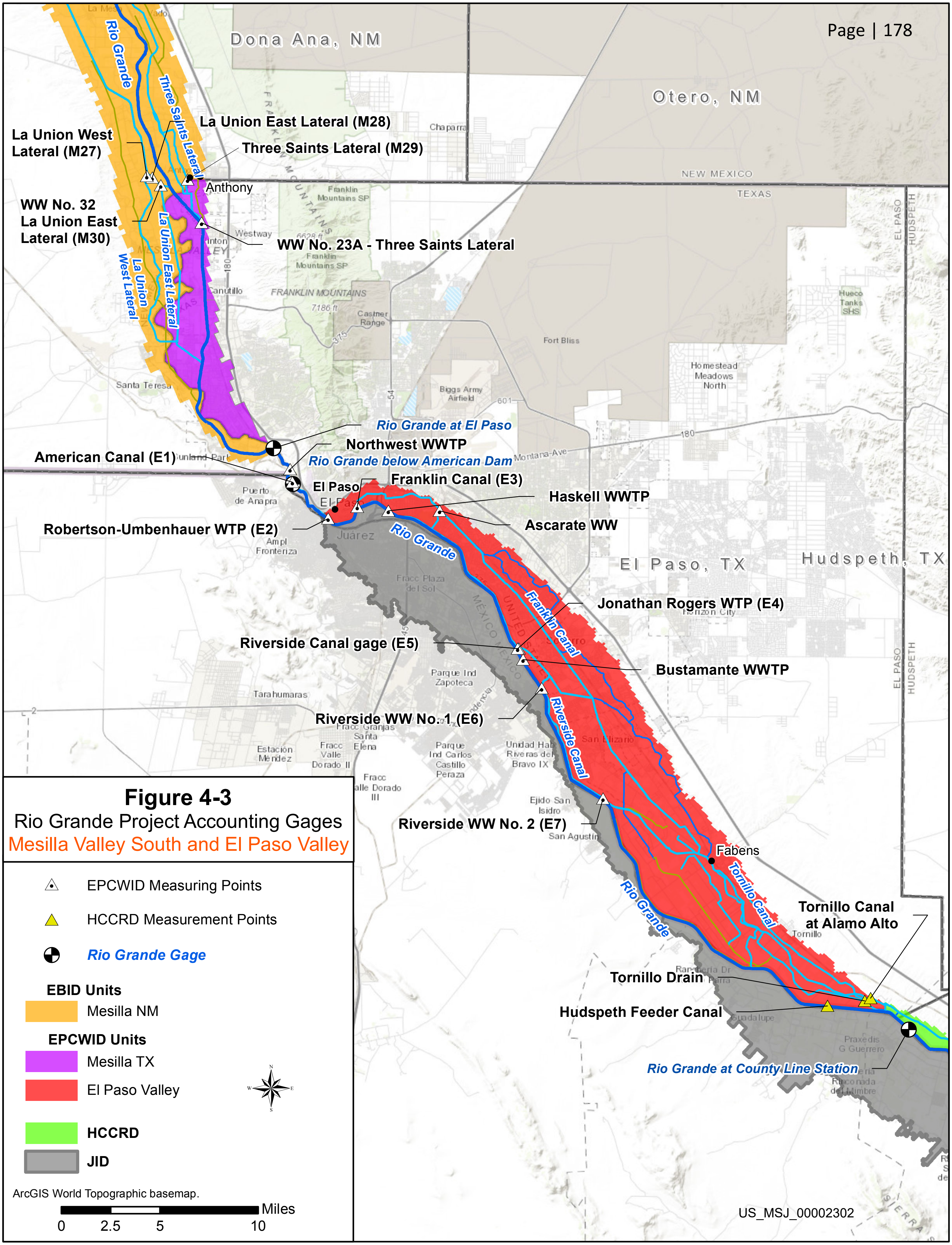
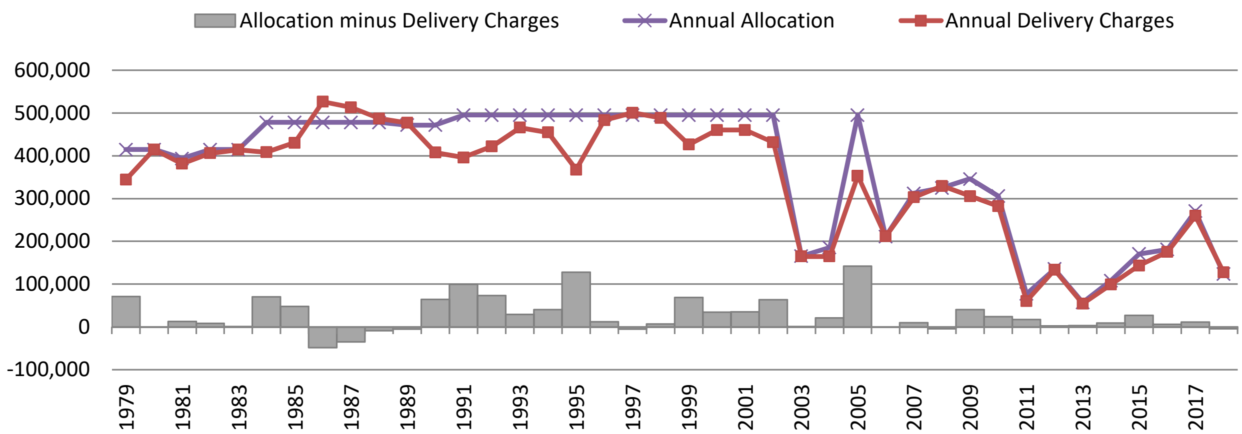


Figure 4-3
Rio Grande Project Accounting Gages
Mesilla Valley South and El Paso Valley

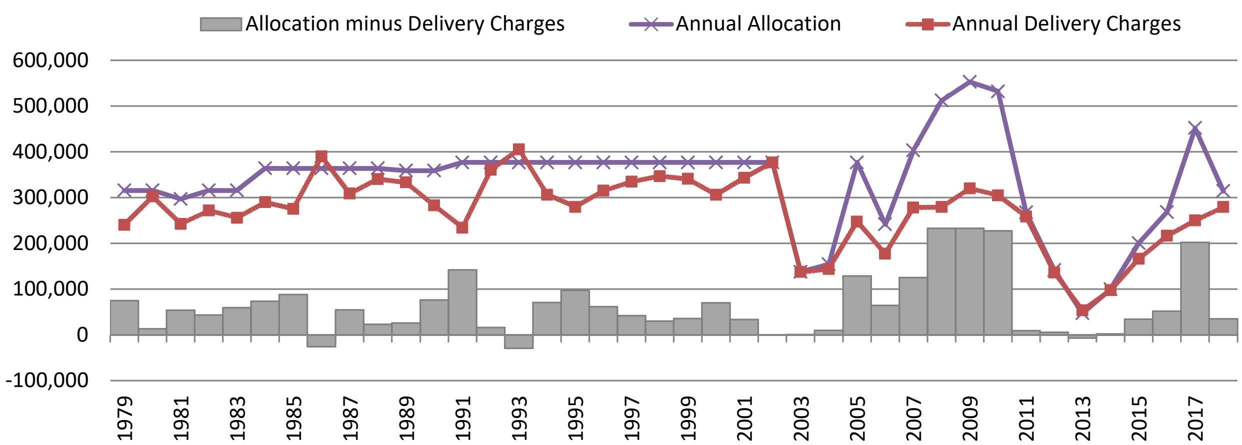
Figure 4-4

Annual Allocation and Delivery Charges
Rio Grande Project Accounting
1979-2018
(acre-feet)

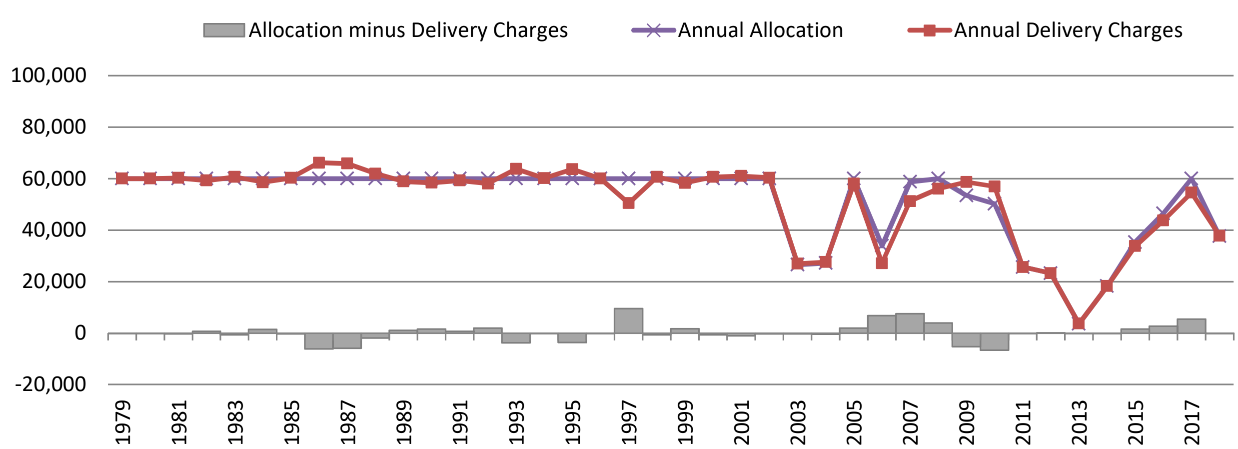
EBID



EPCWID



JID

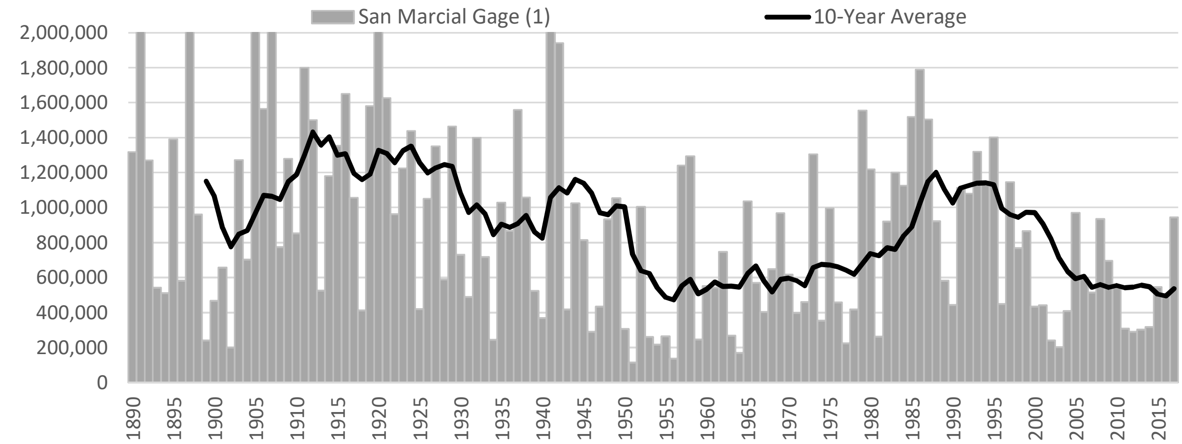


***Note Different Scales**

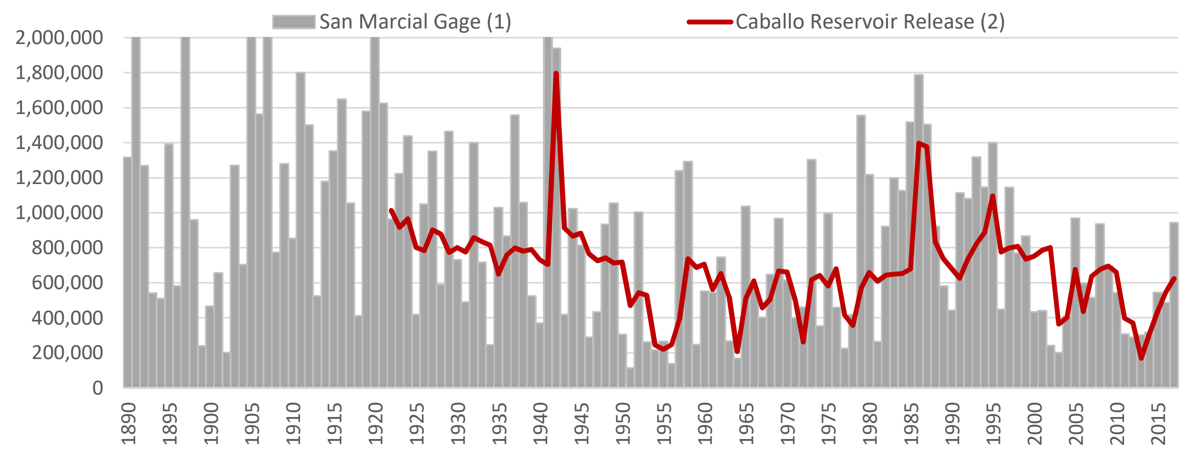
Figure 5-1

Annual Rio Grande Flows
1890 - 2017
(acre-feet)

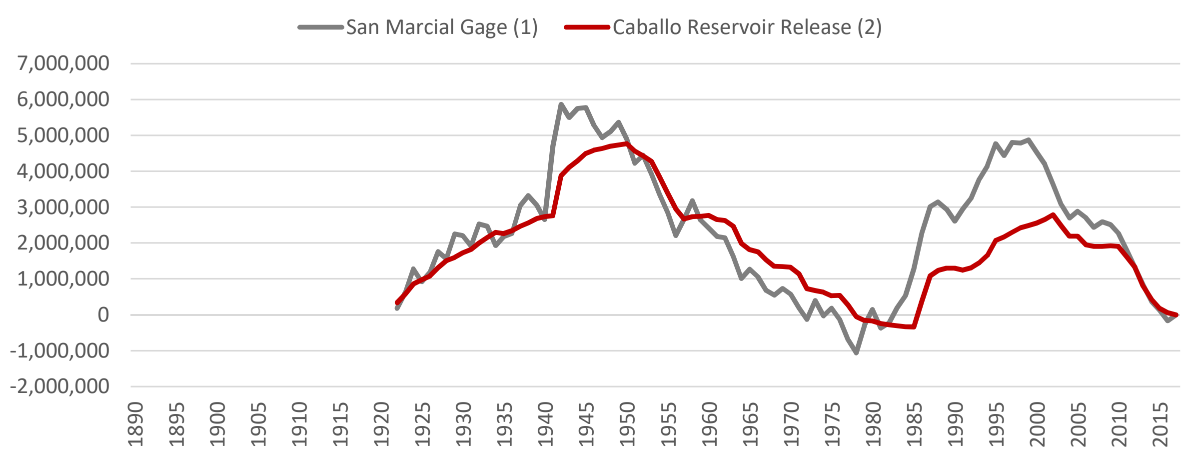
San Marcial Gage



San Marcial Gage and Caballo Reservoir Release



Cumulative Departure from Average



Notes:

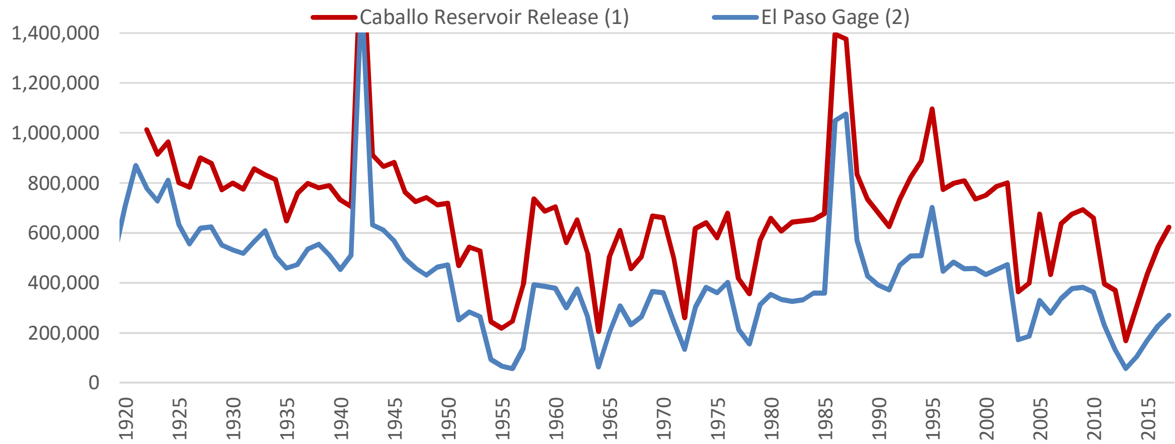
(1) San Marcial gage data from 1938 RGJI (1890-1924) and LRG SWDataSet (1925-2017).

(2) Rio Grande above Percha Dam gage used for Caballo Reservoir Release before 1938. Data from LRG SWDataSet.

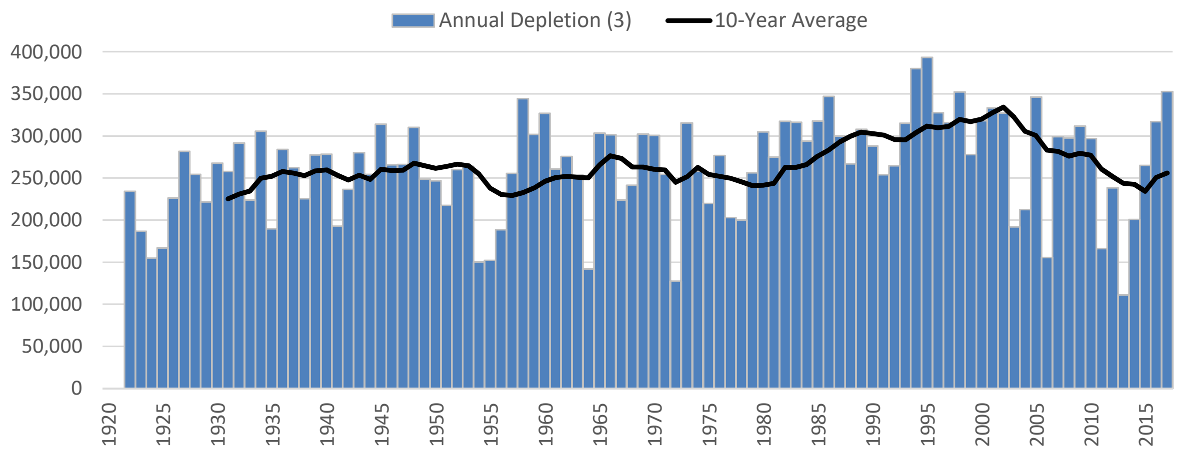
Figure 5-2

Annual Rio Grande Flows
1920 - 2017
(acre-feet)

Caballo Reservoir Release and El Paso Gage



River Depletion: Caballo Reservoir Release minus El Paso Gage



<u>Notes:</u>

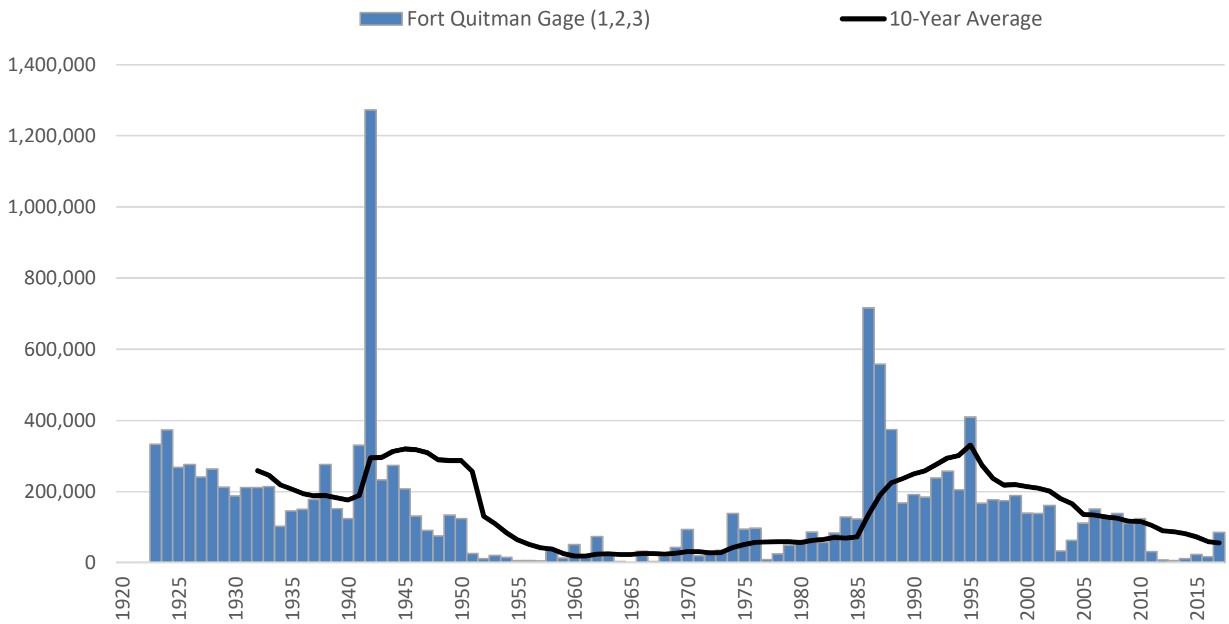
(1) Rio Grande above Percha Dam gage used for Caballo Reservoir Release before 1938. Data from LRG SWDataSet.

(2) El Paso gage data from LRG SWDataSet.

(3) Annual Depletion computed as Caballo Reservoir Release minus El Paso gage.

Figure 5-3

Annual Rio Grande Flows
1920 - 2017
(acre-feet)
Fort Quitman Gage



Notes:

(1) Flows in 1987 are not complete (flood flows went around gage due to broken levees).

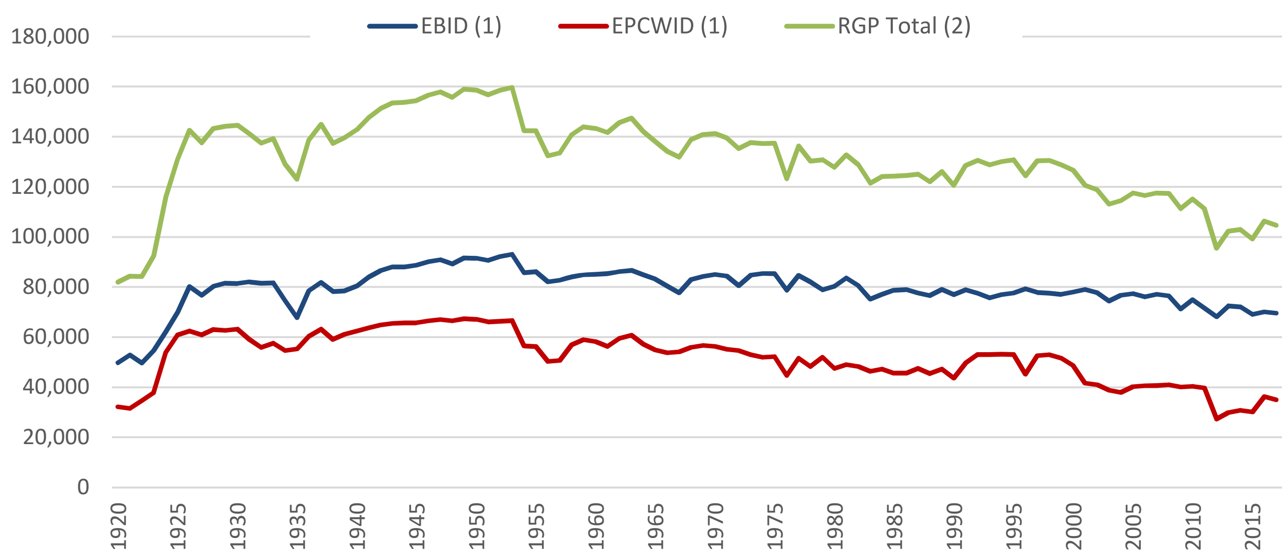
(2) Missing data from August 2016 - April 2017.

(3) Data from LRG SWDataSet. Gage data begins in 1923.

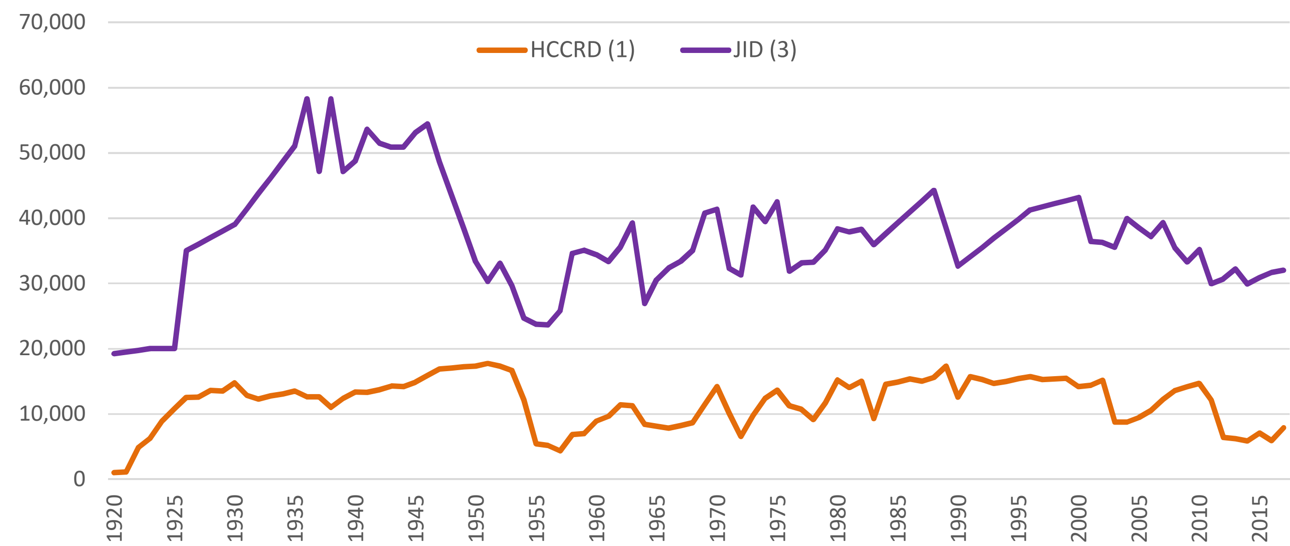
Figure 5-4

Annual Irrigated Area
1920 - 2017
(acres)

Rio Grande Project



HCCRD and JID



Notes:

(1) Data from 1938 Rio Grande Joint Investigation (1920-1935) and DE (1936-2017).

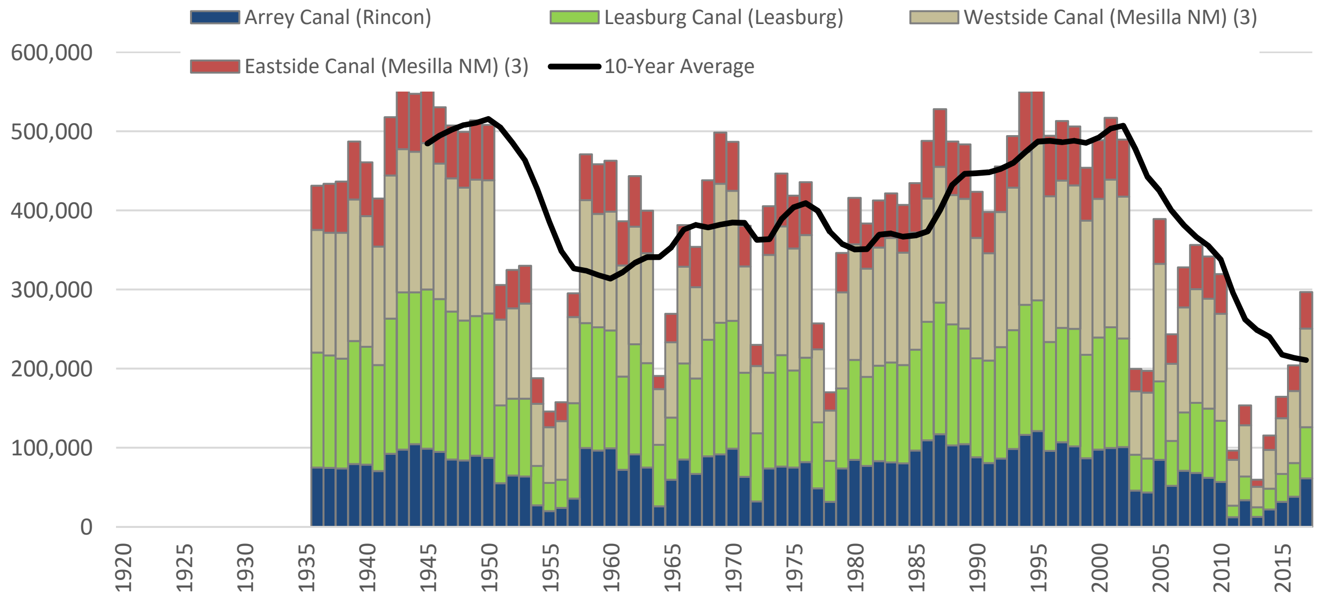
(2) RGP Total calculated as sum of EBID and EPCWID acres.

(3) Data from MMA (1920-1949) and DE (1950-2017).

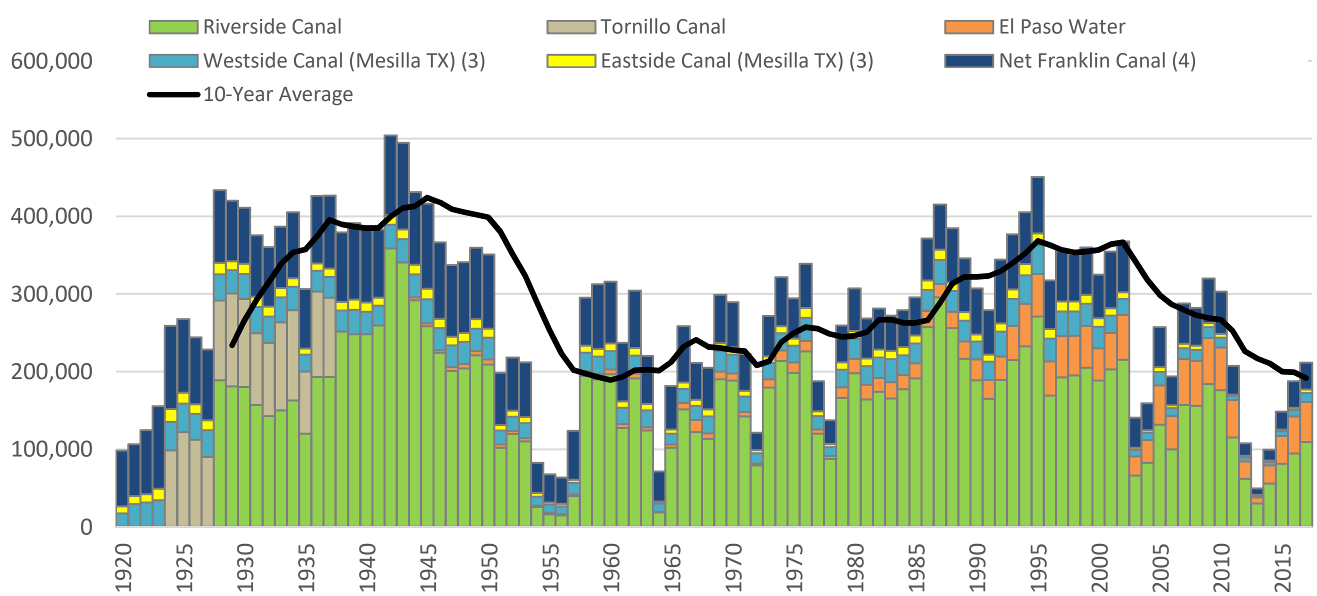
Figure 5-5

Annual Canal Heading Diversions
Irrigation Season (Mar-Oct)
1920 - 2017
(acre-feet)

EBID (1,2)



EPCWID (1)



Notes:

(1) Data from LRG SWDataSet.

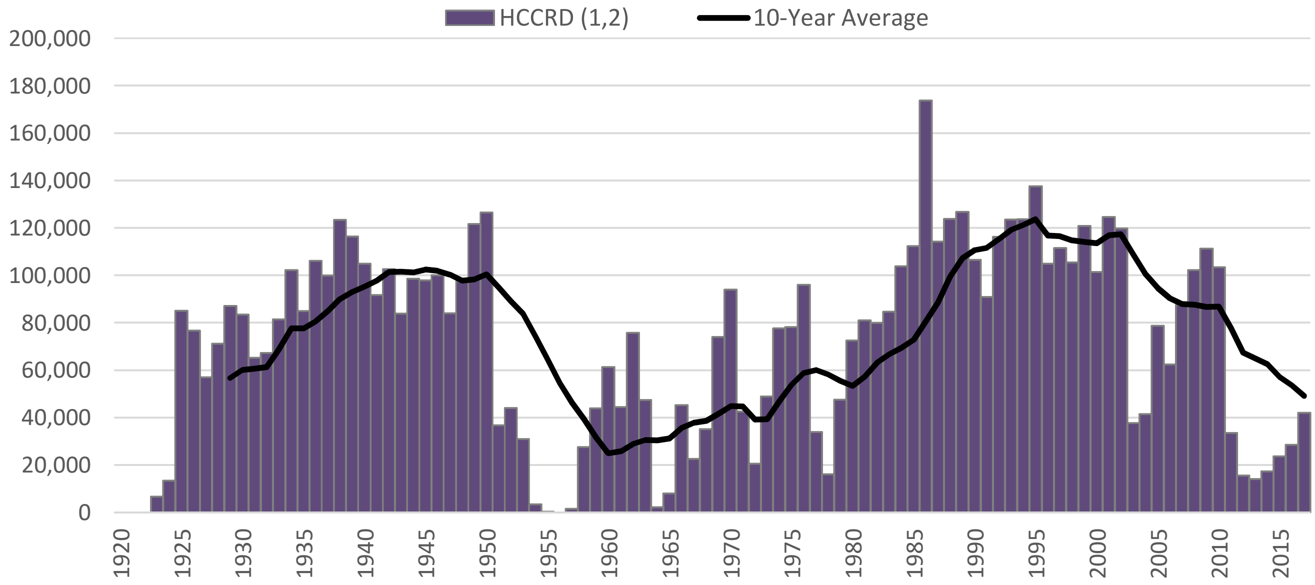
(2) EBID diversion data prior to 1936 are incomplete.

(3) Eastside and Westside Canal diversions split into EBID and EPCWID proportionally based on irrigated area.

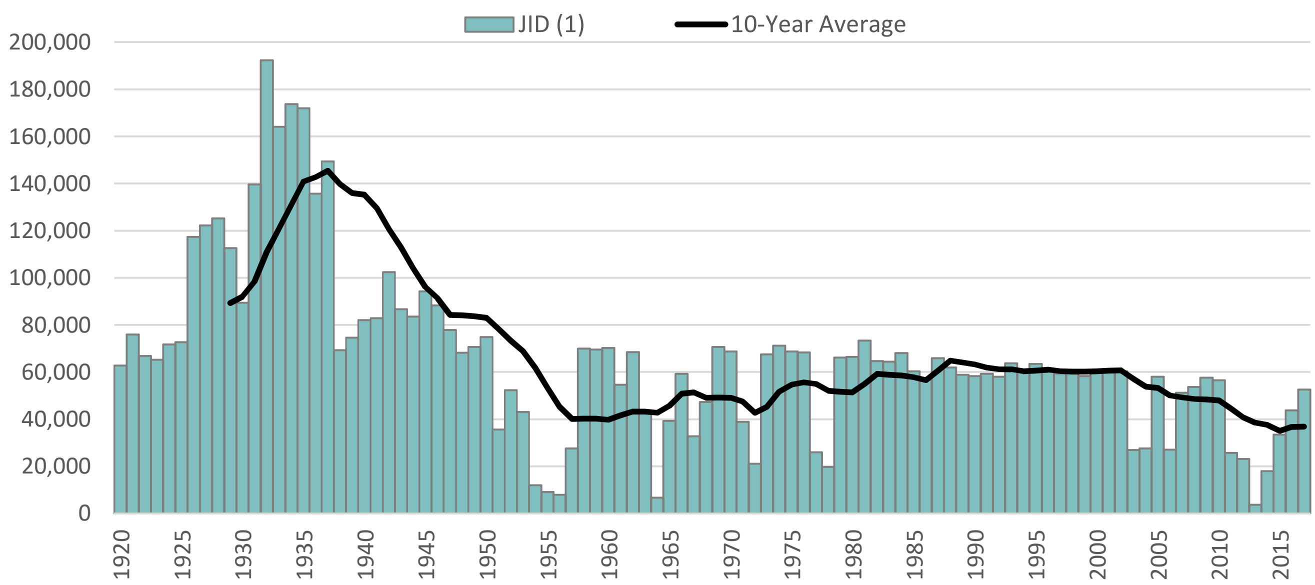
(4) Net Franklin Canal computed as Franklin Canal - Ascarate Wasteway.

Figure 5-6

Annual Canal Heading Diversions
Irrigation Season (Mar-Oct)
1920 - 2017
(acre-feet)
HCCRD



JID



Notes:

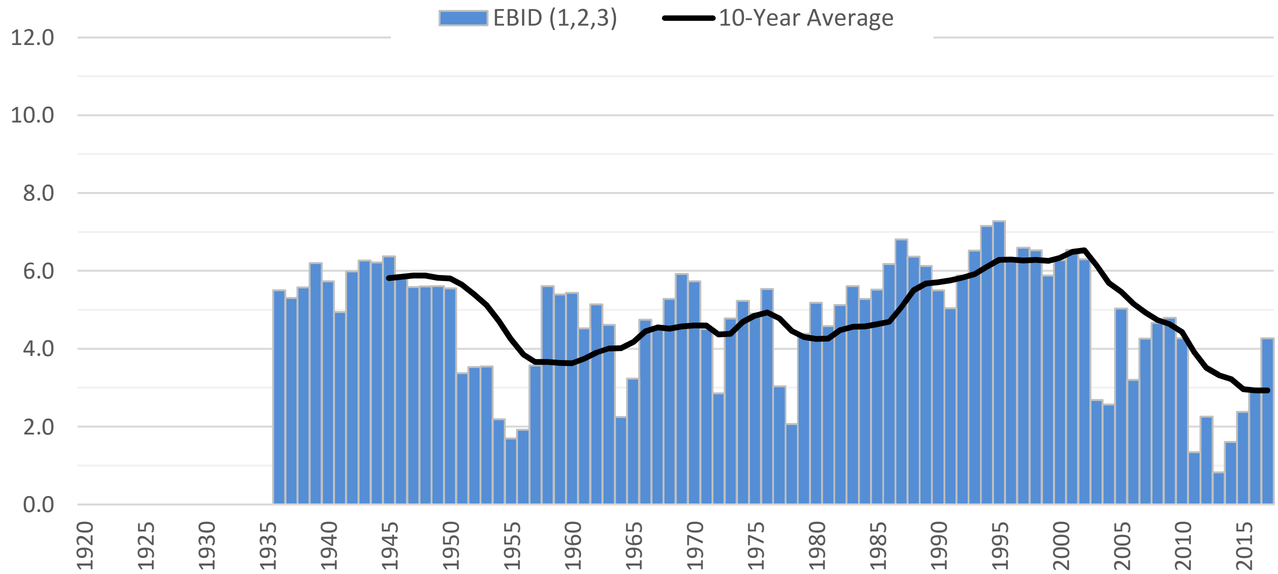
(1) Data from LRG SWDataSet.

(2) HCCRD data begins in 1923.

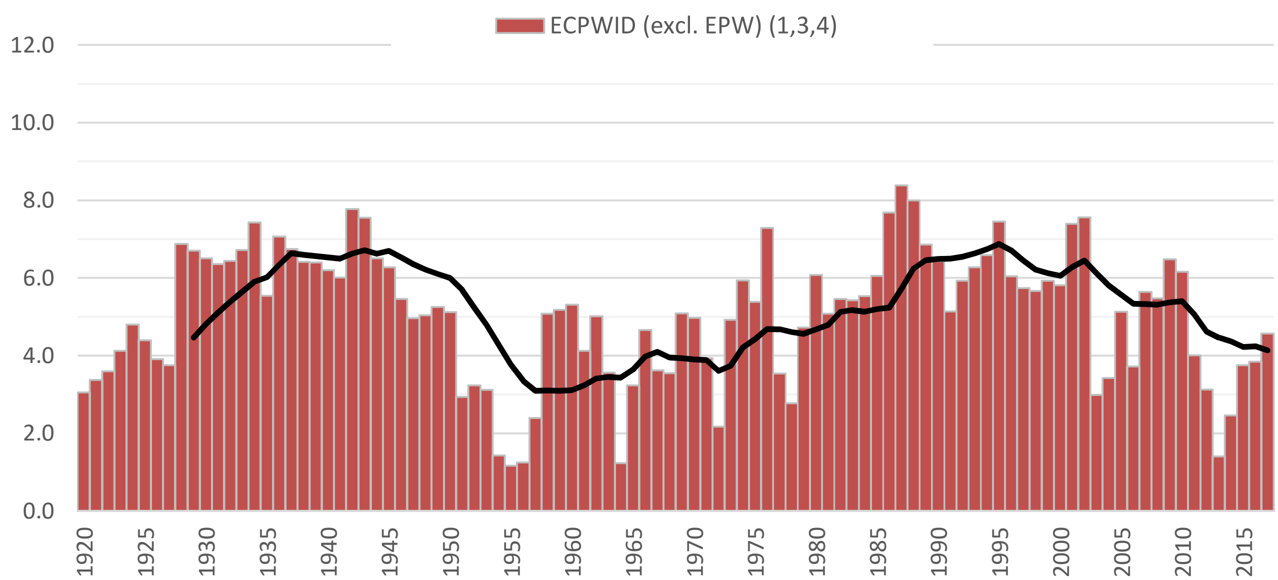
Figure 5-7

Annual UNIT Canal Heading Diversions for Irrigation (Actual Acres)
Irrigation Season (Mar-Oct)
1920 - 2017
(acre-feet/acre)

EBID



EPCWID



Notes:

(1) Data from LRG SWDataSet and Rio Grande Project Canal and Farm Budget.

(2) EBID diversion data prior to 1935 are incomplete.

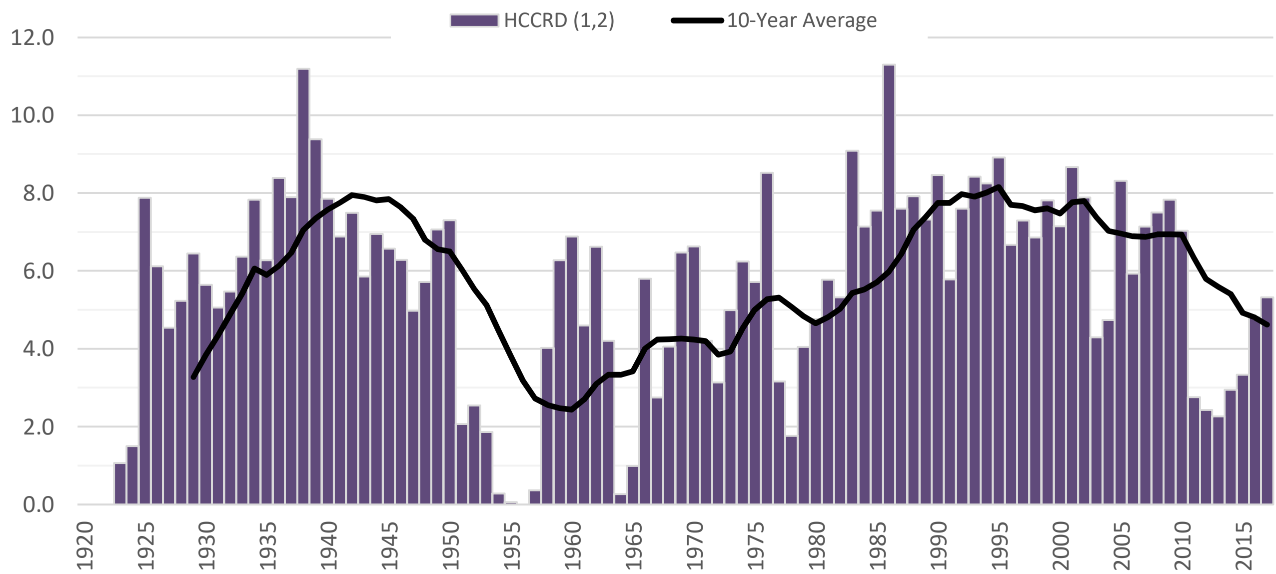
(3) Eastside and Westside Canal diversions split into EBID and EPCWID proportionally based on irrigated area.

(4) EPCWID figures do not include Project water deliveries to EPW.

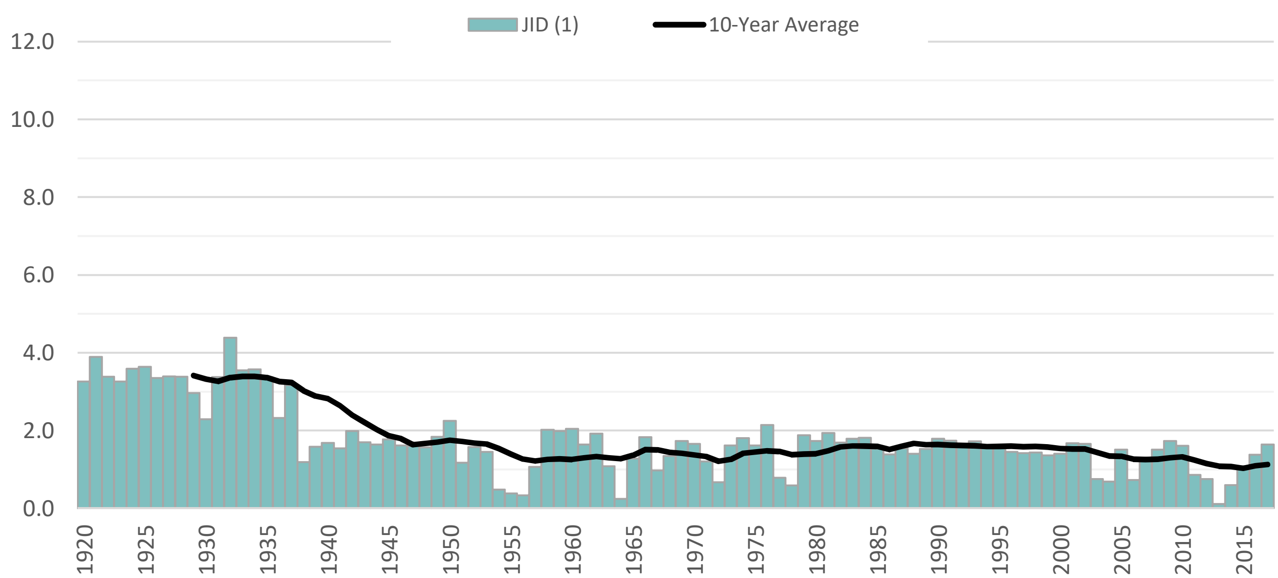
Figure 5-8

Annual UNIT Canal Heading Diversions for Irrigation (Actual Acres)
Irrigation Season (Mar-Oct)
1920 - 2017
(acre-feet/acre)

HCCRD



JID



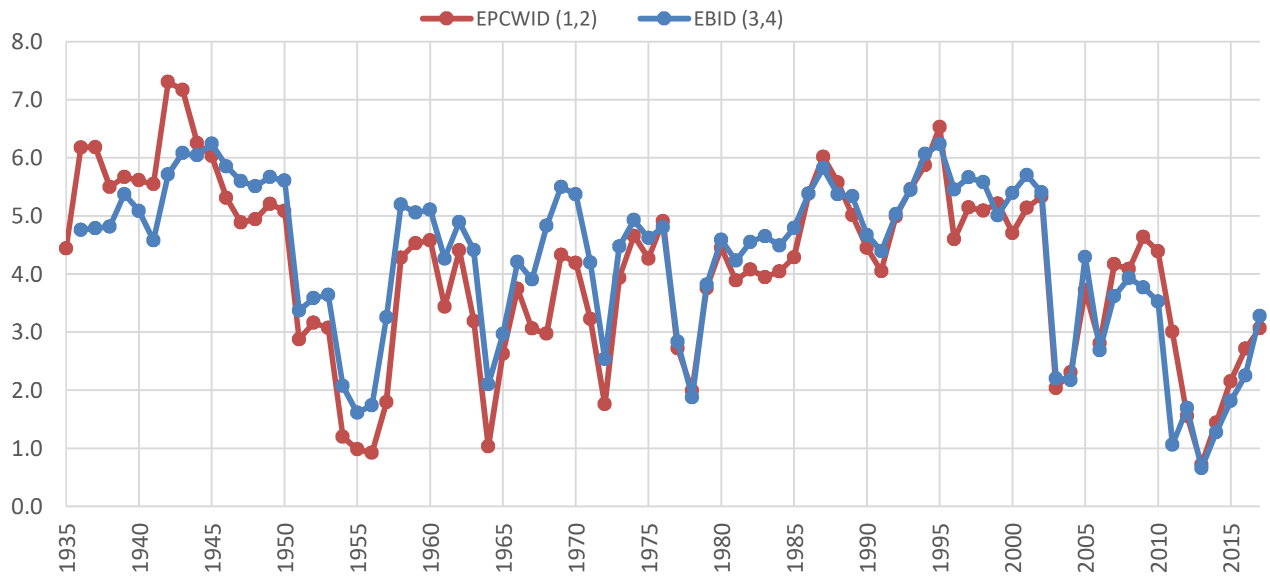
Notes:

(1) Data from LRG SWDataSet and Rio Grande Project Canal and Farm Budget.

(2) HCCRD data begins in 1923.

Figure 5-9

Annual UNIT Canal Heading Diversions for Irrigation (Authorized Acres)
Irrigation Season (Mar-Oct)
1935 - 2017
(acre-feet/acre)

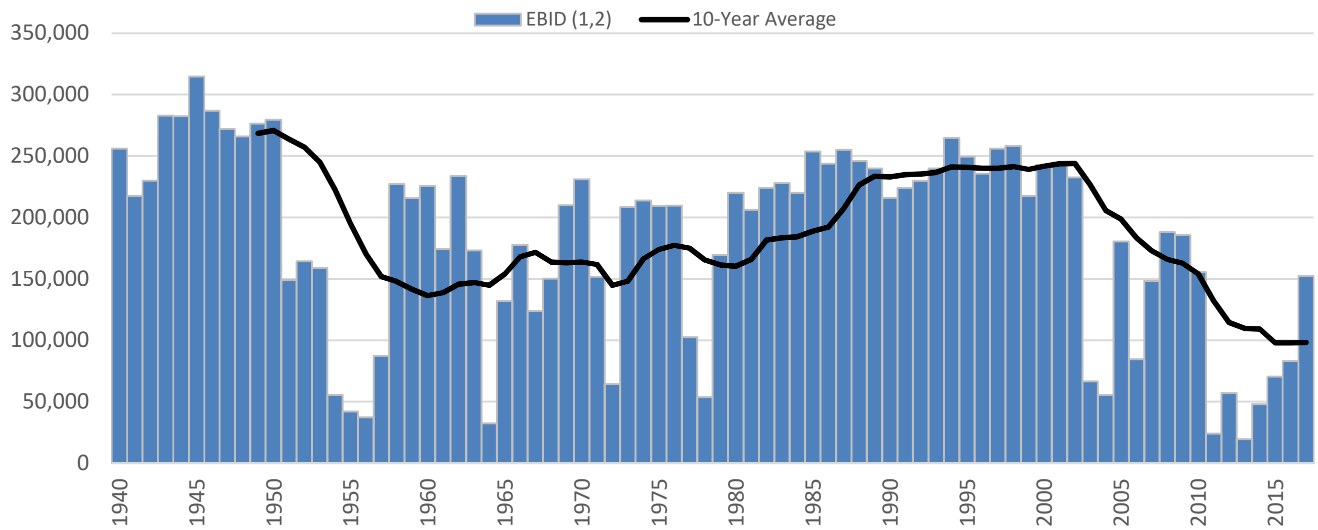


Notes:

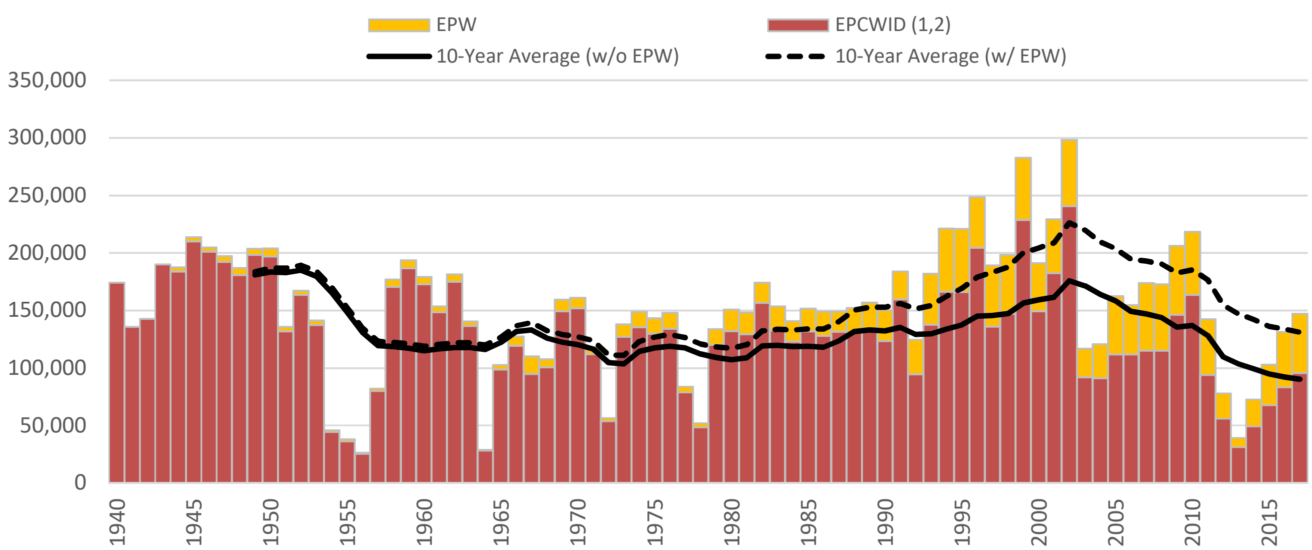
(1) EPCWID includes Project water deliveries to EPW.
(2) EPCWID authorized acres: 69,010 acres.
(3) EBID authorized acres: 90,640 acres.
(4) EBID data incomplete in 1935.
(5) Eastside and Westside Canal diversions split into EBID and EPCWID proportionally based on irrigated area.
(6) RHG data from LRG SWDataSet.

Figure 5-10

Annual Farm Headgate Deliveries
Irrigation Season (Mar-Oct)
1940 - 2017
(acre-feet)
EBID



EPCWID



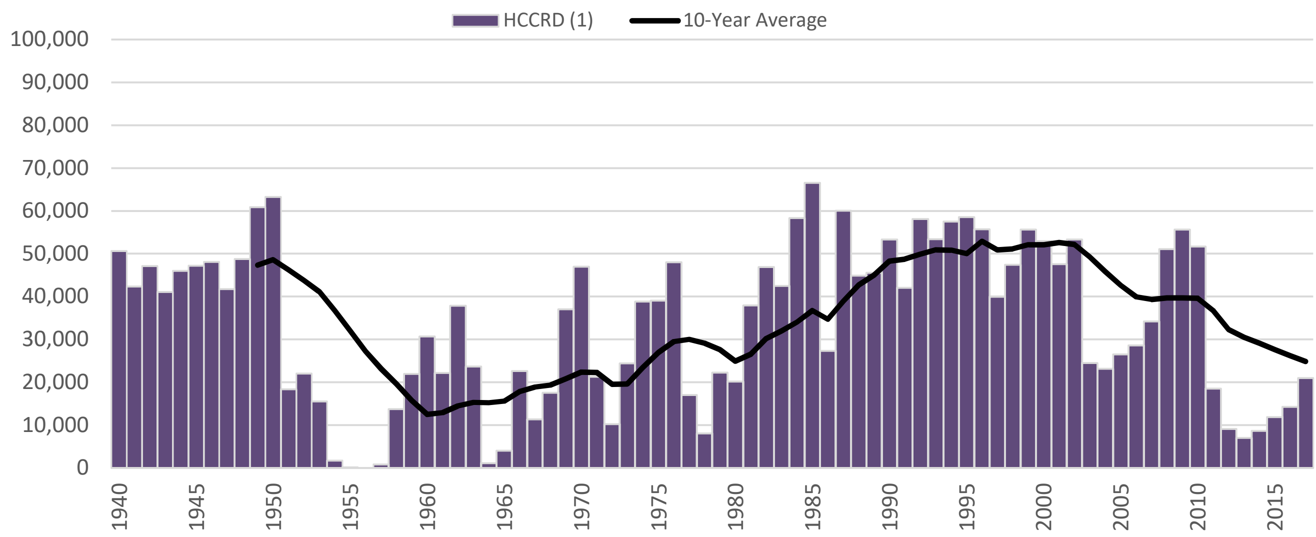
Notes:

(1) Farm deliveries from records except when missing. For years with no records, farm deliveries were estimated as total diversions minus conveyance loss. Loss estimated using monthly average loss % derived from records.

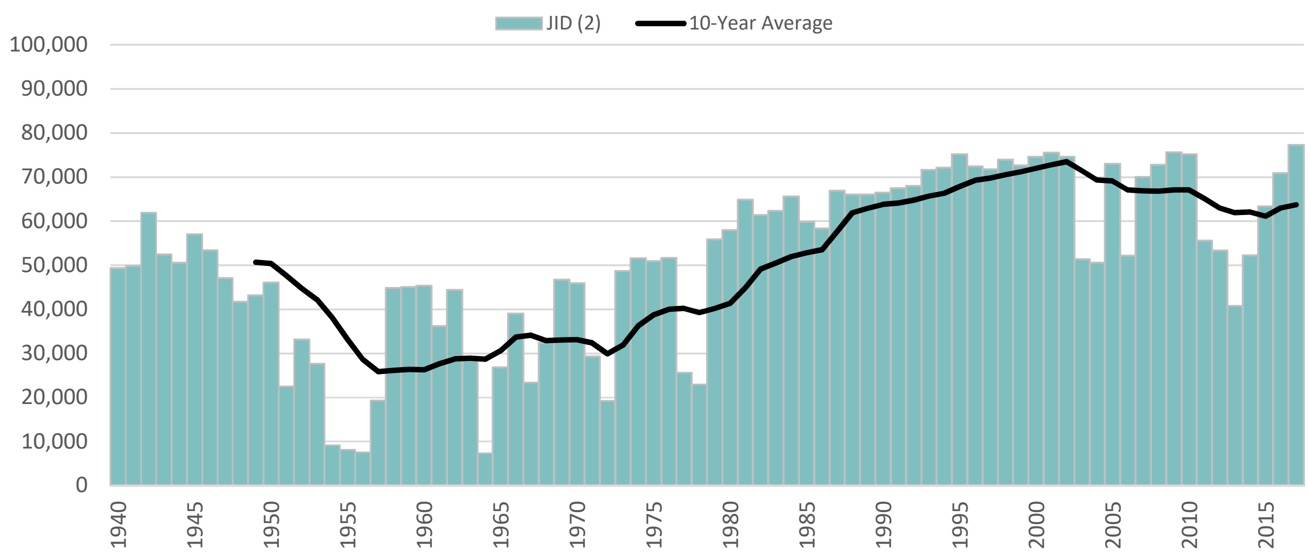
(2) Pre-1979, farm deliveries split between Mesilla NM and Mesilla TX proportionally by acreage.

Figure 5-11

Annual Farm Headgate Deliveries
Irrigation Season (Mar-Oct)
1940 - 2017
(acre-feet)
HCCRD



JID



<u>Notes:</u>

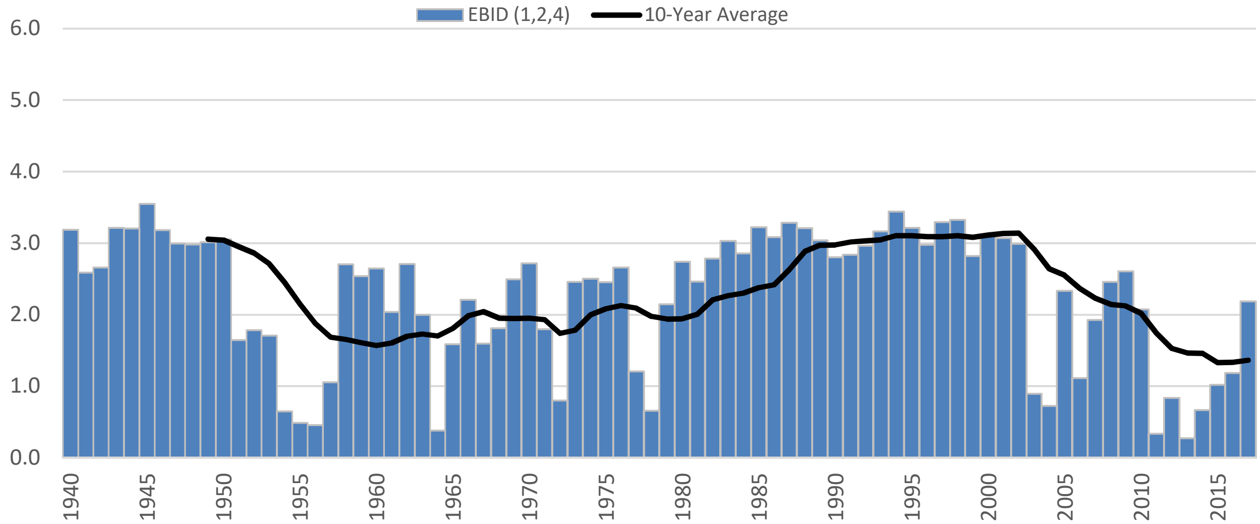
(1) Farm deliveries for HCCRD from records except when missing. For years with no records, farm deliveries were estimated as total diversions minus conveyance loss. Loss estimated using monthly average loss % derived from records.

(2) JID farm deliveries were estimated as total diversions minus canal loss.

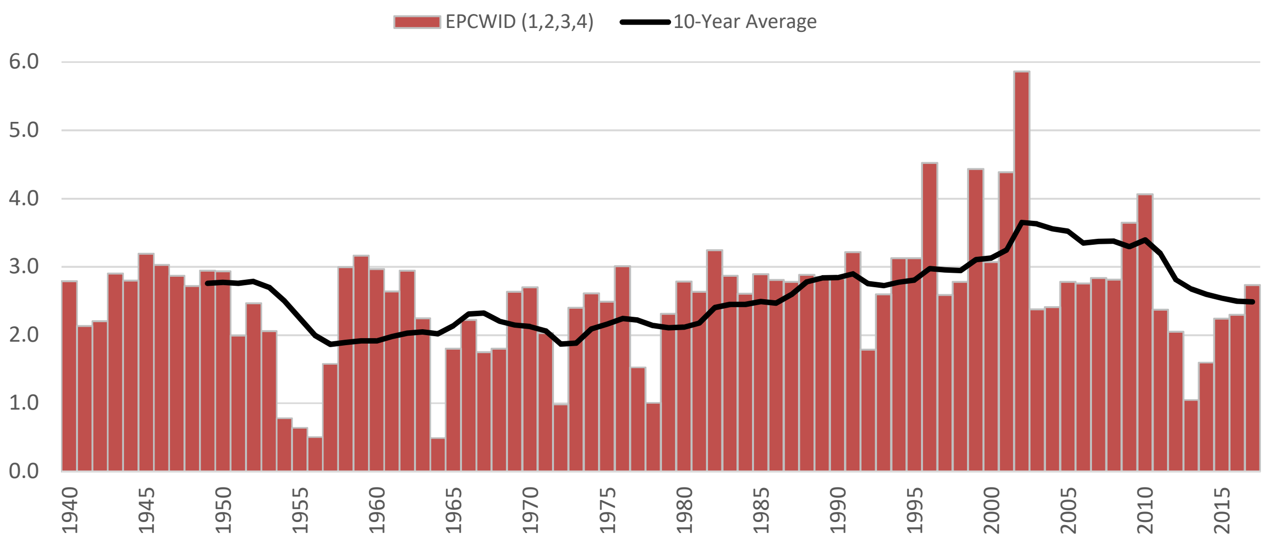
Figure 5-12

Annual UNIT Farm Headgate Deliveries (Actual Acres)
Irrigation Season (Mar-Oct)
1940 - 2017
(acre-feet)

EBID



EPCWID



Notes:

(1) Farm deliveries from records except when missing. For years with no records, farm deliveries were estimated as total diversions minus conveyance loss. Loss estimated using monthly average loss % derived from records.

(2) Pre-1979, farm deliveries split between Mesilla NM and Mesilla TX proportionally by acreage.

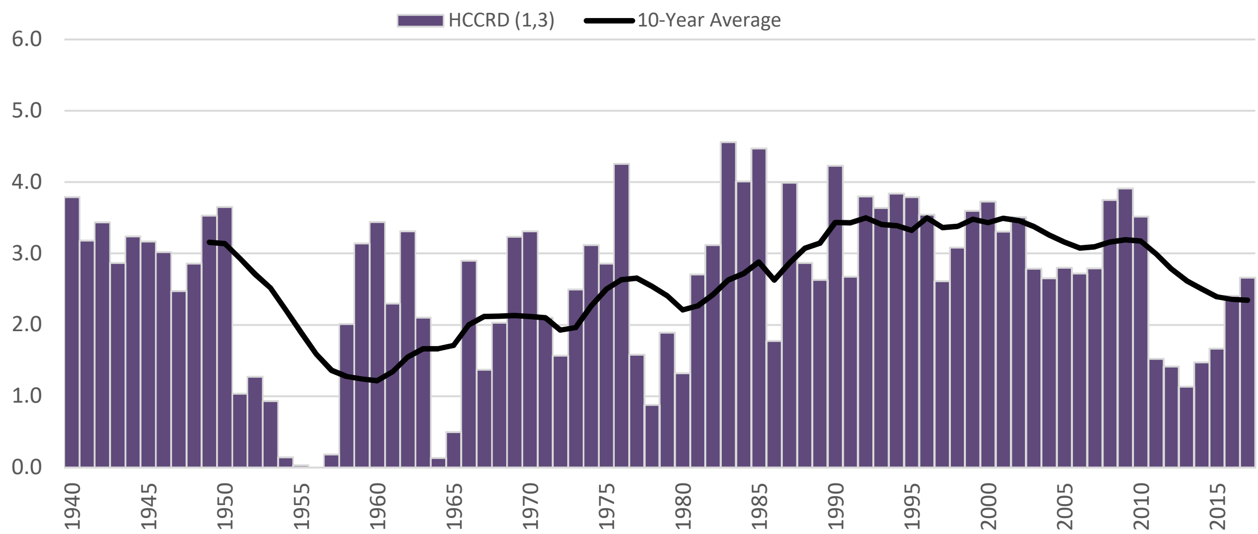
(3) EPCWID FHG deliveries do not include deliveries to EPW.

(4) Acreage data from Rio Grande Project Canal and Farm Budget.

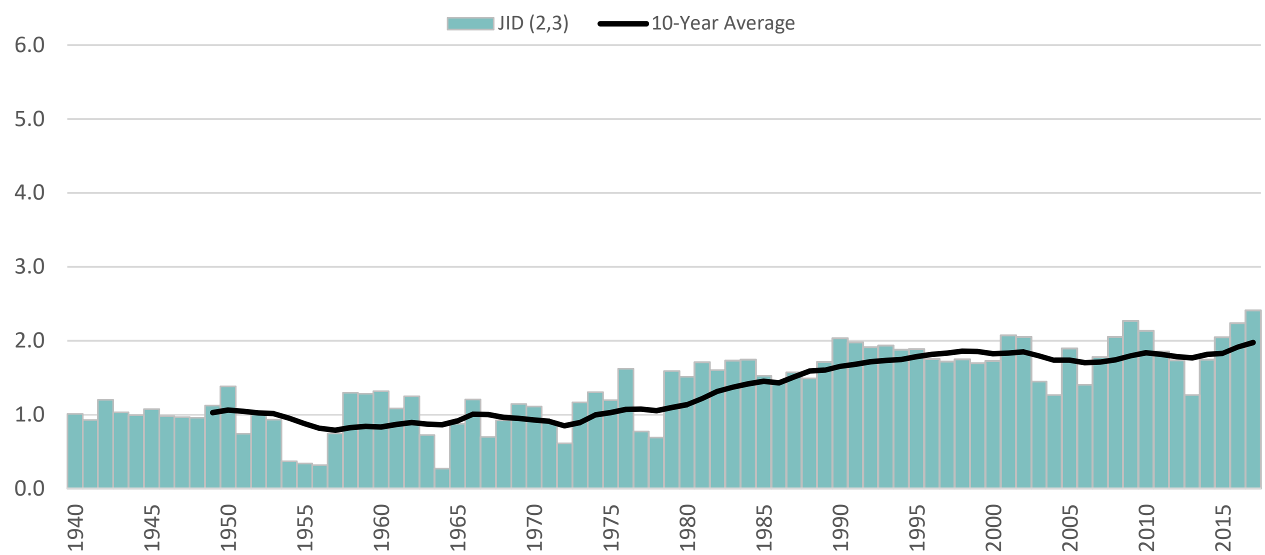
Figure 5-13

Annual UNIT Farm Headgate Deliveries (Actual Acres)
Irrigation Season (Mar-Oct)
1940 - 2017
(acre-feet)

HCCRD



JID



Notes:

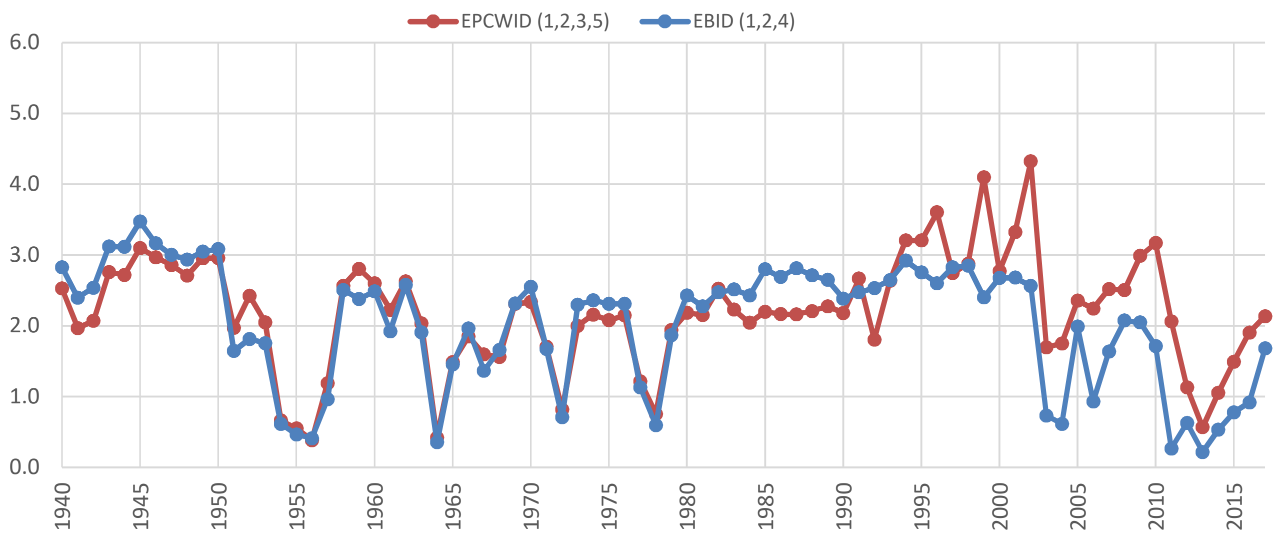
(1) Farm deliveries for HCCRD from records except when missing. For years with no records, farm deliveries were estimated as total diversions minus conveyance loss. Loss estimated using monthly average loss % derived from records.

(2) JID farm deliveries were estimated as total diversions minus canal loss.

(3) Acreage data from Rio Grande Project Canal and Farm Budget.

Figure 5-14

Annual UNIT Farm Headgate Deliveries (Authorized Acres)
Irrigation Season (Mar-Oct)
1940 - 2017
(acre-feet/acre)



Notes:

(1) Farm deliveries from records except when missing. For years with no records, farm deliveries were estimated as total diversions minus conveyance loss. Loss estimated using monthly average loss % derived from records.

(2) Pre-1979, farm deliveries split between Mesilla NM and Mesilla TX proportionally by acreage.

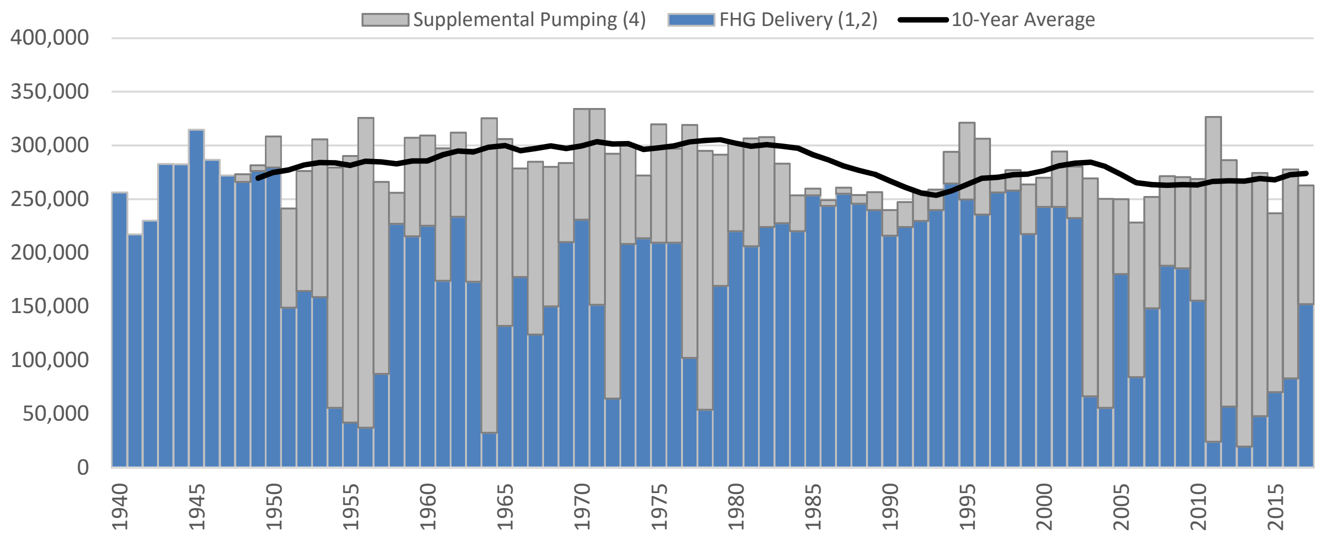
(3) EPCWID include Project water deliveries to EPW.

(4) EBID authorized acres: 90,640 acres.

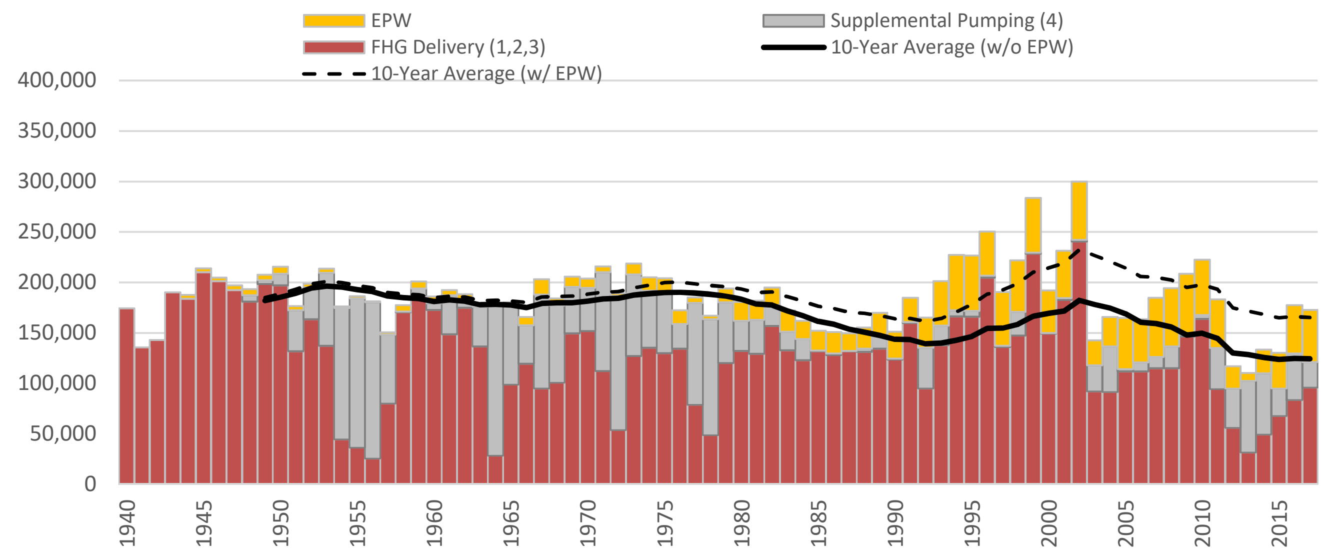
(5) EPCWID authorized acres: 69,010 acres.

Figure 5-15

Annual Total Applied Water (SW + GW)
Irrigation Season (Mar-Oct)
1940 - 2017
(acre-feet)
EBID



EPCWID



Notes:

(1) Farm deliveries from records except when missing. For years with no records, farm deliveries were estimated as total diversions minus conveyance loss. Loss estimated using monthly average loss % derived from records.

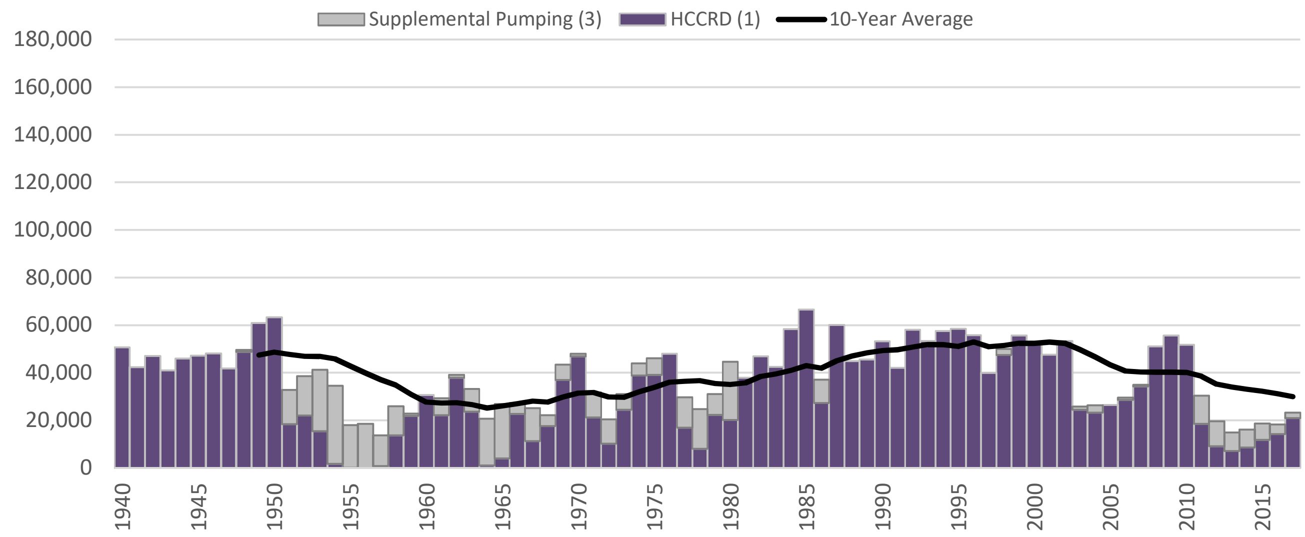
(2) Pre-1979, farm deliveries split between Mesilla NM and Mesilla TX proportionally by acreage.

(3) EPCWID FHG deliveries do not include deliveries to EPW.

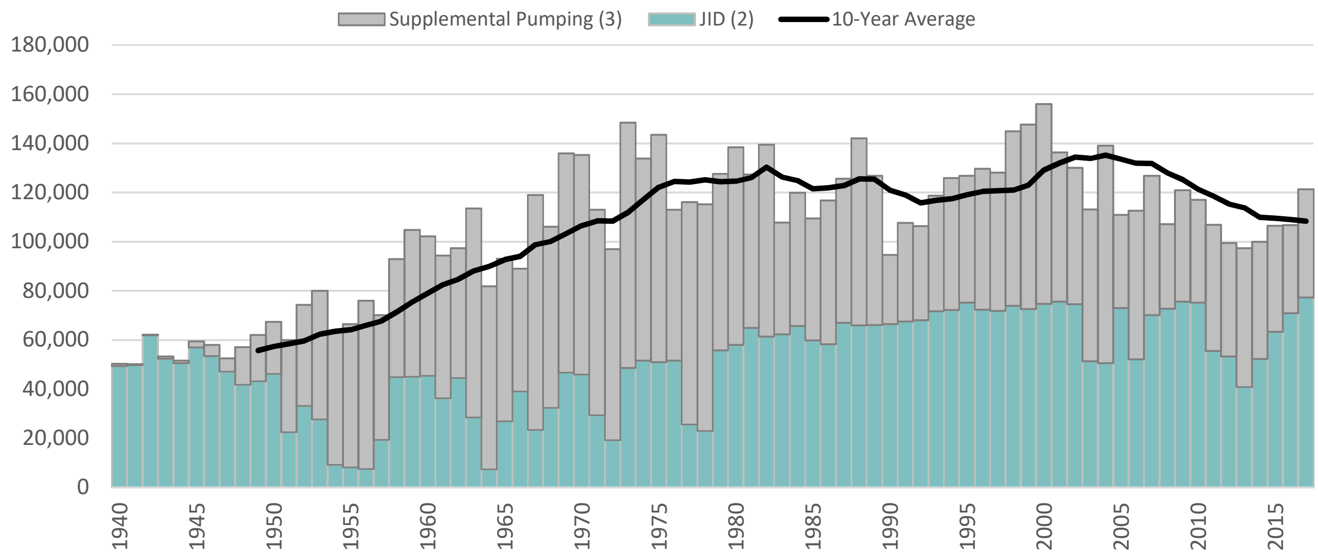
(4) Supplemental pumping computed based on unmet demand from SWE Canal and Farm Budget analysis.

Figure 5-16

Annual Total Applied Water (SW + GW)
Irrigation Season (Mar-Oct)
1940 - 2017
(acre-feet)
HCCRD



JID



Notes:

(1) Farm deliveries for HCCRD from records except when missing. For years with no records, farm deliveries were estimated as total diversions minus conveyance loss. Loss estimated using monthly average loss % derived from records.

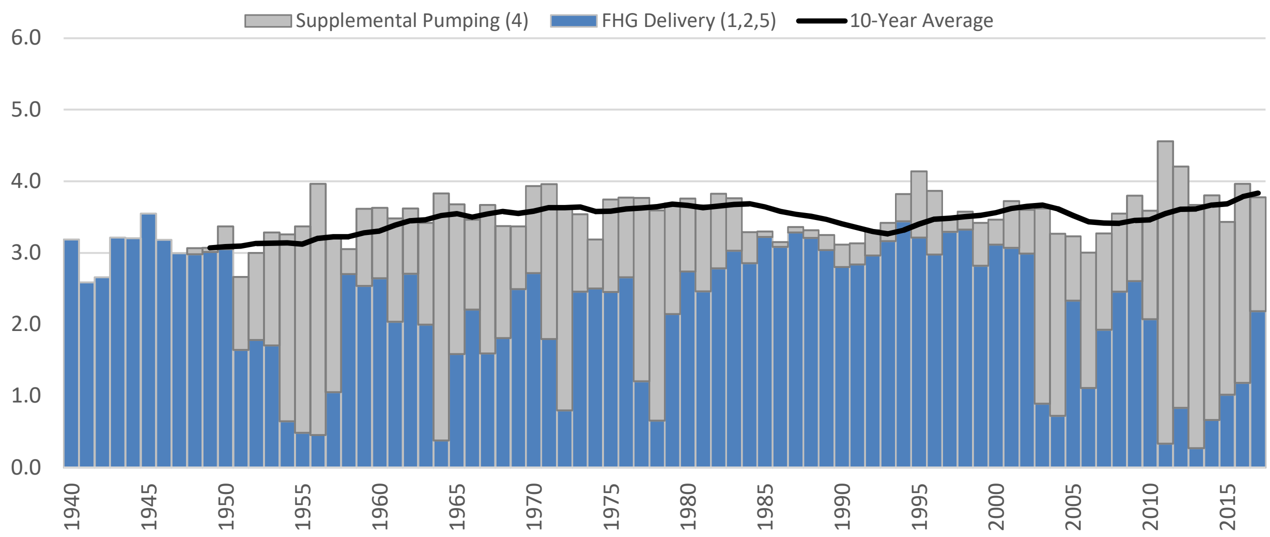
(2) JID farm deliveries were estimated as total diversions minus canal loss.

(3) Supplemental pumping computed based on unmet demand from SWE Canal and Farm Budget analysis.

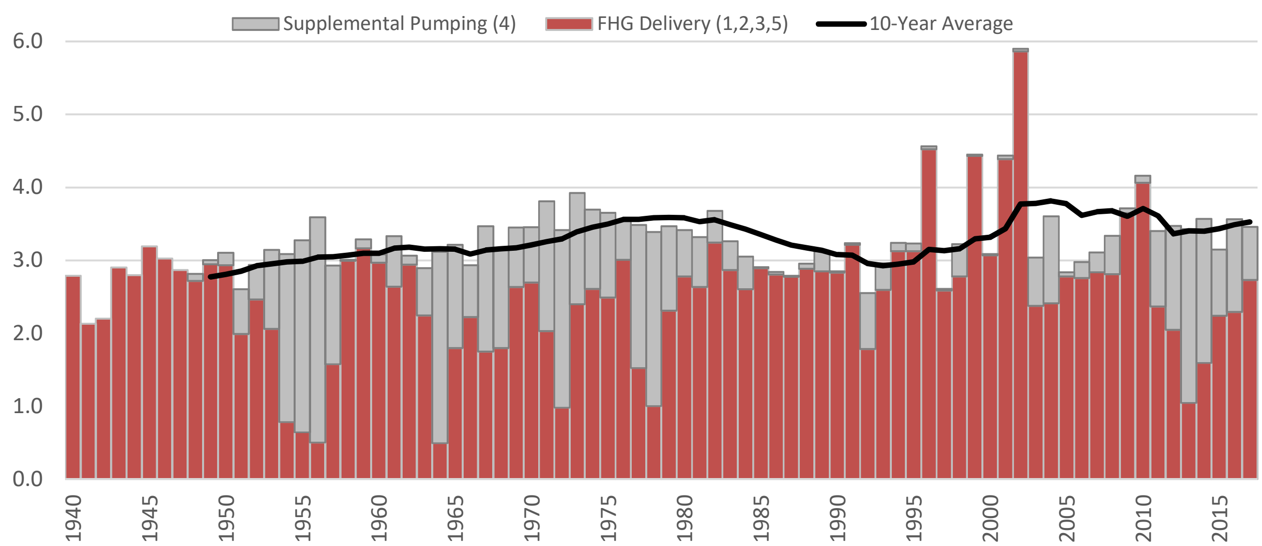
Figure 5-17

Annual UNIT Total Applied Water (SW + GW) (Actual Acres)
Irrigation Season (Mar-Oct)
1940 - 2017
(acre-feet)

EBID



EPCWID



Notes:

(1) Farm deliveries from records except when missing. For years with no records, farm deliveries were estimated as total diversions minus conveyance loss. Loss estimated using monthly average loss % derived from records.

(2) Pre-1979, farm deliveries split between Mesilla NM and Mesilla TX proportionally by acreage.

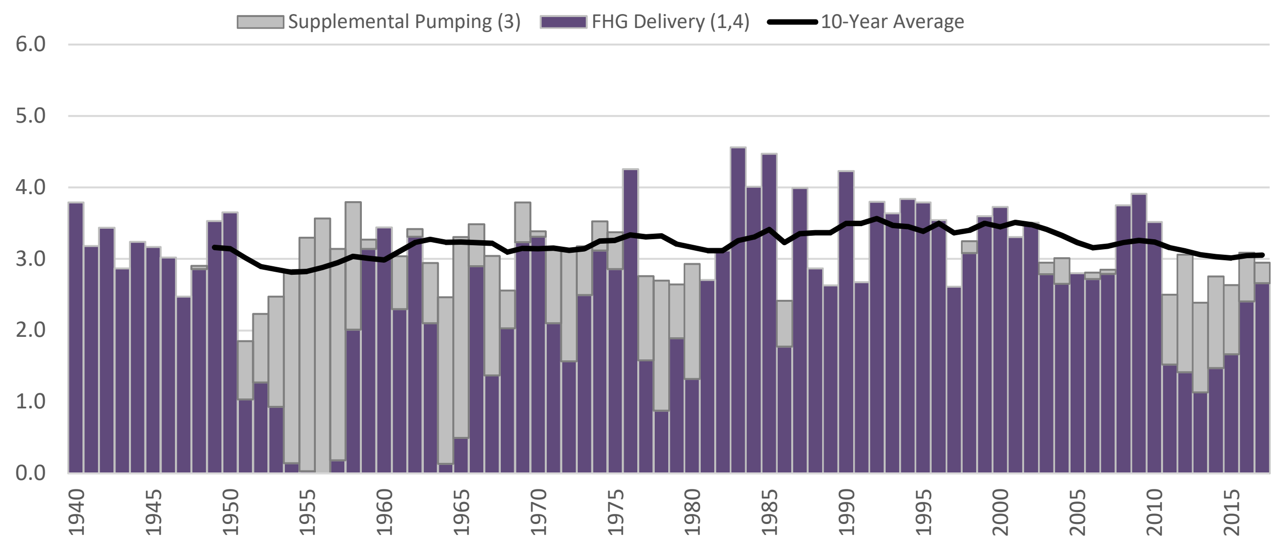
(3) EPCWID FHG deliveries do not include deliveries to EPW.

(4) Supplemental pumping computed based on unmet demand from SWE Canal and Farm Budget analysis.

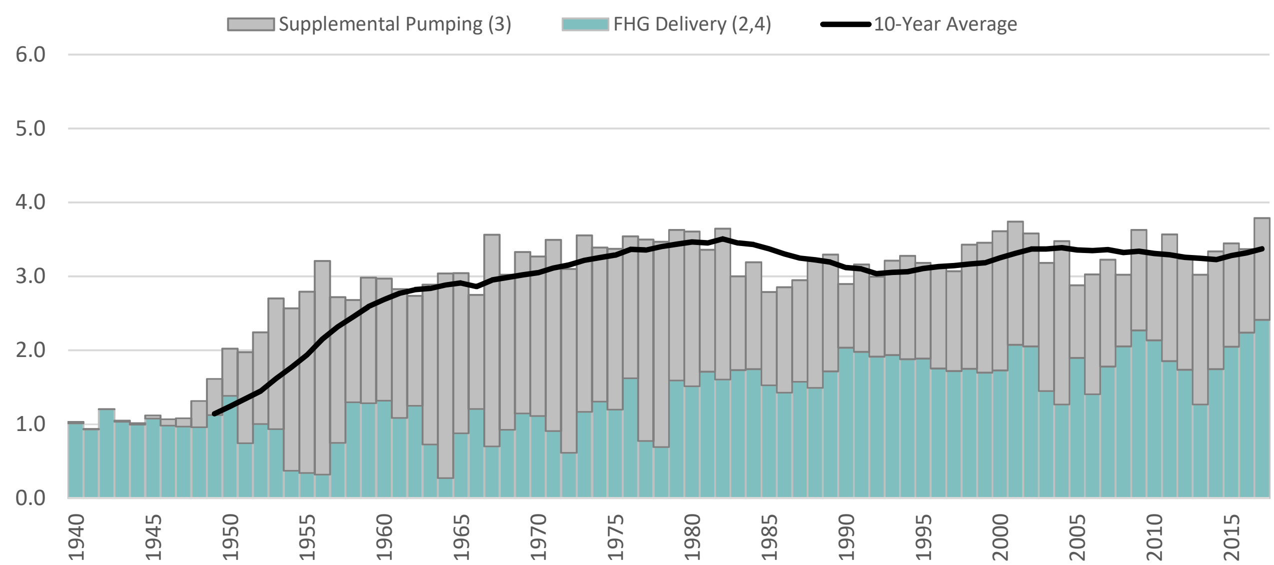
(5) Acreage data from Rio Grande Project Canal and Farm Budget.

Figure 5-18

Annual UNIT Total Applied Water (SW + GW) (Actual Acres)
Irrigation Season (Mar-Oct)
1940 - 2017
(acre-feet)
HCCRD



JID



Notes:

(1) Farm deliveries for HCCRD from records except when missing. For years with no records, farm deliveries were estimated as total diversions minus conveyance loss. Loss estimated using monthly average loss % derived from records.

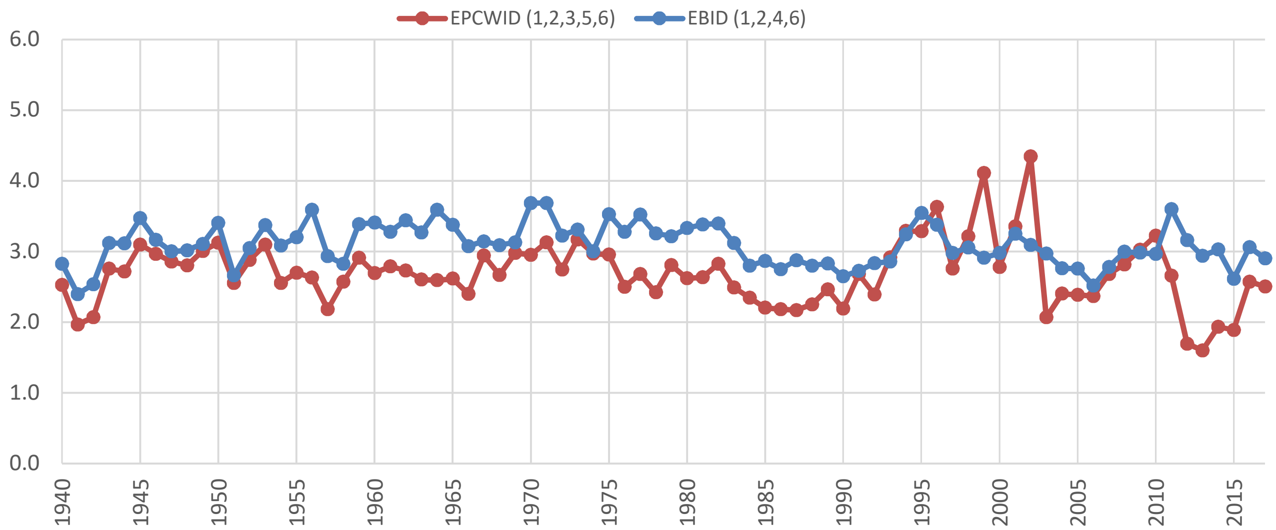
(2) JID farm deliveries were estimated as total diversions minus canal loss.

(3) Supplemental pumping computed based on unmet demand from SWE Canal and Farm Budget analysis.

(4) Acreage data from Rio Grande Project Canal and Farm Budget.

Figure 5-19

Annual UNIT Total Applied Water (SW + GW) (Authorized Acres)
Irrigation Season (Mar-Oct)
1940 - 2017
(acre-feet/acre)



Notes:

(1) Farm deliveries from records except when missing. For years with no records, farm deliveries were estimated as total diversions minus conveyance loss. Loss estimated using monthly average loss % derived from records.

(2) Pre-1979, farm deliveries split between Mesilla NM and Mesilla TX proportionally by acreage.

(3) EPCWID include Project water deliveries to EPW.

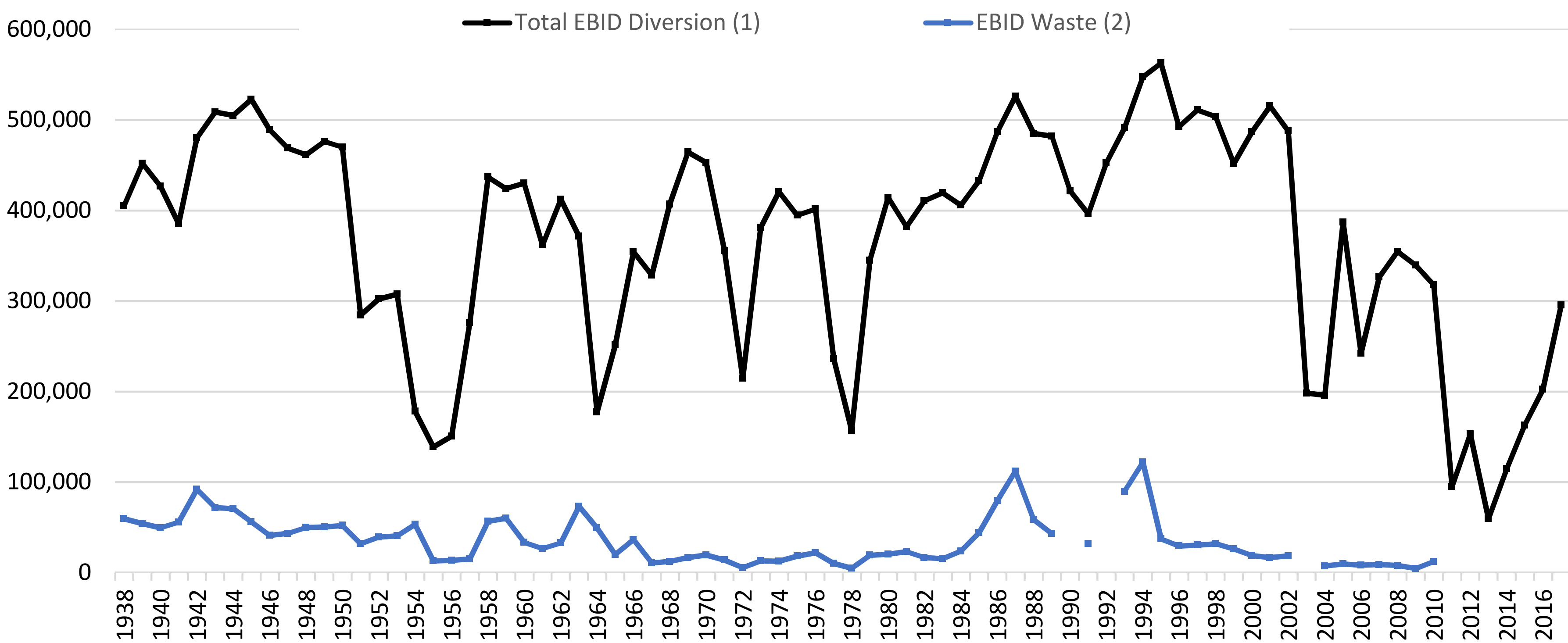
(4) EBID authorized acres: 90,640 acres.

(5) EPCWID authorized acres: 69,010 acres.

(6) Supplemental pumping computed based on unmet demand from SWE Canal and Farm Budget analysis.

Figure 5-20

Annual EBID Diversions and Waste
Irrigation Season
1938 - 2017
(acre-feet)



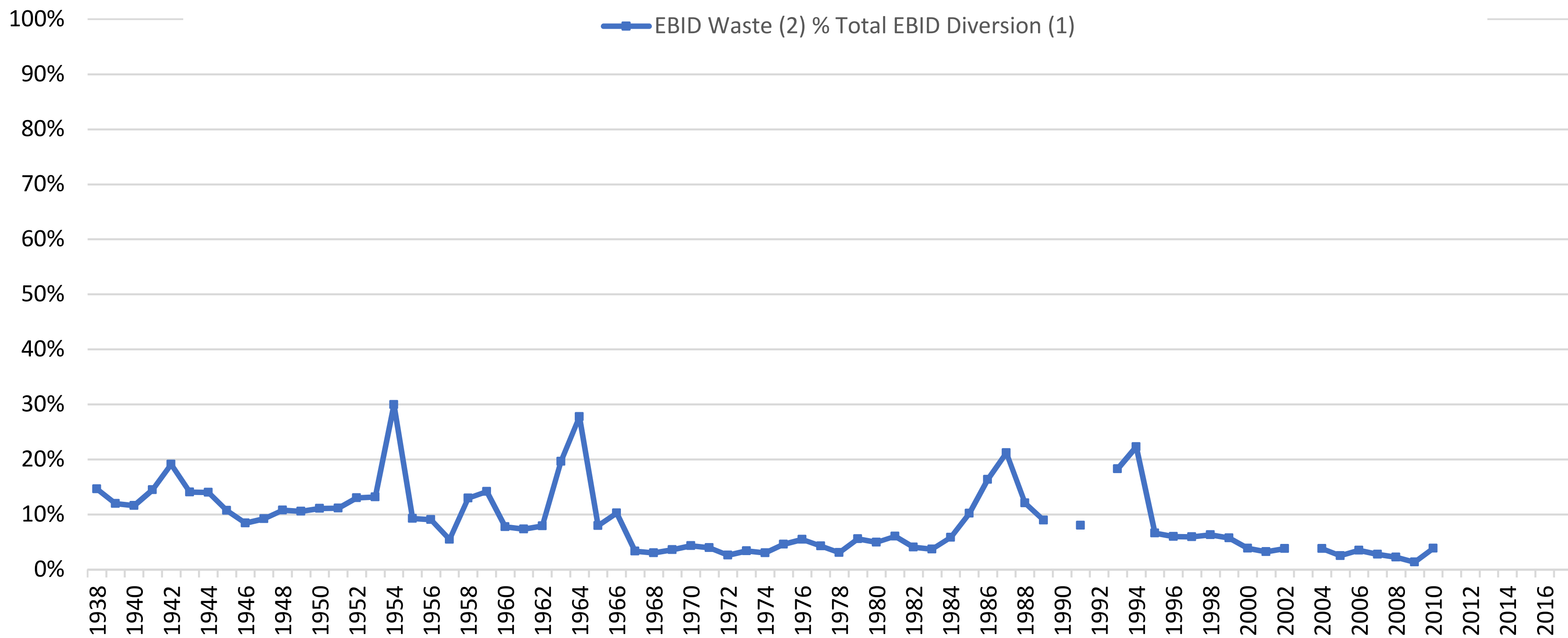
Notes:

(1) Total EBID diversions computed as the sum of diversions for Rincon, Leasburg, and NM portion of the Mesilla diversions. NM portion of the Mesilla diversions are proportional to NM irrigated acres in the Mesilla.

(2) Reported operational waste from Water Distribution Reports (missing for 1990 and 1992). Pre- 1979, waste was computed as the sum of Rincon waste, Leasburg waste, and NM portion of Total Mesilla Waste (NM portion of the total waste is proportionally to the NM irrigated acres in the Mesilla).

Figure 5-21

Annual EBID Waste (% Diversions)
Irrigation Season
1938 - 2017
(% EBID Diversions)



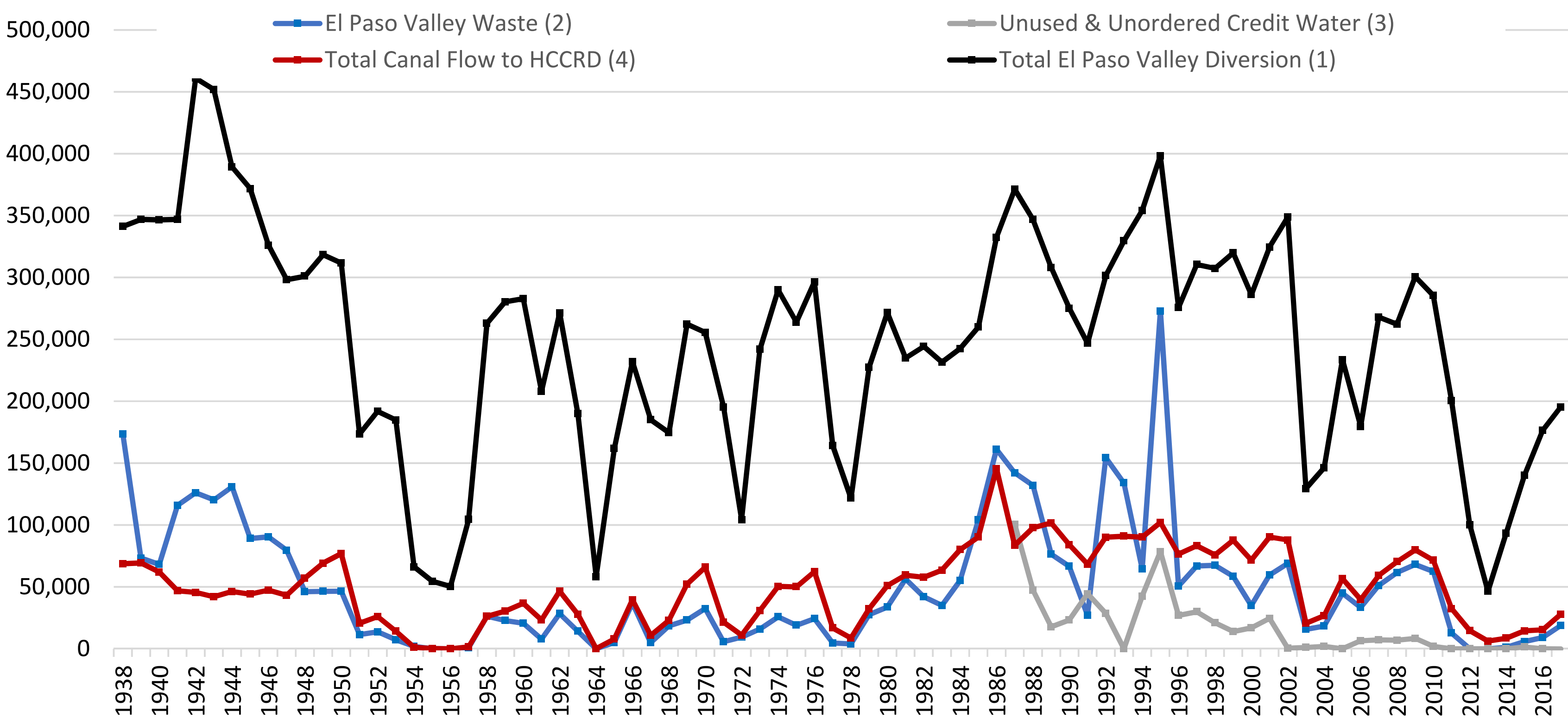
Notes:

(1) Total EBID diversions computed as the sum of diversions for Rincon, Leasburg, and NM portion of the Mesilla diversions. NM portion of the Mesilla diversions are proportional to NM irrigated acres in the Mesilla.

(2) Reported operational waste from Water Distribution Reports (missing for 1990 and 1992). Pre- 1979, waste was computed as the sum of Rincon waste, Leasburg waste, and NM portion of Total Mesilla Waste (NM portion of the total waste is proportionally to the NM irrigated acres in the Mesilla).

Figure 5-22

Annual El Paso Valley Diversions and Waste
Irrigation Season (March - October)
1938 - 2017
(acre-feet)



Notes:

(1) Total El Paso Valley diversions computed as Franklin Canal diversions minus Ascarate Wasteway (pre-ACE completion/2000) flows plus Riverside Canal gaged flows plus City of El Paso Diversions.

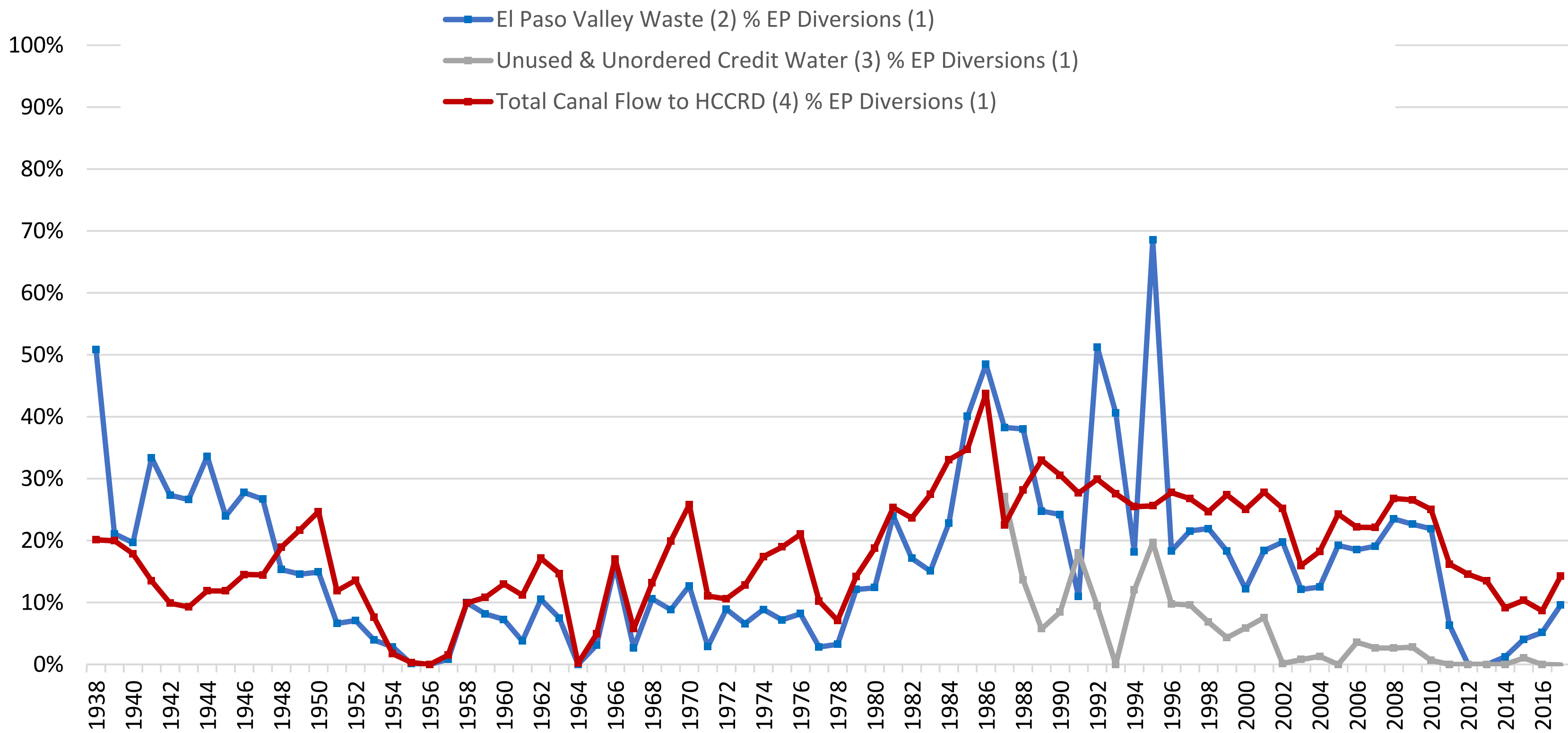
(2) Reported operational waste from Water Distribution Reports. Calculation varies per WDR notes and generally includes Riverside wasteway flows to river plus a portion of the flows to Hudspeth. Values estimated after 2002 based on regression with Hudspeth supply.

(3) Credit water to EPCWID from Accounting Reports for unused and unordered Project water.

(4) Hudspeth (Tornillo End) flows from 1938 - 4/1947 and sum of Hudspeth Feeder Canal and Tornillo Canal at AA from 5/1947 - 2017 (does not include Tornillo Drain flow).

Figure 5-23

Annual El Paso Valley Waste (% Diversions)
Irrigation Season
1938 - 2017
(% El Paso Valley Diversions)



Notes:

(1) Total El Paso Valley diversions computed as Franklin Canal diversions minus Ascarate Wasteway (pre-ACE completion/2000) flows plus Riverside Canal gaged flows plus City of El Paso Diversions.

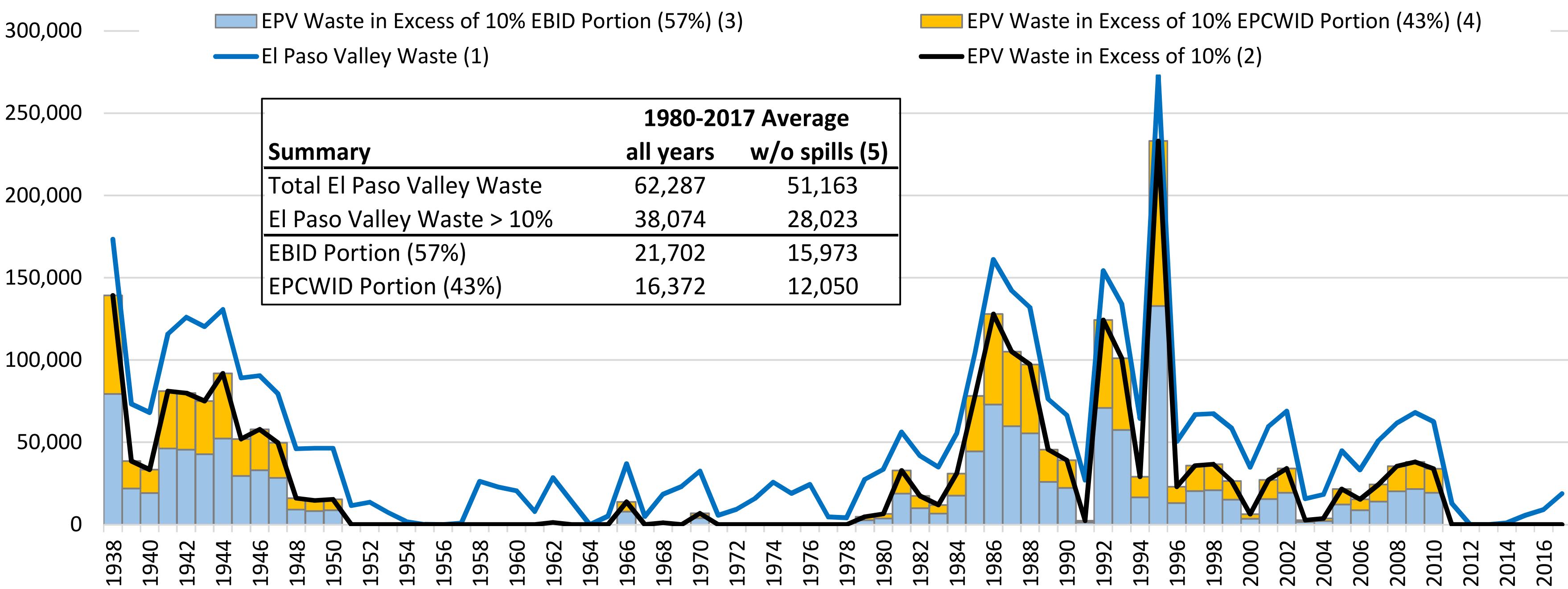
(2) Reported operational waste from Water Distribution Reports. Calculation varies per WDR notes and generally includes Riverside wasteway flows to river plus a portion of the flows to Hudspeth. Values estimated after 2002 based on regression with Hudspeth supply.

(3) Credit water to EPCWID from Accounting Reports for unused and unordered Project water.

(4) Hudspeth (Tornillo End) flows from 1938 - 4/1947 and sum of Hudspeth Feeder Canal and Tornillo Canal at AA from 5/1947 - 2017 (does not include Tornillo Drain flow).

Figure 5-24

Excess El Paso Valley Waste
Irrigation Season (March - October)
1938 - 2017
(acre-feet)



	1980-2017 Average	
Summary	**all years**	**w/o spills (5)**
Total El Paso Valley Waste	62,287	51,163
El Paso Valley Waste > 10%	38,074	28,023
EBID Portion (57%)	21,702	15,973
EPCWID Portion (43%)	16,372	12,050

Notes:

(1) Waste from WDR reports (1938 - 2002). Waste estimated from 2003 - 2017 using 1938 - 2002 regression with total flow to Hudspeth.

(2) Tabulated waste in excess of 10 percent of total river headgate diversions. Total river headgate diversions for EPCWID computed as Franklin Canal gaged flows minus Ascarate Wasteway (pre-ACE completion/2000) flows plus Riverside Canal gaged flows plus EPW Diversions of Project Water.

(3) EPV Waste in Excess of 10% (2) multiplied by 57 percent.

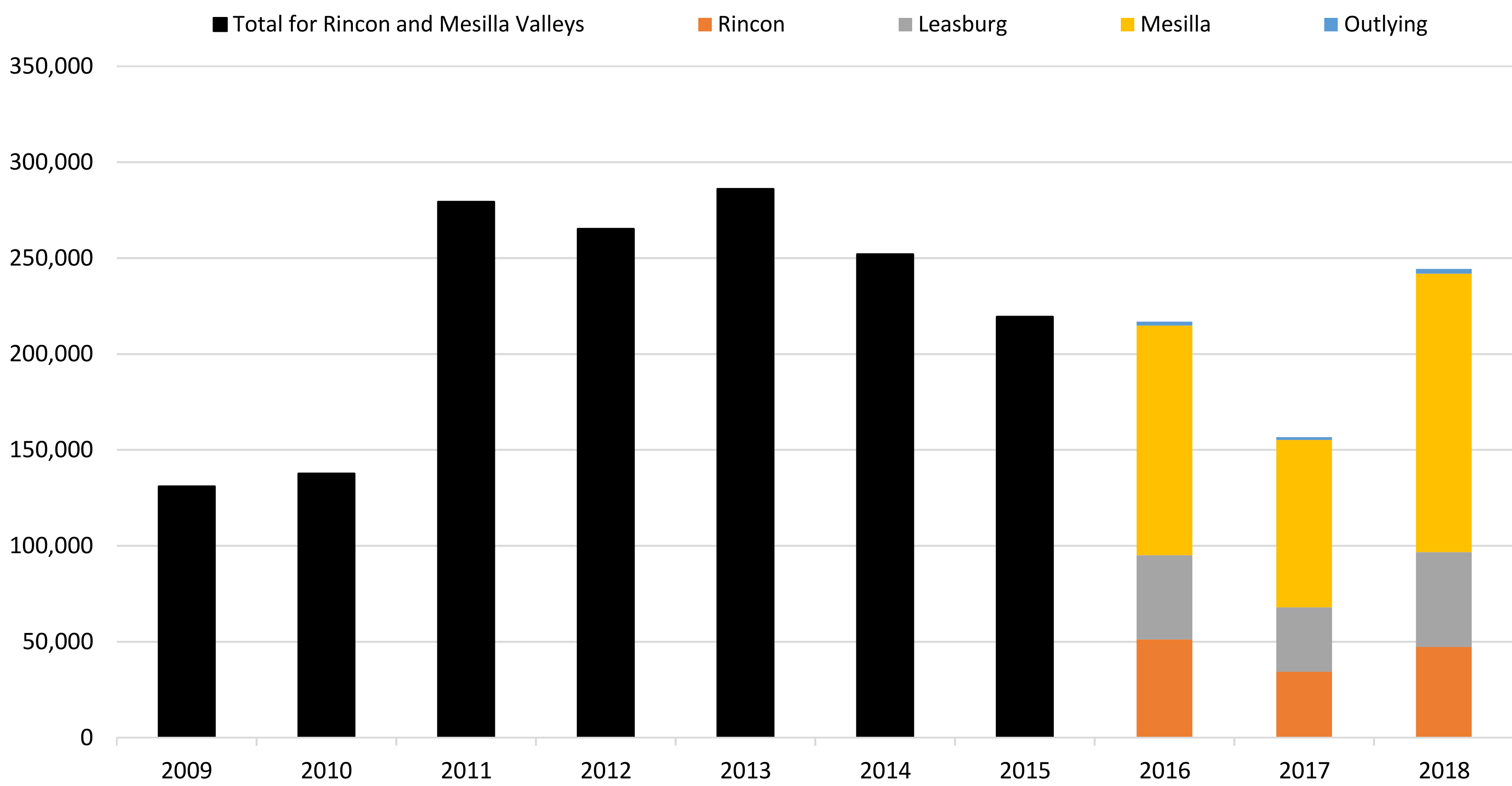
(4) EPV Waste in Excess of 10% (2) multiplied by 43 percent.

(5) Spill years were 1986, 1987, and 1995.

Figure 5-25

Irrigation Pumping in EBID Vicinity

2009 - 2018 (acre-feet)

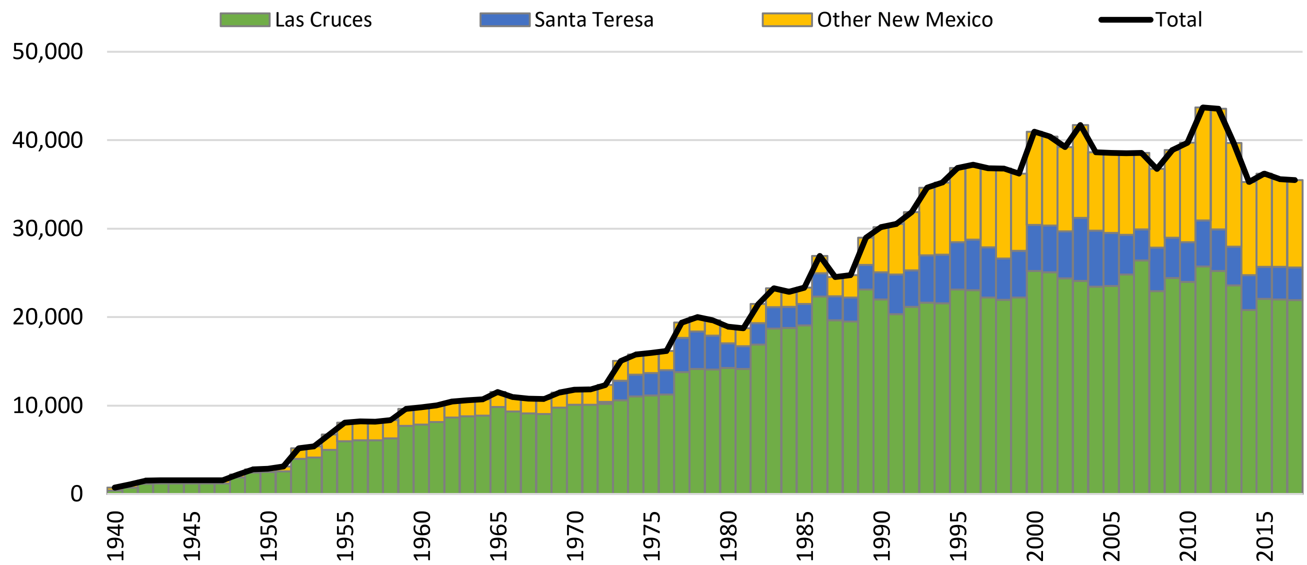


Note:
Metered irrigation pumping data provided by NMOSE (Ryan Serrano and Peggy Barroll).

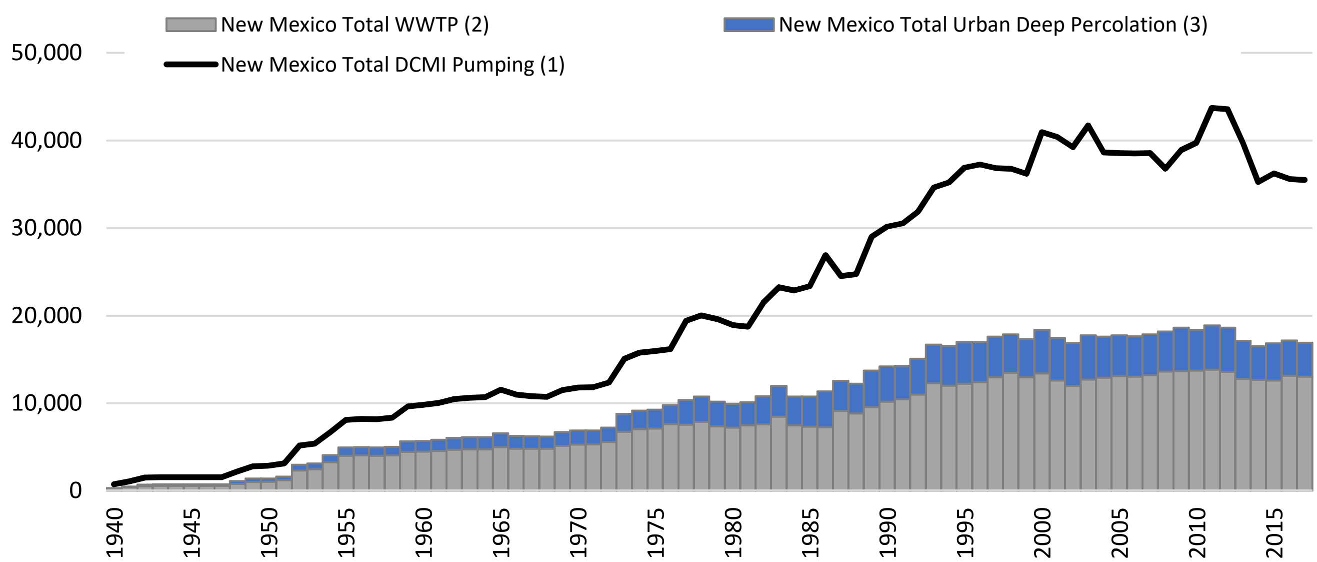
Figure 5-26

Annual Non-Irrigation Pumping and Return Flows
New Mexico
1940 - 2017
(acre-feet)

Annual Non-Irrigation Pumping



Annual Non-Irrigation Pumping and Return Flows



Notes:

(1) All DCMI pumping in the Rincon-Mesilla basin excluding EPW Canutillo and Juarez Conejos Medanos wells.

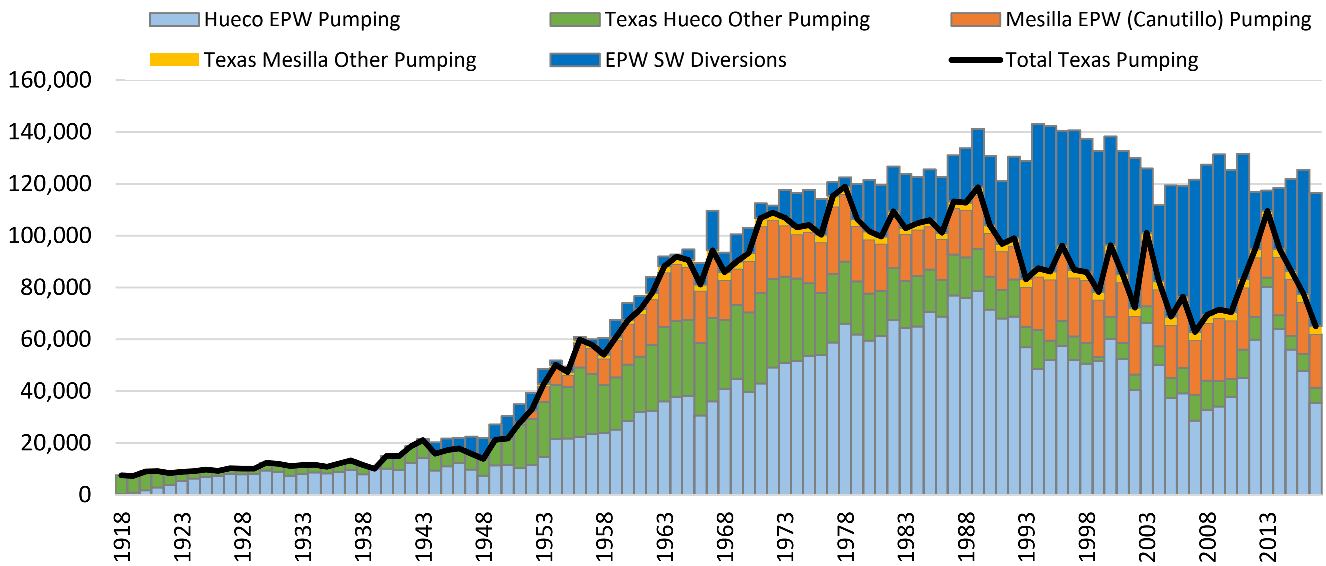
(2) All WWTP discharges compiled for input into the Integrated LRG Model (includes Total Las Cruces, Total Sunland Park/ Santa Teresa, El Paso Electric, South Central Regional, Anthony, Hatch, Salem, and Gadsden Independent School District).

(3) Rincon-Mesilla urban deep percolation computed for Las Cruces, Santa Teresa, Anthony, Mesquite, Berino, Garfield, and Radium Springs urban areas.

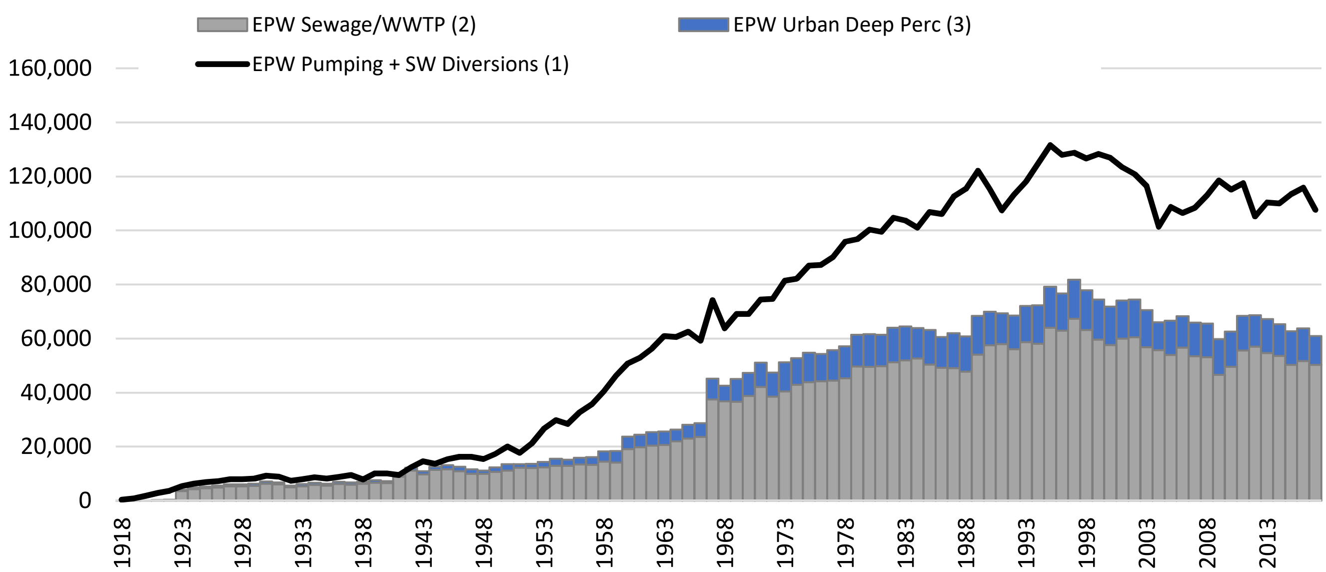
Figure 5-27

Annual Non-Irrigation Water Use and Return Flows
Texas
1918 - 2017
(acre-feet)

Annual Non-Irrigation Water Use



Annual Non-Irrigation Water User and Return Flows



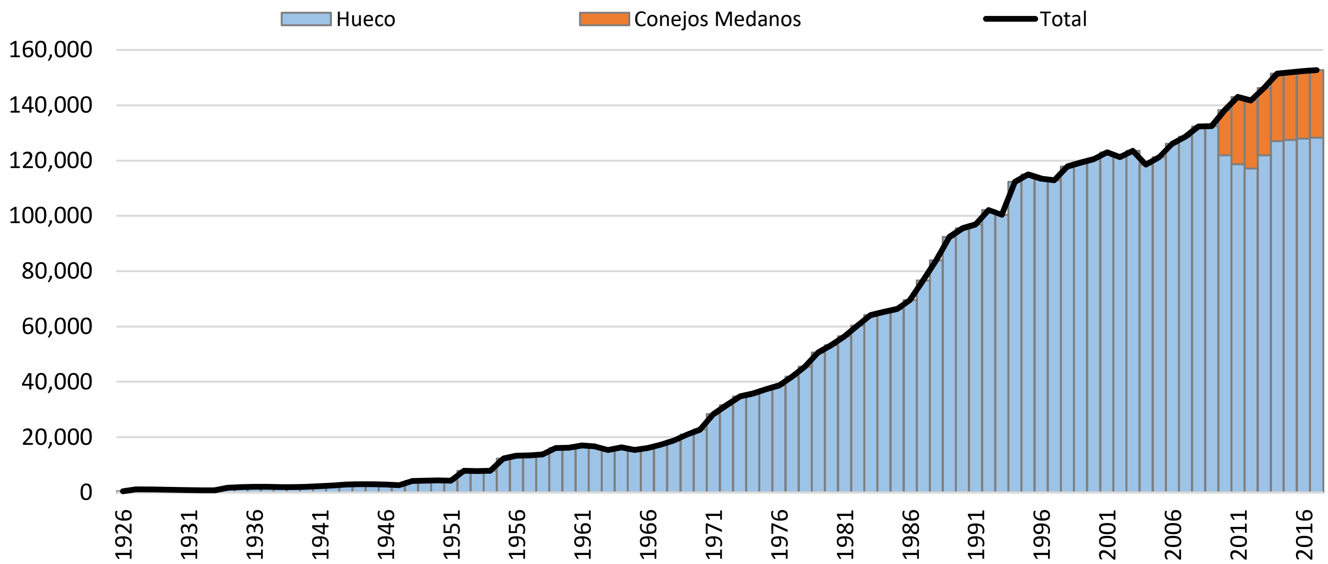
Notes:

(1) Total EPW pumping from the Hueco and Canutillo wells plus surface water (Project) diversions.
(2) Total WWTP discharge from Northwest, Haskell, Socorro, and Bustamante WWTPs.
(3) Urban deep percolation for all of the City of El Paso including areas in the Mesilla basin.

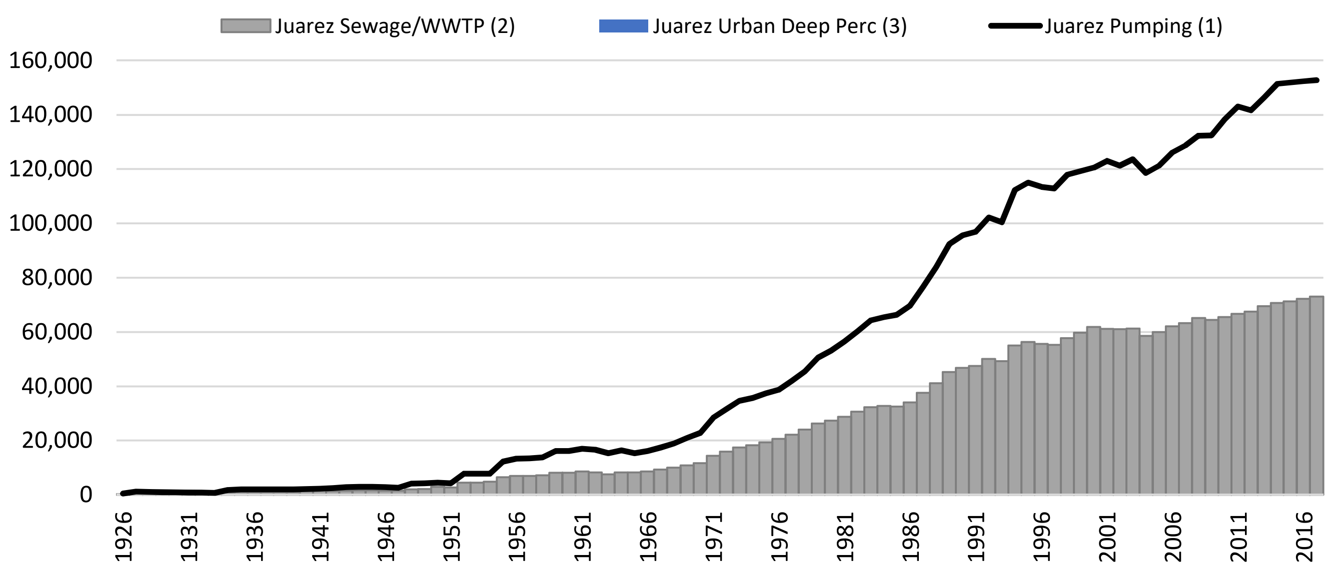
Figure 5-28

Annual Non-Irrigation Pumping and Return Flows
Mexico (Cuidad Juarez in Mesilla and Hueco Valleys)
1926 - 2017
(acre-feet)

Annual Non-Irrigation Pumping



Annual Non-Irrigation Pumping and Return Flows



(1) Total Juarez pumping from the Hueco and Conejos Medanos wells.
(2) Cuidad Juarez sewage/WWTP from IBWC for 1950 - 1984 and estimated as 49% of pumping for 1985-2017.
(3) No urban deep percolation computed for Cuidad Juarez.

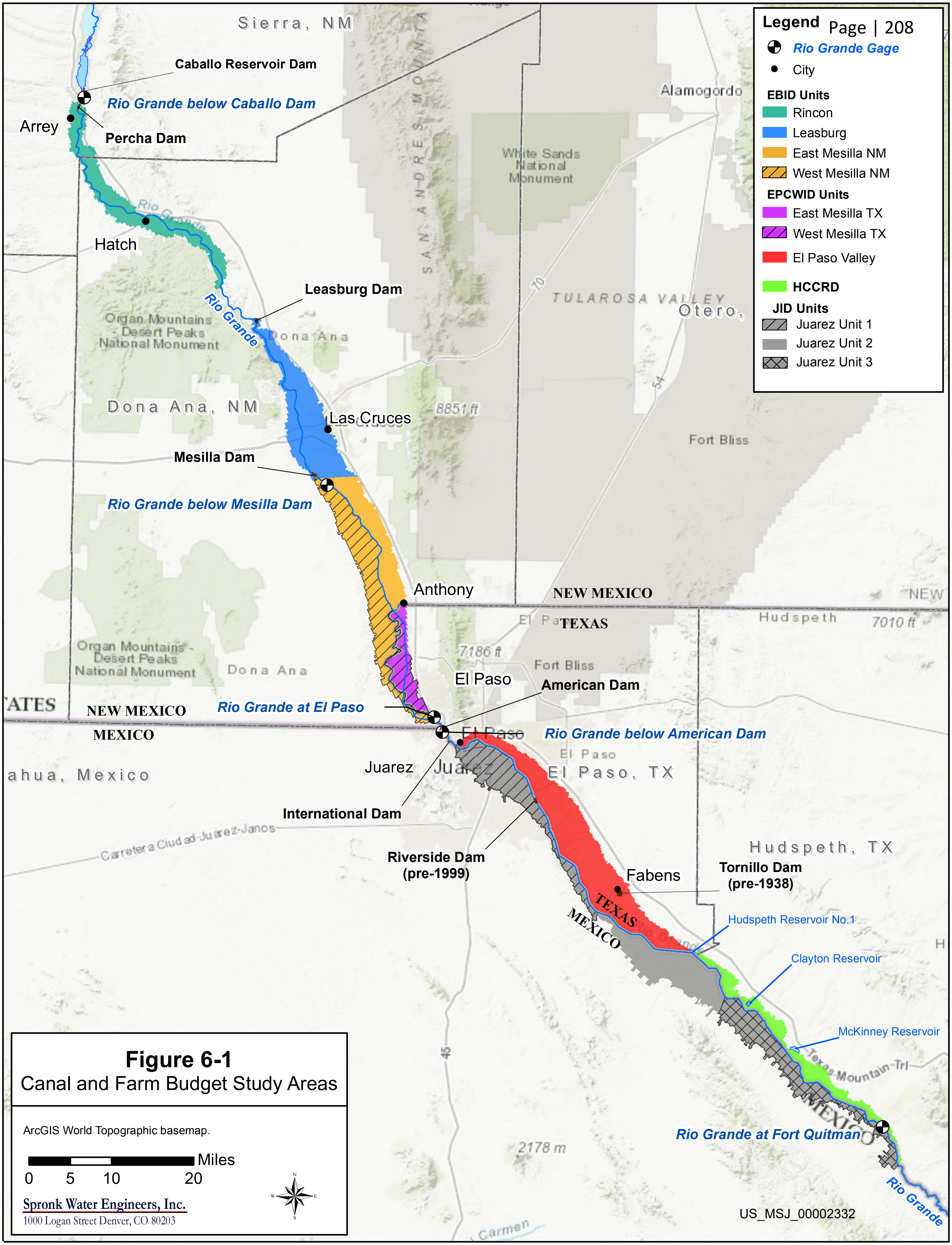


Figure 6-1
Canal and Farm Budget Study Areas

ArcGIS World Topographic basemap.

Miles
0 5 10 20

Spronk Water Engineers, Inc.
1000 Logan Street Denver, CO 80203

Figure 6-2
Canal and Farm Budget Flow Chart

Figure 6-3

Simplified Schematic of El Paso Valley Diversion Works

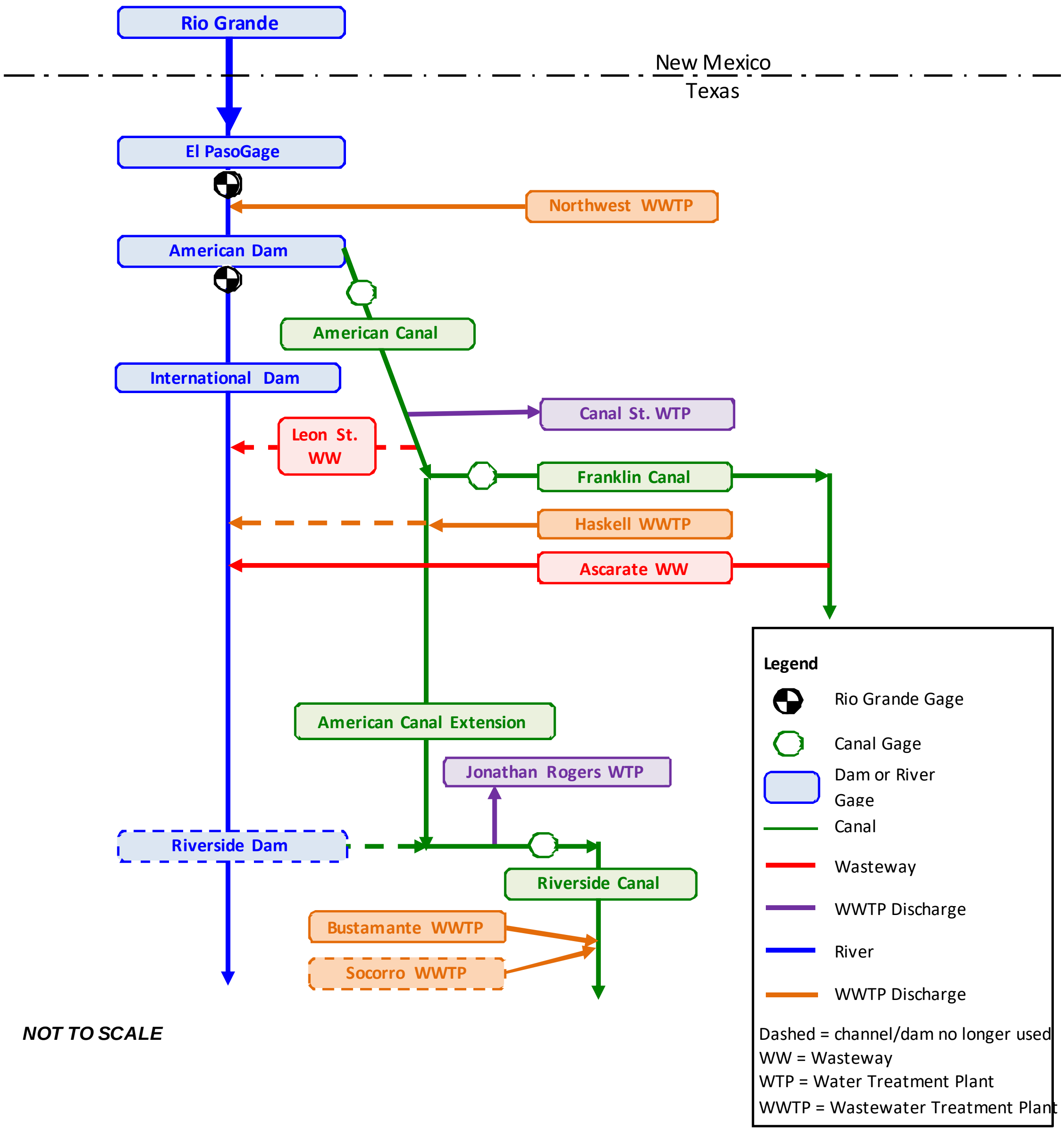
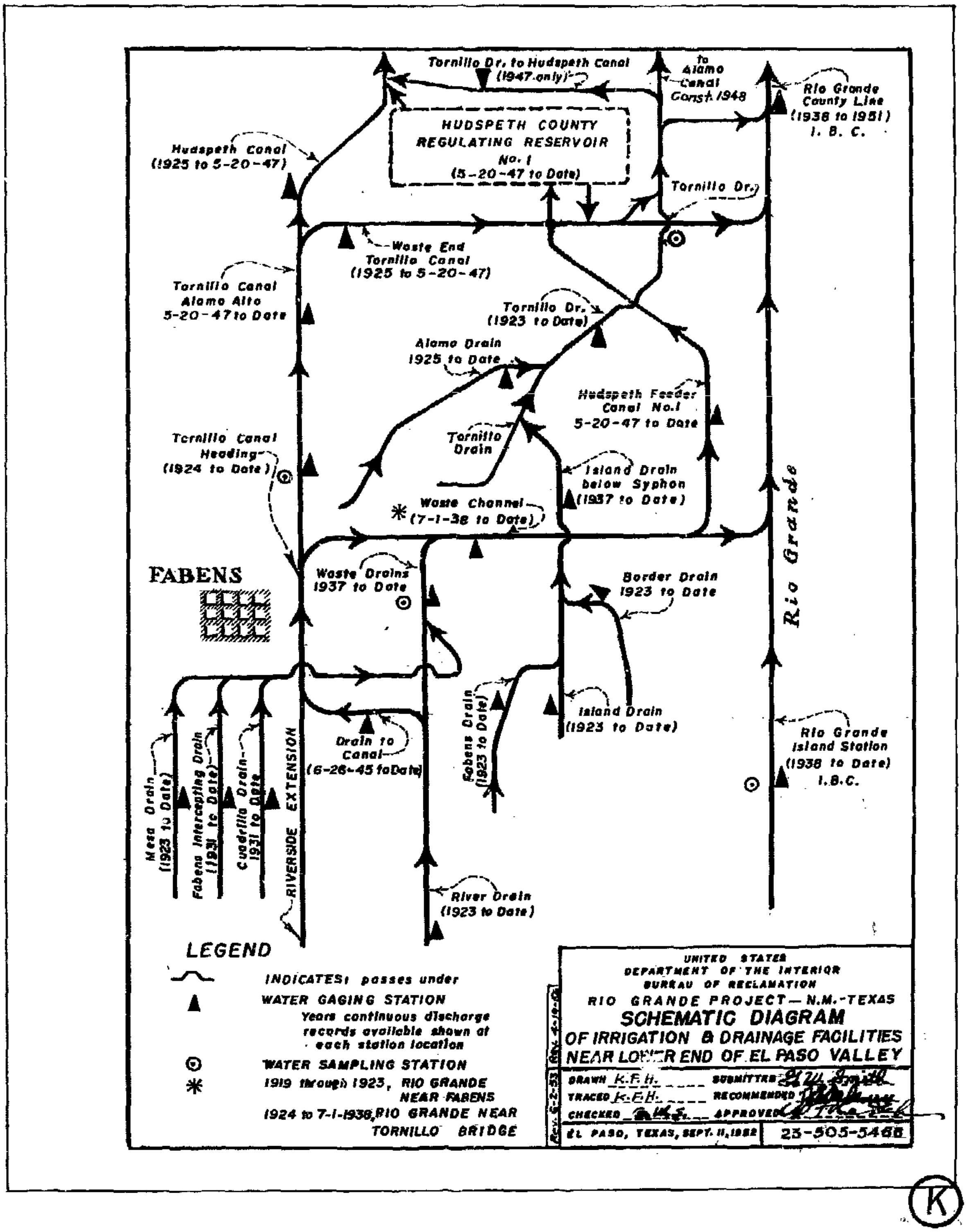


Figure 6-4

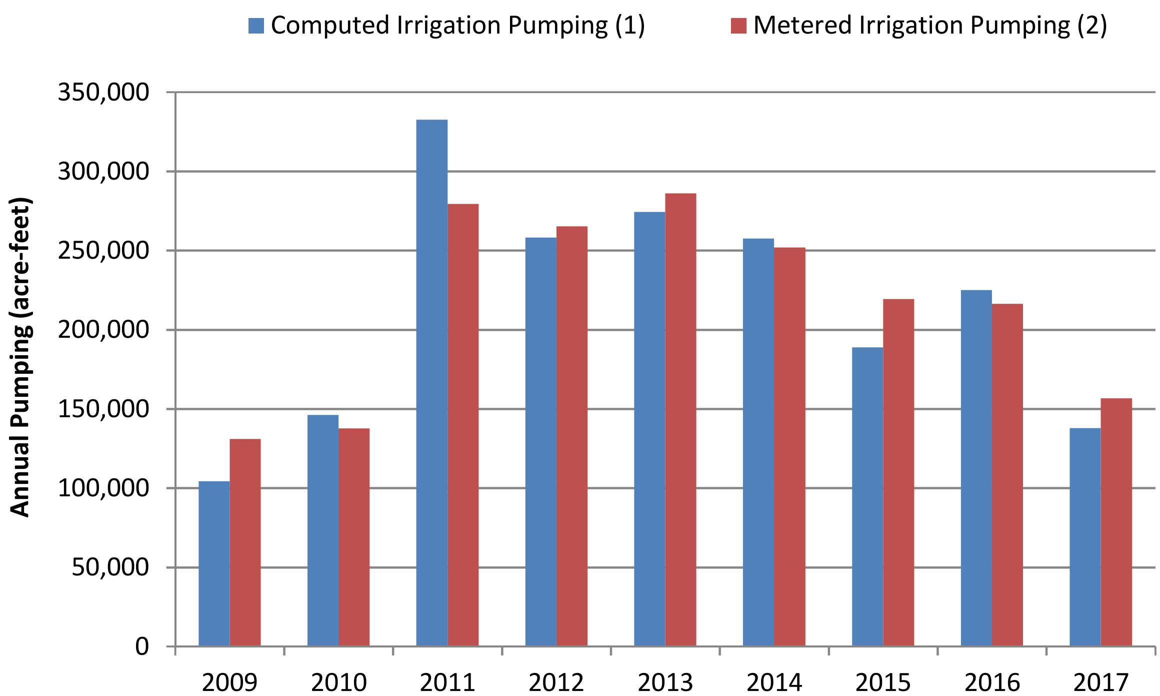
Schematic – Hudspeth Diversion Works



NOVEMBER 25, 1974

Figure 6-5

Comparison of Computed and Reported Annual EBID Irrigation Pumping
Canal and Farm Budget Model
2009-2017
(acre-feet)



<u>2009 - 2017 Averages (AF)</u>

Computed: 213,840

Reported: 215,965

<u>Notes:</u>

(1) Sum of computed supplemental and primary ground water pumping for irrigation.

(2) Metered pumping from NM Water Master Reports and NMOSE data.

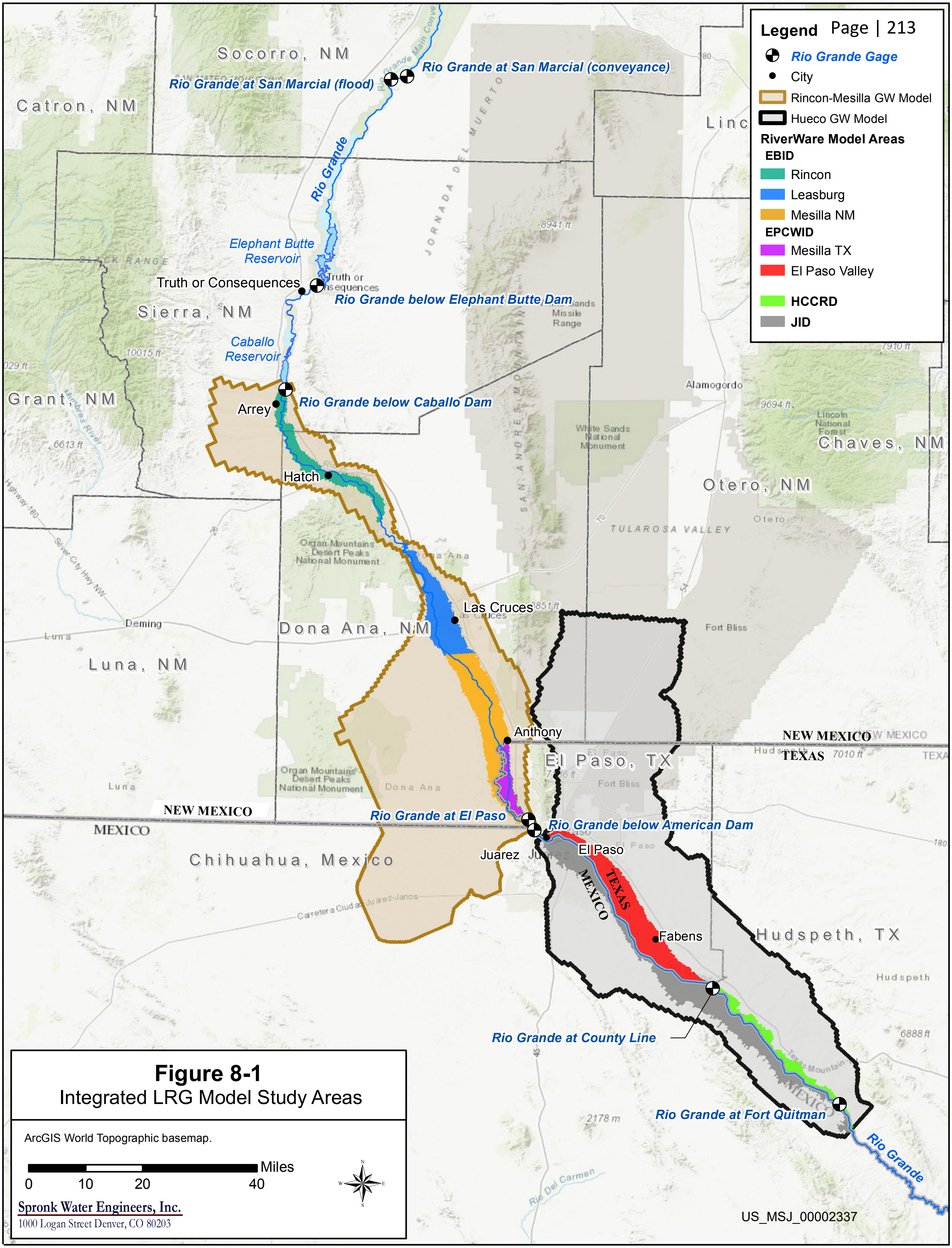
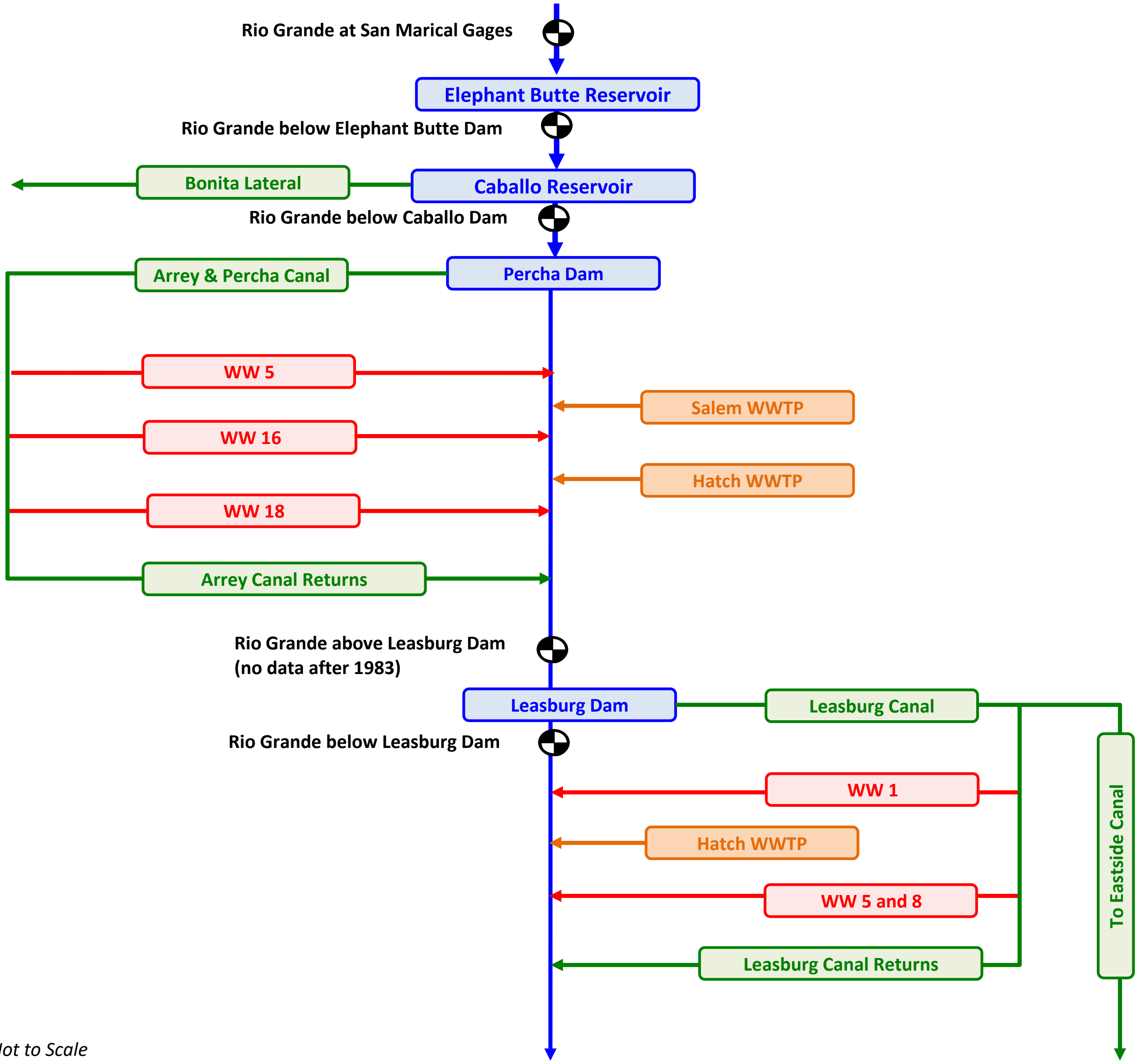


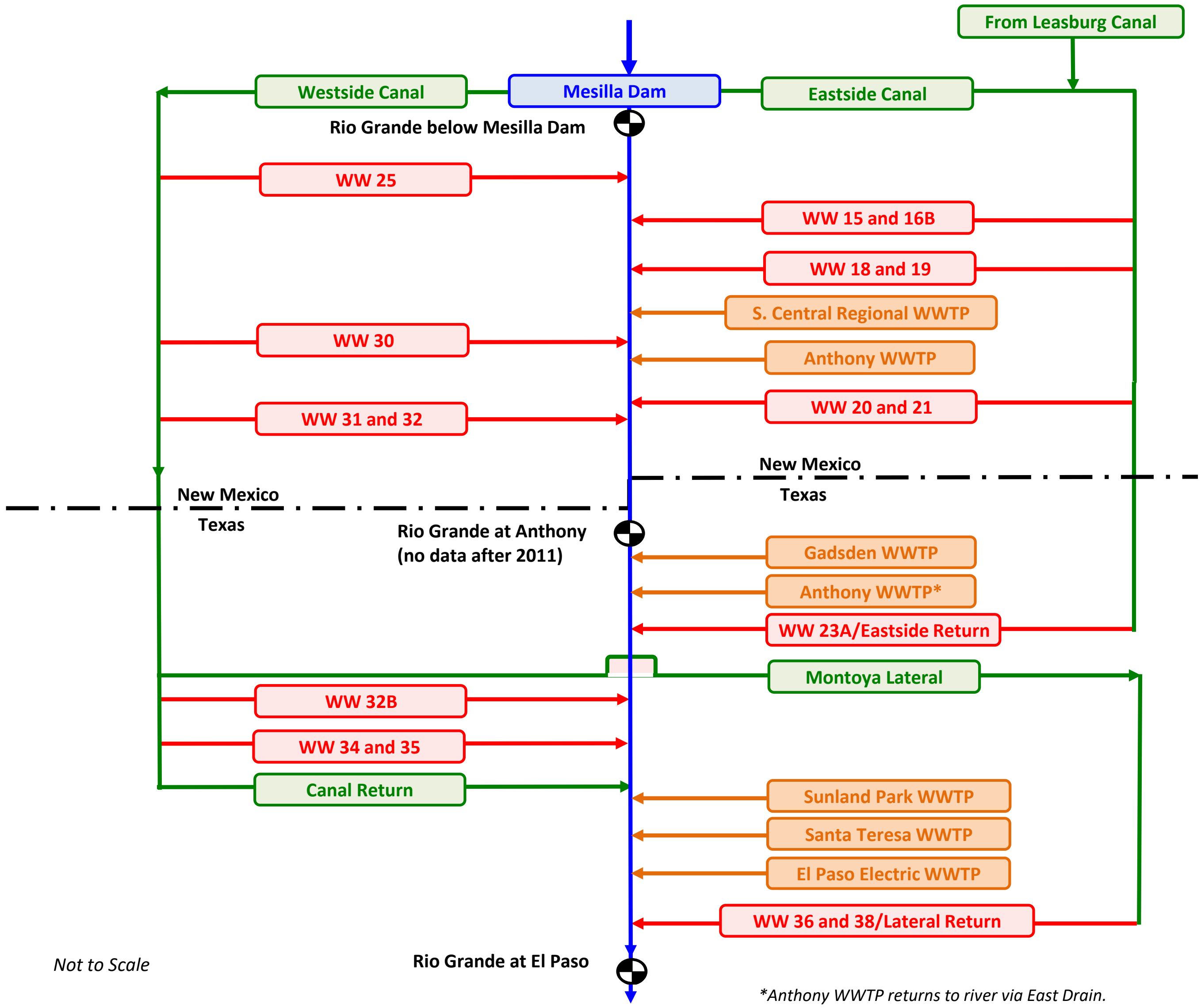
Figure 8-1
Integrated LRG Model Study Areas

Figure 8-2
Simplified RiverWare Model Flow Diagram
Integrated LRG Model
San Marcial Gages to Mesilla Dam



Not to Scale

Figure 8-2
Simplified RiverWare Model Flow Diagram
Integrated LRG Model
Mesilla Dam to El Paso Gage



Anthony WWTP returns to river via East Drain.

Figure 8-2
Simplified RiverWare Model Flow Diagram
Integrated LRG Model
El Paso Gage to County Line Gage

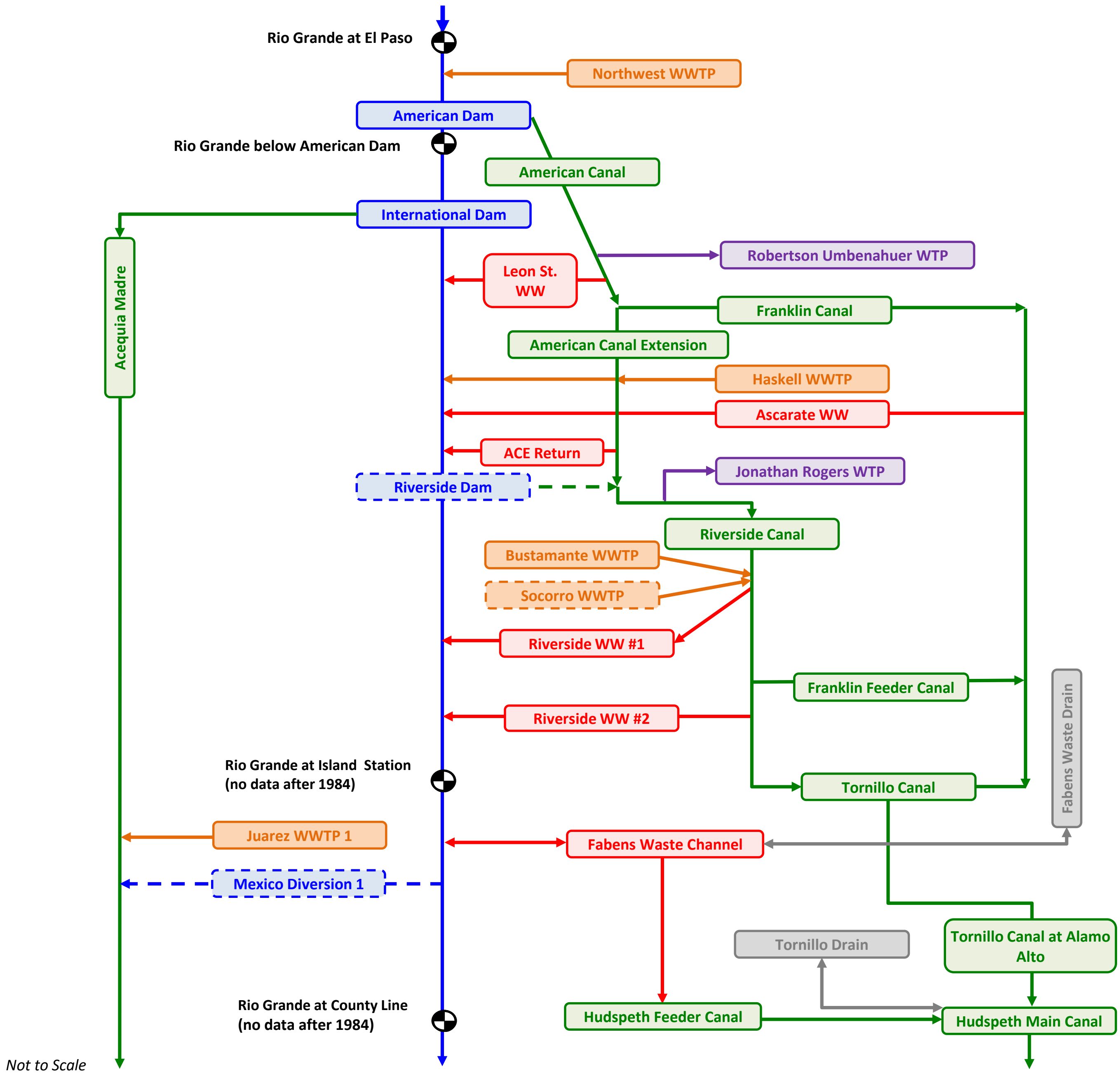
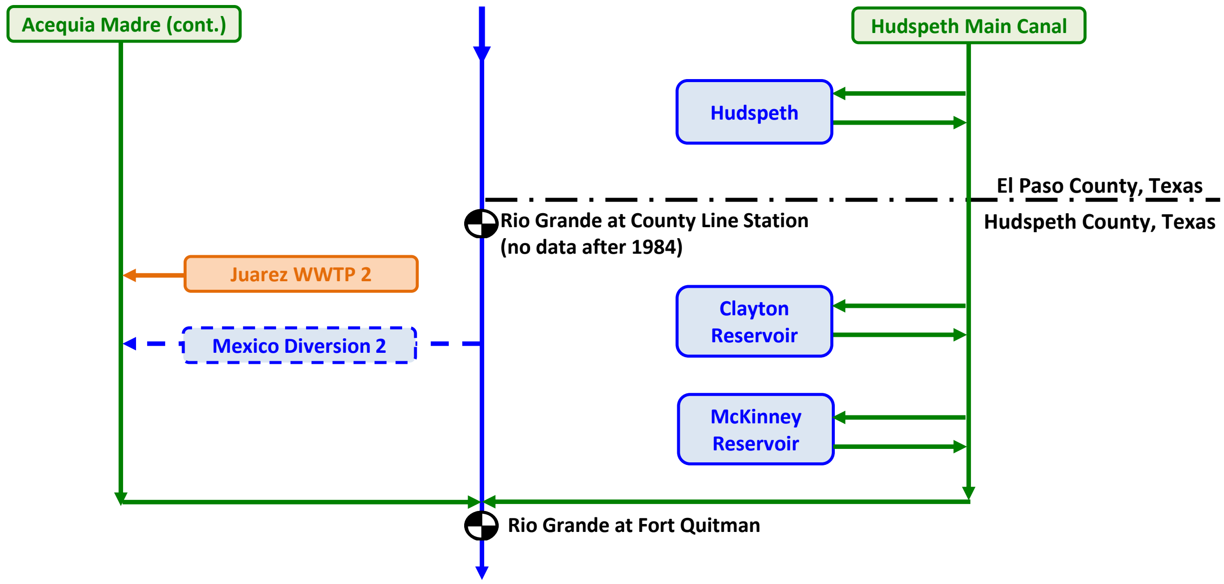


Figure 8-2
Simplified RiverWare Model Flow Diagram
Integrated LRG Model
County Line Gage to Fort Quitman Gage



Not to Scale

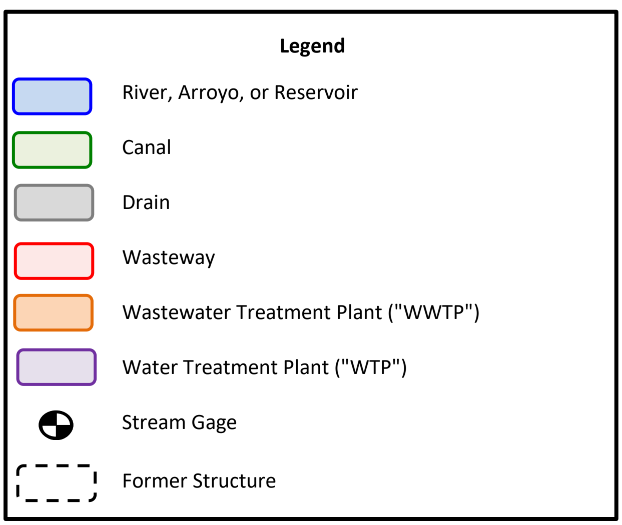


Figure 8-3

System Budget Schematic
RiverWare Model

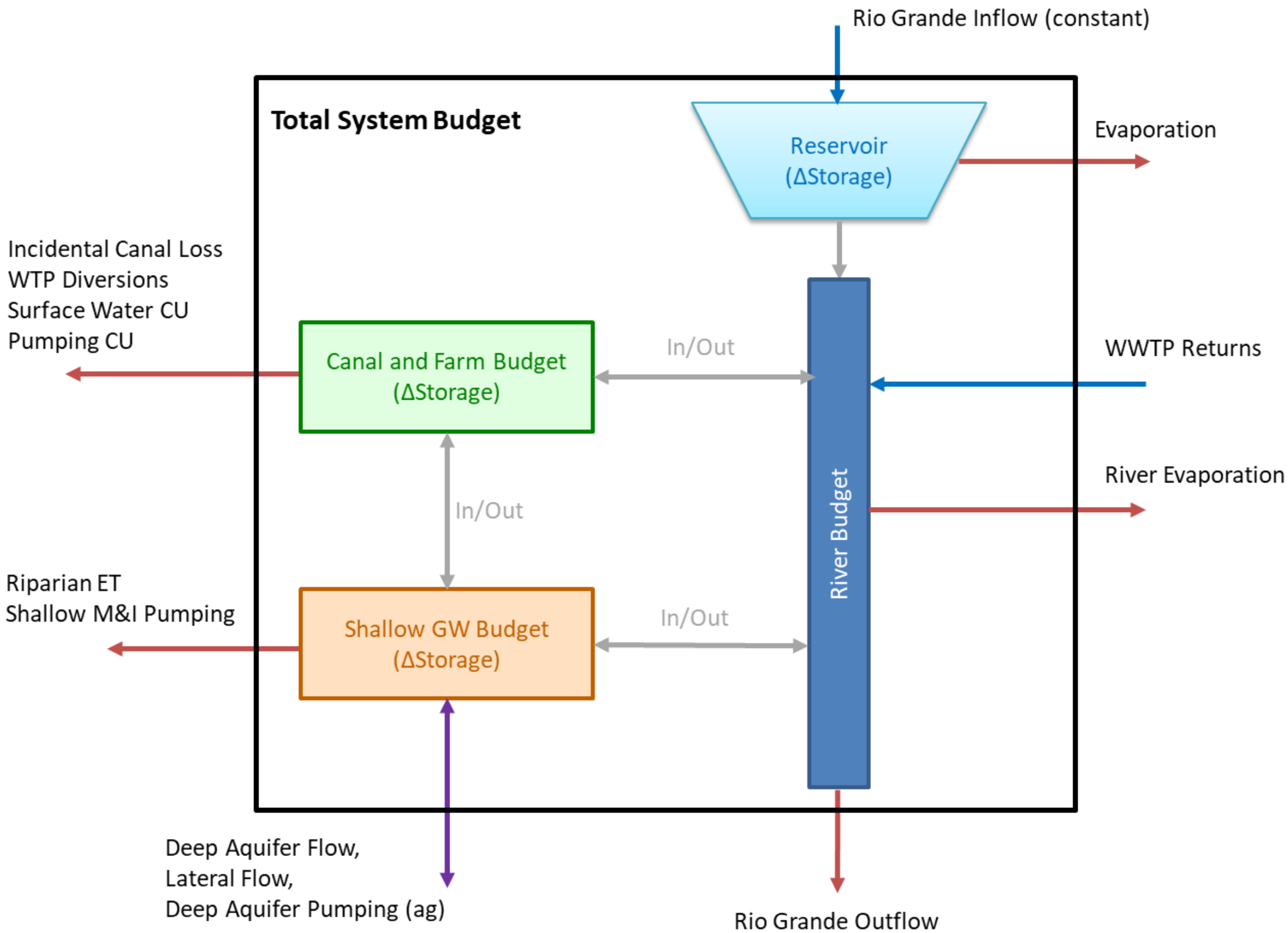


Figure 8-4

Reservoir Budget Schematic
RiverWare Model

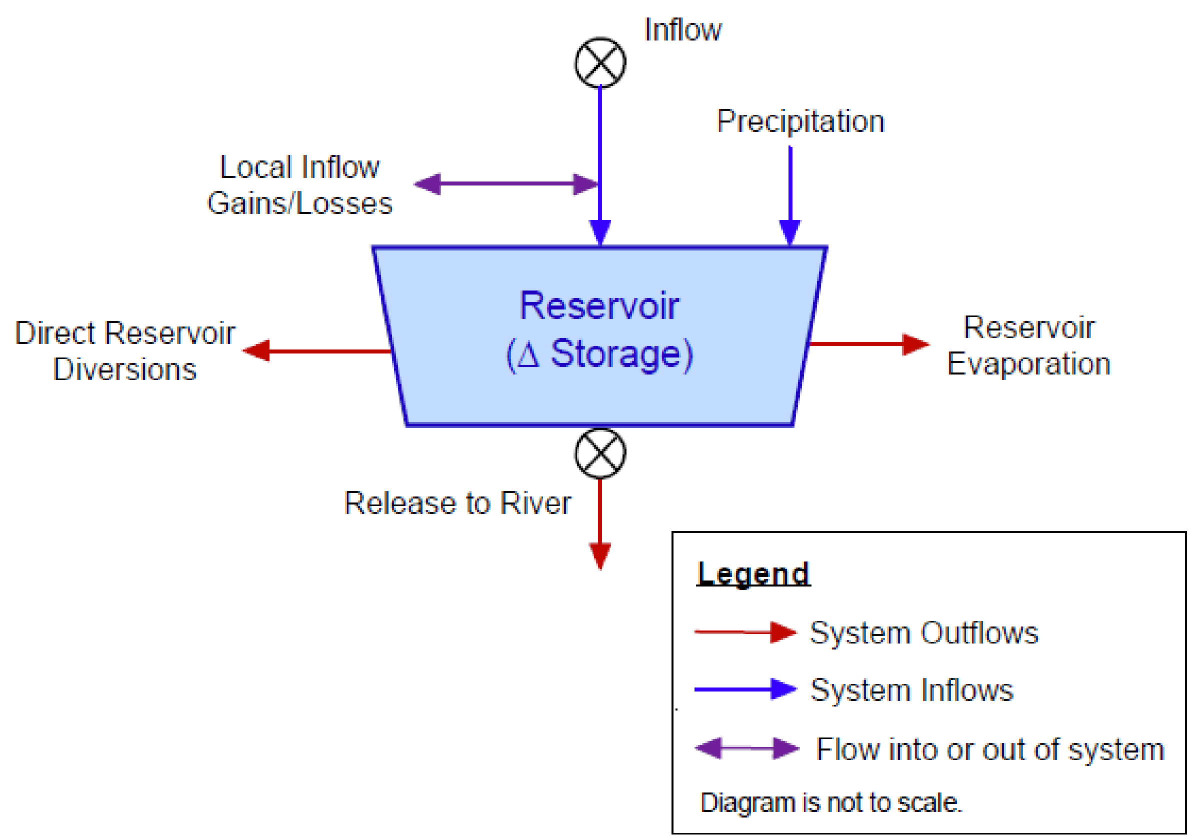


Figure 8-5

River Budget Schematic
RiverWare Model

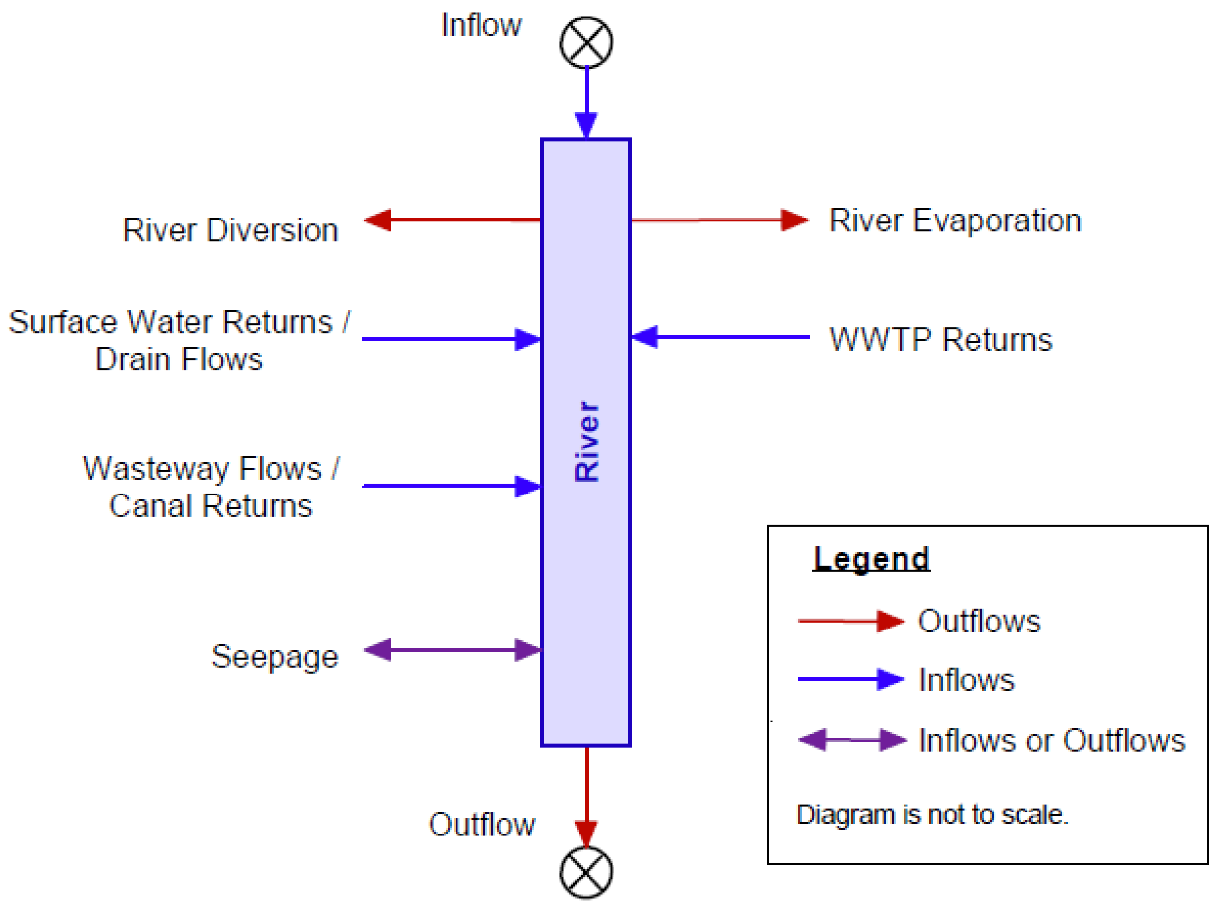


Figure 8-6

Canal and Farm Budget Schematic
RiverWare Model

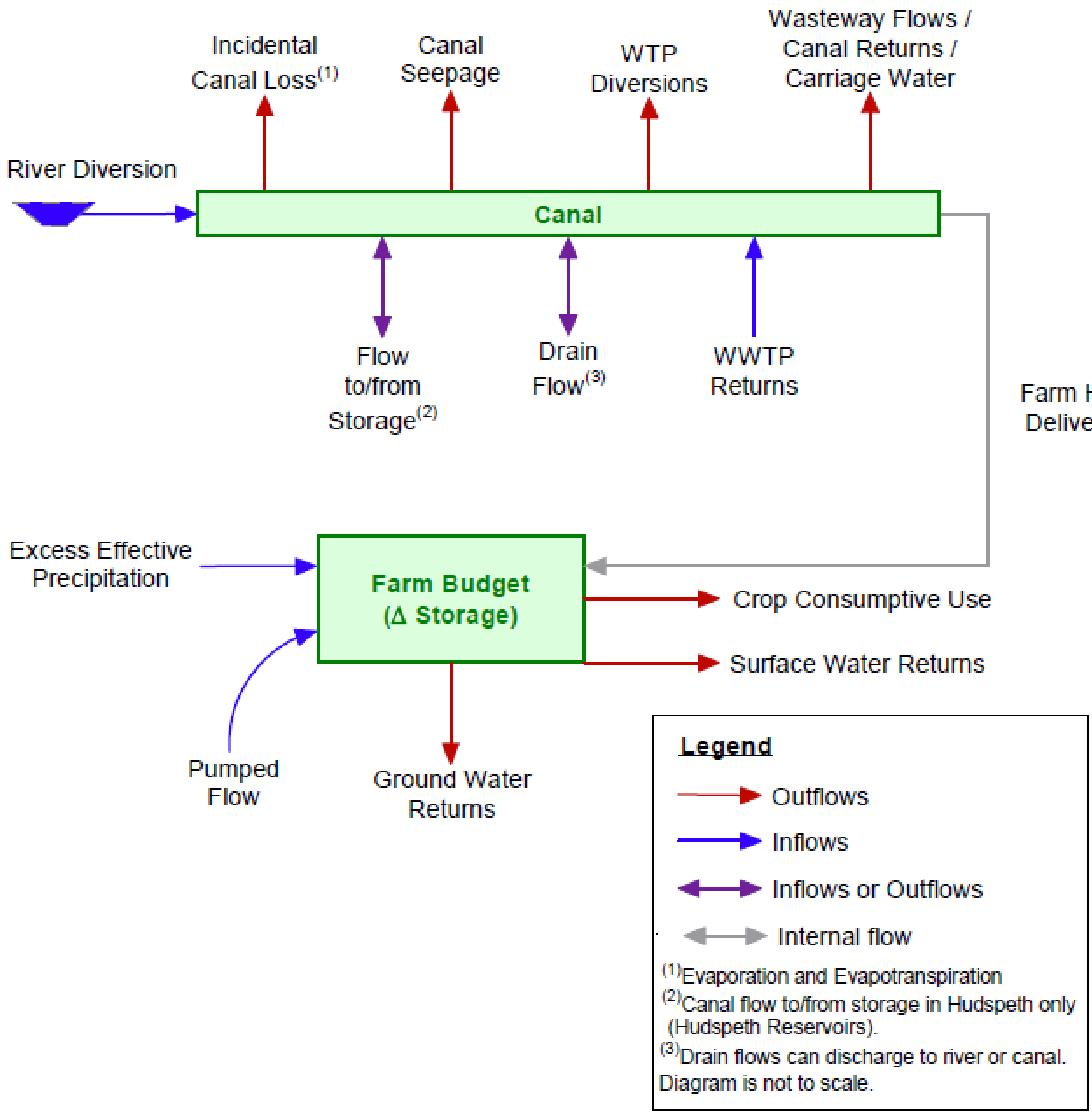


Figure 8-7

Ground Water Budget Schematic
RiverWare Model

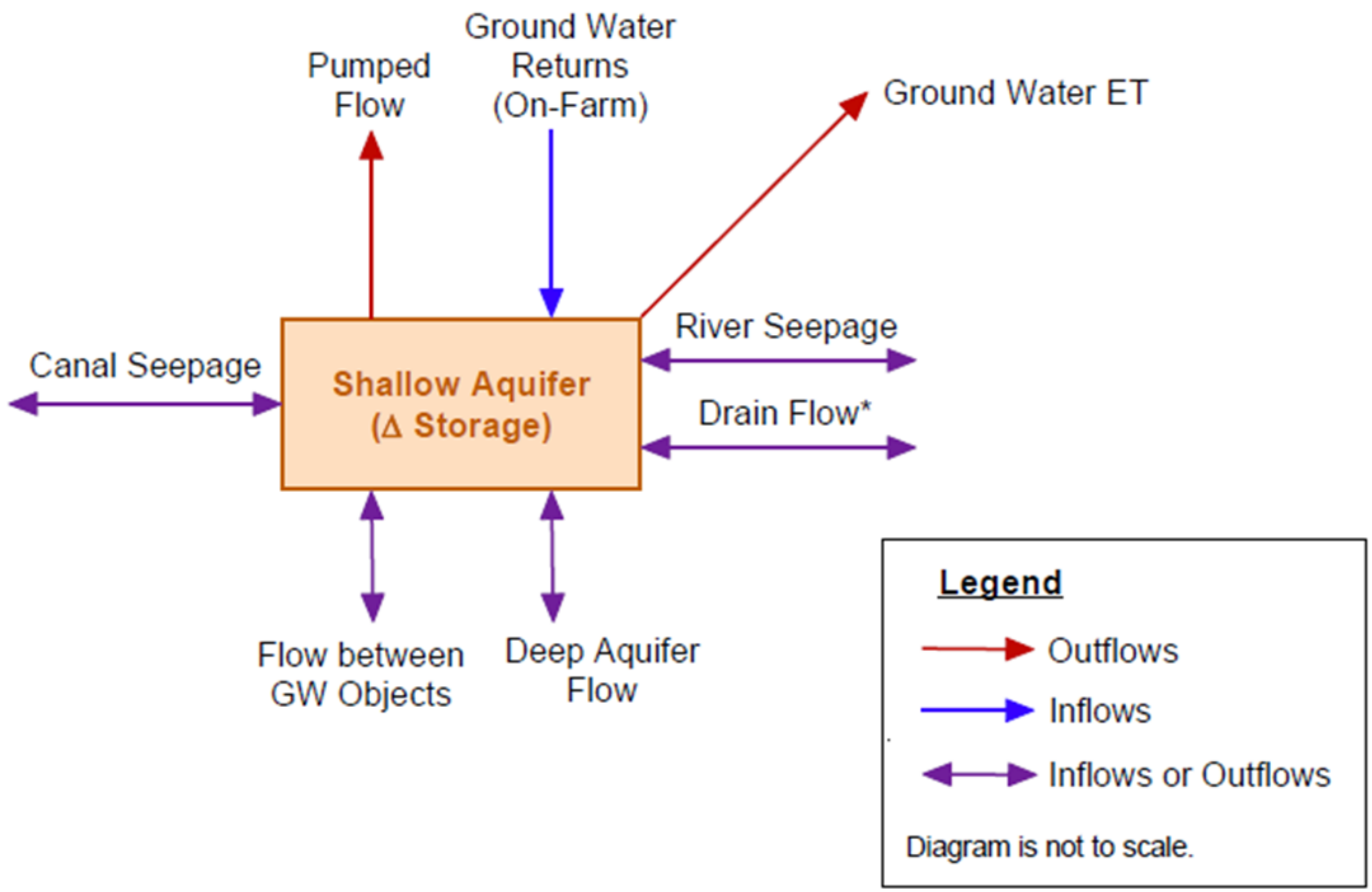


Figure 8-8

Ground Water Model Budget Schematic
Rincon-Mesilla and Hueco Ground Water Models

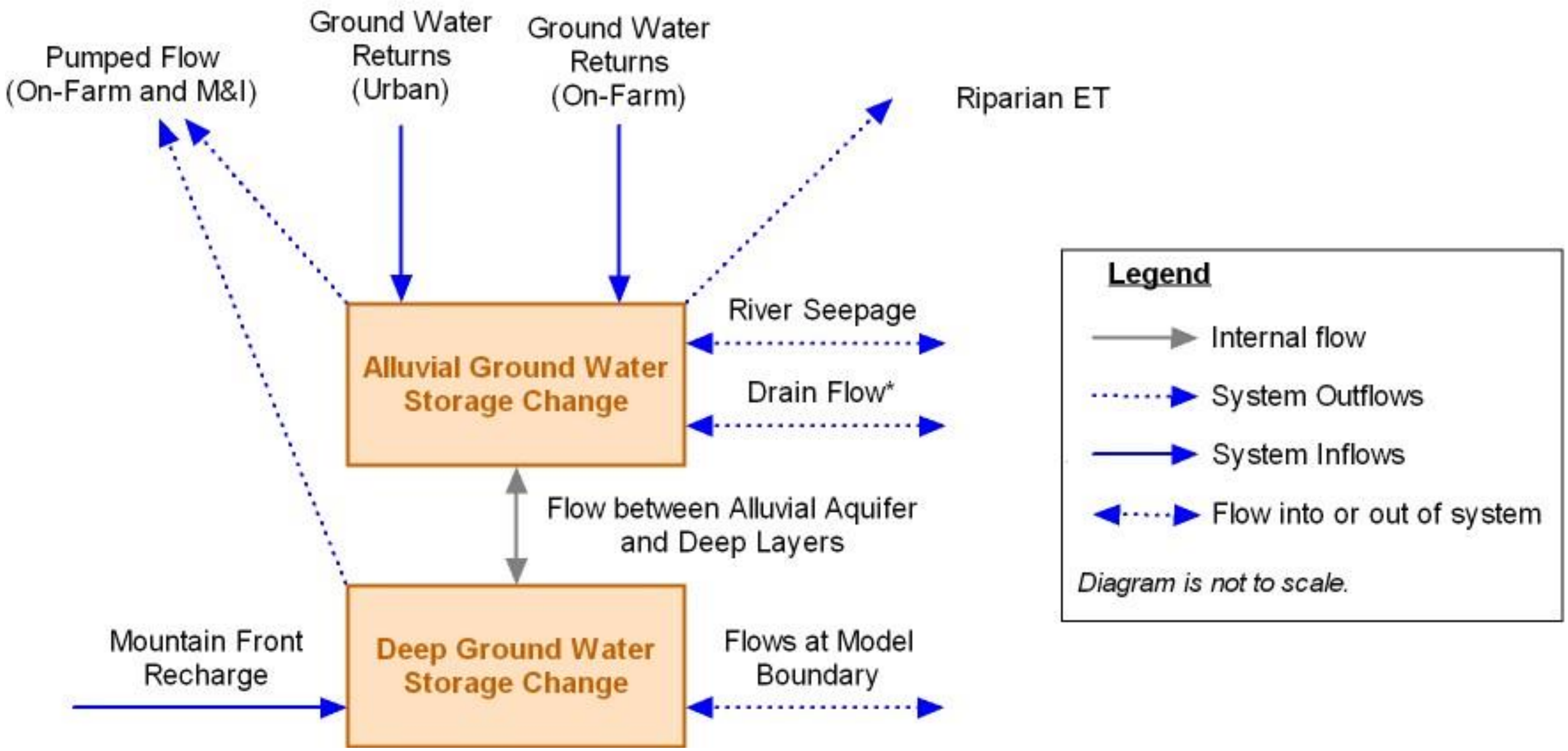
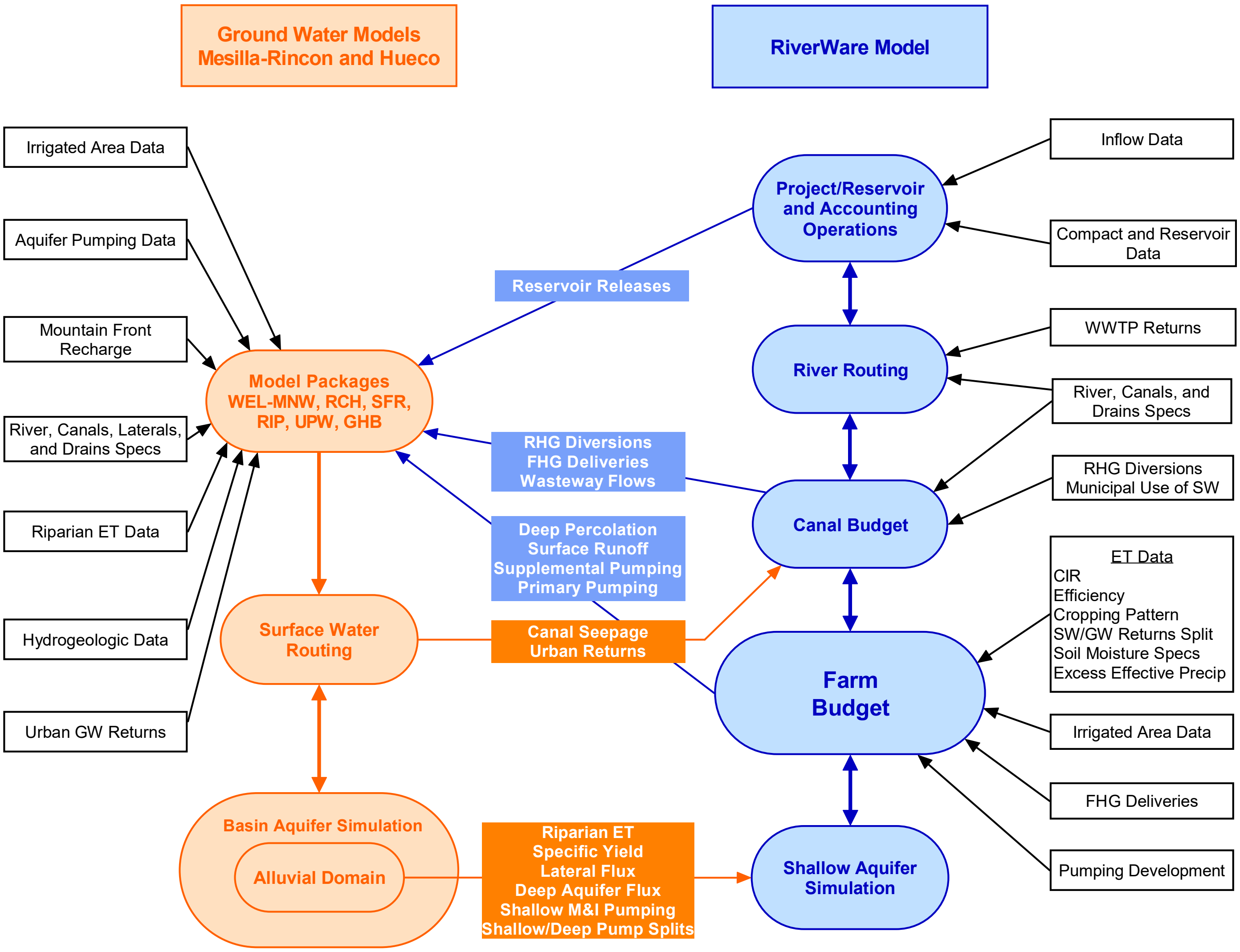


Figure 8-9

Modeling Overview
Integrated LRG Model



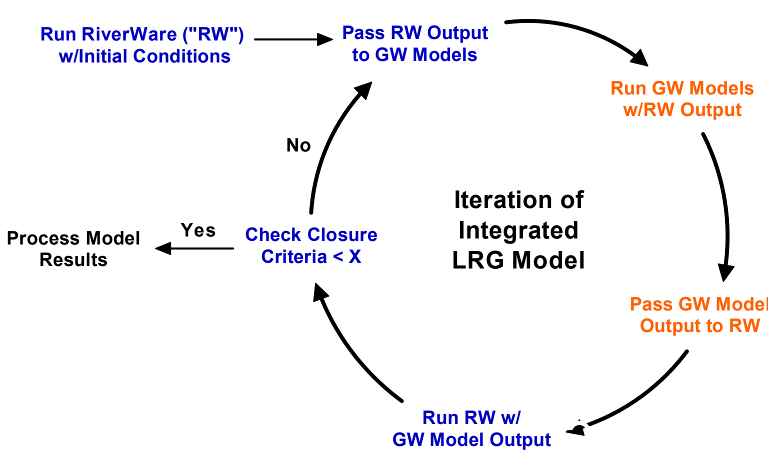


Figure 8-10

Simulation Processes and Calibration Targets
RiverWare Model

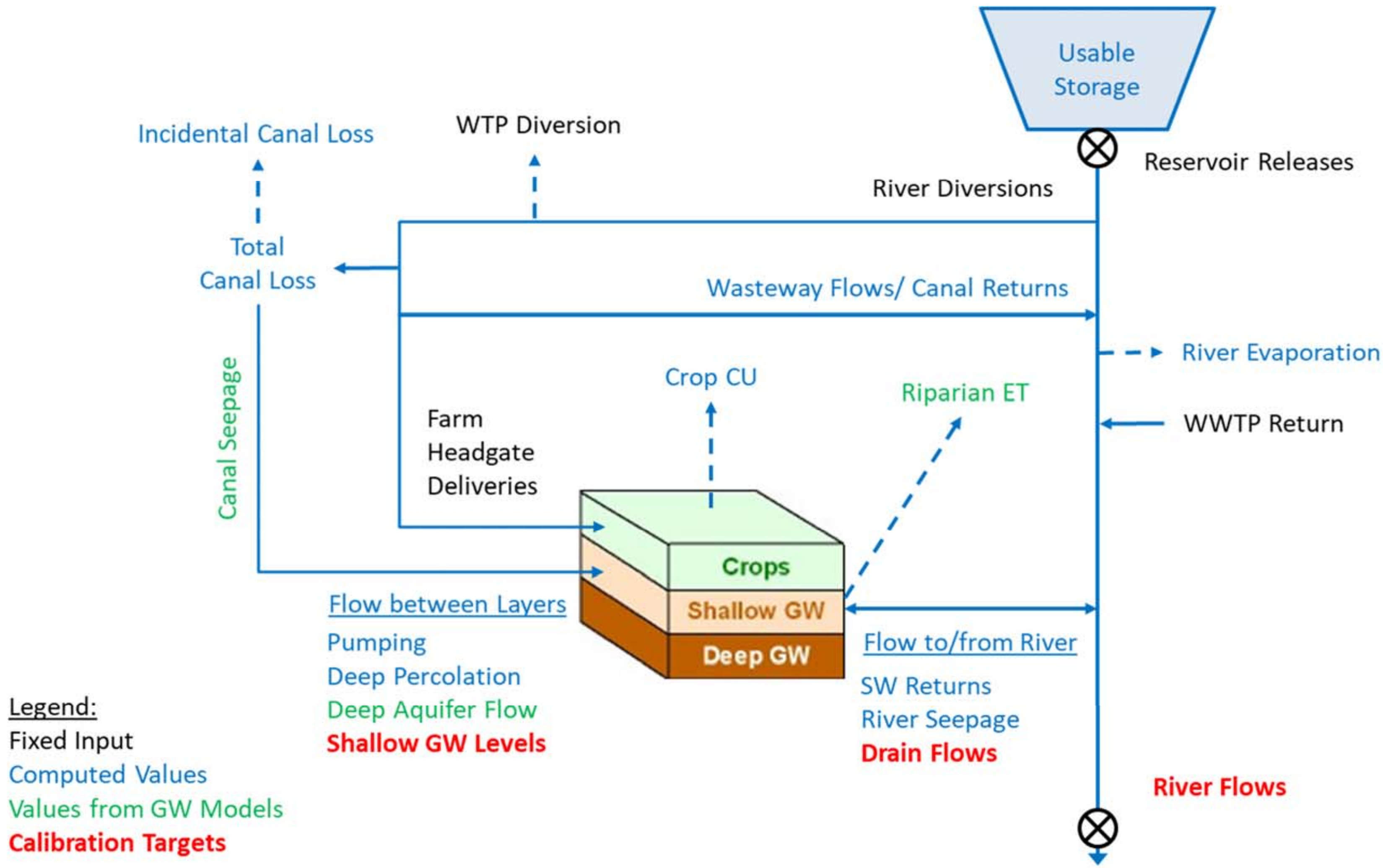
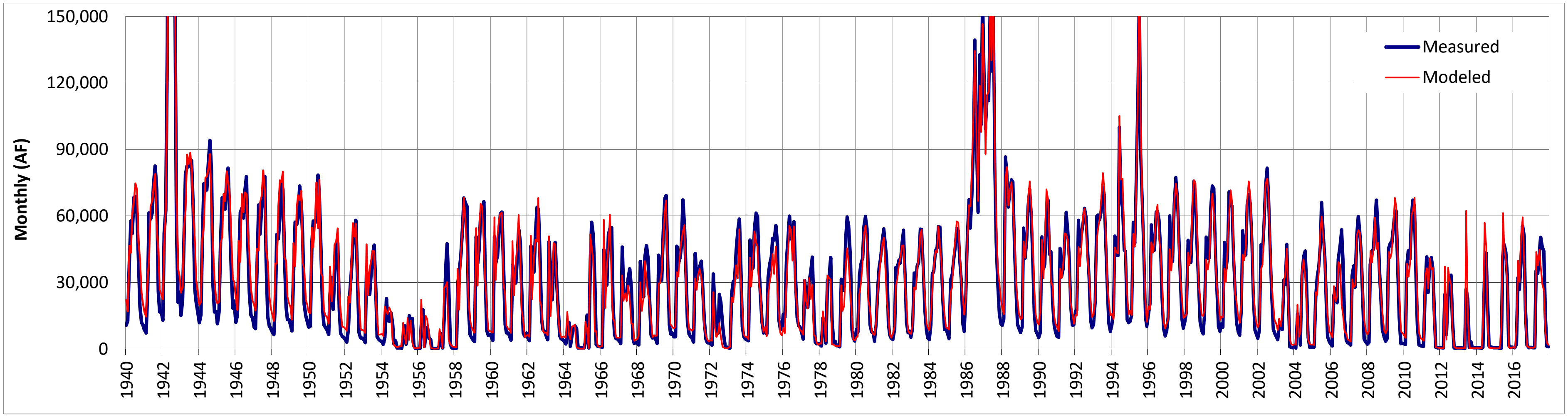
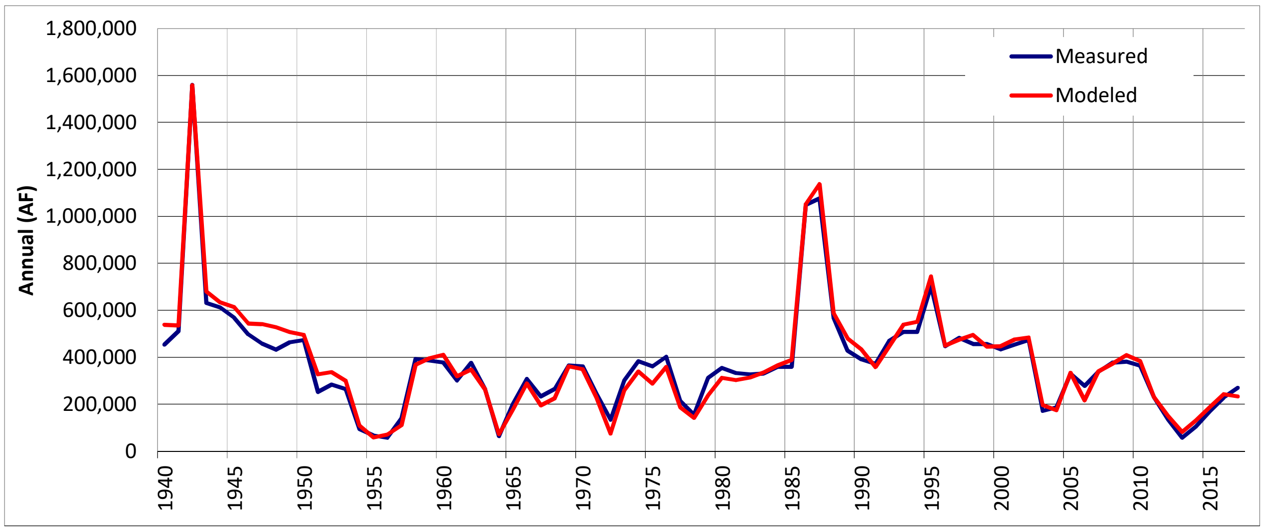
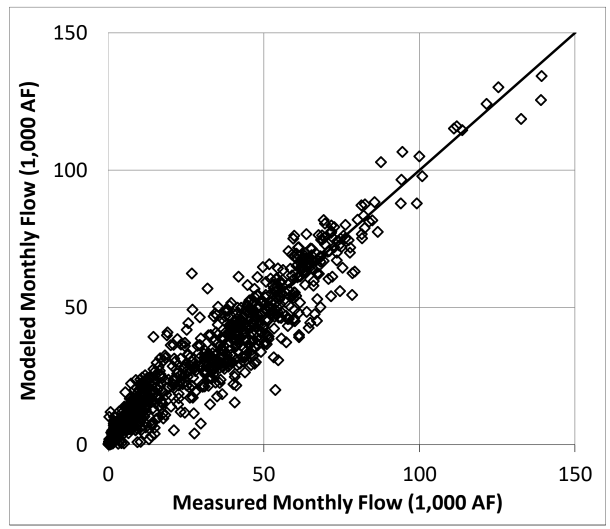


Figure 8-11

RiverWare Model Historical Calibration Results
Rio Grande at El Paso
1940 - 2017







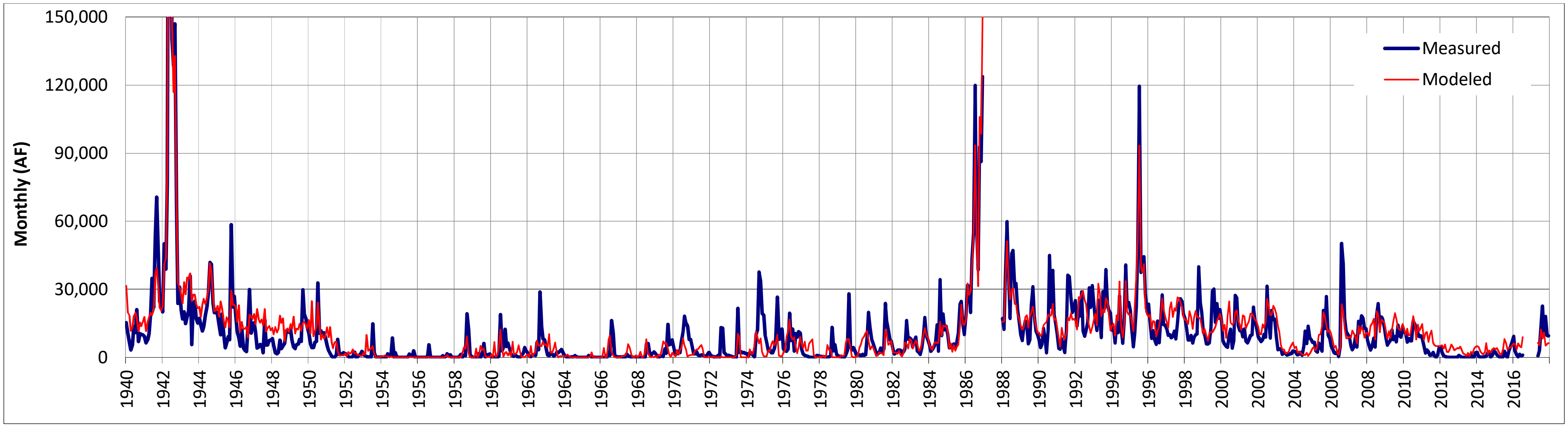
Mean Measured (af/y)	**374,297**	
Mean Modeled (af/y)	**380,374**	2%

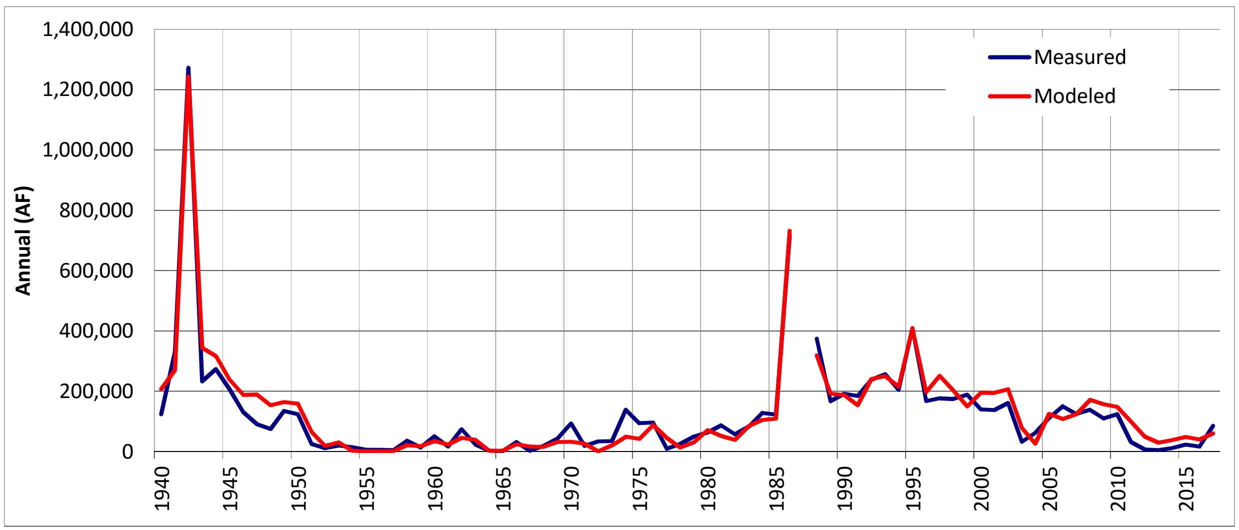
Figure 8-12

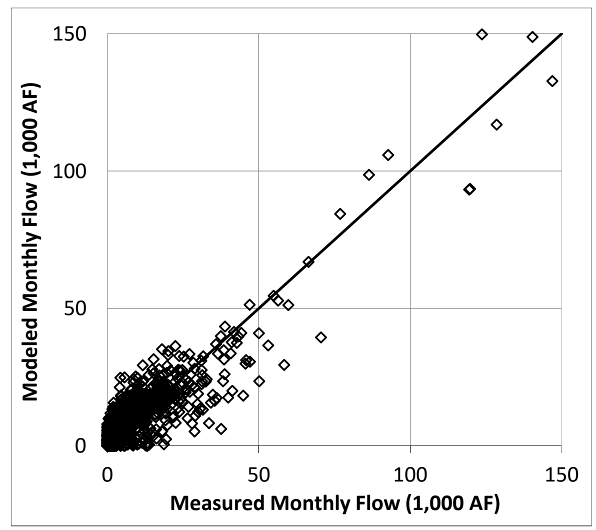
RiverWare Model Historical Calibration Results

Rio Grande at Fort Quitman

1940 - 2017







Mean Measured (af/y)	**124,143**	
Mean Modeled (af/y)	**132,363**	7%

Note:

Data for 1987 and 8/2016-4/2017 is not included.

Figure 8-13

Simulation Processes and Tuning Targets
RiverWare Model

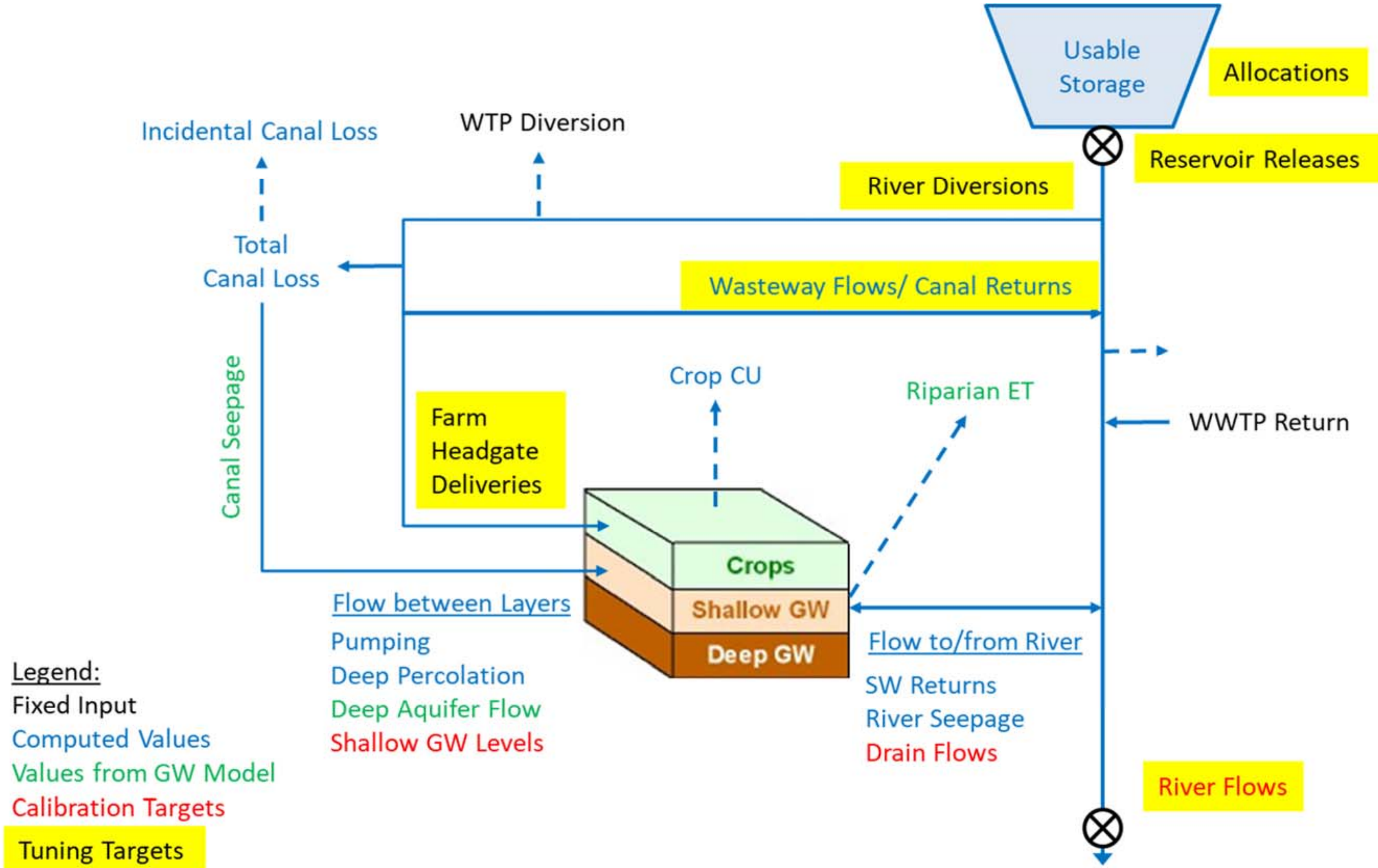
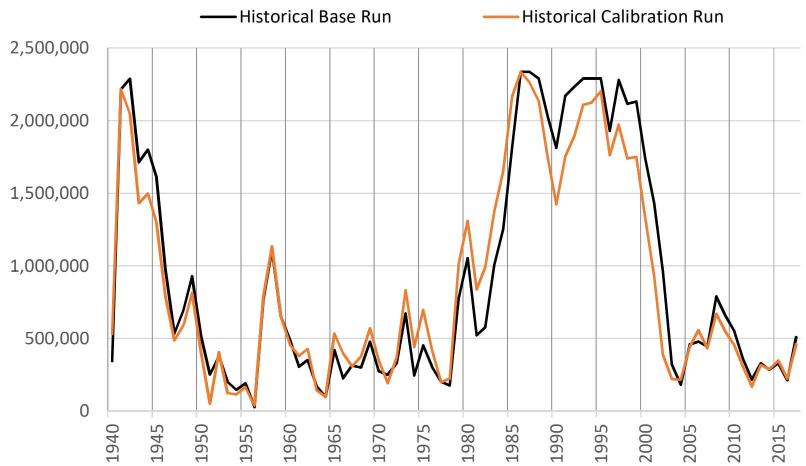


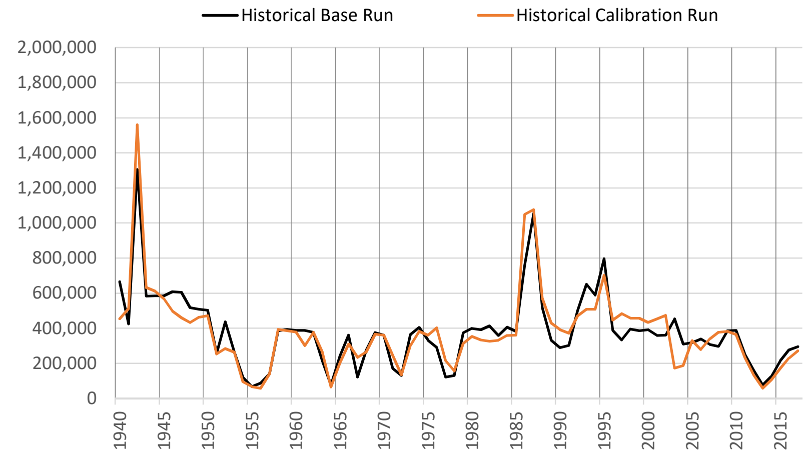
Figure 8-14

Historical Base Run v. Historical Calibration Run
Integrated LRG Model
Annual Project Storage and Rio Grande Flows
1940 - 2017 (acre-feet)

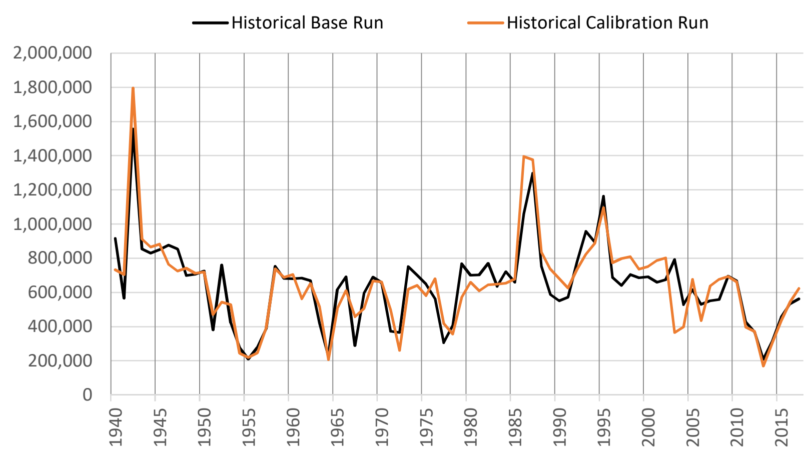
Total Year-End Project Reservoir Storage



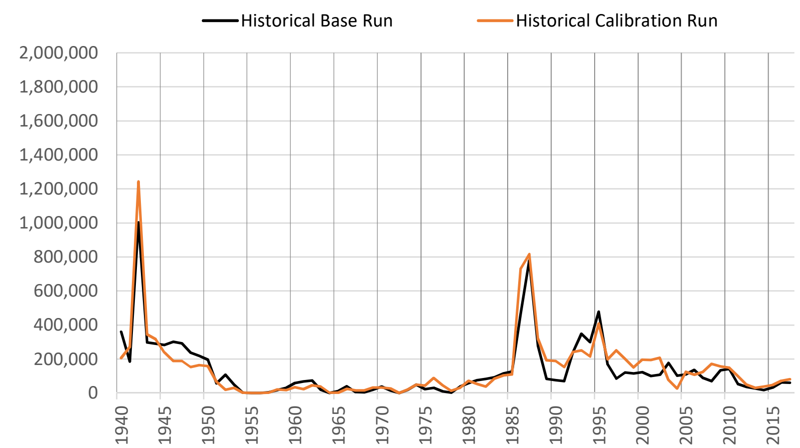
Rio Grande at El Paso



Rio Grande Below Caballo



Rio Grande at Fort Quitman



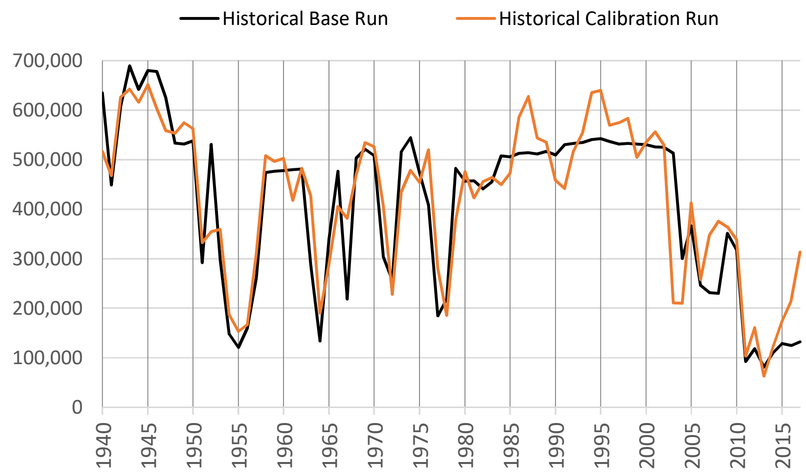
Model Version: Run 1 Summary - Operational - All Pumping On v. Run 0 Summary - Historical Calibration - All Pumping On

Figure 8-15

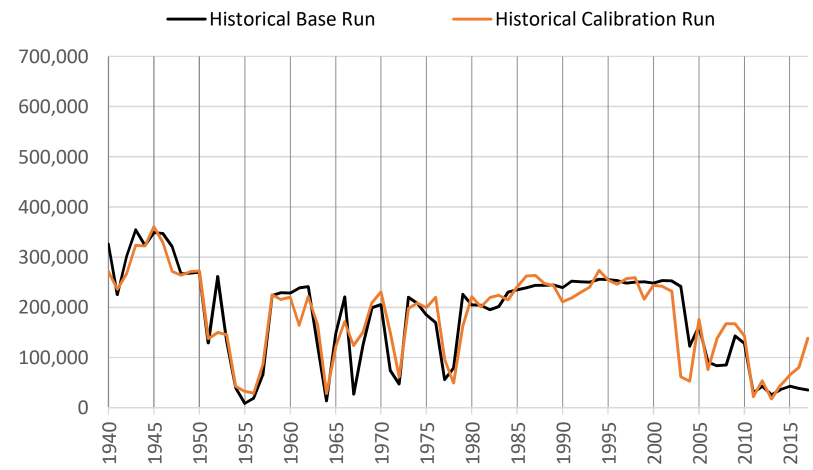
Historical Base Run v. Historical Calibration Run
Integrated LRG Model
Annual Irrigation Operations
1940 - 2017 (acre-feet)

EBID Total

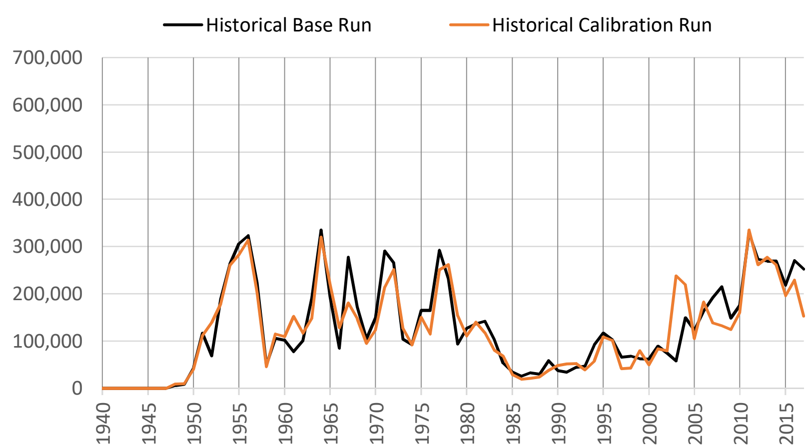
River Headgate Diversions



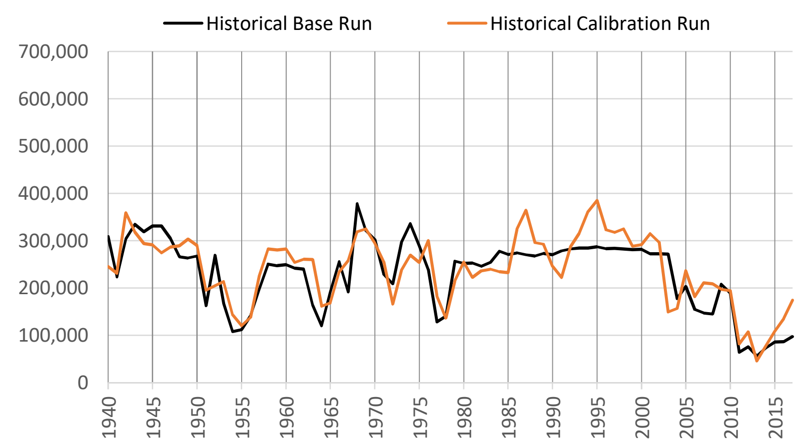
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries



Model Version: Run 1 Summary - Operational - All Pumping On v. Run 0 Summary - Historical Calibration - All Pumping On

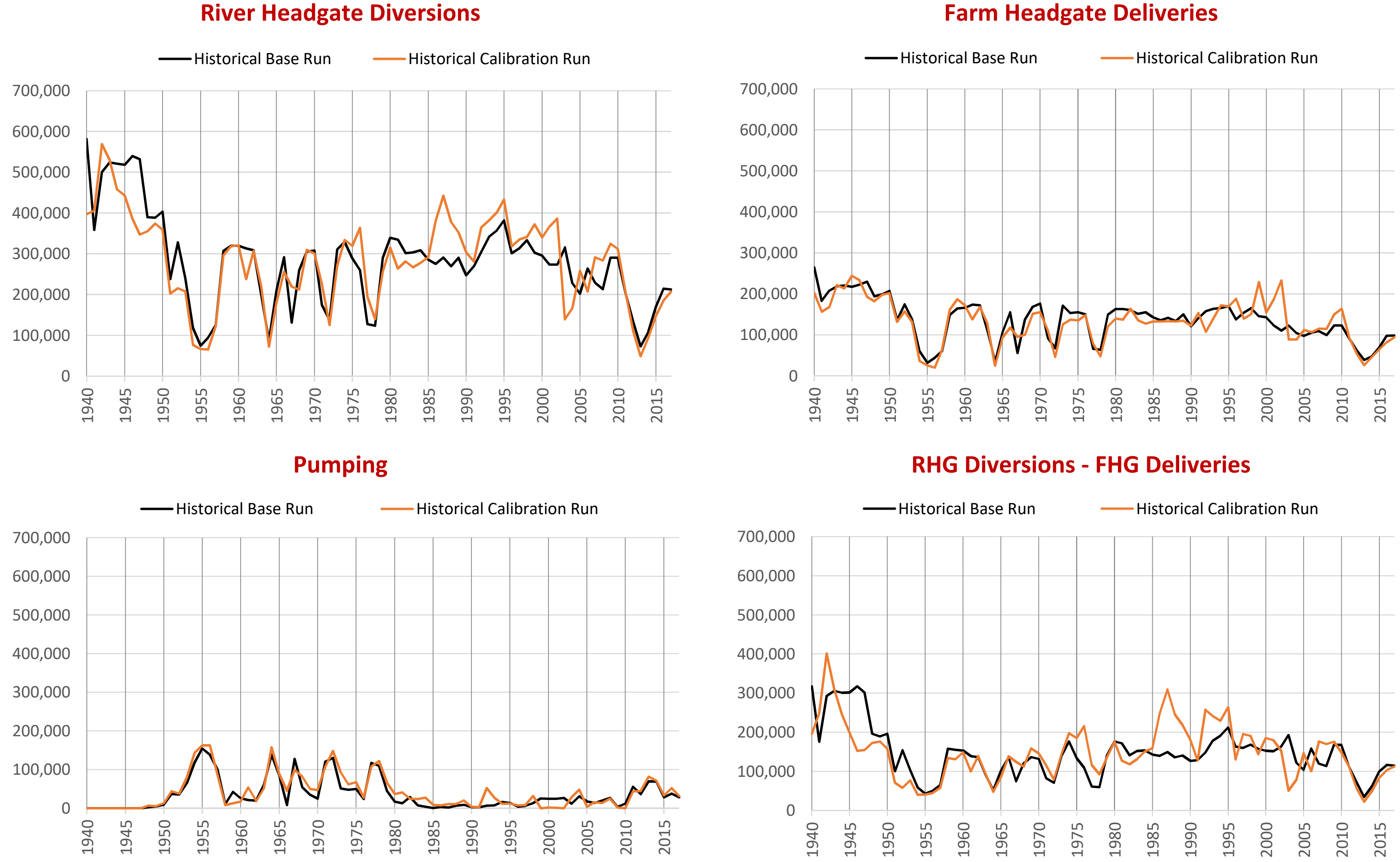
10/27/2019

Sponk Water Engineers , Inc.

Figure 8-16

Historical Base Run v. Historical Calibration Run
Integrated LRG Model
Annual Irrigation Operations
1940 - 2017 (acre-feet)

EPCWID Total



Model Version: Run 1 Summary - Operational - All Pumping On v. Run 0 Summary - Historical Calibration - All Pumping On

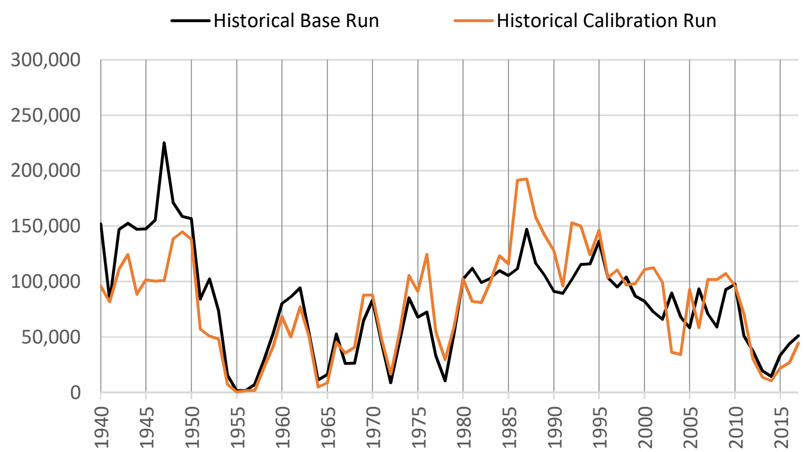
10/27/2019

Figure 8-17

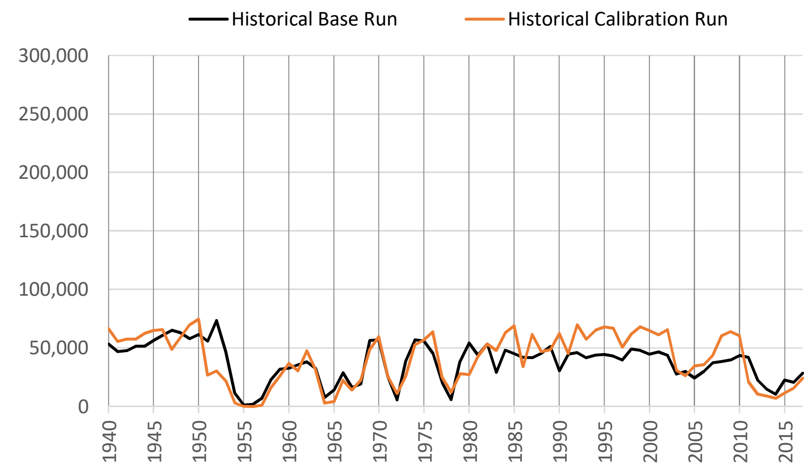
Historical Base Run v. Historical Calibration Run
Integrated LRG Model
Annual Irrigation Operations
1940 - 2017 (acre-feet)

HCCRD Total

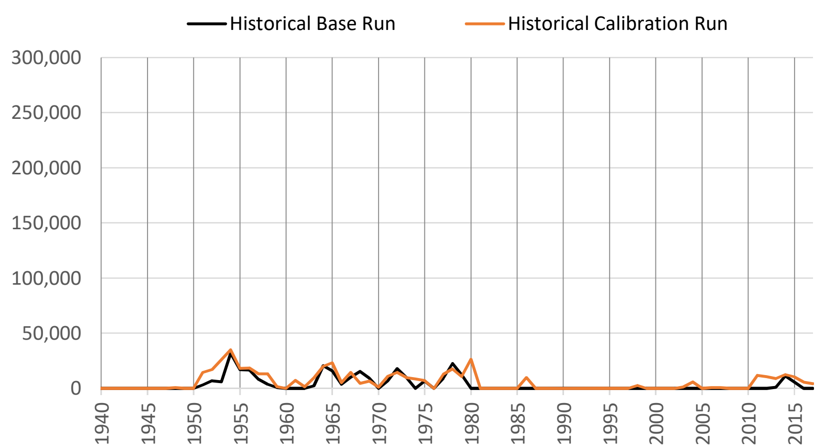
River Headgate Diversions



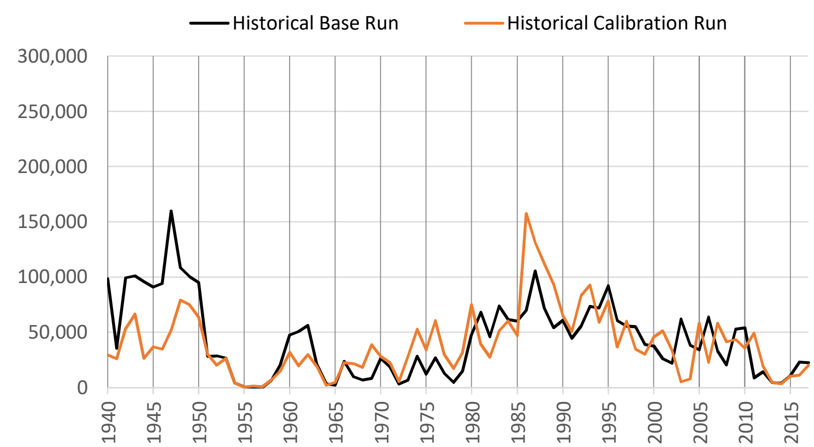
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries



#REF!

Figure 8-18

Historical Base Run v. Historical Calibration Run

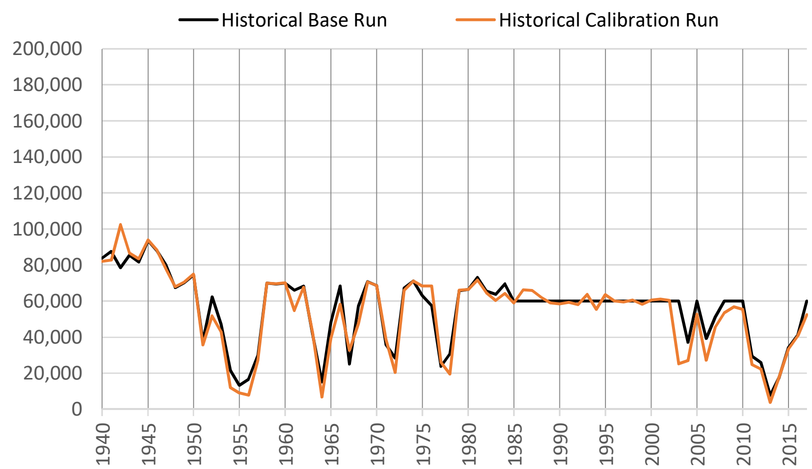
Integrated LRG Model

Annual Irrigation Operations

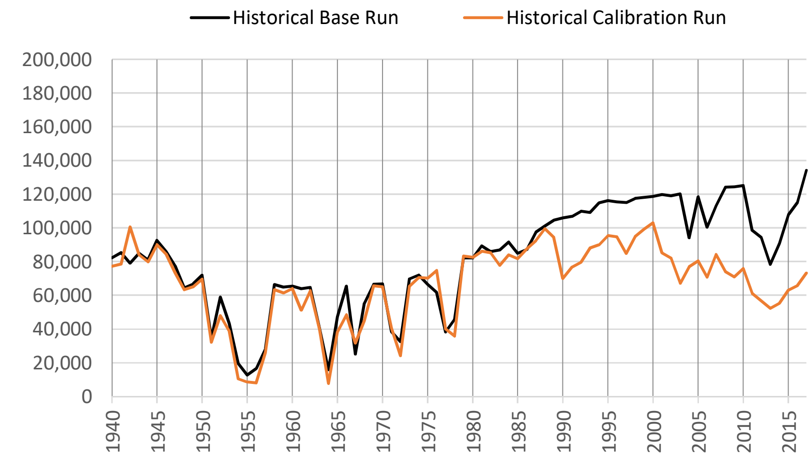
1940 - 2017 (acre-feet)

JID Total

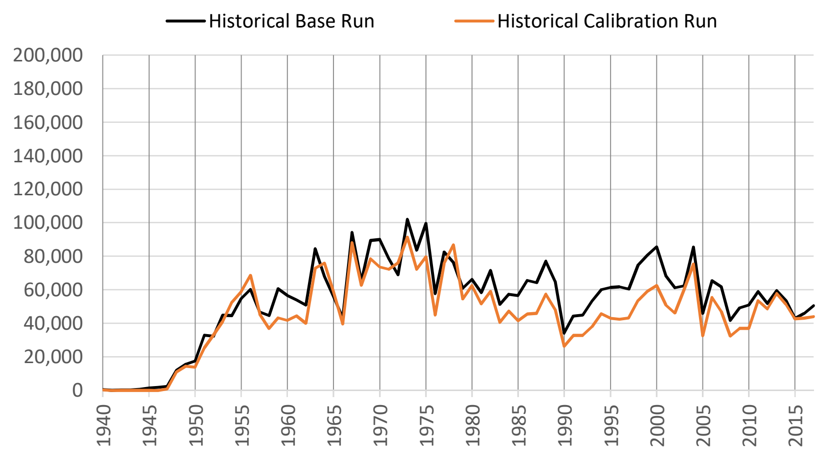
River Headgate Diversions



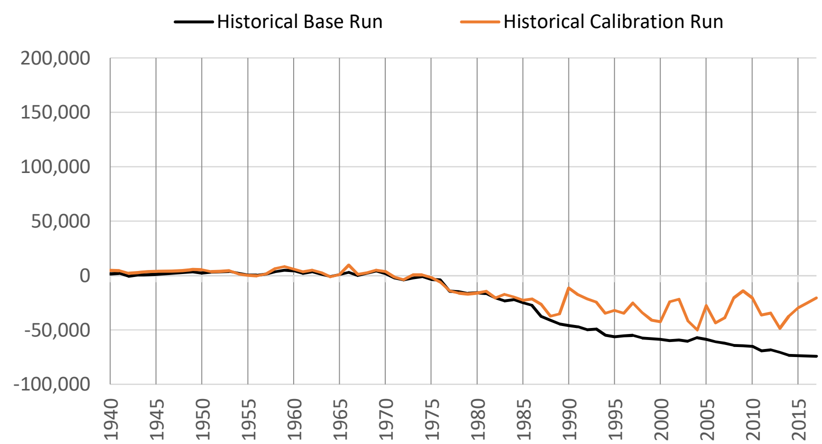
Farm Headgate Deliveries



Pumping



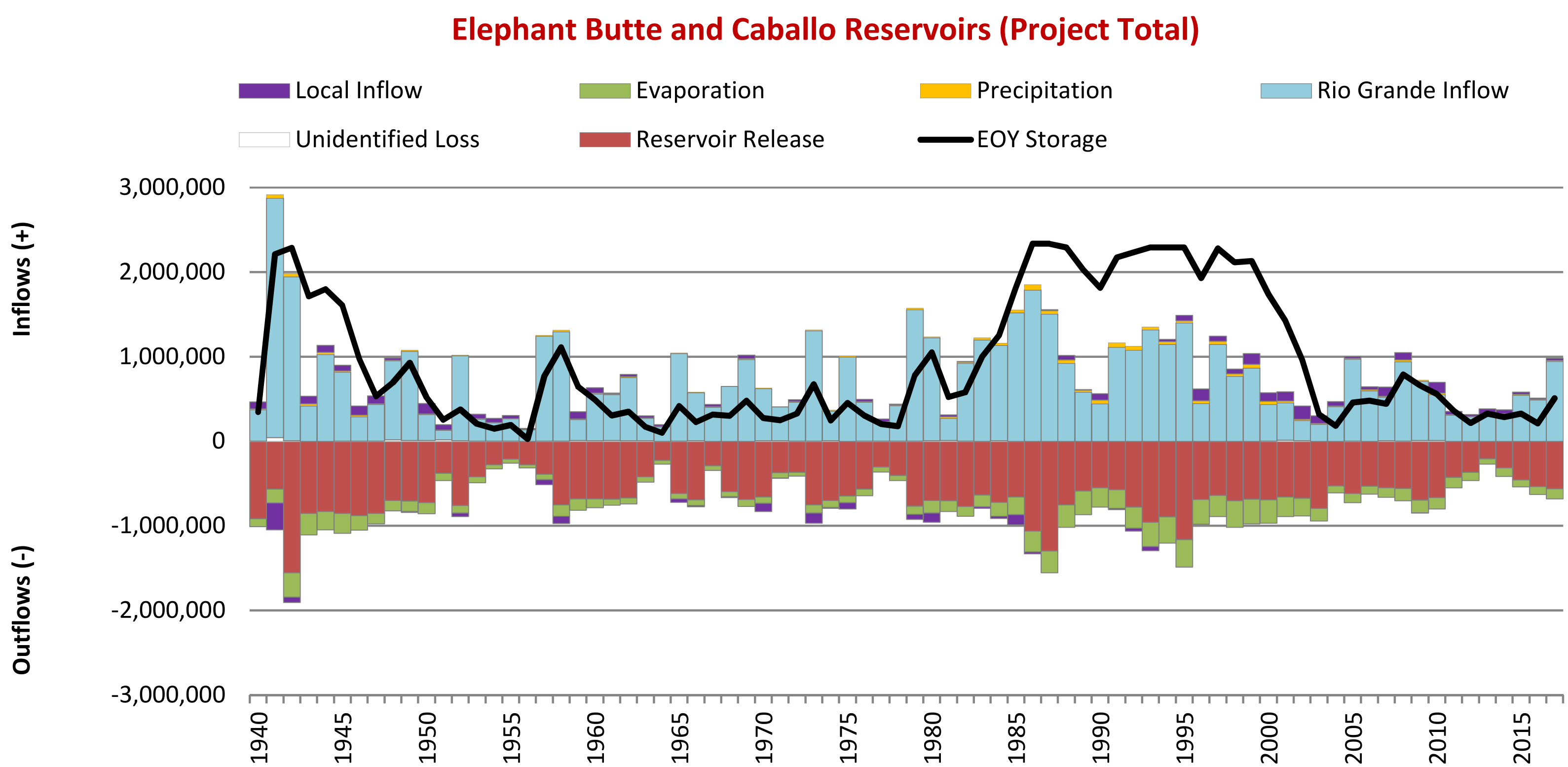
RHG Diversions - FHG Deliveries



#REF!

Figure 9-1

Annual Reservoir Budget Summary
Historical Base Run
Integrated LRG Model
1940 - 2017 (acre-feet)



Model Version: LRG Model v106 Operational Run - Base Run (All Pumping On).

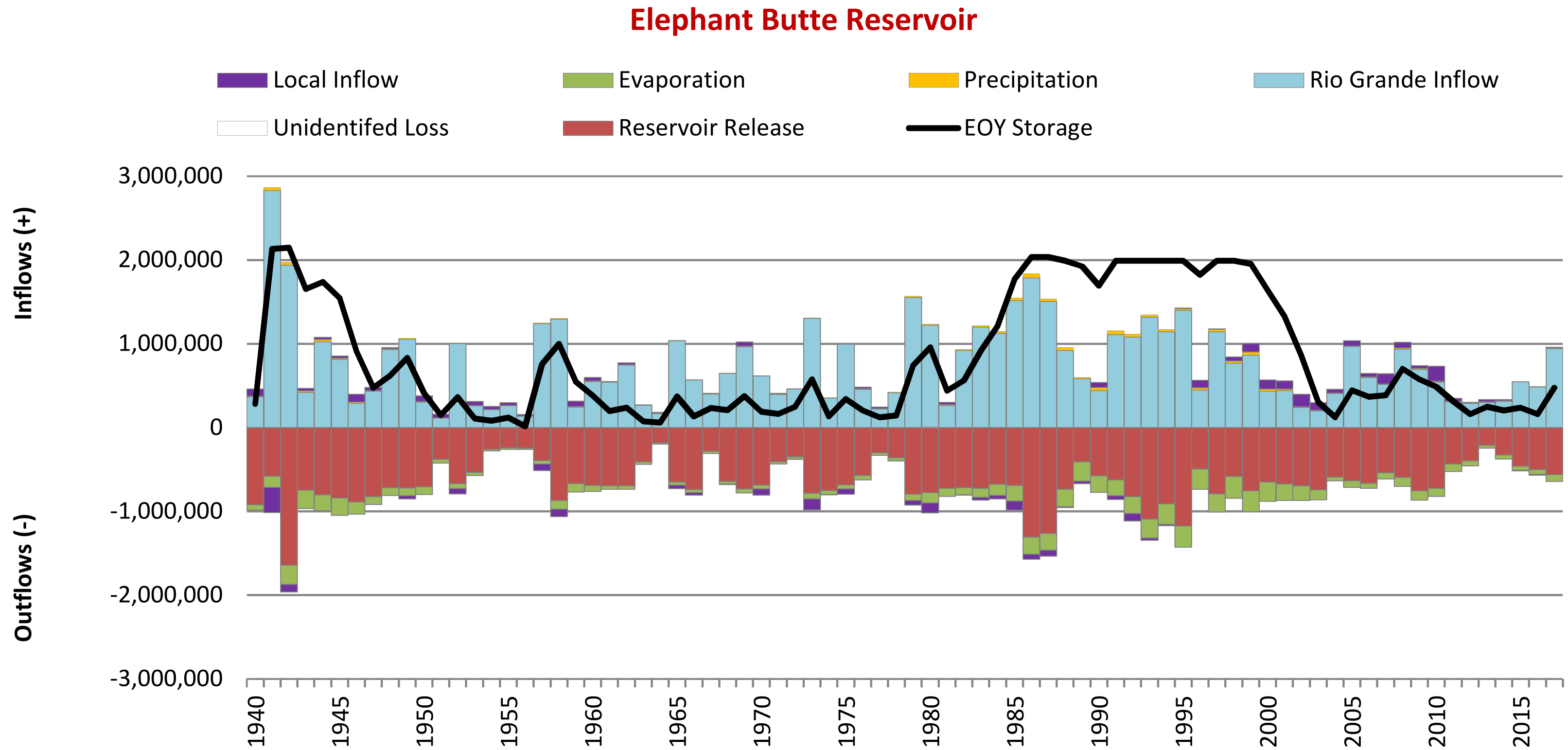
<u>Notes:</u>

Net Reach Effect is the change in streamflow through the stream reach, computed as total inflows minus total outflows.

River inflows and outflows not shown on graph.

Figure 9-1

Annual Reservoir Budget Summary
Historical Base Run
Integrated LRG Model
1940 - 2017 (acre-feet)



Model Version: LRG Model v106 Operational Run - Base Run (All Pumping On).

Notes:

Net Reach Effect is the change in streamflow through the stream reach, computed as total inflows minus total outflows.

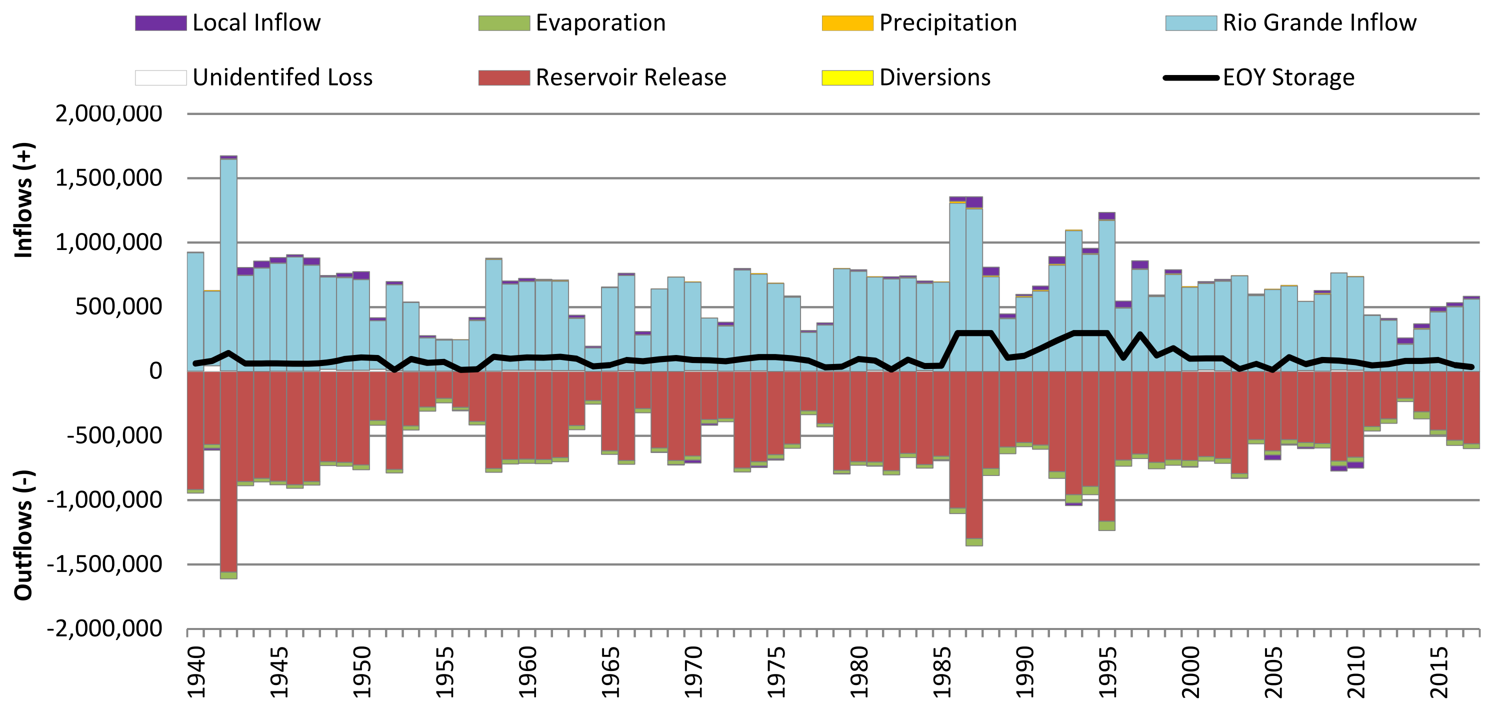
River inflows and outflows not shown on graph.

Figure 9-1

Annual Reservoir Budget Summary
Historical Base Run
Integrated LRG Model

1940 - 2017 (acre-feet)

Caballo Reservoir



Model Version: LRG Model v106 Operational Run - Base Run (All Pumping On).

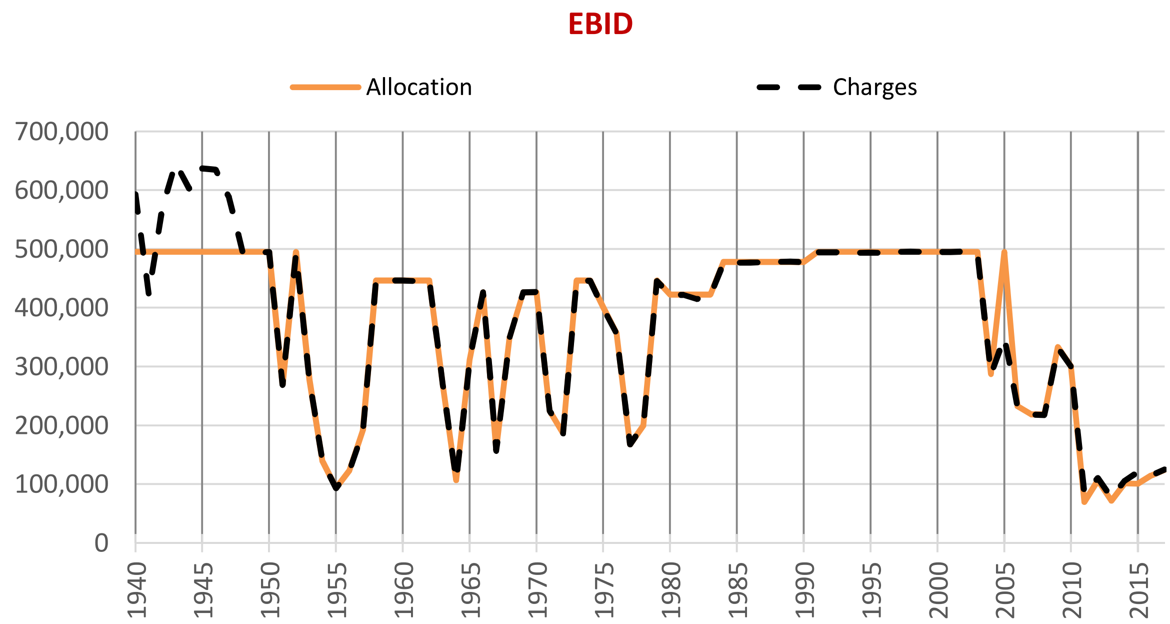
<u>Notes:</u>

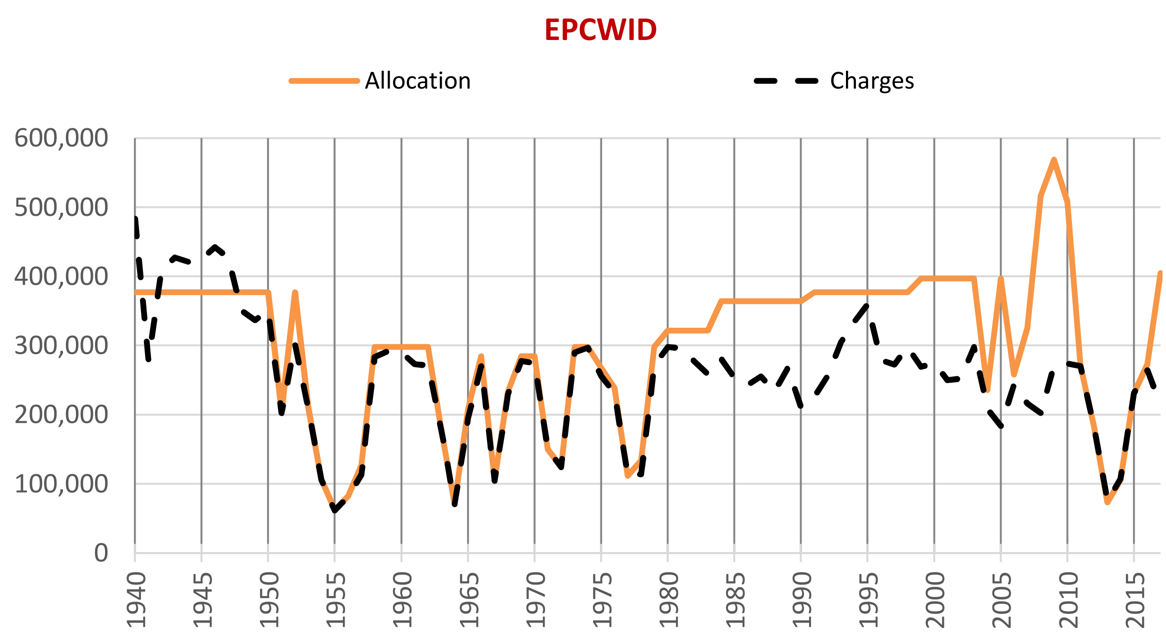
Net Reach Effect is the change in streamflow through the stream reach, computed as total inflows minus total outflows.

River inflows and outflows not shown on graph.

Figure 9-2

Annual Project Allocations and Charges
Historical Base Run
Integrated LRG Model
1940 - 2017 (acre-feet)





Model Version: LRG Model v106 Operational Run - Base Run (All Pumping On).

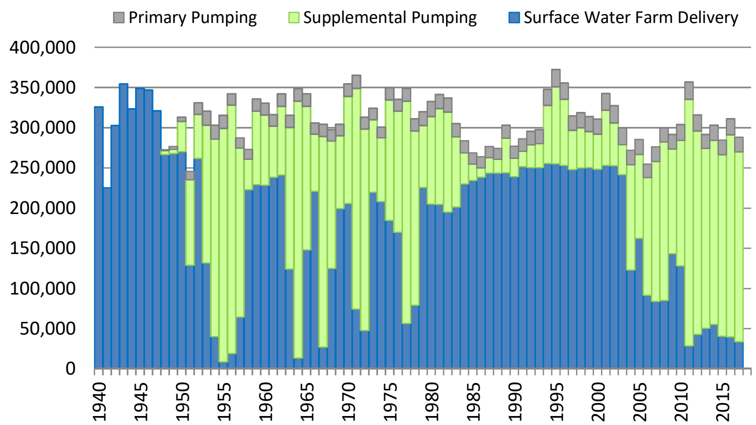
Note:

Allocation includes carryover after 2007.

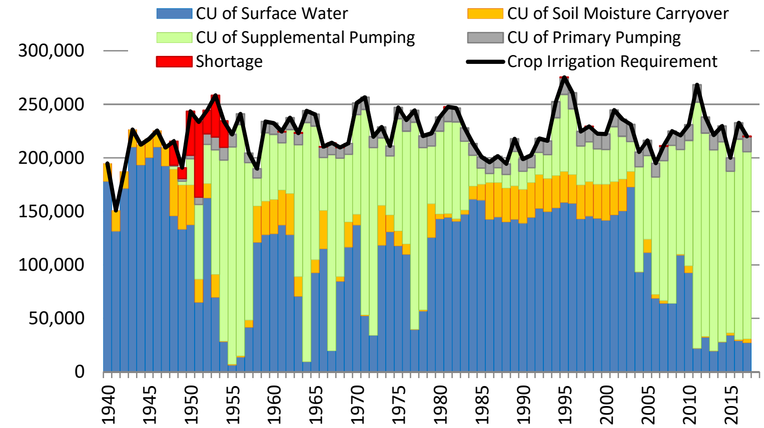
Figure 9-3

Annual Canal and Farm Budget Summary
Historical Base Run
Integrated LRG Model
1940-2017
EBID Total

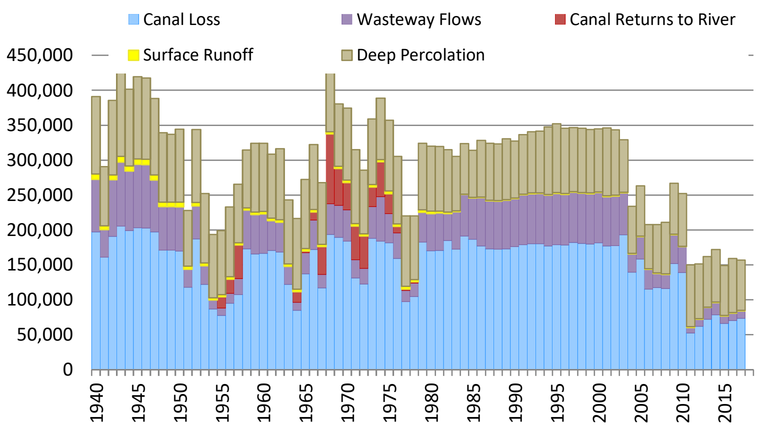
Annual Farm Deliveries (acre-feet)



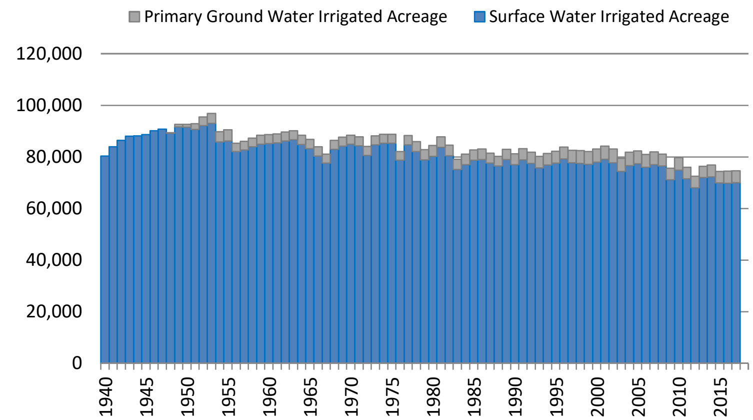
Annual Consumptive Use (acre-feet)



Annual Losses (acre-feet)



Annual Irrigated Acres

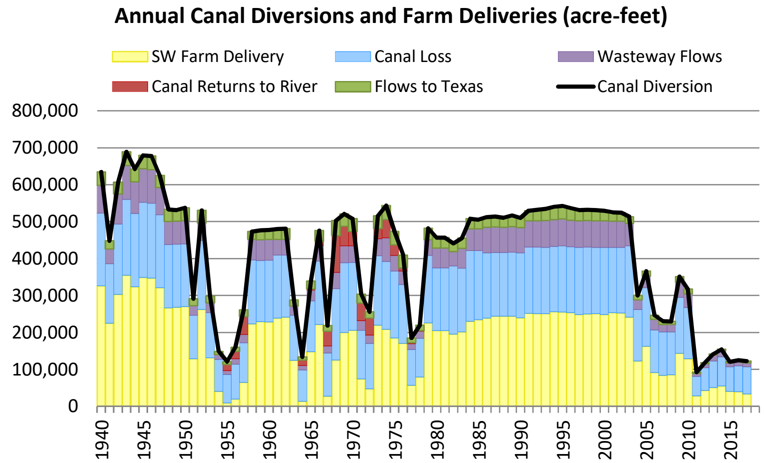


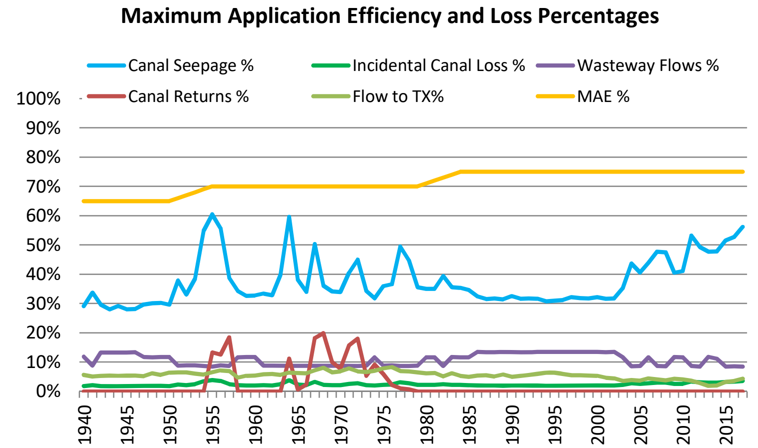
***Note: Different Scales**

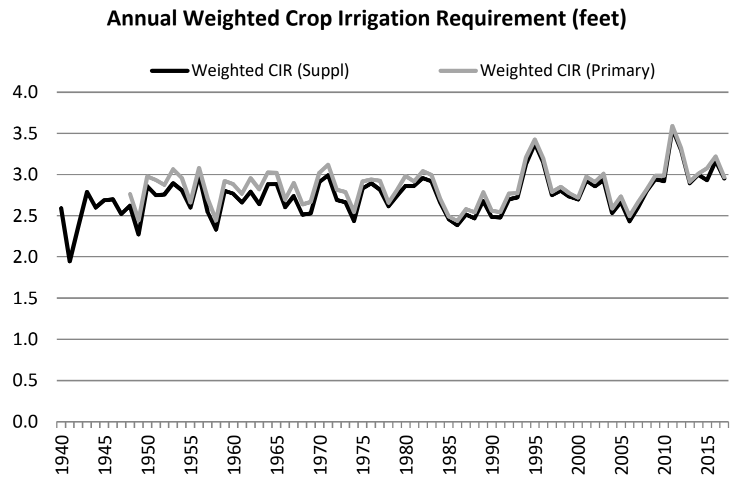
Model Version: LRG Model v106 Operational Run - Base Run (All Pumping On).

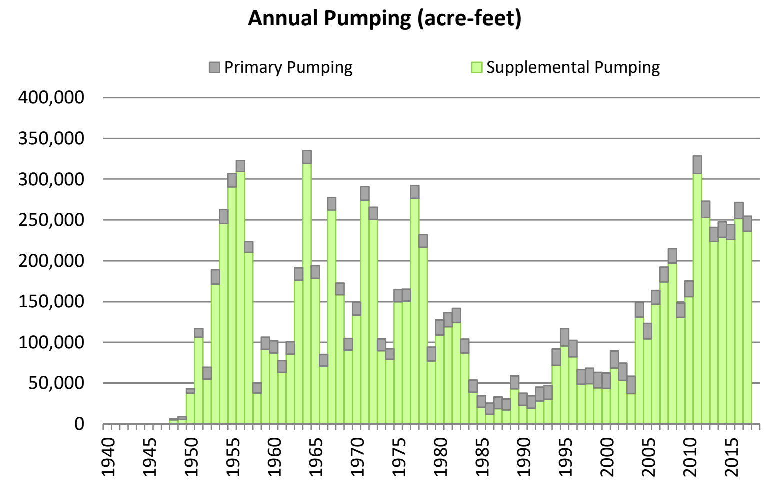
Figure 9-3

Annual Canal and Farm Budget Summary
Historical Base Run
Integrated LRG Model
1940-2017
EBID Total









Model Version: LRG Model v106 Operational Run - Base Run (All Pumping On).

Notes:

(1) Canal loss calculations occur at top of canal and are not in the surface water budget for Mesilla Texas. However a portion of the canal seepage accrues to the ground water objects for Mesilla TX.

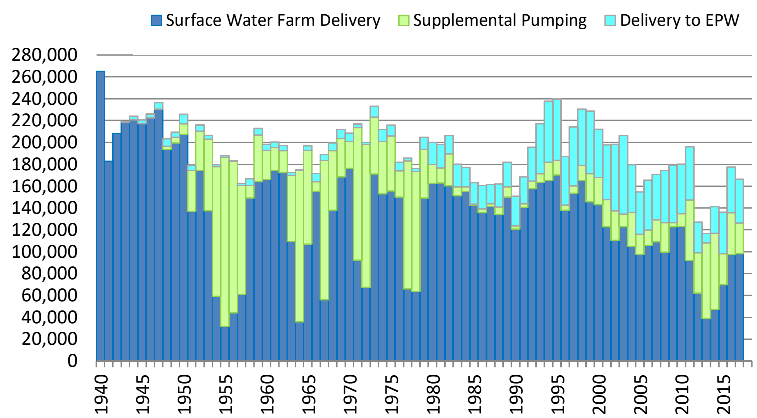
(2) Canal Returns % is equal to canal returns divided by the sum of the canal diversions plus drain flows to canal.

US_MSJ_00002363

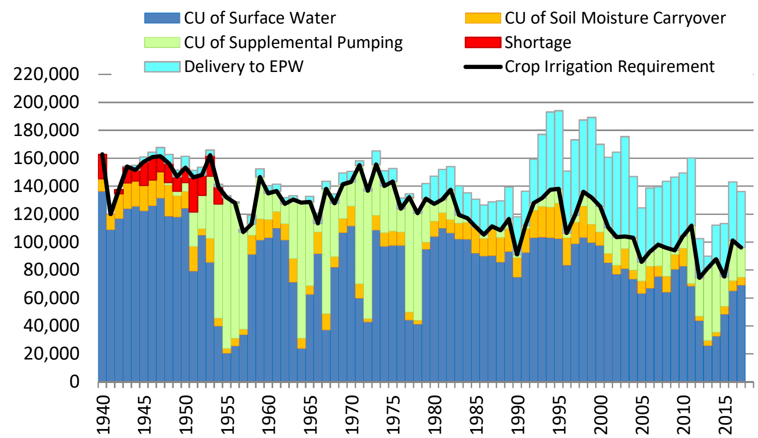
Figure 9-4

Annual Canal and Farm Budget Summary
Historical Base Run
Integrated LRG Model
1940-2017
EPCWID Total

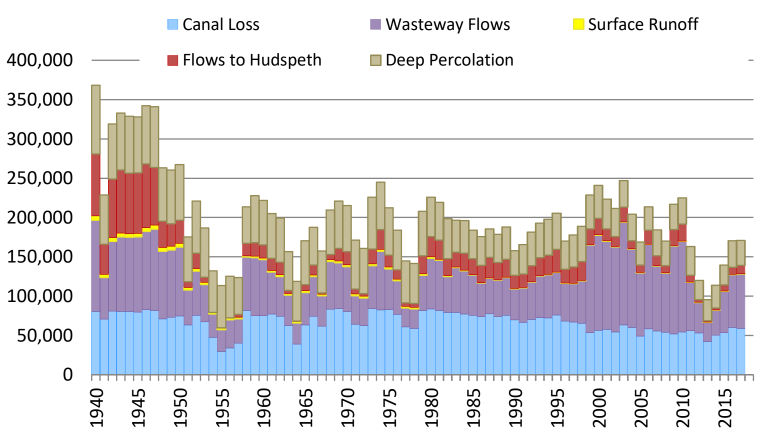
Annual Farm Deliveries (acre-feet)



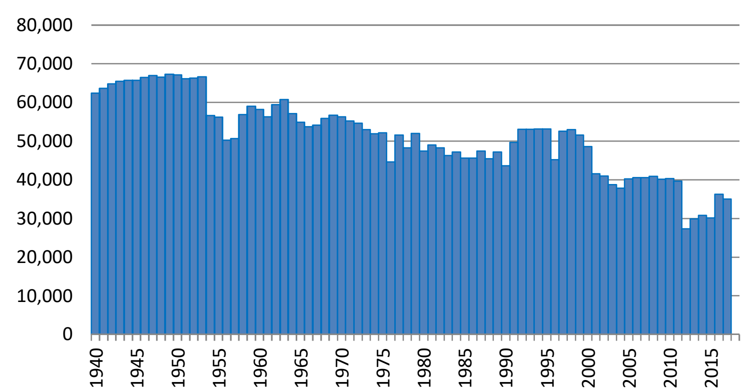
Annual Consumptive Use (acre-feet)



Annual Losses (acre-feet)



Annual Irrigated Acres



***Note: Different Scales**

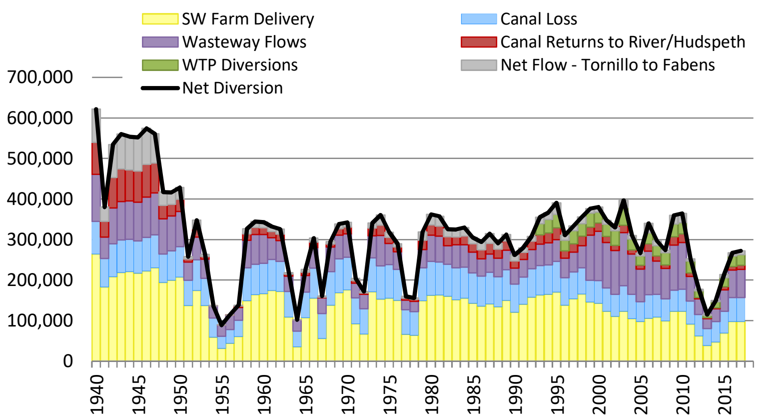
Model Version: LRG Model v106 Operational Run - Base Run (All Pumping On).

US_MSJ_00002364

Figure 9-4

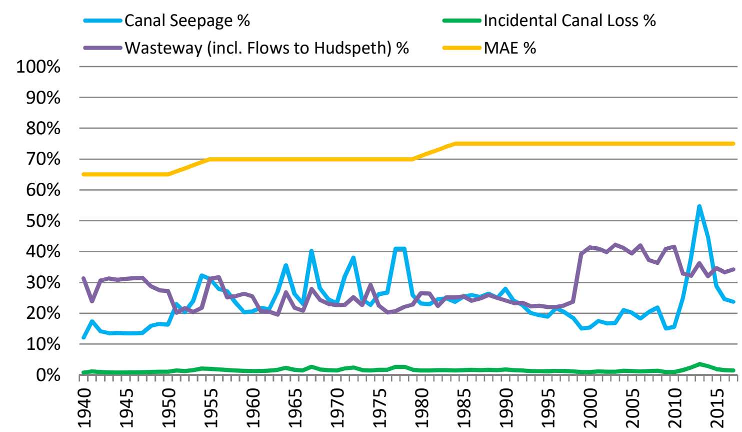
Annual Canal and Farm Budget Summary
Historical Base Run
Integrated LRG Model
1940-2017
EPCWID Total

Annual Canal Diversions and Farm Deliveries (acre-feet)

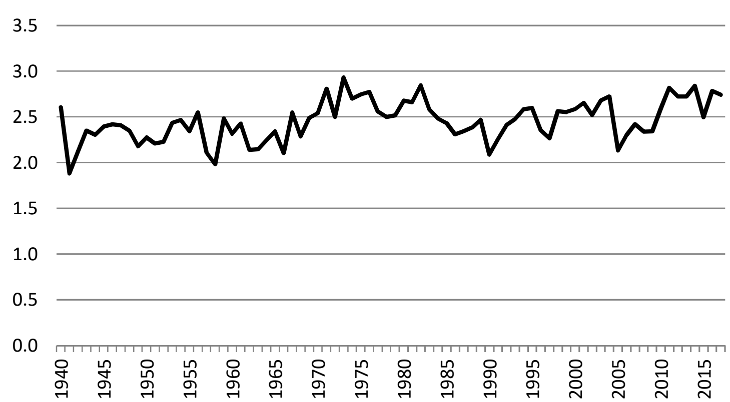


*Includes Canal Diversions, Drain Returns to Canals ,and WWTP Returns to Canals.

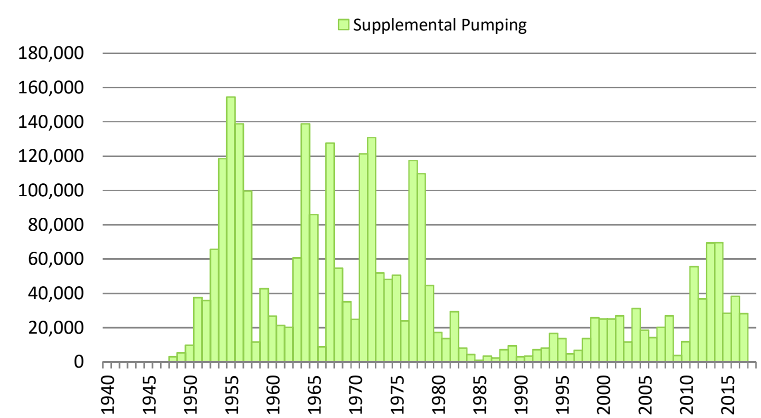
Maximum Application Efficiency and Loss Percentages



Annual Weighted Crop Irrigation Requirement (feet)



Annual Pumping (acre-feet)



Model Version: LRG Model v106 Operational Run - Base Run (All Pumping On).

Notes:

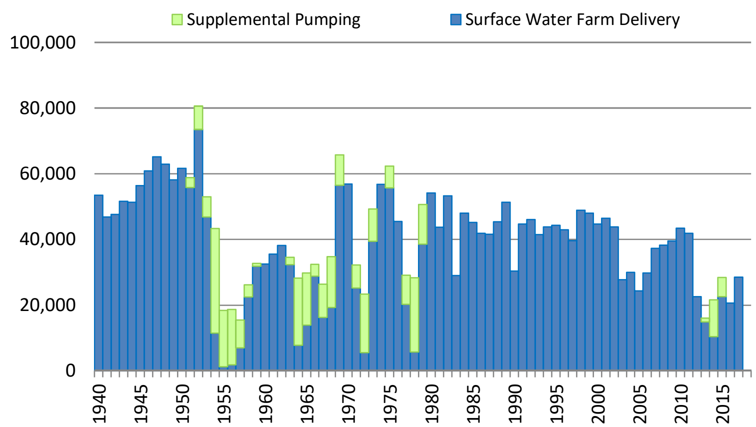
(1) Canal loss calculations occur at top of canal and are not in the surface water budget for Mesilla Texas. However a portion of the canal seepage accrues to the ground water objects for Mesilla TX.

(2) Canal Returns % is equal to canal returns divided by the sum of the canal diversions plus drain flows to canal.

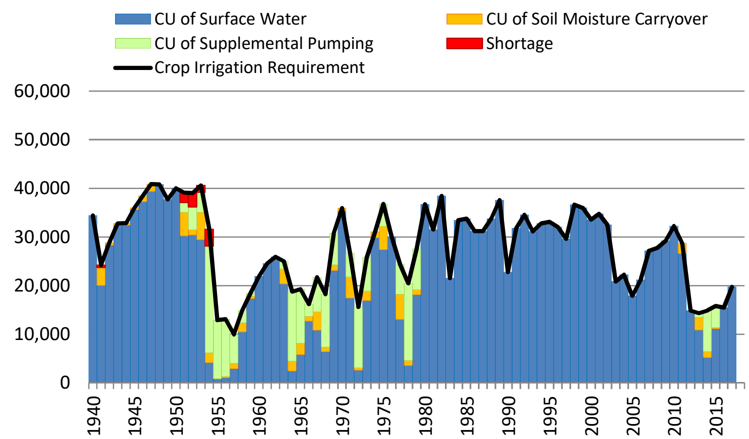
Figure 9-5

Annual Canal and Farm Budget Summary
Historical Base Run
Integrated LRG Model
1940-2017
HCCRD

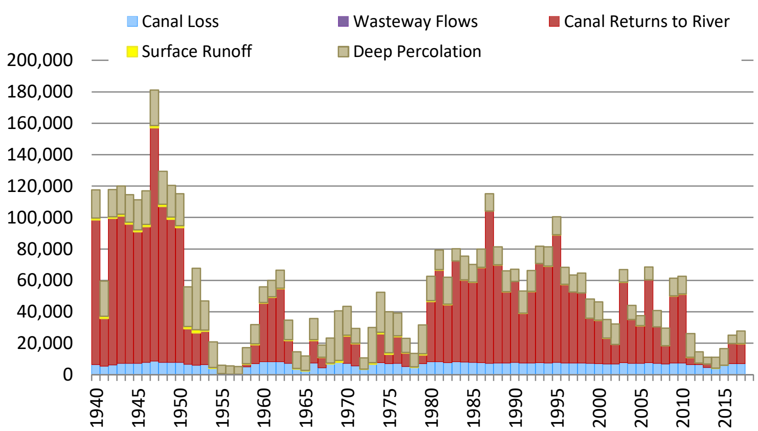
Annual Farm Deliveries (acre-feet)



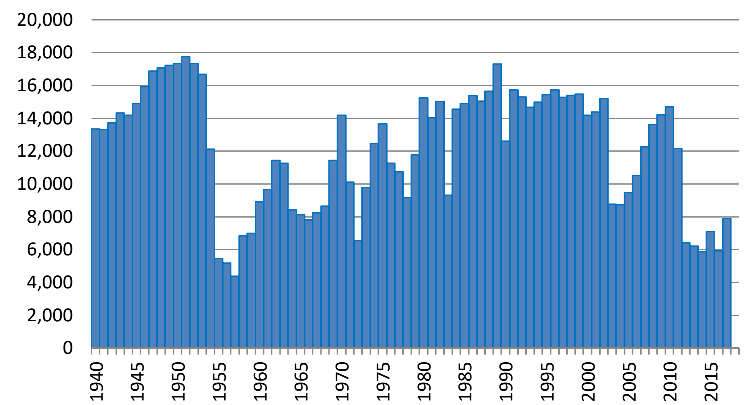
Annual Consumptive Use (acre-feet)



Annual Losses (acre-feet)



Annual Irrigated Acres



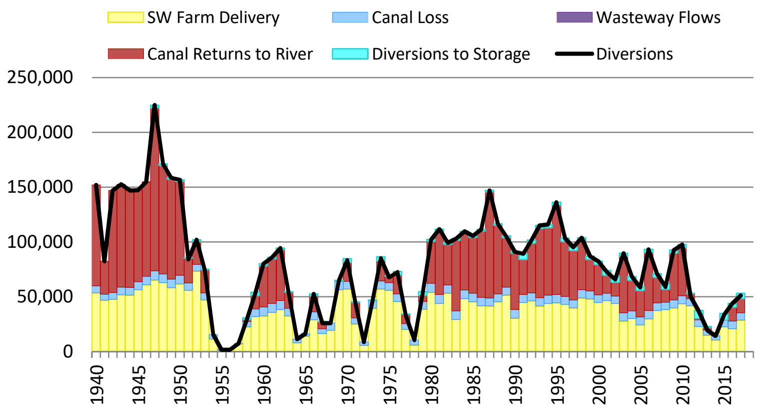
***Note: Different Scales**

Model Version: LRG Model v106 Operational Run - Base Run (All Pumping On).

Figure 9-5

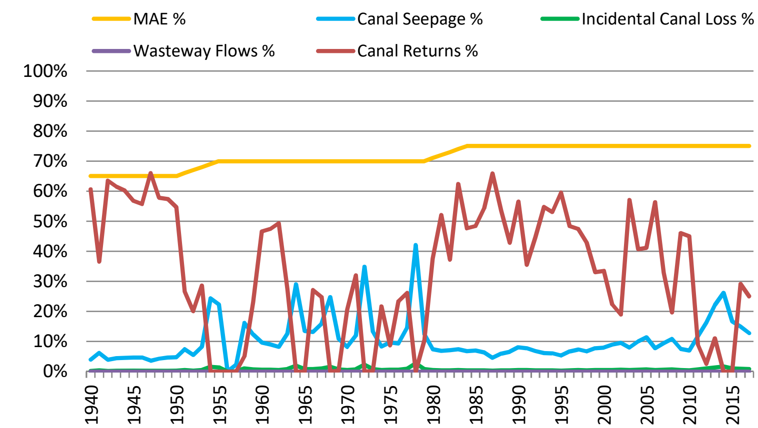
Annual Canal and Farm Budget Summary
Historical Base Run
Integrated LRG Model
1940-2017
HCCRD

Annual Canal Diversions and Farm Deliveries (acre-feet)

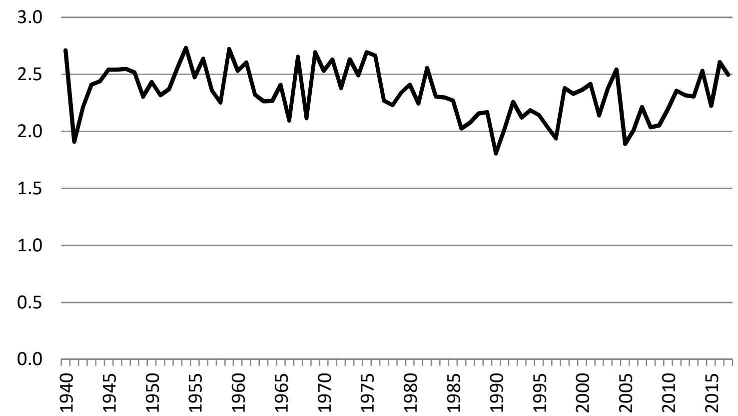


*Includes Canal Diversions, Drain Returns to Canals, and Diversions from Storage.

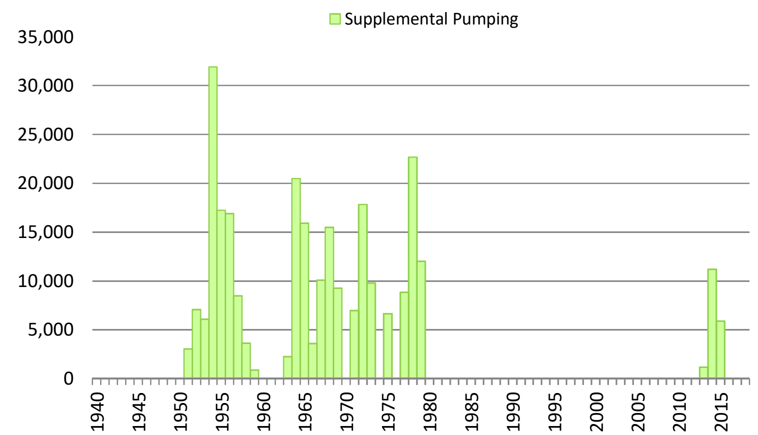
Maximum Application Efficiency and Loss Percentages



Annual Weighted Crop Irrigation Requirement (feet)



Annual Pumping (acre-feet)



Model Version: LRG Model v106 Operational Run - Base Run (All Pumping On).

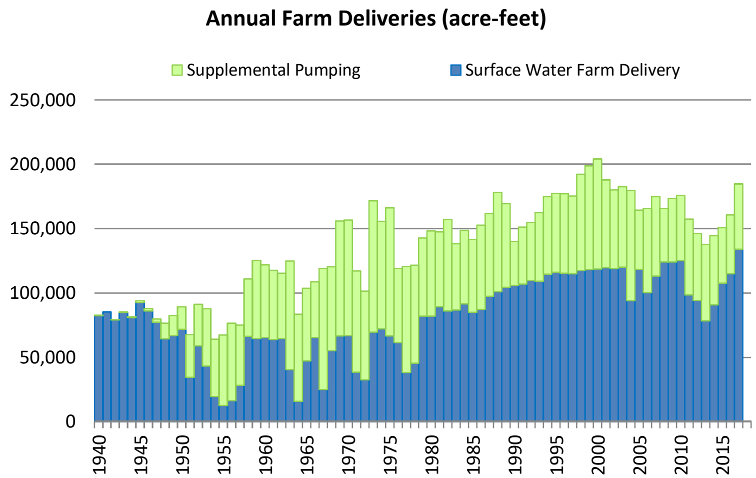
Notes:

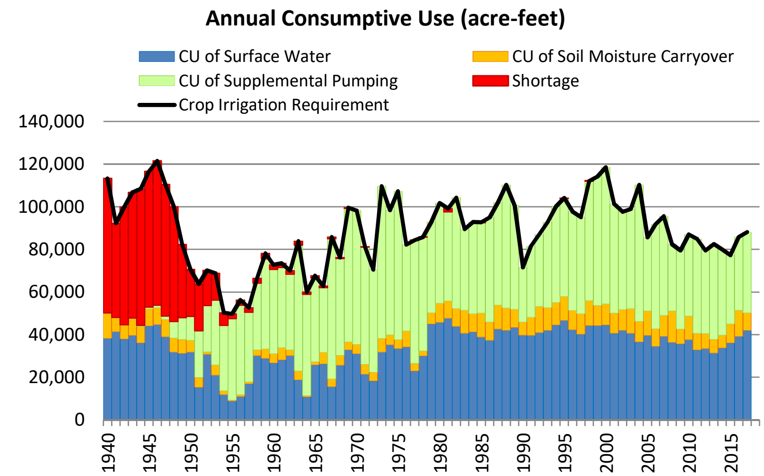
(1) Canal loss calculations occur at top of canal and are not in the surface water budget for Mesilla Texas. However a portion of the canal seepage accrues to the ground water objects for Mesilla TX.

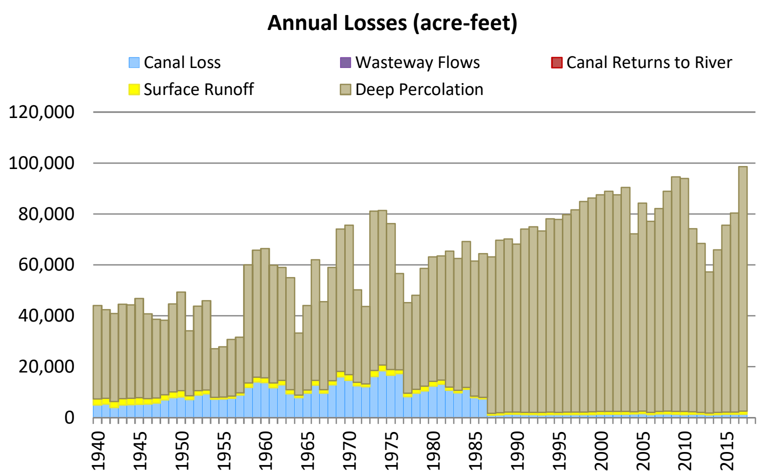
(2) Canal Returns % is equal to canal returns divided by the sum of the canal diversions plus drain flows to canal.

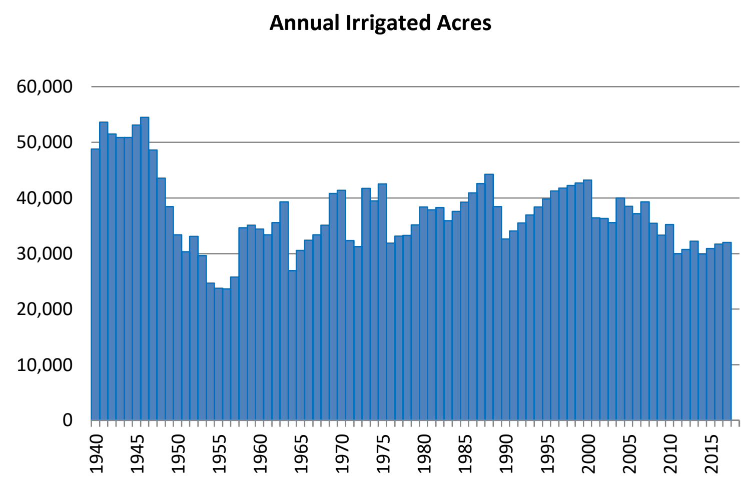
Figure 9-6

Annual Canal and Farm Budget Summary
Historical Base Run
Integrated LRG Model
1940-2017
Juarez Total









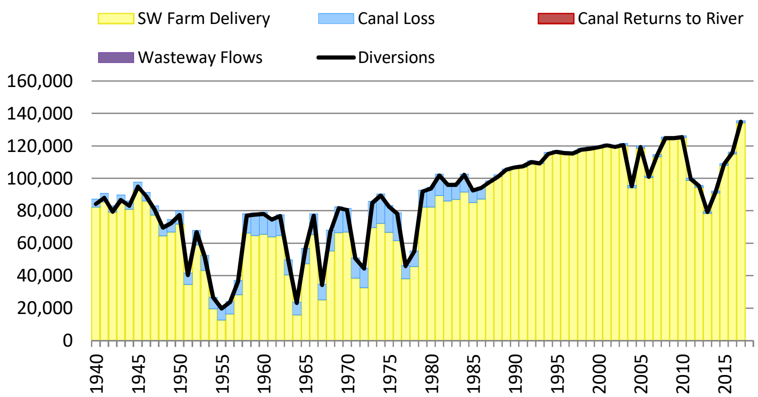
***Note: Different Scales**

Model Version: LRG Model v106 Operational Run - Base Run (All Pumping On).

Figure 9-6

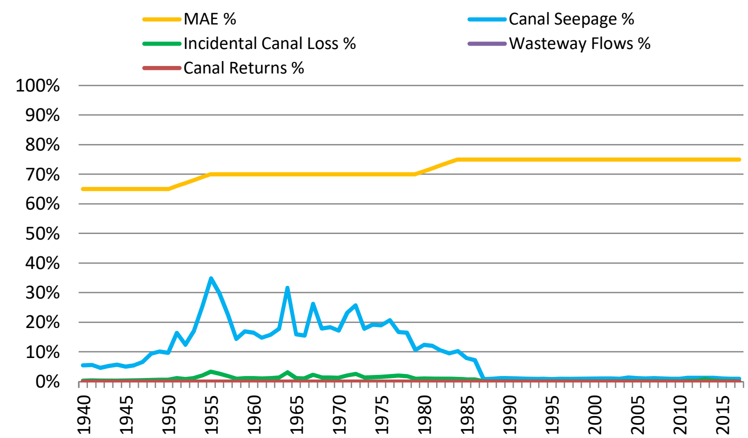
Annual Canal and Farm Budget Summary
Historical Base Run
Integrated LRG Model
1940-2017
Juarez Total

Annual Canal Diversions and Farm Deliveries (acre-feet)

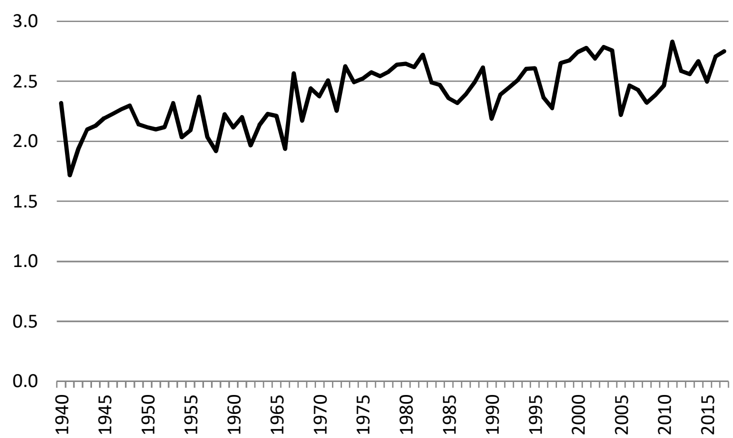


*Includes Canal Diversions, Drain Returns to Canals ,and WWTP Returns to Canals.

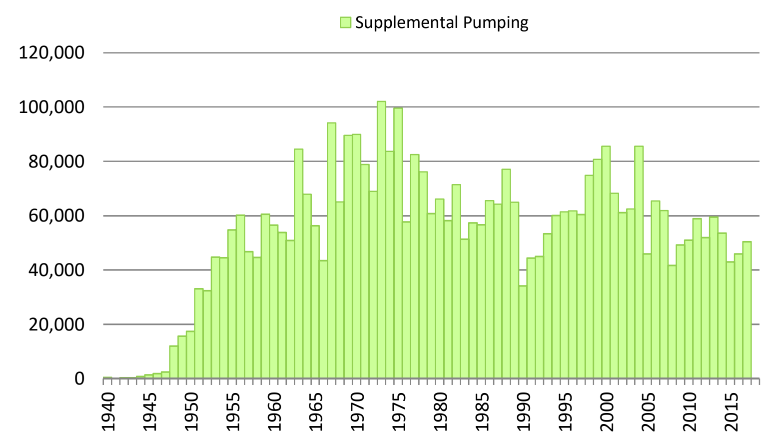
Maximum Application Efficiency and Loss Percentages



Annual Weighted Crop Irrigation Requirement (feet)



Annual Pumping (acre-feet)



Model Version: LRG Model v106 Operational Run - Base Run (All Pumping On).

Notes:

(1) Canal loss calculations occur at top of canal and are not in the surface water budget for Mesilla Texas. However a portion of the canal seepage accrues to the ground water objects for Mesilla TX.

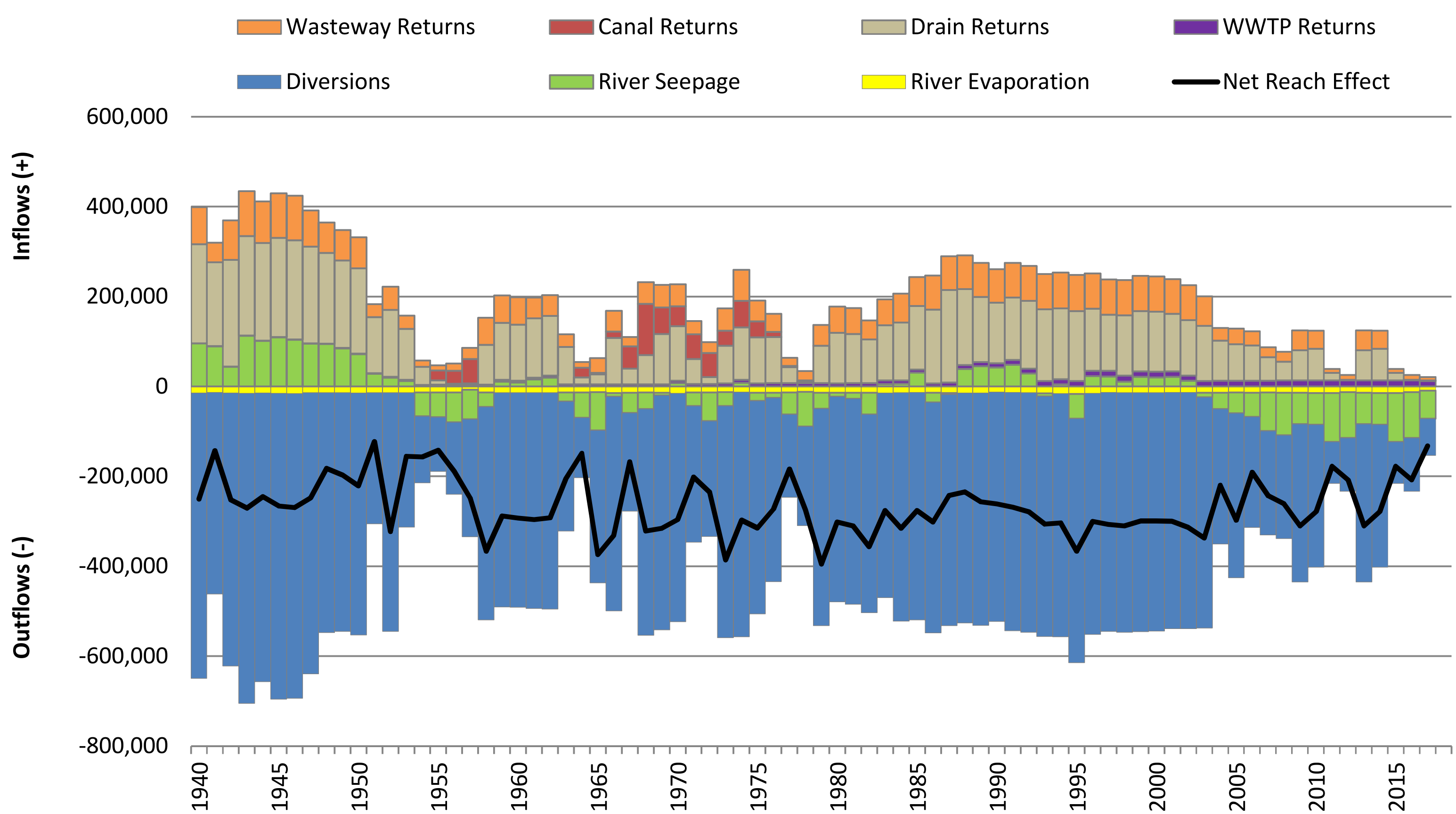
(2) Canal Returns % is equal to canal returns divided by the sum of the canal diversions plus drain flows to canal.

Figure 9-7

Annual River Budget Summary
Historical Base Run
Integrated LRG Model

1940 - 2017 (acre-feet)

Total Rincon-Mesilla (Below Caballo to El Paso)



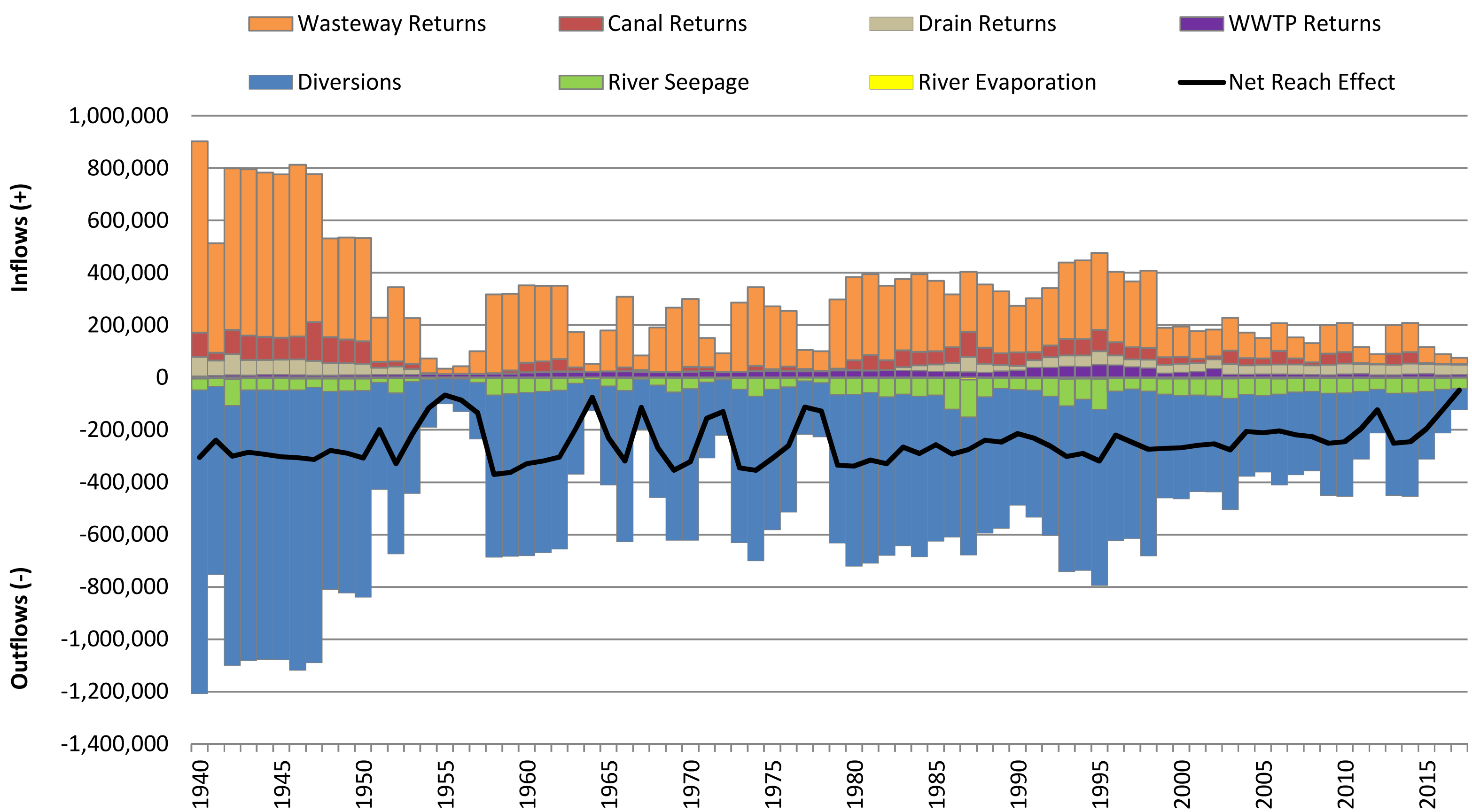
Notes:
Net Reach Effect is the change in streamflow through the stream reach, equal to total inflows minus total outflows.
River inflows and outflows not shown on graph.
Model Version: LRG Model v106 Operational Run - Base Run (All Pumping On).

Figure 9-8

Annual River Budget Summary
Historical Base Run
Integrated LRG Model

1940 - 2017 (acre-feet)

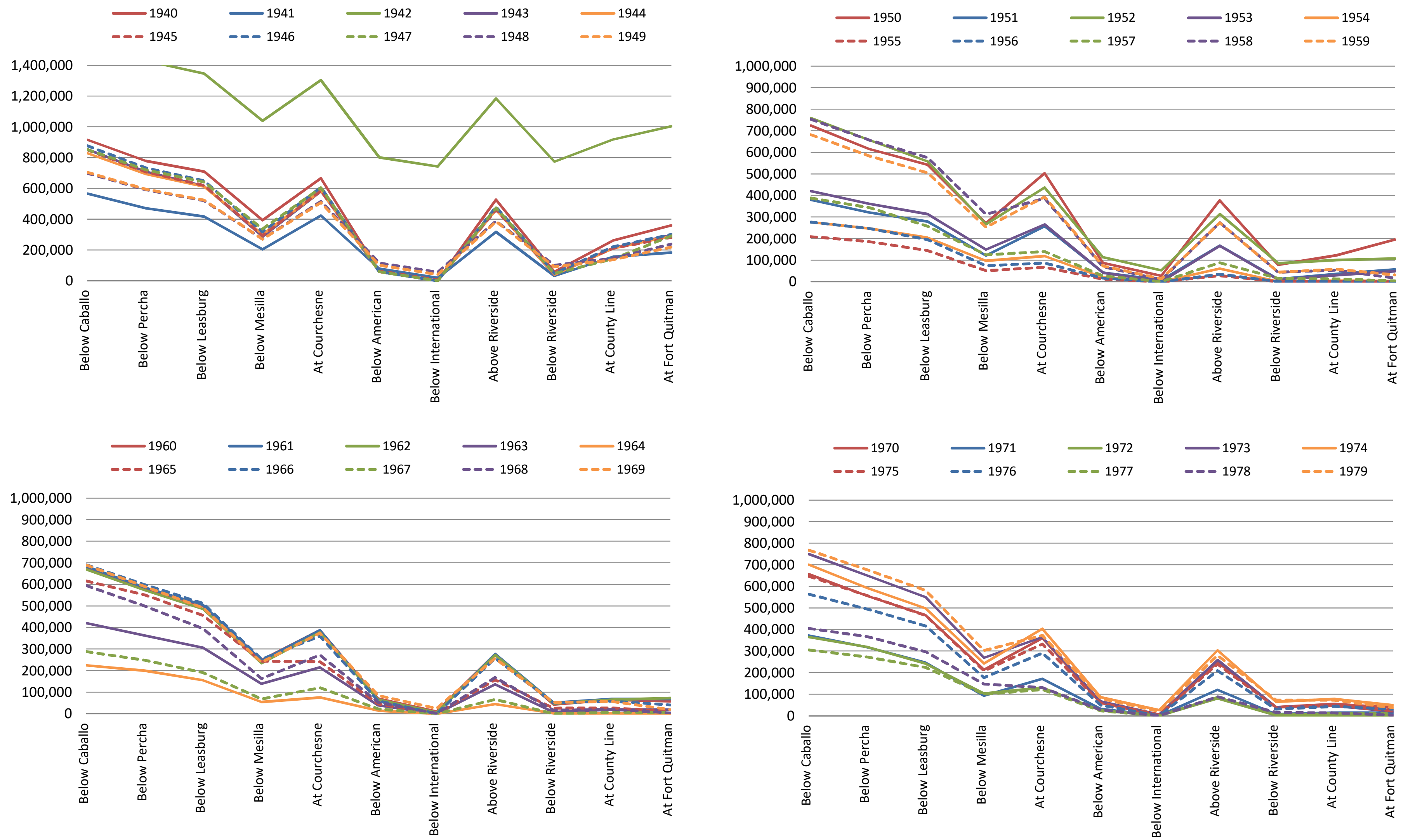
Total El Paso Valley (El Paso to Fort Quitman)



Notes:
Net Reach Effect is the change in streamflow through the stream reach, equal to total inflows minus total outflows.
River inflows and outflows not shown on graph.
Model Version: LRG Model v106 Operational Run - Base Run (All Pumping On).

Figure 9-9

Annual Rio Grande Point Flows
Historical Base Run
Integrated LRG Model
1940-2017 (acre-feet)



***Note Different Scales**

Model Version: LRG Model v106 Operational Run - Base Run (All Pumping On).

Figure 9-9

Annual Rio Grande Point Flows
Historical Base Run
Integrated LRG Model
1940-2017 (acre-feet)

***Note Different Scales**
Model Version: LRG Model v106 Operational Run - Base Run (All Pumping On).

Figure 9-10
Monthly Average Rio Grande Flows
Integrated LRG Model - Historical Base Run
1940 - 2017 (cfs)

Flow Legend (CFS)

	0	10
	10	100
	100	200
	200	500
	500	Max

Year	Month	Below Caballo	Below Percha Dam	Below Leasburg Dam	Below Mesilla Dam	At Courchesne	Below American Dam	Below Intern'l Dam	Below Riverside Dam	At County Line	At Fort Quitman
1940	Jan	0	113	113	172	344	0	0	0	227	470
	Feb	0	74	74	107	251	0	0	0	199	328
	Mar	2145	1819	1583	679	826	139	0	1	243	321
	Apr	2797	2524	1941	942	1354	210	0	138	445	535
	May	1911	1717	1379	685	1206	203	0	51	360	561
	Jun	1773	1658	1343	777	1264	210	0	79	403	547
	Jul	2254	2117	1739	997	1453	203	0	235	546	555
	Aug	2128	1962	1535	712	1274	24	0	216	542	566
	Sep	1228	1270	1075	730	1250	0	0	231	564	648
	Oct	856	861	641	285	751	0	0	19	308	483
	Nov	0	174	174	252	620	0	0	0	255	498
	Dec	0	115	115	163	396	0	0	0	230	441
1941	Jan	0	83	83	119	298	0	0	0	214	439
	Feb	0	64	64	91	241	0	0	0	185	364
	Mar	1058	912	672	307	428	157	0	6	154	206
	Apr	2021	1746	1313	579	808	142	0	33	197	197
	May	1126	1004	714	185	643	121	0	34	171	171
	Jun	1510	1395	1074	447	831	180	0	35	191	138
	Jul	1372	1281	996	453	892	203	0	39	201	119
	Aug	1786	1645	1311	647	1039	183	0	46	241	156
	Sep	58	202	180	258	715	251	251	270	394	322
	Oct	399	398	247	0	363	66	66	80	237	272
	Nov	0	132	132	179	443	0	0	0	199	246
	Dec	0	92	92	127	312	0	0	0	196	425
1942	Jan	0	68	68	95	246	0	0	0	168	357
	Feb	0	54	54	74	206	0	0	0	153	320
	Mar	1499	1256	954	357	510	165	0	9	148	183
	Apr	3334	3023	2499	1537	1782	1047	837	865	963	839
	May	9470	9147	8788	7825	7912	7121	6918	6918	6811	6420
	Jun	6287	6139	5815	5130	5618	4707	4497	4580	4620	4791
	Jul	1778	1701	1269	518	1340	201	0	146	535	962
	Aug	1141	1115	792	290	970	0	0	39	420	622
	Sep	1374	1362	1115	676	1174	0	0	193	549	639
	Oct	787	797	552	218	737	0	0	18	307	515
	Nov	0	173	173	260	630	0	0	0	263	501
	Dec	0	115	115	165	402	0	0	0	230	415
1943	Jan	0	83	83	121	304	0	0	0	222	449
	Feb	0	63	63	91	242	0	0	0	189	360
	Mar	1587	1351	1017	473	614	180	0	11	184	208
	Apr	2550	2263	1668	683	1044	210	0	51	266	319
	May	1748	1549	1156	414	989	203	0	48	247	317
	Jun	1619	1481	1131	498	1040	210	0	45	269	372
	Jul	2493	2299	1835	916	1406	186	0	192	491	439
	Aug	2137	1978	1471	584	1250	0	0	198	510	482
	Sep	1193	1161	909	439	1038	0	0	79	416	586
	Oct	736	734	484	97	652	0	0	14	263	445
	Nov	0	184	184	273	637	0	0	0	243	486
	Dec	0	122	122	173	410	0	0	0	226	469
1944	Jan	0	87	87	126	307	0	0	0	204	440
	Feb	0	65	65	95	245	0	0	0	176	352
	Mar	1393	1196	920	438	579	177	0	10	169	192
	Apr	2564	2269	1696	702	1039	210	0	51	257	299
	May	1502	1308	973	354	904	203	0	45	225	288
	Jun	1898	1730	1340	571	1072	210	0	50	271	341
	Jul	1972	1842	1451	682	1205	189	0	54	346	405
	Aug	1930	1814	1432	692	1250	0	0	225	528	518
	Sep	1403	1380	1133	665	1214	0	0	218	530	628
	Oct	1016	972	691	216	747	0	0	20	283	494
	Nov	0	186	186	280	669	0	0	0	248	473
	Dec	0	121	121	173	414	0	0	0	213	376

Figure 9-10
Monthly Average Rio Grande Flows
Integrated LRG Model - Historical Base Run
1940 - 2017 (cfs)

Flow Legend (CFS)

	0	10
	10	100
	100	200
	200	500
	500	Max

Year	Month	Below Caballo	Below Percha Dam	Below Leasburg Dam	Below Mesilla Dam	At Courchesne	Below American Dam	Below Intern'l Dam	Below Riverside Dam	At County Line	At Fort Quitman
1945	Jan	0	86	86	123	306	0	0	0	213	438
	Feb	0	65	65	93	242	0	0	0	182	359
	Mar	1556	1316	961	314	501	162	0	10	161	183
	Apr	2563	2279	1693	706	1078	210	0	53	255	279
	May	1662	1468	1114	433	987	203	0	49	225	288
	Jun	2080	1890	1470	629	1162	210	0	52	277	372
	Jul	1979	1847	1489	787	1319	203	0	114	414	423
	Aug	2082	1926	1497	653	1251	1	0	202	497	439
	Sep	1636	1577	1276	688	1250	0	0	213	513	537
	Oct	488	530	300	0	599	81	81	94	305	486
	Nov	0	174	174	259	591	0	0	0	233	407
	Dec	0	117	117	165	389	0	0	0	225	473
1946	Jan	0	83	83	121	296	0	0	0	199	407
	Feb	0	64	64	92	240	0	0	0	177	359
	Mar	1400	1202	937	433	575	171	0	10	167	190
	Apr	2537	2241	1699	702	1043	210	0	52	253	268
	May	1847	1641	1284	529	1066	203	0	54	253	333
	Jun	2101	1910	1514	696	1220	210	0	55	332	427
	Jul	2517	2333	1835	899	1445	195	0	207	506	455
	Aug	1974	1825	1416	582	1250	0	0	198	508	493
	Sep	1219	1227	1023	631	1183	0	0	194	511	622
	Oct	864	830	570	126	668	0	0	17	273	481
	Nov	0	186	186	278	649	0	0	0	251	512
	Dec	0	122	122	173	410	0	0	0	228	460
1947	Jan	0	87	87	125	308	0	0	0	208	436
	Feb	0	65	65	94	246	0	0	0	184	360
	Mar	1222	1046	801	356	492	138	0	8	167	193
	Apr	2401	2100	1614	709	1000	210	0	47	256	239
	May	1470	1345	1056	513	984	203	0	50	121	254
	Jun	1705	1575	1247	608	1031	210	0	47	132	313
	Jul	2450	2254	1839	994	1439	203	0	181	288	406
	Aug	1837	1739	1388	719	1275	25	0	220	328	536
	Sep	1746	1656	1347	729	1250	0	0	215	337	555
	Oct	1240	1151	813	219	800	0	0	19	145	507
	Nov	0	203	203	314	733	0	0	0	100	592
	Dec	0	131	131	187	446	0	0	0	80	452
1948	Jan	0	92	92	133	326	76	76	158	189	415
	Feb	0	68	68	99	258	0	0	0	68	398
	Mar	1028	908	720	385	512	128	0	107	157	221
	Apr	1773	1530	1187	485	747	210	0	39	111	163
	May	1205	1142	939	550	922	203	0	129	197	258
	Jun	2499	2238	1613	653	1029	210	0	84	174	276
	Jul	2214	2013	1577	812	1339	203	0	115	234	311
	Aug	2341	2158	1577	692	1284	34	0	176	304	431
	Sep	457	553	444	217	821	0	0	0	118	289
	Oct	4	176	171	151	559	383	383	348	353	391
	Nov	0	111	111	162	412	287	287	307	305	415
	Dec	0	81	81	120	305	180	180	208	215	366
1949	Jan	0	64	64	96	257	7	7	87	119	291
	Feb	0	52	52	76	220	0	0	0	57	252
	Mar	1817	1565	1286	707	796	117	0	185	248	292
	Apr	1910	1635	1209	327	721	195	0	49	114	202
	May	1048	1012	801	431	857	170	0	125	184	256
	Jun	2438	2187	1579	676	1048	210	0	85	174	275
	Jul	2049	1869	1449	746	1266	203	0	108	219	329
	Aug	2305	2133	1658	821	1344	94	0	178	304	419
	Sep	49	247	220	215	776	0	0	0	108	317
	Oct	0	147	147	119	470	287	287	255	269	315
	Nov	0	95	95	139	355	230	230	254	255	350
	Dec	0	70	70	105	273	148	148	188	195	335

Figure 9-10
Monthly Average Rio Grande Flows
Integrated LRG Model - Historical Base Run
1940 - 2017 (cfs)

Flow Legend (CFS)

	0	10
	10	100
	100	200
	200	500
	500	Max

	Month	Below Caballo	Below Percha Dam	Below Leasburg Dam	Below Mesilla Dam	At Courchesne	Below American Dam	Below Intern'l Dam	Below Riverside Dam	At County Line	At Fort Quitman
	Jan	0	55	55	82	229	0	0	63	95	263
	Feb	0	45	45	64	196	0	0	0	51	197
	Mar	2300	1971	1627	905	976	131	0	230	303	324
	Apr	2107	1837	1318	349	791	202	0	56	124	219
	May	1441	1333	1070	527	983	189	0	144	210	267
1950	Jun	2571	2337	1712	763	1209	210	0	101	202	334
	Jul	2170	1986	1539	684	1273	203	0	110	220	425
	Aug	1336	1343	1158	745	1259	54	0	157	271	342
	Sep	9	194	183	159	614	92	92	56	117	193
	Oct	0	107	107	25	305	145	145	108	135	191
	Nov	0	63	63	94	255	130	130	153	160	240
	Dec	0	49	49	74	212	87	87	117	128	240
	Jan	0	42	42	61	187	0	0	22	55	196
	Feb	0	37	37	51	167	0	0	0	39	172
	Mar	1496	1264	1028	458	533	116	0	0	52	125
	Apr	1892	1577	1097	174	510	181	0	0	48	72
	May	949	877	645	217	632	171	0	35	79	110
1951	Jun	1111	1073	888	472	780	67	0	0	69	120
	Jul	506	562	496	348	656	23	0	68	114	61
	Aug	319	343	289	149	363	23	0	0	38	30
	Sep	7	55	47	26	166	48	48	0	18	21
	Oct	0	22	22	20	89	73	73	75	59	15
	Nov	0	14	14	19	78	0	0	0	10	13
	Dec	0	16	16	20	89	0	0	0	11	22
	Jan	0	19	19	21	93	0	0	0	12	32
	Feb	0	21	21	20	92	0	0	0	13	44
	Mar	1336	1127	916	400	427	113	0	0	26	52
	Apr	557	510	414	118	314	40	0	0	24	38
	May	632	575	485	219	336	46	0	0	22	26
1952	Jun	1659	1442	1176	524	613	126	0	0	33	15
	Jul	3273	2926	2301	1248	1453	203	0	328	357	212
	Aug	2865	2610	1985	1015	1453	203	0	194	249	192
	Sep	1945	1746	1389	483	1059	210	0	0	79	229
	Oct	229	330	241	0	582	408	361	326	307	307
	Nov	0	140	140	198	468	343	343	357	333	364
	Dec	0	94	94	132	301	176	176	198	194	266
	Jan	0	69	69	97	233	0	0	63	86	216
	Feb	0	54	54	75	193	0	0	0	37	166
	Mar	1488	1263	1011	441	521	79	0	0	51	101
	Apr	1777	1475	999	110	456	130	0	0	42	69
	May	1017	930	692	241	629	156	0	29	66	72
1953	Jun	662	750	728	593	852	177	0	0	63	100
	Jul	628	634	560	367	568	57	0	63	95	40
	Aug	1255	1122	939	491	579	89	0	0	35	25
	Sep	65	92	71	17	175	0	0	0	13	14
	Oct	32	35	35	0	68	15	15	4	6	6
	Nov	0	8	8	11	53	0	0	0	4	2
	Dec	0	7	7	10	57	0	0	0	5	0
	Jan	0	9	9	10	67	0	0	0	7	1
	Feb	0	13	13	11	69	0	0	0	8	8
	Mar	1013	850	696	301	312	79	0	0	18	15
	Apr	761	668	566	238	328	72	0	0	13	12
	May	573	508	441	221	272	37	0	0	11	5
1954	Jun	530	465	395	178	218	37	0	0	9	2
	Jul	1049	912	774	415	406	74	0	1	13	1
	Aug	475	417	358	187	200	25	0	0	7	1
	Sep	107	89	81	36	51	0	0	0	1	1
	Oct	28	25	22	0	14	1	1	13	4	0
	Nov	0	5	5	5	15	0	0	0	0	0
	Dec	0	5	5	3	15	0	0	0	0	0

Figure 9-10
Monthly Average Rio Grande Flows
Integrated LRG Model - Historical Base Run
1940 - 2017 (cfs)

Flow Legend (CFS)

	0	10
	10	100
	100	200
	200	500
	500	Max

Year	Month	Below Caballo	Below Percha Dam	Below Leasburg Dam	Below Mesilla Dam	At Courchesne	Below American Dam	Below Intern'l Dam	Below Riverside Dam	At County Line	At Fort Quitman
1955	Jan	0	5	5	4	19	0	0	0	0	0
	Feb	0	6	6	5	23	0	0	0	0	0
	Mar	194	157	133	48	54	16	0	0	0	0
	Apr	505	411	334	67	161	47	0	0	0	0
	May	691	575	487	218	210	39	0	0	6	0
	Jun	424	351	293	89	126	23	0	0	2	0
	Jul	682	569	470	193	235	45	0	0	6	0
	Aug	576	476	378	110	195	38	0	0	4	1
	Sep	252	204	176	65	59	0	0	0	0	1
	Oct	118	93	86	36	18	0	0	10	2	0
	Nov	0	3	3	3	4	0	0	0	0	0
	Dec	0	2	2	3	3	0	0	0	0	0
1956	Jan	0	2	2	3	3	0	0	0	0	0
	Feb	0	3	3	3	3	0	0	0	0	0
	Mar	777	649	549	270	212	62	0	0	5	0
	Apr	677	559	457	68	218	56	0	0	5	0
	May	861	740	640	323	266	40	0	0	8	0
	Jun	639	536	440	109	208	47	0	0	5	0
	Jul	774	656	545	205	285	46	0	0	9	1
	Aug	554	464	386	161	183	24	0	0	5	1
	Sep	227	183	162	64	53	0	0	0	1	1
	Oct	43	27	18	0	4	0	0	6	0	0
	Nov	0	2	2	3	3	0	0	0	0	0
	Dec	0	2	2	3	3	0	0	0	0	0
1957	Jan	0	2	2	3	3	0	0	0	0	0
	Feb	0	2	2	3	3	0	0	0	0	0
	Mar	0	4	4	4	4	4	4	20	6	0
	Apr	0	4	4	3	4	4	4	18	3	0
	May	0	2	2	3	4	4	4	19	5	0
	Jun	0	2	2	3	4	4	4	21	4	0
	Jul	1289	1077	729	347	504	132	0	0	9	1
	Aug	3103	2662	2037	1103	1108	203	0	169	170	64
	Sep	1390	1184	900	337	478	88	0	0	11	0
	Oct	575	529	457	171	139	0	0	0	4	0
	Nov	0	52	52	46	25	0	0	0	0	0
	Dec	0	32	32	22	10	0	0	0	0	0
1958	Jan	0	28	28	18	8	0	0	0	0	0
	Feb	0	26	26	16	7	0	0	0	0	0
	Mar	2056	1797	1537	967	855	91	0	197	225	109
	Apr	2499	2178	1739	778	758	174	0	54	79	13
	May	1766	1646	1409	876	938	203	0	132	146	44
	Jun	2717	2456	1831	817	995	210	0	79	107	23
	Jul	2672	2453	1905	918	1212	203	0	101	154	80
	Aug	706	785	698	494	826	107	0	15	59	4
	Sep	9	151	142	120	347	58	58	17	19	0
	Oct	0	89	89	47	186	98	98	75	53	4
	Nov	0	49	49	55	126	1	1	34	23	0
	Dec	0	38	38	41	106	0	0	23	14	0
1959	Jan	0	34	34	34	99	0	0	0	2	0
	Feb	0	31	31	29	89	0	0	0	4	0
	Mar	2302	1991	1667	943	928	109	0	218	249	126
	Apr	2350	2048	1570	554	788	177	0	57	78	9
	May	1572	1451	1210	662	985	203	0	143	171	64
	Jun	2562	2316	1691	712	1044	210	0	85	132	81
	Jul	2285	2083	1655	813	1249	203	0	106	175	209
	Aug	173	319	270	202	667	86	0	0	47	17
	Sep	6	129	123	118	367	142	142	41	47	1
	Oct	0	44	44	41	117	81	81	75	53	5
	Nov	0	20	20	31	76	0	0	0	3	1
	Dec	0	17	17	23	77	0	0	0	4	0

Figure 9-10
Monthly Average Rio Grande Flows
Integrated LRG Model - Historical Base Run
1940 - 2017 (cfs)

Flow Legend (CFS)

Color	From	To
(white)	0	10
(light green)	10	100
(teal)	100	200
(blue)	200	500
(dark blue)	500	Max

Year	Month	Below Caballo	Below Percha Dam	Below Leasburg Dam	Below Mesilla Dam	At Courchesne	Below American Dam	Below Intern'l Dam	Below Riverside Dam	At County Line	At Fort Quitman
1960	Jan	0	19	19	23	82	0	0	0	5	0
	Feb	0	21	21	21	80	0	0	0	9	9
	Mar	2354	2039	1731	1034	990	120	0	233	276	195
	Apr	2462	2141	1647	632	831	210	0	61	99	42
	May	1588	1456	1202	635	956	203	0	139	176	123
	Jun	2600	2350	1725	755	1088	210	0	89	150	176
	Jul	1972	1778	1388	571	1045	203	0	88	152	205
	Aug	247	381	324	231	672	43	0	0	67	51
	Sep	5	119	113	108	339	97	97	15	42	24
	Oct	0	45	45	36	119	74	74	68	59	45
	Nov	0	22	22	38	90	0	0	0	11	38
	Dec	0	19	19	30	89	0	0	14	19	47
1961	Jan	0	21	21	28	94	0	0	0	13	42
	Feb	0	22	22	26	87	0	0	0	12	50
	Mar	1552	1318	1085	504	508	105	0	0	31	29
	Apr	2198	1848	1352	368	555	200	0	0	22	1
	May	1344	1194	928	363	663	196	0	34	50	18
	Jun	1974	1764	1352	583	855	210	0	0	43	55
	Jul	2806	2553	2055	1152	1452	202	0	455	471	365
	Aug	1358	1350	1162	749	1173	76	0	236	270	276
	Sep	16	185	168	152	525	22	22	0	53	64
	Oct	0	88	88	34	206	44	44	22	45	62
	Nov	0	39	39	60	132	7	7	50	59	82
	Dec	0	33	33	49	123	0	0	50	55	79
1962	Jan	0	30	30	42	115	0	0	0	18	53
	Feb	0	28	28	35	102	0	0	0	17	63
	Mar	1539	1311	1072	500	514	125	0	0	33	37
	Apr	2107	1767	1281	326	544	210	0	0	20	13
	May	945	865	666	258	581	122	0	31	48	16
	Jun	2267	1985	1507	622	851	210	0	0	42	48
	Jul	2878	2627	2002	1028	1388	203	0	452	465	354
	Aug	1280	1298	1151	815	1240	119	0	145	195	221
	Sep	10	156	144	116	468	1	1	0	49	134
	Oct	0	71	71	19	177	82	82	84	89	100
	Nov	0	32	32	55	127	2	2	47	57	88
	Dec	0	22	22	38	105	0	0	24	35	79
1963	Jan	0	23	23	34	104	0	0	0	18	82
	Feb	0	23	23	30	95	0	0	0	16	76
	Mar	1399	1170	928	359	401	130	0	0	26	38
	Apr	2011	1667	1199	273	471	210	0	0	20	11
	May	1161	1038	790	298	593	153	0	27	49	24
	Jun	992	980	834	465	704	94	0	0	43	49
	Jul	680	705	637	446	631	28	0	88	111	33
	Aug	579	545	487	317	348	26	0	0	28	1
	Sep	97	100	94	58	100	0	0	0	7	0
	Oct	17	20	20	0	36	7	7	17	9	0
	Nov	0	6	6	8	32	0	0	0	2	0
	Dec	0	5	5	8	32	0	0	0	3	0
1964	Jan	0	7	7	8	35	0	0	0	4	0
	Feb	0	9	9	9	40	0	0	0	4	0
	Mar	480	396	329	133	137	45	0	0	7	0
	Apr	535	438	349	60	190	52	0	0	9	0
	May	659	564	484	232	203	35	0	0	8	1
	Jun	377	315	262	73	130	26	0	0	2	2
	Jul	692	575	470	168	249	52	0	0	7	1
	Aug	601	492	396	130	188	37	0	0	5	1
	Sep	244	196	168	57	54	0	0	3	1	1
	Oct	103	79	71	24	13	0	0	26	10	0
	Nov	0	2	2	3	3	0	0	0	0	0
	Dec	0	1	1	3	3	0	0	0	0	0

Figure 9-10
Monthly Average Rio Grande Flows
Integrated LRG Model - Historical Base Run
1940 - 2017 (cfs)

Flow Legend (CFS)

	0	10
	10	100
	100	200
	200	500
	500	Max

Year	Month	Below Caballo	Below Percha Dam	Below Leasburg Dam	Below Mesilla Dam	At Courchesne	Below American Dam	Below Intern'l Dam	Below Riverside Dam	At County Line	At Fort Quitman
1965	Jan	0	2	2	4	3	0	0	0	0	0
	Feb	0	2	2	4	3	0	0	0	0	0
	Mar	0	3	3	4	4	4	4	32	13	0
	Apr	234	179	146	24	65	21	0	10	1	0
	May	755	626	536	266	205	51	0	0	5	0
	Jun	1346	1138	944	449	380	101	0	0	7	1
	Jul	3345	2899	2313	1202	1107	203	0	192	193	84
	Aug	3426	3032	2480	1391	1294	203	0	187	204	92
	Sep	948	947	878	558	659	173	0	0	22	0
	Oct	40	122	115	25	150	0	0	0	5	0
	Nov	0	39	39	45	67	0	0	0	1	0
	Dec	0	20	20	21	36	0	0	0	0	0
1966	Jan	0	21	21	20	35	0	0	0	0	0
	Feb	0	21	21	20	34	0	0	0	0	0
	Mar	1555	1328	1073	531	523	93	0	0	16	0
	Apr	2124	1779	1262	261	480	167	0	0	0	0
	May	1428	1288	1030	402	652	193	0	30	32	0
	Jun	2028	1768	1265	394	637	202	0	0	14	0
	Jul	2866	2620	2094	1166	1397	203	0	446	450	273
	Aug	1139	1235	1151	938	1258	130	0	277	296	235
	Sep	186	325	320	284	534	0	0	0	43	27
	Oct	56	121	121	37	157	0	0	0	23	34
	Nov	0	39	39	55	113	0	0	35	40	48
	Dec	0	29	29	39	95	0	0	25	31	48
1967	Jan	0	27	27	33	89	0	0	0	15	46
	Feb	0	26	26	28	80	0	0	0	14	51
	Mar	1296	1088	824	399	412	121	0	0	21	13
	Apr	658	592	424	63	331	77	0	0	17	1
	May	533	471	344	73	271	39	0	0	15	1
	Jun	379	337	247	32	155	21	0	0	10	0
	Jul	478	417	339	142	186	27	0	0	7	0
	Aug	902	757	568	246	332	80	0	0	8	1
	Sep	352	295	233	65	90	0	0	0	1	1
	Oct	135	108	93	30	27	0	0	13	4	0
	Nov	0	5	5	5	8	0	0	0	0	0
	Dec	0	4	4	5	8	0	0	0	0	0
1968	Jan	0	7	7	6	7	0	0	0	0	0
	Feb	0	11	11	8	8	0	0	0	0	0
	Mar	1733	1512	1248	636	685	124	0	0	25	0
	Apr	2069	1756	1211	354	602	210	0	0	4	1
	May	959	884	562	51	557	116	0	23	24	1
	Jun	1061	975	682	202	441	69	0	0	10	1
	Jul	1656	1482	1124	620	695	152	0	166	147	51
	Aug	2110	1889	1365	723	903	160	0	77	92	21
	Sep	140	233	122	0	319	6	6	0	19	1
	Oct	50	102	83	0	117	22	22	0	5	0
	Nov	0	36	36	42	81	0	0	0	3	0
	Dec	0	31	31	34	69	0	0	0	5	0
1969	Jan	0	29	29	29	65	0	0	0	6	0
	Feb	0	27	27	24	62	0	0	0	7	0
	Mar	1648	1423	1111	587	619	144	0	0	29	0
	Apr	1893	1596	1090	270	606	210	0	0	17	1
	May	972	897	640	194	565	76	0	35	49	1
	Jun	1438	1299	988	487	639	161	0	0	28	1
	Jul	3294	2964	2339	1307	1387	203	0	309	323	174
	Aug	2044	1839	1452	682	1093	193	0	75	100	25
	Sep	34	207	161	90	538	193	193	141	122	41
	Oct	4	120	115	86	265	153	153	138	118	39
	Nov	0	69	69	94	178	53	53	91	81	19
	Dec	0	50	50	68	141	16	16	68	64	13

Figure 9-10
Monthly Average Rio Grande Flows
Integrated LRG Model - Historical Base Run
1940 - 2017 (cfs)

Flow Legend (CFS)

From	To
0	10
10	100
100	200
200	500
500	Max

Year	Month	Below Caballo	Below Percha Dam	Below Leasburg Dam	Below Mesilla Dam	At Courchesne	Below American Dam	Below Intern'l Dam	Below Riverside Dam	At County Line	At Fort Quitman
1970	Jan	0	43	43	56	130	0	0	0	17	4
	Feb	0	36	36	45	112	0	0	0	16	45
	Mar	1425	1219	951	447	501	135	0	0	29	19
	Apr	2110	1803	1229	284	576	210	0	0	20	1
	May	1473	1297	972	324	710	203	0	32	53	1
	Jun	1586	1449	1089	448	808	168	0	0	39	8
	Jul	2346	2168	1760	1009	1308	156	0	396	408	246
	Aug	1640	1544	1227	697	1055	116	0	176	199	112
	Sep	129	223	177	70	395	0	0	0	38	15
	Oct	94	129	126	41	135	0	0	0	20	50
	Nov	0	28	28	46	104	0	0	14	24	56
	Dec	0	24	24	36	96	0	0	23	29	65
1971	Jan	0	24	24	31	92	0	0	0	15	67
	Feb	0	24	24	28	84	0	0	0	14	63
	Mar	1785	1520	1217	590	613	118	0	0	37	58
	Apr	1565	1339	966	234	603	200	0	0	26	29
	May	705	641	409	49	446	64	0	13	35	19
	Jun	1059	937	674	254	427	82	0	0	22	1
	Jul	666	615	457	205	353	39	0	64	63	8
	Aug	267	263	219	111	157	27	0	0	7	1
	Sep	73	60	51	13	36	0	0	13	5	1
	Oct	26	22	18	1	7	0	0	29	12	0
	Nov	0	5	5	6	4	0	0	0	0	0
	Dec	0	3	3	5	3	0	0	0	0	0
1972	Jan	0	3	3	5	3	0	0	0	0	0
	Feb	0	3	3	5	4	0	0	0	0	0
	Mar	1692	1420	1085	568	569	133	0	0	16	0
	Apr	1429	1214	882	300	489	138	0	0	0	0
	May	1210	1042	801	340	456	72	0	3	15	1
	Jun	448	421	311	77	208	19	0	0	6	0
	Jul	446	414	338	159	190	21	0	0	0	1
	Aug	503	421	335	138	163	32	0	0	3	0
	Sep	206	168	146	63	46	0	0	0	1	0
	Oct	73	58	53	22	10	0	0	20	7	0
	Nov	0	4	4	5	4	0	0	0	0	0
	Dec	0	4	4	5	4	0	0	0	0	0
1973	Jan	0	6	6	6	5	0	0	0	0	0
	Feb	0	9	9	7	6	0	0	0	0	0
	Mar	1775	1532	1304	718	644	143	0	0	23	0
	Apr	2523	2154	1616	588	651	210	0	0	10	1
	May	1550	1404	1099	489	727	140	0	53	59	5
	Jun	1572	1475	1175	579	765	152	0	0	23	1
	Jul	3016	2739	2114	1109	1302	203	0	426	416	246
	Aug	1836	1712	1407	774	1112	140	0	148	168	69
	Sep	40	206	164	60	507	99	99	30	39	1
	Oct	27	96	84	8	131	0	0	0	10	0
	Nov	0	36	36	46	86	0	0	0	5	0
	Dec	0	26	26	31	63	0	0	0	4	0
1974	Jan	0	25	25	27	64	0	0	0	6	0
	Feb	0	25	25	24	64	0	0	0	8	0
	Mar	2589	2267	1924	1160	1135	165	0	265	313	176
	Apr	2546	2242	1673	727	992	210	0	80	126	74
	May	2083	1911	1588	869	1220	203	0	188	244	205
	Jun	2558	2334	1709	786	1196	210	0	100	161	216
	Jul	1542	1422	926	226	881	201	0	40	81	24
	Aug	173	282	138	0	557	231	231	180	159	54
	Sep	75	139	75	0	181	66	66	38	32	0
	Oct	5	70	65	74	151	130	130	138	106	39
	Nov	0	43	43	64	122	0	0	27	24	4
	Dec	0	26	26	40	88	0	0	14	15	9

Figure 9-10
Monthly Average Rio Grande Flows
Integrated LRG Model - Historical Base Run
1940 - 2017 (cfs)

Flow Legend (CFS)

	0	10
	10	100
	100	200
	200	500
	500	Max

Year	Month	Below Caballo	Below Percha Dam	Below Leasburg Dam	Below Mesilla Dam	At Courchesne	Below American Dam	Below Intern'l Dam	Below Riverside Dam	At County Line	At Fort Quitman
1975	Jan	0	27	27	36	93	0	0	0	10	30
	Feb	0	26	26	31	86	0	0	0	10	51
	Mar	1555	1325	1072	492	515	155	0	0	27	13
	Apr	1064	926	718	189	424	84	0	0	16	1
	May	874	783	621	226	431	74	0	10	25	0
	Jun	1156	1014	791	266	447	97	0	0	14	1
	Jul	2840	2478	1947	927	1068	203	0	300	288	147
	Aug	2813	2535	1938	976	1313	203	0	199	221	102
	Sep	283	386	301	104	583	79	0	0	31	0
	Oct	24	121	92	31	245	62	62	40	46	4
	Nov	0	56	56	81	149	24	24	61	58	8
	Dec	0	35	35	53	110	0	0	40	40	11
1976	Jan	0	32	32	46	107	0	0	0	15	21
	Feb	0	29	29	37	95	0	0	0	14	49
	Mar	1589	1371	1097	488	517	130	0	0	31	18
	Apr	2210	1862	1331	322	554	210	0	0	19	1
	May	1182	1105	878	299	638	187	0	39	54	2
	Jun	909	909	771	351	621	63	0	0	31	13
	Jul	2421	2194	1802	951	1060	164	0	342	340	196
	Aug	789	790	629	298	696	57	0	116	128	37
	Sep	87	141	125	25	248	0	0	0	26	29
	Oct	90	110	110	27	98	0	0	0	18	37
	Nov	0	22	22	39	87	0	0	9	19	46
	Dec	0	17	17	26	70	0	0	0	14	64
1977	Jan	0	19	19	25	73	0	0	0	14	52
	Feb	0	20	20	22	69	0	0	0	13	59
	Mar	1118	951	761	305	327	106	0	0	21	33
	Apr	785	700	574	200	295	59	0	0	19	2
	May	1476	1290	1069	495	514	115	0	31	49	4
	Jun	553	520	420	154	293	40	0	0	19	0
	Jul	477	434	378	213	231	24	0	11	15	0
	Aug	466	401	343	179	159	27	0	0	3	1
	Sep	112	88	78	34	32	0	0	8	2	0
	Oct	27	21	17	0	7	0	0	23	8	0
	Nov	0	3	3	6	6	0	0	0	0	0
	Dec	0	3	3	5	5	0	0	0	0	0
1978	Jan	0	3	3	5	5	0	0	0	0	0
	Feb	0	3	3	5	5	0	0	0	0	0
	Mar	0	6	6	6	6	6	6	28	11	0
	Apr	376	310	269	123	85	26	0	1	0	0
	May	1308	1111	925	437	372	100	0	0	11	0
	Jun	647	551	474	235	181	28	0	0	5	1
	Jul	2158	1867	1526	782	696	161	0	129	113	32
	Aug	1963	1726	1432	777	692	125	0	95	78	7
	Sep	86	109	75	0	52	0	0	0	0	0
	Oct	87	97	96	0	14	0	0	0	0	0
	Nov	0	18	18	20	12	0	0	0	0	0
	Dec	0	19	19	16	9	0	0	0	0	0
1979	Jan	0	20	20	17	12	0	0	0	0	0
	Feb	0	21	21	16	11	0	0	0	0	0
	Mar	389	337	284	129	103	33	0	0	1	0
	Apr	1184	1017	842	364	319	93	0	0	2	0
	May	1512	1317	1093	531	494	112	0	34	32	0
	Jun	2610	2277	1811	809	854	210	0	0	25	1
	Jul	3234	2925	2300	1253	1387	203	0	454	441	266
	Aug	2568	2337	1919	1074	1345	203	0	283	288	159
	Sep	1144	1164	967	485	849	136	0	0	37	62
	Oct	14	178	159	96	396	218	218	195	162	66
	Nov	0	96	96	125	230	105	105	149	121	40
	Dec	0	64	64	82	144	19	19	75	62	28

Figure 9-10
Monthly Average Rio Grande Flows
Integrated LRG Model - Historical Base Run
1940 - 2017 (cfs)

Flow Legend (CFS)

	0	10
	10	100
	100	200
	200	500
	500	Max

Year	Month	Below Caballo	Below Percha Dam	Below Leasburg Dam	Below Mesilla Dam	At Courchesne	Below American Dam	Below Intern'l Dam	Below Riverside Dam	At County Line	At Fort Quitman
1980	Jan	0	51	51	64	120	0	0	0	12	9
	Feb	0	42	42	49	100	0	0	0	15	43
	Mar	1739	1559	1308	824	788	147	0	174	203	108
	Apr	1541	1391	1105	594	713	210	0	45	76	10
	May	2165	1924	1506	765	914	203	0	125	166	65
	Jun	2251	2023	1579	782	1060	210	0	81	143	125
	Jul	2395	2177	1715	888	1201	203	0	97	174	173
	Aug	1314	1259	982	491	877	16	0	87	151	155
	Sep	107	220	197	147	418	0	0	0	52	86
	Oct	0	70	70	8	148	40	40	36	47	64
	Nov	0	36	36	60	121	0	0	38	43	70
	Dec	0	27	27	44	98	0	0	24	31	72
1981	Jan	0	26	26	37	93	0	0	0	15	78
	Feb	0	25	25	31	84	0	0	0	17	72
	Mar	1796	1600	1347	840	798	161	0	173	203	139
	Apr	1659	1481	1178	622	726	210	0	45	70	37
	May	2274	2008	1570	784	925	203	0	125	164	100
	Jun	2256	2035	1610	832	1095	210	0	84	144	154
	Jul	2321	2104	1661	853	1184	203	0	95	168	197
	Aug	1071	1035	783	332	752	2	0	76	129	162
	Sep	165	274	253	194	456	0	0	0	57	82
	Oct	0	66	66	0	137	23	23	25	45	85
	Nov	0	33	33	57	116	0	0	35	44	76
	Dec	0	20	20	33	85	0	0	15	26	74
1982	Jan	0	21	21	31	85	0	0	0	16	72
	Feb	0	22	22	27	80	0	0	0	15	83
	Mar	1273	1128	938	563	533	161	0	0	29	37
	Apr	1276	1130	906	500	530	210	0	0	23	16
	May	1621	1435	1157	631	658	203	0	33	51	13
	Jun	1802	1620	1310	736	804	196	0	0	39	16
	Jul	2432	2240	1931	1328	1365	203	0	439	448	273
	Aug	2048	1899	1621	1112	1220	15	0	295	327	272
	Sep	1553	1343	1000	278	538	0	0	0	50	62
	Oct	669	617	401	0	376	249	249	240	216	161
	Nov	0	129	129	186	392	267	267	313	280	232
	Dec	0	77	77	111	223	98	98	157	143	144
1983	Jan	0	58	58	83	175	0	0	26	42	122
	Feb	0	46	46	63	143	0	0	0	27	135
	Mar	1240	1091	870	456	490	106	0	109	128	132
	Apr	1197	1066	815	369	509	187	0	33	61	90
	May	1927	1689	1302	603	768	203	0	96	133	118
	Jun	1935	1728	1328	595	883	210	0	63	118	132
	Jul	1945	1757	1357	632	965	203	0	73	136	149
	Aug	1829	1663	1268	564	919	79	0	81	155	203
	Sep	378	471	408	260	609	0	0	0	78	131
	Oct	0	86	86	39	189	63	63	60	74	108
	Nov	0	48	48	77	154	29	29	77	78	111
	Dec	0	38	38	60	128	3	3	59	62	107
1984	Jan	0	32	32	48	114	0	0	0	20	56
	Feb	0	31	31	40	100	0	0	0	20	105
	Mar	1626	1438	1194	704	688	135	0	152	178	131
	Apr	1532	1363	1086	571	685	210	0	47	76	47
	May	2132	1879	1491	785	908	204	0	126	167	117
	Jun	1877	1680	1304	620	896	210	0	67	117	151
	Jul	2126	1915	1504	749	1042	204	0	80	146	147
	Aug	1170	1095	805	325	695	28	0	68	123	173
	Sep	1417	1219	843	193	557	0	0	0	71	107
	Oct	19	178	153	104	451	357	357	357	325	306
	Nov	0	113	113	158	342	217	217	266	241	310
	Dec	0	79	79	113	219	94	94	151	141	259

Figure 9-10
Monthly Average Rio Grande Flows
Integrated LRG Model - Historical Base Run
1940 - 2017 (cfs)

Flow Legend (CFS)

	From	To
	0	10
	10	100
	100	200
	200	500
	500	Max

Year	Month	Below Caballo	Below Percha Dam	Below Leasburg Dam	Below Mesilla Dam	At Courchesne	Below American Dam	Below Intern'l Dam	Below Riverside Dam	At County Line	At Fort Quitman
1985	Jan	0	61	61	88	189	0	0	34	54	215
	Feb	0	48	48	68	156	0	0	0	32	179
	Mar	1006	884	692	341	401	108	0	84	104	111
	Apr	1349	1206	948	488	609	210	0	32	74	88
	May	2012	1767	1366	653	830	203	0	109	156	119
	Jun	1950	1736	1329	601	898	210	0	65	130	148
	Jul	1837	1657	1268	575	917	203	0	68	137	123
	Aug	1643	1494	1126	480	843	54	0	75	153	139
	Sep	1051	899	553	0	453	2	2	0	67	140
	Oct	16	177	154	115	441	347	347	344	314	280
	Nov	0	114	114	158	341	216	216	259	236	299
	Dec	0	80	80	116	241	116	116	167	155	258
1986	Jan	0	60	60	87	193	0	0	36	54	186
	Feb	0	47	47	67	160	0	0	0	29	166
	Mar	1908	1645	1277	372	514	159	0	50	77	104
	Apr	1559	1323	878	211	558	210	0	0	42	92
	May	1570	1401	1062	214	606	203	0	0	46	98
	Jun	1495	1281	886	218	642	210	0	0	47	66
	Jul	1585	1397	980	235	683	203	0	0	51	40
	Aug	1723	1677	1443	951	1315	774	770	600	573	518
	Sep	1115	1217	1197	1107	1363	923	923	761	721	661
	Oct	2033	2077	2077	1941	2032	1898	1898	1861	1735	1643
	Nov	2296	2314	2314	2237	2261	2136	2136	2152	2018	2055
	Dec	2168	2193	2193	2128	2183	2058	2058	2075	1957	2058
1987	Jan	1314	1363	1363	1344	1474	1228	1228	1293	1228	1439
	Feb	2779	2766	2766	2655	2627	1880	1880	2093	2036	2267
	Mar	2400	2206	1844	1084	1346	1070	937	990	950	1144
	Apr	2083	1874	1417	767	1200	881	671	659	639	744
	May	3509	3318	2976	2061	2390	2005	1802	1720	1632	1572
	Jun	2895	2680	2271	1547	2016	1654	1444	1339	1275	1382
	Jul	3861	3635	3112	2145	2598	2123	1920	1775	1703	1653
	Aug	1194	1242	1070	806	1379	863	832	692	698	860
	Sep	11	184	170	180	597	198	198	61	121	331
	Oct	0	115	115	88	362	223	223	202	207	234
	Nov	540	566	566	554	628	506	506	533	494	528
	Dec	953	956	956	913	929	807	807	840	777	828
1988	Jan	1133	1139	1139	1088	1116	869	869	940	885	983
	Feb	2272	2246	2246	2134	2082	1335	1335	1553	1514	1700
	Mar	1515	1286	874	68	426	140	0	66	115	412
	Apr	2118	1876	1411	718	1062	741	531	506	487	462
	May	1421	1272	914	83	599	203	0	0	62	196
	Jun	1638	1430	974	190	669	210	0	0	62	123
	Jul	1586	1395	952	163	697	203	0	0	65	58
	Aug	217	311	186	43	528	23	0	0	68	72
	Sep	103	219	211	196	456	0	0	0	60	64
	Oct	0	97	97	75	281	108	108	82	91	83
	Nov	0	64	64	96	228	106	106	148	136	170
	Dec	510	509	509	476	498	376	376	417	372	346
1989	Jan	8	57	57	84	193	0	0	32	50	199
	Feb	663	650	650	598	599	0	0	92	134	320
	Mar	1789	1507	1101	218	416	132	0	50	79	152
	Apr	1700	1450	983	286	645	294	84	64	93	120
	May	1574	1401	1048	180	594	203	0	0	50	76
	Jun	1902	1679	1182	310	758	210	0	0	60	52
	Jul	1910	1707	1224	316	826	203	0	0	66	31
	Aug	124	257	203	140	603	31	0	0	63	47
	Sep	65	178	178	143	407	0	0	0	49	59
	Oct	1	67	66	18	193	64	64	63	69	123
	Nov	0	36	36	61	149	28	28	74	74	118
	Dec	0	26	26	45	119	0	0	52	56	113

Figure 9-10
Monthly Average Rio Grande Flows
Integrated LRG Model - Historical Base Run
1940 - 2017 (cfs)

Flow Legend (CFS)

	0	10
	10	100
	100	200
	200	500
	500	Max

Year	Month	Below Caballo	Below Percha Dam	Below Leasburg Dam	Below Mesilla Dam	At Courchesne	Below American Dam	Below Intern'l Dam	Below Riverside Dam	At County Line	At Fort Quitman
1990	Jan	0	27	27	42	116	0	0	0	21	129
	Feb	0	26	26	36	103	0	0	0	20	129
	Mar	1850	1571	1197	371	474	105	0	47	72	108
	Apr	1628	1365	910	237	527	202	0	0	38	88
	May	1574	1400	1079	244	585	203	0	0	42	71
	Jun	1884	1653	1158	295	715	210	0	0	51	69
	Jul	1646	1446	1004	207	705	203	0	0	51	48
	Aug	480	523	364	85	552	66	0	0	50	52
	Sep	11	148	133	127	408	135	135	36	58	149
	Oct	0	98	98	71	266	171	171	171	153	134
	Nov	0	53	53	82	185	63	63	115	108	136
	Dec	0	40	40	61	143	22	22	79	78	139
1991	Jan	0	35	35	50	128	0	0	0	30	76
	Feb	0	31	31	42	113	0	0	0	31	145
	Mar	2018	1700	1282	358	479	98	0	49	86	123
	Apr	1779	1499	992	230	564	210	0	0	51	88
	May	1705	1518	1169	278	645	203	0	0	56	91
	Jun	1882	1661	1154	267	723	210	0	0	62	79
	Jul	1588	1397	987	261	752	203	0	0	66	58
	Aug	424	489	344	131	582	65	0	0	67	74
	Sep	10	146	133	122	403	8	8	0	57	80
	Oct	0	96	96	54	254	80	80	76	95	53
	Nov	0	60	60	89	203	81	81	131	131	155
	Dec	0	39	39	61	147	25	25	85	92	153
1992	Jan	0	38	38	55	143	0	0	0	33	173
	Feb	0	34	34	45	125	0	0	0	34	146
	Mar	1727	1472	1132	382	479	76	0	48	89	137
	Apr	2073	1796	1336	622	860	458	280	251	261	258
	May	4164	3954	3681	2814	2932	2543	2340	2247	2131	1928
	Jun	1902	1704	1207	369	934	412	202	70	143	476
	Jul	1823	1629	1105	218	787	203	0	0	86	92
	Aug	1007	933	685	237	747	118	0	0	90	112
	Sep	83	231	212	171	521	0	0	0	81	101
	Oct	0	113	113	77	313	114	114	77	107	118
	Nov	0	58	58	91	208	87	87	131	139	178
	Dec	0	40	40	65	155	33	33	87	100	184
1993	Jan	256	268	268	255	302	56	56	152	165	247
	Feb	907	888	888	822	791	44	44	276	329	489
	Mar	1651	1420	1074	334	496	113	0	64	119	247
	Apr	1949	1721	1299	652	920	530	320	301	318	319
	May	3348	3135	2814	1912	2135	1622	1418	1320	1270	1176
	Jun	3749	3496	2974	1988	2394	1782	1572	1392	1357	1442
	Jul	1498	1337	904	167	841	203	0	0	110	292
	Aug	1005	948	673	162	698	50	0	0	103	143
	Sep	67	214	194	149	521	0	0	0	85	102
	Oct	0	105	105	66	300	131	131	122	144	185
	Nov	282	311	311	310	383	262	262	308	299	309
	Dec	1140	1124	1124	1055	1021	899	899	939	876	843
1994	Jan	777	794	794	759	793	547	547	627	606	733
	Feb	701	718	718	684	729	0	0	220	289	536
	Mar	1864	1586	1170	294	512	118	0	64	127	268
	Apr	1773	1517	993	217	624	210	0	0	75	161
	May	3146	2928	2601	1675	1956	1474	1270	1170	1123	992
	Jun	3422	3186	2609	1643	2080	1416	1206	1012	1005	1120
	Jul	1781	1609	1139	276	917	203	0	0	113	244
	Aug	455	570	515	349	821	45	0	0	112	139
	Sep	164	256	256	199	469	0	0	0	79	143
	Oct	36	77	77	28	175	0	0	0	50	122
	Nov	0	27	27	54	138	17	17	68	87	118
	Dec	641	615	615	564	544	423	423	469	436	394

Figure 9-10
Monthly Average Rio Grande Flows
Integrated LRG Model - Historical Base Run
1940 - 2017 (cfs)

Flow Legend (CFS)

Color	From	To
	0	10
	10	100
	100	200
	200	500
	500	Max

Year	Month	Below Caballo	Below Percha Dam	Below Leasburg Dam	Below Mesilla Dam	At Courchesne	Below American Dam	Below Intern'l Dam	Below Riverside Dam	At County Line	At Fort Quitman
1995	Jan	902	880	880	821	793	555	555	641	607	658
	Feb	1054	1042	1042	977	951	211	211	442	485	677
	Mar	2022	1719	1272	352	551	123	0	71	135	302
	Apr	1724	1471	963	205	615	210	0	0	75	171
	May	2501	2267	1872	892	1230	709	506	410	426	403
	Jun	3927	3673	3133	2132	2481	1889	1679	1492	1442	1403
	Jul	3870	3647	3242	2340	2788	2087	1884	1677	1642	1685
	Aug	698	843	805	667	1177	437	397	197	288	629
	Sep	386	467	467	403	641	254	254	120	201	315
	Oct	217	256	256	156	298	149	149	120	172	229
	Nov	987	951	951	886	840	727	727	760	716	672
	Dec	951	923	923	867	826	714	714	750	691	770
1996	Jan	855	850	850	801	795	558	558	639	620	730
	Feb	1124	1113	1113	1044	1027	288	288	519	561	811
	Mar	2025	1706	1235	274	502	140	0	65	146	294
	Apr	1729	1479	936	153	571	210	0	0	87	162
	May	1850	1626	1198	263	703	203	0	0	92	115
	Jun	1927	1720	1210	311	787	210	0	0	79	89
	Jul	1569	1385	1037	329	820	203	0	0	71	55
	Aug	124	262	221	126	528	22	0	0	66	92
	Sep	169	242	242	186	372	0	0	0	66	105
	Oct	10	54	54	0	136	16	16	20	74	109
	Nov	0	20	20	41	103	0	0	40	63	110
	Dec	0	15	15	30	86	0	0	29	52	111
1997	Jan	0	17	17	28	87	0	0	0	32	118
	Feb	0	19	19	27	82	0	0	0	30	119
	Mar	2321	1984	1558	614	669	123	0	73	106	145
	Apr	1851	1566	1089	365	627	210	0	0	51	119
	May	1848	1654	1308	411	728	203	0	0	57	118
	Jun	1873	1655	1204	400	793	210	0	0	62	95
	Jul	1970	1767	1312	470	921	203	0	0	75	60
	Aug	624	672	520	229	693	40	0	0	75	103
	Sep	46	179	167	133	429	0	0	0	54	129
	Oct	0	89	89	34	218	70	70	65	76	122
	Nov	0	41	41	66	138	25	25	82	84	133
	Dec	0	28	28	47	105	0	0	54	75	146
1998	Jan	705	683	683	620	580	343	343	428	407	395
	Feb	799	785	785	729	693	0	0	193	250	502
	Mar	1803	1525	1126	270	435	112	0	56	108	212
	Apr	1779	1514	1013	265	597	210	0	0	54	125
	May	1786	1603	1262	381	725	203	0	0	59	101
	Jun	2017	1798	1291	400	818	210	0	0	66	104
	Jul	1815	1620	1176	372	865	203	0	0	70	76
	Aug	731	781	659	373	805	51	0	0	83	95
	Sep	236	354	348	282	562	0	0	0	63	62
	Oct	0	65	65	39	179	28	28	21	41	103
	Nov	0	51	51	77	175	63	63	103	114	129
	Dec	0	31	31	50	119	7	7	55	58	120
1999	Jan	0	30	30	43	109	0	0	0	32	122
	Feb	0	27	27	36	97	0	0	92	99	122
	Mar	2517	2172	1733	746	799	143	0	164	188	203
	Apr	1967	1684	1174	386	711	210	0	62	97	155
	May	2082	1855	1481	531	879	203	0	110	150	157
	Jun	1984	1772	1320	505	923	210	0	30	93	174
	Jul	1800	1609	1208	486	953	203	0	94	151	122
	Aug	774	842	726	456	863	20	0	161	222	165
	Sep	163	289	281	246	528	0	0	113	149	134
	Oct	0	86	86	49	222	47	47	154	166	164
	Nov	0	48	48	73	163	51	51	175	178	197
	Dec	0	32	32	51	121	8	8	143	148	189

Figure 9-10
Monthly Average Rio Grande Flows
Integrated LRG Model - Historical Base Run
1940 - 2017 (cfs)

Flow Legend (CFS)

	0	10
	10	100
	100	200
	200	500
	500	Max

Year	Month	Below Caballo	Below Percha Dam	Below Leasburg Dam	Below Mesilla Dam	At Courchesne	Below American Dam	Below Intern'l Dam	Below Riverside Dam	At County Line	At Fort Quitman
2000	Jan	0	31	31	45	114	0	0	124	131	173
	Feb	0	28	28	36	99	0	0	97	94	129
	Mar	2631	2285	1852	866	912	149	0	195	219	230
	Apr	1967	1686	1198	433	756	210	0	69	101	155
	May	2121	1910	1535	584	926	203	0	119	160	164
	Jun	1363	1197	937	487	866	210	0	28	87	182
	Jul	2313	2107	1605	648	1019	203	0	101	162	106
	Aug	884	901	712	302	789	14	0	150	203	152
	Sep	77	218	203	156	482	0	0	106	135	137
	Oct	0	80	80	47	197	69	69	166	187	182
	Nov	0	48	48	72	154	43	43	168	176	211
	Dec	0	41	41	59	134	23	23	152	156	204
2001	Jan	0	35	35	49	119	0	0	126	133	175
	Feb	0	32	32	40	104	0	0	100	93	142
	Mar	2367	2039	1623	705	760	107	0	168	205	205
	Apr	1893	1615	1114	370	681	210	0	59	104	136
	May	1912	1715	1380	505	829	203	0	103	146	136
	Jun	2132	1911	1392	487	904	210	0	29	96	128
	Jul	1986	1787	1315	467	960	203	0	94	158	91
	Aug	479	563	480	321	765	56	0	136	193	129
	Sep	94	210	205	184	452	0	0	98	134	107
	Oct	0	58	58	21	155	18	18	117	118	107
	Nov	0	25	25	47	107	0	0	123	133	147
	Dec	0	18	18	33	89	0	0	111	124	165
2002	Jan	0	20	20	31	89	0	0	98	104	139
	Feb	0	21	21	28	84	0	0	94	87	137
	Mar	2417	2077	1668	718	764	104	0	167	188	212
	Apr	1969	1675	1204	460	707	210	0	61	110	148
	May	2054	1832	1468	517	846	203	0	104	176	147
	Jun	2268	2043	1512	560	969	210	0	31	129	131
	Jul	1806	1614	1185	347	852	203	0	81	164	102
	Aug	472	568	507	381	789	58	0	138	228	169
	Sep	122	233	230	206	456	0	0	97	159	142
	Oct	0	56	56	38	158	38	38	117	128	112
	Nov	0	35	35	59	131	16	16	138	148	168
	Dec	0	24	24	42	104	0	0	125	136	166
2003	Jan	0	25	25	39	102	0	0	107	105	165
	Feb	0	25	25	34	92	0	0	90	77	135
	Mar	1478	1318	1132	761	723	83	0	172	203	265
	Apr	1198	1048	801	381	489	210	0	39	61	141
	May	1800	1550	1176	533	657	203	0	77	109	132
	Jun	2347	2115	1744	1053	1224	210	0	42	140	286
	Jul	2238	2036	1652	955	1207	203	0	125	217	286
	Aug	2316	2127	1734	1041	1322	80	0	223	356	310
	Sep	1601	1397	969	306	705	0	0	143	226	243
	Oct	63	196	129	24	421	299	299	381	346	335
	Nov	0	123	123	170	334	219	219	332	315	357
	Dec	0	80	80	113	212	97	97	222	206	284
2004	Jan	0	60	60	85	173	0	0	168	163	235
	Feb	0	47	47	66	146	0	0	133	117	193
	Mar	957	849	691	413	431	100	0	90	93	157
	Apr	878	788	619	345	423	197	0	32	66	118
	May	1200	1039	780	337	424	56	0	63	74	90
	Jun	1569	1405	1142	671	747	129	0	24	62	59
	Jul	1595	1427	1142	642	758	103	0	76	105	62
	Aug	1841	1700	1463	1031	1095	32	0	206	243	256
	Sep	648	621	507	271	474	0	0	98	131	96
	Oct	12	77	62	30	183	45	45	143	141	122
	Nov	0	38	38	60	129	13	13	140	136	133
	Dec	0	32	32	47	108	0	0	124	119	171

Figure 9-10
Monthly Average Rio Grande Flows
Integrated LRG Model - Historical Base Run
1940 - 2017 (cfs)

Flow Legend (CFS)

	From	To
	0	10
	10	100
	100	200
	200	500
	500	Max

Year	Month	Below Caballo	Below Percha Dam	Below Leasburg Dam	Below Mesilla Dam	At Courchesne	Below American Dam	Below Intern'l Dam	Below Riverside Dam	At County Line	At Fort Quitman
2005	Jan	0	29	29	38	98	0	0	103	101	144
	Feb	0	28	28	34	90	0	0	91	100	153
	Mar	0	27	27	29	84	83	2	7	9	80
	Apr	1162	1010	826	471	429	98	0	42	49	55
	May	1328	1148	912	471	483	91	0	67	73	65
	Jun	1705	1510	1223	687	728	143	0	24	56	71
	Jul	1856	1659	1358	798	853	203	0	77	103	61
	Aug	1929	1761	1499	1002	1049	203	0	171	196	220
	Sep	1518	1326	1035	409	578	170	0	89	100	99
	Oct	673	602	377	0	323	241	241	284	260	228
	Nov	0	125	125	171	350	233	233	349	336	345
	Dec	0	82	82	109	209	92	92	217	220	281
2006	Jan	0	60	60	79	157	0	0	153	151	191
	Feb	0	47	47	60	127	0	0	116	125	165
	Mar	1693	1519	1303	881	843	108	0	193	233	289
	Apr	1375	1224	966	501	628	210	0	50	86	138
	May	2047	1781	1390	683	823	203	0	99	143	137
	Jun	1471	1461	1369	1121	1262	129	0	49	157	399
	Jul	1261	1199	1099	832	855	0	0	111	187	297
	Aug	721	673	595	423	459	0	0	93	146	144
	Sep	137	163	154	132	211	0	0	46	80	121
	Oct	10	47	47	22	101	0	0	72	88	116
	Nov	0	24	24	31	79	0	0	89	94	122
	Dec	0	15	15	20	53	0	0	73	77	126
2007	Jan	0	18	18	21	54	0	0	65	70	112
	Feb	0	21	21	22	55	0	0	62	59	133
	Mar	1169	1035	884	566	508	109	0	104	102	115
	Apr	1159	1034	865	534	540	210	0	42	53	87
	May	1423	1260	1030	576	595	186	0	68	78	76
	Jun	1246	1146	978	616	673	100	0	24	57	64
	Jul	1474	1325	1121	699	696	166	0	65	87	58
	Aug	1917	1785	1618	1226	1199	70	0	225	264	303
	Sep	548	563	548	447	507	0	0	113	134	154
	Oct	126	137	137	97	137	0	0	74	93	135
	Nov	0	14	14	25	60	0	0	75	86	120
	Dec	0	13	13	19	51	0	0	69	72	127
2008	Jan	0	16	16	20	51	0	0	63	65	107
	Feb	0	18	18	20	49	0	0	55	42	103
	Mar	1349	1193	1016	650	570	108	0	117	118	111
	Apr	1399	1241	1037	641	601	210	0	47	62	97
	May	1684	1485	1224	712	680	203	0	76	87	81
	Jun	1128	1098	1056	878	858	210	0	26	61	57
	Jul	1434	1270	1065	659	598	203	0	51	65	45
	Aug	1634	1486	1273	844	842	55	0	157	178	161
	Sep	391	423	405	308	412	0	0	88	102	104
	Oct	144	156	156	108	141	0	0	104	97	91
	Nov	0	16	16	26	48	0	0	54	77	97
	Dec	0	11	11	17	32	0	0	51	66	109
2009	Jan	0	15	15	18	35	0	0	48	44	93
	Feb	0	17	17	19	34	0	0	41	44	90
	Mar	2041	1826	1609	1133	1008	109	0	234	282	301
	Apr	1556	1368	1115	628	641	210	0	55	88	159
	May	1980	1707	1347	684	742	203	0	89	127	141
	Jun	1494	1443	1311	983	1083	210	0	38	124	291
	Jul	2370	2100	1736	1046	1070	203	0	110	188	207
	Aug	1741	1605	1339	828	1021	54	0	188	269	257
	Sep	239	318	293	241	415	0	0	91	148	223
	Oct	0	64	64	40	129	22	22	83	82	152
	Nov	0	30	30	46	91	0	0	106	93	134
	Dec	0	29	29	40	79	0	0	98	113	166

Figure 9-10
Monthly Average Rio Grande Flows
Integrated LRG Model - Historical Base Run
1940 - 2017 (cfs)

Flow Legend (CFS)

	0	10
	10	100
	100	200
	200	500
	500	Max

	Month	Below Caballo	Below Percha Dam	Below Leasburg Dam	Below Mesilla Dam	At Courchesne	Below American Dam	Below Intern'l Dam	Below Riverside Dam	At County Line	At Fort Quitman
	Jan	0	27	27	33	68	0	0	81	96	154
	Feb	0	27	27	29	63	0	0	69	56	131
	Mar	1651	1477	1279	854	780	72	0	186	236	256
	Apr	1366	1200	941	465	538	178	0	47	77	144
	May	2061	1779	1381	658	745	203	0	89	129	126
2010	Jun	1276	1305	1269	1103	1187	210	0	42	138	325
	Jul	2350	2085	1749	1121	1094	203	0	114	196	252
	Aug	1786	1665	1444	986	1134	122	0	197	284	297
	Sep	397	457	435	367	519	0	0	113	163	211
	Oct	45	84	84	54	127	0	0	95	103	165
	Nov	0	23	23	38	79	0	0	91	100	142
	Dec	0	14	14	22	49	0	0	74	94	140
	Jan	0	17	17	22	49	0	0	66	68	126
	Feb	0	18	18	21	46	0	0	57	58	116
	Mar	1256	1100	929	587	516	94	0	111	126	121
	Apr	1406	1233	1030	647	609	210	0	47	62	92
	May	1059	985	918	712	651	149	0	78	89	71
2011	Jun	915	862	862	749	637	2	0	26	58	48
	Jul	983	912	912	791	646	14	0	77	99	59
	Aug	1211	1130	1130	1005	832	18	0	155	178	111
	Sep	191	161	161	139	91	0	0	17	23	39
	Oct	0	1	1	9	10	16	16	29	19	27
	Nov	0	0	0	10	9	0	0	18	22	30
	Dec	0	0	0	9	7	0	0	30	31	52
	Jan	0	0	0	9	6	0	0	30	31	80
	Feb	0	0	0	9	6	0	0	25	15	72
	Mar	1080	918	754	448	364	84	0	77	70	88
	Apr	1207	1024	834	482	397	185	0	28	32	70
	May	1342	1112	857	395	335	65	0	48	50	50
2012	Jun	830	773	773	666	533	72	0	18	43	37
	Jul	766	703	703	601	473	22	0	52	68	43
	Aug	777	712	712	617	485	2	0	91	101	60
	Sep	49	33	33	33	18	0	0	6	11	23
	Oct	0	1	1	9	7	13	13	27	18	17
	Nov	0	0	0	9	7	0	0	23	29	22
	Dec	0	0	0	8	6	0	0	25	39	45
	Jan	0	0	0	8	6	0	0	29	33	61
	Feb	0	0	0	9	6	0	0	26	13	65
	Mar	1069	908	757	444	362	53	0	84	76	86
	Apr	1086	901	708	329	272	39	0	32	35	70
	May	769	674	618	416	324	21	0	54	56	60
2013	Jun	433	386	386	312	224	7	0	8	21	31
	Jul	0	1	1	9	8	19	19	19	10	17
	Aug	79	57	57	44	22	6	0	6	1	14
	Sep	0	0	0	9	7	16	16	20	6	12
	Oct	0	1	1	9	6	15	15	28	11	9
	Nov	0	0	0	8	6	0	0	17	27	15
	Dec	0	0	0	8	6	0	0	19	20	18
	Jan	0	0	0	8	6	0	0	21	21	26
	Feb	0	0	0	8	6	0	0	23	9	35
	Mar	1170	1003	841	510	419	88	0	91	79	74
	Apr	1210	1025	838	466	385	143	0	34	31	50
	May	1179	991	817	430	355	31	0	59	56	47
2014	Jun	721	655	651	537	417	2	0	17	35	24
	Jul	547	481	466	360	269	22	0	26	32	15
	Aug	335	294	294	242	169	7	0	27	21	6
	Sep	0	0	0	9	8	20	20	22	7	3
	Oct	0	1	1	9	7	19	19	30	12	3
	Nov	0	0	0	8	6	0	0	20	18	6
	Dec	0	0	0	8	6	0	0	21	8	6

Figure 9-10
Monthly Average Rio Grande Flows
Integrated LRG Model - Historical Base Run
1940 - 2017 (cfs)

Flow Legend (CFS)

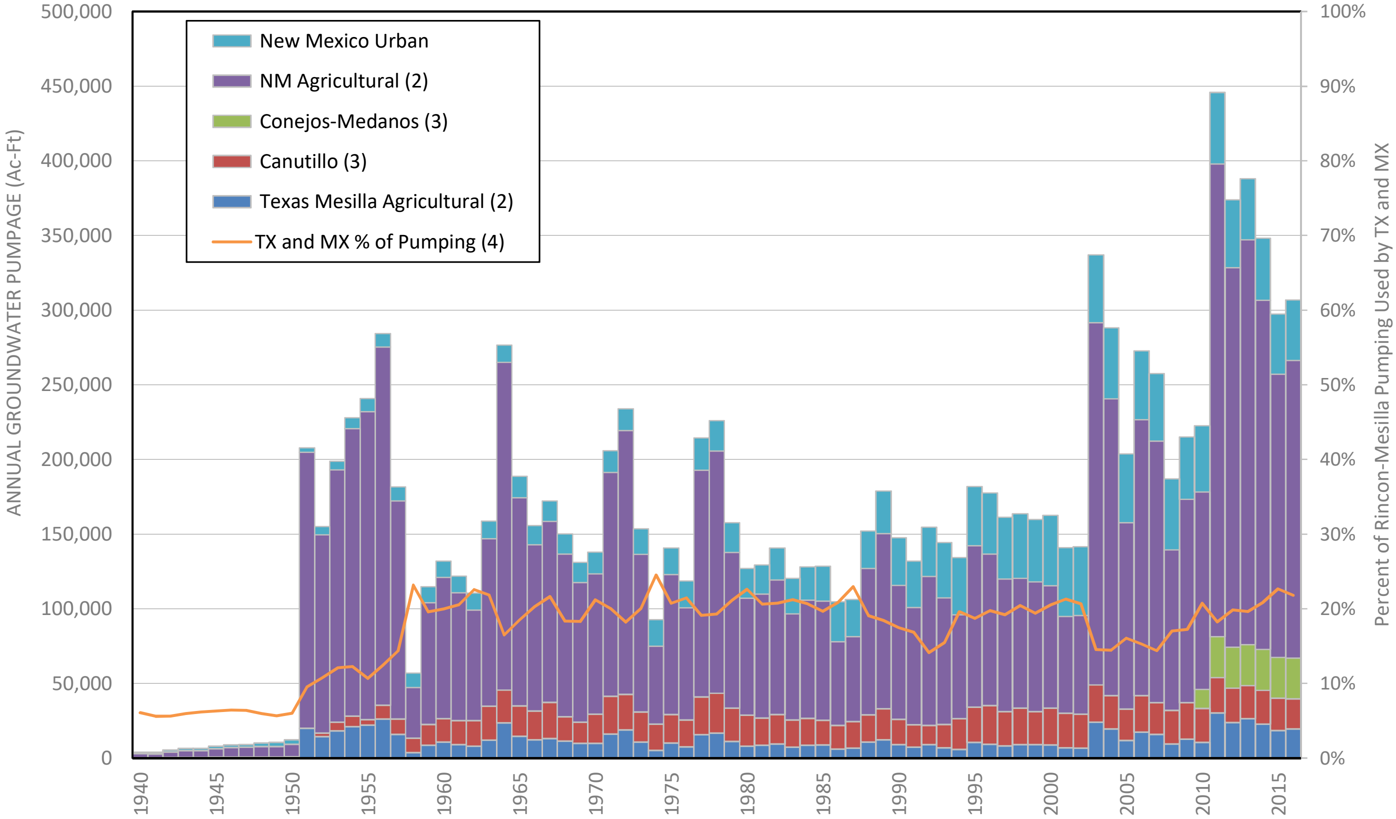
	0	10
	10	100
	100	200
	200	500
	500	Max

Year	Month	Below Caballo	Below Percha Dam	Below Leasburg Dam	Below Mesilla Dam	At Courchesne	Below American Dam	Below Intern'l Dam	Below Riverside Dam	At County Line	At Fort Quitman
2015	Jan	0	0	0	8	6	0	0	25	22	20
	Feb	0	0	0	8	5	0	0	24	21	38
	Mar	1017	869	727	448	362	72	0	82	69	69
	Apr	1145	972	799	466	381	165	0	32	27	51
	May	1433	1203	954	478	407	120	0	53	49	43
	Jun	1100	973	889	636	516	39	0	20	40	27
	Jul	881	815	815	700	557	78	0	58	70	33
	Aug	1615	1521	1521	1351	1140	90	0	207	235	134
	Sep	293	257	257	205	142	0	0	23	30	27
	Oct	0	0	0	9	8	15	15	30	30	25
	Nov	0	0	0	9	7	0	0	28	23	35
	Dec	0	0	0	9	6	0	0	31	23	43
2016	Jan	0	1	1	9	6	0	0	20	15	64
	Feb	0	1	1	9	6	0	0	18	13	61
	Mar	1241	1073	909	574	473	75	0	103	95	93
	Apr	1264	1094	925	577	477	172	0	38	42	71
	May	1532	1338	1150	730	616	166	0	71	78	70
	Jun	960	908	908	779	627	39	0	24	52	58
	Jul	1169	1096	1096	948	778	81	0	86	108	68
	Aug	1641	1509	1448	1185	1002	143	0	172	192	212
	Sep	686	630	625	508	398	0	0	86	93	92
	Oct	297	265	265	191	135	0	0	96	103	103
	Nov	0	1	1	9	8	0	0	25	49	80
	Dec	0	1	1	9	7	0	0	32	49	74
2017	Jan	0	1	1	9	6	0	0	28	44	70
	Feb	0	2	2	9	6	0	0	22	24	69
	Mar	1163	1004	852	546	447	96	0	94	84	90
	Apr	1233	1057	876	522	431	145	0	38	41	67
	May	1237	1084	954	633	521	107	0	68	73	62
	Jun	1310	1213	1174	959	793	210	0	24	53	43
	Jul	1336	1203	1121	859	713	203	0	63	80	47
	Aug	1798	1680	1637	1409	1201	203	0	199	228	229
	Sep	902	847	846	723	585	24	0	124	136	121
	Oct	282	251	251	193	136	0	0	90	80	107
	Nov	0	2	2	10	8	0	0	24	18	58
	Dec	0	1	1	9	7	0	0	30	19	54

Model Version: LRG Model v106 Operational Run - Base Run (All Pumping On).

Figure 11-1

Total Annual Groundwater Pumpage for Irrigation and Urban Uses (Texas Estimates) in Rincon and Mesilla Basins 1940 - 2016

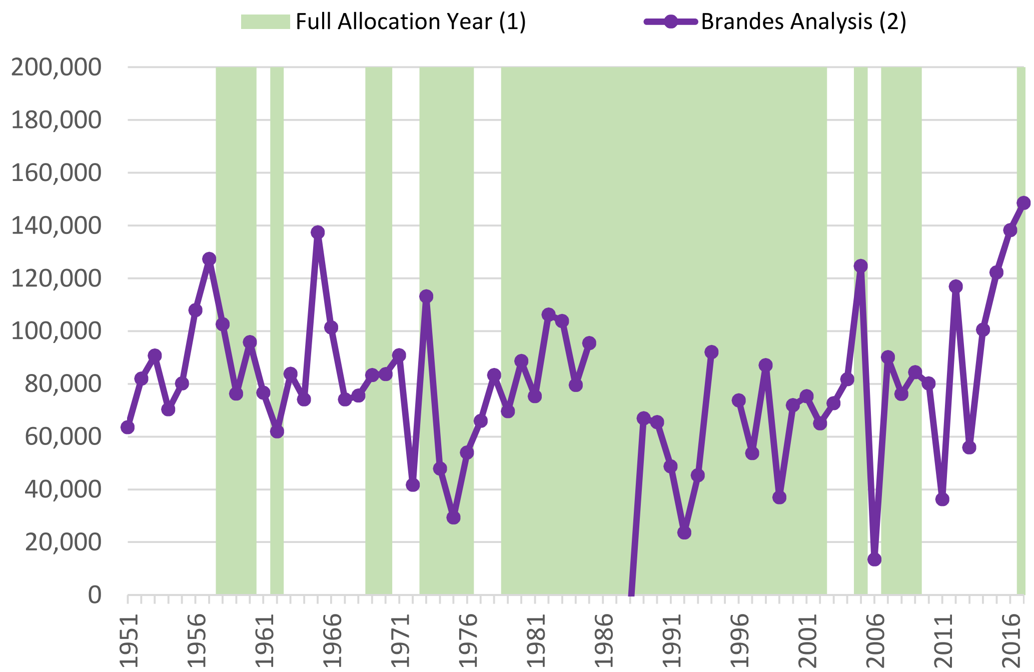


Notes:

(1) Data from Figure 4.5 in Expert Report of Robert J. Brandes disaggregated into NM, TX, and MX portions.
(2) Agriculture groundwater pumping split based on acreage according to Montgomery and Associates file FD_disagg_RinMes.xlsx.
(3) Canutillo and Conejos-Medanos data from Montgomery and Associates file tbl4.3_M&I_Pumping_Summary.xlsx.
(4) Calculated as sum of Texas Mesilla Agricultural, Canutillo, and Conejos-Medanos pumping by total Rincon-Mesilla Pumping.

Figure 11-2

Annual Impact of Pumping on Rio Grande at El Paso Flows
Brandes Double-Mass Curve Analysis
1951 - 2017
(acre-feet)



Averages	Annual Average	
1985 - 2016	71,996	(3)
1951 - 2017	78,667	(3)

Notes:

(1) Difference between historical flows and estimates flows without effects of pumping from Figure 5.5 of the Brandes report.

(2) See Section 4.3 of SWE report for description of how full allocation years are defined.

(3) Annual average values exclude spill years (1986, 1987, and 1995).

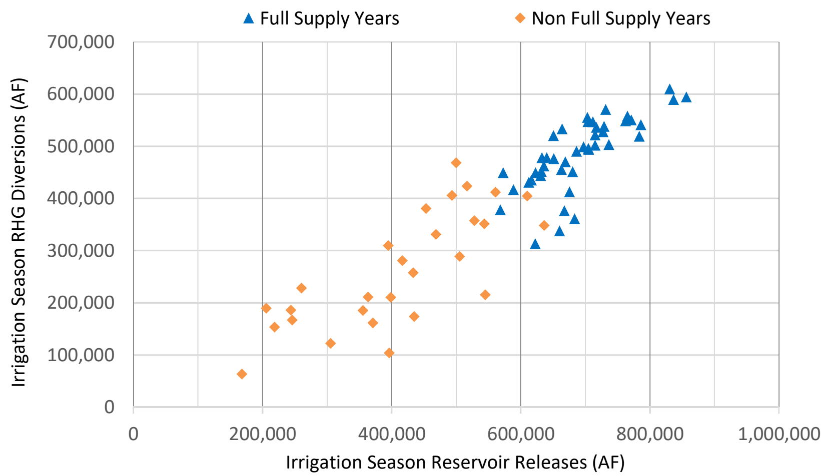
Figure 11-3

River Headgate Diversions v. Reservoir Releases

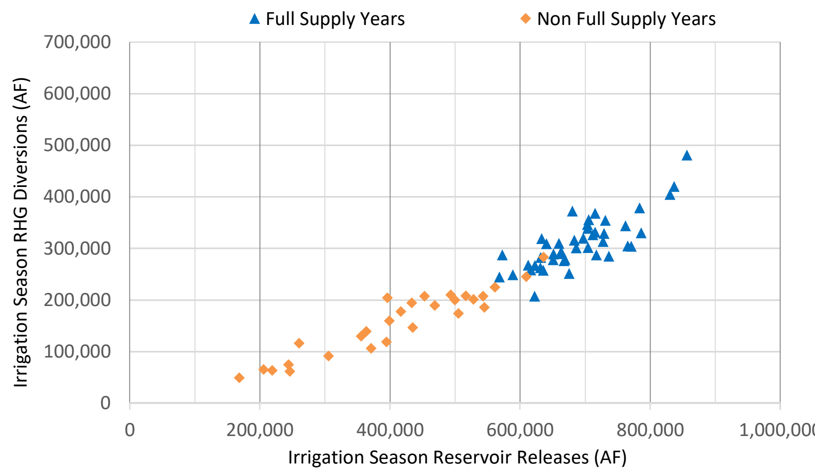
Historical Project Data

March-October 1940 - 2017 (acre-feet)

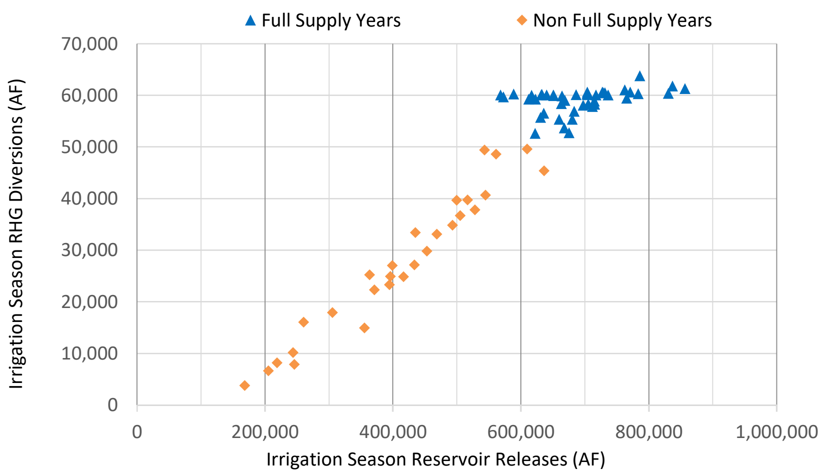
EBID Total (1)



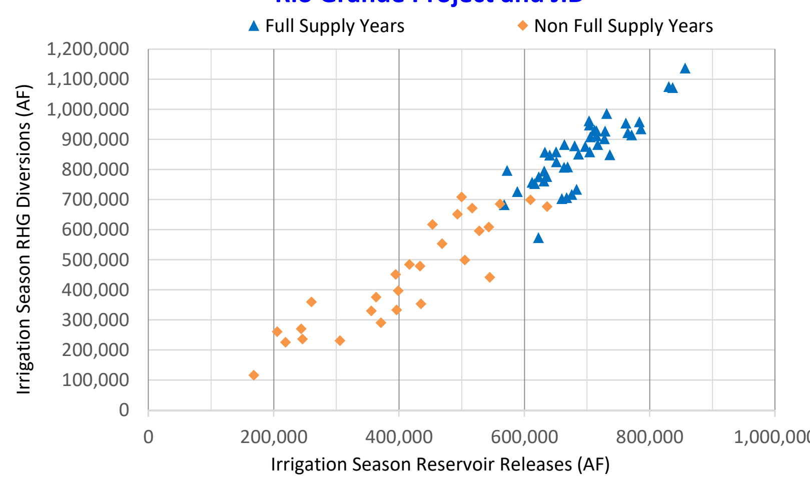
EPCWID Total (2)



JID (3)



Rio Grande Project and JID



***Note different scales.**

Notes:

(1) EBID Total RHG Diversions include diversions at Percha, Leasburg and Mesilla Dams minus Mesilla flows to TX.

(2) EPCWID Total RHG Diversions include Mesilla flows to TX, Franklin Canal minus Ascarate Wasteway (pre-ACE), Riverside Canal, and EPW diversions.

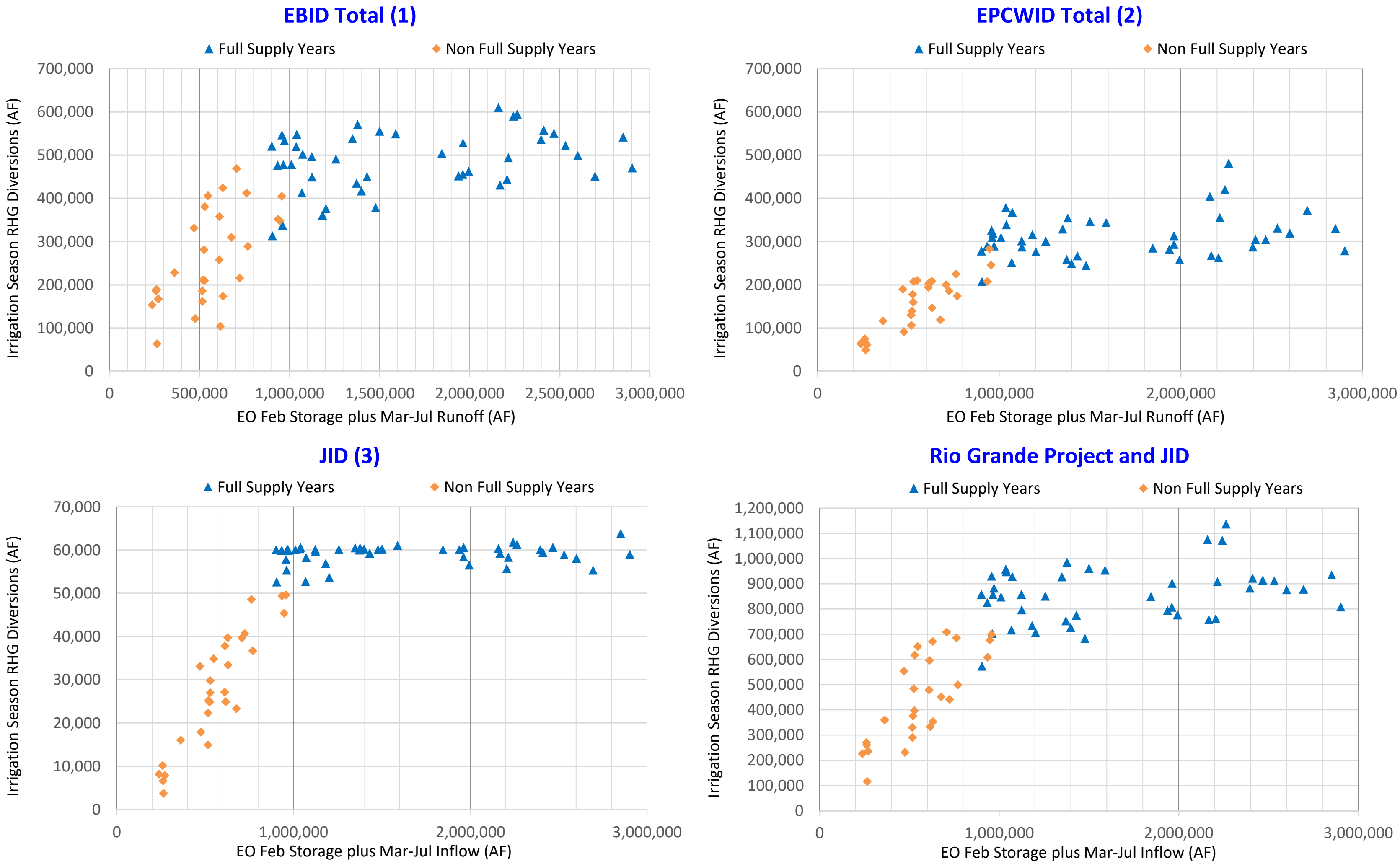
(3) JID RHG Diversions consist of Acequia Madre diversions only.

Figure 11-4

River Headgate Diversions v. Project Supply

Historical Project Data

March-October 1940 - 2017 (acre-feet)



***Note different scales.**

Notes:

(1) EBID Total RHG Diversions include diversions at Percha, Leasburg and Mesilla Dams minus Mesilla flows to TX.

(2) EPCWID Total RHG Diversions include Mesilla flows to TX, Franklin Canal minus Ascarate Wasteway (pre-ACE), Riverside Canal, and EPW diversions.

(3) JID RHG Diversions consist of Acequia Madre diversions only.

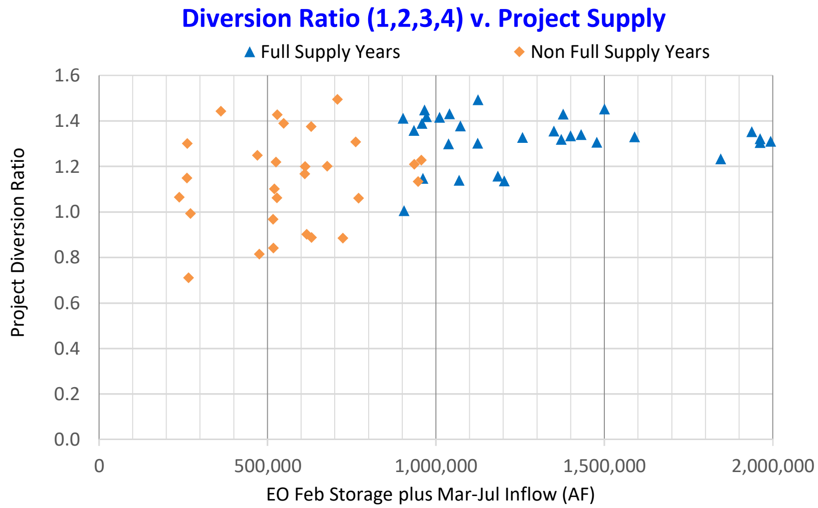
10/25/2019

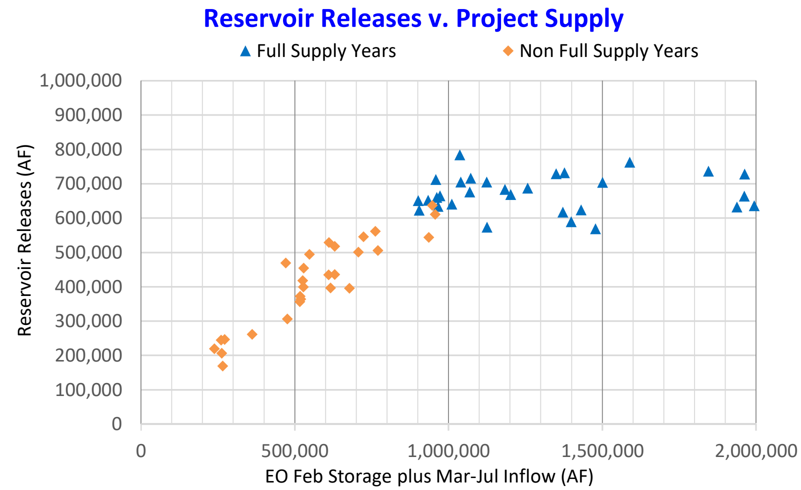
Figure 11-5

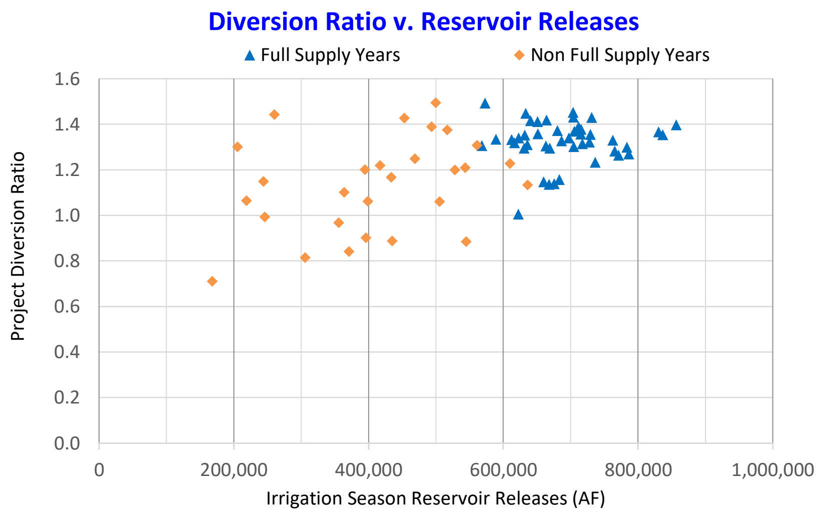
Comparison of Diversion Ratio, Project Supply, and Reservoir Releases

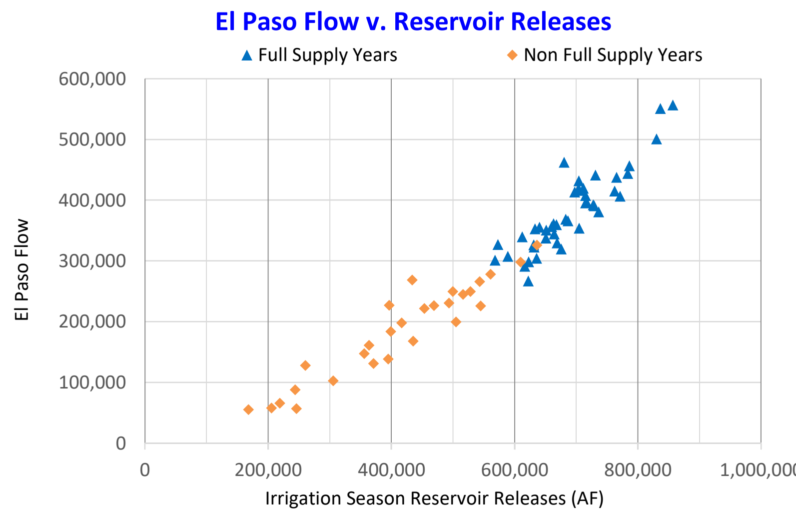
Historical Project Data

March-October 1940 - 2017 (acre-feet)









Notes:

(1) Diversion ratio is computed as the total RHG diversions (EBID, EPCWID, and JID) divided by Caballo Reservoir releases.

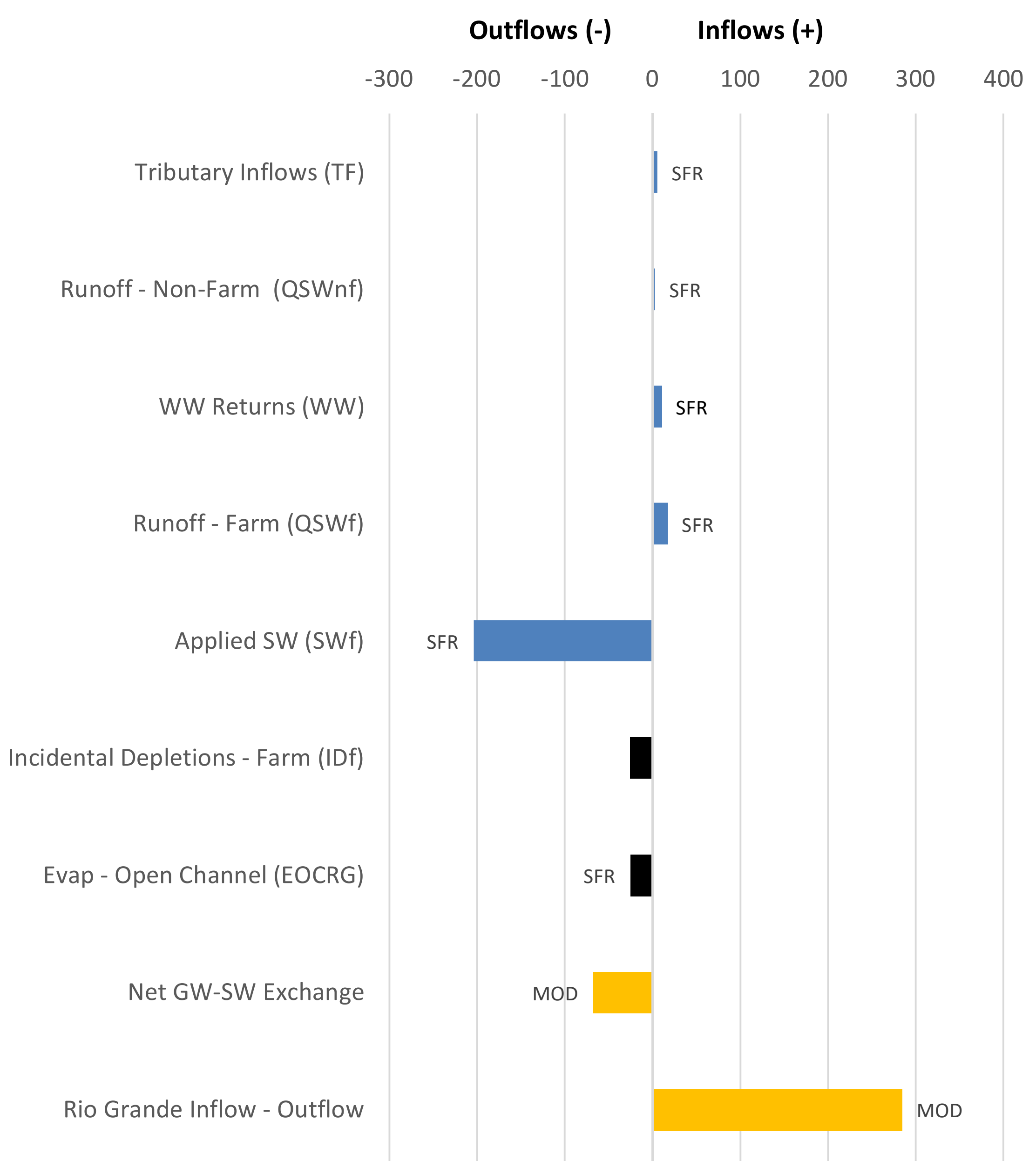
(2) EBID Total RHG Diversions include diversions at Percha, Leasburg and Mesilla Dams minus Mesilla flows to TX.

(3) EPCWID Total RHG Diversions include Mesilla flows to TX, Franklin Canal minus Ascarate Wasteway (pre-ACE), Riverside Canal, and EPW diversions.

(4) JID RHG Diversions consist of Acequia Madre diversions only.

Figure 12-1

Summary of Texas WaterBudget (M&A)
Surface Water Budget
Rincon and Mesilla Basins
1985 - 2016 Average Annual (1,000 acre-feet)



Legend

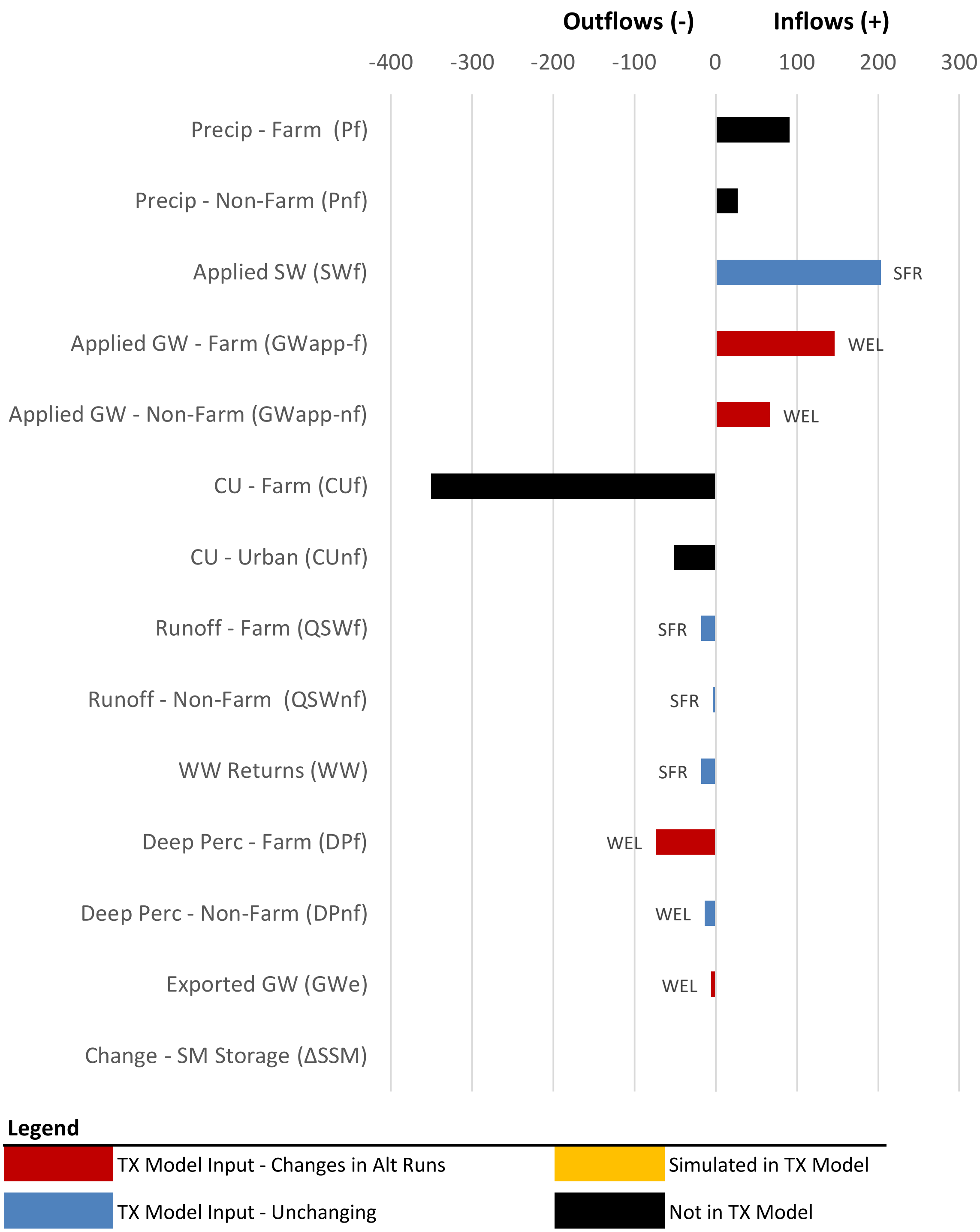
TX Model Input - Changes in Alt Runs	Simulated in TX Model
TX Model Input - Unchanging	Not in TX Model

<u>MODFLOW Simulation:</u>

WEL - Input in WEL Package; SFR - Input in SFR Package; MOD - Simulated in model

Figure 12-2

Summary of Texas WaterBudget (M&A)
Land Surface Budget
Rincon and Mesilla Basins
1985 - 2016 Average Annual (1,000 acre-feet)



MODFLOW Simulation:
WEL - Input in WEL Package; SFR - Input in SFR Package; MOD - Simulated in model

Figure 12-3

Summary of Texas WaterBudget (M&A)
Ground Water Budget
Rincon and Mesilla Basins
1985 - 2016 Average Annual (1,000 acre-feet)

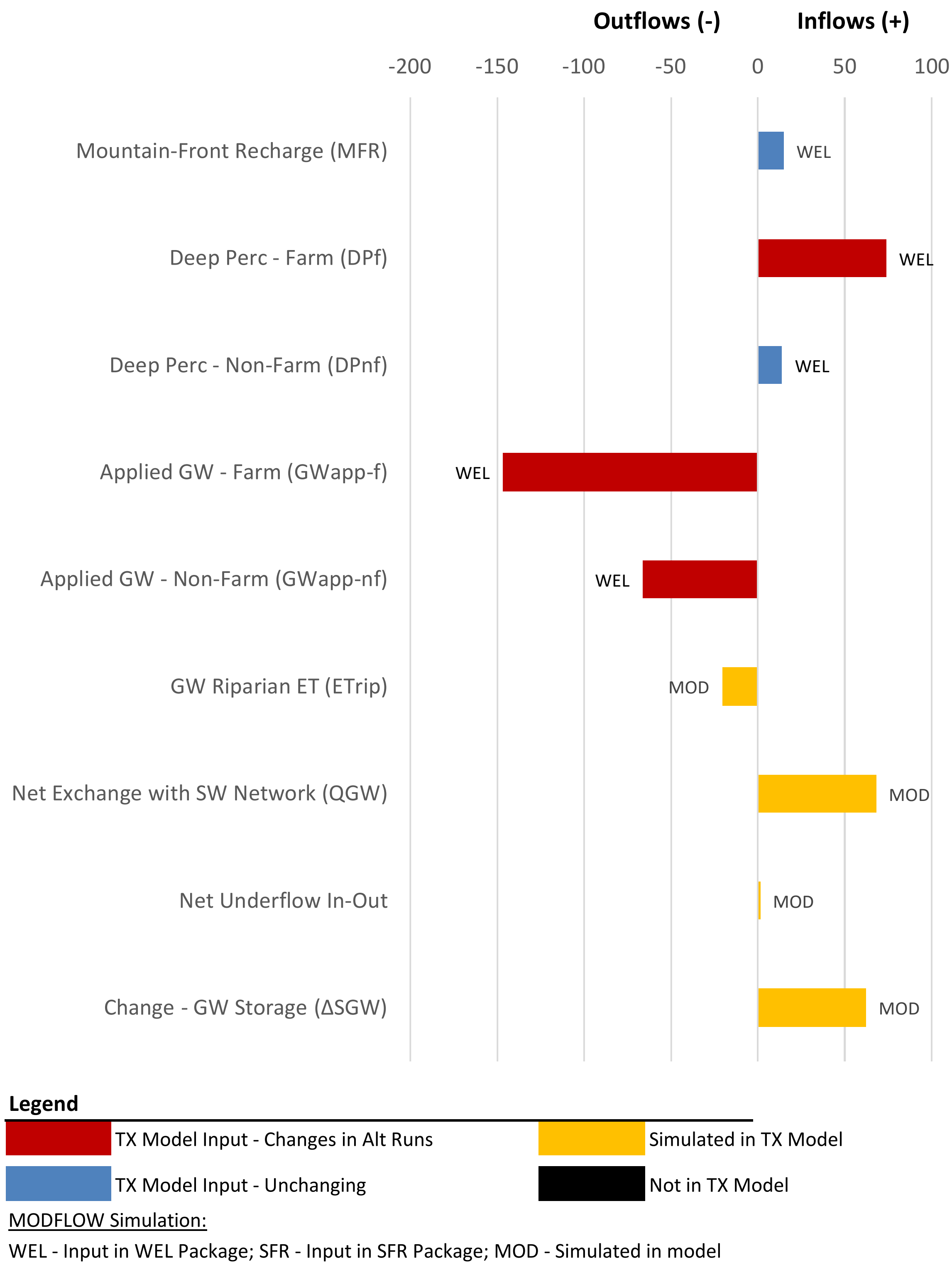


Figure 12-4

Monthly Soil Moisture Simulation (ft/ft)
M&A Soil Water Balance Model
(Theta Max, Theta Min, Theta Computed, and Soil Properties)
1938-2016
Rincon In District

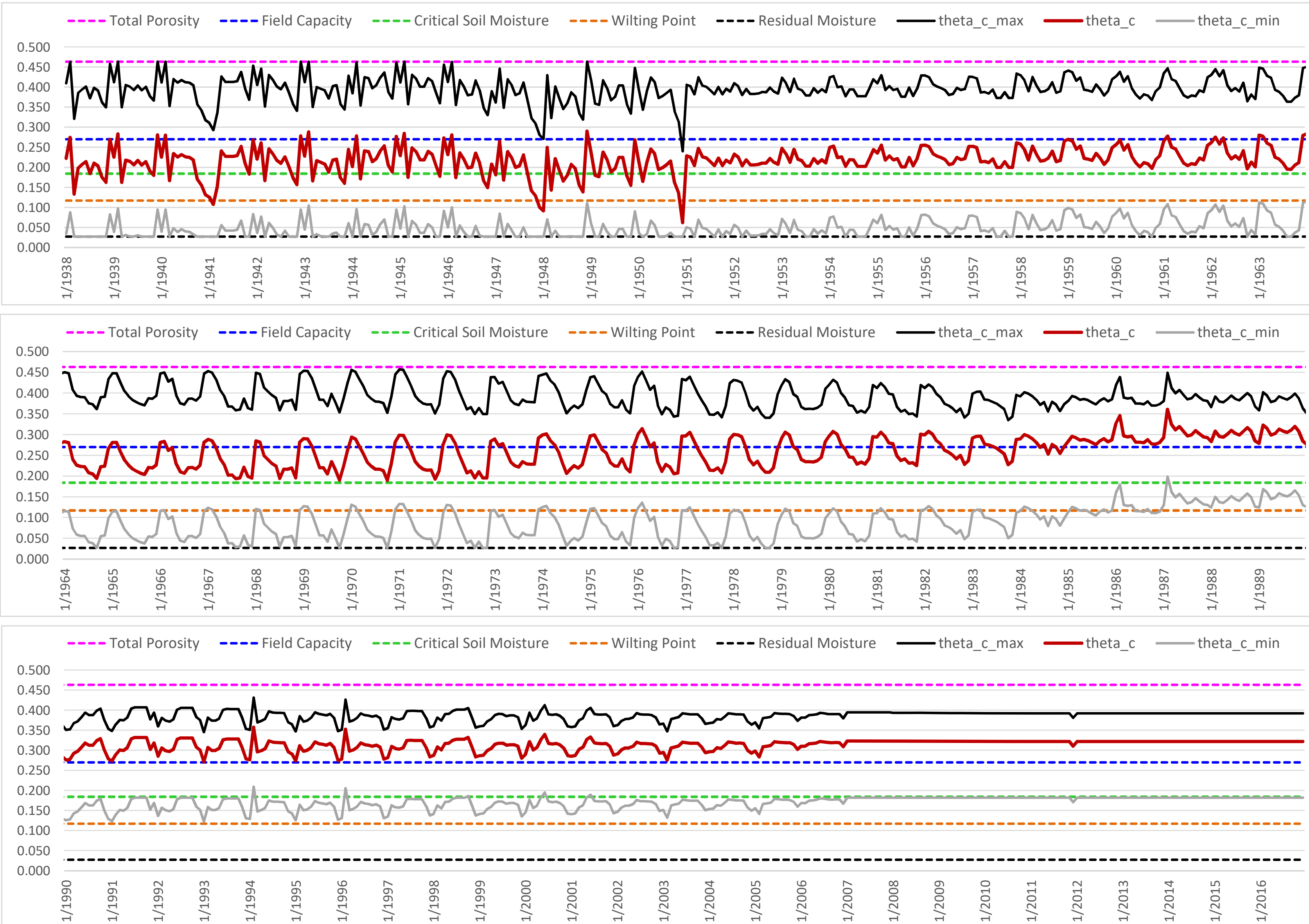


Figure 12-5

Monthly Soil Moisture Simulation (ft/ft)
M&A Soil Water Balance Model
(Theta Max, Theta Min, Theta Computed, and Soil Properties)
1938-2016
Mesilla In District

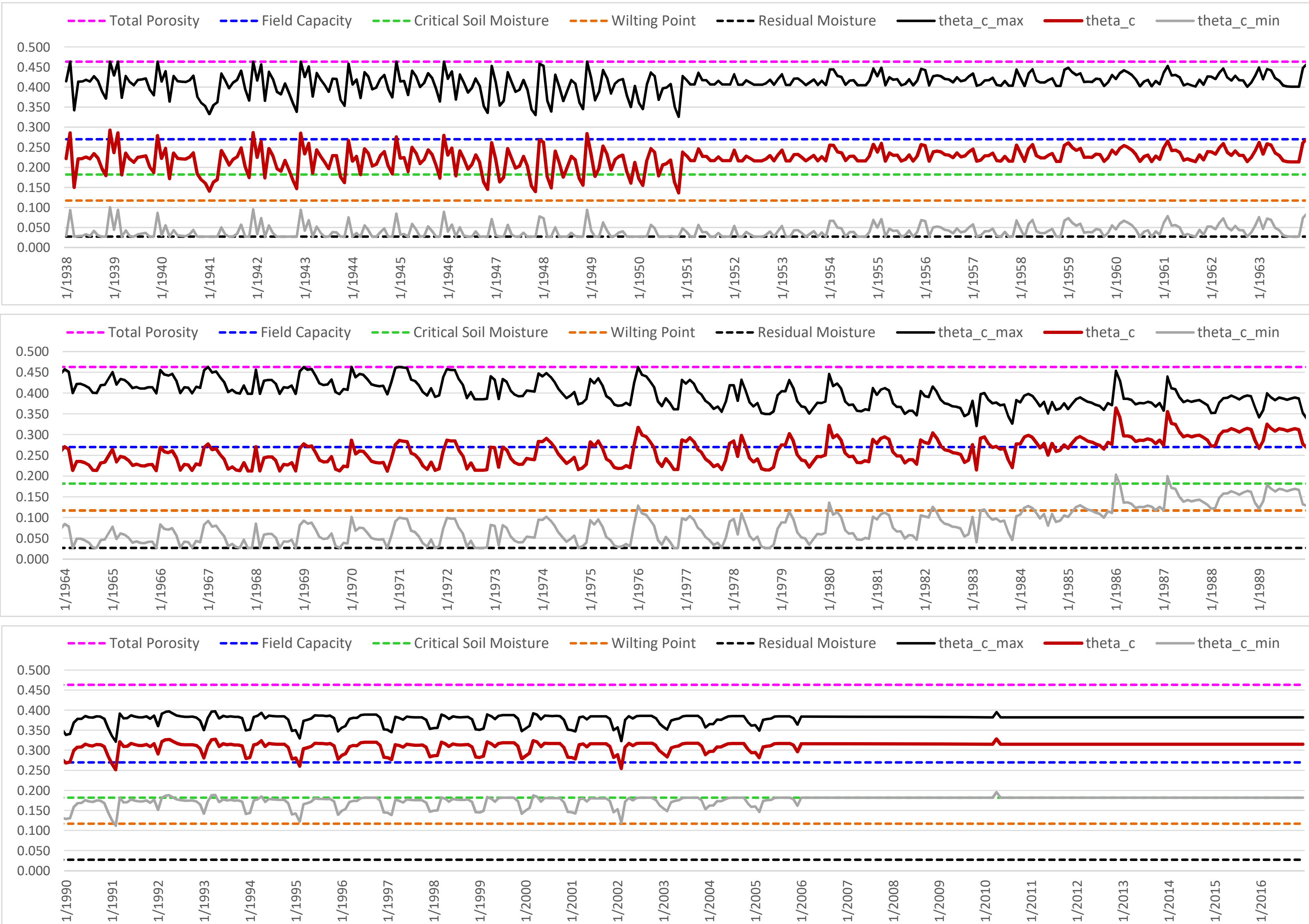
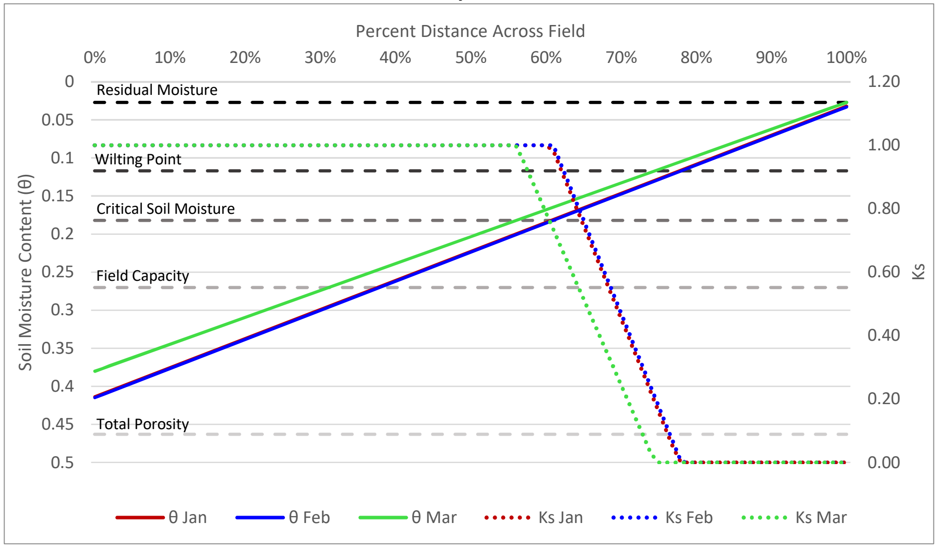


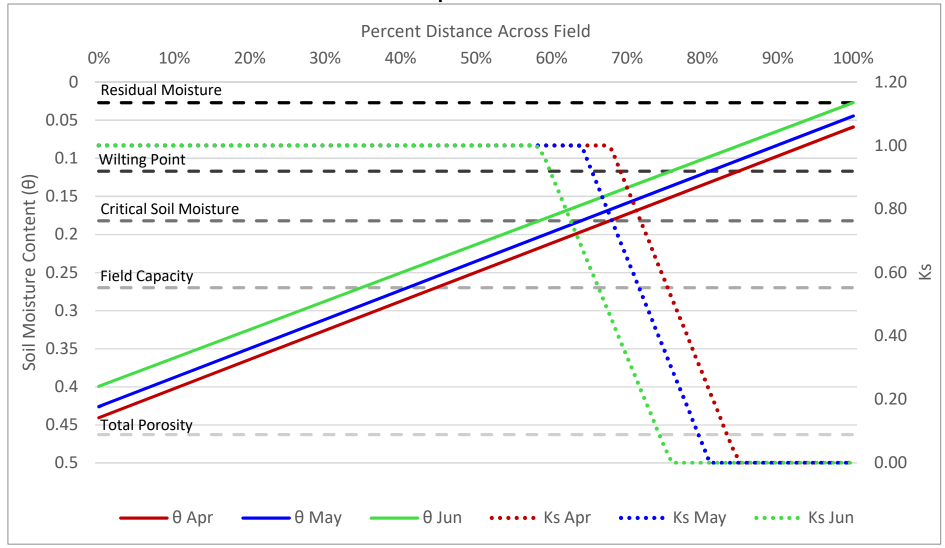
Figure 12-6

Monthly Simulated Soil Moisture (θ) and Water Stress Coefficient (Ks) Across Virtual Field
M&A Soil Water Balance Model
Mesilla In District
1945

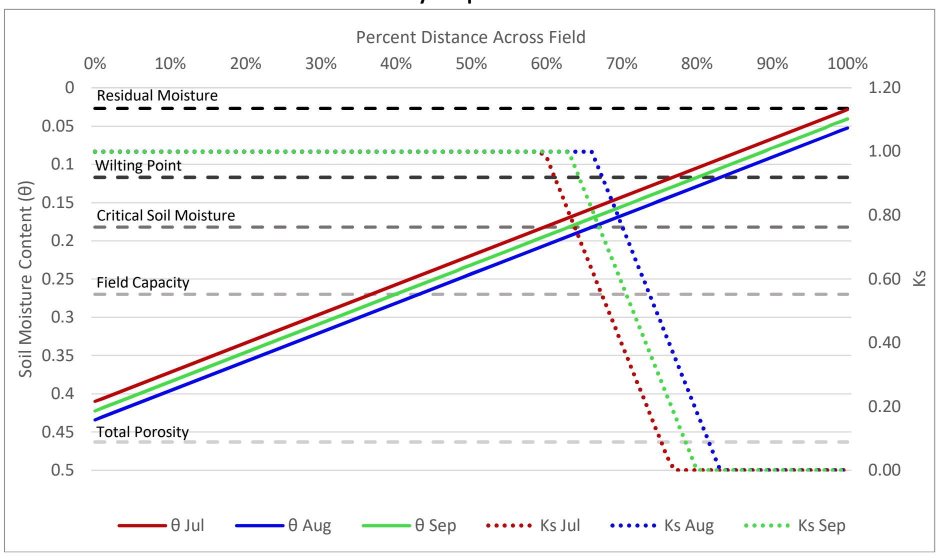
January - March



April - June



July - September



October - December

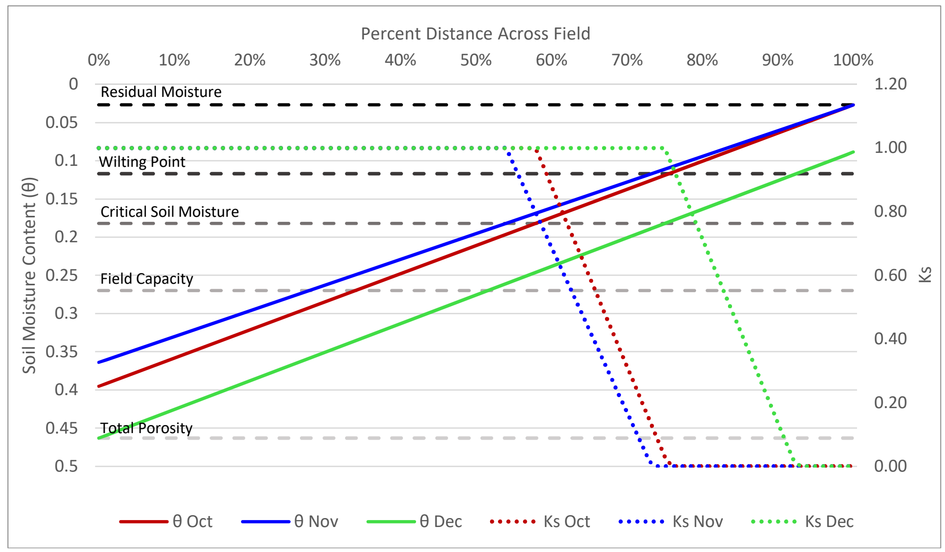
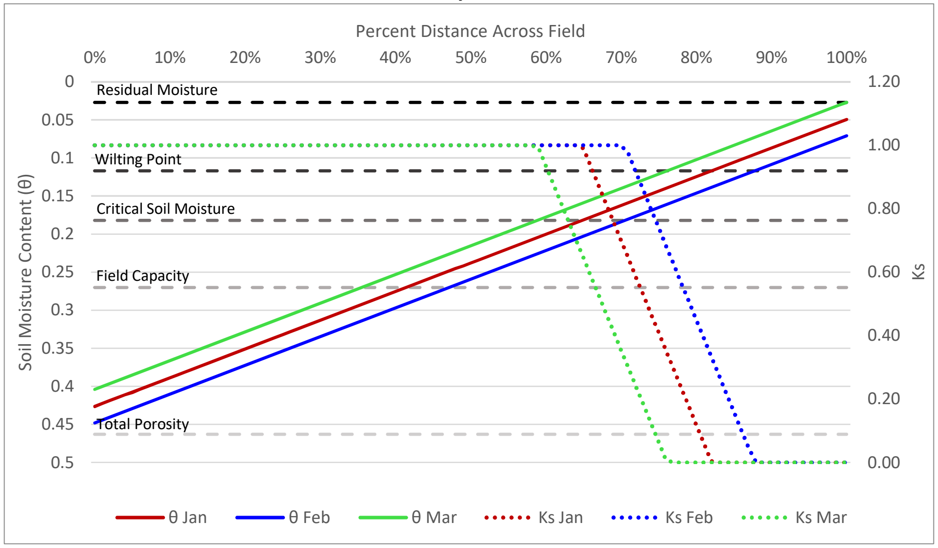


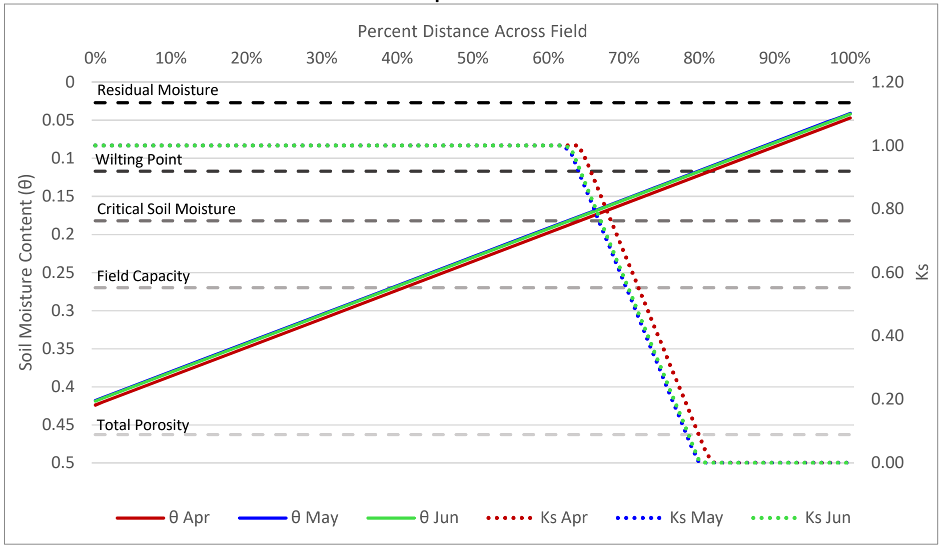
Figure 12-6

Monthly Simulated Soil Moisture (θ) and Water Stress Coefficient (Ks) Across Virtual Field
M&A Soil Water Balance Model
Mesilla In District
1955

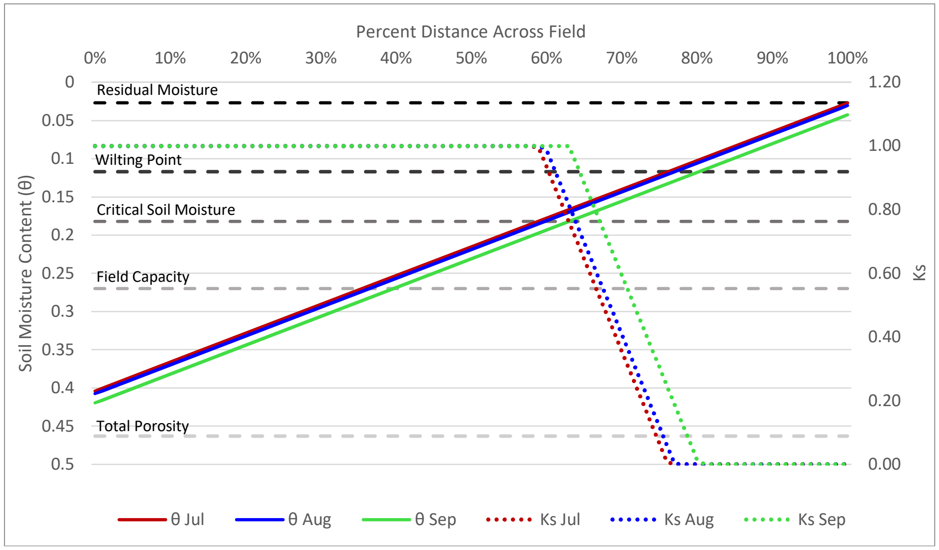
January - March



April - June



July - September



October - December

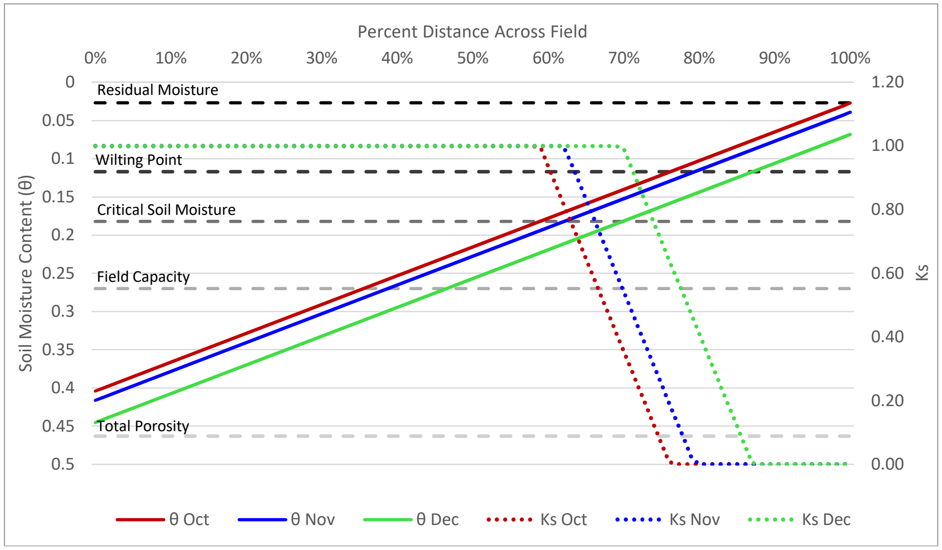
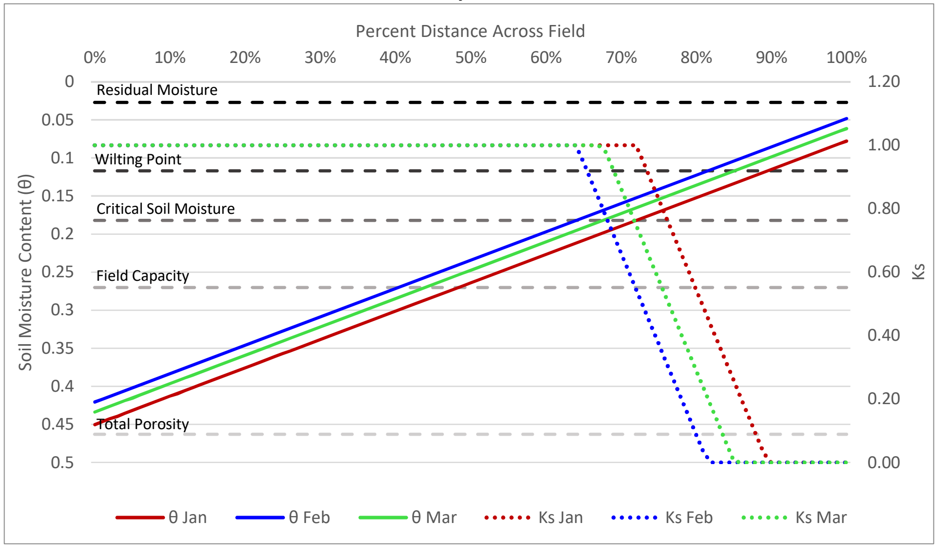


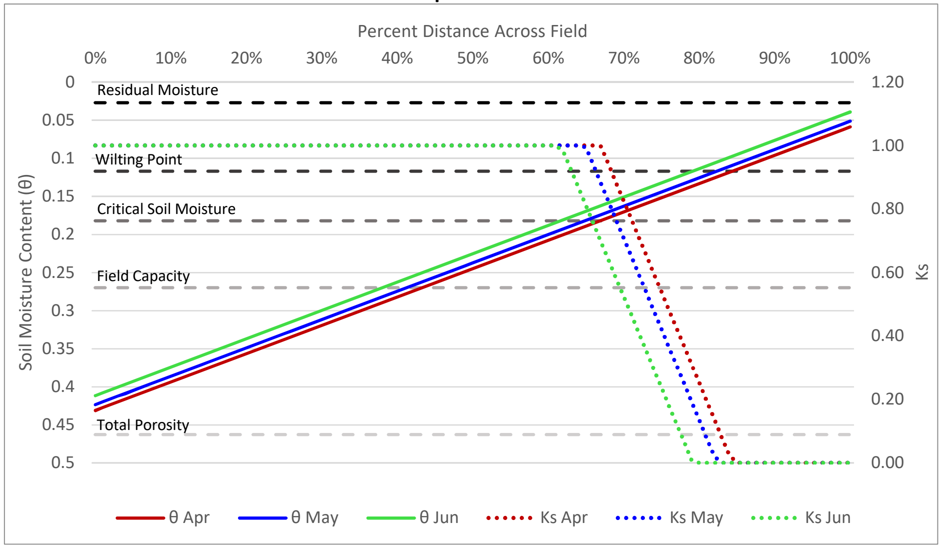
Figure 12-6

Monthly Simulated Soil Moisture (θ) and Water Stress Coefficient (Ks) Across Virtual Field
M&A Soil Water Balance Model
Mesilla In District
1965

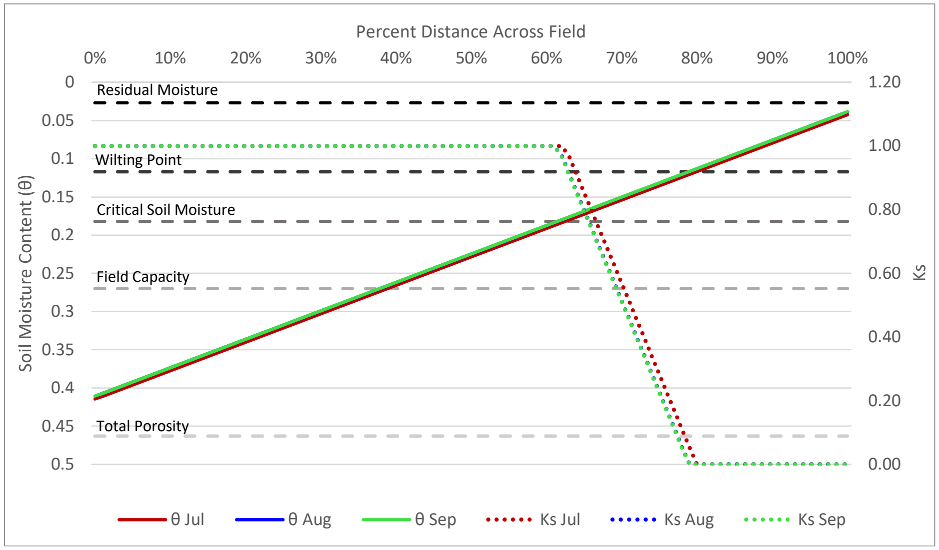
January - March



April - June



July - September



October - December

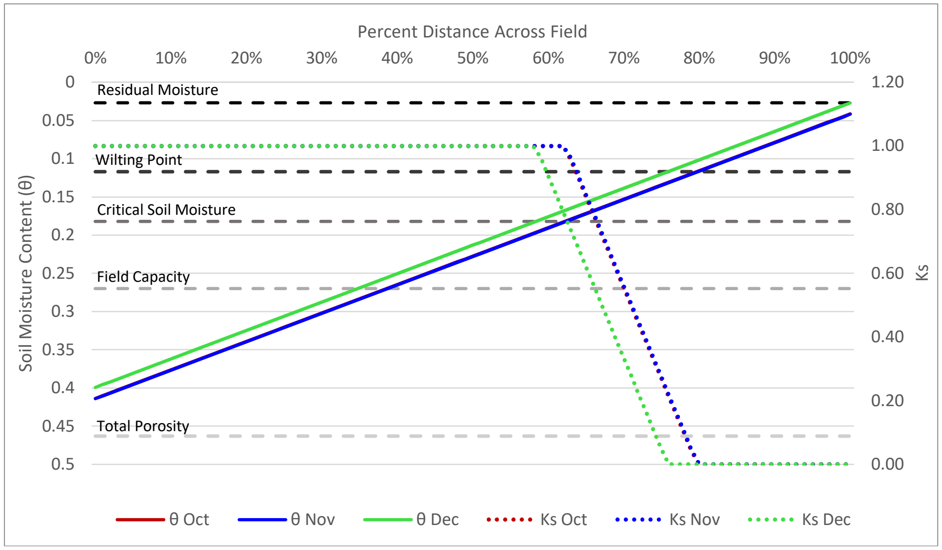


Figure 12-6

Monthly Simulated Soil Moisture (θ) and Water Stress Coefficient (Ks) Across Virtual Field
M&A Soil Water Balance Model
Mesilla In District
1975

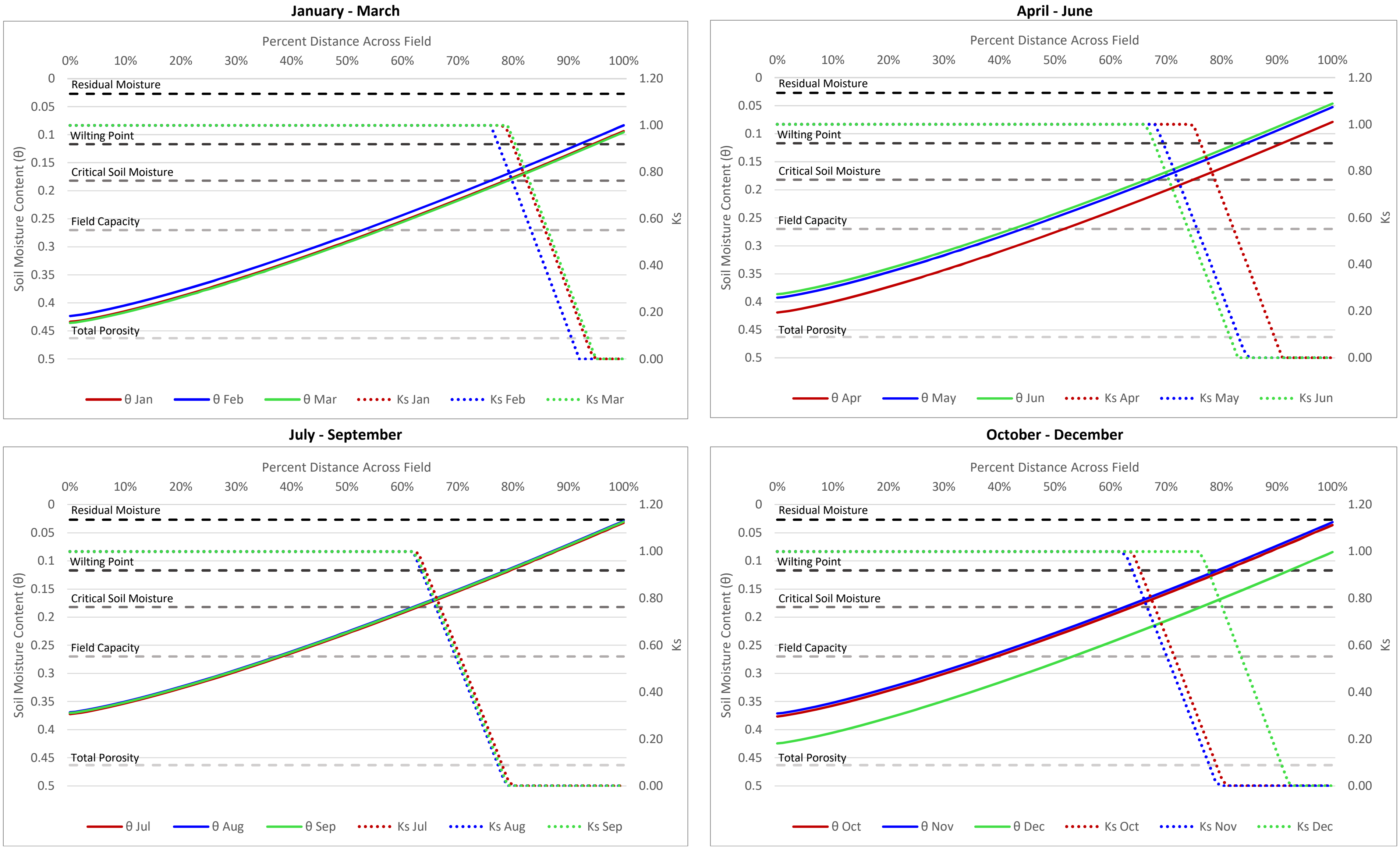
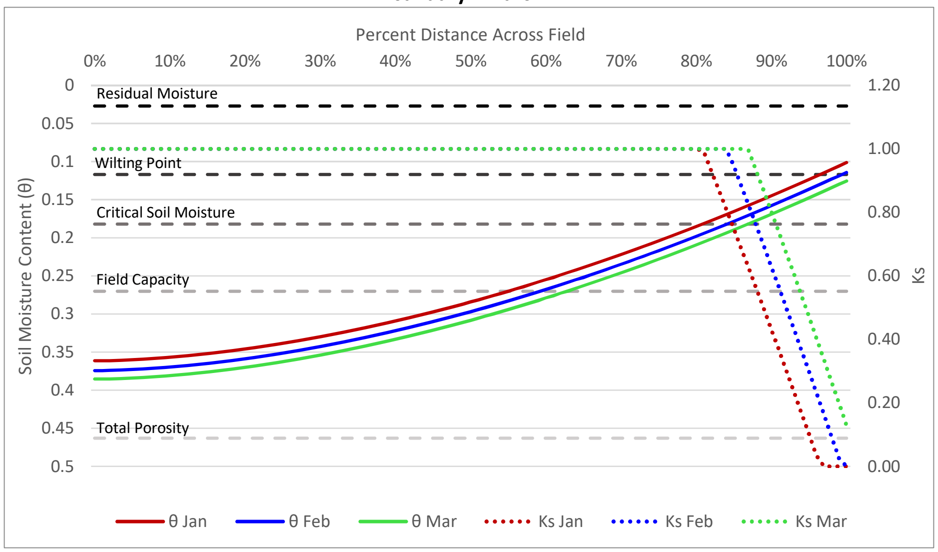


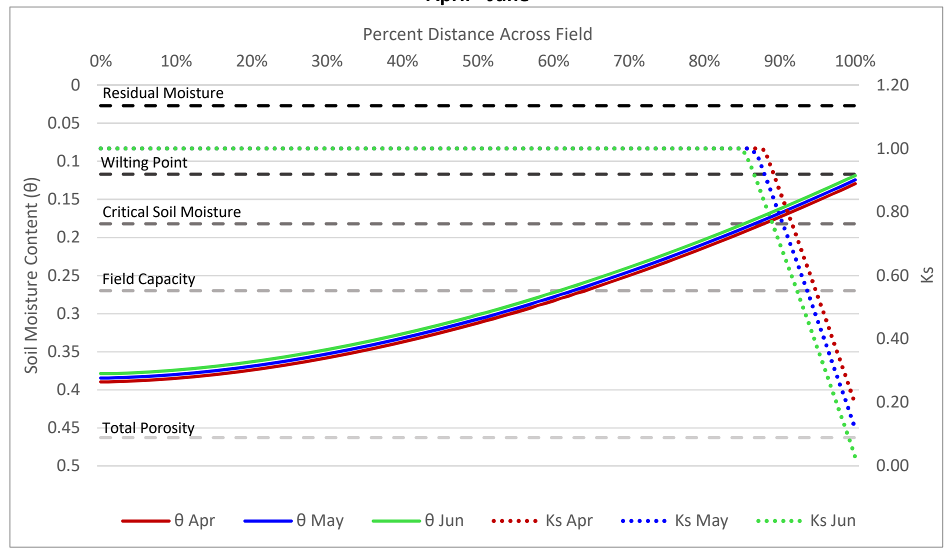
Figure 12-6

Monthly Simulated Soil Moisture (θ) and Water Stress Coefficient (Ks) Across Virtual Field
M&A Soil Water Balance Model
Mesilla In District
1985

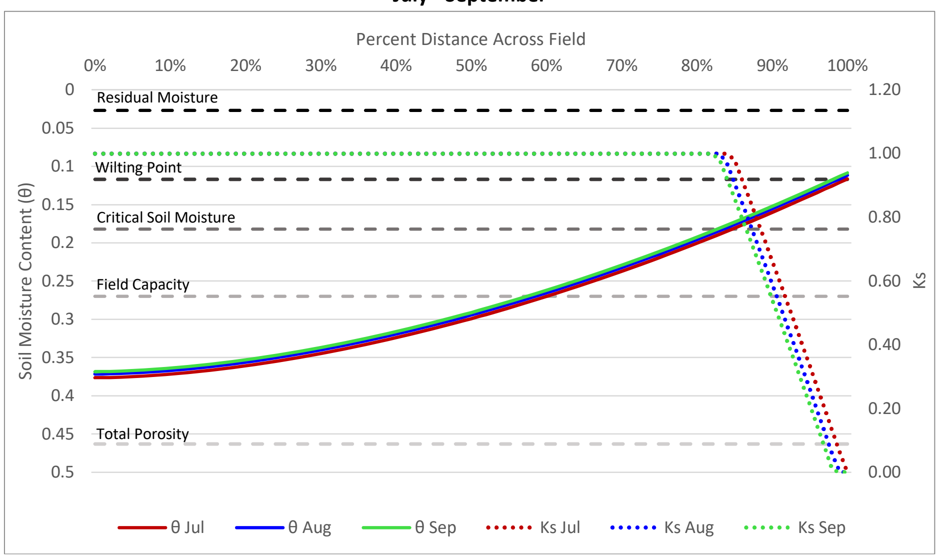
January - March



April - June



July - September



October - December

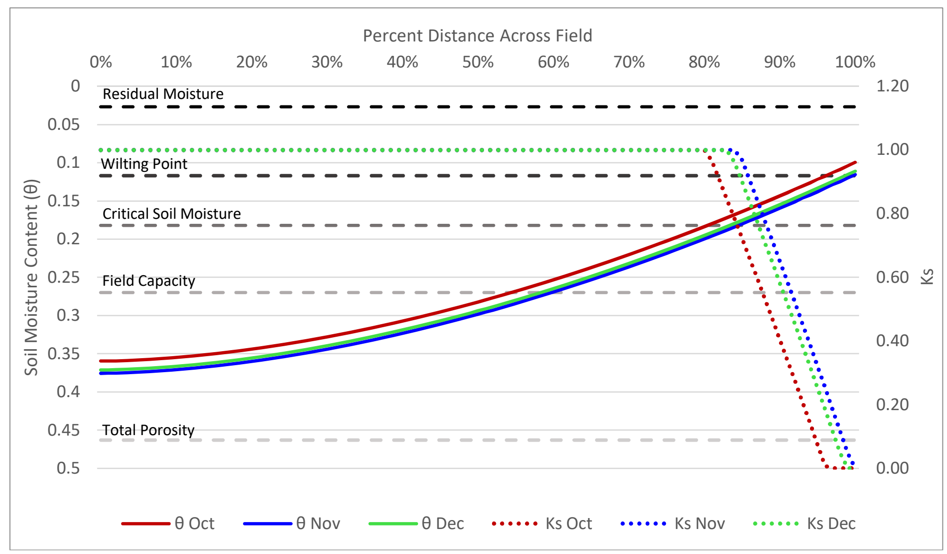
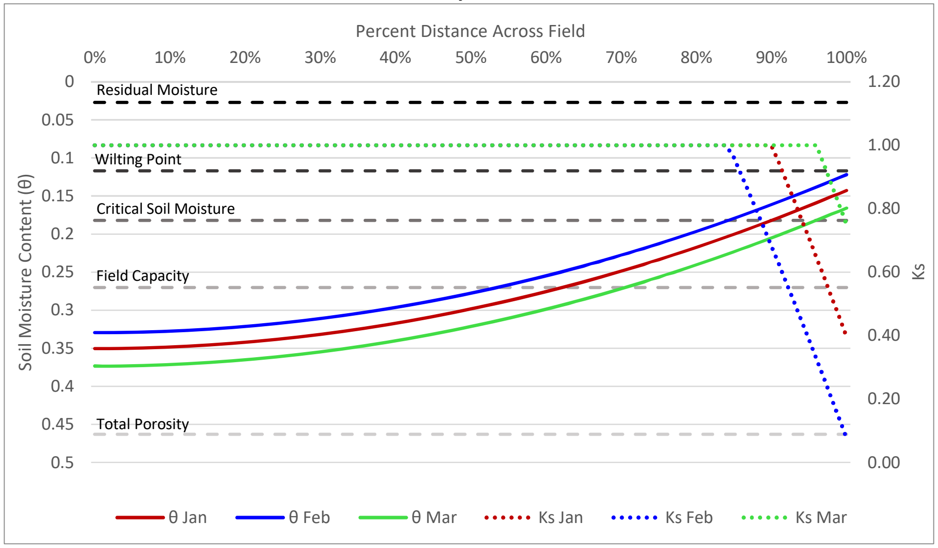


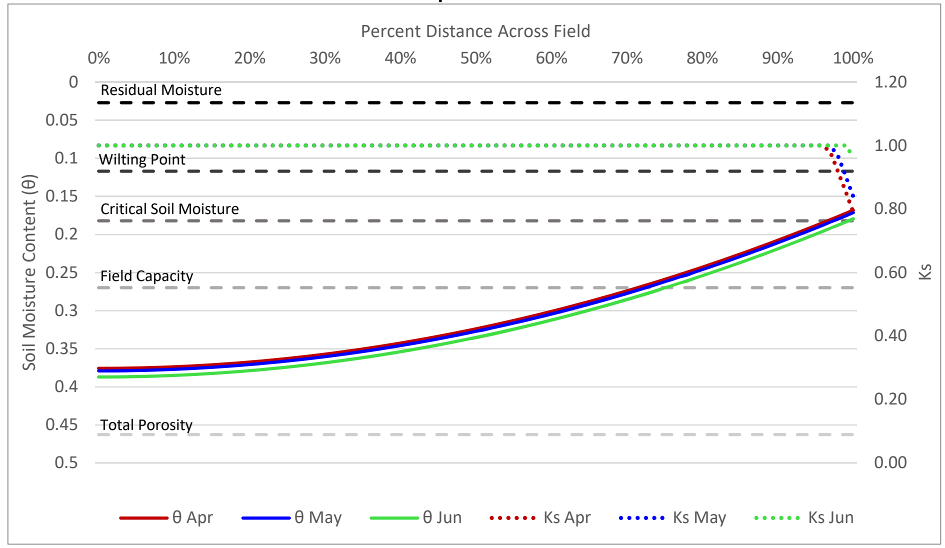
Figure 12-6

Monthly Simulated Soil Moisture (θ) and Water Stress Coefficient (Ks) Across Virtual Field
M&A Soil Water Balance Model
Mesilla In District
1995

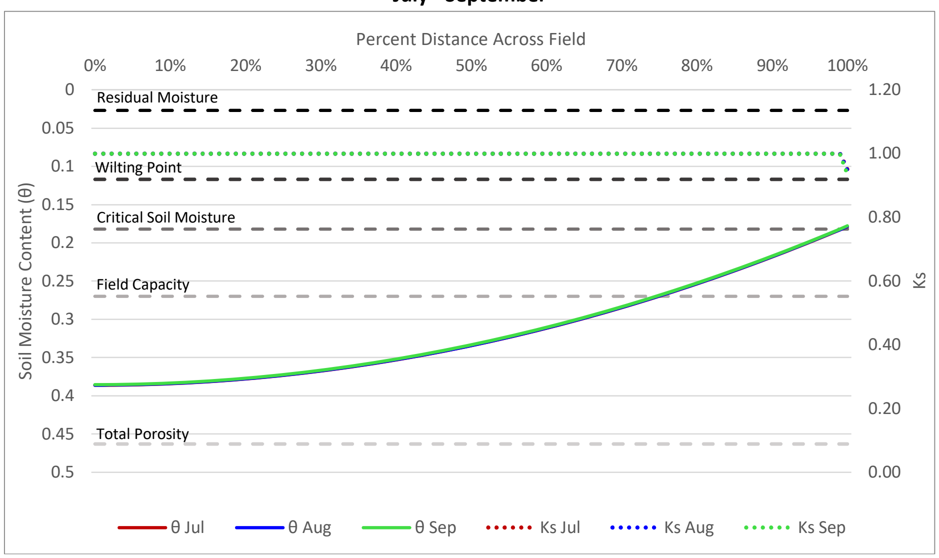
January - March



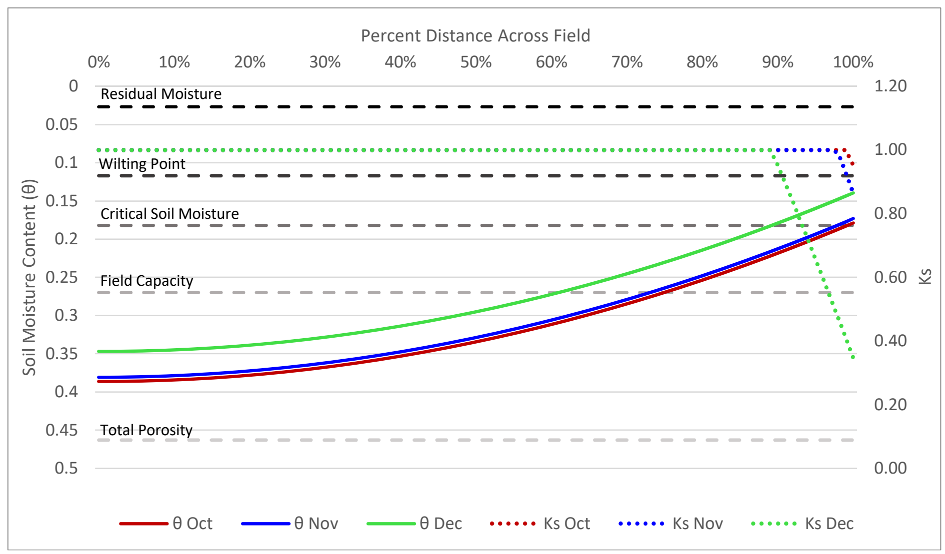
April - June



July - September



October - December

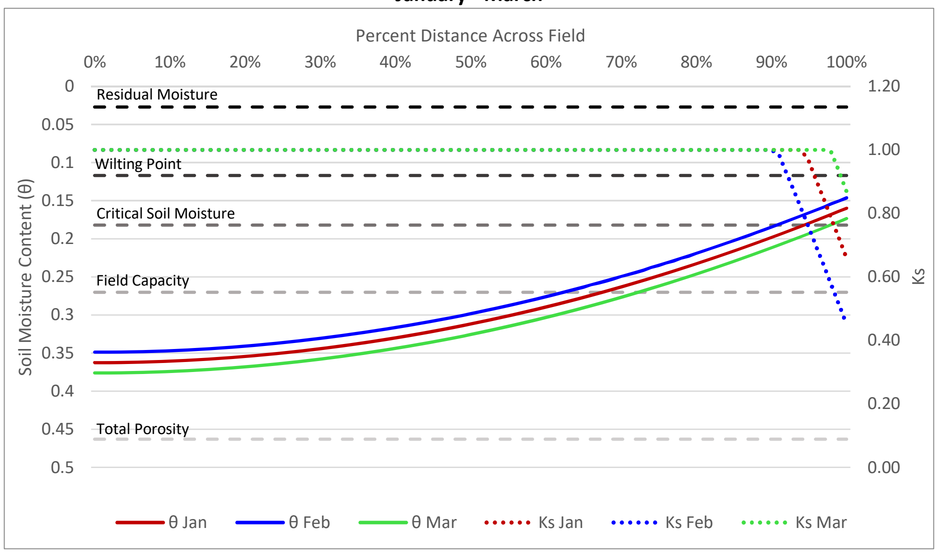


US_MSJ_00002405

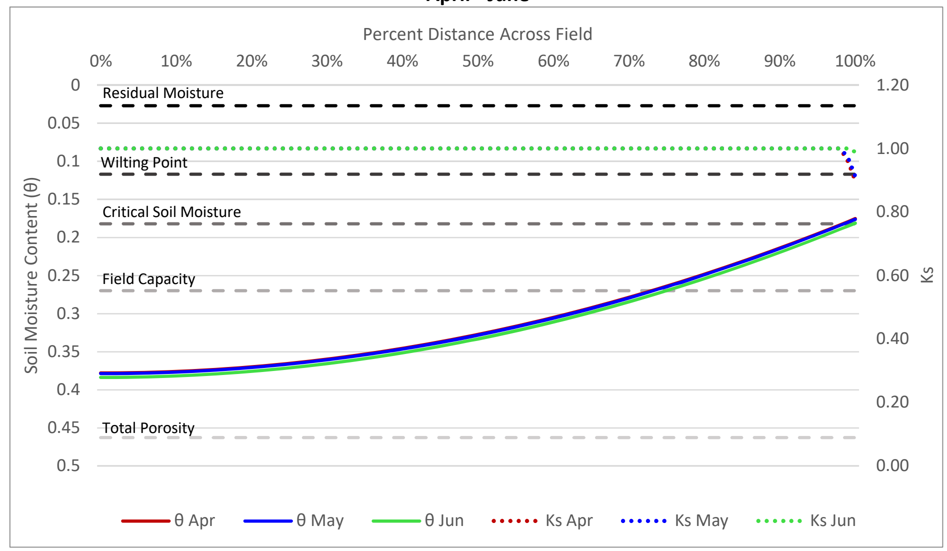
Figure 12-6

Monthly Simulated Soil Moisture (θ) and Water Stress Coefficient (Ks) Across Virtual Field
M&A Soil Water Balance Model
Mesilla In District
2005

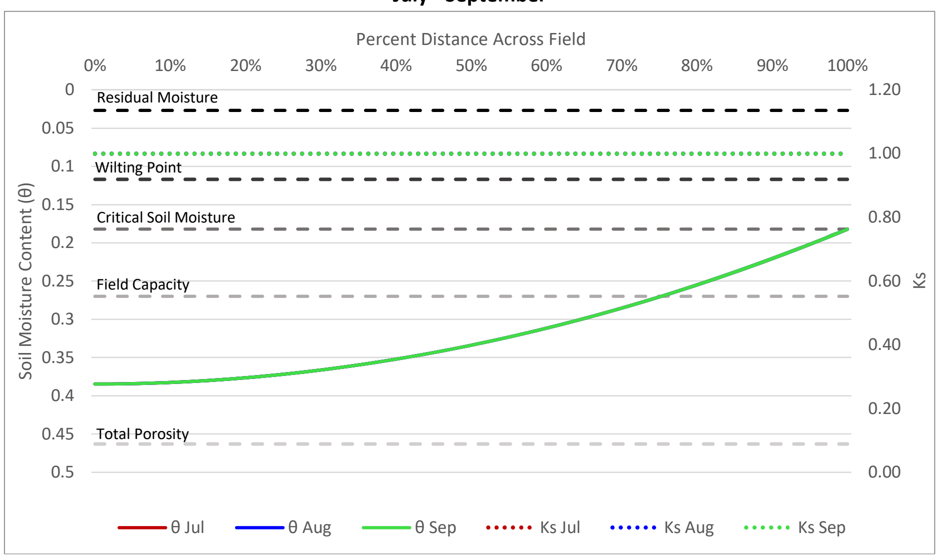
January - March



April - June



July - September



October - December

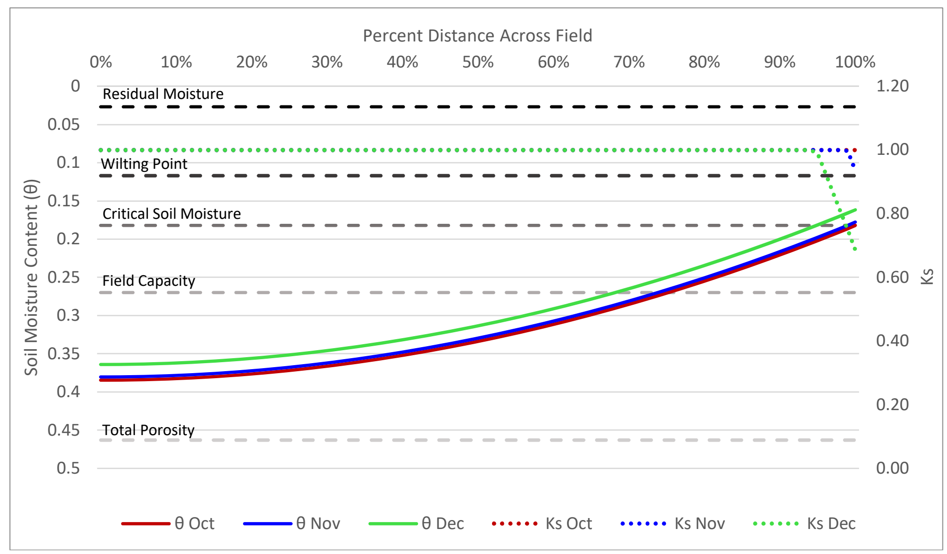
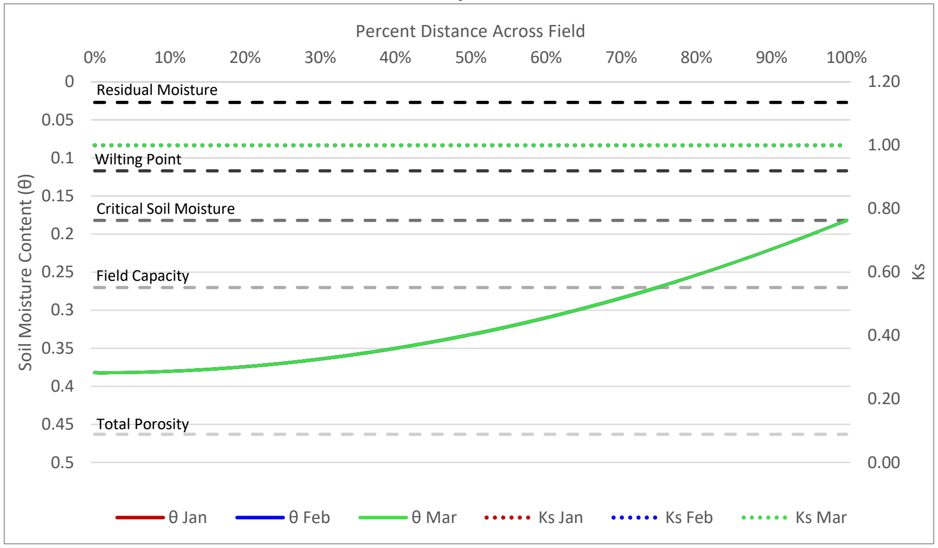


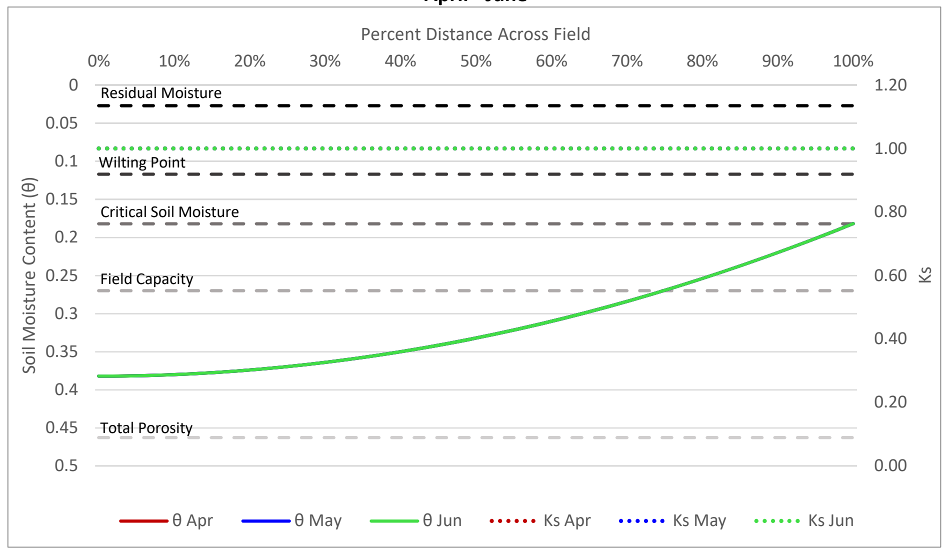
Figure 12-6

Monthly Simulated Soil Moisture (θ) and Water Stress Coefficient (Ks) Across Virtual Field
M&A Soil Water Balance Model
Mesilla In District
2015

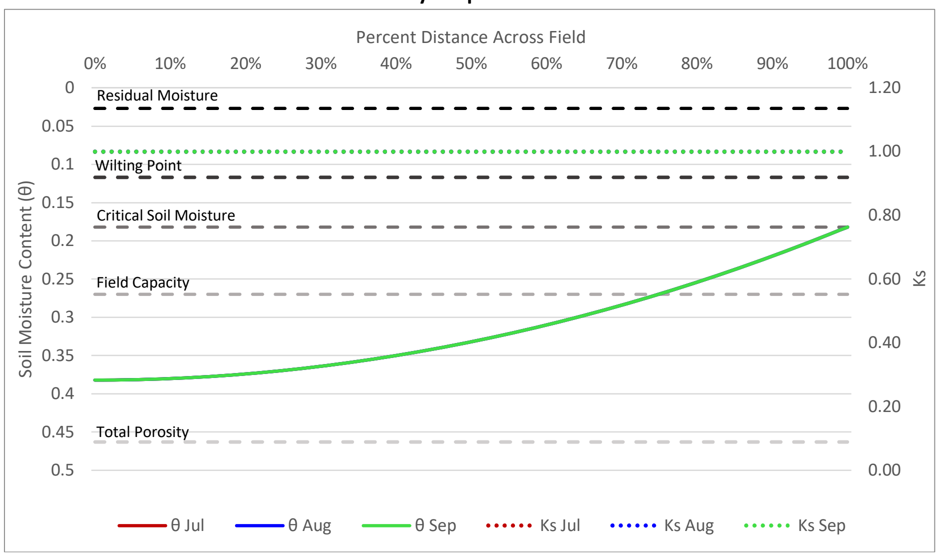
January - March



April - June



July - September



October - December

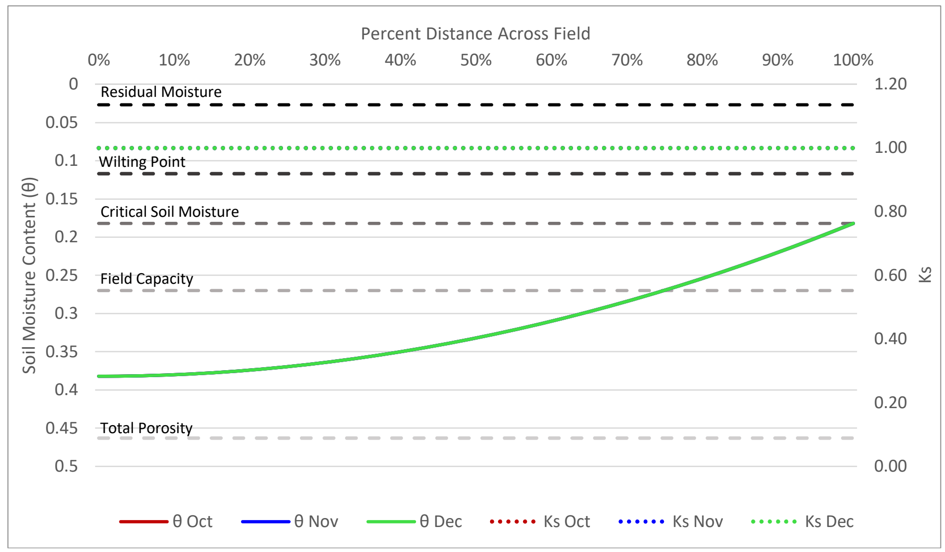
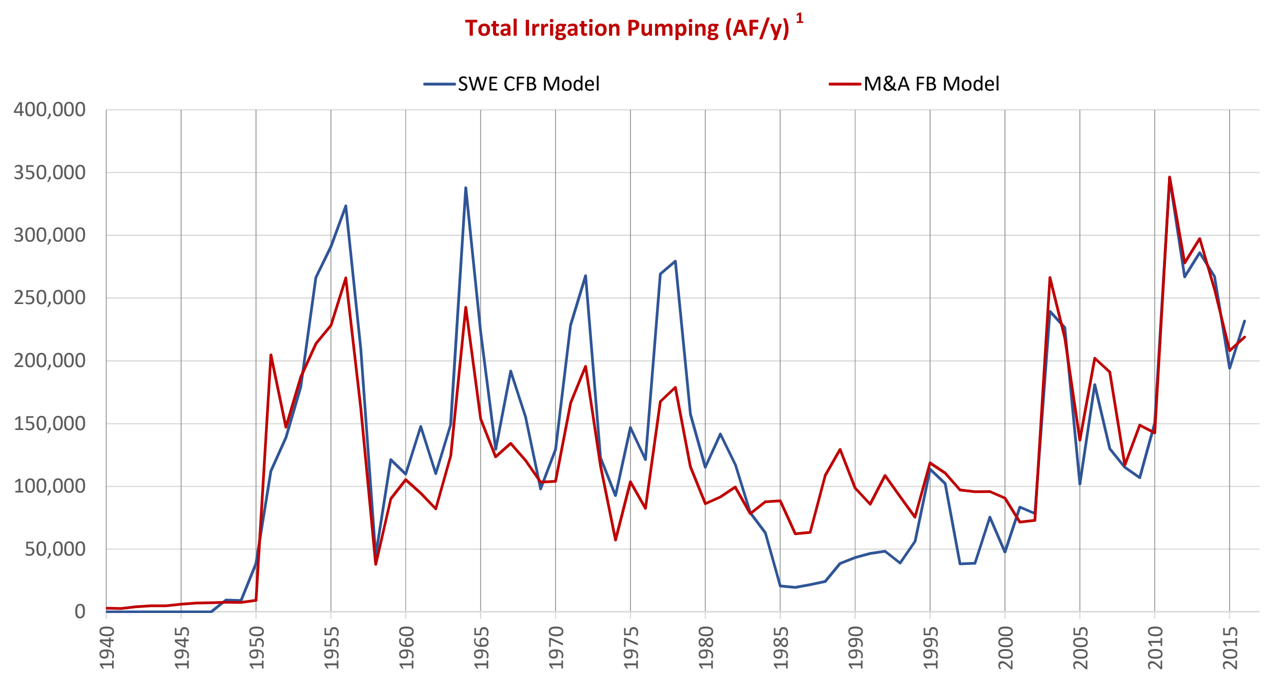


Figure 12-7

Comparison of Annual Quantities
SWE Farm Budget vs. M&A Farm Budget
1940-2016
Rincon-Mesilla



	SWE	M&A	Difference	% Diff
Average 1951-2016	143,207	140,127	-3,080	-2.2%
Average 1951-1984	166,825	133,926	-32,900	-19.7%
Average 1985-2016	118,113	146,715	28,602	24.2%

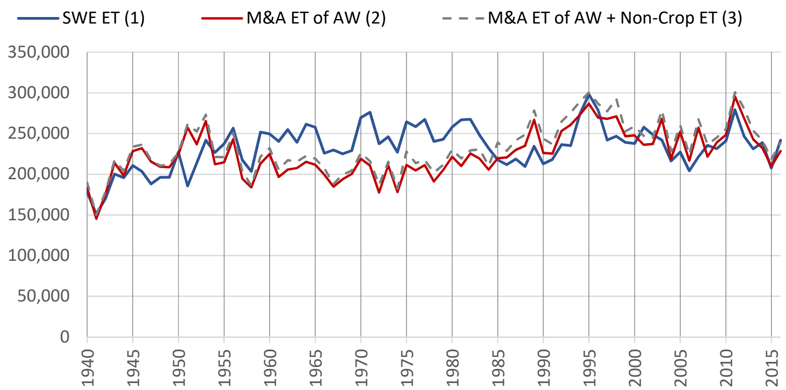
Note:

(1) Sum of supplemental and primary groundwater pumping for Rincon Basin and Mesilla Basin, including Texas Mesilla.

Figure 12-8

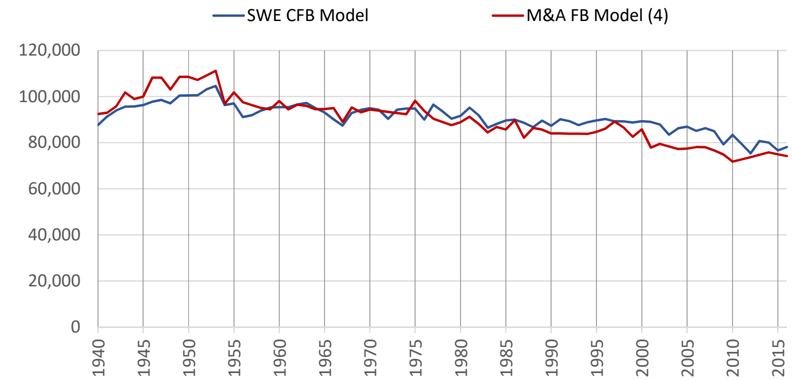
Comparison of Annual Quantities
SWE Farm Budget vs. M&A Farm Budget
1940-2016
Rincon-Mesilla

Actual ET Volume (AF/y)



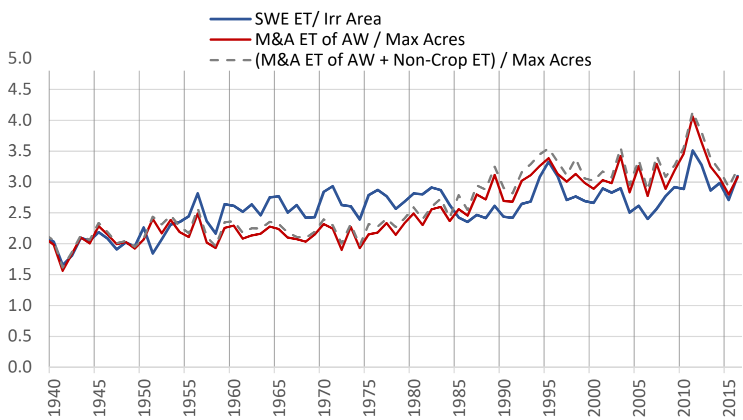
	(1) SWE	(3) M&A	Difference	% Diff
Average 1951-2016	239,858	237,240	-2,618	-1.1%
Average 1951-1984	242,628	218,300	-24,329	-10.0%
Average 1985-2016	236,916	257,364	20,449	8.6%

Irrigated Area (acres)



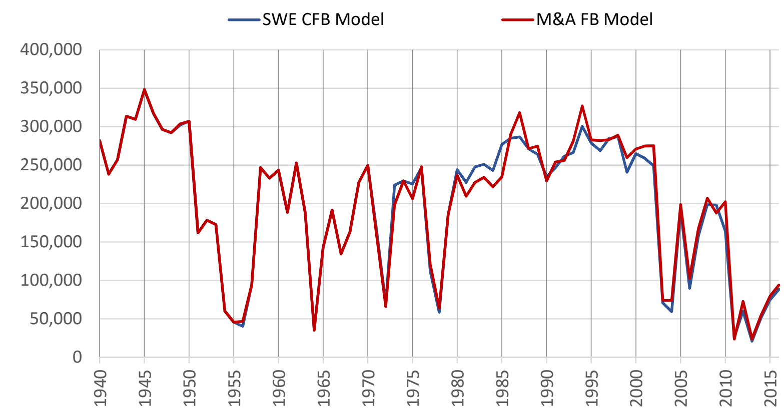
	SWE	M&A	Difference	% Diff
Average 1951-2016	90,092	87,907	-2,185	-2.4%
Average 1951-1984	94,077	94,747	670	0.7%
Average 1985-2016	85,857	80,639	-5,218	-6.1%

Unit ET (ft/y)



	(1) SWE	(3) M&A	Difference	% Diff
Average 1951-2016	2.67	2.74	0.07	2.5%
Average 1951-1984	2.58	2.31	-0.28	-10.8%
Average 1985-2016	2.77	3.20	0.43	15.7%

FHG Deliveries (AF/y)



	SWE	M&A	Difference	% Diff
Average 1951-2016	185,731	187,587	1,856	1.0%
Average 1951-1984	175,855	172,451	-3,404	-1.9%
Average 1985-2016	196,225	203,669	7,444	3.8%

Notes:

(1) SWE ET calculated as sum of Consumptive Use (CU) of Surface Water and Groundwater.

(2) M&A ET is CU of applied water.

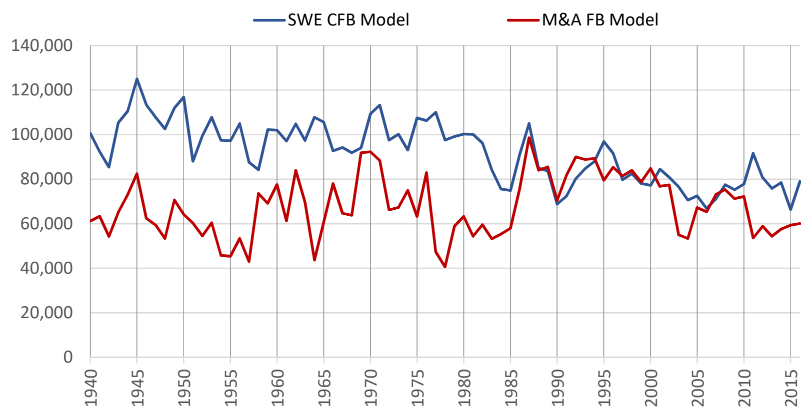
(3) Volume of bare ground ET within footprint of maximum monthly crop acres.

(4) M&A FB irrigated area is the maximum monthly crop acreage during each year.

Figure 12-9

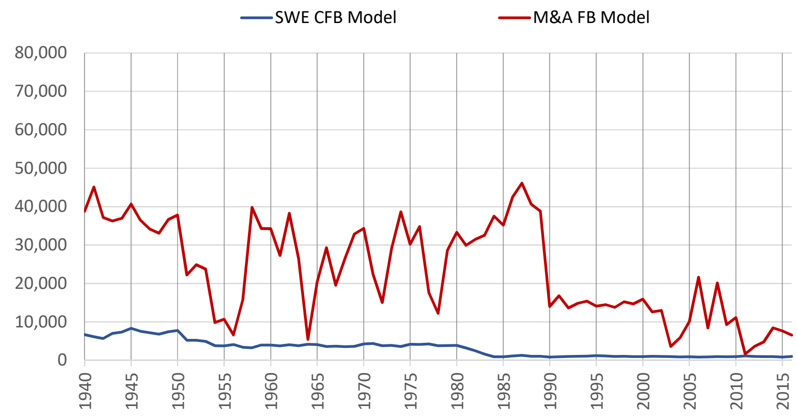
Comparison of Annual Quantities
SWE Farm Budget vs. M&A Farm Budget
1940-2016
Rincon-Mesilla

Deep Percolation of Applied Water (AF/y)



	SWE	M&A	Difference	% Diff
Average 1951-2016	89,588	68,435	-21,153	-23.6%
Average 1951-1984	98,442	63,802	-34,640	-35.2%
Average 1985-2016	80,182	73,358	-6,824	-8.5%

Surface Runoff of Applied Water (AF/y)

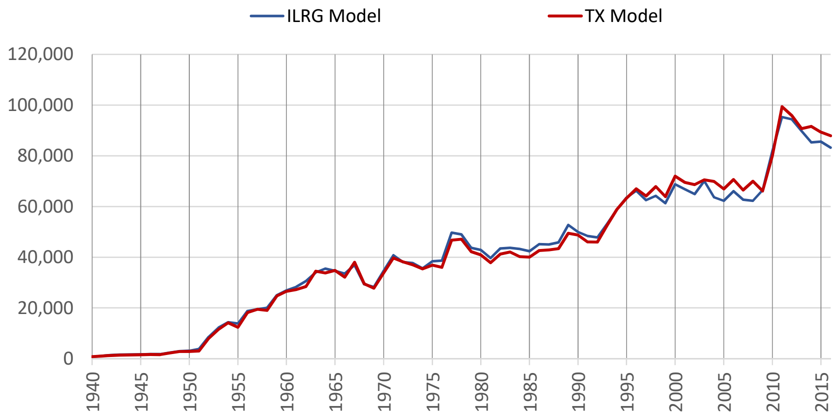


	SWE	M&A	Difference	% Diff
Average 1951-2016	2,442	21,072	18,630	762.9%
Average 1951-1984	3,785	25,771	21,985	580.8%
Average 1985-2016	1,015	16,080	15,065	1484.3%

Figure 12-10

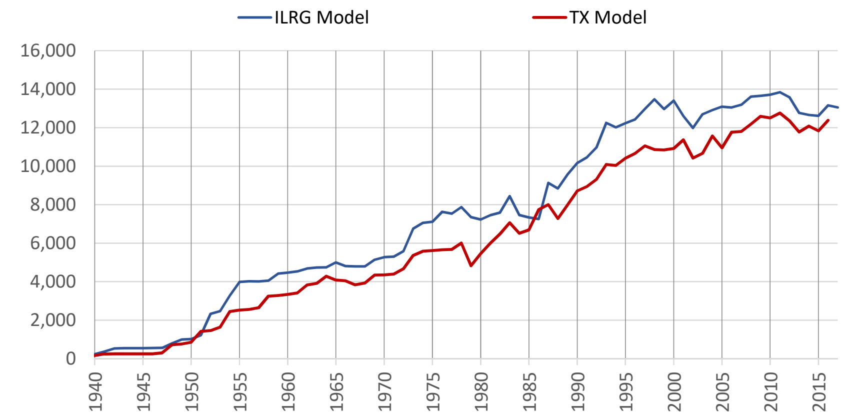
Comparison of Annual Quantities
Integrated LRG Model vs. Texas Model
1940-2016
Rincon-Mesilla

Non-Irrigation Pumping (AF/y)



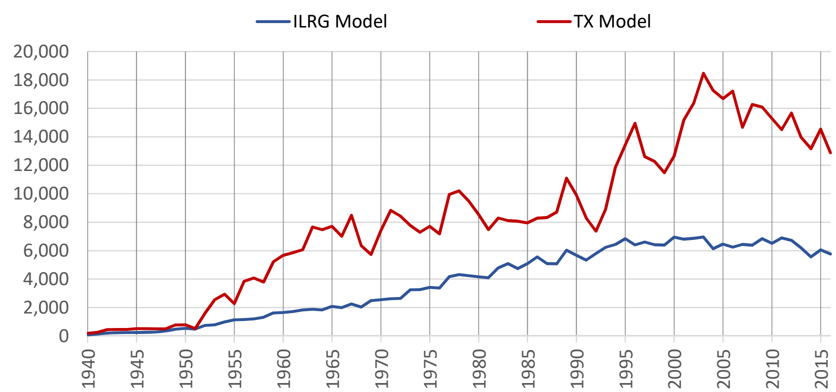
Averages	ILRG Model	TX Model	Difference	% Diff
1951-2016	47,729	47,889	161	0.3%
1951-1984	31,577	30,544	-1,033	-3.3%
1985-2016	64,890	66,319	1,429	2.2%

WWTP Discharge (AF/y)[1]



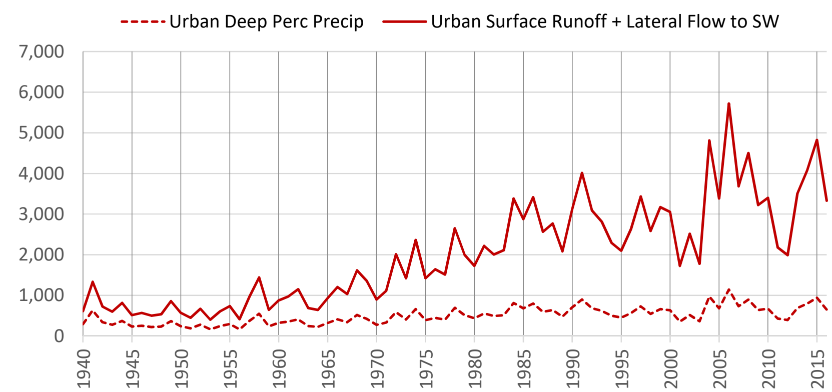
Averages	ILRG Model	TX Model	Difference	% Diff
1951-2016	8,601	7,310	-1,291	-15.0%
1951-1984	5,385	4,232	-1,153	-21.4%
1985-2016	12,017	10,580	-1,437	-12.0%

Urban Deep Percolation (AF/y)



Averages	ILRG Model	TX Model	Difference	% Diff
1951-2016	4,313	9,637	5,324	123.5%
1951-1984	2,527	6,458	3,931	155.6%
1985-2016	6,211	13,016	6,805	109.6%

Urban Deep Percolation and SurfaceRunoff from Precipitation (TX Model) (AF/y)



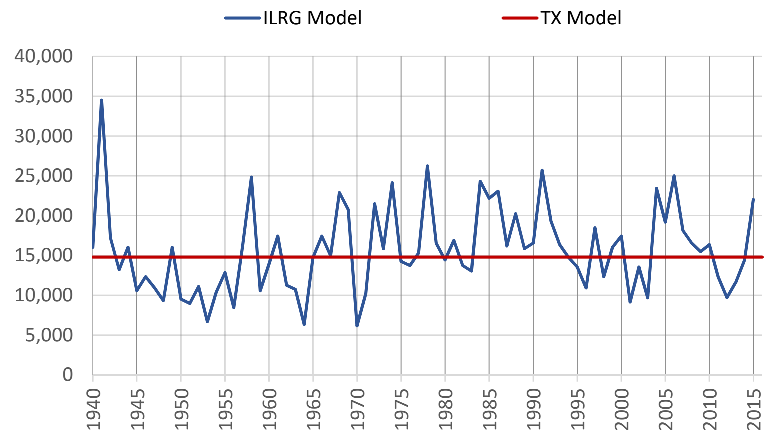
Averages	Urban DP Precip (TX Model)	Urban SRO (TX Model)
1951-2016	524	2,211
1951-1984	398	1,331
1985-2016	657	3,146

Note:

(1) WWTP discharges does not include Northwest Plant.

Figure 12-11

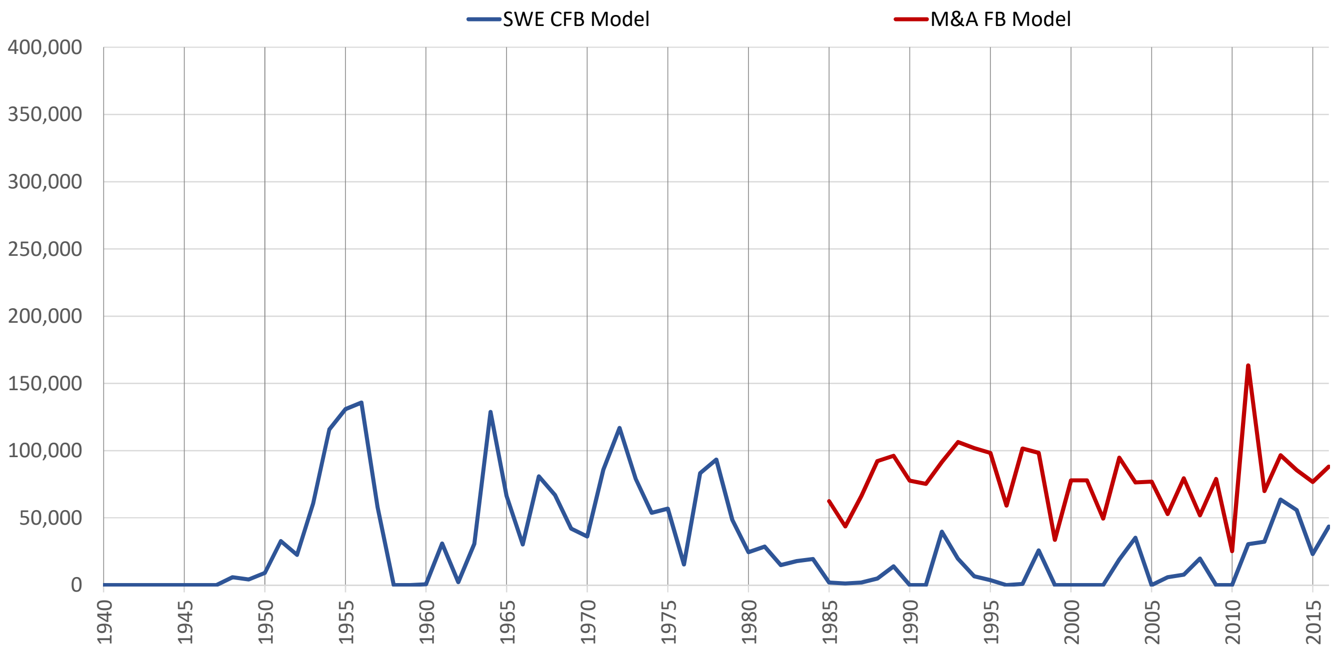
Comparison of Annual Quantities
Integrated LRG Model vs. Texas Model
1940-2016
Rincon-Mesilla
Mountain Front Recharge (AF)



	ILRG Model	Difference	% Diff
Average 1951-2016	15,724	-932	-5.9%
Average 1951-1984	14,912	-120	-0.8%
Average 1985-2016	16,587	-1,795	-10.8%

Figure 12-12

Comparison of Annual Quantities
SWE Farm Budget vs. M&A Farm Budget
1940-2016
El Paso Valley
Total Irrigation Pumping (AF/y) [1]



Averages	SWE	M&A	Difference	% Diff
1951-2016	34,340			
1985-2016	14,258	78,941	64,683	453.7%

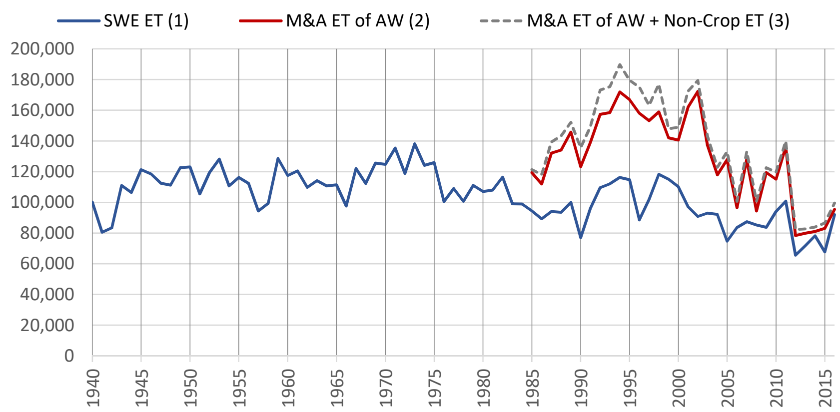
Note:

(1) Supplemental pumping for El Paso Valley.

Figure 12-13

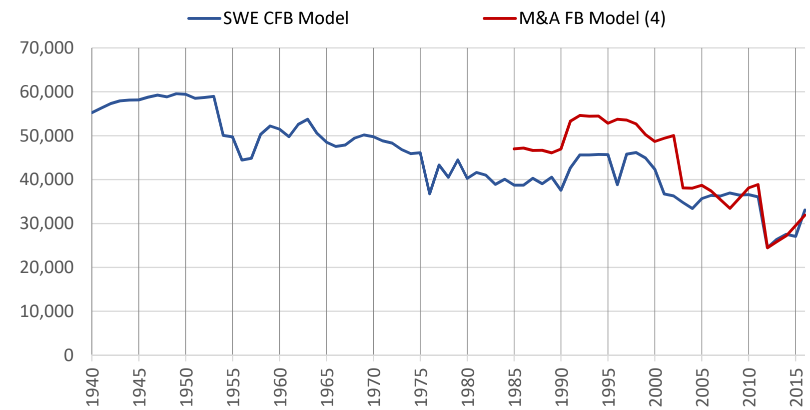
Comparison of Annual Quantities
SWE Farm Budget vs. M&A Farm Budget
1940-2016
El Paso Valley

Actual ET Volume (AF/y)



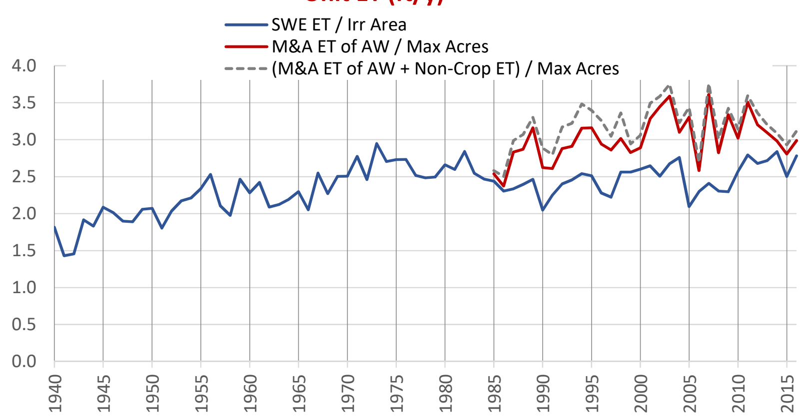
Averages	(1) SWE	(3) M&A	Difference	% Diff
1951-2016	103,997			
1985-2016	93,408	137,228	43,820	46.9%

Irrigated Area (acres)



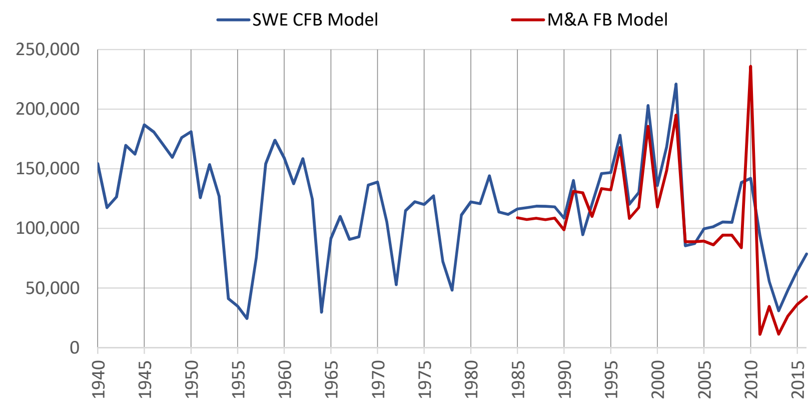
Averages	SWE	M&A	Difference	% Diff
1951-2016	42,952			
1985-2016	37,895	43,174	5,279	13.9%

Unit ET (ft/y)



Averages	(1) SWE	(3) M&A	Difference	% Diff
1951-2016	2.44			
1985-2016	2.48	3.18	0.71	28.6%

FHG Deliveries (AF/y)



Averages	SWE	M&A	Difference	% Diff
1951-2016	112,196			
1985-2016	116,818	104,402	-12,417	-10.6%

Notes:

(1) SWE ET calculated as sum of Consumptive Use (CU) of Surface Water and Groundwater.

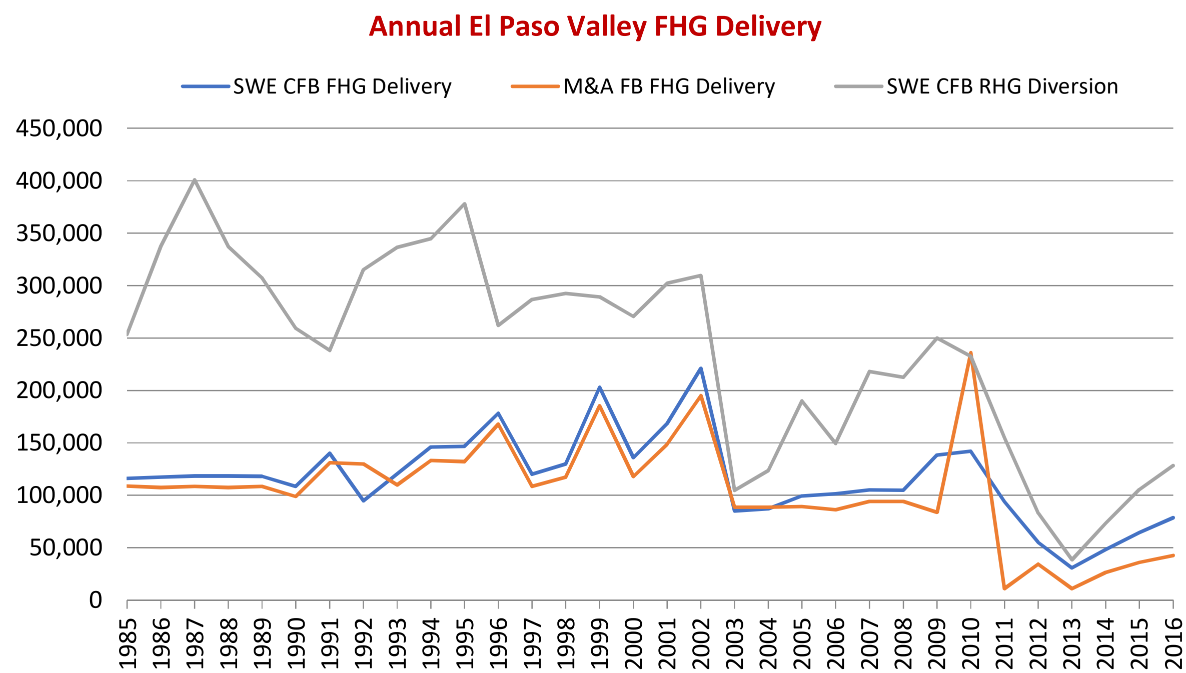
(2) M&A ET is CU of applied water.

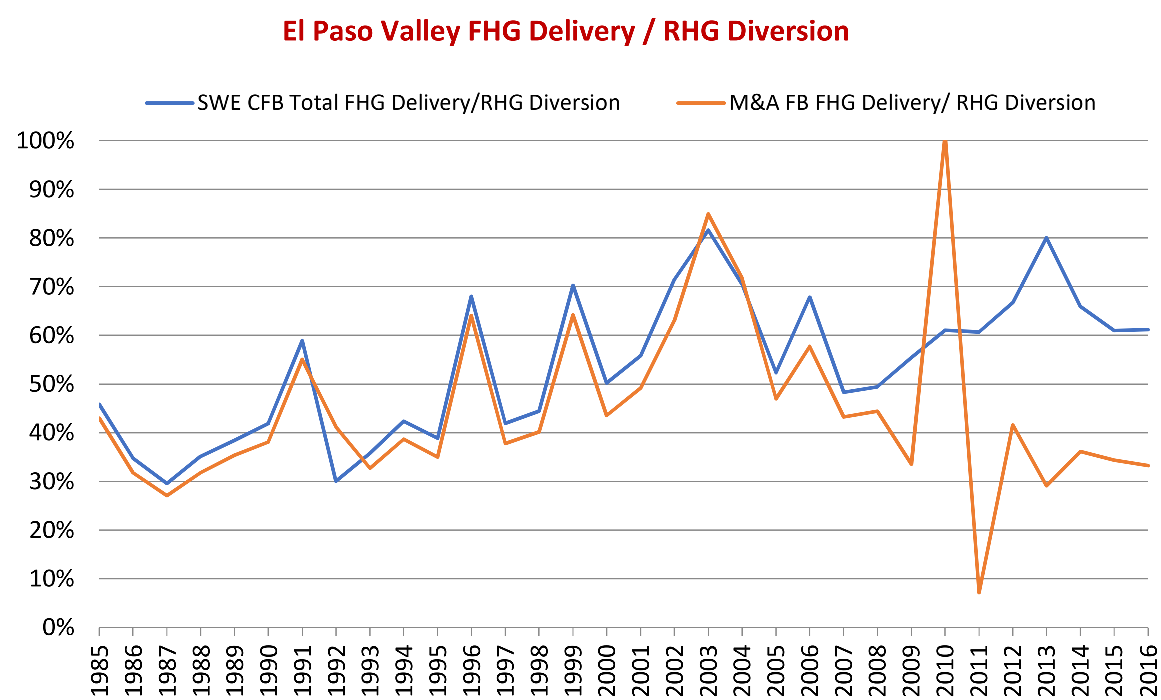
(3) Volume of bare ground ET within footprint of maximum monthly crop acres.

(4) M&A FB irrigated area is the maximum monthly crop acreage during each year.

Figure 12-14

Comparison of Annual FHG Deliveries
SWE Farm Budget vs. M&A Farm Budget
1985 - 2016





Notes:

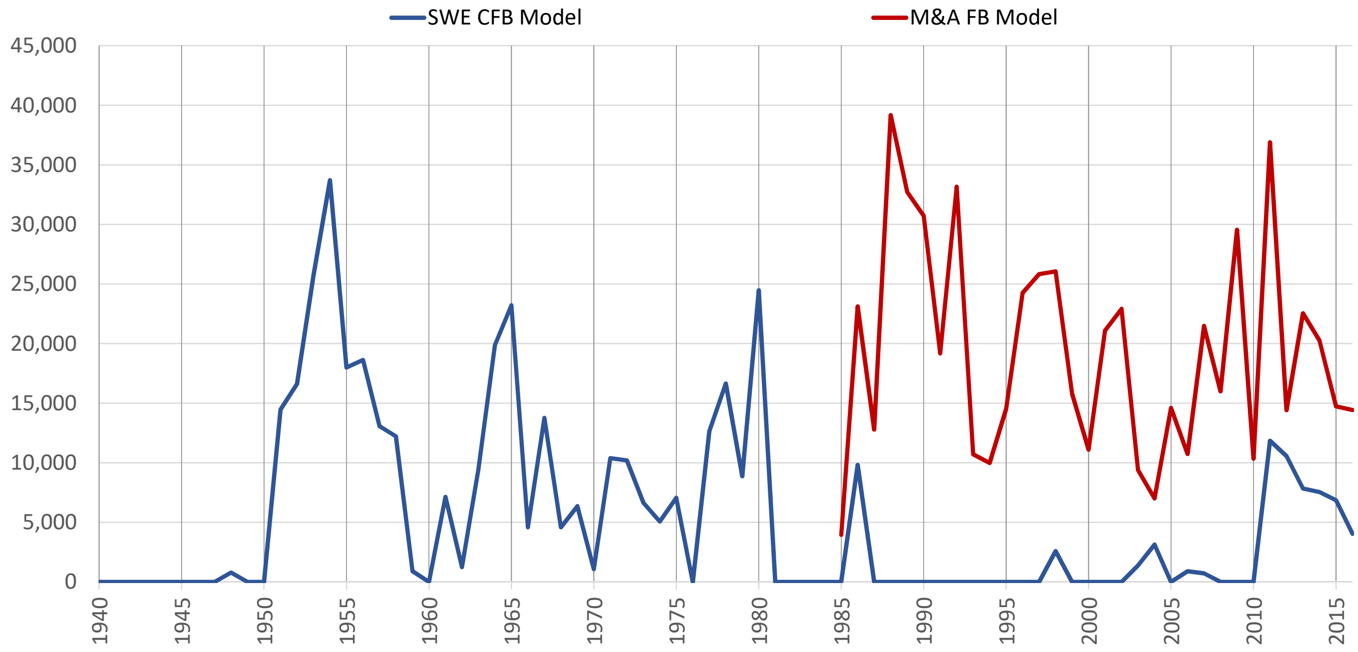
El Paso RHG Diversion is equal to Franklin Canal diversions minus Ascarate Wasteway (Pre-1999) plus Riverside Canal diversions.

Figure 12-15

Comparison of Annual Quantities
SWE Farm Budget vs. M&A Farm Budget
1940-2016

Hudspeth

Total Irrigation Pumping (AF/y) [1]



Averages	SWE	M&A	Difference	% Diff
1951-2016	6,270			
1985-2016	2,100	19,356	17,255	821.5%

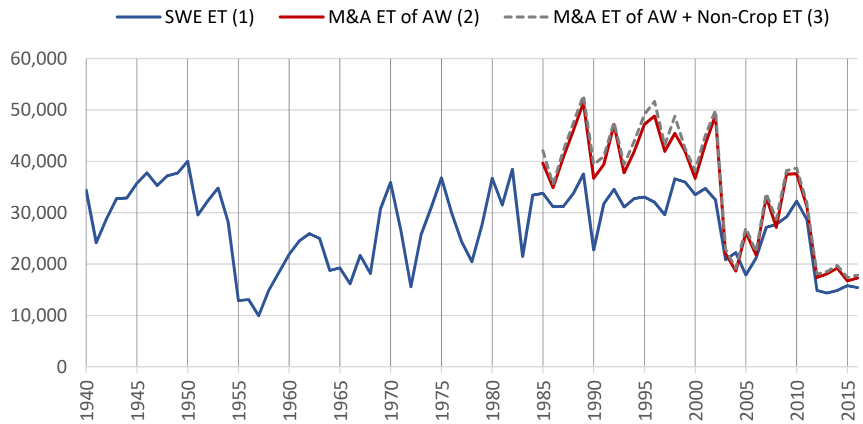
Notes:

(1) Supplemental pumping for Hudspeth.

Figure 12-16

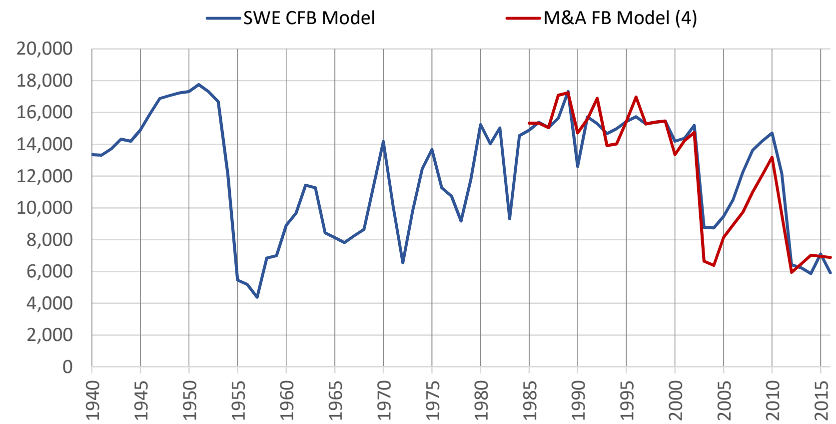
Comparison of Annual Quantities
SWE Farm Budget vs. M&A Farm Budget
1940-2016
Hudspeth

Actual ET Volume (AF/y)



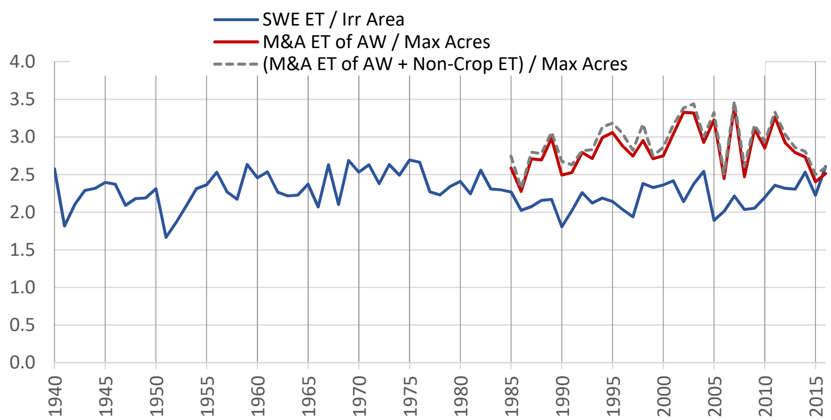
Averages	(1) SWE	(3) M&A	Difference	% Diff
1951-2016	26,402			
1985-2016	27,840	36,050	8,210	29.5%

Irrigated Area (acres)



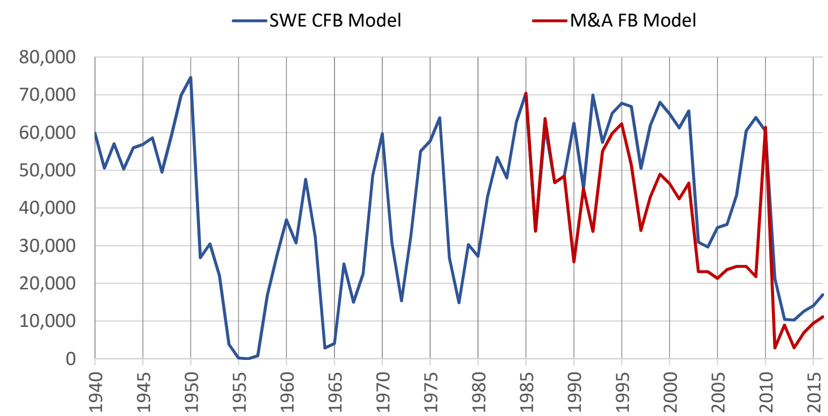
Averages	SWE	M&A	Difference	% Diff
1951-2016	11,713			
1985-2016	12,766	12,341	-426	-3.3%

Unit ET (ft/y)



Averages	(1) SWE	(3) M&A	Difference	% Diff
1951-2016	2.28			
1985-2016	2.20	2.93	0.73	33.0%

FHG Deliveries (AF/y)



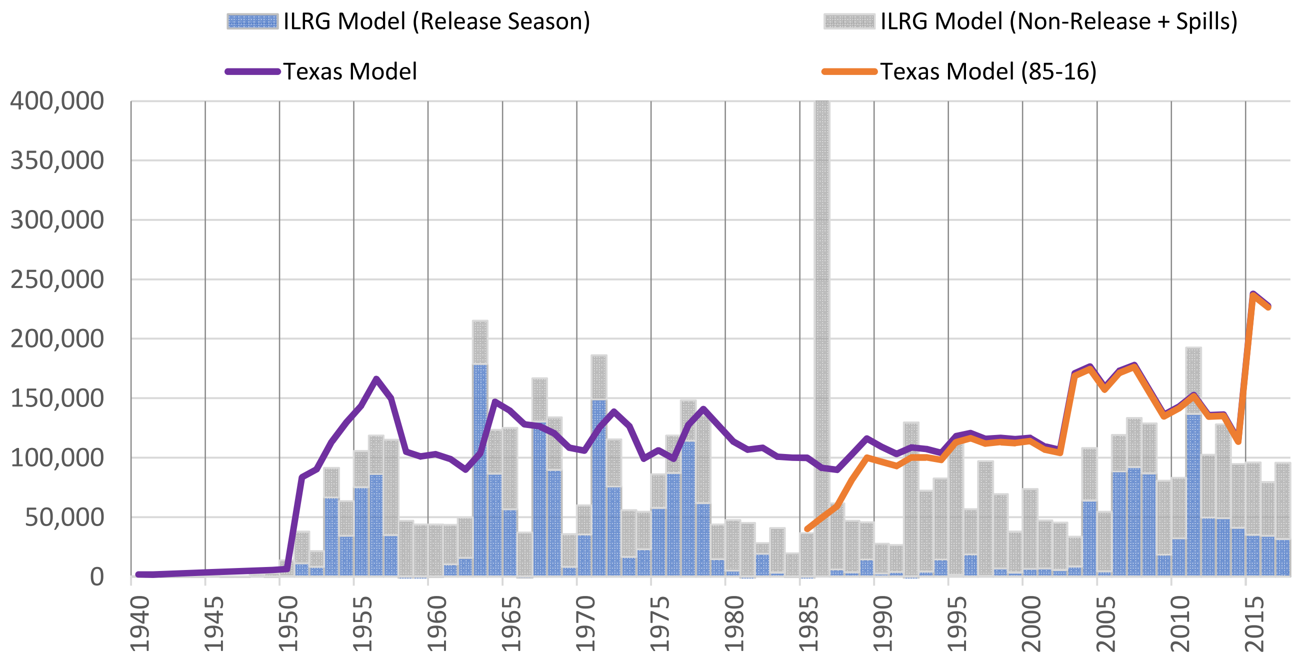
Averages	SWE	M&A	Difference	% Diff
1951-2016	38,307			
1985-2016	47,270	35,095	-12,175	-25.8%

Notes:

(1) SWE ET calculated as sum of Consumptive Use (CU) of Surface Water and Groundwater.
(2) M&A ET is CU of applied water.
(3) Volume of bare ground ET within footprint of maximum monthly crop acres.
(4) M&A FB irrigated area is the maximum monthly crop acreage during each year.

Figure 13-1

Annual Impact of Pumping on Rio Grande at El Paso Flows
Integrated LRG Model (No R-M Pumping)
vs.
Texas Model (100% Reduction in R-M Pumping)
(acre-feet)

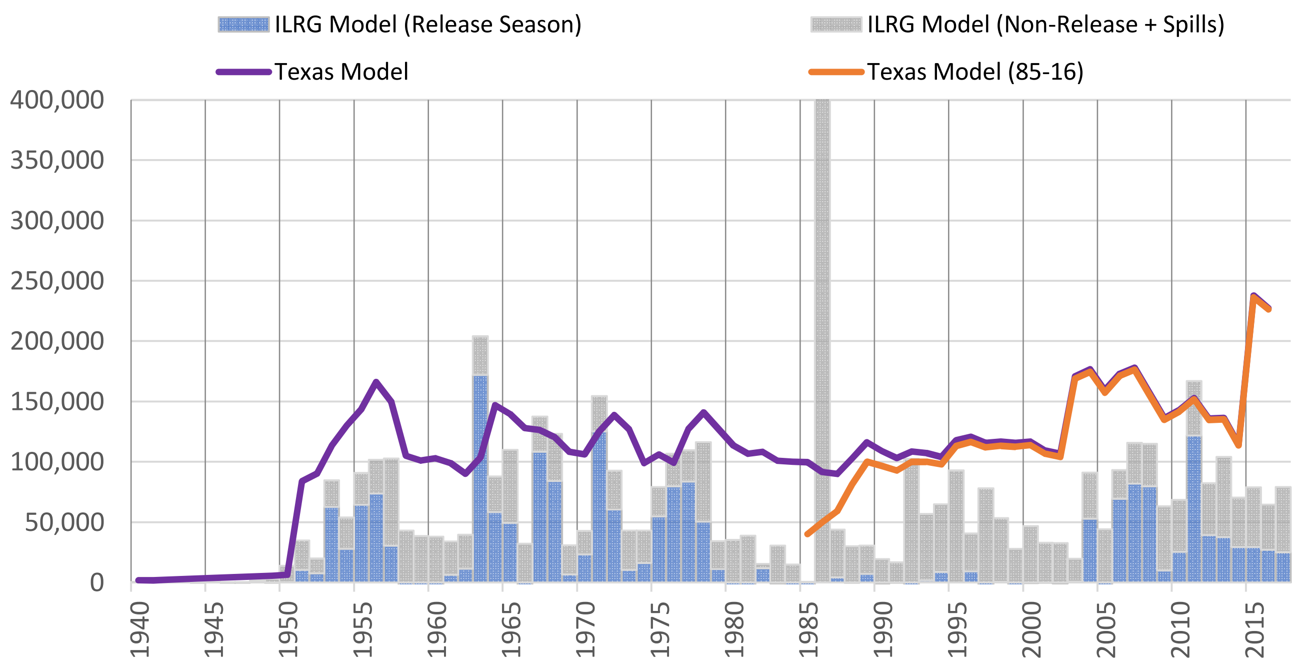


Averages	(1) ILRG Model (No R-M Pump)	(2) Texas Model (100% Reduction)	(3) Texas Model 85-16 (100% Reduction)
1985 - 2016 Annual (af):	93,910	132,866	124,658
1951 - 2016 Annual (af):	87,697	124,667	
1985 - 2016 Release Season (af):	25,098		
1951 - 2016 Release Season (af):	35,448		

Notes:
(1) ILRG Model change is computed as flows in Run 6 (no Rincon-Mesilla pumping) minus Run 1 (Historical Base Run).
(2) Texas Model (1938 - 2016 run) change is computed as the simulated flows with reduced pumping (100%) minus flows with no pumping reduction (historical simulation).
(3) Texas Model (1985 - 2016 run) change is computed as the simulated flows with reduced pumping (100%) minus flows with no pumping reduction (historical simulation).

Figure 13-2

Annual Impact of Pumping on Rio Grande at El Paso Flows
Integrated LRG Model (No NM Pumping)
vs.
Texas Model (100% Reduction in R-M Pumping)
(acre-feet)



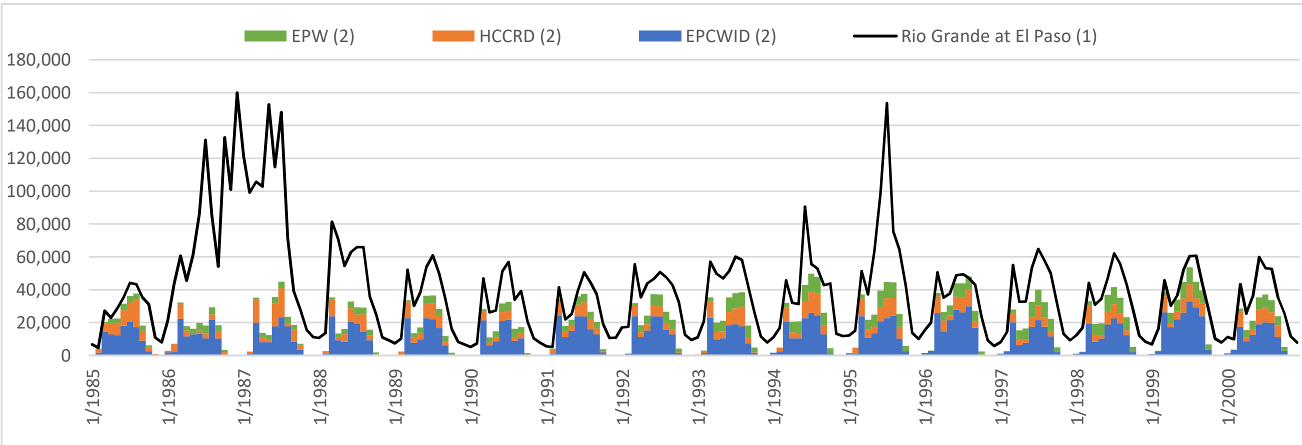
Averages	(1) ILRG Model (No NM Pump)	(2) Texas Model (100% Reduction)	(3) Texas Model 85-16 (100% Reduction)
1985 - 2016 Annual (af):	74,402	132,866	124,658
1951 - 2016 Annual (af):	71,169	124,667	
1985 - 2016 Release Season (af):	17,560		
1951 - 2016 Release Season (af):	27,523		

Notes:
(1) ILRG Model change is computed as flows in Run 3 (no New Mexico pumping) minus Run 1 (Historical Base Run).
(2) Texas Model (1938 - 2016 run) change is computed as the simulated flows with reduced pumping (100%) minus flows with no pumping reduction (historical simulation).
(3) Texas Model (1985 - 2016 run) change is computed as the simulated flows with reduced pumping (100%) minus flows with no pumping reduction (historical simulation).

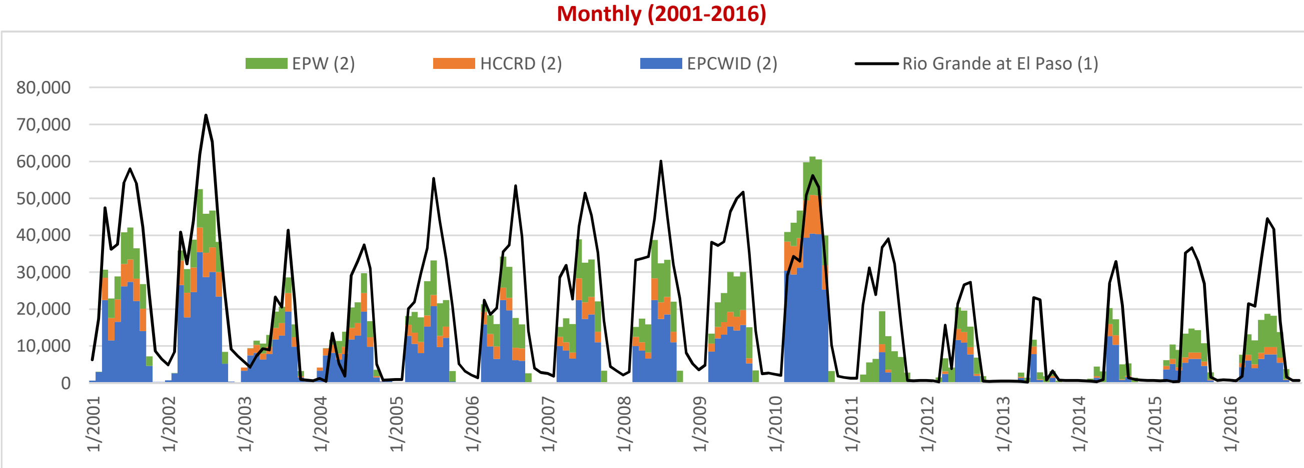
Figure 14-1

Historical Adjusted Rio Grande at El Paso Flows and Texas Deliveries
Dorrance Analysis
(acre-feet)

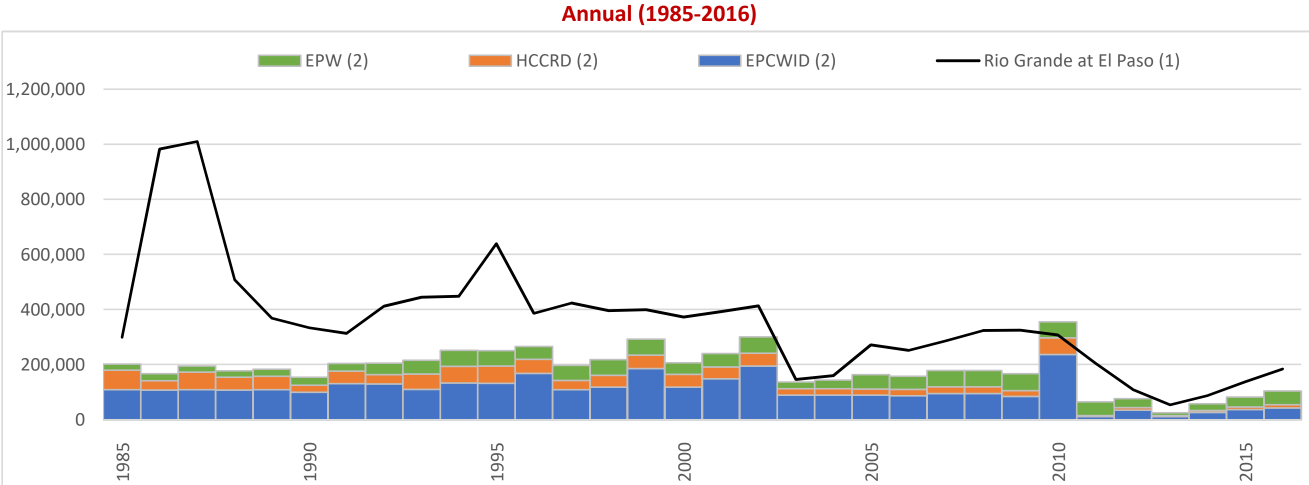
Monthly (1985-2000)



Monthly (2001-2016)



Annual (1985-2016)



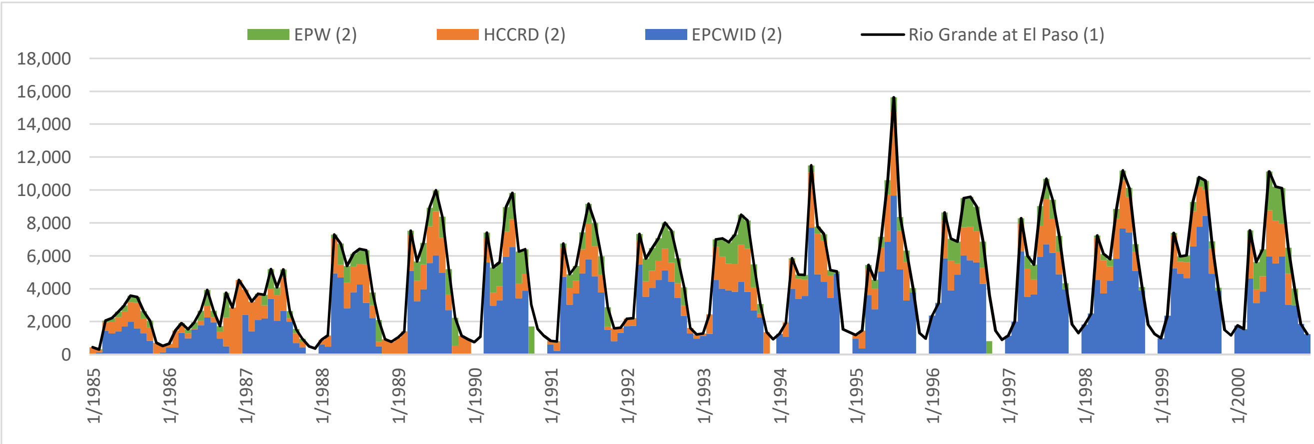
Notes:

(1) Rio Grande at El Paso is equal to historical Rio Grande at El Paso flow minus Acequia Madre diversions.
(2) Actual and estimated deliveries to Texas water users.

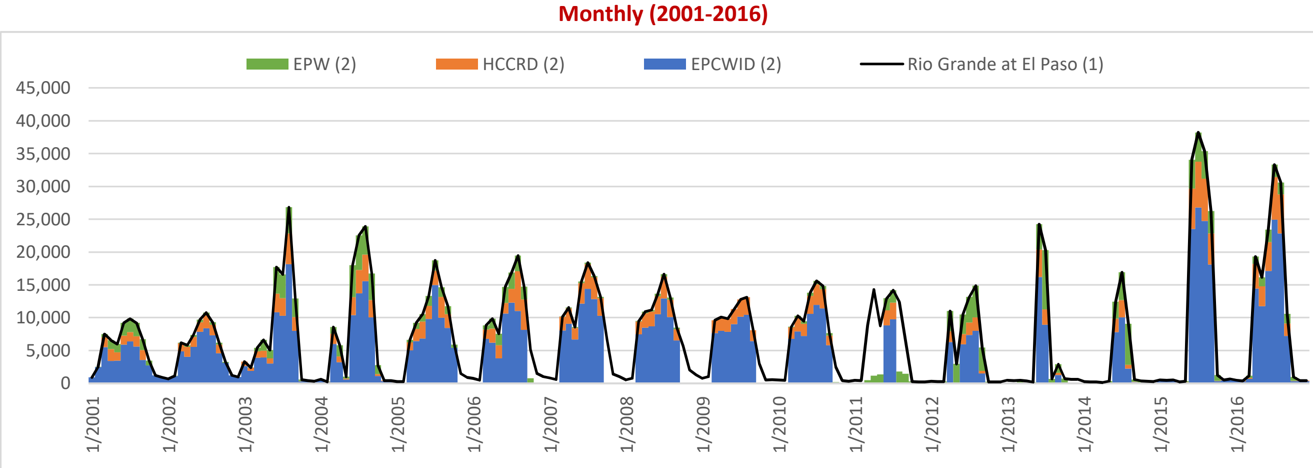
Figure 14-2

Increased Rio Grande at El Paso Flow and Amounts Made Available to Texas Water Users
Dorrance Analysis
(acre-feet)

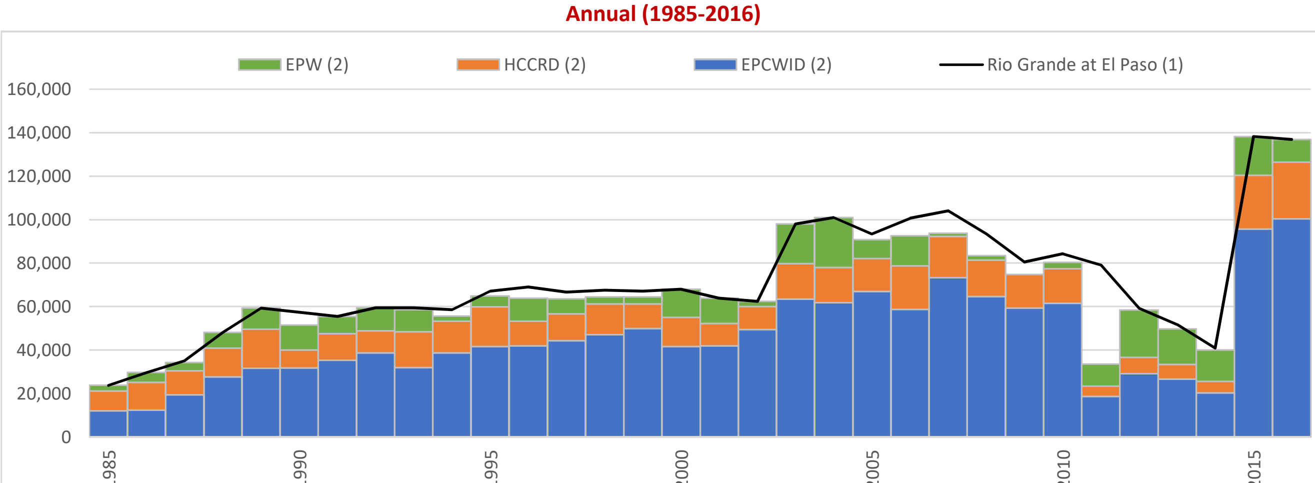
Monthly (1985-2000)



Monthly (2001-2016)



Annual (1985-2016)

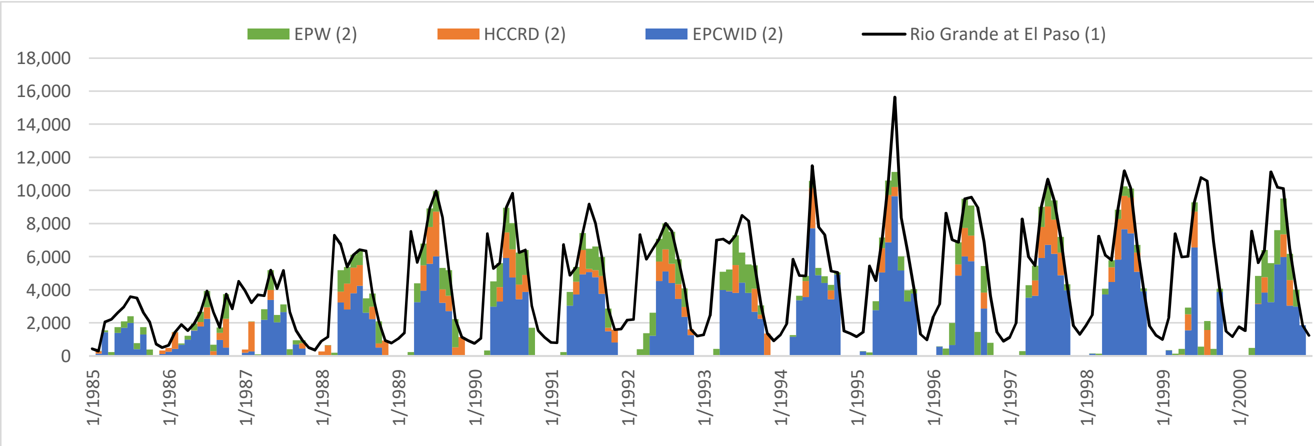


Notes:
(1) Increased Rio Grande at El Paso flow in 60% Rincon-Mesilla pumping reduction scenario simulated in Texas Model.
(2) Amounts of increased Rio Grande at El Paso flow made available for delivery to Texas water users.

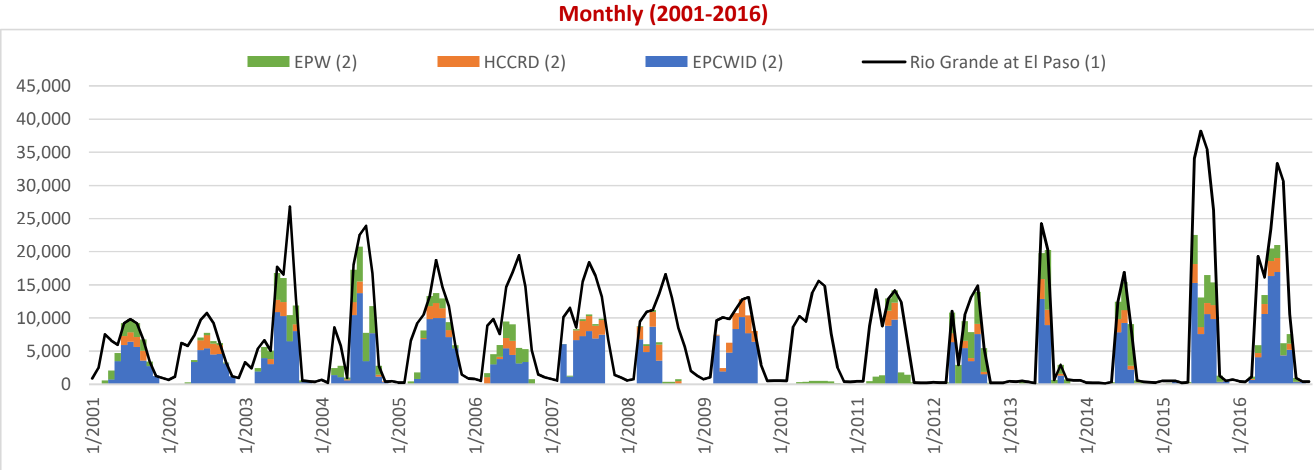
Figure 14-3

Increased Rio Grande at El Paso Flow and Increased Deliveries to Texas Water Users
Dorrance Analysis
(acre-feet)

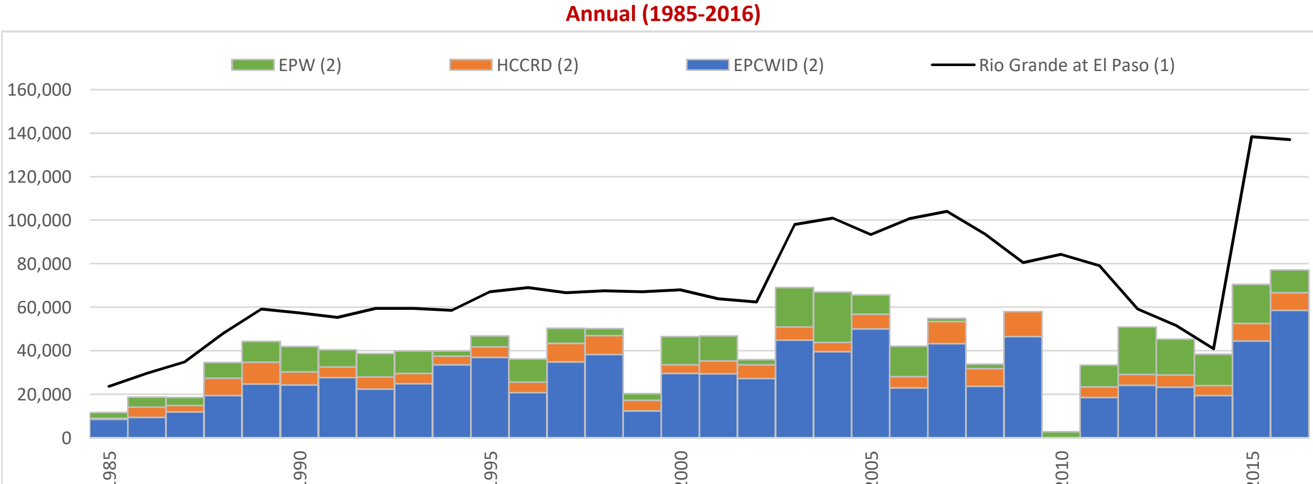
Monthly (1985-2000)



Monthly (2001-2016)



Annual (1985-2016)

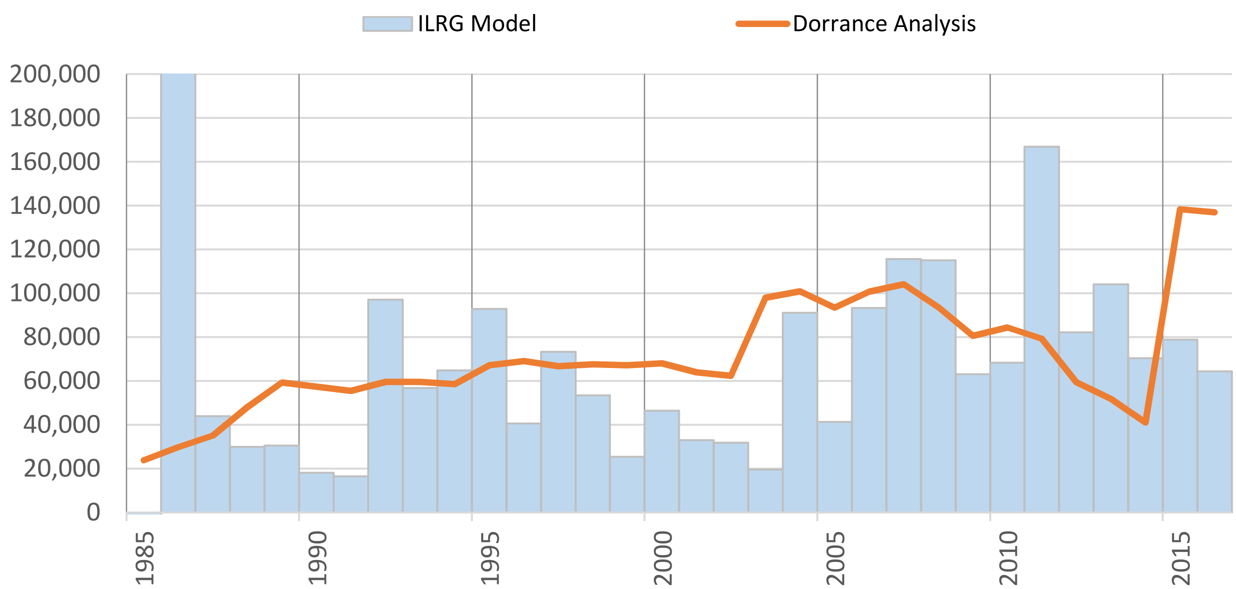


Notes:

(1) Increased Rio Grande at El Paso flow in 60% Rincon-Mesilla pumping reduction scenario simulated in Texas Model.
(2) Amounts of increased Rio Grande at El Paso flow assumed delivered to Texas water users to replace historical pumping.

Figure 14-4

Annual Impact of Pumping on Rio Grande at El Paso Flows
Integrated LRG Model (No NM Pumping)
vs.
Dorrance (60% Reduction in R-M Pumping)
(acre-feet)

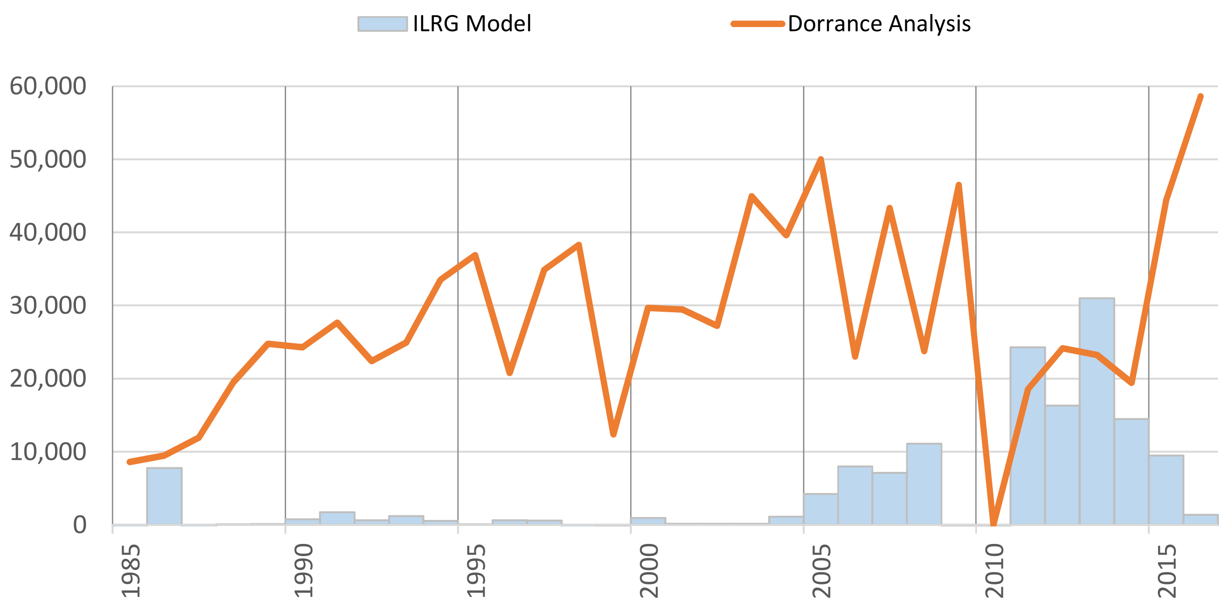


	(1) ILRG Model (No NM Pump)	(2) Dorrance (60% Reduction)
1985 - 2016 Average Annual (af):	74,402	71,232

Notes:
(1) ILRG Model change computed as flows in Run 3 (no New Mexico pumping) minus Run 1 (all pumping on).
(2) Dorrance change computed as the increase in El Paso gage flows (Texas Model simulation of 60% reduction in R-M pumping minus historical El Paso gage flows) from 1985 - 2016 only.

Figure 14-5

Annual Impact of Pumping on EPCWID Irrigation Deliveries
Integrated LRG Model (No NM Pumping)
vs.
Dorrance (60% Reduction in R-M Pumping)
(acre-feet)



	(1) ILRG Model (No NM Pump)	(2) Dorrance (60% Reduction)
1985 - 2016 Average Annual (af):	4,084	28,007

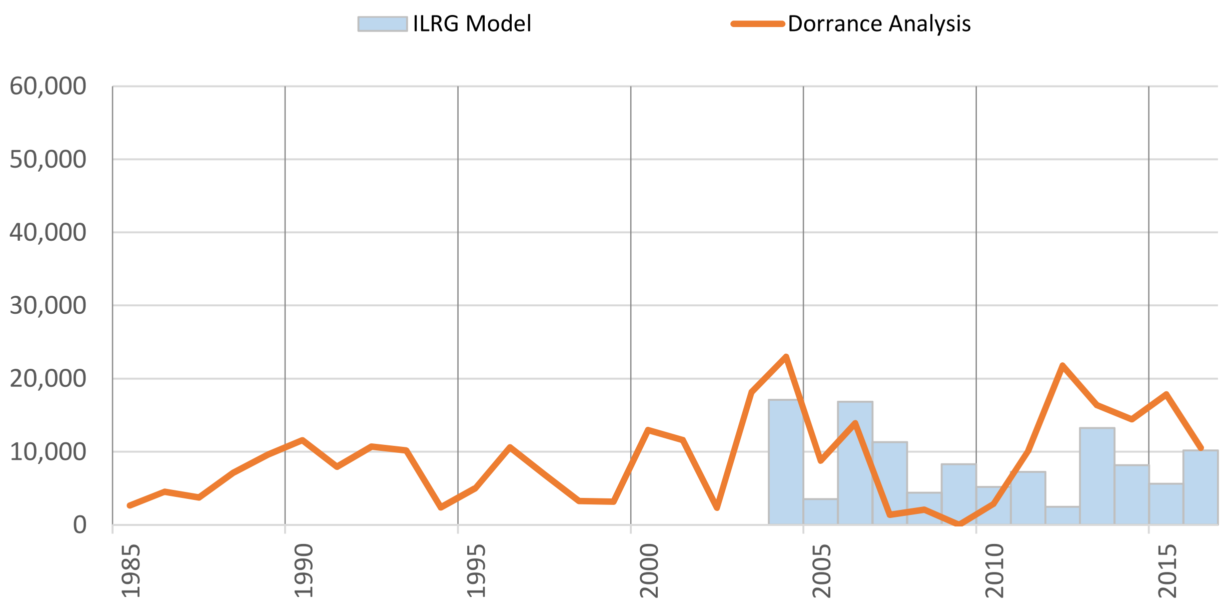
Notes:

(1) ILRG Model change computed as the El Paso Valley EPCWID farm deliveries in Run 3 (no New Mexico pumping) minus Run 1 (all pumping on).

(2) Dorrance change computed as the increase in El Paso gage flows (Texas Model simulation of 60% reduction in R-M pumping minus historical El Paso gage flows) distributed monthly using historical ratios of monthly to annual El Paso flows and ratios to historical EPCWID El Paso Valley deliveries.

Figure 14-6

Annual Impact of Pumping on EPW Deliveries
Integrated LRG Model (No NM Pumping)
vs.
Dorrance (60% Reduction in R-M Pumping)
(acre-feet)



	(1) ILRG Model (No NM Pump)	(2) Dorrance (60% Reduction)
1985 - 2016 Average Annual (af):	3,547	8,984

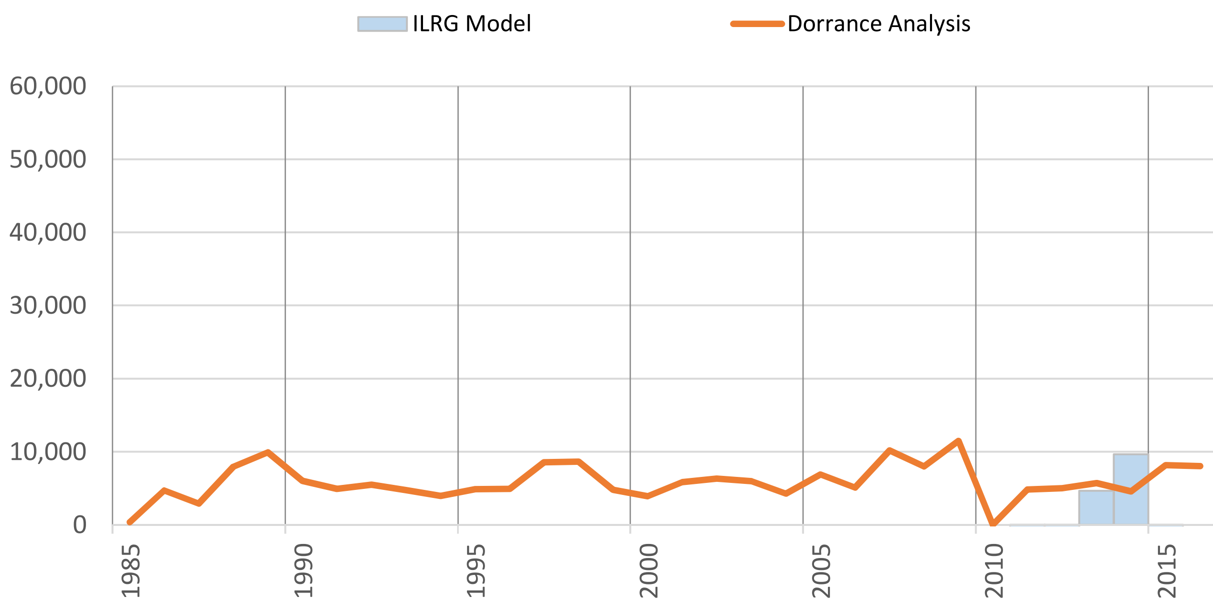
Notes:

(1) ILRG Model change computed as flows in Run 3 (no New Mexico pumping) minus Run 1 (all pumping on).

(2) Dorrance change computed as the increase in El Paso gage flows (Texas Model simulation of 60% reduction in R-M pumping minus historical El Paso gage flows) distributed monthly using historical ratios of monthly to annual El Paso flows and ratios to historical EPW deliveries. EPW deliveries limited maximum historical monthly deliveries.

Figure 14-7

Annual Impact of Pumping on HCCRD Deliveries
Integrated LRG Model (No NM Pumping)
vs.
Dorrance (60% Reduction in R-M Pumping)
(acre-feet)



	(1) ILRG Model (No NM Pump)	(2) Dorrance (60% Reduction)
1985 - 2016 Average Annual (af):	223	5,844

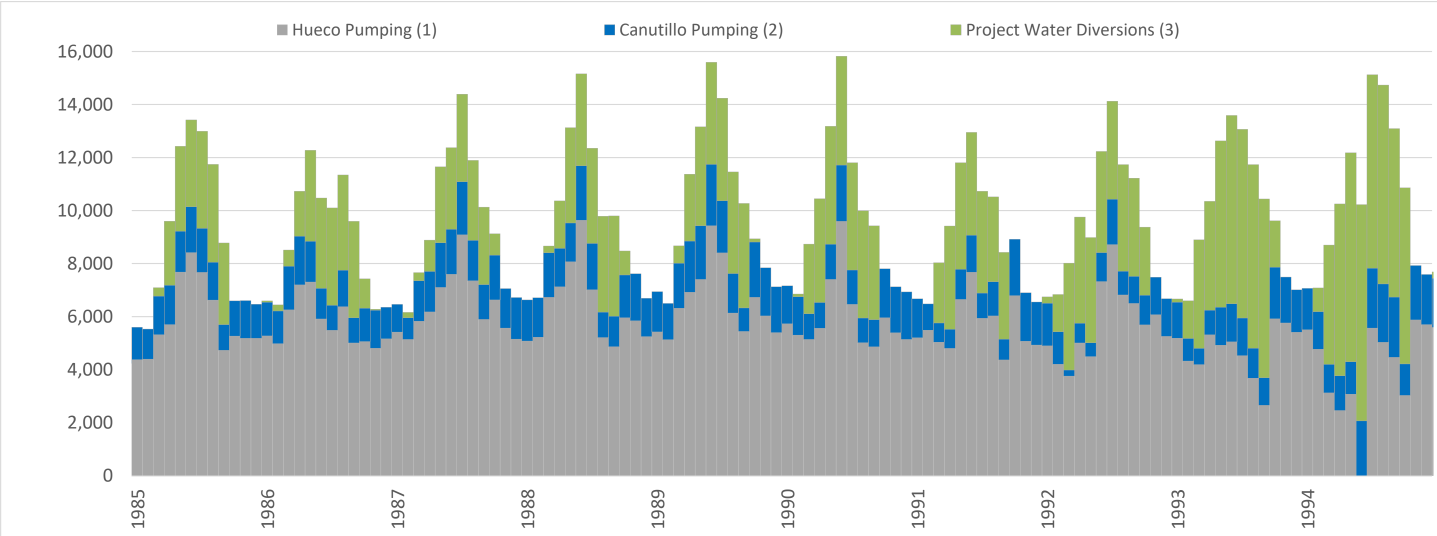
Notes:

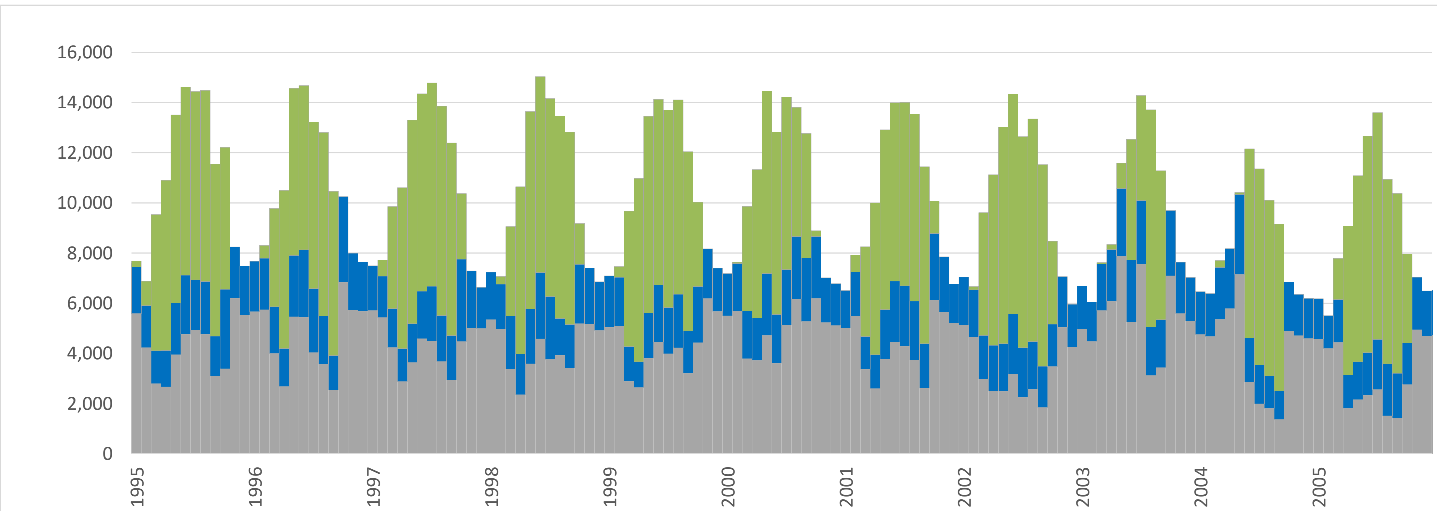
(1) ILRG Model change computed as the HCCRD farm deliveries in Run 3 (no New Mexico pumping) minus Run 1 (all pumping on).

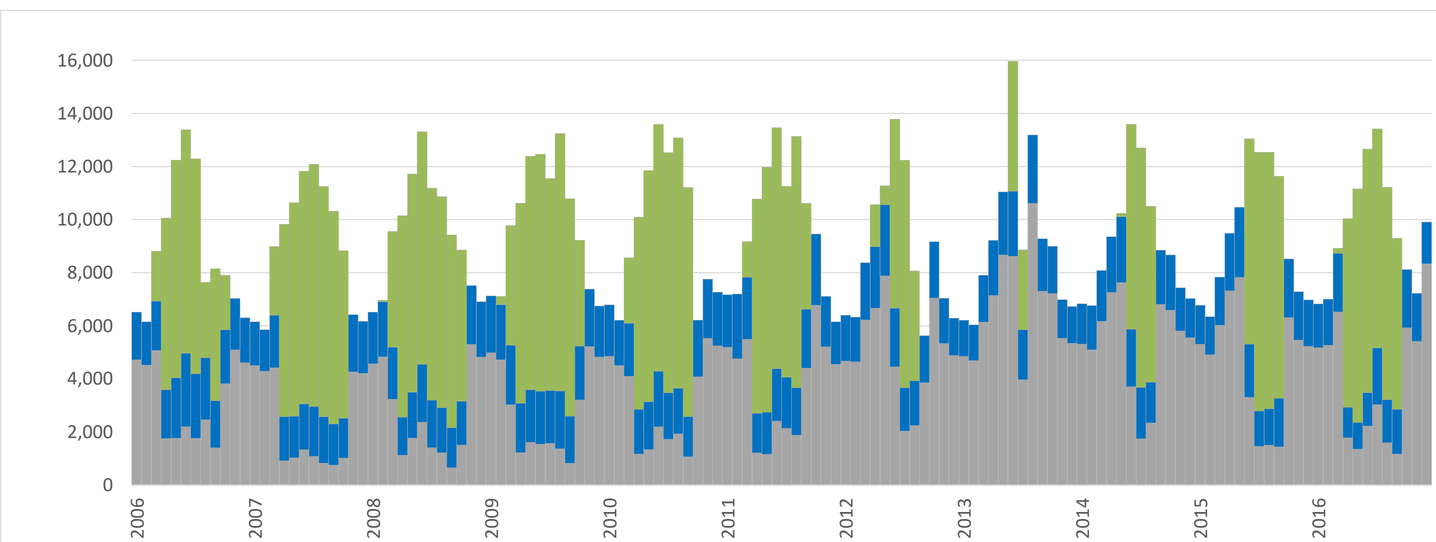
(2) Dorrance change computed as the increase in El Paso gage flows (Texas Model simulation of 60% reduction in R-M pumping minus historical El Paso gage flows) distributed monthly using historical ratios of monthly to annual El Paso flows and ratios to historical HCCRD deliveries.

Figure 15-1

Historical Monthly EPW Diversions
1985 - 2016
(acre-feet)







Notes:
(1) Data supplied by MMA (6/25/2019).
(2) Data supplied by SSPA (7/2/2019).
(3) Data from LRG SWDataSet.

TABLES

Table 3-1
Summary of Flow Measurement Sites for Surface Water Dataset
Rio Grande Project, Hudspeth County, and Mexico

	(1)	(2)	(3)	(4)	(5)	(6)	(7)		(8)
Location/ Basin	**Measurement Site**	**Gage No. /NPDES**	**OSE SW Dataset Site No.**	**Avail. Period of Record**	**Location Known**	**Start Date**	**Avg Ann Flow (af)**	**(cfs)**	**Estimated Records**
				River Gages					
Project Inflows	Rio Grande at San Marcial (old)	8358500	1R-42.0	1899-1964	Y		802,827	1,109	
	Rio Grande at San Marcial (conveyance)	8358300		1951-2017	Y		242,759	335	
	Rio Grande at San Marcial (flood)	8358400		1949-2017	Y		469,281	648	
	Rio Grande below Elephant Butte Dam	8361000	1R1.1	1913-2017	Y		712,431	984	
	Rio Grande below Caballo Dam	8362500	1R28.3	1938-2017	Y		651,805	900	
Rincon	Rio Grande below Percha Dam		2R30.0	1922-1937	Y		832,210	1,149	
	Rio Grande at Haynor Bridge	8363300	4R200.1	2000-2005	Y		580,351	802	
	Rio Grande at Tonuco		2R62.0	2000-2003			639,175	883	
Leasburg	Rio Grande above Leasburg Dam		2R74.6	1924-1983			642,435	887	
	Rio Grande below Leasburg Dam	8363500	3R75.1	1919-2017	Y		497,755	688	
	Rio Grande at Picacho Bridge		3R89.2	1991-2005	Y		569,053	786	
	Las Cruces Arroyo near Las Cruces	8363600	LCA.1A	1958-1966	Y		58	0	
Mesilla	Rio Grande below Mesilla Dam	RGBMES	4R96.6	1980-2017	Y		269,811	373	
	Rio Grande at Vado Bridge		4R107.2	1985-1995	Y		451,721	624	
	Rio Grande at Anthony		4R115.8	1986-2011	Y		428,648	592	
	Rio Grande at Vinton Bridge	8363840	4R119.2	1970-1991	Y		401,138	554	
	Rio Grande at Canutillo Bridge	8363900	4R122.3	1985-2017	Y		364,945	504	
El Paso	Rio Grande at El Paso (Courchesne)	8364000	4R133.4	1889-2017	Y		515,875	713	
	Rio Grande below American Dam	8365000	5R135.1	1938-2017	Y		104,489	144	
	Rio Grande at Juarez Station			1938-1956	*		286,343	396	
	Rio Grande at Island Station			1938-1984	Y		52,578	73	
	Rio Grande at Tornillo Bridge Station			1931-1938	Y		140,691	194	
Hudspeth	Rio Grande at County Line Station			1938-1984	*		85,380	118	
	Rio Grande at Fort Quitman	8370500	8370500	1923-2017	Y		148,854	206	
El Paso	Rio Grande at Coffer Dam		5R000.0	1988-2009			28,026	39	
				Canals and Laterals					
Other	Bonita Lateral		1C27.5	1938-2017	Y		1,050	2	
Rincon	Arrey Canal		2C29.5A	1918-2017	Y		79,399	163	
	Percha Canal (Lateral)		2C29.5B	1953-2017	Y		713	1	
	Hatch Main Canal		2C44.4	2001-2002	Y		29,094	60	
Leasburg	Irrigation above Leasburg Heading		3CA	1984-1988			1,061	2	
	Leasburg Canal (above or below 1st check)			1908-1935	n/a		214,410	441	
	Leasburg Canal Above 1st Check		3C73.1	1936-1998	Y		218,561	450	
	Leasburg Canal (net diversion blw 1st check)		3C74.8	1936-2017	Y		126,160	260	
	Las Cruces Lateral		3C87.3	2001-2002	Y		13,425	28	
	California Extension		3C94.5	1985-2017	*		284	1	
	Green and Duran River Pumps		P	1985-2017			259	1	
Mesilla	Westside Canal		4C95.8A	1916-2017	Y		176,021	362	
	Eastside Canal		4C95.8B	1916-2017	Y		68,078	140	
	Del Rio Lateral		4C95.8C	1955-2017	Y		2,905	6	
	Three Saints Lateral		4C108.6	1979-2017	Y		33,010	68	
	La Union East Lateral		4C115.3A	1979-2017	Y		46,680	96	
	La Union West Lateral		4C115.3B	1979-2017	Y		5,595	12	
	Three Saints West Lateral		4C118.6	1979-2005	Y		5,703	12	
	Canutillo Lateral		4C130.4	1979-1982	*		15,686	32	
El Paso	American Canal	8364500	5C135.1A	1938-2017	Y	1938	277,804	572	1990
	Franklin Canal		5C135.1B	1903-2017	*	1889	95,611	197	1903-1913, 1917**
	Riverside Canal	8366400	5C151.8A	1928-2017	Y	1928	184,356	379	**
Mexico	Acequia Madre		5C137.2	1903-2017	Y	1800s?	60,655	125	1903-1923,1926-1929, 1937
	River Diversions			1903-1984			25,342	52	1903-1929, 1937, 1948-1949
Mexico	Acequia Madre en el Sauzal			1938-1956			5,581	11	
Hudspeth	Tornillo Canal at Alamo Alto		9TC.1A	1947-2017	Y	1947	18,601	38	1995-1996**
	Hudspeth Feeder Canal	8368900	6C	1947-2017	Y	1947	42,960	88	2011-2012**
	Tornillo Canal	8368300	9TC.1B	1924-1999	Y	1924	78,160	161	
	Tornillo Waste End			1924-1947		1924	16,923	35	

Table 3-1
Summary of Flow Measurement Sites for Surface Water Dataset
Rio Grande Project, Hudspeth County, and Mexico

Location/ Basin	(1) Measurement Site	(2) Gage No. /NPDES	(3) OSE SW Dataset Site No.	(4) Avail. Period of Record	(5) Location Known	(6) Start Date	(7) Avg Ann Flow (af)	(7) Avg Ann Flow (cfs)	(8) Estimated Records
	Canals and Laterals (cont.)								
Hudspeth	Tornillo Canal near Alamo Check			1947-1949		1947	26,056	54	
(cont.)	End of Tornillo Canal			1925-1955		1925	42,721	88	1925-1934
	Drains								
Rincon	Garfield Drain		2D48.4	1923-2005	Y		6,300	0	
	Hatch Drain		2D54.2	1923-2005	Y		6,156	12	
	Angostura Drain		2D58.8	1926-1983	Y		1,257	11	
	Rincon Drain		2D65.0	1925-2005	Y		6,616	2	
Leasburg	Selden Drain		3D79.2	1923-1983	Y		1,785	12	
	Leasburg Drain		Leasburg Drain	1923-1983	Y		4,595	3	
	Picacho Drain		3D94.4	1923-2005	Y		3,905	8	
	Mesilla Drain		4D108.2B	1923-1983	Y		4,048	7	
Mesilla	Santo Tomas River Drain		4D102.0	1985-1990	Y		1,449	7	
	Santo Tomas Drain		4D102.1	1980-1985			494	3	
	La Mesa Drain		4D112.8A	1923-2013	Y		19,583	1	
	Chamberino Drain		4D112.8B	1923-2013	Y		18,045	36	
	Del Rio Drain		4D108.2A	1923-1983	Y		1,784	33	
	Mesquite Drain		4D109.5	1923-2013	Y		9,102	3	
	East Drain		4D118.6C	1923-2013	Y		43,602	17	
	Anthony Drain		4D118.6B	1997-2001	Y		4,012	80	
	East Drain (EPCWID)		4D118.6A	1930-2013	Y		12,566	7	
	West Drain		4D131.8A	1923-2005	Y		2,207	23	
	Nemexas Drain		4D131.8B	1923-2017	Y		41,603	4	
	Montoya Drain		4D133.0A	1923-2017	Y		14,244	76	
	Montoya Intercepting Drain		4D133.0C	1985-1990			3,111	26	
El Paso	Franklin Drain		Franklin Drain	1921-1983	Y	1918	17,082	6	
	Playa Drain		Playa Drain	1923-1983	Y	1920	11,824	31	
	Middle Drain		Middle Drain	1921-1983	Y	1917	26,446	22	
	River Drain		River Drain	1923-1983	Y	1917	9,964	48	
	Cuadrilla Drain		Cuadrilla drain	1931-1983	Y	1924	3,100	18	
	Mesa Drain		Mesa Drain	1921-1983	Y	1918	9,054	6	
	Fabens Intercepting Drain		Fabens Intercepting	1931-1971	Y	1928	2,405	0	
	Border Drain		Border Drain	1923-1983	Y		6,809	4	
	Island Drain		Island Drain	1921-1983	Y	1920	8,424	12	
	Island Syphon Drain		Island Syphon Drain	1936-1983	Y	1920?	17,874	15	
	Alamo Alto Drain		Alamo Alto Drain	1925-1983	Y	1924	6,628	33	
	Drain Water Diverted at Fabens			1945-1982		1945	6,309	12	Est. monthly
Hudspeth	Fabens Waste Drain		10CFWD.1A	1984-2017	Y	1936?	32,401	12	
	Fabens Drain		Fabens Drain	1923-1983	Y	6/1921	5,571	59	
	Tornillo Drain	8368000	9TD.1A	1923-2017	Y	12/1922	31,067	10	
Juarez	Dren de Descarga			1938-1956			4,489	57	
	Dren de Interceptacion			1938-1956			12,814	8	
	Wasteways								
Rincon	WW No. 5 – Hatch Siphon		2W44.4	1979-2017	Y		4,575	9	
	WW No. 16 – Hatch Canal		2W52.9	1979-2017	Y		2,942	6	
	WW No. 18 – Rincon Lateral		2W61.2	1979-2017	Y		1,940	4	
Leasburg	WW No. 1A – Leasburg Canal			1989-2002			76,765	158	
	WW No. 1 – Leasburg Canal		3W74.8	1992-2002	*		14,662	30	
	WW No. 3 – Picacho Lateral		3W84.0	2001-2017	*		2,338	5	
	WW No. 5 – Leasburg Canal		3W85.0	1979-2017	Y		2,559	5	
	WW No. 8 – Leasburg Canal		3W87.3	1979-2017	Y		6,610	14	
	WW No. 40 – Picacho Lateral		3W91.6	1991-2017	Y		2,008	4	
	WW No. 13 – California Extension		3W94.5A	1984-1991	Y		597	1	
Mesilla	WW 25 – Santo Tomas Lateral		4W98.4	1985-2001	Y		1,507	3	
	WW 26 – Upper Chamberino Lateral		4W102.0	1979-2003	Y		1,288	3	
	WW 30 – Chamberino East Lateral		4W102.8	1985-2003	*		2,840	6	
	WW 31 – La Union Main Canal		4W103.2	1981-2003	Y		3,230	7	
	WW 31B – Jimenez Lateral		4W105.8	1985-2003	Y		455	1	
	WW 32 – La Union East Lateral		4W109.2	1979-2017	Y		11,279	23	

Table 3-1
Summary of Flow Measurement Sites for Surface Water Dataset
Rio Grande Project, Hudspeth County, and Mexico

Location/ Basin	(1) Measurement Site	(2) Gage No. /NPDES	(3) OSE SW Dataset Site No.	(4) Avail. Period of Record	(5) Location Known	(6) Start Date	(7) Avg Ann Flow (af)	(cfs)	(8) Estimated Records
	Wasteways (cont.)								
Mesilla	WW 32A – Rowley Lateral		4W111.0	1985-1988	*		242	0	
(cont.)	WW 32B – Vinton Cutoff Lateral		4W113.0	1985-2017	*		2,288	5	
	WW 34 – Canutillo Lateral		4W113.1	1983-2017	*		2,619	5	
	WW 34A – Pence Lateral		4W115.2	1985-1988	Y		329	1	
	WW 35 – Westside Canal		4W115.3	1980-2017	Y		5,639	12	
	WW 35C – Schutz Lateral		4W116.1	1985-1988	Y		638	1	
	WW 15 – Eastside Canal		4W117.1	1985-2003	*		2,336	5	
	WW 16B – Brazito Lateral		4W118.5	1985-1990	Y		1,869	4	
	WW 18 – Eastside Canal		4W121.0	1985-2003	*		2,671	5	
	WW 19 – Three Saints Lateral		4W124.5	1982-2003	Y		823	2	
	WW 20 – Three Saints West Lateral		4W125.2	1979-1988	Y		262	1	
	WW 21 – Three Saints West Lateral		4W125.7	1985-2003	*		2,747	6	
	WW 23A – Three Saints Lateral		4W127.2	1985-2017	Y		2,333	5	
	WW 36 – Montoya Lateral		4W129.1	1985-2017	Y		1,078	2	
	WW 38 – Montoya Lateral		4W133.0B	1985-2017	*		2,027	4	
El Paso	Leon Street WW			1938-1999	*	1938?	87,427	180	6/1938-2/1999
	Franklin Settling Basin WW			1938-1999	*	1938?	87,427	180	6/1938-2/1999
	Santa Fe WW (El Paso Electric)			1940-1960	*	1938?	528	1	
	Ascarate WW		5W144.1	1916-2017	Y	1916?	27,722	57	1916-1937**
	Riverside WW No. 1		4W10.RC1	1928-2017	*	1928?	11,572	24	1928-1937, 1956-1980, 1985-1992, 2004**
	Riverside WW No. 2		4W10.RC2	1930-2017	*	1930?	9,691	20	1930-1937, 1956-1980, 1985-1992, 2004**
Hudspeth	Fabens Waste Channel		10CFWC.1	1935-2017	*	1935?	48,954	101	1935-1937**
	Tornillo Canal WW No. 1		9TC.1W	1981-2017	*	1936?	47,612	98	
	Municipal								
Rincon	Hatch WWTP	NM0020010		1940-2017	Y		153	0	1940-1999**
	Salem WWTP	NM0030457		2003-2017	Y	2003	41	0	
Leasburg	City of Las Cruces WWTP	NM0023311	3D90.5	1976-2017	Y		7,631	11	**
	Las Cruces East Mesa WRF	NM0030872		2010-2017	Y	2010	232	0	
	Total Las Cruces WWTP			**1940-2017**			**5,011**	**7**	**1940-1975**
Mesilla	South Central Regional WWTP	NM0030490		2003-2017	Y	2003	309	0	
	Anthony WWTP	NM0029629		1989-2017	Y	1989?	510	1	1989-2001**
	Sunland Park WWTP	NM0000108		1987-2017	Y	2002?	1,205	2	**
	El Paso Electric	NM0029483		1950-2017	Y	1950?	1,053	1	1950-2003**
	Gadsden Independent School District	NM0028487		1992-2017	Y	1992?	12	0	1992-2002**
	Total Sunland Park + Santa Teresa			**1972-2017**		**1972?**	**1,414**	**2**	**1972-2003**
El Paso	Northwest WWTP	TX0087149		1987-2017	Y	1987	5,663	8	1987-8/2002**
	Umbenhauer-Robertson WTP	n/a		1943-2017	*	11/1943	12,710	18	11/1943-2006**
	Haskell WWTP to Rio Grande	TX0026751		1923-2017	Y	1923	14,969	21	1923-1935, 1976, 1998**
	Jonathan Rogers WTP	n/a		1993-2017	*	1993	27,209	56	1993-2006**
	Total City of El Paso WTP	**n/a**		**1943-2017**		**1943**	**21,024**	**43**	
	Bustamante WWTP to Rio Grande/Drain	TX0101605		1991-2017	Y	1991	9,569	13	1991-8/1995**
	Fabens WWTP	TX0065013		2001-2017	Y		528	1	
	Haskell WWTP to ACE	TX0026751		1998-2017	Y	10/1998	16,411	23	**
	Total Haskell WWTP	**TX0026751**		**1923-2017**		**11/1943**	**16,522**	**23**	
	Bustamante WWTP to Riverside Canal	TX0101605		1991-2017	Y	1991	20,564	28	1991-8/1995**
	Total Bustamante WWTP	**TX0101605**		**1991-2017**		**1991**	**30,133**	**42**	
	Socorro WWTP	TX0026778		1967-1993	*	1967?	20,232	28	1967 - 1988**
	Total City of El Paso WWTP	**n/a**		**1923-2017**			**32,043**	**44**	
	Anthony TX WWTP	TX0090522		1953-2017	Y	1953?	235	0	1953-2004**
Mexico	Juarez Sewage to Rio Grande			1940-1950			344	0	
	Juarez Sewage to Canals			1926-2017			24,624	34	1926-1949, 1985-2017
	Juarez North Plant & South Plant								

Table 3-1
Summary of Flow Measurement Sites for Surface Water Dataset
Rio Grande Project, Hudspeth County, and Mexico

Location/ Basin	(1) Measurement Site	(2) Gage No. /NPDES	(3) OSE SW Dataset Site No.	(4) Avail. Period of Record	(5) Location Known	(6) Start Date	(7) Avg Ann Flow (af)	(7) Avg Ann Flow (cfs)	(8) Estimated Records
	Reservoir								
Elephant Butte Reservoir	Elephant Butte Reservoir End-of-Month Storage			1915 - 2017	n/a		888,827		
	Elephant Butte Reservoir Releases			1940 - 2017	n/a		658,362	1,355	
	Elephant Butte Reservoir Pan Evaporation (inches)			1940 - 2017	n/a		117		
	Elephant Butte Reservoir Precipitation (inches)			1940 - 2017	n/a		9		
Caballo Reservoir	Caballo Reservoir End-of-Month Storage			1938 - 2017	n/a		76,175		
	Caballo Reservoir Releases			1940 - 2017	n/a		648,257	1,334	
	Caballo Reservoir Pan Evaporation (inches)			1940 - 2017	n/a		111		
	Caballo Reservoir Precipitation (inches)			1940 - 2017	n/a		10		
	Bonito Ditch Blw Caballo			1940 - 2017	n/a		1,036	2	
New Mexico	Annual Otowi Index Supply			1940 - 2017	n/a		990,377		
	New Mexico Annual EOY Accrued Debit/Credit			1940 - 2017	n/a		49,662		
	New Mexico Annual Credit Water Relinquishment			1940 - 2017	n/a		11,759		
Colorado	Colorado Annual EOY Accrued Debit/Credit			1940 - 2017	n/a		-159,910		
	Colorado Annual Credit Water Relinquishment			1940 - 2017	n/a		205		
San Juan Chama Pool	San Juan Chama Deliveries			1975 - 2017	n/a		5,232		
	San Juan Chama Evaporative Losses			1975 - 2017	n/a		2,506		
	San Juan Chama EOY Pool Storage			1975 - 2017	n/a		23,099		
	Irrigation Pumping								
New Mexico	EBID Annual Irrigation Pumping			2009 - 2018	n/a		218,800		
Texas	EPCWID Annual Irrigation Pumping								
	HCCRD Annual Irrigation Pumping								
Mexico	Juarez Annual Irrigation Pumping								

Notes:

Data from Bureau of Reclamation accounting is typically irrigation season only and may not contain any winter diversions.

(1) Availability of data has not yet been determined.
Annual data only or only annual data available for certain years.
Blue text indicates that records for this gage have been updated through 2017.
(2) Gage numbers from U.S.G.S. or IBWC for river gages and some canals and NPDES permit numbers for WWTP returns
(3) Unique identifier from the NM OSE database.
(4) Period of data record in data compilation. There may be missing data within the available period of record.
(5) Y = location known from USGS, EBID, IBWC, or GPS coordinates.
* = approximate location known.
(6) Approximate start date of site (structure/gage/outfall).
(7) Average annual volume throughout period of available records. Annual volume converted to a rate assuming the volumes for river gages and WWTP returns are year-round (365 days); canal diverisons, wasteways, WTP diversions, and reservoir releases occur for an average of 245 days per year; and, drain flows occur for an average of 275 days per year.
(8) Records for periods of missing data estimated for use in modeling. Efforts are ongoing to obtain actual flow data for the missing records.
** = one or more additional missing months in dataset.

Table 3-2
Summary of Backup Data Sources for Surface Water DataSet

Source Code	Entity	Period of Record			Summary	Location
LRG.Doc.SW001	EBID	1993	-	2000	Daily flow records	NM
LRG.Doc.SW002	EBID	1930	-	2000	Monthly drain flow data	NM
LRG.Doc.SW003	USBR	1995	-	2002	Daily flow and storage data	NM, TX
LRG.Doc.SW004	USGS	1916	-	2004	Daily flow data	NM, TX
LRG.Doc.SW005	IBWC	1889	-	2004	Daily flow data	NM, TX
LRG.Doc.SW006	USBR	1923	-	1983	Monthly drain flow data	NM, TX
LRG.Doc.SW007	Boyle-Parsons/SSPA	1889	-	1996	Boyle-Parsons data compilation with SSPA updates	NM, TX, Mexico
LRG.Doc.SW008	EBID	2001	-	2002	Annual allotment charges (accounting)	NM, TX
LRG.Doc.SW016	NMSU	1889	-	2004	Daily flow data (NMSU, 2004)	NM, TX, Mexico
LRG.Doc.SW020	USGS	1899	-	2007	Daily flow data	NM, TX
LRG.Doc.SW022	EBID	2004	-	2005	Daily flow data	NM
LRG.Doc.SW025	NMOSE	1900	-	2005	Daily flow data with monthly aggregation	NM, TX, Mexico
LRG.Doc.SW026	EBID	2004	-	2005	Daily flow data	NM
LRG.Doc.SW027	EPCWID	2003	-	2006	Daily flow data	TX
LRG.Doc.SW100	USGS	1899	-	2014	Daily river flow data	NM, TX
LRG.Doc.SW101	IBWC	1889	-	2017	Daily flow data	NM, TX, Mexico
LRG.Doc.SW102	IBWC	1931	-	2017	Monthly and annual flow data	NM, TX, Mexico
LRG.Doc.SW103	USBR	1999	-	2010	Monthly accounting data	NM, TX
LRG.Doc.SW104	USBR	2006	-	2011	Daily and monthly accounting data	NM, TX
LRG.Doc.SW105	USBR	2011	-	2018	Daily and monthly accounting data	NM, TX
LRG.Doc.SW106	USBR	1979	-	2010	Daily and monthly accounting data	NM, TX
LRG.Doc.SW107	EPA	1995	-	2017	Average monthly discharge data	NM, TX
LRG.Doc.SW108	RGCC	1940	-	2017	Monthly reservoir data	NM
LRG.Doc.SW109	USBR	1938	-	2016	Monthly Water Distribution Report data	NM, TX
LRG.Doc.SW110	EBID	2008	-	2018	Daily telemetry flow data	NM
LRG.Doc.SW111	USBR	1923	-	1983	Drain flow data	NM, TX
LRG.Doc.SW112	NMOSE	1947	-	2010	Hudspeth Feeder Canal daily flow data	TX
LRG.Doc.SW113	PDNWC	1942	-	2008	Daily flow data	TX
LRG.Doc.SW114	IBWC	1950	-	1984	Monthly data	TX, Mexico
LRG.Doc.SW115	NMSU Vol. 3	1950	-	1984	Annual data	NM, TX, Mexico
LRG.Doc.SW116	SHRA	1924	-	1925	Data from SHRA archive research	Mexico
LRG.Doc.SW117	U.S. NRC	1900s	-	1937	Data from the RGJI (U.S. NRC, February 1938)	NM, TX, Mexico
LRG.Doc.SW118	SWE	1903	-	2017	Missing data calculations	NM, TX, Mexico
LRG.Doc.SW119	NMOSE	1908	-	2013	Correction/clarification on Leasburg Canal data	NM
LRG.Doc.SW120	MMA	1925	-	2004	Correction of Tornillo Canal at Alamo Alto data	TX
LRG.Doc.SW121	Carreno 1957	1938	-	1947	Annual river diversions	Mexico
LRG.Doc.SW122	USBR	1923	-	1983	Drain notes and drain flow data (USBR).	NM, TX
LRG.Doc.SW123	USACE	1975	-	2011	USACE - URGWOM data provided by Hydros Consulting.	NM
LRG.Doc.SW124	USGS	1940	-	2015	Flow input data from USGS RGTIHM GW model.	NM
LRG.Doc.SW125	United States	1908	-	2017	Flow data from from U.S. disclosures.	NM, TX, Mexico
LRG.Doc.SW126	U.S. NRC	1930	-	1939	Flow data from Rio Grande Project Histories.	NM, TX, Mexico
LRG.Doc.SW127	EPCWID	2004	-	2018	Flow & accounting data from EPCWID disclosures.	TX
LRG.Doc.SW128	EPW	2005	-	2018	Flow data from EPW disclosures.	TX
LRG.Doc.SW129	City of Las Cruces	2009	-	2017	Flow data from City of Las Cruces.	NM
LRG.Doc.SW130	NMOSE	2009	-	2018	Irrigation pumping data from NMOSE.	NM

Acronym	Full Name
EBID	Elephant Butte Irrigation District
EPCWID	El Paso County Water Improvement District No. 1
EPA	Environmental Protection Agency
EPW	El Paso Water
IBWC	International Boundary and Water Commission
MMA	McDonald-Morrissey and Associates, Inc.
NM	New Mexico
NMSU	New Mexico State University
NMOSE	New Mexico Office of the State Engineer
NMISC	New Mexico Interstate Stream Commission
NRC	Natural Resource Committee, Department of Interior
PDNWC	Paso del Norte Watershed Council
RGTIHM	Rio Grande Transboundary Integrated Hydrologic Model

Acronym	Full Name
RGCC	Rio Grande Compact Commission
PDNWC	Paso del Norte Watershed Council
RGCC	Rio Grande Compact Commission
RGJI	Rio Grande Joint Investigation
SHRA	Stevens Historical Research Associates
SSPA	S.S. Papadopoulos and Associates, Inc.
SWE	Spronk Water Engineers, Inc.
TX	Texas
USACE	United State Army Corps of Engineers
USBR	United States Bureau of Reclamation
USGS	United States Geological Survey
URGWOM	Upper Rio Grande Water Operations Model

Table 3-3
Summary of Estimated Data for Surface Water Dataset
Rio Grande Project, Hudspeth County, and Mexico
1903 - 2017

Structure	Start	Period of Record	Missing Data	Method for Estimating Missing Data
Canals - Hueco				
Acequia Madre	Pre-1903	1924 - 1925, 1930 - 1936, 6/1938 - 2006, 2008 - 2017	1903 - 1923, 1926 - 1929, 1937 - 5/1938, 2007	1903 -1923: Used 1924 - 1925 monthly regression with Courchesne gage capped at an estimated diversion capacity (300 cfs) and limited to season of use Mar 1 – Nov 30.
				1926 - 1929 and 1937: Used 1930 - 1936 monthly regression with Courchesne gage capped at an estimated diversion capacity (300 cfs) and limited to season of use Mar 1 – Nov 30.
				1/1938 – 5/1938: Used 1938 annual value less data for period of record in 1938 distributed from Mar - May using Franklin Canal flows.
				2007: Used reported 2007 annual diversion in Rio Grande Compact Commission Report distributed monthly using Franklin Canal diversions.
Franklin Canal	1889	1914 -1916, 1918 - 2017*	1903 – 1913, 1917	1903 -1913 and 1917: Used 1938 - 1949 monthly regression with Courchesne gage capped at an estimated diversion capacity (320 cfs) and limited to season of use Mar 1 – Nov 30. Do not have complete winter diversions in recent years - these winter diversions were not estimated.
Tornillo Canal at Alamo Alto	1947	1947 - 2016*	Various months 1995 – 1996 and 2004 – 2005	Various months 1995 - 1996 and 2004 - 2005: Used 1985 - 1994 monthly regression with Riverside Canal.
Hudspeth Feeder Canal	May-47	5/1947 - 2010	2011 - 2012	2011 - 2012: Used 2005 - 2010 monthly regression with Franklin Canal.
Hudspeth Canal (Tornillo End)	1925	1935 - 1947 (ann)	1925 - 1934	1925 - 1934: Estimated flow using water balance (Tornillo Canal heading flow less seepage loss (15%*Tornillo Canal heading) less crop demand for Tornillo acres (CIR*acres/irrigation efficiency) less Tornillo Waste End flows).
				1935 - 1947: Annual data distributed monthly using Tornillo Canal heading flows.

Table 3-3
Summary of Estimated Data for Surface Water Dataset
Rio Grande Project, Hudspeth County, and Mexico
1903 - 2017

Structure	Start	Period of Record	Missing Data	Method for Estimating Missing Data
Canals - Hueco (cont.)				
Juarez River Diversions (below International Dam)	Pre-1903	Annual estimates 1930-1936, 1938-1947, and 1950-1984	1903 - 1929, 1937, 1948-1949, 1985 - 2016	1903 - 1929: Estimated flows based minimum of unmet demand (Farm Budget spreadsheet) limited by estimated flow below International Dam (Courchesne minus Franklin Canal minus Acequia Madre) minus Riverside Canal when applicable.
				1930-1936, 1938-1947, and 1950-1984: Distributed annual estimates monthly using Acequia Madre flows.
				1937: Set equal to 1936 annual estimate.
				1948 - 1949: Estimated flows based on gage differences from Island Station to Fort Quitman.
				1985 - 2016: Did not estimate because there are no gage records.
Wasteways - Hueco				
Franklin Settling Basin WW	1938?	No data		6/1938 – 1998: Data provided by Peggy Barroll, NMOSE. Computed using water balance approach (American Canal diversions less Franklin Canal diversions less City of El Paso municipal diversions). Split total computed waste 50/50 between Franklin Settling Basin and Leon St. wasteways. Estimates do not consider transit losses.
Leon St WW	1938?	No data		
Ascarate WW	1916?	1938 - 1954 (ann), 1955 - 2005*	1916 - 1937, 2004, 2005 - 2017	1916 - 1937: Used annual regression (1938 - 1949) with Franklin Canal and distributed annual data into monthly values proportional to Franklin Canal flows.
				1938 - 1955: Distributed annual data into monthly values proportional to Franklin Canal flows.
				2004 and 2006 - 2017: Assumed no Ascarate Wasteway flows until more data become available due to little to zero flows reported since the completion of the American Canal Extension.

Table 3-3
Summary of Estimated Data for Surface Water Dataset
Rio Grande Project, Hudspeth County, and Mexico
1903 - 2017

Structure	Start	Period of Record	Missing Data	Method for Estimating Missing Data
Wasteways - Hueco (cont.)				
Riverside WW#1	1928?	1938 - 1955 (ann combined)**, 1981 - 1984, 1993 - 2017*	Pre-1938, 1956 - 1980,1985 - 1982, 2004	1928 – 1937: Used annual regression for combined Riverside WW#1 and WW#2 with Riverside Canal (1938 - 1949) and distributed annual data into monthly values using Riverside Canal diversions. Split between WW#1 and WW#2 using 1981 - 2013 average annual split. Assumed Riverside WW#2 flows do not start until 1930.
				1938 – 1955: Distributed annual data into monthly values proportional to Riverside Canal diversions. Split between WW#1 and WW#2 using 1981 – 2013 average annual split.
Riverside WW#2	1930?			1956 - 1980, 1985 - 1992, and 2004: Used annual regression for combined Riverside WW#1 and WW#2 with Riverside Canal (1991 - 2003) and distributed annual data into monthly values using Riverside Canal diversions. Split between WW#1 and WW#2 using 1981 - 2013 average annual split.
Municipal - Hueco				
Northwest WWTP Returns	1987	9/2002 - 2017*	1987 - 8/2002	1987 - 8/2002: Data provided by Nabil Shafike, NMISC - computed using regression with Mesilla EPWU ground water pumping.
Haskell WWTP Returns (1)	1923	1936 - 1939, 1940 - 1948**, 1949 - 1959, 1960 - 1975**, 1977 - 2017*	1923 - 1935, 1976, 1/1998 - 9/1998	1923 - 1935: Used annual 1936 - 1940 regression with EPWU pumping. Distributed annual data evenly in each month (divide by 12).
				1976: Used average 1975 and 1977 monthly flow data (i.e., Jan 1976 flow = average Jan 1975 and Jan 1977).
				1/1998 - 9/1998: Used average 1997 and 1999 monthly flow data.
Bustamante WWTP Returns	1991	9/1995 - 2017*	1991 – 8/1995	1991 - 1994: Annual volume derived from reported 1996 influent in gallons per day per capita scaled to Bustamante service area proportion of total City of El Paso population and subtracted Socorro WWTP flows (1991 - 1993). Annual volume divided by 12 to obtain monthly values.
				1/1995 - 8/1995: Annual reported value minus sum of remainder monthly flows (9/1995-12/1995) divided by 8.

Table 3-3
Summary of Estimated Data for Surface Water Dataset
Rio Grande Project, Hudspeth County, and Mexico
1903 - 2017

Structure	Start	Period of Record	Missing Data	Method for Estimating Missing Data
Municipal - Hueco (cont.)				
Socorro WWTP	1967?	1989 - 2/1993	1967 - 1988; 10/1991	1967 - 1988: Annual volume derived from reported 1996 influent in gallons per day per capita scaled to Bustamante service area proportion of total City of El Paso population. Annual volume divided by 12 to estimate monthly values.
				10/1991: Computed as average 9/1991 and 11/1991 flows.
Juarez Sewage to river	1926?	1940 - 1950 ann	1926 - 1939; 1951 - 2013	1926 - 1939: Data not estimated (not enough information available to estimate).
				1940 - 1950: Distributed annual reported estimates evenly into each month (divided by 12).
				1951 - 2013: Assume zero (discharge zero by late 1940s).
Juarez Sewage to canals	1926	1950 - 1984	1926 - 1949 and 1985 - 2017	1950 - 1984: Annual reported estimates divided by 12.
				1926 - 1949 and 1985 - 2017: Used JMAS pumping provided by MMA multiplied by 49% (same methodology as IBWC 1989 report) minus Juarez Sewage to river (1940 - 1950).
Robertson-Umbenhauer WTP (aka Canal St. WTP)	Nov-43	11/1943 - 2017**	Records for total El Paso WTP prior to 2007	1943 - 1992: Robertson-Umbenhauer WTP equal to total City of El Paso until Jonathan Rogers comes online in 1993.
Jonathan Rogers WTP	1993	1993 - 2017**		1993 - 2006: Split total City of El Paso into each WTP using distribution from available data from 2007 - 2013.
Fabens WWTP	2001	2001 - 2017**	1/2001 - 5/2001, 7/2004, 10/2004	1/2001 - 5/2001 , 7/2004, and 10/2004: Computed using monthly averages from prior and subsequent year.
Municipal - Rincon-Mesilla				
Hatch WWTP	1940	2000 - 2017*	1940 - 1999	1940 - 1999: Computed using regression with population (no pumping data available).
			1/2000 - 9/2000, 11/2005, 10/2013	1/2000 - 9/2000, 11/2005, and 10/2013: Computed using monthly averages from prior and subsequent year.
Las Cruces WWTP	1940	1976 - 2017*	1940 - 3/1976, 5/1979 - 6/1979, 4/1985, 9/1985 - 10/1985	1/1976 - 3/1976, 5/1979 - 6/1979, 4/1985, and 9/1985 - 10/1985: Computed using regression with pumping.
Anthony NM WWTP	1989	1989 - 2017*	1989-1995	1989 - 1995: Computed using regression with pumping.

Table 3-3
Summary of Estimated Data for Surface Water Dataset
Rio Grande Project, Hudspeth County, and Mexico
1903 - 2017

Structure	Start	Period of Record	Missing Data	Method for Estimating Missing Data
Municipal - Rincon-Mesilla (cont.)				
Anthony TX WWTP	1953	1953 - 2017*	1953-2004, 1/2005-4/2005, 2/2006, 11/2006, 8/2007, 8/2016-12/2017	1953 - 2004: Computed using regression with pumping. 1/2005 - 4/2005, 2/2006, 11/2006, 8/2007, and 8/2016 - 12/2017: Computed using monthly averages from prior and subsequent year.
El Paso Electric WWTP	1950	1950 - 2017*	1950 - 2003, 2/2005, 10/2005 - 12/2005, 8/2006, 5/2009	1950 - 2003, 2/2005, 10-12/2005, 8/2006, 5/2009: Computed using regression with pumping. 2/2005, 10/2005 - 12/2005, 8/2006, and 5/2009: Computed using monthly averages from prior and subsequent year.
Gadsden School District WWTP	1992	1992 - 2017*	1/2016 - 4/2016, 11/2016, 1/2017, 6/2017, 12/2017	1/2016 - 4/2016, 11/2016, 1/2017, 6/2017, 12/2017: Computed using monthly averages from prior and subsequent year.
Total Sunland Park + Santa Teresa	1972	2004 - 2017	1972 - 2003	1972 - 2003: Computed using monthly averages from prior and subsequent year.

Notes:
All estimated data calculations in source folder: LRG.Doc.SW118.
*Missing months of data within period of record.
**Records combined with other flows, split total diversions out by structure.
(1) Records from 1940 - 1948 and 1960 - 1975 include Ascarate and Yselta EPCWID plant discharges.
(2) Annual estimates from Rio Grande Joint Investigations (1938), Carreno (1957), and IBWC (1989).

Table 4-1
Annual Farm Headgate Deliveries
Water Distribution Report Data
1938 - 2017 (acre-feet)

Year	Rincon (EBID)	Leasburg (EBID)	Mesilla (EBID + EPCWID)	Total Leasburg-Mesilla (EBID)	Mesilla East (EBID)	Mesilla West (EBID)	Total EBID	Mesilla East TX (EPCWID)	Mesilla West TX (EPCWID)	El Paso Valley (EPCWID)	Total EPCWID	HCCRD
1938	33,707	79,893	133,086	192,852	38,172	74,786	226,559	2,206	17,921	122,842	142,969	
1939	39,913	94,143	153,707	224,180	45,052	84,985	264,093	2,683	20,987	148,996	172,666	
1940	41,123	89,823	151,043	217,728	44,807	83,098	258,851	2,662	20,475	154,284	177,422	
1941	35,145	74,238	128,967	183,629	36,909	72,482	218,774	2,141	17,435	117,414	136,990	
1942	41,593	79,425	136,299	195,449	40,489	75,535	237,042	2,321	17,954	126,240	146,515	
1943	49,339	100,990	163,144	240,129	49,307	89,832	289,468	2,806	21,199	169,683	193,688	
1944	47,873	98,394	163,346	237,623	49,069	90,160	285,496	2,798	21,319	162,200	186,317	
1945	50,820	113,430	184,150	270,606	55,890	101,286	321,426	3,168	23,806	186,850	213,824	
1946	47,500	99,630	170,810	245,169	49,472	96,068	292,669	2,792	22,479	181,020	206,291	
1947	43,493	95,210	157,830	229,473	44,157	90,105	272,966	2,491	21,077	170,370	193,937	
1948	40,960	93,730	157,440	227,723	46,050	87,943	268,683	2,629	20,818	159,620	183,067	
1949	44,960	95,140	163,440	234,775	49,312	90,322	279,735	2,770	21,036	176,050	199,855	
1950	48,038	100,290	158,691	235,769	47,140	88,339	283,807	2,647	20,566	181,004	204,216	
1951	24,702	49,982	87,227	124,355	24,865	49,508	149,057	1,389	11,466	125,707	138,561	
1952	28,181	54,828	95,340	136,445	28,402	53,215	164,626	1,565	12,158	153,497	167,220	
1953	26,638	51,494	94,579	132,316	26,721	54,101	158,954	1,464	12,293	137,729	151,486	
1954	8,021	18,383	33,932	47,675	9,358	19,934	55,696	472	4,168	41,934	46,574	
1955	5,563	14,843	25,278	36,540	5,797	15,901	42,103	289	3,291	34,779	38,360	
1956	5,610	12,386	22,300	31,747	5,559	13,803	37,357	260	2,679	29,162	32,101	
1957	12,041	30,963	51,412	75,365	10,980	33,422	87,406	515	6,495	75,568	82,578	
1958	38,245	73,232	135,383	189,478	35,857	80,388	227,723	1,859	17,279	153,927	173,064	
1959	36,595	75,164	121,247	179,433	35,961	68,308	216,028	1,912	15,057	173,983	190,951	
1960	41,068	75,032	127,321	184,710	37,312	72,366	225,778	1,951	15,692	158,979	176,622	
1961	26,833	57,745	104,043	147,635	29,210	60,680	174,468	1,472	12,681	137,360	151,513	
1962	38,424	77,027	137,436	195,421	41,315	77,078	233,845	2,180	16,863	158,533	177,575	
1963	27,886	56,665	103,541	145,379	29,061	59,653	173,265	1,559	13,268	124,914	139,741	
1964	5,304	10,865	19,117	27,131	3,829	12,437	32,435	197	2,654	29,682	32,533	
1965	22,328	41,203	79,473	109,740	21,363	47,174	132,068	1,077	9,859	91,596	102,532	
1966	32,192	58,937	100,412	145,653	29,147	57,569	177,845	1,490	12,206	109,927	123,623	
1967	20,788	40,826	72,867	103,419	21,231	41,361	124,207	1,132	9,143	90,788	101,062	
1968	29,334	47,035	86,440	121,437	23,822	50,581	150,771	1,228	10,810	92,912	104,950	
1969	37,184	66,662	123,908	173,074	32,304	74,108	210,258	1,664	15,832	136,314	153,810	
1970	40,581	76,274	132,824	190,655	35,084	79,297	231,236	1,778	16,665	138,870	157,313	
1971	27,548	48,425	87,663	124,112	23,677	52,010	151,660	1,185	10,791	105,454	117,430	
1972	11,354	20,258	38,342	53,076	9,385	23,433	64,430	487	5,038	52,698	58,222	
1973	38,282	65,034	120,648	170,010	34,184	70,792	208,292	1,635	14,038	114,805	130,477	
1974	38,463	66,013	125,089	175,244	35,531	73,700	213,707	1,652	14,207	122,339	138,197	
1975	38,542	67,073	119,992	171,892	34,961	69,858	210,434	1,634	13,539	120,079	135,252	
1976	44,460	71,673	130,553	180,573	37,038	71,861	225,033	3,208	18,445	127,261	148,914	
1977	19,969	35,614	56,311	82,397	13,758	33,025	102,366	1,269	8,258	72,279	81,807	
1978	11,786	18,006	28,766	42,087	7,385	16,696	53,873	657	4,027	48,165	52,850	
1979	36,187	49,763	99,038	133,191	26,774	56,654	169,378	4,522	11,088	111,215	126,825	30,297
1980	46,320	68,226	126,684	177,389	34,717	74,446	223,709	4,972	12,548	122,183	139,704	27,199
1981	43,367	61,204	122,135	165,495	33,860	70,431	208,862	5,240	12,605	120,730	138,574	43,038
1982	47,372	66,019	136,614	179,351	35,773	77,559	226,723	6,625	16,656	144,054	167,336	53,392
1983	44,435	68,830	137,639	183,541	34,370	80,341	227,976	6,031	16,897	113,809	136,737	47,978
1984	45,039	67,428	127,604	177,406	36,360	73,619	222,445	5,227	12,398	111,766	129,391	62,832
1985	58,080	74,772	140,327	197,135	40,152	82,210	255,215	5,323	12,642	116,255	134,220	70,370
1986	60,847	80,676	137,723	202,736	42,886	79,174	263,583	4,982	10,681	117,344	133,007	33,868
1987	58,647	83,177	136,997	205,259	41,310	80,772	263,906	4,571	10,344	118,556	133,471	63,688

Table 4-1
Annual Farm Headgate Deliveries
Water Distribution Report Data
1938 - 2017 (acre-feet)

Year	Rincon (EBID)	Leasburg (EBID)	Mesilla (EBID + EPCWID)	Total Leasburg-Mesilla (EBID)	Mesilla East (EBID)	Mesilla West (EBID)	Total EBID	Mesilla East TX (EPCWID)	Mesilla West TX (EPCWID)	El Paso Valley (EPCWID)	Total EPCWID	HCCRD
1988	53,563	78,939	132,481	197,111	38,314	79,859	250,674	4,190	10,118	118,483	132,791	46,714
1989	54,588	73,688	132,489	189,738	38,068	77,981	244,326	4,879	11,561	118,088	134,528	48,406
1990								4,148	10,820	108,658	123,626	
1991	48,576	73,202	127,266	178,827	32,975	72,651	227,403	5,999	15,642	140,160	161,801	45,252
1992								3,455	10,479	94,696	108,630	
1993	49,527	73,178	139,471	192,364	35,736	83,450	241,891	5,276	15,008	120,429	140,713	55,071
1994	60,037	81,338	158,292	213,988	42,142	90,509	274,025	7,184	18,457	146,048	171,690	59,659
1995	60,533	72,806	144,336	194,316	39,325	82,185	254,849	6,540	16,285	146,765	169,591	62,302
1996	51,325	67,736	160,207	196,048	41,532	86,780	247,373	9,237	22,659	178,169	210,064	51,348
1997	52,362	74,527	153,930	208,169	43,516	90,126	260,531	5,842	14,447	120,217	140,505	34,010
1998	61,914	73,877	149,291	201,811	41,652	86,282	263,725	6,095	15,263	129,957	151,315	42,895
1999	51,695	60,656	138,790	169,560	34,690	74,214	221,255	8,426	21,460	203,138	233,024	48,942
2000	55,585	69,008	140,709	189,698	40,198	80,492	245,283	5,926	14,093	135,916	155,935	46,466
2001	57,194	68,540	137,028	186,696	38,563	79,594	243,890	5,510	13,362	168,480	187,351	42,378
2002	55,628	63,490	139,418	178,990	36,951	78,549	234,618	6,834	17,085	221,097	245,015	46,606
2003	12,342	12,975	39,011	43,377	8,768	21,634	55,719	2,232	6,376	98,112	106,721	23,391
2004	12,967	12,283	39,340	42,678	8,473	21,922	55,645	2,206	6,739	102,320	111,264	20,077
2005	41,213	45,685	105,729	139,144	28,613	64,846	180,357	3,386	8,884	99,595	111,866	21,333
2006	19,206	19,345	56,370	65,277	13,967	31,966	84,483	2,894	7,544	101,333	111,771	23,667
2007	35,117	32,834	90,336	113,375	24,475	56,066	148,492	2,700	7,095	105,310	115,105	27,826
2008	43,081	45,045	109,874	144,820	30,578	69,197	187,901	2,822	7,277	105,006	115,105	
2009	43,797	46,214		143,897	30,601	67,082	187,694					
2010	33,647	36,415	107,088	121,770	25,743	59,611	155,417	5,879	15,854	263,031	284,765	
2011	5,139	4,993		19,010	3,785	10,232	24,149					
2012	12,570	11,208			10,096	23,140	57,014					
2013	4,157	4,086			3,230	8,238	19,711					
2014	9,271	11,050			8,274	19,540	48,135					
2015	13,701	15,144			12,607	28,963	70,416					
2016	15,670	17,479			14,298	35,656	83,103					
2017												
Avg	35,806	57,946	114,995	158,115	30,290	62,509	186,550	3,201	13,588	126,621	143,410	43,667
Max	61,914	113,430	184,150	270,606	55,890	101,286	321,426	9,237	23,806	263,031	284,765	70,370
Min	4,157	4,086	19,117	19,010	3,230	8,238	19,711	197	2,654	29,162	32,101	20,077
Avg 38-78	31,766	63,317	109,351	156,881	31,193	62,371	188,646	1,739	14,048	122,337	138,124	
Avg 79-05	46,337	62,061	121,764	165,500	33,217	70,222	211,837	5,062	12,996	125,748	143,805	45,100
Avg 06-17	21,396	22,165	90,917	101,358	16,150	37,245	96,956	3,574	9,443	143,670	156,687	25,747
Avg 40-17	35,780	57,170	114,159	156,675	29,988	62,045	184,983	3,222	13,420	126,356	142,998	43,667

Notes:
Values in black text are reported values.
Values in blue text are computed values.
Gray-highlighted cells indicate no data.

Table 4-2

Annual Allotments
Rio Grande Project
1951 - 1978 (AF/acre)

	Year	(1) Full Supply Year?	Initial Allotment to Project Lands	Final Allotment to Project Lands	Initial Release Date from Caballo
	1951	No	1.00	1.75	6-Mar
	1952	No	0.21	2.50	20-Mar
	1953	No	1.00	1.90	10-Mar
	1954	No	0.42	0.50	20-Mar
	1955	No	0.21	0.42	20-Mar
	1956	No	0.33	0.39	18-Mar
	1957	No	0.10	1.17	20-Mar
	1958	Yes	1.75	4.00	1-Mar
	1959	Yes	3.00	3.50	2-Mar
	1960	Yes	2.25	3.25	2-Mar
	1961	No	1.25	2.45	10-Mar
	1962	Yes	1.75	3.25	5-Mar
	1963	No	1.85	2.00	5-Mar
	1964	No	0.25	0.33	15-Mar
	1965	No	0.17	1.85	20-Mar
	1966	No	1.75	2.50	5-Mar
	1967	No	1.25	1.50	27-Feb
	1968	No	1.00	2.00	27-Feb
(2)	1969	Yes	1.25	3.00	27-Feb
	1970	Yes	2.00	3.00	23-Feb
	1971	No	1.50	1.75	26-Feb
	1972	No	0.60	0.80	1-Mar
	1973	Yes	1.00	3.00	9-Mar
	1974	Yes	3.00	3.00	2-Mar
	1975	Yes	1.00	3.00	24-Jan
	1976	Yes	2.50	3.00	16-Jan
	1977	No	1.00	1.25	3-Mar
	1978	No	0.25	0.75	10-Mar
	Avg		1.20	2.06	4-Mar
	Max		3.00	4.00	20-Mar
	Min		0.10	0.33	16-Jan

Source: USBR handout in DC_11282012.pdf.
Note: (1) Full supply years are years with final allotment greater than or equal to 3.00 AF/ac.
(2) Annual allotment value in the USBR 1986 Annual Operating Plan for this year is 1.33.

Table 4-3

Annual Allocations and Deliveries
Rio Grande Project
1979 - 2018 (acre-feet)

	Year	(1) Full Supply Year?	EBID Allocation	EBID Delivery	EBID First Month Used	EBID Last Month Used	EPCWID Allocation	EPCWID Delivery	EPCWID First Month Used	EPCWID Last Month Used	Mexico Allocation	Mexico Delivery	Total US + Mex Allocation
(2)	1979	Yes	414,448	343,811	Mar	Sep	315,548	240,471	Mar	Sep	60,000	60,055	789,996
	1980	Yes	414,448	414,452	Feb	Sep	315,548	302,339	Feb	Sep	60,000	60,033	789,996
(3)	1981	Yes	393,671	381,211	Mar	Sep	296,980	242,754	Mar	Sep	60,000	60,262	750,650
	1982	Yes	414,448	406,059	Feb	Sep	315,548	271,797	Feb	Sep	60,000	59,257	789,996
	1983	Yes	414,448	414,069	Mar	Aug	315,548	256,034	Mar	Sep	60,000	60,621	789,996
	1984	Yes	478,037	408,028	Mar	Oct	363,960	289,976	Mar	Oct	60,000	58,588	901,997
	1985	Yes	478,037	430,098	Feb	Oct	363,963	275,540	Feb	Oct	60,000	60,276	902,000
	1986	Yes	478,037	526,325	Jan	Oct	363,963	389,740	Jan	Oct	60,000	66,163	902,000
	1987	Yes	478,037	513,174	Feb	Oct	363,963	308,850	Feb	Oct	60,000	65,866	902,000
	1988	Yes	478,037	487,021	Feb	Oct	363,963	340,574	Feb	Oct	60,000	61,935	902,000
	1989	Yes	471,735	477,083	Feb	Sep	359,165	333,183	Feb	Oct	60,000	58,854	890,900
	1990	Yes	471,735	407,662	Feb	Oct	359,165	282,749	Feb	Oct	60,000	58,353	890,900
	1991	Yes	494,979	395,933	Feb	Oct	376,862	234,303	Mar	Oct	60,000	59,242	931,841
	1992	Yes	494,979	421,533	Feb	Oct	376,862	360,712	Jan	Oct	60,000	58,080	931,841
	1993	Yes	494,979	465,666	Feb	Oct	376,862	405,681	Jan	Oct	60,000	63,763	931,841
	1994	Yes	494,979	454,492	Feb	Oct	376,862	306,247	Jan	Oct	60,000	60,167	931,841
	1995	Yes	494,979	367,520	Feb	Oct	376,862	279,723	Jan	Oct	60,000	63,618	931,841
	1996	Yes	494,979	483,214	Jan	Sep	376,862	315,001	Jan	Sep	60,000	60,063	931,841
	1997	Yes	494,979	500,483	Feb	Oct	376,862	334,751	Jan	Oct	60,000	50,442	931,841
	1998	Yes	494,979	488,516	Feb	Oct	376,862	346,782	Jan	Oct	60,000	60,626	931,841
	1999	Yes	494,979	426,132	Feb	Oct	376,862	340,727	Jan	Oct	60,000	58,306	931,841
	2000	Yes	494,979	460,278	Feb	Oct	376,862	306,375	Jan	Oct	60,000	60,611	931,841
	2001	Yes	494,979	460,182	Feb	Oct	376,862	343,365	Feb	Oct	60,000	61,037	931,841
	2002	Yes	494,979	431,521	Feb	Oct	376,862	376,926	Feb	Oct	60,000	60,324	931,841
	2003	No	165,144	164,740	Mar	Sep	137,862	137,250	Mar	Sep	26,616	26,948	329,622
	2004	No	185,507	164,572	Mar	Oct	154,265	144,005	Mar	Sep	27,197	27,613	366,969
	2005	Yes	494,979	353,261	Mar	Oct	376,862	247,607	Mar	Oct	60,000	58,091	931,841
(4)	2006	No	211,385	211,841	Mar	Oct	241,657	177,183	Mar	Oct	33,895	27,112	486,937
	2007	Yes	312,140	302,665	Mar	Oct	403,491	278,252	Mar	Oct	58,769	51,245	774,400
	2008	Yes	324,990	329,294	Mar	Oct	512,055	279,173	Feb	Oct	60,000	56,048	897,045
	2009	Yes	345,817	305,475	Feb	Sep	552,997	320,083	Feb	Oct	53,386	58,688	952,200
	2010	No	305,870	282,082	Mar	Sep	532,158	304,937	Mar	Sep	50,235	56,883	888,263
	2011	No	77,104	59,771	Jun	Jul	267,813	258,772	Mar	Sep	25,649	25,650	370,566
	2012	No	135,633	133,060	Apr	Aug	141,977	136,380	Apr	Sep	23,196	23,187	300,806
	2013	No	57,011	54,002	Jun	Jul	47,043	53,530	Jun	Jul	3,665	3,709	107,719
	2014	No	107,659	99,007	May	Aug	100,103	97,418	May	Aug	18,216	18,261	225,978
	2015	No	170,592	143,404	May	Sep	200,314	165,872	May	Sep	35,355	33,772	406,262
	2016	No	180,912	175,199	Apr	Sep	268,381	216,309	Mar	Sep	46,497	43,787	495,790
	2017	Yes	270,749	259,510	Apr	Oct	452,021	249,919	Mar	Oct	60,000	54,506	782,770
	2018	No	123,315	127,487	Apr	Aug	314,520	279,211	Mar	Sep	37,670	37,735	475,504
	Average		369,842	343,246			333,079	270,762			51,509	51,244	754,430
	1979-2007		437,725	405,570			342,545	292,031			56,775	56,467	837,045
	2008-2016		189,510	175,699			291,427	203,608			35,133	35,554	516,070
	2008-2018		190,877	178,936			308,126	214,691			37,624	37,475	536,627

Note: (1) From 1979 - 2005 full supply years are years with Mexico allocations (rounded to nearest 1,000) equal to or greater than 60,000 acre-feet. From 2006 - 2018, full supply years are years with EPCWID current year allocation greater than 360,000 acre-feet.
(2) Annual total allotment for 1979 from USBR table (USBR handout in DC_11282012.pdf).
(3) Full supply year per reported allotment to EBID of 3.00 af/acre.

Table 5-1

**Comparison of
Historical Average Annual Flows
to Rio Grande Joint Investigation
for Various Periods
(1,000 AF)**

	Period	(1) San Marcial	(2) Reservoir Release	(3) El Paso	(4) Caballo to El Paso Depletion
(5,6)	RGJI	1,031	773		
	1922 - 2017	780	678	414	264
	1936 - 1950	961	845	583	263
	1936 - 2017	754	651	381	269
	1922 - 1950	949	843	594	248
	1930 - 1950	906	829	568	261
	1951 - 2017	707	607	336	271
	1951 - 1979	602	508	261	247
	1980 - 2002	951	806	493	313
	2003 - 2017	537	493	242	251
	1951 - 1984	652	528	273	255
	1985 - 2002	953	852	536	316
	2003 - 2007	538	502	261	241
	2008 - 2017	537	488	232	256

Notes:

(1) Rio Grande at San Marcial gage.

(2) Rio Grande above Percha Dam gage for 1922-1938 and Caballo Reservoir release for 1938-2017.

(3) Rio Grande at El Paso gage.

(4) Reservoir release minus El Paso gage.

Table 6-1
Example of the Canal and Farm Budget Calculations

Single Input
Monthly Input
Annual Input

Rincon Unit

Heading	Units	Col.	Equation
Date		a	Date
Mo		b	Month
Year		c	Year
Days in Mo.		d	Days in month
Pump Seas		e	Pumping season (1 = yes, 0 = no)
Surface Water Irrigated Lands	(ac)	f	Irrigated Acreage with Surface Water Supplies
Primary Ground Water Irrigated Lands	(ac)	g	Irrigated Acreage with Only Ground Water Supplies
Surface Water Diversion	(af)	h	Total Surface Water Diversions
Crop Irrigation Req.	(af/ac)	I	Crop Irrigation Requirement of lands with Surface Water Supplies
Crop Irrigation Req. GW Only	(af/ac)	j	Crop Irrigation Requirement of lands with Only Ground Water Supplies
Excess Effective Precipitation	(af)	k	Excess Effective Precipitation
SW Lands Crop Irrigation Req.	(af)	l	Surface Water Irrigated Land * Crop Irrigation Req.
Total Crop Irrigation Req.	(af)	m	(Surface Water Irrigated Lands + Primary Ground Water Irrigated Lands) * Crop Irrigation Req.
Total Canal Loss	(af)	n	Surface Water Diversions * Total Canal Loss %
Incidental Canal Loss	(af)	o	Total Canal Loss * Incidental Loss %
Canal Seepage	(af)	p	Total Canal Loss - Incidental Conveyance Loss
Wasteway Flows	(af)	q	Surface Water Diversion * Wasteway Flows %
MFE	(%)	r	Maximum On-farm Irrigation Efficiency
El Paso Valley Carriage	(af)	s	Surface Water Diversions * El Paso Valley Carriage %
FHG Delivery	(af)	t	Surface Water Diversion - (Total Canal Loss + Wasteway Flows + El Paso Valley Carriage)
BOM Soil Moisture	(af)	u	EOM Soil Moisture + Excess Effective Precipitation
FHG Surface Water Available	(af)	v	FHG Delivery * Maximum On-farm Irrigation Efficiency %
CU of Surface Water	(af)	w	MIN(SW Lands Crop Irrigation Req., FHG Surface Water Available)
CU of Soil Moisture Carryover	(af)	x	MIN((SW Lands Crop Irrigation Req. - CU of Surface Water), BOM Soil Moisture)
Max Suppl Ground Water	(af)	y	((Supplemental Pumping Capacity / 226.29 * Days in Mo.) * Maximum On-farm Irrigation Efficiency % * Supplemental Pumping Development % * Pump Seas * Simulate Ground Water Pumping (1=y, 0=n)
CU of Suppl Ground Water Pumping	(af)	z	MIN(Max Suppl Ground Water, (SW Lands Crop Irrigation Req. - (CU of Surface Water + CU of Soil Moisture)) * Supplemental Pumping Development %) * % Unmet Demand met by Suppl Pumping
Suppl Ground Water Pumping	(af)	aa	CU of Suppl Ground Water Pumping / Maximum On-farm Irrigation Efficiency %
CU of Primary Ground Water Pumping	(af)	ab	MIN(Primary Pumping Capacity * Maximum On-farm Irrigation Efficiency %), Crop Irrigation Req. * Primary Ground Water Irrigated Lands)* % Unmet Demand met by Primary Pumping * Pump Seas * Simulate Ground Water Pumping (1=y, 0=n)
Primary Ground Water Pumping	(af)	ac	CU of Primary Ground Water Pumping / Maximum On-farm Irrigation Efficiency %
Total Ground Water Pumping	(af)	ad	Suppl Ground Water Pumping + Primary Ground Water Pumping
Available for Soil Moisture Carryover	(af)	ae	BOM Soil Moisture + FHG Surface Water Available - CU of Surface Water - CU of Soil Moisture Carryover+ Suppl Ground Water Pumping * Maximum On-farm Irrigation Efficiency % - CU of Suppl Ground Water Pumping
EOM Soil Moisture	(af)	af	MIN(Soil Moisture Reservoir Capacity / 12 * Surface Water Irrigated Lands, Available for Soil Moisture Carryover)

Table 6-1
Example of the Canal and Farm Budget Calculations

Single Input
Monthly Input
Annual Input

Rincon Unit

Heading	**Units**	**Col.**	**Equation**
Excess Supply	(af)	ag	Available for Soil Moisture Carryover - EOM Soil Moisture
Surface Runoff	(af)	ah	((FHG Delivery + Total Ground Water Pumping)*(1 - Maximum On-farm Irrigation Efficiency %) + Excess Supply) * Surface Runoff %
Deep Percolation	(af)	ai	((FHG Delivery + Total Ground Water Pumping)*(1 - Maximum On-farm Irrigation Efficiency %) + Excess Supply) * (1 - Surface Runoff %)
Total On-Farm Loss	(af)	aj	Surface Runoff + Deep Percolation
Net Recharge	(af)	ak	(Canal Seepage + Deep Percolation) - Total Ground Water Pumping
Actual On-Farm Efficiency of SW	(%)	al	IFERROR((CU of Surface Water + MAX((EOM Soil Moisture - BOM Soil Moisture),0)/(FHG Delivery), " ")
Shortage on SW Lands	(af)	am	SW Lands Crop Irrigation Req. - CU of Surface Water - CU of Soil Moisture Carryover- CU of Suppl Ground Water Pumping
Balance	(af)	an	(Surface Water Diversion - Total Canal Loss - Wasteway Flows - El Paso Valley Carriage) + Primary Ground Water Pumping + Suppl Ground Water Pumping - Total On-Farm Loss - CU of Surface Water - CU of Soil Moisture Carryover- CU of Suppl Ground Water Pumping - CU of Primary Ground Water Pumping - (EOM Soil Moisture - BOM Soil Moisture)

<u>Example Column Headings:</u>

					Rincon (EBID)															
Date	Mo	Year	Days in Mo.	Pump Seas	Surface Water Irrigated Lands (ac)	Primary Ground Water Irrigated Lands (ac)	Surface Water Diversion (af)	Crop Irrigation Req. (af/ac)	Crop Irrigation Req. GW only (af/ac)	Excess Effective Precipitation (af)	SW Lands Crop Irrigation Req. (af)	Total Crop Irrigation Req. (af)	Total Canal Loss (af)	Incidental Canal Loss (af)	Canal Seepage (af)	Wasteway Flows (af)	MFE (%)	El Paso Valley Carriage (af)	FHG Delivery (af)	BOM Soil Moisture (af)
a	b	c	d	e	f	g	h	I	j	k	l	m	n	o	p	q	r	s	t	u

Rincon (EBID)																		
FHG Surface Water Available (af)	CU of Surface Water (af)	CU of Soil Moisture Carryover (af)	Max Suppl Ground Water (af)	CU of Suppl Ground Water Pumping (af)	Suppl Ground Water Pumping (af)	CU of Primary Ground Water Pumping (af)	Primary Ground Water Pumping (af)	Total Ground Water Pumping (af)	Available for Soil Moisture Carryover (af)	EOM Soil Moisture (af)	Excess Supply (af)	Surface Runoff (af)	Deep Percolation (af)	Total On-Farm Loss (af)	Net Recharge (af)	Actual On-Farm Efficiency of SW (%)	Shortage on SW Lands (af)	Balance (af)
v	w	x	y	z	aa	ab	ac	ad	ae	af	ag	ah	ai	aj	ak	al	am	an

Table 6-2

Annual Farm Headgate Deliveries

Canal and Farm Budget Models

1938 - 2017 (acre-feet)

Year	Rincon (EBID)	Leasburg (EBID)	Mesilla (EBID + EPCWID)	Total Mesilla (EBID)	Mesilla East (EBID)	Mesilla West (EBID)	Total EBID	Mesilla East TX (EPCWID)	Mesilla West TX (EPCWID)	El Paso Valley (EPCWID)	Total EPCWID	HCCRD	Total JID
1938	33,707	79,893	133,086	192,852	38,172	74,786	226,559	2,206	17,921	122,842	142,969	68,782	42,082
1939	39,913	94,143	153,712	224,185	45,057	84,985	264,098	2,683	20,987	148,996	172,667	65,845	45,238
1940	41,123	89,823	151,043	217,728	44,807	83,098	258,851	2,662	20,475	154,284	177,422	59,794	49,406
1941	35,146	74,238	128,967	183,629	36,909	72,482	218,775	2,141	17,435	117,414	136,990	50,544	49,894
1942	41,593	79,425	136,299	195,449	40,489	75,535	237,042	2,321	17,954	126,240	146,515	56,993	61,999
1943	49,335	100,990	163,144	240,129	49,307	89,832	289,464	2,806	21,199	169,683	193,688	50,307	52,595
1944	47,873	98,394	163,346	237,623	49,069	90,160	285,496	2,798	21,319	162,200	186,317	55,941	50,741
1945	50,532	113,430	184,150	270,606	55,890	101,286	321,139	3,168	23,806	186,850	213,824	56,830	57,165
1946	46,929	99,630	170,810	245,169	49,472	96,068	292,098	2,792	22,479	180,950	206,221	58,580	53,548
1947	43,420	95,210	157,827	229,470	44,157	90,103	272,890	2,491	21,076	170,370	193,937	49,489	47,218
1948	40,890	93,728	157,439	227,720	46,050	87,942	268,610	2,629	20,818	159,580	183,027	59,240	41,959
1949	43,594	95,140	163,440	234,775	49,312	90,322	278,368	2,770	21,036	176,050	199,855	69,881	43,423
1950	48,038	100,290	158,691	235,769	47,140	88,339	283,807	2,647	20,566	181,004	204,216	74,588	46,417
1951	24,702	49,982	87,227	124,355	24,865	49,508	149,057	1,389	11,466	125,707	138,561	26,787	22,751
1952	28,181	54,825	95,340	136,442	28,402	53,215	164,623	1,565	12,158	153,497	167,220	30,449	33,624
1953	26,638	51,494	94,579	132,316	26,721	54,101	158,954	1,464	12,293	127,154	140,911	21,901	28,132
1954	8,021	18,383	33,932	47,675	9,358	19,934	55,696	472	4,168	41,064	45,704	3,819	9,625
1955	5,554	14,843	25,278	36,540	5,797	15,901	42,095	289	3,291	34,779	38,360	224	8,787
1956	5,610	12,386	22,300	31,747	5,559	13,803	37,357	260	2,679	24,382	27,321	2	8,237
1957	12,041	30,963	51,412	75,365	10,980	33,422	87,406	515	6,495	75,568	82,578	794	20,000
1958	38,245	73,232	135,383	189,478	35,857	80,388	227,723	1,859	17,279	153,927	173,064	16,846	45,578
1959	36,595	75,152	121,237	179,421	35,961	68,308	216,016	1,912	15,057	173,983	190,951	27,534	45,877
1960	41,068	75,015	127,321	184,693	37,312	72,366	225,761	1,951	15,692	158,979	176,622	36,882	46,219
1961	26,833	57,745	104,043	147,635	29,210	60,680	174,468	1,472	12,681	137,360	151,513	30,728	37,097
1962	38,424	77,027	137,436	195,421	41,315	77,078	233,845	2,180	16,863	158,533	177,575	47,586	45,245
1963	27,886	56,665	103,541	145,379	29,061	59,653	173,265	1,559	13,268	124,914	139,741	32,239	29,263
1964	5,304	10,864	19,117	27,130	3,829	12,437	32,434	197	2,654	29,682	32,533	2,865	8,155
1965	22,328	41,176	79,473	109,713	21,363	47,174	132,041	1,077	9,859	91,596	102,532	4,062	27,671
1966	32,192	58,937	100,412	145,653	29,147	57,569	177,845	1,490	12,206	109,927	123,623	25,143	39,903
1967	20,788	40,823	72,854	103,405	21,231	41,351	124,193	1,132	9,140	90,788	101,060	15,006	24,298
1968	29,334	46,800	86,440	121,202	23,822	50,581	150,536	1,228	10,810	92,912	104,950	22,558	33,421
1969	37,184	66,661	123,908	173,073	32,304	74,108	210,257	1,664	15,832	136,314	153,810	48,605	47,828
1970	40,581	76,274	132,824	190,655	35,084	79,297	231,236	1,778	16,665	138,870	157,313	59,685	47,120
1971	27,545	48,425	87,663	124,112	23,677	52,010	151,657	1,185	10,791	105,454	117,430	30,752	30,796
1972	11,354	20,258	38,342	53,076	9,385	23,433	64,430	487	5,038	52,698	58,222	15,390	20,808
1973	38,282	65,031	120,648	170,007	34,184	70,792	208,289	1,635	14,038	114,805	130,477	32,756	50,422
1974	38,463	66,013	125,076	175,231	35,518	73,700	213,694	1,651	14,207	122,339	138,197	55,013	53,429
1975	38,488	67,073	119,898	171,803	34,872	69,858	210,290	1,630	13,539	120,079	135,247	57,729	52,922
1976	44,460	71,518	130,553	180,418	37,038	71,861	224,878	3,208	18,445	127,261	148,914	63,878	53,749
1977	19,967	35,614	56,311	82,397	13,758	33,025	102,364	1,269	8,258	72,279	81,807	26,800	27,834
1978	11,782	18,006	28,763	42,085	7,385	16,694	53,867	657	4,027	48,165	52,849	14,846	25,466
1979	36,187	49,763	99,045	133,199	26,782	56,654	169,386	4,522	11,088	111,215	126,825	30,297	58,755
1980	46,320	68,226	126,731	177,436	34,764	74,446	223,756	4,972	12,548	122,183	139,704	27,199	61,168
1981	43,367	60,979	122,136	165,271	33,861	70,431	208,639	5,240	12,605	120,730	138,574	43,038	68,337
1982	47,372	66,010	136,616	179,344	35,776	77,559	226,717	6,625	16,656	144,054	167,336	53,392	65,205

Table 6-2

Annual Farm Headgate Deliveries

Canal and Farm Budget Models

1938 - 2017 (acre-feet)

Year	Rincon (EBID)	Leasburg (EBID)	Mesilla (EBID + EPCWID)	Total Mesilla (EBID)	Mesilla East (EBID)	Mesilla West (EBID)	Total EBID	Mesilla East TX (EPCWID)	Mesilla West TX (EPCWID)	El Paso Valley (EPCWID)	Total EPCWID	HCCRD	Total JID
1983	44,435	68,830	137,639	183,541	34,370	80,341	227,976	6,031	16,897	113,809	136,737	47,978	66,440
1984	45,039	67,408	127,604	177,387	36,360	73,619	222,425	5,227	12,398	111,766	129,391	62,832	69,855
1985	58,080	74,772	140,327	197,135	40,152	82,210	255,215	5,323	12,642	116,255	134,220	70,370	64,116
1986	60,847	80,676	137,723	202,736	42,886	79,174	263,583	4,982	10,681	117,344	133,007	33,868	69,641
1987	58,647	83,177	136,997	205,259	41,310	80,772	263,906	4,571	10,344	118,556	133,471	61,586	71,952
1988	53,563	78,939	132,481	197,111	38,314	79,859	250,674	4,190	10,118	118,483	132,791	46,714	71,493
1989	54,588	73,688	132,489	189,738	38,068	77,981	244,326	4,879	11,561	118,088	134,528	48,406	72,072
1990	38,003	68,009	125,966	179,007	33,960	77,038	217,010	4,148	10,820	108,658	123,626	62,458	72,725
1991	48,576	73,202	127,266	178,827	32,975	72,651	227,403	5,999	15,642	140,160	161,801	45,252	73,822
1992	39,796	75,940	135,125	197,131	34,346	86,845	236,927	3,455	10,479	94,696	108,630	69,902	74,692
1993	49,527	73,178	139,471	192,364	35,736	83,450	241,891	5,276	15,008	120,429	140,713	57,376	78,188
1994	60,037	81,338	158,292	213,988	42,142	90,509	274,025	7,184	18,457	146,048	171,690	65,058	79,490
1995	60,533	72,806	144,336	194,316	39,325	82,185	254,849	6,540	16,285	146,765	169,591	67,762	82,711
1996	51,325	67,736	160,207	196,048	41,532	86,780	247,373	9,237	22,659	178,169	210,064	66,866	79,802
1997	52,362	74,527	153,930	208,169	43,516	90,126	260,531	5,842	14,447	120,217	140,505	50,508	79,166
1998	61,914	73,877	149,291	201,811	41,652	86,282	263,725	6,095	15,263	129,957	151,315	61,917	81,643
1999	51,695	60,656	138,790	169,560	34,690	74,214	221,255	8,426	21,460	203,138	233,024	68,023	80,435
2000	55,585	69,008	140,709	189,698	40,198	80,492	245,283	5,926	14,093	135,916	155,935	64,940	82,505
2001	57,194	68,540	137,028	186,696	38,563	79,594	243,890	5,510	13,362	168,480	187,351	61,211	83,602
2002	55,628	63,490	139,418	178,990	36,951	78,549	234,618	6,834	17,085	221,097	245,015	65,712	82,489
2003	12,342	12,975	49,782	54,148	12,104	29,069	66,490	2,232	6,376	85,346	93,955	30,907	59,448
2004	12,967	12,283	39,340	42,678	8,473	21,922	55,645	2,206	6,739	87,262	96,206	29,632	58,295
2005	41,213	45,685	105,729	139,144	28,613	64,846	180,357	3,386	8,884	99,595	111,866	34,793	80,932
2006	19,206	19,345	56,370	65,277	13,967	31,966	84,483	2,894	7,544	101,333	111,771	35,633	60,394
2007	35,117	32,834	90,336	113,375	24,475	56,066	148,492	2,700	7,095	105,310	115,105	43,481	78,459
2008	43,081	45,045	109,874	144,820	30,578	69,197	187,901	2,822	7,277	105,006	115,105	60,443	81,392
2009	43,311	46,214	108,601	143,897	30,601	67,082	187,208	637	10,282	138,510	149,428	63,977	84,267
2010	33,647	36,415	107,088	121,770	25,743	59,611	155,417	5,879	15,854	142,018	163,751	60,352	83,883
2011	5,139	4,993	15,601	19,010	3,785	10,232	24,149	84	1,500	93,938	95,522	21,202	64,921
2012	12,570	11,208	36,269	44,444	10,096	23,140	57,014	232	2,801	55,380	58,413	10,423	62,567
2013	4,157	4,086	12,679	15,554	3,230	8,238	19,711	74	1,137	30,891	32,102	10,254	50,321
2014	9,271	11,050	30,701	38,864	8,274	19,540	48,135	190	2,697	48,303	51,190	12,579	62,100
2015	13,701	15,144	45,857	56,715	12,607	28,963	70,416	289	3,998	64,256	68,543	14,056	73,280
2016	15,670	17,479	55,204	67,433	14,298	35,656	83,103	328	4,922	78,579	83,829	16,972	80,821
2017	25,925	35,456	100,370	126,355	26,729	64,170	152,280	613	8,858	87,209	96,680	25,993	87,240
Avg	35,723	58,006	109,084	151,497	30,383	63,108	187,221	2,911	12,682	119,358	134,951	41,638	55,057
Max	61,914	113,430	184,150	270,606	55,890	101,286	321,139	9,237	23,806	221,097	245,015	74,588	87,240
Min	4,157	4,086	12,679	15,554	3,230	8,238	19,711	74	1,137	24,382	27,321	2	8,155
Avg 38-78	31,706	63,305	109,348	156,867	31,191	62,370	188,573	1,739	14,048	121,939	137,725	37,261	38,194
Avg 79-07	45,824	62,736	122,743	167,421	33,399	71,287	213,245	5,062	12,996	124,788	142,846	50,677	69,734
Avg 08-17	20,647	22,709	62,225	77,886	16,594	38,583	98,533	1,115	5,933	84,409	91,456	29,625	73,079
Avg 40-17	35,696	57,262	108,204	150,035	30,095	62,678	185,731	2,923	12,508	118,933	134,364	40,980	55,349

Notes:

Farm headgate deliveries from WDR data with estimated and adjusted data for input into Integrated LRG Model.

Table 7-1

Summary of Required Simulation Processes
For LRG Simulation Models

Physical Process	Management Process
	Project water allocation and accounting
	Reservoir releases
Reservoir evaporation	
Reservoir storage	
Reservoir spills	
River evaporation	
River routing	
River seepage	
	Canal diversions
	Wasteway flows
Canal conveyance losses	
	Farm headgate deliveries
On-farm losses	
Soil moisture storage	
Crop ET	
	Irrigation pumping
Drain flows	
	EPWU water use (1)
	Other non-irrigation pumping (2)
Riparian/bare ground ET	
Ground water flow and storage	

Notes
(1) EPWU use of Project water and pumping.
(2) Non-irrigation pumping and returns are specified model inputs

Table 10-1

List of Model Runs
Integrated LRG Model

Run No.	Name	Compare To Run	Notes
0	Historical Calibration Run		
1	Historical Base Run (All Pumping On)	0	
2	All Pumping Off	1	(1)
3	NM Pumping Off	1	(1)
4	TX Pumping Off	1	(1,2)
5	MX Pumping Off	1	(1)
6	R-M Pumping Off	1	(1,3)
7	TX Mesilla Pumping Off	1	(1)
8	TX Non-Irrigation Pumping Off	1	(1)
9	NM Non-Irrigation Pumping Off	1	(1)
10	MX Non-Irrigation Pumping Off	1	(1)
11	D1/D2 Allocation (All Pumping On)	--	(4)
12	D3+Carryover Allocation (All Pumping On)	11	(4)
13	Reduced Waste	1	

Notes:

(1) Corresponding WWTP returns and urban deep percolation returns are also turned off (no UDP simulated in Mexico).

(2) Including Texas Mesilla (EPCWID Mesilla and EPW Canutillo Wellfield).

(3) Including Texas Mesilla and Mexico Conejos-Medanos.

(4) Project allocation procedure simulated for 1948-2017.

Appendix 1A
Professional Resume of
Gregory K. Sullivan, P.E.

Gregory K. Sullivan, P.E.

Principal Water Resources Engineer

Education: M.S., Civil Engineering, 1990, University of Colorado - Denver.
B.S., Civil Engineering, 1985, Colorado State University.

Professional Registration:

Professional Engineer in Colorado #26802, Idaho #8387, Nevada #10868, and New Mexico #22620

Professional Experience:

1990 - Present: ***Spronk Water Engineers, Inc., Principal and Senior Water Resources Engineer***

Mr. Sullivan is responsible for the management and successful completion of water rights engineering and water resources planning projects. Projects include water supply planning, changes of water rights, plans for augmentation, historical consumptive use and stream depletion analyses, water rights evaluations and appraisals, water supply planning, reservoir operations studies, ground water modeling and water rights accounting. Mr. Sullivan has extensive experience in litigation support and has provided expert testimony before courts and state agencies on numerous occasions.

Summary of Experience:

Mr. Sullivan has over thirty years of experience completing a wide variety of water resources engineering projects. Mr. Sullivan has extensive experience performing historical consumptive use analyses, stream depletions analyses, and reservoir operations studies. Mr. Sullivan serves as the primary consultant to numerous water providers for water supply planning and water rights engineering. In that role, he has been responsible for technical analyses in supporting changes of water rights, exchanges, augmentation plans, and other water right matters. He has led the development of complex surface water operations models that simulate municipal water demands and how those demands maybe met by available water supplies and water rights. Mr. Sullivan has served on the Eastern Snake Hydrologic Modeling Committee that guides the development and use of a regional ground water model of the Eastern Snake River Plain Aquifer since 1996. Mr. Sullivan has provided expert testimony in the U.S. Supreme Court, Colorado Water Courts, Snake River Basin Adjudication Court (Idaho), and in administrative hearings before the Idaho Department of Water Resources.

Gregory K. Sullivan, P.E.

Principal Water Resources Engineer

Description of Representative Projects:

Change of Water Rights, City of Loveland

Mr. Sullivan was the principal investigator for ditch-wide historical use analyses of the major Big Thompson River irrigation ditches that serve lands in and around the City of Loveland. These analyses served as the basis for successful changes of water rights that were approved by the Division 1 Water Court to allow the City to divert its ditch shares at the City's municipal water intakes to help meet its water supply needs.

Water Supply Yield Modeling, City of Loveland

Mr. Sullivan led the development of a model to simulate the daily water supply and demand of the City of Loveland over a study period from 1950 - 2017. The water supplies that are simulated in the model include the ditch shares that have been changed to municipal use, Colorado-Big Thompson Project units, Windy Gap Project units, and the operation of the City's Green Ridge Glade Reservoir. The model is used by the City to evaluate the firm yield of its water supply, and how that yield can be increased through acquisition of additional supplies, development of additional storage, changes in water supply operations and other actions.

Water Supply Planning, ACWWA

Mr. Sullivan has provided water resources and water rights consulting for the Arapahoe County Water and Wastewater Authority ("ACWWA") for almost 30 years. ACWWA serves lands in the Cherry Creek basin south of Denver through a combination of shallow alluvial wells and deep nontributary Denver Basin wells. Water use from these sources is integrated and optimized through operation of a complex plan for augmentation that provides for replacement of out-of-priority depletions to Cherry Creek to protect downstream senior water users. Mr. Sullivan has performed numerous analyses to evaluate the yield of ACWWA's water supplies, including completion of a raw water master plan in 2018.

Plan for Augmentation, Upper Cherry Creek Water Association

Mr. Sullivan led the development of an umbrella plan for augmentation for five major water users in the Cherry Creek Basin upstream of Cherry Creek Reservoir. The members have pooled their augmentation sources to replace the combined out-of-priority depletions resulting from alluvial well pumping and out-of-priority storage in Cherry Creek Reservoir. The plan includes an innovative method of computing depletions that considers times when Cherry Creek is dry in the area of the member wells.

Gregory K. Sullivan, P.E.

Principal Water Resources Engineer

Cherry Creek Aquifer Modeling Project
Mr. Sullivan led the development of a basin-wide simulation model of the hydrology and water use in the Cherry Creek basin upstream of Cherry Creek Reservoir. The model simulates the water supplies and water rights of the all of the municipal water providers in the study area and optimizes the alluvial pumping of the water users and the use of Denver Basin ground water replacement supplies. The model also simulates the operation of Cherry Creek Reservoir and Rueter-Hess Reservoir. The model is used by the study participants to evaluate changes in water supply operations and acquisition of new water supplies.

Snake River Delivery Calls, City of Pocatello, Idaho
Mr. Sullivan has provided technical analysis and expert testimony to the City of Pocatello in their participation in complex litigation involving water right delivery calls by senior surface water users on the Snake River in Idaho. Pocatello's water supply is derived primarily from junior priority wells that are tributary to the Snake River, and its water supply is threatened by the delivery calls. Mr. Sullivan analyzed the historical operation of seven major irrigation districts that placed the delivery calls to assess the extent of their claimed irrigation water shortages. The irrigation districts serve a combined area of 560,000 acres with annual diversions averaging 3.2 million acre-feet per year.

ESPA Cities Mitigation Plan, Idaho
Mr. provided technical expertise and analysis to develop a mitigation plan for Pocatello, Idaho Falls, and more than a dozen other cities to mitigate the impacts of pumping ground water from the Eastern Snake Plain Aquifer in Idaho. The plan relies largely on aquifer recharge to mitigate the impacts of aquifer depletions from pumping that is projected to increase from about 60,000 acre-feet per year to over 120,000 acre-feet per year over the next 50 years.

Division 3 Rules Case, Rio Grande Basin, Colorado
Mr. Sullivan represented a group of surface water right owners that opposed the enactment of administrative rules governing the withdrawal and use of ground water in the Rio Grande Basin in Colorado (Water Division 3). The primary basis for their opposition was that the rules did not provide for mitigation of impacts to a large spring that was the source of their surface water rights and which dried up in conjunction with the large-scale development of ground water irrigation in the area. Mr. Sullivan's work included analysis of the historical irrigation water use by his clients, review of hydrologic data and records, and review of a ground

water modeling of the San Luis Valley performed by the State of Colorado. Mr. Sullivan provided expert testimony on behalf of his clients in a trial before the Division 3 Water Court.

Administration of Rocky Hill Seepage and Overflow Ditch, Rio Grande Basin, Colorado

Mr. Sullivan represented a majority owner of the Rocky Hill Seepage and Overflow Ditch in the northwestern portion of the San Luis Valley in an action brought to overturn a change in administration by the Division 3 Engineer that curtailed use of the ditch on the basis that the source of water for the ditch that has been used for almost 100 years is not described in the decree for the ditch. Mr. Sullivan's work involved research of historical documents related to adjudication of the water right and historical disputes among water users in the vicinity, compilation and analysis of historical hydrologic data, and development of opinions on the decreed source of the water for the ditch. Mr. Sullivan provided expert testimony in a trial over the dispute in the Division 3 Water Court.

Surface and Ground Water Modeling, Kansas v. Colorado

Mr. Sullivan was involved in the refinement and use of the H-I Model of the Arkansas River system in Colorado that was developed to support claims by the State of Kansas that Colorado was violating the terms of the 1948 Arkansas River Compact. The model simulates daily operation of irrigation water uses under approximately two dozen canal systems along the Arkansas River in Colorado between the City of Pueblo and the Colorado-Kansas from 1950 to the present. In addition, the model simulates the operation of sole-source and supplemental irrigation wells, and the impact of those wells on the flow of the Arkansas River. Mr. Sullivan provided expert testimony before a Special Master appointed by the U.S. Supreme Court regarding the use of the H-I Model to evaluate the effects on state-line flows resulting from post-compact well development in Colorado.

Injury Analysis, Kansas v. Colorado

Mr. Sullivan developed a model that was used as part of an analysis to compute the economic impacts and monetary damages to Kansas resulting from the compact violations by Colorado that were determined in the Kansas v. Colorado lawsuit. The model was used to translate monthly depletions to usable stateline flows during 1950 - 1994 into impacts to (a) surface water users in Kansas, (b) to supplemental pumping demands in Kansas and (c) to recharge of the regional ground water system. Mr.

Gregory K. Sullivan, P.E.

Principal Water Resources Engineer

Sullivan testified before the Special Master regarding the model development, operation, and results.

Analysis of Replacement Plans, Kansas v. Colorado
In order to continue their use of post-compact Arkansas River alluvial wells, the well owners were required to develop Replacement Plans to offset the impacts of pumping on senior surface water rights in Colorado and on usable stateline flows to Kansas. Mr. Sullivan analyzed the adequacy of these replacement plans through preparation of historical use analyses, water budgets, and other analyses. In addition, Mr. Sullivan used the H-I Model to simulate the effectiveness of the replacement plans in meeting Colorado's delivery obligations under the Arkansas River Compact. Mr. Sullivan provided expert testimony before the Special Master concerning his analyses of the Colorado Replacement Plans.

1985 – 1990: ***J. W. Patterson & Associates, Inc., Water Resources Engineer***
Performed water supply, hydraulic and hydrologic analyses for agricultural, industrial, commercial and municipal developments. Managed yield and impact analyses of water rights adjudications, transfers, exchanges and plans for augmentation. Conducted ground water studies including aquifer testing, project dewatering and water well design and construction monitoring.

Continuing Education

Applied Ground-Water Flow Modeling. International Ground Water Modeling Center, Colorado School of Mines, Golden, CO. March 1993

Introduction to Simulation Training in RiverWare, Center for Advanced Decision Support for Water and Environmental Systems, University of Colorado, May 2016.

List of Expert Reports Authored by
Gregory K. Sullivan, P.E.
During the Last Five Years

Report Date	Name of Report	Applicant	Case No.	Client
11/10/14	Applicant Expert Report, Applcation for Conditional Water Rights, Change of Water Rights, Plan for Augmentation, and Exchange, Case No. 10CW318, Water Division 1	Cherry Creek Project Water Authority	10CW318	CCPWA
12/08/14	Objector Expert Report - Change of Water Rights and Plan for Augmentation - Mount Carbon Metropolitan District Water Rights - Case Nos. 04CW196 and 04CW197	Mount Carbon Metro politan District	04CW196 & 04CW197	Genesee Water and Sanitation District
01/06/15	Applicant Expert Report - Application for Finding of Diligence, Cherry Creek Project Water Authority, Case No. 11CW120	Cherry Creek Project Water Authority	11CW120	CCPWA
03/09/15	Supplemental Applicant Expert Report - Change of Loveland Gard Right, Case No. 07CW325	City of Loveland	07CW325	Ryley Carlock & Applewhite
03/31/15	Applicant Expert Report - Application for Conditional Water Rights, Appropriative Rights of Exchange, Approval of Plan for Augmentation - Case No. 12CW124	Climax Molybdenum Company	12CW124	Climax Molybdenum Company
04/27/15	Rebuttal Expert Report - Application for Conditional Water Rights, Change of Water Rights, Plan for Augmentation, and Exchange, Case No. 10CW318, Water Division 1	Cherry Creek Project Water Authority	10CW318	CCPWA
06/01/15	Rebuttal Expert Report - Change of Loveland Gard Right, Case No. 07CW325, Water Division 1	City of Loveland	07CW325	Ryley Carlock & Applewhite
06/02/15	Supplemental Expert Report - Application for Conditional Water Rights, Appropriative Rights of Exchange, and Approval of Plan for Augmentation, Case No. 12CW124, Water Division 2	Climax Molybdenum Company	12CW124	Climax Molybdenum Company
07/20/15	Objector Expert Report - Change of Water Rights - Colorado Sweet Gold and Al Water, LLC - Case No. 12CW262	Colorado Sweet Gold, LLC	12CW262	City of Loveland
08/31/15	Rebuttal Expert Report - Application for Water Rights, Appropriative Rights of Exchange, and Plan for Augmentation	Climax Molybdenum Company	12CW124	Climax Molybdenum Company
12/28/15	Applicant Revised Expert Report - Arapahoe County Water and Wastewater Authority Plan for Augmentation - Case No. 96CW1144	ACWWA	96CW1144	Arapahoe County Water and Wastewater Authority
02/24/16	Rebuttal Expert Report - Arapahoe County Water and Wastewater Authority Plan for Augmentation - Case No. 96CW1144	ACWWA	96CW1144	Arapahoe County Water and Wastewater Authority
03/16/16	Supplemental Expert Report - Arapahoe County Water and Wastewater Authority Plan for Augmentation - Case No. 96CW1144	ACWWA	96CW1144	Arapahoe County Water and Wastewater Authority
04/18/16	Objector Expert Report - Denver Southeast Suburban Water and Sanitation District Plan for Augmentation - Case No. 11CW198	ACWWA and CWSD	11CW198	Arapahoe County Water and Wastewater Authority

List of Expert Reports Authored by Gregory K. Sullivan, P.E. During the Last Five Years

Report Date	Name of Report	Applicant	Case No.	Client
01/30/17	Expert Report - Application for Change of Water Rights - Case No. 16CW3003	2J Ranches, et. al.	16CW3003	2J Ranches, et. al.
05/25/17	Opposers Expert Report - Rules Governing the Withdrawal of Groundwater in Water Division No. 3 - Case No. 15CW3024	Colorado State Engineer	15CW3024	2J Ranches, et. al.
06/29/17	Rebuttal Expert Report - Application for Change of Water Rights - Case No. 16CW3003	2J Ranches, et. al.	16CW3003	2J Ranches, et. al.
07/13/17	Expert Report - Loveland Eisenhower Investments, LLC v. City of Loveland and Greeley and Loveland Irrigation Company - Case No. 16CV30362	Loveland Eisenhower Investments, LLC	16CV30362	City of Loveland
08/04/17	Sur-rebuttal Expert Report - Rules Governing the Withdrawal of Groundwater in Water Division No. 3 - Case No. 15CW3024	Colorado State Engineer	15CW3024	2J Ranches, et. al.
09/25/17	Objector Expert Report - Application for Water Rights, Change of Water Rights, and Plan for Augmentation - Sylvan Dale Ranch - Case No. 14CW3016	Sylvan Dale Ranch, LLP	14CW3016	City of Loveland
08/07/18	Expert Report, Protest of Application for Permit 63-34348 by Elmore County, Idaho	Elmore County, Idaho	n/a	City of Boise
09/18/18	Rebuttal Expert Report, Protest of Application for Permit 63-34348 by Elmore County, Idaho	Elmore County, Idaho	n/a	City of Boise
12/17/18	Applicant Expert Report, Application of Interpretation of Decree, Rocky Hill Seepage and Overflow Ditch, Case No. 2017CW3003, Water Division 3	State of Colorado	2017CW3003	Mike and Jim Kruse Partnership
01/30/19	Applicant Rebuttal Expert Report, Application of Interpretation of Decree, Rocky Hill Seepage and Overflow Ditch, Case No. 2017CW3003, Water Division 3	State of Colorado	2017CW3003	Mike and Jim Kruse Partnership

List of Cases in Which
Gregory K. Sullivan, P.E.
Has Testified as an Expert Witness
During the Past Four Years

Case No.	Court	Description	Client
10CW318	District Court, Water Division 1, Colorado	Application for Water Rights of Cherry Creek Project Water Authority	Cherry Creek Project Water Authority (Applicant)
16CW3003	District Court, Water Division 3, Colorado	Application for Water Rights of 2J Ranches, et. al.	2J Ranches, et. al.
15CW3024	District Court, Water Division 3, Colorado	Rules Governing the Withdrawal of Ground Water in Water Division 3	2J Ranches, et. al.
n/a	Idaho Department of Water Resources	Application for Permit No. 63-34348 by Elmore County Board of County Commissioners	City of Boise
17CW3003	District Court, Water Division 3, Colorado	Application of Interpretation of Decree, Rocky Hill Seepage and Overflow Ditch	Mike and Jim Kruse Partnership

Appendix 1B
Professional Resume of
Adelheid M Welsh

Heidi M. Welsh, P.H.

Senior Watershed Scientist

Education: B.S. Watershed Science, 2007, Colorado State University

Professional Registration: Professional Hydrologist, American Institute of Hydrology

Professional Experience:

2009 - Present: ***Spronk Water Engineers, Inc., Senior Watershed Scientist***
Responsible for compilation and analysis of water resources, water rights and hydrologic data including climatological data, streamflow data, diversion records, cropping patterns, call records, water rights tabulations and decrees. Analyses include quantification of historical consumptive use, crop evapotranspiration calculations, water availability analyses, stream depletion modeling, point flow modeling, and other surface water modeling. Assists with water rights protection, substitute water supply plans, augmentation plans, and water rights accounting. Responsible for GIS mapping and modeling related to water resources including georeferencing and digitizing, delineation and quantification of irrigated area, hydrologic analyses, and geospatial analysis.

Summary of Experience:

Ms. Welsh has over ten years of experience working in the water resources field in Colorado, Wyoming, New Mexico, Montana, and Idaho. She has provided engineering support and assistance with water rights protection, substitute water supply plans, and augmentation plans. She is experienced in the review, development and maintenance of water rights accounting. She has extensive experience in GIS applications and modeling related to water resources and has prepared numerous court exhibits.

Description of Representative Projects:

Town of La Salle, Water Supply Consulting.
Assisted the Town in developing a water supply for irrigation of parks, ballfield, and subdivision lawns. Assisted with a substitute supply plan and assisted in change of Godfrey Ditch and Union Reservoir water rights

Heidi M. Welsh, P.H.

Senior Watershed Scientist

application to allow use of an irrigation well, replacing depletions with leased water supplies from the reservoir. Engineering analyses include calculation of water demands, water consumption and timing of stream depletions to the South Platte River. Responsible for daily augmentation plan accounting.

City of Pocatello, Water Rights Protection and Water Supply.
Assists in preparation of exhibits and water rights analyses for administrative hearings. Engineering analyses include analysis and review of water rights data and water measurements, summarizing and mapping depletions using Eastern Snake Plain Aquifer Model runs, and mapping water rights data.

State of New Mexico, Rio Grande Compact.
Responsible for review, compilation, and maintenance of surface water data. Assists in the review of surface water modeling efforts, including RiverWare modeling.

Cherry Creek Project Water Authority.
Assists with analysis and mapping of the Cherry Creek Basin in support of water rights applications and basin modeling. Analyses include water availability analyses, point flow modeling, consumptive use analyses, and stream depletion modeling.

Climax Molybdenum, Plan for Augmentation in Division 2.
Assists with analysis in support of a water rights application. Analyses include computation of current and historical depletions, point flow and exchange potential modeling, and probability analyses. Responsible for GIS analyses and mapping for the project.

Centennial Water & Sanitation District, Water Rights Protection.
Assists with review of water court applications and substitute water supply plans for water rights protection. Analyses include return flow and consumptive use calculations, delineation of irrigated area, compilation of diversion records, and stream depletion modeling.

Yellowstone River Compact.
Delineated current and historic irrigated fields along the Powder and Tongue Rivers in Montana. Compiled and analyzed historical agricultural data from the U.S. Agricultural Census.

Heidi M. Welsh, P.H.

Senior Watershed Scientist

2007 – 2009: ***AATA International, Inc., Environmental/GIS Specialist***
Compiled and interpreted social and environmental data for preparation of large-scale environmental impact assessments and other technical reports. Responsible for collection and maintenance of databases. Conducted impact analysis, assessed water supply sources, and developed mitigation and monitoring plans for natural resource development projects. Utilized GIS software in mapping and analyses of environmental data and prepared numerous figures for technical reports.

2006 – 2007: ***USDA Forest Service, Hydrologic Technician***
Completed soil, stream crossing, and stream health surveys for timber sale units. Managed grazing by the completion of soil inventories for NEPA compliance. Mapped streams and forest roads using GPS and GIS. Evaluated Best Management Practices for feasibility and effectiveness.

2006: ***Teton Science School, Hydrology Intern***
Measured stream discharge, monitored ground water well levels and collected water quality samples weekly at twelve sites. Entered and analyzed data for technical documentation. Taught watershed science and hydrology field methods to adults and children.

Professional Memberships:
American Institute of Hydrology
American Water Resources Association
Colorado Ground Water Association

Appendix 3A
Monthly and Annual Data Availability Matrices

Summary of River Gage Data (red highlight = data available)

Monthly Data
1940 - 1949

River Gages	POR	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949
		J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D
Rio Grande at San Marcial (old)	1899-1964										
Rio Grande at San Marcial (conveyance)	1951-2017										
Rio Grande at San Marcial (flood)	1949-2017										
Rio Grande below Elephant Butte Dam	1913-2017										
Rio Grande below Caballo Dam	1938-2017										
Rio Grande below Percha Dam	1922-1937										
Rio Grande at Haynor Bridge	2000-2005										
Rio Grande at Tonuco	2000-2003										
Rio Grande above Leasburg Dam	1924-1983										
Rio Grande below Leasburg Dam	1919-2017										
Rio Grande at Picacho Bridge	1991-2005										
Las Cruces Arroyo near Las Cruces	1958-1966										
Rio Grande below Mesilla Dam	1980-2017										
Rio Grande at Vado Bridge	1985-1995										
Rio Grande at Anthony	1986-2011										
Rio Grande at Vinton Bridge	1970-1991										
Rio Grande at Canutillo Bridge	1985-2017										
Rio Grande at El Paso (Courchesne)	1889-2017										
Rio Grande below American Dam	1938-2017										
Rio Grande at Juarez Station	1938-1956										
Rio Grande at Island Station	1938-1984										
Rio Grande at Tornillo Bridge Station	1931-1938										
Rio Grande at County Line Station	1938-1984										
Rio Grande at Fort Quitman	1923-2017										

1950 - 1959

River Gages	POR	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959
		J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D
Rio Grande at San Marcial (old)	1899-1964										
Rio Grande at San Marcial (conveyance)	1951-2017										
Rio Grande at San Marcial (flood)	1949-2017										
Rio Grande below Elephant Butte Dam	1913-2017										
Rio Grande below Caballo Dam	1938-2017										
Rio Grande below Percha Dam	1922-1937										
Rio Grande at Haynor Bridge	2000-2005										
Rio Grande at Tonuco	2000-2003										
Rio Grande above Leasburg Dam	1924-1983										
Rio Grande below Leasburg Dam	1919-2017										
Rio Grande at Picacho Bridge	1991-2005										
Las Cruces Arroyo near Las Cruces	1958-1966										
Rio Grande below Mesilla Dam	1980-2017										
Rio Grande at Vado Bridge	1985-1995										
Rio Grande at Anthony	1986-2011										
Rio Grande at Vinton Bridge	1970-1991										
Rio Grande at Canutillo Bridge	1985-2017										
Rio Grande at El Paso (Courchesne)	1889-2017										
Rio Grande below American Dam	1938-2017										
Rio Grande at Juarez Station	1938-1956										
Rio Grande at Island Station	1938-1984										
Rio Grande at Tornillo Bridge Station	1931-1938										
Rio Grande at County Line Station	1938-1984										
Rio Grande at Fort Quitman	1923-2017										

1960 - 1969

River Gages	POR	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
		J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D
Rio Grande at San Marcial (old)	1899-1964										
Rio Grande at San Marcial (conveyance)	1951-2017										
Rio Grande at San Marcial (flood)	1949-2017										
Rio Grande below Elephant Butte Dam	1913-2017										
Rio Grande below Caballo Dam	1938-2017										
Rio Grande below Percha Dam	1922-1937										
Rio Grande at Haynor Bridge	2000-2005										
Rio Grande at Tonuco	2000-2003										
Rio Grande above Leasburg Dam	1924-1983										
Rio Grande below Leasburg Dam	1919-2017										
Rio Grande at Picacho Bridge	1991-2005										
Las Cruces Arroyo near Las Cruces	1958-1966										
Rio Grande below Mesilla Dam	1980-2017										
Rio Grande at Vado Bridge	1985-1995										
Rio Grande at Anthony	1986-2011										
Rio Grande at Vinton Bridge	1970-1991										
Rio Grande at Canutillo Bridge	1985-2017										
Rio Grande at El Paso (Courchesne)	1889-2017										
Rio Grande below American Dam	1938-2017										
Rio Grande at Juarez Station	1938-1956										
Rio Grande at Island Station	1938-1984										
Rio Grande at Tornillo Bridge Station	1931-1938										
Rio Grande at County Line Station	1938-1984										
Rio Grande at Fort Quitman	1923-2017										

Summary of River Gage Data (red highlight = data available)

Monthly Data

1970 - 1979

Years: 1970, 1971, 1972, 1973, 1974, 1975, 1976, 1977, 1978, 1979 (months J F M A M J J A S O N D)

River Gages	POR
Rio Grande at San Marcial (old)	1899-1964
Rio Grande at San Marcial (conveyance)	1951-2017
Rio Grande at San Marcial (flood)	1949-2017
Rio Grande below Elephant Butte Dam	1913-2017
Rio Grande below Caballo Dam	1938-2017
Rio Grande below Percha Dam	1922-1937
Rio Grande at Haynor Bridge	2000-2005
Rio Grande at Tonuco	2000-2003
Rio Grande above Leasburg Dam	1924-1983
Rio Grande below Leasburg Dam	1919-2017
Rio Grande at Picacho Bridge	1991-2005
Las Cruces Arroyo near Las Cruces	1958-1966
Rio Grande below Mesilla Dam	1980-2017
Rio Grande at Vado Bridge	1985-1995
Rio Grande at Anthony	1986-2011
Rio Grande at Vinton Bridge	1970-1991
Rio Grande at Canutillo Bridge	1985-2017
Rio Grande at El Paso (Courchesne)	1889-2017
Rio Grande below American Dam	1938-2017
Rio Grande at Juarez Station	1938-1956
Rio Grande at Island Station	1938-1984
Rio Grande at Tornillo Bridge Station	1931-1938
Rio Grande at County Line Station	1938-1984
Rio Grande at Fort Quitman	1923-2017

1980 - 1989

Years: 1980, 1981, 1982, 1983, 1984, 1985, 1986, 1987, 1988, 1989 (months J F M A M J J A S O N D)

River Gages	POR
Rio Grande at San Marcial (old)	1899-1964
Rio Grande at San Marcial (conveyance)	1951-2017
Rio Grande at San Marcial (flood)	1949-2017
Rio Grande below Elephant Butte Dam	1913-2017
Rio Grande below Caballo Dam	1938-2017
Rio Grande below Percha Dam	1922-1937
Rio Grande at Haynor Bridge	2000-2005
Rio Grande at Tonuco	2000-2003
Rio Grande above Leasburg Dam	1924-1983
Rio Grande below Leasburg Dam	1919-2017
Rio Grande at Picacho Bridge	1991-2005
Las Cruces Arroyo near Las Cruces	1958-1966
Rio Grande below Mesilla Dam	1980-2017
Rio Grande at Vado Bridge	1985-1995
Rio Grande at Anthony	1986-2011
Rio Grande at Vinton Bridge	1970-1991
Rio Grande at Canutillo Bridge	1985-2017
Rio Grande at El Paso (Courchesne)	1889-2017
Rio Grande below American Dam	1938-2017
Rio Grande at Juarez Station	1938-1956
Rio Grande at Island Station	1938-1984
Rio Grande at Tornillo Bridge Station	1931-1938
Rio Grande at County Line Station	1938-1984
Rio Grande at Fort Quitman	1923-2017

1990 - 1999

Years: 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999 (months J F M A M J J A S O N D)

River Gages	POR
Rio Grande at San Marcial (old)	1899-1964
Rio Grande at San Marcial (conveyance)	1951-2017
Rio Grande at San Marcial (flood)	1949-2017
Rio Grande below Elephant Butte Dam	1913-2017
Rio Grande below Caballo Dam	1938-2017
Rio Grande below Percha Dam	1922-1937
Rio Grande at Haynor Bridge	2000-2005
Rio Grande at Tonuco	2000-2003
Rio Grande above Leasburg Dam	1924-1983
Rio Grande below Leasburg Dam	1919-2017
Rio Grande at Picacho Bridge	1991-2005
Las Cruces Arroyo near Las Cruces	1958-1966
Rio Grande below Mesilla Dam	1980-2017
Rio Grande at Vado Bridge	1985-1995
Rio Grande at Anthony	1986-2011
Rio Grande at Vinton Bridge	1970-1991
Rio Grande at Canutillo Bridge	1985-2017
Rio Grande at El Paso (Courchesne)	1889-2017
Rio Grande below American Dam	1938-2017
Rio Grande at Juarez Station	1938-1956
Rio Grande at Island Station	1938-1984
Rio Grande at Tornillo Bridge Station	1931-1938
Rio Grande at County Line Station	1938-1984
Rio Grande at Fort Quitman	1923-2017

Summary of River Gage Data (red highlight = data available)

Monthly Data
2000 - 2009

River Gages	POR	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
		J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D
Rio Grande at San Marcial (old)	1899-1964										
Rio Grande at San Marcial (conveyance)	1951-2017										
Rio Grande at San Marcial (flood)	1949-2017										
Rio Grande below Elephant Butte Dam	1913-2017										
Rio Grande below Caballo Dam	1938-2017										
Rio Grande below Percha Dam	1922-1937										
Rio Grande at Haynor Bridge	2000-2005										
Rio Grande at Tonuco	2000-2003										
Rio Grande above Leasburg Dam	1924-1983										
Rio Grande below Leasburg Dam	1919-2017										
Rio Grande at Picacho Bridge	1991-2005										
Las Cruces Arroyo near Las Cruces	1958-1966										
Rio Grande below Mesilla Dam	1980-2017										
Rio Grande at Vado Bridge	1985-1995										
Rio Grande at Anthony	1986-2011										
Rio Grande at Vinton Bridge	1970-1991										
Rio Grande at Canutillo Bridge	1985-2017										
Rio Grande at El Paso (Courchesne)	1889-2017										
Rio Grande below American Dam	1938-2017										
Rio Grande at Juarez Station	1938-1956										
Rio Grande at Island Station	1938-1984										
Rio Grande at Tornillo Bridge Station	1931-1938										
Rio Grande at County Line Station	1938-1984										
Rio Grande at Fort Quitman	1923-2017										

2010 - 2017

River Gages	POR	2010	2011	2012	2013	2014	2015	2016	2017
		J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D
Rio Grande at San Marcial (old)	1899-1964								
Rio Grande at San Marcial (conveyance)	1951-2017								
Rio Grande at San Marcial (flood)	1949-2017								
Rio Grande below Elephant Butte Dam	1913-2017								
Rio Grande below Caballo Dam	1938-2017								
Rio Grande below Percha Dam	1922-1937								
Rio Grande at Haynor Bridge	2000-2005								
Rio Grande at Tonuco	2000-2003								
Rio Grande above Leasburg Dam	1924-1983								
Rio Grande below Leasburg Dam	1919-2017								
Rio Grande at Picacho Bridge	1991-2005								
Las Cruces Arroyo near Las Cruces	1958-1966								
Rio Grande below Mesilla Dam	1980-2017								
Rio Grande at Vado Bridge	1985-1995								
Rio Grande at Anthony	1986-2011								
Rio Grande at Vinton Bridge	1970-1991								
Rio Grande at Canutillo Bridge	1985-2017								
Rio Grande at El Paso (Courchesne)	1889-2017								
Rio Grande below American Dam	1938-2017								
Rio Grande at Juarez Station	1938-1956								
Rio Grande at Island Station	1938-1984								
Rio Grande at Tornillo Bridge Station	1931-1938								
Rio Grande at County Line Station	1938-1984								
Rio Grande at Fort Quitman	1923-2017								

Summary of River Gage Data (red highlight = data available)

Annual Data 1889 - 2017

River Gages	POR	1889 - 1900	1901 - 1912	1913 - 1924	1925 - 1936	1937 - 1948	1949 - 1960	1961 - 1972	1973 - 1984	1985 - 1996	1997 - 2008	2009 - 2017
Rio Grande at San Marcial (old)	1899-1964											
Rio Grande at San Marcial (conveyance)	1951-2017											
Rio Grande at San Marcial (flood)	1949-2017											
Rio Grande below Elephant Butte Dam	1913-2017											
Rio Grande below Caballo Dam	1938-2017											
Rio Grande below Percha Dam	1922-1937											
Rio Grande at Haynor Bridge	2000-2005											
Rio Grande at Tonuco	2000-2003											
Rio Grande above Leasburg Dam	1924-1983											
Rio Grande below Leasburg Dam	1919-2017											
Rio Grande at Picacho Bridge	1991-2005											
Las Cruces Arroyo near Las Cruces	1958-1966											
Rio Grande below Mesilla Dam	1980-2017											
Rio Grande at Vado Bridge	1985-1995											
Rio Grande at Anthony	1986-2011											
Rio Grande at Vinton Bridge	1970-1991											
Rio Grande at Canutillo Bridge	1985-2017											
Rio Grande at El Paso (Courchesne)	1889-2017											
Rio Grande below American Dam	1938-2017											
Rio Grande at Juarez Station	1938-1956											
Rio Grande at Island Station	1938-1984											
Rio Grande at Tornillo Bridge Station	1931-1938											
Rio Grande at County Line Station	1938-1984											
Rio Grande at Fort Quitman	1923-2017											
Rio Grande at Coffer Dam	1988-2009											

Note: There may be missing months of data within the year.

Summary of Canal/Lateral Data (red highlight = data available)

Monthly Data 1940 - 1949

	Canals/Laterals	POR	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949
			J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D
2	Bonita Lateral	1938-2017										
3	Arrey Canal	1918-2017										
4	Percha Lateral	1953-2017										
5	Hatch Main Canal	2001-2002										
6	Above Leasburg Heading	1984-1988										
7	Leasburg Canal Unknown (above or be	1908-1935										
8	Leasburg Canal Above 1st Check	1936-1998										
9	Leasburg Canal (net diversion below 1s	1936-2017										
10	Las Cruces Lateral	2001-2002										
11	California Extension	1985-2017										
12	Pumped from River	1985-2017										
13	Westside Canal	1916-2017										
14	Eastside Canal	1916-2017										
15	Del Rio Lateral	1955-2017										
16	La Union West	1979-2017										
17	La Union East	1979-2017										
18	3 Saints Lateral	1979-2017										
19	3 Saints West Lateral	1979-2005										
20	Canutillo Lateral	1979-1982										
21	American Canal	1938-2017										
22	Franklin Canal	1903-2017										
23	Riverside Canal	1928-2017										
24	Acequia Madre	1903-2017										
25	River Diversions	1903-1984										
26	Tornillo Canal at Alamo Alto (aka Tornil	1947-2017										
27	Hudspeth Feeder Canal	1947-2017										
28	Tornillo Canal	1924-1999										
29	Tornillo Waste End	1924-1947										
30	Tornillo Canal near Alamo Check	1947-1949										
31	Hudspeth Canal (Tornillo End)	1925-1955										

1950 - 1959

	Canals/Laterals	POR	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959
			J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D
2	Bonita Lateral	1938-2017										
3	Arrey Canal	1918-2017										
4	Percha Lateral	1953-2017										
5	Hatch Main Canal	2001-2002										
6	Above Leasburg Heading	1984-1988										
7	Leasburg Canal Unknown (above or be	1908-1935										
8	Leasburg Canal Above 1st Check	1936-1998										
9	Leasburg Canal (net diversion below 1s	1936-2017										
10	Las Cruces Lateral	2001-2002										
11	California Extension	1985-2017										
12	Pumped from River	1985-2017										
13	Westside Canal	1916-2017										
14	Eastside Canal	1916-2017										
15	Del Rio Lateral	1955-2017										
16	La Union West	1979-2017										
17	La Union East	1979-2017										
18	3 Saints Lateral	1979-2017										
19	3 Saints West Lateral	1979-2005										
20	Canutillo Lateral	1979-1982										
21	American Canal	1938-2017										
22	Franklin Canal	1903-2017										
23	Riverside Canal	1928-2017										
24	Acequia Madre	1903-2017										
25	River Diversions	1903-1984										
26	Tornillo Canal at Alamo Alto (aka Tornil	1947-2017										
27	Hudspeth Feeder Canal	1947-2017										
28	Tornillo Canal	1924-1999										
29	Tornillo Waste End	1924-1947										
30	Tornillo Canal near Alamo Check	1947-1949										
31	Hudspeth Canal (Tornillo End)	1925-1955										

1960 - 1969

	Canals/Laterals	POR	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
			J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D
2	Bonita Lateral	1938-2017										
3	Arrey Canal	1918-2017										
4	Percha Lateral	1953-2017										
5	Hatch Main Canal	2001-2002										
6	Above Leasburg Heading	1984-1988										
7	Leasburg Canal Unknown (above or be	1908-1935										
8	Leasburg Canal Above 1st Check	1936-1998										
9	Leasburg Canal (net diversion below 1s	1936-2017										
10	Las Cruces Lateral	2001-2002										
11	California Extension	1985-2017										
12	Pumped from River	1985-2017										
13	Westside Canal	1916-2017										
14	Eastside Canal	1916-2017										
15	Del Rio Lateral	1955-2017										
16	La Union West	1979-2017										
17	La Union East	1979-2017										
18	3 Saints Lateral	1979-2017										
19	3 Saints West Lateral	1979-2005										
20	Canutillo Lateral	1979-1982										
21	American Canal	1938-2017										
22	Franklin Canal	1903-2017										
23	Riverside Canal	1928-2017										
24	Acequia Madre	1903-2017										
25	River Diversions	1903-1984										
26	Tornillo Canal at Alamo Alto (aka Tornil	1947-2017										
27	Hudspeth Feeder Canal	1947-2017										
28	Tornillo Canal	1924-1999										
29	Tornillo Waste End	1924-1947										
30	Tornillo Canal near Alamo Check	1947-1949										
31	Hudspeth Canal (Tornillo End)	1925-1955										

Summary of Canal/Lateral Data (red highlight = data available)

1970 - 1979

1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 (each year: J F M A M J J A S O N D)

	Canals/Laterals	POR
2	Bonita Lateral	1938-2017
3	Arrey Canal	1918-2017
4	Percha Lateral	1953-2017
5	Hatch Main Canal	2001-2002
6	Above Leasburg Heading	1984-1988
7	Leasburg Canal Unknown (above or be	1908-1935
8	Leasburg Canal Above 1st Check	1936-1998
9	Leasburg Canal (net diversion below 1s	1936-2017
10	Las Cruces Lateral	2001-2002
11	California Extension	1985-2017
12	Pumped from River	1985-2017
13	Westside Canal	1916-2017
14	Eastside Canal	1916-2017
15	Del Rio Lateral	1955-2017
16	La Union West	1979-2017
17	La Union East	1979-2017
18	3 Saints Lateral	1979-2017
19	3 Saints West Lateral	1979-2005
20	Canutillo Lateral	1979-1982
21	American Canal	1938-2017
22	Franklin Canal	1903-2017
23	Riverside Canal	1928-2017
24	Acequia Madre	1903-2017
25	River Diversions	1903-1984
26	Tornillo Canal at Alamo Alto (aka Tornil	1947-2017
27	Hudspeth Feeder Canal	1947-2017
28	Tornillo Canal	1924-1999
29	Tornillo Waste End	1924-1947
30	Tornillo Canal near Alamo Check	1947-1949
31	Hudspeth Canal (Tornillo End)	1925-1955

1980 - 1989

1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 (each year: J F M A M J J A S O N D)

	Canals/Laterals	POR
2	Bonita Lateral	1938-2017
3	Arrey Canal	1918-2017
4	Percha Lateral	1953-2017
5	Hatch Main Canal	2001-2002
6	Above Leasburg Heading	1984-1988
7	Leasburg Canal Unknown (above or be	1908-1935
8	Leasburg Canal Above 1st Check	1936-1998
9	Leasburg Canal (net diversion below 1s	1936-2017
10	Las Cruces Lateral	2001-2002
11	California Extension	1985-2017
12	Pumped from River	1985-2017
13	Westside Canal	1916-2017
14	Eastside Canal	1916-2017
15	Del Rio Lateral	1955-2017
16	La Union West	1979-2017
17	La Union East	1979-2017
18	3 Saints Lateral	1979-2017
19	3 Saints West Lateral	1979-2005
20	Canutillo Lateral	1979-1982
21	American Canal	1938-2017
22	Franklin Canal	1903-2017
23	Riverside Canal	1928-2017
24	Acequia Madre	1903-2017
25	River Diversions	1903-1984
26	Tornillo Canal at Alamo Alto (aka Tornil	1947-2017
27	Hudspeth Feeder Canal	1947-2017
28	Tornillo Canal	1924-1999
29	Tornillo Waste End	1924-1947
30	Tornillo Canal near Alamo Check	1947-1949
31	Hudspeth Canal (Tornillo End)	1925-1955

1990 - 1999

1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 (each year: J F M A M J J A S O N D)

	Canals/Laterals	POR
2	Bonita Lateral	1938-2017
3	Arrey Canal	1918-2017
4	Percha Lateral	1953-2017
5	Hatch Main Canal	2001-2002
6	Above Leasburg Heading	1984-1988
7	Leasburg Canal Unknown (above or be	1908-1935
8	Leasburg Canal Above 1st Check	1936-1998
9	Leasburg Canal (net diversion below 1s	1936-2017
10	Las Cruces Lateral	2001-2002
11	California Extension	1985-2017
12	Pumped from River	1985-2017
13	Westside Canal	1916-2017
14	Eastside Canal	1916-2017
15	Del Rio Lateral	1955-2017
16	La Union West	1979-2017
17	La Union East	1979-2017
18	3 Saints Lateral	1979-2017
19	3 Saints West Lateral	1979-2005
20	Canutillo Lateral	1979-1982
21	American Canal	1938-2017
22	Franklin Canal	1903-2017
23	Riverside Canal	1928-2017
24	Acequia Madre	1903-2017
25	River Diversions	1903-1984
26	Tornillo Canal at Alamo Alto (aka Tornil	1947-2017
27	Hudspeth Feeder Canal	1947-2017
28	Tornillo Canal	1924-1999
29	Tornillo Waste End	1924-1947
30	Tornillo Canal near Alamo Check	1947-1949
31	Hudspeth Canal (Tornillo End)	1925-1955

Summary of Canal/Lateral Data (red highlight = data available)

2000 - 2009

2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009

(each year: J F M A M J J A S O N D)

	Canals/Laterals	POR
2	Bonita Lateral	1938-2017
3	Arrey Canal	1918-2017
4	Percha Lateral	1953-2017
5	Hatch Main Canal	2001-2002
6	Above Leasburg Heading	1984-1988
7	Leasburg Canal Unknown (above or bel	1908-1935
8	Leasburg Canal Above 1st Check	1936-1998
9	Leasburg Canal (net diversion below 1s	1936-2017
10	Las Cruces Lateral	2001-2002
11	California Extension	1985-2017
12	Pumped from River	1985-2017
13	Westside Canal	1916-2017
14	Eastside Canal	1916-2017
15	Del Rio Lateral	1955-2017
16	La Union West	1979-2017
17	La Union East	1979-2017
18	3 Saints Lateral	1979-2017
19	3 Saints West Lateral	1979-2005
20	Canutillo Lateral	1979-1982
21	American Canal	1938-2017
22	Franklin Canal	1903-2017
23	Riverside Canal	1928-2017
24	Acequia Madre	1903-2017
25	River Diversions	1903-1984
26	Tornillo Canal at Alamo Alto (aka Tornil	1947-2017
27	Hudspeth Feeder Canal	1947-2017
28	Tornillo Canal	1924-1999
29	Tornillo Waste End	1924-1947
30	Tornillo Canal near Alamo Check	1947-1949
31	Hudspeth Canal (Tornillo End)	1925-1955

2010 - 2017

2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017

(each year: J F M A M J J A S O N D)

	Canals/Laterals	POR
2	Bonita Lateral	1938-2017
3	Arrey Canal	1918-2017
4	Percha Lateral	1953-2017
5	Hatch Main Canal	2001-2002
6	Above Leasburg Heading	1984-1988
7	Leasburg Canal Unknown (above or bel	1908-1935
8	Leasburg Canal Above 1st Check	1936-1998
9	Leasburg Canal (net diversion below 1s	1936-2017
10	Las Cruces Lateral	2001-2002
11	California Extension	1985-2017
12	Pumped from River	1985-2017
13	Westside Canal	1916-2017
14	Eastside Canal	1916-2017
15	Del Rio Lateral	1955-2017
16	La Union West	1979-2017
17	La Union East	1979-2017
18	3 Saints Lateral	1979-2017
19	3 Saints West Lateral	1979-2005
20	Canutillo Lateral	1979-1982
21	American Canal	1938-2017
22	Franklin Canal	1903-2017
23	Riverside Canal	1928-2017
24	Acequia Madre	1903-2017
25	River Diversions	1903-1984
26	Tornillo Canal at Alamo Alto (aka Tornil	1947-2017
27	Hudspeth Feeder Canal	1947-2017
28	Tornillo Canal	1924-1999
29	Tornillo Waste End	1924-1947
30	Tornillo Canal near Alamo Check	1947-1949
31	Hudspeth Canal (Tornillo End)	1925-1955

Summary of Canal/Lateral Data (red highlight = data available)

Annual Data 1903 - 2017

	Canals/Laterals	POR	1903-1907	1908 - 1919	1920 - 1931	1932 - 1943	1944 - 1955	1956 - 1967	1968 - 1979	1980 - 1991	1992 - 2003	2004 - 2015	16 - 20
2	Bonita Lateral	1938-2017											
3	Arrey Canal	1918-2017											
4	Percha Lateral	1953-2017											
5	Hatch Main Canal	2001-2002											
6	Above Leasburg Heading	1984-1988											
7	Leasburg Canal Unknown (above or be	1908-1935											
8	Leasburg Canal Above 1st Check	1936-1998											
9	Leasburg Canal (net diversion below 1s	1936-2017											
10	Las Cruces Lateral	2001-2002											
11	California Extension	1985-2017											
12	Pumped from River	1985-2017											
13	Westside Canal	1916-2017											
14	Eastside Canal	1916-2017											
15	Del Rio Lateral	1955-2017											
16	La Union West	1979-2017											
17	La Union East	1979-2017											
18	3 Saints Lateral	1979-2017											
19	3 Saints West Lateral	1979-2005											
20	Canutillo Lateral	1979-1982											
21	American Canal	1938-2017											
22	Franklin Canal	1903-2017											
23	Riverside Canal	1928-2017											
24	Acequia Madre	1903-2017											
25	River Diversions	1903-1984											
26	Tornillo Canal at Alamo Alto (aka Tornil	1947-2017											
27	Hudspeth Feeder Canal	1947-2017											
28	Tornillo Canal	1924-1999											
29	Tornillo Waste End	1924-1947											
30	Tornillo Canal near Alamo Check	1947-1949											
31	Hudspeth Canal (Tornillo End)	1925-1955											
32	Acequia Madre en el Sauzal	1938-1956											

Note: There may be missing months of data within the year.

Summary of Drain Data (red highlight = data available)

Monthly Data 1940 - 1949

Years: 1940, 1941, 1942, 1943, 1944, 1945, 1946, 1947, 1948, 1949 (each divided into months J F M A M J J A S O N D)

	Drains	POR
2	Garfield Drain	1923-2005
3	Hatch Drain	1923-2005
4	Angostura Drain	1926-1983
5	Rincon Drain	1925-2005
6	Selden Drain	1923-1983
7	Leasburg Drain	1923-1983
8	Picacho Drain	1923-2005
9	Mesilla Drain	1923-1983
10	Santo Tomas River Drain	1985-1990
11	Santo Tomas Drain	1980-1985
12	West Drain	1923-2013
13	La Mesa Drain	1923-2013
14	Chamberino Drain	1923-1983
15	Nemexas Drain	1923-2013
16	Del Rio Drain	1923-2013
17	Mesquite Drain	1997-2001
18	East Drain	1930-2013
19	Anthony Drain	1923-2005
20	Montoya Drain	1923-2017
21	East Drain (EPCWID)	1923-2017
22	Montoya Intercepting Drain	1985-1990
23	Franklin Drain	1921-1983
24	Playa Drain	1923-1983
25	Middle Drain	1921-1983
26	River Drain	1923-1983
27	Cuadrilla Drain	1931-1983
28	Mesa Drain	1921-1983
29	Fabens Intercepting Drain	1931-1971
30	Border Drain	1923-1983
31	Island Drain	1921-1983
32	Island Syphon Drain	1936-1983
33	Alamo Alto Drain	1925-1983
34	Drain Water Diverted at Fabens	1945-1982
35	Fabens Waste Drain	1984-2017
36	Fabens Drain	1923-1983
37	Tornillo Drain	1923-2017

1950 - 1959

Years: 1950, 1951, 1952, 1953, 1954, 1955, 1956, 1957, 1958, 1959 (each divided into months J F M A M J J A S O N D)

	Drains	POR
2	Garfield Drain	1923-2005
3	Hatch Drain	1923-2005
4	Angostura Drain	1926-1983
5	Rincon Drain	1925-2005
6	Selden Drain	1923-1983
7	Leasburg Drain	1923-1983
8	Picacho Drain	1923-2005
9	Mesilla Drain	1923-1983
10	Santo Tomas River Drain	1985-1990
11	Santo Tomas Drain	1980-1985
12	West Drain	1923-2013
13	La Mesa Drain	1923-2013
14	Chamberino Drain	1923-1983
15	Nemexas Drain	1923-2013
16	Del Rio Drain	1923-2013
17	Mesquite Drain	1997-2001
18	East Drain	1930-2013
19	Anthony Drain	1923-2005
20	Montoya Drain	1923-2017
21	East Drain (EPCWID)	1923-2017
22	Montoya Intercepting Drain	1985-1990
23	Franklin Drain	1921-1983
24	Playa Drain	1923-1983
25	Middle Drain	1921-1983
26	River Drain	1923-1983
27	Cuadrilla Drain	1931-1983
28	Mesa Drain	1921-1983
29	Fabens Intercepting Drain	1931-1971
30	Border Drain	1923-1983
31	Island Drain	1921-1983
32	Island Syphon Drain	1936-1983
33	Alamo Alto Drain	1925-1983
34	Drain Water Diverted at Fabens	1945-1982
35	Fabens Waste Drain	1984-2017
36	Fabens Drain	1923-1983
37	Tornillo Drain	1923-2017

Summary of Drain Data (red highlight = data available)

Monthly Data 1960 - 1969

	Drains	POR	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
			J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D
2	Garfield Drain	1923-2005										
3	Hatch Drain	1923-2005										
4	Angostura Drain	1926-1983										
5	Rincon Drain	1925-2005										
6	Selden Drain	1923-1983										
7	Leasburg Drain	1923-1983										
8	Picacho Drain	1923-2005										
9	Mesilla Drain	1923-1983										
10	Santo Tomas River Drain	1985-1990										
11	Santo Tomas Drain	1980-1985										
12	West Drain	1923-2013										
13	La Mesa Drain	1923-2013										
14	Chamberino Drain	1923-1983										
15	Nemexas Drain	1923-2013										
16	Del Rio Drain	1923-2013										
17	Mesquite Drain	1997-2001										
18	East Drain	1930-2013										
19	Anthony Drain	1923-2005										
20	Montoya Drain	1923-2017										
21	East Drain (EPCWID)	1923-2017										
22	Montoya Intercepting Drain	1985-1990										
23	Franklin Drain	1921-1983										
24	Playa Drain	1923-1983										
25	Middle Drain	1921-1983										
26	River Drain	1923-1983										
27	Cuadrilla Drain	1931-1983										
28	Mesa Drain	1921-1983										
29	Fabens Intercepting Drain	1931-1971										
30	Border Drain	1923-1983										
31	Island Drain	1921-1983										
32	Island Syphon Drain	1936-1983										
33	Alamo Alto Drain	1925-1983										
34	Drain Water Diverted at Fabens	1945-1982										
35	Fabens Waste Drain	1984-2017										
36	Fabens Drain	1923-1983										
37	Tornillo Drain	1923-2017										

1970 - 1979

	Drains	POR	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
			J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D
2	Garfield Drain	1923-2005										
3	Hatch Drain	1923-2005										
4	Angostura Drain	1926-1983										
5	Rincon Drain	1925-2005										
6	Selden Drain	1923-1983										
7	Leasburg Drain	1923-1983										
8	Picacho Drain	1923-2005										
9	Mesilla Drain	1923-1983										
10	Santo Tomas River Drain	1985-1990										
11	Santo Tomas Drain	1980-1985										
12	West Drain	1923-2013										
13	La Mesa Drain	1923-2013										
14	Chamberino Drain	1923-1983										
15	Nemexas Drain	1923-2013										
16	Del Rio Drain	1923-2013										
17	Mesquite Drain	1997-2001										
18	East Drain	1930-2013										
19	Anthony Drain	1923-2005										
20	Montoya Drain	1923-2017										
21	East Drain (EPCWID)	1923-2017										
22	Montoya Intercepting Drain	1985-1990										
23	Franklin Drain	1921-1983										
24	Playa Drain	1923-1983										
25	Middle Drain	1921-1983										
26	River Drain	1923-1983										
27	Cuadrilla Drain	1931-1983										
28	Mesa Drain	1921-1983										
29	Fabens Intercepting Drain	1931-1971										
30	Border Drain	1923-1983										
31	Island Drain	1921-1983										
32	Island Syphon Drain	1936-1983										
33	Alamo Alto Drain	1925-1983										
34	Drain Water Diverted at Fabens	1945-1982										
35	Fabens Waste Drain	1984-2017										
36	Fabens Drain	1923-1983										
37	Tornillo Drain	1923-2017										

Summary of Drain Data (red highlight = data available)

Monthly Data
1980 - 1989

1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 (J F M A M J J A S O N D)

	Drains	POR
2	Garfield Drain	1923-2005
3	Hatch Drain	1923-2005
4	Angostura Drain	1926-1983
5	Rincon Drain	1925-2005
6	Selden Drain	1985-1990
7	Leasburg Drain	1923-1983
8	Picacho Drain	1923-2005
9	Mesilla Drain	1923-1983
10	Santo Tomas River Drain	1985-1990
11	Santo Tomas Drain	1980-1985
12	West Drain	1923-2013
13	La Mesa Drain	1923-2013
14	Chamberino Drain	1923-1983
15	Nemexas Drain	1923-2013
16	Del Rio Drain	1923-2013
17	Mesquite Drain	1997-2001
18	East Drain	1930-2013
19	Anthony Drain	1923-2005
20	Montoya Drain	1923-2017
21	East Drain (EPCWID)	1923-2017
22	Montoya Intercepting Drain	1985-1990
23	Franklin Drain	1921-1983
24	Playa Drain	1923-1983
25	Middle Drain	1921-1983
26	River Drain	1923-1983
27	Cuadrilla Drain	1931-1983
28	Mesa Drain	1921-1983
29	Fabens Intercepting Drain	1931-1971
30	Border Drain	1923-1983
31	Island Drain	1921-1983
32	Island Syphon Drain	1936-1983
33	Alamo Alto Drain	1925-1983
34	Drain Water Diverted at Fabens	1945-1982
35	Fabens Waste Drain	1984-2017
36	Fabens Drain	1923-1983
37	Tornillo Drain	1923-2017

1990 - 1999

1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 (J F M A M J J A S O N D)

	Drains	POR
2	Garfield Drain	1923-2005
3	Hatch Drain	1923-2005
4	Angostura Drain	1926-1983
5	Rincon Drain	1925-2005
6	Selden Drain	1923-1983
7	Leasburg Drain	1923-1983
8	Picacho Drain	1923-2005
9	Mesilla Drain	1923-1983
10	Santo Tomas River Drain	1985-1990
11	Santo Tomas Drain	1980-1985
12	West Drain	1923-2013
13	La Mesa Drain	1923-2013
14	Chamberino Drain	1923-1983
15	Nemexas Drain	1923-2013
16	Del Rio Drain	1923-2013
17	Mesquite Drain	1997-2001
18	East Drain	1930-2013
19	Anthony Drain	1923-2005
20	Montoya Drain	1923-2017
21	East Drain (EPCWID)	1923-2017
22	Montoya Intercepting Drain	1985-1990
23	Franklin Drain	1921-1983
24	Playa Drain	1923-1983
25	Middle Drain	1921-1983
26	River Drain	1923-1983
27	Cuadrilla Drain	1931-1983
28	Mesa Drain	1921-1983
29	Fabens Intercepting Drain	1931-1971
30	Border Drain	1923-1983
31	Island Drain	1921-1983
32	Island Syphon Drain	1936-1983
33	Alamo Alto Drain	1925-1983
34	Drain Water Diverted at Fabens	1945-1982
35	Fabens Waste Drain	1984-2017
36	Fabens Drain	1923-1983
37	Tornillo Drain	1923-2017

Summary of Drain Data (red highlight = data available)

Monthly Data

2000 - 2009

(Years 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009; months J F M A M J J A S O N D for each year)

	Drains	POR
2	Garfield Drain	1923-2005
3	Hatch Drain	1923-2005
4	Angostura Drain	1926-1983
5	Rincon Drain	1925-2005
6	Selden Drain	1923-1983
7	Leasburg Drain	1923-1983
8	Picacho Drain	1923-2005
9	Mesilla Drain	1923-1983
10	Santo Tomas River Drain	1985-1990
11	Santo Tomas Drain	1980-1985
12	West Drain	1923-2013
13	La Mesa Drain	1923-2013
14	Chamberino Drain	1923-1983
15	Nemexas Drain	1923-2013
16	Del Rio Drain	1923-2013
17	Mesquite Drain	1997-2001
18	East Drain	1930-2013
19	Anthony Drain	1923-2005
20	Montoya Drain	1923-2017
21	East Drain (EPCWID)	1923-2017
22	Montoya Intercepting Drain	1985-1990
23	Franklin Drain	1921-1983
24	Playa Drain	1923-1983
25	Middle Drain	1921-1983
26	River Drain	1923-1983
27	Cuadrilla Drain	1931-1983
28	Mesa Drain	1921-1983
29	Fabens Intercepting Drain	1931-1971
30	Border Drain	1923-1983
31	Island Drain	1921-1983
32	Island Syphon Drain	1936-1983
33	Alamo Alto Drain	1925-1983
34	Drain Water Diverted at Fabens	1945-1982
35	Fabens Waste Drain	1984-2017
36	Fabens Drain	1923-1983
37	Tornillo Drain	1923-2017

2010 - 2017

(Years 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017; months J F M A M J J A S O N D for each year)

	Drains	POR
2	Garfield Drain	1923-2005
3	Hatch Drain	1923-2005
4	Angostura Drain	1926-1983
5	Rincon Drain	1925-2005
6	Selden Drain	1923-1983
7	Leasburg Drain	1923-1983
8	Picacho Drain	1923-2005
9	Mesilla Drain	1923-1983
10	Santo Tomas River Drain	1985-1990
11	Santo Tomas Drain	1980-1985
12	West Drain	1923-2013
13	La Mesa Drain	1923-2013
14	Chamberino Drain	1923-1983
15	Nemexas Drain	1923-2013
16	Del Rio Drain	1923-2013
17	Mesquite Drain	1997-2001
18	East Drain	1930-2013
19	Anthony Drain	1923-2005
20	Montoya Drain	1923-2017
21	East Drain (EPCWID)	1923-2017
22	Montoya Intercepting Drain	1985-1990
23	Franklin Drain	1921-1983
24	Playa Drain	1923-1983
25	Middle Drain	1921-1983
26	River Drain	1923-1983
27	Cuadrilla Drain	1931-1983
28	Mesa Drain	1921-1983
29	Fabens Intercepting Drain	1931-1971
30	Border Drain	1923-1983
31	Island Drain	1921-1983
32	Island Syphon Drain	1936-1983
33	Alamo Alto Drain	1925-1983
34	Drain Water Diverted at Fabens	1945-1982
35	Fabens Waste Drain	1984-2017
36	Fabens Drain	1923-1983
37	Tornillo Drain	1923-2017

Summary of Drain Data (red highlight = data available)

Annual Data
1908 - 2017

1903-1907 | 1908 - 1919 | 1920 - 1931 | 1932 - 1943 | 1944 - 1955 | 1956 - 1967 | 1968 - 1979 | 1980 - 1991 | 1992 - 2003 | 2004 - 2015 | 16 - 20

	Drains	POR
1	Garfield Drain	1923-2005
2	Hatch Drain	1923-2005
3	Angostura Drain	1926-1983
4	Rincon Drain	1925-2005
5	Selden Drain	1923-1983
6	Leasburg Drain	1923-1983
7	Picacho Drain	1923-2005
8	Mesilla Drain	1923-1983
9	Santo Tomas River Drain	1985-1990
10	Santo Tomas Drain	1980-1985
11	West Drain	1923-2013
12	La Mesa Drain	1923-2013
13	Chamberino Drain	1923-1983
14	Nemexas Drain	1923-2013
15	Del Rio Drain	1923-2013
16	Mesquite Drain	1997-2001
17	East Drain	1930-2013
18	Anthony Drain	1923-2005
19	Montoya Drain	1923-2017
20	East Drain (EPCWID)	1923-2017
21	Montoya Intercepting Drain	1985-1990
22	Franklin Drain	1921-1983
23	Playa Drain	1923-1983
24	Middle Drain	1921-1983
25	River Drain	1923-1983
26	Cuadrilla Drain	1931-1983
27	Mesa Drain	1921-1983
28	Fabens Intercepting Drain	1931-1971
29	Border Drain	1923-1983
30	Island Drain	1921-1983
31	Island Syphon Drain	1936-1983
32	Alamo Alto Drain	1925-1983
33	Drain Water Diverted at Fabens	1945-1982
34	Fabens Waste Drain	1984-2017
35	Fabens Drain	1923-1983
36	Tornillo Drain	1923-2017
37	Dren de Descarga	1938-1956
38	Dren de Interceptacion	1938-1956

Note: There may be missing months of data within the year. Blanks indicate drain flow data is either missing or annual drain flows equal zero.

Summary of Wasteway Data (red highlight = data available)

Monthly Data 1940 - 1949

	Wasteway	POR	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949
			J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D
2	WW No. 5 – Hatch Siphon	1979-2017										
3	WW No. 16 – Hatch Canal	1979-2017										
4	WW No. 18 – Rincon Lateral	1979-2017										
5	WW No. 1A – Leasburg Canal	1989-2002										
6	WW No. 1 – Leasburg Canal	1992-2002										
7	WW No. 3 – Picacho Lateral	2001-2017										
8	WW No. 5 – Leasburg Canal	1979-2017										
9	WW No. 8 – Leasburg Canal	1979-2017										
10	WW No. 40 – Picacho Lateral	1991-2017										
11	WW No. 13 – California Extension	1984-1991										
12	WW 25 – Santo Tomas Lateral	1985-2001										
13	WW 26 – Upper Chamberino Lateral	1979-2003										
14	WW 30 – Chamberino East Lateral	1985-2003										
15	WW 31 – La Union Main Canal	1981-2003										
16	WW 31B – Jimenez Lateral	1985-2003										
17	WW 32 – La Union East Lateral	1979-2017										
18	WW 32A – Rowley Lateral	1985-1988										
19	WW 32B – Vinton Cutoff Lateral	1985-2017										
20	WW 34 – Canutillo Lateral	1983-2017										
21	WW 34A – Pence Lateral	1985-1988										
22	WW 35 – Westside Canal	1980-2017										
23	WW 35C – Schutz Lateral	1985-1988										
24	WW 15 – Eastside Canal	1985-2003										
25	WW 16B – Brazito Lateral	1985-1990										
26	WW 18 – Eastside Canal	1985-2003										
27	WW 19 – Three Saints Lateral	1982-2003										
28	WW 20 – Three Saints West Lateral	1979-1988										
29	WW 21 – Three Saints West Lateral	1985-2003										
30	WW 23A – Three Saints Lateral	1985-2017										
31	WW 36 – Montoya Lateral	1985-2017										
32	WW 38 – Montoya Lateral	1985-2017										
33	Leon Street WW	1938-1999										
34	Franklin Settling Basin WW	1938-1999										
35	Santa Fe WW (El Paso Electric)	1940-1960										
36	Ascarate WW	1916-2017										
37	Riverside WW No. 1	1928-2017										
38	Riverside WW No. 2	1930-2017										
39	Fabens Waste Channel	1935-2017										
40	Tornillo Canal WW No. 1	1981-2017										

1950 - 1959

	Wasteway	POR	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959
			J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D
2	WW No. 5 – Hatch Siphon	1979-2017										
3	WW No. 16 – Hatch Canal	1979-2017										
4	WW No. 18 – Rincon Lateral	1979-2017										
5	WW No. 1A – Leasburg Canal	1989-2002										
6	WW No. 1 – Leasburg Canal	1992-2002										
7	WW No. 3 – Picacho Lateral	2001-2017										
8	WW No. 5 – Leasburg Canal	1979-2017										
9	WW No. 8 – Leasburg Canal	1979-2017										
10	WW No. 40 – Picacho Lateral	1991-2017										
11	WW No. 13 – California Extension	1984-1991										
12	WW 25 – Santo Tomas Lateral	1985-2001										
13	WW 26 – Upper Chamberino Lateral	1979-2003										
14	WW 30 – Chamberino East Lateral	1985-2003										
15	WW 31 – La Union Main Canal	1981-2003										
16	WW 31B – Jimenez Lateral	1985-2003										
17	WW 32 – La Union East Lateral	1979-2017										
18	WW 32A – Rowley Lateral	1985-1988										
19	WW 32B – Vinton Cutoff Lateral	1985-2017										
20	WW 34 – Canutillo Lateral	1983-2017										
21	WW 34A – Pence Lateral	1985-1988										
22	WW 35 – Westside Canal	1980-2017										
23	WW 35C – Schutz Lateral	1985-1988										
24	WW 15 – Eastside Canal	1985-2003										
25	WW 16B – Brazito Lateral	1985-1990										
26	WW 18 – Eastside Canal	1985-2003										
27	WW 19 – Three Saints Lateral	1982-2003										
28	WW 20 – Three Saints West Lateral	1979-1988										
29	WW 21 – Three Saints West Lateral	1985-2003										
30	WW 23A – Three Saints Lateral	1985-2017										
31	WW 36 – Montoya Lateral	1985-2017										
32	WW 38 – Montoya Lateral	1985-2017										
33	Leon Street WW	1938-1999										
34	Franklin Settling Basin WW	1938-1999										
35	Santa Fe WW (El Paso Electric)	1940-1960										
36	Ascarate WW	1916-2017										
37	Riverside WW No. 1	1928-2017										
38	Riverside WW No. 2	1930-2017										
39	Fabens Waste Channel	1935-2017										
40	Tornillo Canal WW No. 1	1981-2017										

Summary of Wasteway Data (red highlight = data available)

Monthly Data
1960 - 1969

	Wasteway	POR	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
			J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D
2	WW No. 5 – Hatch Siphon	1979-2017										
3	WW No. 16 – Hatch Canal	1979-2017										
4	WW No. 18 – Rincon Lateral	1979-2017										
5	WW No. 1A – Leasburg Canal	1989-2002										
6	WW No. 1 – Leasburg Canal	1992-2002										
7	WW No. 3 – Picacho Lateral	2001-2017										
8	WW No. 5 – Leasburg Canal	1979-2017										
9	WW No. 8 – Leasburg Canal	1979-2017										
10	WW No. 40 – Picacho Lateral	1991-2017										
11	WW No. 13 – California Extension	1984-1991										
12	WW 25 – Santo Tomas Lateral	1985-2001										
13	WW 26 – Upper Chamberino Lateral	1979-2003										
14	WW 30 – Chamberino East Lateral	1985-2003										
15	WW 31 – La Union Main Canal	1981-2003										
16	WW 31B – Jimenez Lateral	1985-2003										
17	WW 32 – La Union East Lateral	1979-2017										
18	WW 32A – Rowley Lateral	1985-1988										
19	WW 32B – Vinton Cutoff Lateral	1985-2017										
20	WW 34 – Canutillo Lateral	1983-2017										
21	WW 34A – Pence Lateral	1985-1988										
22	WW 35 – Westside Canal	1980-2017										
23	WW 35C – Schutz Lateral	1985-1988										
24	WW 15 – Eastside Canal	1985-2003										
25	WW 16B – Brazito Lateral	1985-1990										
26	WW 18 – Eastside Canal	1985-2003										
27	WW 19 – Three Saints Lateral	1982-2003										
28	WW 20 – Three Saints West Lateral	1979-1988										
29	WW 21 – Three Saints West Lateral	1985-2003										
30	WW 23A – Three Saints Lateral	1985-2017										
31	WW 36 – Montoya Lateral	1985-2017										
32	WW 38 – Montoya Lateral	1985-2017										
33	Leon Street WW	1938-1999										
34	Franklin Settling Basin WW	1938-1999										
35	Santa Fe WW (El Paso Electric)	1940-1960										
36	Ascarate WW	1916-2017										
37	Riverside WW No. 1	1928-2017										
38	Riverside WW No. 2	1930-2017										
39	Fabens Waste Channel	1935-2017										
40	Tornillo Canal WW No. 1	1981-2017										

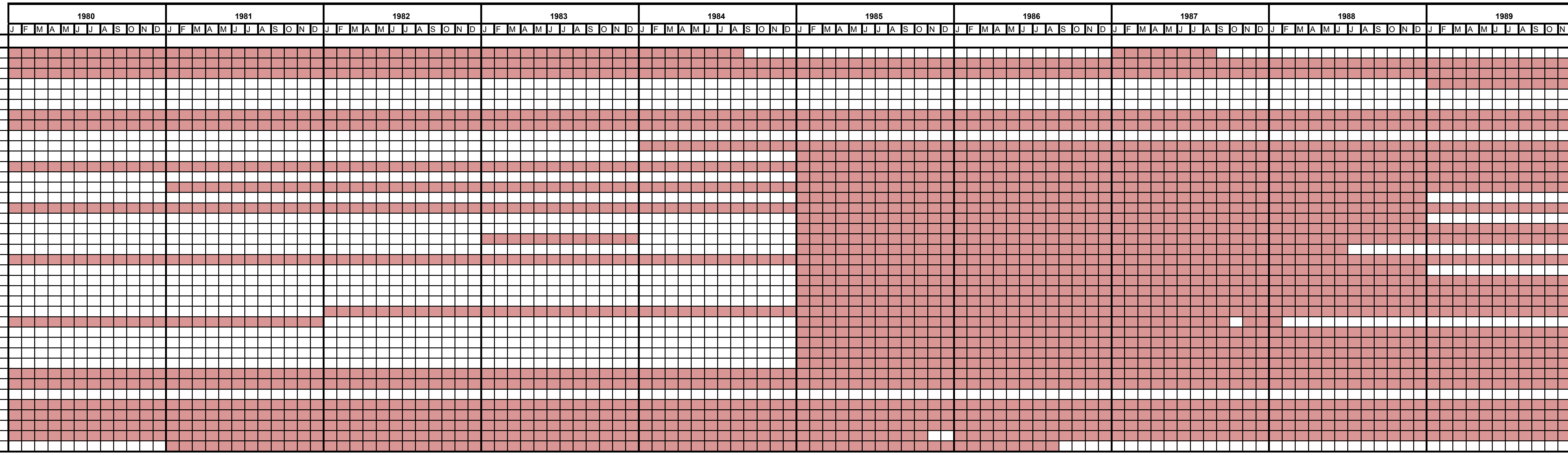
1970 - 1979

	Wasteway	POR	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
			J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D
2	WW No. 5 – Hatch Siphon	1979-2017										
3	WW No. 16 – Hatch Canal	1979-2017										
4	WW No. 18 – Rincon Lateral	1979-2017										
5	WW No. 1A – Leasburg Canal	1989-2002										
6	WW No. 1 – Leasburg Canal	1992-2002										
7	WW No. 3 – Picacho Lateral	2001-2017										
8	WW No. 5 – Leasburg Canal	1979-2017										
9	WW No. 8 – Leasburg Canal	1979-2017										
10	WW No. 40 – Picacho Lateral	1991-2017										
11	WW No. 13 – California Extension	1984-1991										
12	WW 25 – Santo Tomas Lateral	1985-2001										
13	WW 26 – Upper Chamberino Lateral	1979-2003										
14	WW 30 – Chamberino East Lateral	1985-2003										
15	WW 31 – La Union Main Canal	1981-2003										
16	WW 31B – Jimenez Lateral	1985-2003										
17	WW 32 – La Union East Lateral	1979-2017										
18	WW 32A – Rowley Lateral	1985-1988										
19	WW 32B – Vinton Cutoff Lateral	1985-2017										
20	WW 34 – Canutillo Lateral	1983-2017										
21	WW 34A – Pence Lateral	1985-1988										
22	WW 35 – Westside Canal	1980-2017										
23	WW 35C – Schutz Lateral	1985-1988										
24	WW 15 – Eastside Canal	1985-2003										
25	WW 16B – Brazito Lateral	1985-1990										
26	WW 18 – Eastside Canal	1985-2003										
27	WW 19 – Three Saints Lateral	1982-2003										
28	WW 20 – Three Saints West Lateral	1979-1988										
29	WW 21 – Three Saints West Lateral	1985-2003										
30	WW 23A – Three Saints Lateral	1985-2017										
31	WW 36 – Montoya Lateral	1985-2017										
32	WW 38 – Montoya Lateral	1985-2017										
33	Leon Street WW	1938-1999										
34	Franklin Settling Basin WW	1938-1999										
35	Santa Fe WW (El Paso Electric)	1940-1960										
36	Ascarate WW	1916-2017										
37	Riverside WW No. 1	1928-2017										
38	Riverside WW No. 2	1930-2017										
39	Fabens Waste Channel	1935-2017										
40	Tornillo Canal WW No. 1	1981-2017										

Summary of Wasteway Data (red highlight = data available)

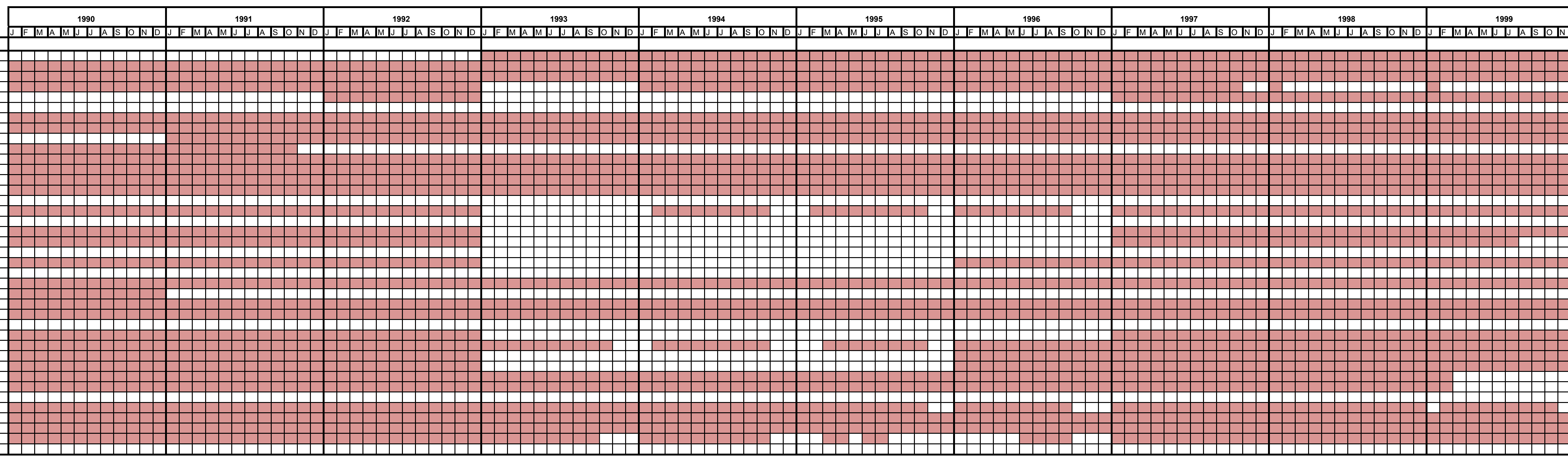
Monthly Data 1980 - 1989

	Wasteway	POR
2	WW No. 5 – Hatch Siphon	1979-2017
3	WW No. 16 – Hatch Canal	1979-2017
4	WW No. 18 – Rincon Lateral	1979-2017
5	WW No. 1A – Leasburg Canal	1989-2002
6	WW No. 1 – Leasburg Canal	1992-2002
7	WW No. 3 – Picacho Lateral	2001-2017
8	WW No. 5 – Leasburg Canal	1979-2017
9	WW No. 8 – Leasburg Canal	1979-2017
10	WW No. 40 – Picacho Lateral	1991-2017
11	WW No. 13 – California Extension	1984-1991
12	WW 25 – Santo Tomas Lateral	1985-2001
13	WW 26 – Upper Chamberino Lateral	1979-2003
14	WW 30 – Chamberino East Lateral	1985-2003
15	WW 31 – La Union Main Canal	1981-2003
16	WW 31B – Jimenez Lateral	1985-2003
17	WW 32 – La Union East Lateral	1979-2017
18	WW 32A – Rowley Lateral	1985-1988
19	WW 32B – Vinton Cutoff Lateral	1985-2017
20	WW 34 – Canutillo Lateral	1983-2017
21	WW 34A – Pence Lateral	1985-1988
22	WW 35 – Westside Canal	1980-2017
23	WW 35C – Schutz Lateral	1985-1988
24	WW 15 – Eastside Canal	1985-2003
25	WW 16B – Brazito Lateral	1985-1990
26	WW 18 – Eastside Canal	1985-2003
27	WW 19 – Three Saints Lateral	1982-2003
28	WW 20 – Three Saints West Lateral	1979-1988
29	WW 21 – Three Saints West Lateral	1985-2003
30	WW 23A – Three Saints Lateral	1985-2017
31	WW 36 – Montoya Lateral	1985-2017
32	WW 38 – Montoya Lateral	1985-2017
33	Leon Street WW	1938-1999
34	Franklin Settling Basin WW	1938-1999
35	Santa Fe WW (El Paso Electric)	1940-1960
36	Ascarate WW	1916-2017
37	Riverside WW No. 1	1928-2017
38	Riverside WW No. 2	1930-2017
39	Fabens Waste Channel	1935-2017
40	Tornillo Canal WW No. 1	1981-2017



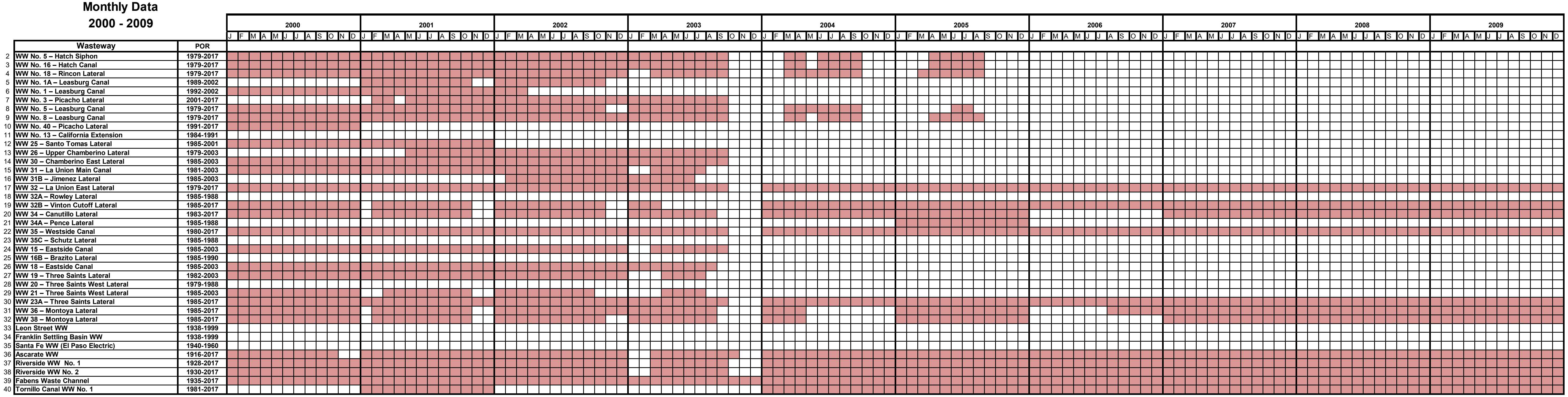
1990 - 1999

	Wasteway	POR
2	WW No. 5 – Hatch Siphon	1979-2017
3	WW No. 16 – Hatch Canal	1979-2017
4	WW No. 18 – Rincon Lateral	1979-2017
5	WW No. 1A – Leasburg Canal	1989-2002
6	WW No. 1 – Leasburg Canal	1992-2002
7	WW No. 3 – Picacho Lateral	2001-2017
8	WW No. 5 – Leasburg Canal	1979-2017
9	WW No. 8 – Leasburg Canal	1979-2017
10	WW No. 40 – Picacho Lateral	1991-2017
11	WW No. 13 – California Extension	1984-1991
12	WW 25 – Santo Tomas Lateral	1985-2001
13	WW 26 – Upper Chamberino Lateral	1979-2003
14	WW 30 – Chamberino East Lateral	1985-2003
15	WW 31 – La Union Main Canal	1981-2003
16	WW 31B – Jimenez Lateral	1985-2003
17	WW 32 – La Union East Lateral	1979-2017
18	WW 32A – Rowley Lateral	1985-1988
19	WW 32B – Vinton Cutoff Lateral	1985-2017
20	WW 34 – Canutillo Lateral	1983-2017
21	WW 34A – Pence Lateral	1985-1988
22	WW 35 – Westside Canal	1980-2017
23	WW 35C – Schutz Lateral	1985-1988
24	WW 15 – Eastside Canal	1985-2003
25	WW 16B – Brazito Lateral	1985-1990
26	WW 18 – Eastside Canal	1985-2003
27	WW 19 – Three Saints Lateral	1982-2003
28	WW 20 – Three Saints West Lateral	1979-1988
29	WW 21 – Three Saints West Lateral	1985-2003
30	WW 23A – Three Saints Lateral	1985-2017
31	WW 36 – Montoya Lateral	1985-2017
32	WW 38 – Montoya Lateral	1985-2017
33	Leon Street WW	1938-1999
34	Franklin Settling Basin WW	1938-1999
35	Santa Fe WW (El Paso Electric)	1940-1960
36	Ascarate WW	1916-2017
37	Riverside WW No. 1	1928-2017
38	Riverside WW No. 2	1930-2017
39	Fabens Waste Channel	1935-2017
40	Tornillo Canal WW No. 1	1981-2017

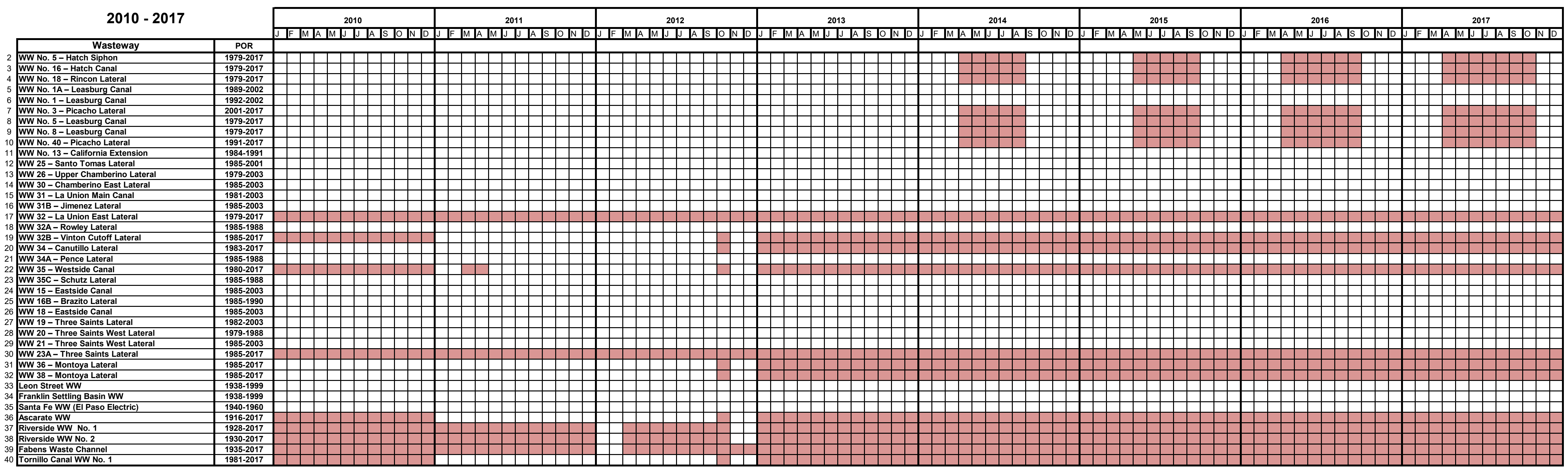


Summary of Wasteway Data (red highlight = data available)

Monthly Data 2000 - 2009

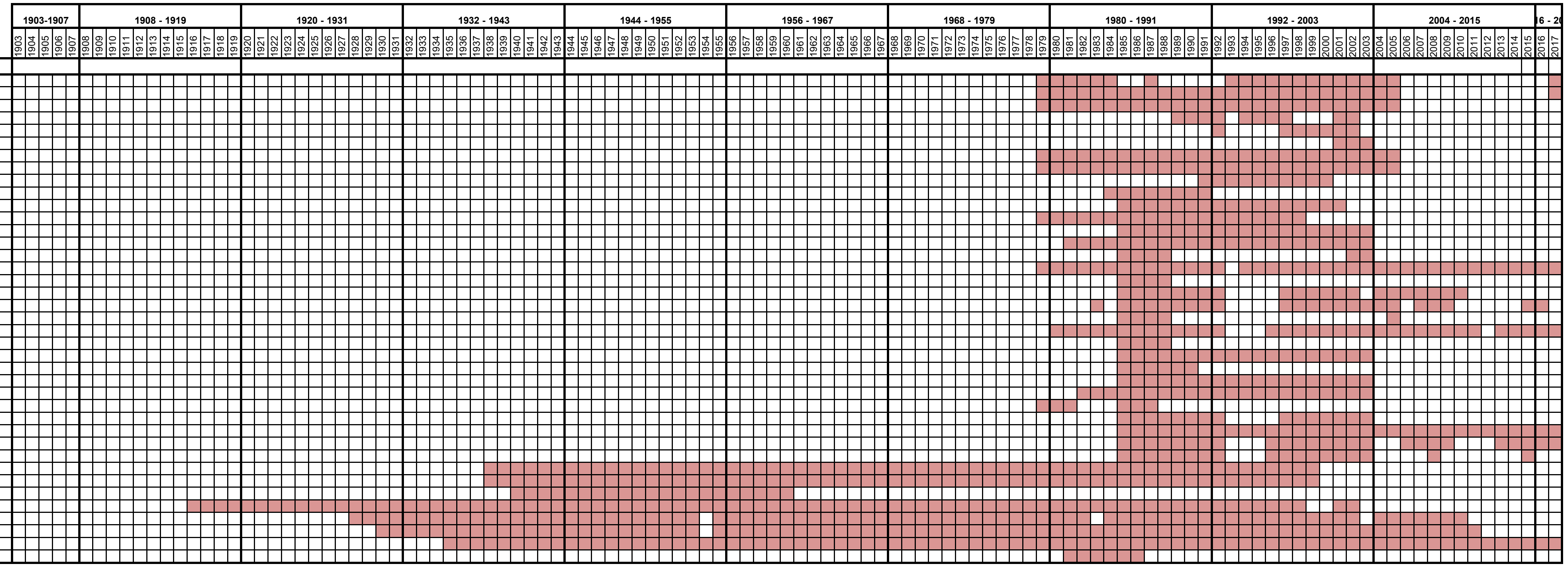


2010 - 2017



Summary of Wasteway Data (red highlight = data available)

Annual Data 1903 - 2017



	Wasteway	POR
2	WW No. 5 – Hatch Siphon	1979-2017
3	WW No. 16 – Hatch Canal	1979-2017
4	WW No. 18 – Rincon Lateral	1979-2017
5	WW No. 1A – Leasburg Canal	1989-2002
6	WW No. 1 – Leasburg Canal	1992-2002
7	WW No. 3 – Picacho Lateral	2001-2017
8	WW No. 5 – Leasburg Canal	1979-2017
9	WW No. 8 – Leasburg Canal	1979-2017
10	WW No. 40 – Picacho Lateral	1991-2017
11	WW No. 13 – California Extension	1984-1991
12	WW 25 – Santo Tomas Lateral	1985-2001
13	WW 26 – Upper Chamberino Lateral	1979-2003
14	WW 30 – Chamberino East Lateral	1985-2003
15	WW 31 – La Union Main Canal	1981-2003
16	WW 31B – Jimenez Lateral	1985-2003
17	WW 32 – La Union East Lateral	1979-2017
18	WW 32A – Rowley Lateral	1985-1988
19	WW 32B – Vinton Cutoff Lateral	1985-2017
20	WW 34 – Canutillo Lateral	1983-2017
21	WW 34A – Pence Lateral	1985-1988
22	WW 35 – Westside Canal	1980-2017
23	WW 35C – Schutz Lateral	1985-1988
24	WW 15 – Eastside Canal	1985-2003
25	WW 16B – Brazito Lateral	1985-1990
26	WW 18 – Eastside Canal	1985-2003
27	WW 19 – Three Saints Lateral	1982-2003
28	WW 20 – Three Saints West Lateral	1979-1988
29	WW 21 – Three Saints West Lateral	1985-2003
30	WW 23A – Three Saints Lateral	1985-2017
31	WW 36 – Montoya Lateral	1985-2017
32	WW 38 – Montoya Lateral	1985-2017
33	Leon Street WW	1938-1999
34	Franklin Settling Basin WW	1938-1999
35	Santa Fe WW (El Paso Electric)	1940-1960
36	Ascarate WW	1916-2017
37	Riverside WW No. 1	1928-2017
38	Riverside WW No. 2	1930-2017
39	Fabens Waste Channel	1935-2017
40	Tornillo Canal WW No. 1	1981-2017

Note: There may be missing months of data within the year.

Summary of Municipal Data (red highlight = data available)

Monthly Data 1940 - 1949

	Municipal	POR	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949
2	Hatch WWTP	1940-2017										
3	City of Las Cruces WWTP	1976-2017										
4	South Central Regional WWTP	2003-2017										
5	Anthony WWTP	1989-2017										
6	Sunland Park WWTP	1987-2017										
7	El Paso Electric	1950-2017										
8	Northwest WWTP	1987-2017										
9	Umbenhauer-Robertson WTP	1943-2017										
20	Total Haskell Street WWTP	1923-2017										
11	Jonathan Rogers WTP	1993-2017										
12	Total City of El Paso WTP	1943-2017										
22	Total Bustamante WWTP	1991-2017										
14	Fabens WWTP	2001-2017										
23	Socorro WWTP	1967-1993										

1950 - 1959

	Municipal	POR	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959
2	Hatch WWTP	1940-2017										
3	City of Las Cruces WWTP	1976-2017										
4	South Central Regional WWTP	2003-2017										
5	Anthony WWTP	1989-2017										
6	Sunland Park WWTP	1987-2017										
7	El Paso Electric	1950-2017										
8	Northwest WWTP	1987-2017										
9	Umbenhauer-Robertson WTP	1943-2017										
20	Total Haskell Street WWTP	1923-2017										
11	Jonathan Rogers WTP	1993-2017										
12	Total City of El Paso WTP	1943-2017										
22	Total Bustamante WWTP	1991-2017										
14	Fabens WWTP	2001-2017										
23	Socorro WWTP	1967-1993										

1960 - 1969

	Municipal	POR	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
2	Hatch WWTP	1940-2017										
3	City of Las Cruces WWTP	1976-2017										
4	South Central Regional WWTP	2003-2017										
5	Anthony WWTP	1989-2017										
6	Sunland Park WWTP	1987-2017										
7	El Paso Electric	1950-2017										
8	Northwest WWTP	1987-2017										
9	Umbenhauer-Robertson WTP	1943-2017										
20	Total Haskell Street WWTP	1923-2017										
11	Jonathan Rogers WTP	1993-2017										
12	Total City of El Paso WTP	1943-2017										
22	Total Bustamante WWTP	1991-2017										
14	Fabens WWTP	2001-2017										
23	Socorro WWTP	1967-1993										

1970 - 1979

	Municipal	POR	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
2	Hatch WWTP	1940-2017										
3	City of Las Cruces WWTP	1976-2017										
4	South Central Regional WWTP	2003-2017										
5	Anthony WWTP	1989-2017										
6	Sunland Park WWTP	1987-2017										
7	El Paso Electric	1950-2017										
8	Northwest WWTP	1987-2017										
9	Umbenhauer-Robertson WTP	1943-2017										
20	Total Haskell Street WWTP	1923-2017										
11	Jonathan Rogers WTP	1993-2017										
12	Total City of El Paso WTP	1943-2017										
22	Total Bustamante WWTP	1991-2017										
14	Fabens WWTP	2001-2017										
23	Socorro WWTP	1967-1993										

1980 - 1989

	Municipal	POR	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
2	Hatch WWTP	1940-2017										
3	City of Las Cruces WWTP	1976-2017										
4	South Central Regional WWTP	2003-2017										
5	Anthony WWTP	1989-2017										
6	Sunland Park WWTP	1987-2017										
7	El Paso Electric	1950-2017										
8	Northwest WWTP	1987-2017										
9	Umbenhauer-Robertson WTP	1943-2017										
20	Total Haskell Street WWTP	1923-2017										
11	Jonathan Rogers WTP	1993-2017										
12	Total City of El Paso WTP	1943-2017										
22	Total Bustamante WWTP	1991-2017										
14	Fabens WWTP	2001-2017										
23	Socorro WWTP	1967-1993										

Summary of Municipal Data (red highlight = data available)

1990 - 1999

Years: 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999 (months J F M A M J J A S O N D)

	Municipal	POR
2	Hatch WWTP	1940-2017
3	City of Las Cruces WWTP	1976-2017
4	South Central Regional WWTP	2003-2017
5	Anthony WWTP	1989-2017
6	Sunland Park WWTP	1987-2017
7	El Paso Electric	1950-2017
8	Northwest WWTP	1987-2017
9	Umbenhauer-Robertson WTP	1943-2017
20	Total Haskell Street WWTP	1923-2017
11	Jonathan Rogers WTP	1993-2017
12	Total City of El Paso WTP	1943-2017
22	Total Bustamante WWTP	1991-2017
14	Fabens WWTP	2001-2017
23	Socorro WWTP	1967-1993

2000 - 2009

Years: 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009 (months J F M A M J J A S O N D)

	Municipal	POR
2	Hatch WWTP	1940-2017
3	City of Las Cruces WWTP	1976-2017
4	South Central Regional WWTP	2003-2017
5	Anthony WWTP	1989-2017
6	Sunland Park WWTP	1987-2017
7	El Paso Electric	1950-2017
8	Northwest WWTP	1987-2017
9	Umbenhauer-Robertson WTP	1943-2017
20	Total Haskell Street WWTP	1923-2017
11	Jonathan Rogers WTP	1993-2017
12	Total City of El Paso WTP	1943-2017
22	Total Bustamante WWTP	1991-2017
14	Fabens WWTP	2001-2017
23	Socorro WWTP	1967-1993

2010 - 2017

Years: 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017 (months J F M A M J J A S O N D)

	Municipal	POR
2	Hatch WWTP	1940-2017
3	City of Las Cruces WWTP	1976-2017
4	South Central Regional WWTP	2003-2017
5	Anthony WWTP	1989-2017
6	Sunland Park WWTP	1987-2017
7	El Paso Electric	1950-2017
8	Northwest WWTP	1987-2017
9	Umbenhauer-Robertson WTP	1943-2017
20	Total Haskell Street WWTP	1923-2017
11	Jonathan Rogers WTP	1993-2017
12	Total City of El Paso WTP	1943-2017
22	Total Bustamante WWTP	1991-2017
14	Fabens WWTP	2001-2017
23	Socorro WWTP	1967-1993

Summary of Municipal Data (red highlight = data available)

Annual Data 1903 - 2017

	Municipal	POR
2	Hatch WWTP	1940-2017
3	Las Cruces WWTP	1976-2017
4	South Central Regional WWTP	2003-2017
5	Anthony WWTP	1989-2017
6	Sunland Park WWTP	1987-2017
7	El Paso Electric	1950-2017
8	Northwest WWTP	1987-2017
9	Umbenhauer-Robertson WTP	1943-2017
10	Haskell WWTP to Rio Grande	1923-2017
11	Jonathan Rogers WTP	1993-2017
12	Total City of El Paso WTP	1943-2017
13	Bustamante WWTP to Rio Grande/Drain	1991-2017
14	Fabens WWTP	2001-2017
15	Juarez Sewage to Rio Grande	1940-1950
16	Juarez Sewage to Canals	1926-2017
17	Juarez North Plant	No Data
18	Juarez South Plant	No Data
19	Haskell WWTP to ACE	1998-2017
20	Total Haskell WWTP	1923-2017
21	Bustamante WWTP to Riverside Canal	1991-2017
22	Total Bustamante WWTP	1991-2017
23	Socorro WWTP	1967-1993
24	Total City of El Paso WWTP	1923-2017

Note: There may be missing months of data within the year.

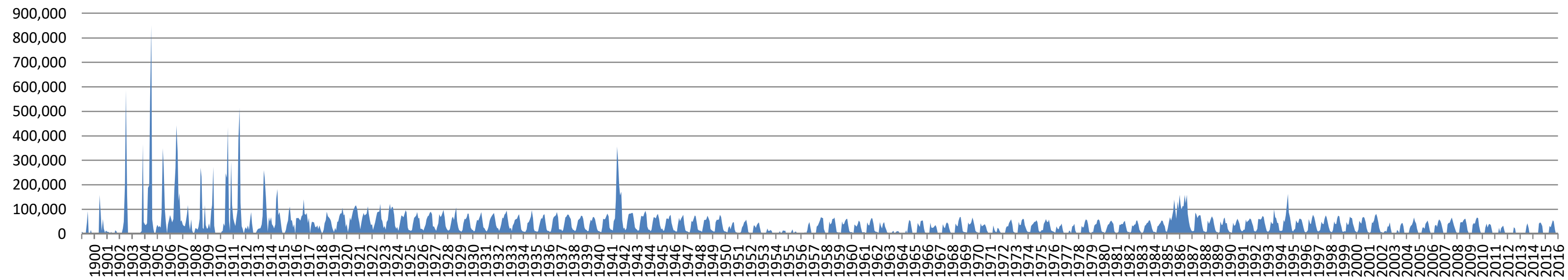
Appendix 3B
Example SWDataSet Data Summaries

River Flows

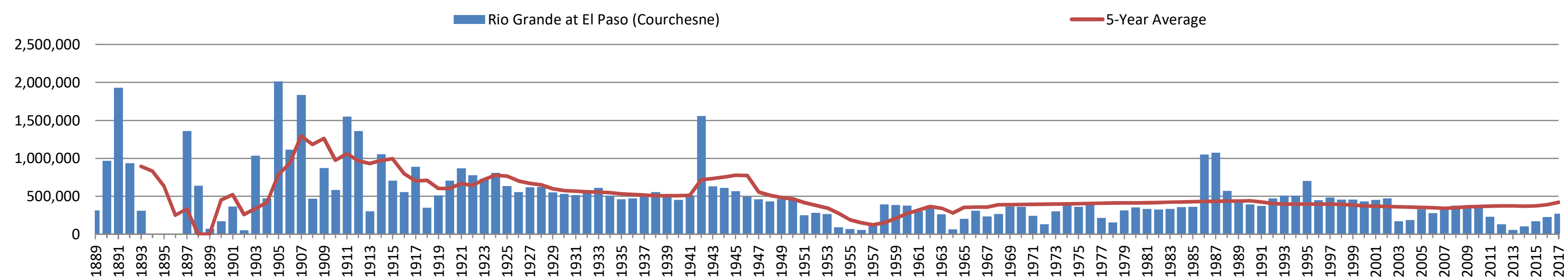
Rio Grande at El Paso (Courchesne)

1889 - 2017

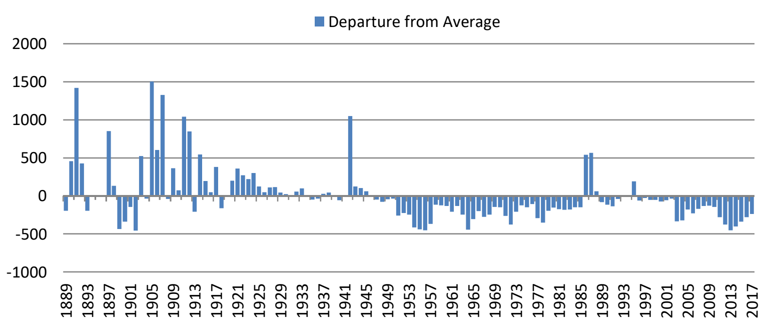
Total Monthly Flow (Acre-Feet)



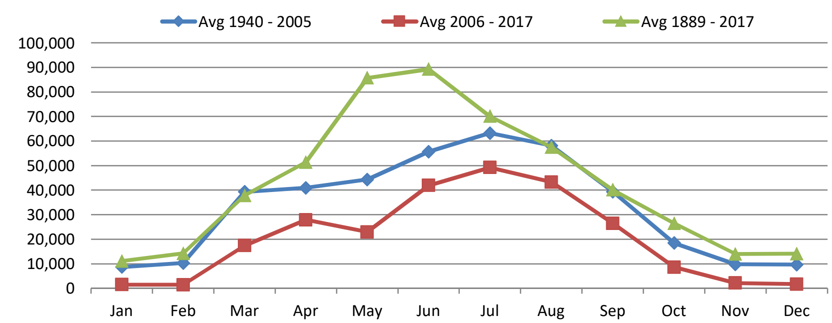
Total Annual Flow (Acre-Feet)



Annual Departure from Average (1,000 Acre-Feet)



Average Monthly Flow (Acre-Feet)



	Start	End
Period 1:	1940	2005
Period 2:	2006	2017

Rio Grande Project Flow Data

Total Monthly Flow (Acre-Feet)

1889 - 2017

Rio Grande at El Paso (Courchesne)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1889	-	-	-	-	136,241	156,950	14,709	0	0	0	0	4,380	312,280
1890	12,099	16,141	26,047	130,259	353,742	265,876	52,532	45,156	10,471	3,997	16,959	32,953	966,232
1891	27,590	45,352	114,716	256,078	727,845	399,608	139,605	40,703	45,669	91,436	20,285	21,185	1,930,072
1892	20,093	27,378	46,231	187,293	436,243	174,988	41,264	700	0	0	0	0	934,190
1893	7,678	8,023	2,162	48,095	231,634	13,400	-	-	-	-	-	-	310,992
1894	-	-	-	-	-	-	-	-	-	-	-	-	-
1895	-	-	-	-	-	-	-	-	-	-	-	-	-
1896	-	-	-	-	-	-	-	-	-	-	-	-	-
1897	18,768	10,760	4,413	103,555	511,198	362,543	81,711	8,128	41,958	108,061	67,373	41,806	1,360,274
1898	0	33,872	20,023	97,918	140,221	111,576	196,383	31,206	2,233	161	119	5,734	639,446
1899	13,111	11,326	7,041	8,832	10,348	0	19,583	436	0	0	0	2,836	73,513
1900	8,112	5,683	466	298	44,826	93,158	69	0	16,487	0	0	732	169,831
1901	278	4,502	3,669	0	158,172	77,074	12,565	60,653	20,999	5,334	12,811	7,993	364,050
1902	8,291	5,772	635	7,904	526	307	0	14,491	9,322	1,428	298	1,775	50,749
1903	615	1,289	22,602	49,482	203,585	587,004	158,225	4,364	1,031	2,033	298	2,440	1,032,968
1904	972	0	0	0	0	0	0	7,394	10,967	366,460	48,399	38,237	472,429
1905	35,919	43,309	188,418	197,835	546,145	851,149	58,800	19,781	3,322	4,225	25,474	37,470	2,011,847
1906	27,003	31,686	25,313	88,046	348,978	270,589	96,559	49,160	2,817	38,186	59,320	76,253	1,113,910
1907	60,430	46,621	60,050	175,763	269,341	442,621	337,482	135,253	166,891	49,987	54,946	37,636	1,837,021
1908	32,979	31,164	47,750	80,138	116,882	40,167	16,320	58,627	14,255	0	5,078	23,391	466,751
1909	22,330	17,159	28,776	61,531	270,214	233,558	24,801	19,031	117,820	35,367	20,618	22,806	874,011
1910	43,480	20,908	92,932	117,021	273,695	33,118	69	0	129	0	0	595	581,947
1911	9,257	11,891	43,547	31,849	247,918	229,182	435,475	53,572	11,589	294,397	118,909	62,382	1,549,968
1912	48,607	32,303	60,373	95,958	382,334	514,483	125,988	30,815	20,273	1,230	18,391	26,999	1,357,754
1913	18,819	34,955	15,636	50,700	88,645	43,012	5,695	0	0	6,754	17,133	21,150	302,499
1914	21,884	23,147	38,735	73,037	259,541	227,474	146,930	70,096	8,212	68,075	50,975	67,482	1,055,588
1915	39,273	32,029	22,185	37,785	143,258	183,612	76,699	88,310	59,911	19,444	1,930	0	704,436
1916	3,441	16,312	36,553	53,800	93,800	111,669	53,760	55,345	25,878	39,915	595	64,645	555,713
1917	64,770	65,726	58,806	54,244	73,250	76,195	141,404	81,066	78,303	85,071	43,779	65,829	888,443
1918	2,337	31,956	48,827	48,543	46,594	28,661	26,961	33,935	19,496	33,896	20,315	6,397	347,918
1919	3,525	17,117	42,881	56,410	90,171	71,048	67,156	61,974	50,874	26,941	16,504	7,261	511,862
1920	24,196	13,103	49,478	50,368	72,496	82,600	84,103	106,703	74,763	79,755	28,203	41,060	706,828
1921	6,639	24,817	67,008	53,913	76,592	93,654	104,709	113,839	115,851	100,316	69,168	43,906	870,412
1922	17,806	47,927	67,511	85,549	74,860	78,984	83,238	112,417	82,294	54,093	36,662	37,831	779,172
1923	16,499	33,697	47,211	72,153	87,350	90,300	90,863	122,902	60,422	51,558	23,258	32,261	728,474
1924	17,520	48,583	56,868	91,174	122,263	98,180	110,624	107,248	77,207	32,019	21,064	27,699	810,449
1925	11,603	29,199	56,688	75,053	73,156	68,416	79,771	96,875	87,360	25,331	15,287	14,860	633,599
1926	12,151	15,423	41,254	65,441	69,459	75,235	88,931	63,102	64,957	21,049	21,013	18,797	556,812
1927	13,896	24,577	38,081	58,943	71,746	73,785	86,757	90,700	80,640	30,309	29,457	20,579	619,470
1928	12,734	26,584	43,503	80,053	68,668	72,895	86,233	97,652	67,279	31,740	22,336	14,273	623,950
1929	13,226	18,002	37,083	62,577	70,481	56,210	82,762	106,913	51,540	25,912	14,311	12,720	551,737
1930	8,208	16,298	42,819	62,263	58,780	67,972	82,336	83,300	51,892	25,761	16,685	16,114	532,428
1931	9,098	13,902	40,423	56,820	53,649	63,257	76,423	88,621	52,469	26,735	22,255	14,130	517,782
1932	9,134	16,879	34,524	57,227	62,454	73,634	78,462	85,763	65,810	34,863	24,369	22,473	565,592
1933	11,821	24,883	39,632	66,422	63,479	79,081	82,621	95,687	66,666	33,622	20,460	24,760	609,134
1934	11,226	33,112	43,446	56,648	60,674	61,997	73,827	80,227	48,024	18,313	11,355	9,590	508,439

Rio Grande Project Flow Data
Total Monthly Flow (Acre-Feet)
1889 - 2017
Rio Grande at El Paso (Courchesne)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1935	8,509	8,797	18,375	44,894	47,605	56,686	69,868	95,889	65,766	20,186	11,472	11,457	459,504
1936	8,569	10,659	29,369	50,826	62,555	62,822	76,542	79,686	50,448	17,837	12,506	12,018	473,837
1937	8,545	10,163	26,200	60,387	69,467	73,287	76,296	88,512	68,200	19,825	17,088	18,155	536,125
1938	10,895	16,814	43,934	66,327	71,100	78,540	77,978	68,940	60,976	27,300	16,612	15,523	554,939
1939	10,328	15,673	36,708	56,015	59,566	64,088	73,480	72,240	61,166	27,540	18,220	16,475	511,499
1940	10,748	12,732	38,672	57,753	52,163	68,253	68,858	61,000	41,667	19,039	11,889	11,000	453,774
1941	8,495	7,234	26,465	61,386	58,598	61,638	74,178	82,463	71,611	25,795	16,655	16,812	511,330
1942	13,014	52,199	62,543	139,061	356,533	304,421	197,881	157,620	171,453	57,923	21,021	25,605	1,559,274
1943	15,138	21,836	52,368	78,555	82,500	82,124	85,613	84,908	63,459	27,128	21,281	16,865	631,775
1944	11,939	15,519	46,143	74,519	71,685	71,738	83,919	94,007	79,254	29,510	16,695	16,969	611,897
1945	11,387	16,655	49,016	68,275	66,718	63,047	76,215	81,568	60,540	35,375	18,377	21,604	568,777
1946	12,038	15,243	38,446	61,390	63,461	59,117	71,100	77,667	45,078	25,214	15,217	14,013	497,984
1947	9,864	9,136	37,252	64,979	51,816	63,215	69,693	77,784	40,552	14,573	10,395	9,457	458,716
1948	7,775	6,508	22,278	51,616	49,724	59,841	74,741	71,772	41,841	18,869	13,377	13,258	431,600
1949	10,800	8,140	34,455	57,219	56,188	59,044	73,456	65,474	51,548	20,077	14,896	12,248	463,545
1950	9,830	10,175	48,054	57,669	56,676	59,548	78,395	68,795	44,521	18,315	10,939	9,703	472,620
1951	8,456	6,571	24,633	32,295	17,903	33,919	45,485	47,736	17,125	6,934	5,641	5,304	252,002
1952	4,290	3,197	8,959	26,099	34,383	47,076	51,427	57,975	32,686	7,416	5,119	5,000	283,627
1953	4,324	2,876	34,941	33,005	24,664	35,234	42,403	46,802	26,850	5,530	4,284	3,699	264,612
1954	3,257	2,003	5,468	22,679	12,748	12,484	16,171	11,691	2,428	3,790	541	444	93,704
1955	540	282	4,588	10,538	2,126	6,018	14,973	12,067	13,803	1,484	391	278	67,088
1956	236	210	10,992	17,780	1,218	7,335	9,917	4,871	4,304	149	228	204	57,444
1957	224	133	1,779	6,821	538	14,537	36,992	47,494	27,697	2,370	551	432	139,568
1958	399	359	29,653	34,986	42,944	55,006	68,104	65,931	64,425	19,410	6,557	5,048	392,822
1959	4,009	3,342	50,696	38,662	44,751	60,897	62,178	66,395	33,737	8,471	6,121	6,569	385,828
1960	5,710	3,832	50,715	38,664	41,583	52,782	60,863	61,757	36,613	10,994	7,402	7,216	378,131
1961	5,814	3,963	37,807	33,140	29,808	40,618	53,978	48,226	26,947	7,484	5,825	7,196	300,806
1962	5,014	3,693	46,487	35,867	34,707	52,128	63,852	62,993	41,183	13,307	8,832	8,100	376,163
1963	6,065	4,266	48,434	32,731	22,173	41,191	48,056	29,429	16,520	6,089	4,566	4,197	263,717
1964	3,517	2,325	7,878	12,056	1,210	6,317	9,652	10,419	9,429	536	480	502	64,321
1965	488	448	3,598	15,245	530	39,546	57,130	51,215	29,820	2,087	1,194	1,079	202,380
1966	992	746	44,759	36,712	28,786	51,509	54,387	54,714	20,269	6,583	4,748	4,576	308,781
1967	3,723	2,406	46,064	25,351	24,210	25,299	31,670	36,111	27,485	5,086	2,513	2,809	232,727
1968	2,781	1,874	39,556	27,261	23,466	41,403	46,592	40,703	23,889	6,629	5,004	5,228	264,386
1969	4,683	2,573	42,307	33,705	30,952	52,810	67,708	69,237	36,601	10,842	6,793	7,180	365,391
1970	5,601	5,578	46,374	38,239	40,808	46,774	67,252	54,204	31,743	11,837	6,740	5,548	360,698
1971	5,012	3,189	43,170	30,849	33,572	37,087	39,602	28,078	13,144	4,824	2,844	2,769	244,140
1972	2,495	1,743	33,840	16,312	8,894	7,160	24,670	21,144	10,441	5,131	916	805	133,551
1973	470	359	24,912	30,405	31,242	44,293	53,274	58,602	38,160	10,009	5,514	4,542	301,782
1974	4,272	3,735	49,182	35,833	36,460	55,025	61,273	59,778	35,825	22,138	12,143	7,230	382,894
1975	9,070	6,706	32,154	38,418	41,472	49,821	49,123	55,575	47,048	13,450	9,047	9,078	360,962
1976	15,580	14,168	40,108	50,005	59,972	50,608	48,585	57,384	31,561	14,340	10,475	9,999	402,785
1977	7,630	4,473	30,867	22,661	18,710	31,269	34,493	41,383	14,961	3,271	2,265	2,600	214,583
1978	2,097	1,382	13,942	10,754	2,604	30,781	32,069	41,187	13,113	2,924	3,537	1,603	155,993
1979	1,458	1,039	31,537	26,327	28,013	50,664	59,591	55,696	40,832	8,688	5,066	3,652	312,563
1980	8,805	7,458	33,128	38,289	40,854	55,260	59,784	54,242	30,163	11,074	7,674	7,277	354,008
1981	3,540	10,990	27,342	36,492	41,060	48,914	54,111	48,165	40,257	11,197	6,464	4,812	333,344

Rio Grande Project Flow Data

Total Monthly Flow (Acre-Feet)

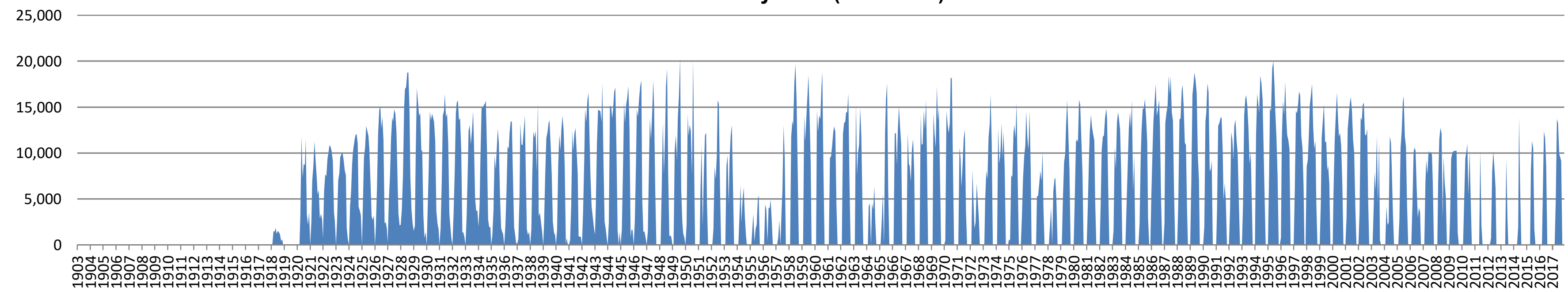
1889 - 2017

Rio Grande at El Paso (Courchesne)

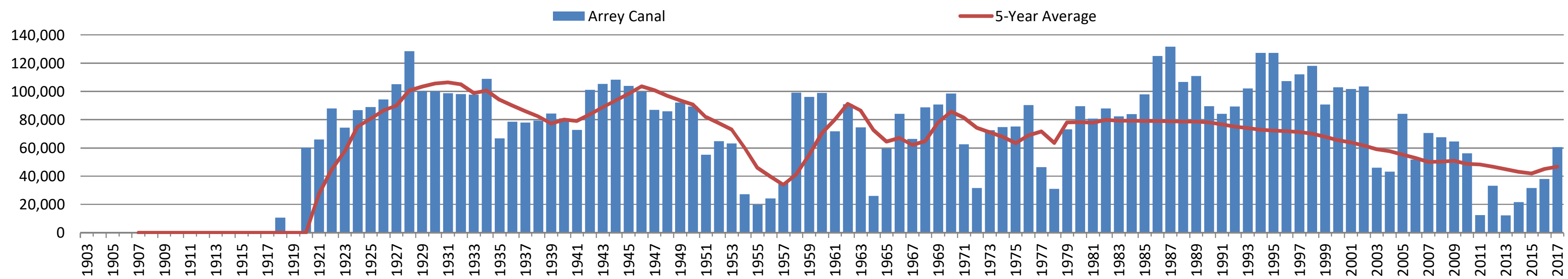
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1982	4,257	8,309	36,768	36,920	40,072	38,822	47,484	53,520	33,162	11,825	7,392	8,067	326,598
1983	5,304	9,189	34,181	30,744	37,260	39,152	54,087	53,915	37,133	17,589	8,422	4,969	331,945
1984	4,199	10,768	33,640	35,369	44,136	45,539	55,142	54,831	36,666	21,178	8,801	9,064	359,333
1985	6,776	4,739	31,260	33,802	39,741	45,521	54,409	53,246	40,183	31,277	11,016	7,940	359,910
1986	23,242	51,148	67,422	54,555	69,275	94,562	139,299	94,221	61,577	132,714	100,911	160,007	1,048,933
1987	121,644	99,178	113,835	112,030	159,386	125,415	159,047	81,457	47,994	29,324	15,642	11,266	1,076,218
1988	10,766	13,716	86,644	80,124	64,024	72,706	76,280	75,352	44,807	25,031	11,201	9,293	569,944
1989	7,448	10,161	54,474	40,903	49,127	64,516	72,113	60,575	37,557	16,167	8,333	6,778	428,152
1990	5,240	7,412	50,606	36,184	38,370	61,281	67,164	42,783	43,819	20,694	10,596	7,738	391,887
1991	5,595	5,361	45,356	32,826	36,238	49,922	61,640	53,901	40,167	19,327	10,770	10,975	372,078
1992	17,248	17,496	58,058	46,231	51,304	56,069	63,380	59,492	46,340	32,342	12,762	9,660	470,382
1993	11,042	20,898	59,843	60,381	58,306	62,386	72,639	69,709	46,889	26,271	11,685	7,968	508,017
1994	11,094	16,967	50,894	42,323	42,188	100,011	67,613	63,675	44,707	43,922	13,303	11,889	508,586
1995	12,371	15,219	57,039	47,716	74,995	111,092	163,668	87,630	66,155	42,403	13,926	10,215	702,429
1996	15,437	20,323	55,978	45,588	44,535	61,581	62,160	58,173	44,547	23,332	9,318	5,871	446,843
1997	8,277	14,469	60,046	43,404	39,540	65,391	77,334	68,198	52,215	31,472	13,331	9,445	483,122
1998	12,347	16,871	49,000	41,268	39,176	59,897	75,630	68,493	45,427	27,733	12,254	8,483	456,579
1999	6,849	16,106	50,487	40,804	41,149	63,358	73,519	72,099	47,002	27,729	10,284	7,987	457,373
2000	11,320	9,882	48,087	35,889	40,816	70,863	65,042	64,481	41,405	25,599	11,925	7,942	433,251
2001	6,246	17,417	53,320	46,631	42,434	65,248	69,709	65,381	47,746	24,230	8,626	6,508	453,496
2002	4,844	8,412	47,014	43,928	55,599	73,640	81,519	70,631	46,969	24,601	9,076	7,261	473,494
2003	5,782	4,191	9,495	11,671	8,842	31,125	29,109	47,149	22,677	950	758	591	172,340
2004	1,160	381	15,894	10,740	1,803	33,320	41,738	44,216	30,972	5,101	768	801	186,894
2005	942	899	23,278	32,491	37,109	46,992	66,094	51,567	41,453	20,673	5,155	3,142	329,795
2006	2,122	1,328	24,360	27,161	20,914	40,556	46,685	53,753	40,641	14,124	4,071	2,793	278,508
2007	2,587	1,799	33,058	37,425	27,832	50,313	59,643	53,059	42,678	21,706	4,474	3,272	337,846
2008	2,132	2,964	38,245	44,016	45,123	55,048	67,096	52,674	34,255	22,948	8,139	5,207	377,847
2009	3,541	4,828	45,523	47,785	46,636	53,661	60,484	62,158	38,178	14,107	2,468	2,666	382,035
2010	2,293	2,057	37,154	44,268	40,668	59,475	67,096	63,853	32,991	10,704	1,807	1,453	363,819
2011	1,301	1,247	25,693	41,509	25,516	37,635	41,165	36,052	18,336	699	560	681	230,394
2012	696	572	544	24,694	6,581	23,396	29,509	33,313	12,218	497	440	483	132,943
2013	495	460	531	382	165	26,862	22,489	731	3,220	755	680	680	57,450
2014	626	581	527	301	796	31,964	43,421	23,286	1,371	951	774	671	105,270
2015	636	591	631	285	376	41,950	47,091	43,582	32,351	1,547	635	831	170,506
2016	749	600	1,899	32,207	26,892	39,008	55,546	50,923	17,591	1,595	675	690	228,375
2017	729	599	572	35,207	34,105	42,888	50,306	45,935	44,002	13,982	1,240	930	270,497
Avg	11,065	14,191	37,775	51,390	85,724	89,266	70,099	57,486	40,069	26,460	13,958	14,094	511,577

Canal Flows
Arrey Canal
1903 - 2017

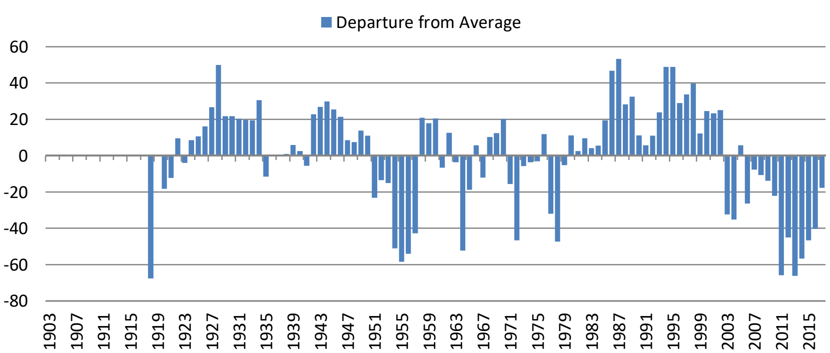
Total Monthly Flow (Acre-Feet)



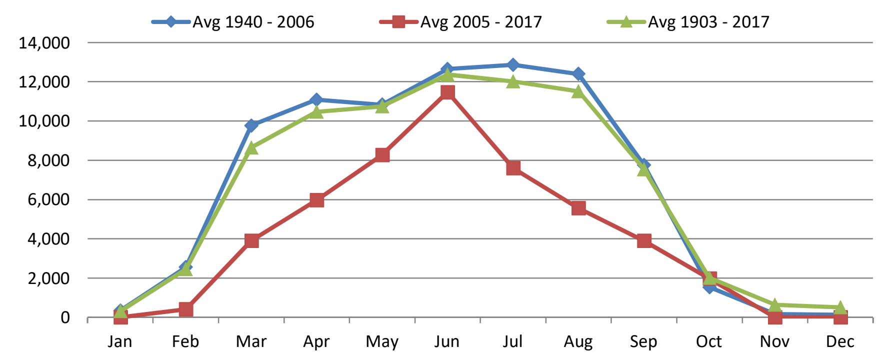
Total Annual Flow (Acre-Feet)



Annual Departure from Average (1,000 Acre-Feet)



Average Monthly Flow (Acre-Feet)



	Start	End
Period 1:	1940	2005
Period 2:	2006	2017

US_MSJ_00002490

Rio Grande Project Flow Data

Total Monthly Flow (Acre-Feet)

1903 - 2017

Arrey Canal

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1903	-	-	-	-	-	-	-	-	-	-	-	-	-
1904	-	-	-	-	-	-	-	-	-	-	-	-	-
1905	-	-	-	-	-	-	-	-	-	-	-	-	-
1906	-	-	-	-	-	-	-	-	-	-	-	-	-
1907	-	-	-	-	-	-	-	-	-	-	-	-	-
1908	-	-	-	-	-	-	-	-	-	-	-	-	-
1909	-	-	-	-	-	-	-	-	-	-	-	-	-
1910	-	-	-	-	-	-	-	-	-	-	-	-	-
1911	-	-	-	-	-	-	-	-	-	-	-	-	-
1912	-	-	-	-	-	-	-	-	-	-	-	-	-
1913	-	-	-	-	-	-	-	-	-	-	-	-	-
1914	-	-	-	-	-	-	-	-	-	-	-	-	-
1915	-	-	-	-	-	-	-	-	-	-	-	-	-
1916	-	-	-	-	-	-	-	-	-	-	-	-	-
1917	-	-	-	-	-	-	-	-	-	-	-	-	-
1918	0	0	1,458	1,398	1,825	1,170	1,468	1,369	1,111	377	563	0	10,739
1919	-	-	-	-	-	-	-	-	-	-	-	-	-
1920	0	0	0	3,074	11,851	7,317	8,779	8,648	11,488	3,273	2,156	3,499	60,085
1921	0	2,460	6,922	8,549	11,238	9,152	7,301	5,480	5,948	2,817	3,356	2,729	65,952
1922	714	5,802	7,686	7,440	9,364	10,155	10,832	10,677	10,104	9,047	3,507	2,539	87,867
1923	0	2,700	7,025	7,807	9,489	9,864	10,044	9,251	8,104	7,537	1,855	567	74,243
1924	0	4,356	5,998	8,900	10,264	11,197	11,927	12,069	10,984	4,126	3,725	3,197	86,743
1925	0	5,480	9,501	10,600	12,908	12,377	11,823	10,387	6,912	3,108	2,660	3,174	88,930
1926	0	1,918	6,135	12,040	14,654	15,084	12,666	13,876	11,405	2,311	2,461	1,763	94,313
1927	198	4,848	7,440	11,742	13,870	13,408	14,737	14,289	12,238	6,783	3,360	2,099	105,012
1928	2,148	3,870	7,537	14,870	16,969	17,137	18,754	18,754	14,658	7,388	3,882	2,313	128,280
1929	1,501	2,025	9,733	17,046	15,539	14,033	14,340	10,183	10,286	3,253	720	1,357	100,016
1930	0	3,513	8,200	14,503	13,571	14,277	13,757	13,337	11,276	3,648	2,299	1,648	100,029
1931	0	1,763	6,700	14,095	14,555	16,407	13,900	14,273	11,000	3,360	1,801	722	98,576
1932	0	3,414	8,001	14,311	15,451	15,715	13,565	13,777	10,233	1,289	1,371	855	97,982
1933	0	2,941	7,916	12,413	13,006	10,953	12,417	14,535	11,030	5,084	3,634	3,747	97,676
1934	1,932	4,393	9,580	14,947	14,858	15,160	15,376	15,681	10,381	2,755	1,874	1,932	108,869
1935	0	996	3,663	9,723	8,204	10,616	12,607	11,094	5,427	1,797	1,394	1,168	66,689
1936	0	1,952	5,657	10,739	10,429	12,212	13,446	13,394	7,269	1,894	1,214	206	78,412
1937	95	621	4,943	13,212	10,883	10,856	12,430	13,987	6,730	1,692	1,051	1,416	77,916
1938	0	1,698	7,234	12,294	11,647	12,415	7,989	15,542	3,092	3,475	2,444	1,420	79,250
1939	0	2,321	7,632	11,633	12,252	13,271	13,543	10,979	7,712	2,505	1,321	1,045	84,214
1940	0	1,583	8,751	12,008	10,268	12,448	14,015	12,518	8,533	69	688	0	80,881
1941	0	498	4,338	12,419	10,241	12,054	12,702	10,243	7,674	904	841	865	72,779
1942	0	3,626	9,156	14,739	13,315	15,709	16,526	11,248	7,509	4,187	3,059	1,904	100,978
1943	1,061	4,221	11,086	14,711	14,624	14,549	13,384	17,587	9,156	2,505	1,714	581	105,179
1944	0	2,390	15,118	15,088	13,749	14,735	16,649	17,101	10,387	1,595	0	1,380	108,192
1945	0	1,666	8,003	15,552	13,263	15,170	15,983	17,276	12,883	793	1,622	1,585	103,796

Rio Grande Project Flow Data
Total Monthly Flow (Acre-Feet)
1903 - 2017
Arrey Canal

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1946	0	2,624	8,733	14,717	13,948	15,878	17,258	17,901	5,028	1,375	1,442	752	99,656
1947	0	1,474	6,887	13,793	11,459	14,055	17,885	15,108	6,129	0	0	0	86,790
1948	0	0	6,026	13,267	7,763	12,147	17,246	19,142	7,480	906	998	787	85,762
1949	0	0	10,251	11,923	9,082	13,872	16,229	20,337	5,893	2,422	1,228	766	92,003
1950	0	2,188	14,221	11,873	13,045	12,377	7,569	20,176	7,878	0	0	0	89,327
1951	0	0	5,794	10,804	2,045	7,864	11,905	12,177	4,544	0	0	0	55,133
1952	0	0	1,730	8,477	7,125	9,820	15,727	15,368	6,551	0	0	0	64,798
1953	0	0	8,577	9,697	4,374	9,197	11,897	13,055	6,387	0	0	0	63,184
1954	0	0	3,088	6,536	2,436	4,881	6,210	3,059	992	0	0	0	27,202
1955	0	0	1,920	3,362	341	1,678	2,210	5,060	5,294	0	0	0	19,865
1956	0	0	4,372	3,812	327	3,993	3,993	4,917	2,743	0	0	0	24,157
1957	0	0	734	2,678	0	3,717	5,952	12,974	9,420	0	0	0	35,475
1958	0	0	11,754	13,462	12,966	17,562	19,666	15,665	8,025	0	0	0	99,100
1959	0	0	14,150	11,242	13,498	15,985	18,478	13,958	8,795	0	0	0	96,106
1960	0	0	14,688	12,309	14,053	13,678	17,197	18,768	8,039	0	0	0	98,732
1961	0	0	9,475	9,614	10,885	12,323	12,881	12,272	4,259	0	0	0	71,709
1962	0	0	12,032	13,263	13,371	14,410	14,428	16,457	6,936	0	0	0	90,897
1963	0	0	15,316	7,559	9,874	10,959	14,860	11,742	4,245	0	0	0	74,555
1964	0	0	4,149	4,497	0	4,506	3,810	6,377	2,733	0	0	0	26,072
1965	0	0	2,448	5,572	0	12,222	15,780	17,587	5,921	0	0	0	59,530
1966	0	0	12,054	12,206	8,626	12,422	15,090	12,766	10,863	0	0	0	84,027
1967	0	0	12,190	8,765	8,606	6,859	10,405	11,504	7,930	0	0	0	66,259
1968	0	0	14,138	10,861	11,006	14,640	12,561	15,723	9,699	0	0	0	88,628
1969	0	0	14,297	12,093	10,580	17,230	13,466	14,938	8,011	0	0	0	90,615
1970	0	446	14,509	13,146	12,141	13,256	18,240	18,065	8,632	0	0	0	98,435
1971	0	0	10,586	9,376	6,264	8,594	11,576	12,561	3,624	0	0	0	62,581
1972	0	0	8,140	5,345	1,795	2,404	6,653	4,677	2,598	0	0	0	31,612
1973	0	0	4,939	8,045	7,152	11,704	13,061	16,383	11,266	0	0	0	72,550
1974	0	0	12,670	8,801	10,003	13,303	9,354	12,258	8,231	0	0	0	74,620
1975	545	446	7,549	7,359	12,085	13,049	11,607	15,410	7,097	0	0	0	75,147
1976	3,136	7,317	9,660	10,818	14,481	11,675	10,316	14,511	8,239	0	0	0	90,153
1977	0	0	5,266	5,298	6,561	8,045	6,974	10,171	4,020	0	0	0	46,335
1978	0	0	1,916	4,076	107	5,859	7,117	7,263	4,675	0	0	0	31,013
1979	0	0	5,131	8,975	9,896	13,027	15,727	12,077	8,150	0	0	0	72,983
1980	0	5,286	11,193	11,460	11,171	15,777	15,223	11,506	7,870	0	0	0	89,486
1981	0	4,189	9,382	12,288	14,116	12,764	12,004	11,338	4,643	0	0	0	80,724
1982	0	5,179	10,310	11,752	11,907	13,821	14,842	13,757	6,240	0	0	0	87,808
1983	0	1,575	10,645	8,301	13,311	14,430	13,730	12,545	7,799	0	0	0	82,336
1984	0	4,237	8,577	12,657	14,416	12,670	15,739	5,837	9,719	0	0	0	83,852
1985	0	2,344	9,461	12,500	14,747	14,852	15,880	13,880	11,224	2,900	0	0	97,788
1986	5,794	10,453	13,468	15,503	17,488	14,039	14,769	15,802	12,887	4,766	0	0	124,969
1987	2,261	13,242	14,378	15,070	18,424	16,415	18,351	14,414	13,498	5,534	0	0	131,587
1988	0	4,629	13,634	13,755	16,778	17,379	14,916	11,103	10,861	3,550	0	0	106,605

Rio Grande Project Flow Data
Total Monthly Flow (Acre-Feet)
1903 - 2017
Arrey Canal

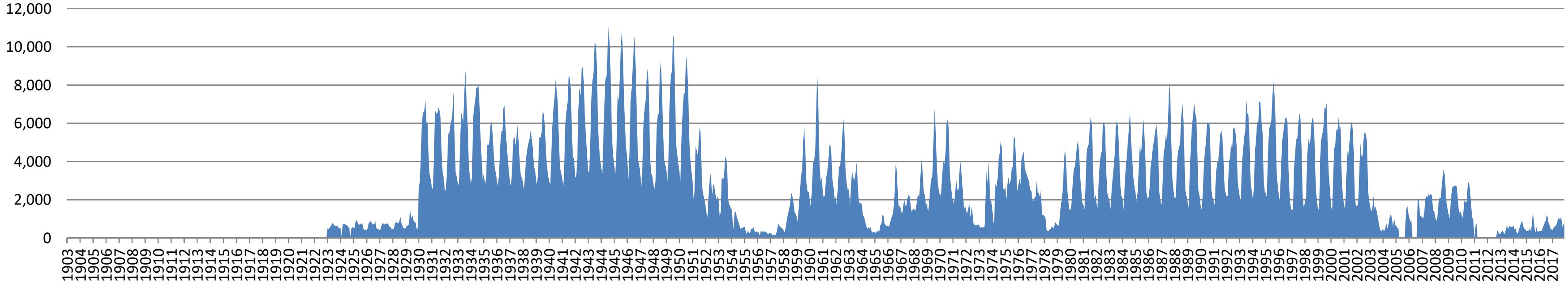
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1989	0	6,847	16,348	17,574	18,744	17,923	16,497	9,721	7,031	0	0	0	110,685
1990	0	1,999	13,454	14,392	17,589	16,620	7,970	8,289	9,144	0	0	0	89,457
1991	0	3,870	12,940	13,212	13,785	13,860	10,193	4,727	6,690	4,766	0	0	84,043
1992	0	3,769	12,268	11,482	9,255	12,932	13,615	11,387	9,818	4,721	0	0	89,247
1993	0	4,502	14,136	15,905	16,284	15,078	12,728	8,819	10,080	4,526	0	0	102,058
1994	0	11,974	16,421	15,552	14,382	18,413	17,572	15,830	11,451	5,482	0	0	127,077
1995	0	7,464	14,872	14,549	19,178	19,970	17,399	14,499	11,702	7,581	0	0	127,214
1996	776	11,478	15,652	14,134	17,718	13,738	11,940	11,397	10,429	0	0	0	107,262
1997	0	6,044	14,586	14,315	15,437	16,693	16,260	11,867	10,510	6,355	0	0	112,067
1998	8,499	9,211	12,272	15,160	16,314	17,506	12,801	10,417	11,280	4,556	0	0	118,016
1999	0	4,502	11,623	13,438	15,308	11,183	11,183	8,085	8,588	6,664	0	0	90,574
2000	0	5,917	11,292	14,152	16,556	13,609	11,778	12,175	10,742	6,621	0	0	102,842
2001	0	3,057	12,587	14,130	15,501	16,078	14,644	11,457	9,993	4,112	0	0	101,559
2002	0	3,493	13,843	13,523	15,203	15,465	12,016	11,863	12,623	5,320	0	0	103,349
2003	-	-	4,112	7,876	5,935	11,869	4,497	11,187	442	-	-	-	45,918
2004	-	-	4,175	2,106	2,428	11,792	11,141	8,200	3,326	-	-	-	43,168
2005	-	-	2,789	10,508	12,325	15,495	16,183	11,814	10,699	4,201	0	0	84,014
2006	0	0	4,350	10,015	10,586	10,261	6,147	2,916	4,034	3,517	0	0	51,824
2007	0	0	6,901	9,181	7,668	10,213	9,884	10,104	9,775	6,791	0	0	70,516
2008	0	0	6,901	11,462	12,700	12,133	2,854	9,546	6,736	5,258	0	0	67,591
2009	0	2,878	9,366	9,975	10,165	10,203	10,249	10,233	1,351	0	0	0	64,420
2010	0	0	4,840	9,447	10,159	11,002	5,379	10,316	5,012	0	0	0	56,155
2011	-	0	0	0	0	10,294	2,065	0	0	0	-	-	12,359
2012	-	-	0	698	7,972	10,171	8,287	6,121	0	0	-	-	33,249
2013	-	0	0	0	0	9,354	2,817	0	0	0	-	-	12,171
2014	-	-	-	0	1,900	13,877	5,908	0	-	-	-	-	21,685
2015	-	-	-	-	8,108	11,308	10,493	1,726	0	-	-	-	31,634
2016	-	-	-	5,373	12,329	11,623	8,608	0	0	-	-	-	37,934
2017	-	-	-	5,076	13,678	13,206	9,906	9,593	9,128	0	-	-	60,588
Avg	322	2,458	8,648	10,469	10,745	12,370	12,028	11,520	7,543	2,016	647	511	79,277

Drain Flows

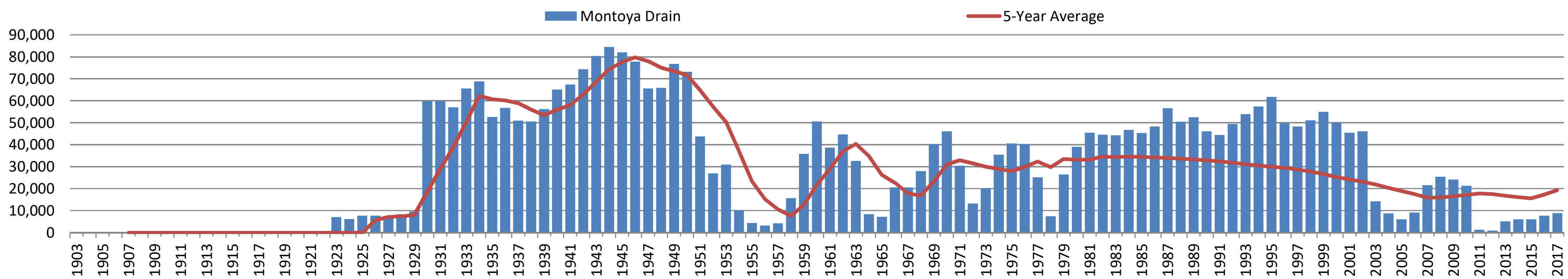
Montoya Drain

1903 - 2017

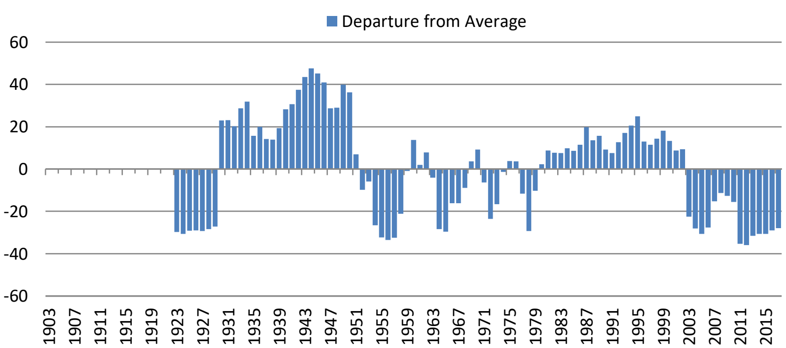
Total Monthly Flow (Acre-Feet)



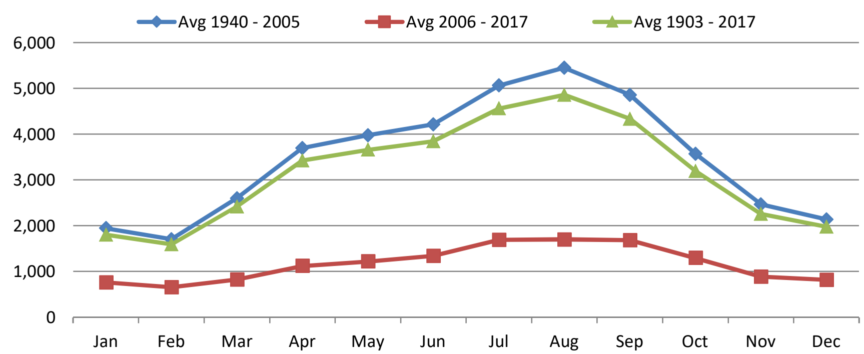
Total Annual Flow (Acre-Feet)



Annual Departure from Average (1,000 Acre-Feet)



Average Monthly Flow (Acre-Feet)



	Start	End
Period 1:	1940	2005
Period 2:	2006	2017

Rio Grande Project Flow Data

Total Monthly Flow (Acre-Feet)

1903 - 2017

Montoya Drain

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1903	-	-	-	-	-	-	-	-	-	-	-	-	-
1904	-	-	-	-	-	-	-	-	-	-	-	-	-
1905	-	-	-	-	-	-	-	-	-	-	-	-	-
1906	-	-	-	-	-	-	-	-	-	-	-	-	-
1907	-	-	-	-	-	-	-	-	-	-	-	-	-
1908	-	-	-	-	-	-	-	-	-	-	-	-	-
1909	-	-	-	-	-	-	-	-	-	-	-	-	-
1910	-	-	-	-	-	-	-	-	-	-	-	-	-
1911	-	-	-	-	-	-	-	-	-	-	-	-	-
1912	-	-	-	-	-	-	-	-	-	-	-	-	-
1913	-	-	-	-	-	-	-	-	-	-	-	-	-
1914	-	-	-	-	-	-	-	-	-	-	-	-	-
1915	-	-	-	-	-	-	-	-	-	-	-	-	-
1916	-	-	-	-	-	-	-	-	-	-	-	-	-
1917	-	-	-	-	-	-	-	-	-	-	-	-	-
1918	-	-	-	-	-	-	-	-	-	-	-	-	-
1919	-	-	-	-	-	-	-	-	-	-	-	-	-
1920	-	-	-	-	-	-	-	-	-	-	-	-	-
1921	-	-	-	-	-	-	-	-	-	-	-	-	-
1922	-	-	-	-	-	-	-	-	-	-	-	-	-
1923	479	444	523	607	726	786	652	602	601	621	512	504	7,057
1924	504	47	726	714	707	649	658	565	518	48	494	559	6,189
1925	516	516	896	892	738	684	688	738	756	468	410	405	7,707
1926	398	484	781	809	890	678	744	682	875	498	458	424	7,721
1927	400	461	676	779	664	750	707	750	726	578	553	437	7,481
1928	461	449	707	827	793	732	861	1,088	785	639	500	486	8,328
1929	486	661	621	708	1,488	1,023	1,162	916	821	824	482	436	9,628
1930	2,656	2,955	4,821	6,069	6,561	6,593	7,243	6,057	5,986	4,433	3,314	3,062	59,750
1931	2,650	2,516	4,470	6,653	6,542	6,456	6,825	6,671	6,236	4,292	3,439	3,136	59,886
1932	2,466	2,525	3,702	5,486	5,362	5,843	6,093	6,567	7,640	4,728	3,439	3,191	57,042
1933	2,835	2,744	4,901	6,575	6,333	6,046	7,588	8,756	6,974	5,829	3,660	3,296	65,537
1934	2,835	3,149	6,284	6,849	7,219	7,855	7,852	8,043	6,831	4,876	3,892	3,044	68,729
1935	3,339	2,760	3,117	4,861	4,851	4,957	5,860	6,069	5,427	4,359	3,582	3,388	52,570
1936	2,964	2,715	3,462	4,861	5,558	5,593	6,788	6,917	5,683	4,802	4,017	3,394	56,754
1937	2,976	2,666	3,714	5,088	5,294	4,838	5,202	5,909	5,022	3,855	3,225	3,142	50,931
1938	2,798	2,516	3,394	4,266	4,679	4,969	5,190	5,608	5,219	4,710	3,779	3,499	50,627
1939	3,056	2,644	3,652	5,266	5,220	5,498	6,585	6,487	5,855	4,882	3,689	3,345	56,179
1940	2,951	2,755	4,058	5,772	6,727	7,349	8,270	7,588	7,140	5,392	3,677	3,406	65,085
1941	3,117	2,627	3,640	5,903	6,598	7,039	8,522	8,313	7,700	5,583	4,207	4,150	67,399
1942	3,136	3,282	4,255	6,635	7,827	7,426	8,811	8,953	7,872	6,413	5,296	4,359	74,265
1943	3,437	3,493	5,300	7,254	8,221	8,622	10,275	10,066	8,670	6,081	4,737	4,107	80,263
1944	3,671	3,371	5,436	7,176	8,289	8,461	10,022	11,117	9,628	7,532	5,355	4,329	84,387
1945	3,769	3,332	4,569	7,486	7,194	8,039	9,807	10,908	9,449	7,133	5,599	4,673	81,958

Rio Grande Project Flow Data

Total Monthly Flow (Acre-Feet)

1903 - 2017

Montoya Drain

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1946	4,236	3,027	4,482	7,164	7,852	8,836	9,900	10,551	8,271	5,534	3,993	3,868	77,714
1947	3,351	2,644	3,861	6,111	6,862	7,289	8,381	8,922	7,390	4,169	3,368	3,204	65,552
1948	2,853	2,531	2,945	5,712	6,425	6,510	8,608	9,186	7,765	5,442	4,082	3,794	65,853
1949	3,622	2,955	4,126	7,135	8,467	8,700	10,453	10,588	7,569	4,876	4,385	3,837	76,713
1950	3,425	2,860	5,251	6,635	7,514	7,587	9,586	9,106	7,997	5,546	4,094	3,499	73,100
1951	2,988	1,927	2,460	4,778	4,538	4,284	5,337	5,977	4,570	2,644	2,261	1,992	43,756
1952	1,660	1,225	1,082	2,327	3,093	3,386	2,134	2,773	2,761	2,373	1,987	2,146	26,947
1953	2,017	1,111	1,377	3,154	3,068	3,118	4,114	4,273	3,368	1,986	1,738	1,593	30,917
1954	1,494	889	461	1,392	1,334	1,047	873	713	452	516	488	547	10,206
1955	584	344	178	399	264	214	455	449	559	357	298	320	4,421
1956	283	270	120	399	295	333	307	320	274	215	173	228	3,217
1957	246	205	106	158	146	143	397	753	613	553	500	480	4,300
1958	387	278	578	970	1,267	1,440	1,777	2,361	2,178	1,838	1,333	1,242	15,649
1959	1,107	844	1,648	2,511	3,240	3,570	4,962	5,731	4,528	2,865	2,392	2,416	35,814
1960	2,060	1,628	2,484	3,903	4,009	4,558	6,481	8,614	6,783	3,923	2,951	3,130	50,524
1961	2,324	2,099	2,232	3,118	3,406	3,915	4,802	4,907	4,338	3,013	2,582	1,955	38,691
1962	2,177	1,733	2,748	3,695	3,763	4,368	5,479	6,210	5,611	3,554	2,844	2,496	44,678
1963	2,527	1,644	2,601	3,475	3,197	2,987	3,320	3,935	3,225	2,091	1,779	1,869	32,650
1964	1,703	1,087	1,156	863	639	464	541	473	553	332	262	320	8,393
1965	283	250	332	357	295	649	719	1,205	1,119	726	655	609	7,199
1966	627	561	781	1,000	1,125	1,380	2,127	3,849	3,558	2,361	1,583	1,672	20,624
1967	1,494	1,200	1,648	2,011	1,679	1,678	2,054	2,238	2,148	1,605	1,351	1,482	20,588
1968	1,537	1,380	1,629	2,095	2,244	2,095	3,234	4,107	3,374	2,312	2,243	1,691	27,941
1969	1,814	1,283	1,918	2,654	3,111	3,178	5,140	6,770	5,522	3,738	2,731	2,496	40,355
1970	2,201	2,255	3,296	4,011	3,861	4,493	5,915	6,180	5,724	3,308	2,672	2,121	46,037
1971	1,949	1,738	2,423	3,023	2,484	2,541	3,511	4,009	3,189	2,373	1,482	1,679	30,401
1972	1,482	1,242	1,537	1,761	1,094	1,630	1,174	701	672	639	655	689	13,276
1973	652	516	553	530	541	601	2,460	3,517	2,844	4,107	1,952	1,943	20,216
1974	1,543	744	996	2,826	2,675	3,142	4,144	4,476	5,088	4,642	2,618	2,490	35,384
1975	2,675	1,899	2,718	3,154	2,798	3,005	3,659	3,720	5,224	5,257	4,034	2,423	40,566
1976	2,705	3,077	2,798	4,046	4,323	4,493	3,720	3,400	3,291	3,074	2,975	2,472	40,374
1977	2,490	1,972	1,906	2,071	2,121	2,975	2,349	2,324	2,089	2,490	1,190	1,217	25,194
1978	1,138	1,061	400	357	357	446	443	627	476	566	803	750	7,424
1979	664	622	922	1,619	1,894	2,452	3,671	4,735	3,898	2,570	1,970	1,500	26,517
1980	1,427	1,731	2,718	3,529	3,732	4,082	4,728	5,097	4,504	3,160	2,458	1,832	38,998
1981	1,738	1,482	2,763	4,483	4,806	4,881	5,772	6,407	5,687	3,197	2,049	2,235	45,500
1982	1,859	1,537	2,785	3,892	4,332	4,556	5,881	6,129	5,661	3,469	2,339	2,108	44,548
1983	2,005	1,492	2,430	3,136	3,784	4,620	5,778	6,157	5,693	4,284	2,739	2,192	44,310
1984	2,033	1,436	2,537	3,638	4,300	5,094	5,821	6,734	5,070	4,140	3,170	2,690	46,663
1985	2,315	1,888	2,364	3,612	4,867	4,350	5,163	6,236	5,760	4,348	2,396	2,051	45,350
1986	2,128	2,696	3,689	4,130	4,766	5,088	5,526	5,927	5,570	4,457	2,360	1,904	48,241
1987	1,718	3,043	4,332	4,770	5,419	5,042	6,309	8,154	7,200	5,107	3,090	2,448	56,632
1988	2,079	2,097	3,683	4,391	4,711	4,913	6,161	7,073	6,184	4,491	2,505	2,166	50,454

Rio Grande Project Flow Data

Total Monthly Flow (Acre-Feet)

1903 - 2017

Montoya Drain

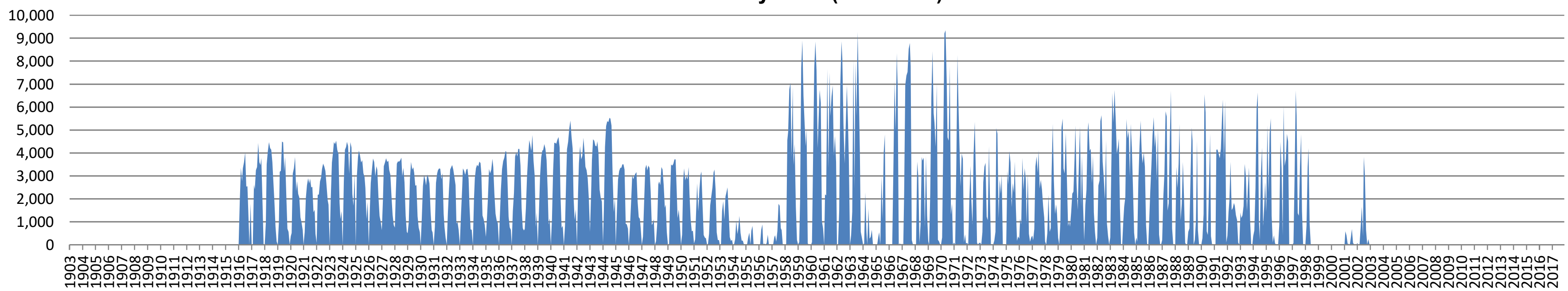
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1989	1,841	1,557	3,596	4,639	5,847	6,341	7,065	6,516	6,262	4,145	2,450	2,206	52,465
1990	1,670	1,462	2,491	3,959	4,502	5,048	6,069	5,919	6,050	4,276	2,513	2,106	46,065
1991	1,894	1,664	3,273	3,901	4,007	4,457	5,377	5,617	5,246	4,054	2,543	2,346	44,379
1992	2,152	2,184	3,995	4,171	5,018	4,479	5,699	5,776	5,532	4,865	2,961	2,573	49,405
1993	2,152	1,885	3,859	4,594	5,299	5,602	7,278	6,532	6,388	5,004	2,869	2,396	53,858
1994	2,034	2,463	4,463	5,173	6,061	5,991	7,107	7,128	6,110	5,512	2,947	2,399	57,388
1995	2,335	2,130	4,385	5,702	5,854	6,155	7,410	8,142	7,496	6,067	3,348	2,662	61,686
1996	2,138	1,940	3,473	5,036	5,494	5,940	6,296	6,282	6,050	3,499	2,023	1,549	49,720
1997	1,400	1,565	3,588	4,419	5,141	5,222	6,063	6,510	6,210	4,614	2,023	1,549	48,304
1998	1,892	2,089	3,854	5,226	4,919	5,060	5,984	6,307	6,101	5,038	2,703	1,894	51,067
1999	1,531	1,432	4,217	5,117	5,385	5,730	6,831	6,756	7,033	4,984	3,320	2,580	54,916
2000	1,670	1,400	3,227	4,651	4,885	5,653	5,645	6,325	5,629	5,823	3,076	2,091	50,075
2001	1,779	1,400	3,130	4,564	4,276	4,889	5,760	6,087	5,665	4,157	2,118	1,670	45,495
2002	1,642	1,771	3,439	4,961	4,324	4,229	5,127	5,542	5,421	5,088	2,545	1,997	46,086
2003	1,666	1,365	1,515	2,204	1,466	1,646	1,412	1,111	762	444	325	403	14,319
2004	442	335	504	752	480	676	1,055	1,208	1,065	541	1,049	625	8,732
2005	672	480	522	-	-	-	-	-	-	1,305	1,743	1,327	6,049
2006	1,115	815	908	-	-	-	-	-	2,202	1,880	1,156	1,119	9,195
2007	1,041	1,006	1,347	2,033	2,194	2,124	2,323	2,170	2,299	2,184	1,432	1,384	21,537
2008	1,069	859	1,067	1,767	2,104	2,089	2,799	3,328	3,612	3,160	2,003	1,611	25,468
2009	1,291	986	1,543	2,273	2,674	2,692	2,701	2,743	2,650	1,890	1,281	1,392	24,116
2010	1,228	1,025	1,307	1,950	1,864	1,886	2,866	2,904	2,444	1,799	1,081	942	21,296
2011	-	621	756	-	-	-	-	-	-	-	-	-	1,377
2012	-	-	-	-	-	-	-	-	-	399	300	194	893
2013	208	309	377	248	188	417	662	415	637	571	553	565	5,150
2014	633	428	492	236	202	375	589	770	891	587	460	434	6,097
2015	331	361	365	482	341	653	1,363	766	208	561	337	303	6,071
2016	373	349	369	530	664	853	889	1,291	819	692	486	430	7,745
2017	383	508	581	601	770	990	1,039	940	1,111	563	728	682	8,896
Avg	1,807	1,596	2,419	3,425	3,661	3,849	4,562	4,858	4,333	3,197	2,258	1,979	37,944

Wasteway Flows

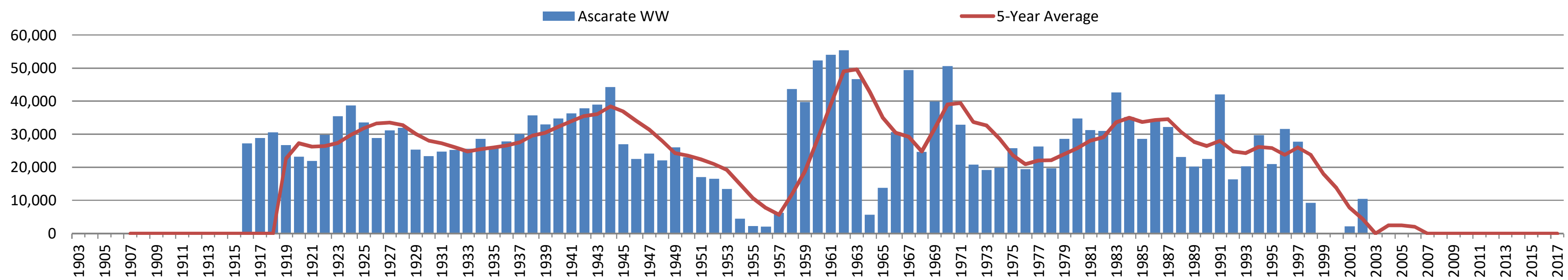
Ascarate WW

1903 - 2017

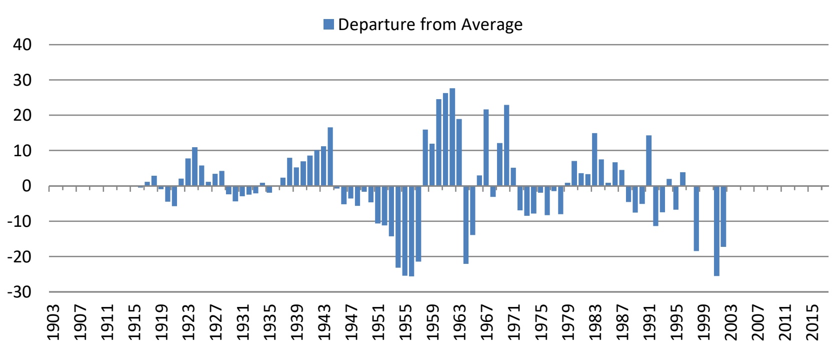
Total Monthly Flow (Acre-Feet)



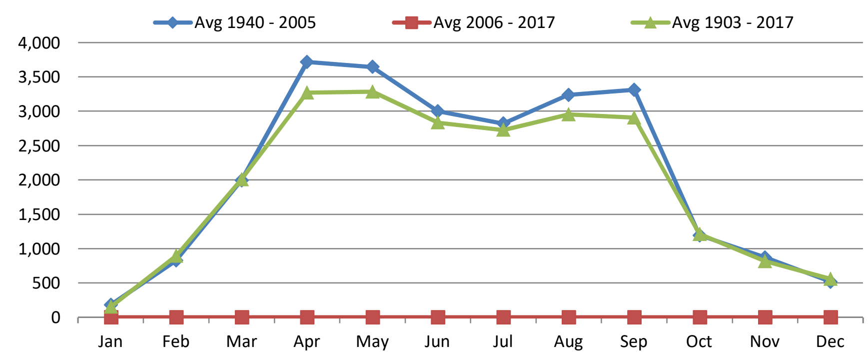
Total Annual Flow (Acre-Feet)



Annual Departure from Average (1,000 Acre-Feet)



Average Monthly Flow (Acre-Feet)



	Start	End
Period 1:	1940	2005
Period 2:	2006	2017

Rio Grande Project Flow Data
Total Monthly Flow (Acre-Feet)
1903 - 2017
Ascarate WW

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1903	-	-	-	-	-	-	-	-	-	-	-	-	-
1904	-	-	-	-	-	-	-	-	-	-	-	-	-
1905	-	-	-	-	-	-	-	-	-	-	-	-	-
1906	-	-	-	-	-	-	-	-	-	-	-	-	-
1907	-	-	-	-	-	-	-	-	-	-	-	-	-
1908	-	-	-	-	-	-	-	-	-	-	-	-	-
1909	-	-	-	-	-	-	-	-	-	-	-	-	-
1910	-	-	-	-	-	-	-	-	-	-	-	-	-
1911	-	-	-	-	-	-	-	-	-	-	-	-	-
1912	-	-	-	-	-	-	-	-	-	-	-	-	-
1913	-	-	-	-	-	-	-	-	-	-	-	-	-
1914	-	-	-	-	-	-	-	-	-	-	-	-	-
1915	-	-	-	-	-	-	-	-	-	-	-	-	-
1916	0	1,872	3,344	2,758	3,323	3,588	4,011	2,526	2,542	1,462	0	1,779	27,205
1917	0	0	2,605	2,403	3,245	3,376	4,432	3,592	3,469	3,769	1,940	0	28,831
1918	0	943	3,502	4,075	4,460	4,199	4,133	3,590	2,862	1,912	785	131	30,592
1919	0	959	3,172	3,222	4,489	4,448	3,194	3,809	2,186	690	555	0	26,724
1920	372	505	3,093	3,325	3,812	2,332	2,758	2,202	2,041	1,180	951	621	23,192
1921	0	537	2,017	2,594	2,880	2,658	2,867	2,488	2,510	1,405	1,512	462	21,930
1922	69	2,171	2,186	2,753	2,930	3,291	3,526	3,405	3,208	2,571	1,935	1,732	29,777
1923	0	2,053	3,572	4,036	4,459	4,375	4,528	4,119	3,947	1,808	1,108	1,447	35,452
1924	0	2,745	4,132	4,255	4,474	4,289	3,086	4,469	4,228	2,196	1,690	3,083	38,647
1925	0	2,984	3,819	4,097	3,884	3,576	3,672	3,106	2,949	2,468	1,106	1,848	33,509
1926	0	1,606	2,681	3,240	3,743	3,594	2,969	3,418	3,259	2,090	1,245	999	28,844
1927	630	1,972	3,411	3,577	3,766	3,595	3,644	3,253	3,050	2,117	1,291	846	31,152
1928	740	2,139	3,527	3,620	3,608	3,671	3,782	2,957	3,341	2,710	1,257	554	31,906
1929	486	974	2,840	3,596	3,269	3,361	3,130	2,561	2,590	1,236	737	545	25,325
1930	0	1,155	2,549	3,035	2,828	2,572	3,046	2,917	2,665	1,408	630	528	23,333
1931	0	763	2,682	3,091	3,245	3,317	3,309	2,842	3,108	1,346	760	279	24,742
1932	0	1,396	2,423	3,265	3,359	3,467	3,264	2,931	2,586	921	970	631	25,213
1933	0	1,256	2,349	3,319	3,221	3,027	3,268	3,302	2,854	1,712	657	641	25,606
1934	0	1,981	2,900	3,328	3,479	3,406	3,612	3,554	3,100	1,273	1,106	844	28,583
1935	328	1,208	1,984	3,292	3,103	3,271	3,733	3,374	2,198	1,340	1,043	920	25,794
1936	0	1,155	2,417	3,288	3,637	3,786	4,070	4,041	2,833	1,219	749	635	27,830
1937	0	1,450	2,245	3,836	4,016	3,833	4,163	4,167	3,438	1,576	710	617	30,051
1938	673	1,559	2,948	3,866	4,554	4,364	4,083	4,777	3,649	3,004	762	1,406	35,645
1939	0	1,395	2,966	3,802	4,092	4,117	4,377	4,170	3,686	2,311	872	1,143	32,931
1940	0	1,085	3,199	4,425	4,438	4,388	4,561	4,686	4,224	2,155	724	815	34,700
1941	0	800	2,802	4,156	4,475	5,046	5,402	4,704	4,181	2,103	1,076	1,542	36,287
1942	0	2,244	3,533	4,292	3,710	3,876	4,645	4,008	3,386	3,236	2,879	2,010	37,819
1943	553	2,187	3,703	4,582	4,530	4,308	4,279	4,497	3,984	2,393	2,037	1,872	38,925
1944	62	1,482	4,252	5,169	5,381	5,339	5,524	5,491	5,174	2,975	1,410	2,003	44,262
1945	13	1,460	2,835	3,206	3,335	3,350	3,490	3,498	3,268	914	871	690	26,930

Rio Grande Project Flow Data
Total Monthly Flow (Acre-Feet)
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Ascarate WW

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1946	0	749	1,813	3,002	2,846	2,989	3,079	3,157	1,869	1,199	1,120	698	22,521
1947	0	341	1,846	3,311	3,482	3,224	3,438	3,338	2,329	850	922	1,097	24,178
1948	0	149	867	2,620	2,750	2,589	3,375	3,266	2,595	1,595	1,739	542	22,087
1949	0	0	2,283	3,487	3,445	3,513	3,711	3,711	2,286	1,151	1,525	908	26,020
1950	0	431	2,838	3,318	2,799	2,982	2,831	3,378	2,189	1,095	572	607	23,040
1951	42	226	1,294	2,664	1,441	2,404	3,035	3,185	1,748	419	307	265	17,030
1952	0	0	471	1,696	2,111	2,493	3,139	3,266	2,408	528	196	191	16,499
1953	0	0	1,470	1,890	1,069	2,099	2,260	2,488	1,435	328	160	212	13,411
1954	0	0	225	1,044	452	694	1,248	507	165	174	0	0	4,509
1955	0	0	307	520	0	593	809	4	0	0	0	0	2,233
1956	0	0	637	877	22	38	6	44	426	0	0	0	2,050
1957	0	0	315	409	119	587	1,773	1,692	716	627	0	0	6,238
1958	0	0	4,552	4,917	6,760	7,045	3,779	6,871	3,461	4,391	1,644	200	43,620
1959	0	113	1,880	7,708	8,894	6,460	5,278	4,288	5,028	42	0	0	39,691
1960	0	111	3,866	7,680	8,848	7,591	4,207	5,338	6,744	6,175	1,014	714	52,288
1961	0	2,176	2,142	7,648	3,330	7,490	5,605	6,450	6,928	3,856	4,740	3,592	53,957
1962	0	0	1,482	7,049	8,854	8,110	5,270	3,525	5,207	6,938	5,264	3,677	55,376
1963	0	407	1,430	8,023	2,430	7,926	5,595	9,263	6,885	3,862	555	288	46,664
1964	8	36	2,267	557	0	1,553	258	327	635	0	0	0	5,641
1965	0	0	345	543	0	2,959	1,109	4,034	4,800	0	0	0	13,790
1966	0	0	0	0	3,251	7,121	4,959	8,337	6,962	0	46	0	30,676
1967	30	0	2,227	6,958	7,361	7,523	8,521	8,779	7,767	196	0	0	49,362
1968	0	0	3,618	2,951	56	889	3,806	3,660	3,786	746	3,846	1,267	24,625
1969	145	0	2,208	6,440	8,428	5,722	5,306	4,259	7,018	210	131	0	39,867
1970	0	311	4,516	9,209	9,348	7,172	4,671	4,524	7,767	1,305	1,769	0	50,592
1971	77	0	3,445	8,255	5,861	4,397	2,529	3,953	3,735	97	440	50	32,839
1972	65	0	1,989	3,433	1,932	861	3,981	5,345	3,011	87	0	61	20,765
1973	79	0	545	2,713	3,394	3,560	1,220	1,061	4,284	2,352	0	0	19,208
1974	0	173	555	5,070	4,828	1,142	2,832	2,220	3,055	0	0	0	19,875
1975	0	3,215	2,614	4,070	3,578	1,630	2,674	2,257	3,612	1,585	159	353	25,747
1976	256	1,117	891	3,773	2,366	3,330	2,836	873	3,068	468	123	311	19,412
1977	393	179	678	3,402	3,840	3,114	4,112	2,444	2,824	2,398	1,696	1,166	26,246
1978	127	0	502	2,154	555	712	3,148	5,252	2,805	1,327	1,751	1,353	19,686
1979	290	0	964	5,094	5,492	3,318	3,094	4,867	2,836	801	1,057	768	28,581
1980	1,404	2,218	2,299	3,747	5,179	2,686	1,498	3,376	5,137	1,646	3,886	1,702	34,778
1981	177	1,720	2,384	4,917	5,328	4,078	4,181	2,676	3,872	1,398	540	0	31,271
1982	298	2,577	2,791	5,379	5,641	3,614	2,910	1,932	4,554	930	381	0	31,007
1983	317	3,721	6,597	5,310	6,740	5,486	3,949	4,262	4,618	1,597	0	0	42,597
1984	1,043	1,652	2,067	5,466	4,620	4,957	2,938	5,254	4,213	2,460	512	0	35,182
1985	303	117	2,753	4,266	5,407	3,959	3,535	4,009	3,386	877	0	0	28,612
1986	942	2,333	3,461	4,764	5,556	4,237	4,822	2,777	5,048	424	0	0	34,364
1987	190	2,075	3,124	5,810	5,576	1,480	1,803	4,703	6,710	702	0	0	32,173
1988	0	3,382	2,460	3,523	5,252	1,053	1,773	3,604	2,017	83	0	0	23,147

Rio Grande Project Flow Data
Total Monthly Flow (Acre-Feet)
1903 - 2017
Ascarate WW

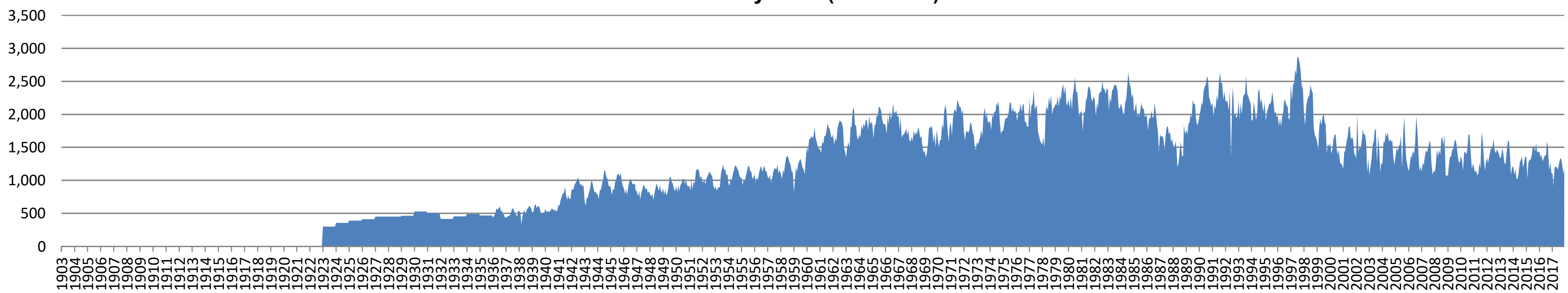
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1989	549	704	2,969	5,088	4,528	0	194	1,023	4,512	609	0	0	20,176
1990	0	280	1,329	6,549	5,754	579	422	2,458	4,818	367	0	0	22,556
1991	0	0	4,132	4,138	3,959	3,759	4,183	5,540	6,319	3,660	6,252	85	42,027
1992	375	1,416	1,910	3,596	1,505	1,591	1,809	1,684	1,283	1,073	79	0	16,321
1993	1,390	1,160	1,267	1,680	3,509	2,987	1,452	2,414	3,358	1,049	0	0	20,266
1994	369	619	2,434	5,913	6,625	1,099	190	2,973	4,221	793	1,700	2,727	29,663
1995	1,400	5,197	2,265	4,840	5,502	1,250	79	409	40	0	-	-	20,982
1996	857	4,481	3,324	381	6,034	3,433	3,723	4,822	4,485	-	-	-	31,540
1997	0	63	2,999	6,708	5,621	1,369	1,256	3,427	4,804	1,454	0	0	27,701
1998	0	819	3,378	4,193	899	0	0	0	0	0	0	0	9,289
1999	-	0	0	0	0	0	0	0	0	0	-	-	-
2000	0	0	0	0	0	0	0	0	0	0	-	-	-
2001	0	575	391	38	24	8	365	674	73	0	0	0	2,148
2002	52	0	0	756	1,650	359	3,828	2,967	629	0	232	0	10,473
2003	-	-	0	0	0	0	0	0	0	0	-	-	-
2004	0	0	0	0	0	0	0	0	0	0	0	0	-
2005	0	0	0	0	0	0	0	0	0	0	0	0	-
2006	0	0	0	0	0	0	0	0	0	0	0	0	-
2007	0	0	0	0	0	0	0	0	0	0	0	0	-
2008	0	0	0	0	0	0	0	0	0	0	0	0	-
2009	0	0	0	0	0	0	0	0	0	0	0	0	-
2010	0	0	0	0	0	0	0	0	0	0	0	0	-
2011	-	-	-	-	-	-	-	-	-	-	-	-	-
2012	-	-	-	-	-	-	-	-	-	0	-	-	-
2013	0	0	0	0	0	0	0	0	0	0	0	0	-
2014	0	0	0	0	0	0	0	0	0	0	0	0	-
2015	0	0	0	0	0	0	0	0	0	0	0	0	-
2016	0	0	0	0	0	0	0	0	0	0	0	0	-
2017	0	0	0	0	0	0	0	0	0	0	0	0	-
Avg	154	898	2,011	3,271	3,286	2,836	2,730	2,954	2,910	1,214	818	563	23,644

Municipal Flows

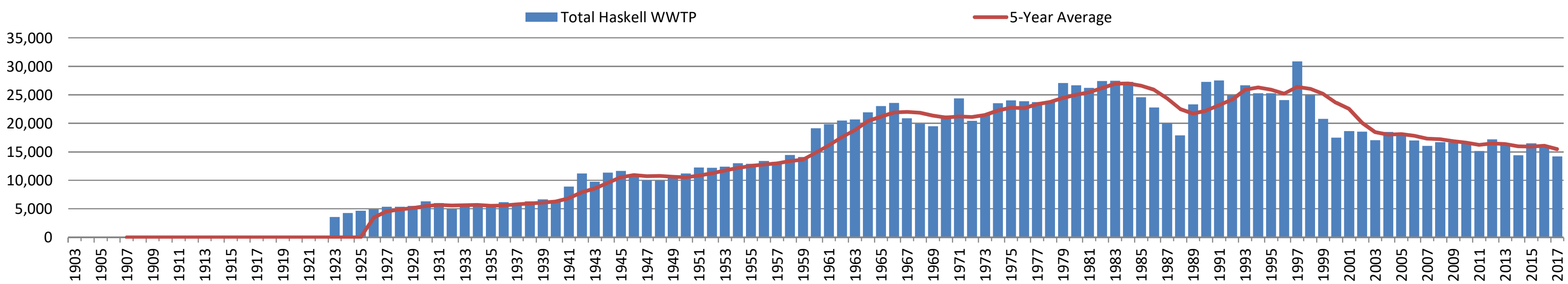
Total Haskell WWTP

1903 - 2017

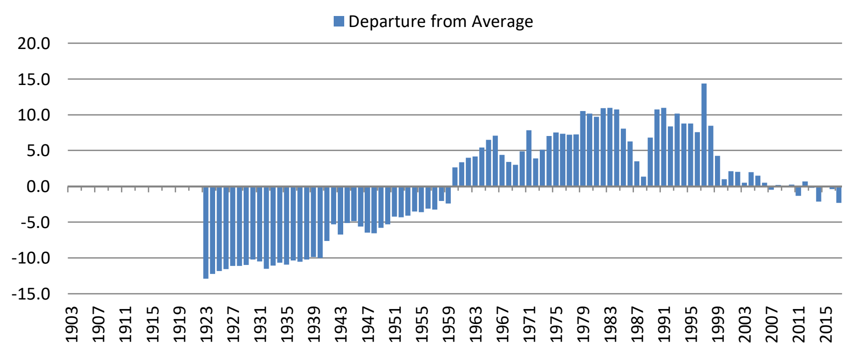
Total Monthly Flow (Acre-Feet)



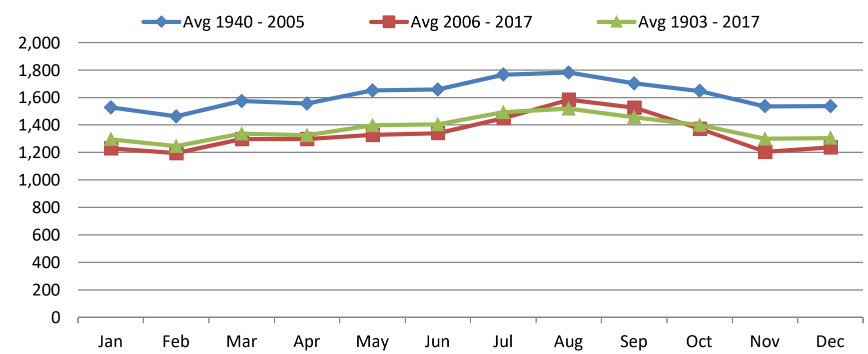
Total Annual Flow (Acre-Feet)



Annual Departure from Average (1,000 Acre-Feet)



Average Monthly Flow (Acre-Feet)



	Start	End
Period 1:	1940	2005
Period 2:	2006	2017

Rio Grande Project Flow Data
Total Monthly Flow (Acre-Feet)
1903 - 2017
Total Haskell WWTP

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1903	-	-	-	-	-	-	-	-	-	-	-	-	-
1904	-	-	-	-	-	-	-	-	-	-	-	-	-
1905	-	-	-	-	-	-	-	-	-	-	-	-	-
1906	-	-	-	-	-	-	-	-	-	-	-	-	-
1907	-	-	-	-	-	-	-	-	-	-	-	-	-
1908	-	-	-	-	-	-	-	-	-	-	-	-	-
1909	-	-	-	-	-	-	-	-	-	-	-	-	-
1910	-	-	-	-	-	-	-	-	-	-	-	-	-
1911	-	-	-	-	-	-	-	-	-	-	-	-	-
1912	-	-	-	-	-	-	-	-	-	-	-	-	-
1913	-	-	-	-	-	-	-	-	-	-	-	-	-
1914	-	-	-	-	-	-	-	-	-	-	-	-	-
1915	-	-	-	-	-	-	-	-	-	-	-	-	-
1916	-	-	-	-	-	-	-	-	-	-	-	-	-
1917	-	-	-	-	-	-	-	-	-	-	-	-	-
1918	-	-	-	-	-	-	-	-	-	-	-	-	-
1919	-	-	-	-	-	-	-	-	-	-	-	-	-
1920	-	-	-	-	-	-	-	-	-	-	-	-	-
1921	-	-	-	-	-	-	-	-	-	-	-	-	-
1922	-	-	-	-	-	-	-	-	-	-	-	-	-
1923	298	298	298	298	298	298	298	298	298	298	298	298	3,581
1924	355	355	355	355	355	355	355	355	355	355	355	355	4,255
1925	387	387	387	387	387	387	387	387	387	387	387	387	4,643
1926	410	410	410	410	410	410	410	410	410	410	410	410	4,918
1927	447	447	447	447	447	447	447	447	447	447	447	447	5,370
1928	446	446	446	446	446	446	446	446	446	446	446	446	5,355
1929	460	460	460	460	460	460	460	460	460	460	460	460	5,520
1930	524	524	524	524	524	524	524	524	524	524	524	524	6,284
1931	501	501	501	501	501	501	501	501	501	501	501	501	6,013
1932	413	413	413	413	413	413	413	413	413	413	413	413	4,953
1933	450	450	450	450	450	450	450	450	450	450	450	450	5,402
1934	487	487	487	487	487	487	487	487	487	487	487	487	5,846
1935	464	464	464	464	464	464	464	464	464	464	464	464	5,565
1936	430	460	488	567	551	575	605	544	535	495	473	430	6,153
1937	436	445	455	460	491	552	576	550	505	474	454	538	5,936
1938	534	516	332	448	525	543	482	555	575	611	596	574	6,291
1939	513	517	613	636	583	601	614	562	483	495	504	506	6,627
1940	565	515	534	515	525	547	567	558	537	560	524	545	6,492
1941	627	618	708	748	798	808	899	766	704	766	714	715	8,871
1942	862	852	869	936	964	1,005	1,039	981	926	944	906	917	11,201
1943	669	611	727	737	816	875	988	979	902	816	829	795	9,744
1944	780	712	847	859	951	1,019	1,151	1,139	1,050	1,019	914	908	11,349
1945	898	774	872	848	973	1,019	1,083	1,101	1,055	1,114	979	905	11,621

Rio Grande Project Flow Data
Total Monthly Flow (Acre-Feet)
1903 - 2017
Total Haskell WWTP

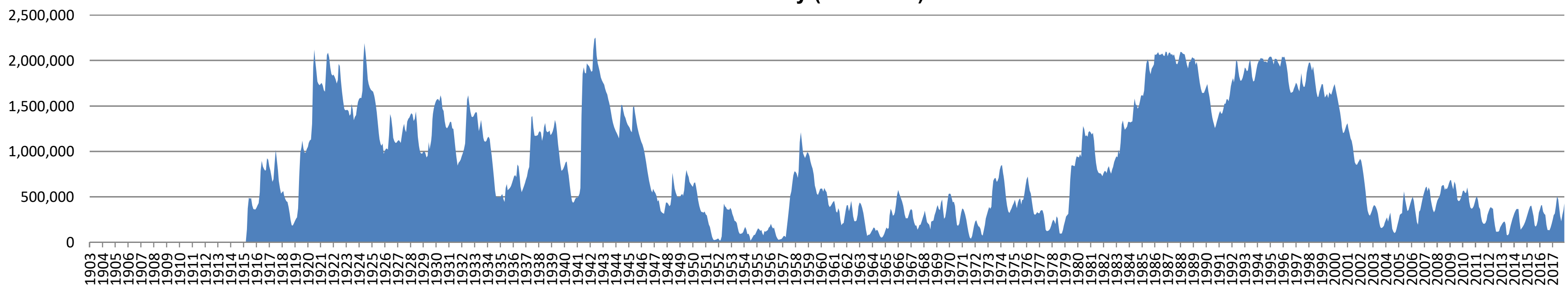
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1946	887	795	869	777	904	969	1,020	996	937	945	945	847	10,891
1947	830	755	832	712	821	855	928	908	852	884	807	832	10,016
1948	795	755	792	697	776	872	955	893	835	921	847	810	9,948
1949	875	783	856	773	804	899	1,044	1,047	960	954	865	838	10,698
1950	900	818	934	834	926	958	1,019	1,025	942	1,013	927	901	11,193
1951	913	848	1,005	863	972	954	1,130	1,163	1,169	1,142	1,026	1,066	12,247
1952	975	970	998	940	1,040	1,070	1,120	1,120	1,080	1,073	922	863	12,171
1953	908	845	871	896	887	1,097	1,157	1,234	1,157	1,160	1,075	1,088	12,376
1954	955	913	1,028	993	1,100	1,141	1,222	1,216	1,180	1,142	1,066	1,038	12,994
1955	1,034	925	1,018	975	1,078	1,125	1,216	1,210	1,135	1,126	1,019	1,041	12,902
1956	1,093	959	1,049	996	1,099	1,174	1,217	1,127	1,185	1,217	1,137	1,134	13,387
1957	1,049	1,023	1,085	956	1,019	1,114	1,174	1,178	1,166	1,234	1,104	1,156	13,258
1958	1,091	1,019	1,163	1,102	1,251	1,348	1,368	1,333	1,277	1,234	1,134	1,117	14,437
1959	816	1,033	1,196	1,124	1,248	1,291	1,323	1,254	1,191	1,165	1,093	1,354	14,088
1960	1,513	1,418	1,609	1,629	1,669	1,636	1,673	1,805	1,640	1,578	1,504	1,468	19,142
1961	1,480	1,411	1,579	1,553	1,673	1,667	1,745	1,859	1,796	1,771	1,661	1,644	19,839
1962	1,697	1,535	1,638	1,587	1,792	1,844	1,902	1,896	1,870	1,794	1,476	1,437	20,468
1963	1,351	1,497	1,574	1,489	1,825	1,790	2,060	2,108	1,840	1,828	1,672	1,612	20,646
1964	1,696	1,639	1,839	1,762	1,862	1,810	1,914	1,906	1,755	1,982	1,848	1,887	21,900
1965	1,848	1,625	1,838	1,833	1,979	1,971	2,119	2,098	2,045	1,932	1,859	1,844	22,991
1966	1,847	1,701	1,971	1,841	2,049	1,927	1,994	2,171	2,018	2,024	2,053	1,966	23,562
1967	1,967	1,752	1,973	1,650	1,685	1,701	1,732	1,779	1,683	1,760	1,612	1,584	20,878
1968	1,661	1,582	1,748	1,676	1,734	1,698	1,809	1,758	1,639	1,668	1,509	1,413	19,895
1969	1,456	1,344	1,406	1,552	1,802	1,786	1,820	1,791	1,569	1,704	1,493	1,763	19,486
1970	1,646	1,499	1,606	1,616	1,846	1,786	2,042	2,145	2,045	1,756	1,580	1,793	21,360
1971	1,885	1,680	1,944	2,056	2,077	2,020	2,221	2,171	2,106	2,111	2,011	2,067	24,349
1972	1,747	1,606	1,743	1,738	1,713	1,756	1,885	1,839	1,724	1,680	1,498	1,462	20,391
1973	1,581	1,539	1,612	1,649	1,763	1,662	1,988	2,102	1,936	2,027	1,883	1,875	21,617
1974	1,899	1,762	1,996	1,951	2,033	2,041	2,174	2,125	2,202	1,889	1,698	1,748	23,518
1975	1,747	1,861	1,932	1,935	1,954	2,021	2,176	2,177	2,032	2,092	2,028	2,054	24,009
1976	1,998	1,895	2,029	2,048	2,163	2,039	2,148	2,152	1,885	1,880	1,808	1,809	23,852
1977	2,249	1,928	2,126	2,160	2,371	2,056	2,120	2,127	1,737	1,668	1,588	1,564	23,694
1978	1,535	1,649	1,480	2,038	2,121	2,055	2,259	2,149	2,289	1,989	2,089	2,102	23,755
1979	2,154	2,136	2,273	2,111	2,282	2,210	2,378	2,456	2,306	2,430	2,137	2,150	27,023
1980	2,221	2,091	2,271	2,074	2,289	2,404	2,556	2,335	2,342	2,076	1,963	2,031	26,653
1981	2,050	1,739	2,033	2,030	2,206	2,247	2,409	2,416	2,366	2,243	2,195	2,275	26,209
1982	2,217	1,964	2,176	2,089	2,311	2,331	2,348	2,508	2,392	2,385	2,308	2,390	27,419
1983	2,369	2,059	2,261	2,174	2,355	2,382	2,453	2,435	2,437	2,359	2,090	2,090	27,464
1984	2,163	2,117	2,024	1,996	2,175	2,239	2,478	2,632	2,468	2,401	2,253	2,303	27,249
1985	2,041	2,063	2,178	1,960	2,013	1,966	2,060	2,173	2,090	2,079	1,953	1,992	24,568
1986	1,955	1,758	1,947	1,935	2,057	1,941	1,959	2,166	2,038	1,859	1,725	1,429	22,769
1987	1,690	1,657	1,675	1,628	1,456	1,647	1,793	1,824	1,702	1,729	1,571	1,635	20,007
1988	1,542	1,489	1,590	1,481	1,204	1,253	1,434	1,590	1,374	1,360	1,836	1,695	17,848

Rio Grande Project Flow Data
Total Monthly Flow (Acre-Feet)
1903 - 2017
Total Haskell WWTP

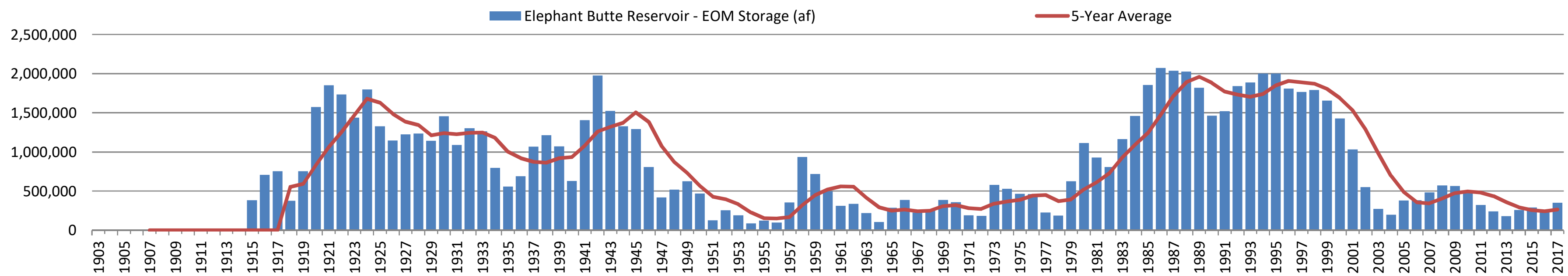
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1989	1,759	1,698	1,862	1,876	2,003	1,945	2,216	2,145	2,159	1,941	1,832	1,868	23,304
1990	1,967	2,057	2,174	2,143	2,354	2,423	2,452	2,580	2,508	2,263	2,200	2,124	27,245
1991	2,174	1,951	2,131	2,082	2,286	2,196	2,508	2,633	2,472	2,474	2,224	2,342	27,474
1992	2,193	2,207	2,184	2,056	2,374	1,335	2,210	2,407	1,976	2,007	1,940	1,994	24,883
1993	2,220	1,921	2,170	1,989	2,252	2,302	2,298	2,578	2,309	2,267	2,206	2,153	26,666
1994	1,899	1,915	2,191	2,049	1,914	2,026	2,326	2,392	2,171	2,233	2,096	2,039	25,252
1995	2,182	1,901	2,026	2,086	2,167	2,144	2,199	2,340	2,189	2,018	2,037	1,959	25,248
1996	1,974	1,818	1,935	1,813	1,951	2,028	2,225	2,197	2,126	2,117	1,929	1,927	24,040
1997	2,451	2,205	2,465	2,464	2,677	2,601	2,872	2,858	2,773	2,660	2,425	2,397	30,848
1998	2,020	1,830	2,117	2,200	2,256	2,282	2,444	2,360	2,316	1,810	1,685	1,650	24,970
1999	1,589	1,455	1,768	1,935	1,835	1,962	2,015	1,862	1,859	1,408	1,550	1,509	20,747
2000	1,562	1,408	1,449	1,608	1,680	1,699	1,468	1,387	1,463	1,275	1,249	1,230	17,478
2001	1,173	1,426	1,447	1,580	1,654	1,810	1,818	1,625	1,642	1,633	1,417	1,371	18,596
2002	1,332	2,005	1,424	1,509	1,479	1,604	1,768	1,690	1,691	1,571	1,115	1,336	18,523
2003	1,075	1,196	1,319	1,531	1,593	1,755	1,782	1,263	1,677	1,449	1,118	1,261	17,017
2004	1,242	1,586	1,573	1,730	1,656	1,722	1,585	1,620	1,584	1,598	1,364	1,234	18,493
2005	1,347	1,489	1,439	1,520	1,532	1,670	1,186	1,710	1,954	1,612	1,309	1,218	17,986
2006	1,133	1,222	1,373	1,343	1,447	1,396	1,561	1,968	1,740	1,457	1,139	1,210	16,989
2007	1,130	1,267	1,220	1,360	1,450	1,420	1,501	1,571	1,595	1,270	1,085	1,139	16,008
2008	1,126	1,250	1,461	1,358	1,460	1,384	1,626	1,659	1,528	1,692	1,069	1,070	16,683
2009	1,072	1,208	1,354	1,358	1,460	1,476	1,592	1,616	1,547	1,384	1,278	1,269	16,614
2010	1,359	1,316	1,146	1,431	1,420	1,391	1,473	1,695	1,683	1,407	1,166	1,257	16,744
2011	1,200	1,114	1,154	1,075	1,104	1,265	1,176	1,724	1,607	1,322	1,145	1,266	15,152
2012	1,336	1,259	1,364	1,453	1,489	1,493	1,624	1,453	1,407	1,467	1,443	1,391	17,179
2013	1,331	1,363	1,492	1,371	1,265	1,242	1,428	1,583	1,603	1,353	1,083	1,190	16,304
2014	1,214	1,079	1,172	1,029	1,014	1,115	1,267	1,309	1,365	1,192	1,261	1,365	14,382
2015	1,345	1,016	1,258	1,317	1,307	1,377	1,515	1,513	1,428	1,559	1,420	1,438	16,494
2016	1,426	1,343	1,390	1,285	1,331	1,375	1,377	1,587	1,492	1,146	1,269	1,105	16,125
2017	1,101	908	1,194	1,202	1,194	1,160	1,261	1,323	1,329	1,224	1,103	1,160	14,159
Avg	1,297	1,247	1,338	1,327	1,398	1,406	1,494	1,520	1,458	1,400	1,301	1,306	16,492

Reservoir Data
Elephant Butte Reservoir - EOM Storage (af)
1903 - 2017

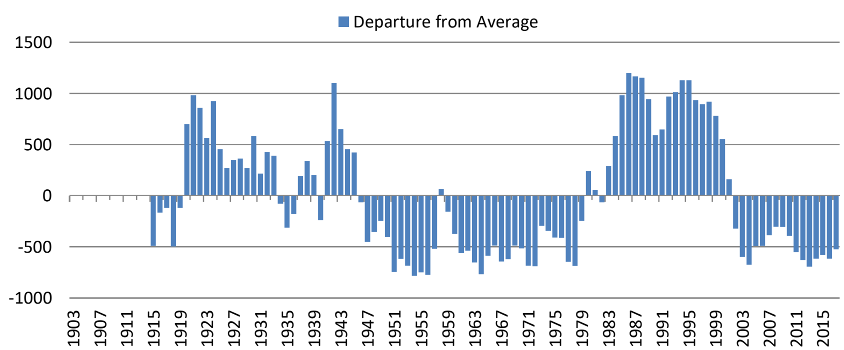
Total Monthly (Acre-Feet)



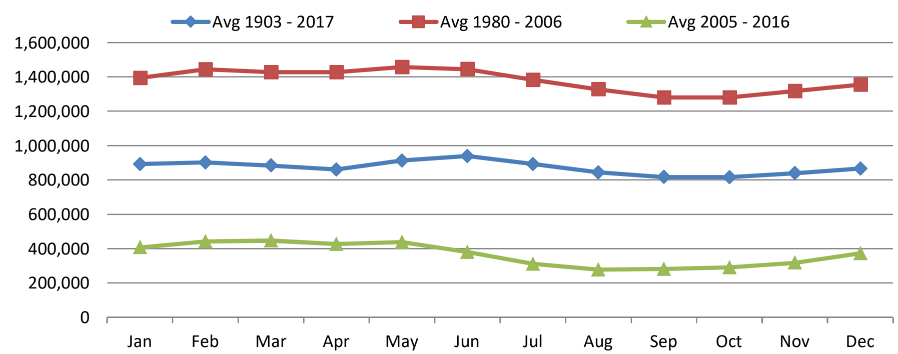
Average Annual (Acre-Feet)



Annual Departure from Average (1,000 Acre-Feet)



Average Monthly (Acre-Feet)



	Start	End
Period 1:	1980	2005
Period 2:	2006	2016

Rio Grande Project Data
Total Monthly
1903 - 2017
Elephant Butte Reservoir - EOM Storage (af)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1903	-	-	-	-	-	-	-	-	-	-	-	-	-
1904	-	-	-	-	-	-	-	-	-	-	-	-	-
1905	-	-	-	-	-	-	-	-	-	-	-	-	-
1906	-	-	-	-	-	-	-	-	-	-	-	-	-
1907	-	-	-	-	-	-	-	-	-	-	-	-	-
1908	-	-	-	-	-	-	-	-	-	-	-	-	-
1909	-	-	-	-	-	-	-	-	-	-	-	-	-
1910	-	-	-	-	-	-	-	-	-	-	-	-	-
1911	-	-	-	-	-	-	-	-	-	-	-	-	-
1912	-	-	-	-	-	-	-	-	-	-	-	-	-
1913	-	-	-	-	-	-	-	-	-	-	-	-	-
1914	-	-	-	-	-	-	-	-	-	-	-	-	-
1915	-	-	-	136,550	367,890	486,632	478,407	484,491	402,777	361,676	361,464	357,898	381,976
1916	376,729	404,182	428,720	548,812	782,142	892,476	830,592	804,299	784,972	791,536	922,836	907,032	706,194
1917	832,560	785,123	717,299	661,835	689,303	863,176	1,013,198	903,895	788,495	670,712	594,981	532,227	754,400
1918	547,635	559,781	511,797	474,957	450,386	439,873	384,231	311,714	241,473	184,845	181,063	204,340	374,341
1919	234,066	257,891	269,268	371,751	725,470	983,097	1,041,994	1,116,269	1,028,519	984,427	984,493	1,023,037	751,690
1920	1,048,041	1,092,057	1,118,203	1,129,648	1,301,624	1,927,910	2,117,216	2,002,281	1,889,982	1,765,478	1,739,264	1,726,000	1,571,475
1921	1,738,607	1,750,936	1,723,680	1,672,054	1,655,749	1,894,727	2,060,096	2,085,702	2,032,153	1,921,170	1,848,733	1,831,531	1,851,262
1922	1,843,129	1,823,533	1,790,172	1,746,224	1,785,227	1,961,690	1,937,144	1,775,978	1,652,981	1,549,459	1,467,714	1,452,932	1,732,182
1923	1,451,652	1,454,118	1,442,567	1,391,094	1,408,875	1,520,111	1,460,812	1,341,193	1,378,675	1,396,309	1,466,659	1,540,922	1,437,749
1924	1,576,982	1,588,634	1,584,584	1,666,323	1,987,807	2,190,542	2,089,009	1,956,357	1,791,118	1,743,460	1,701,393	1,677,284	1,796,124
1925	1,666,623	1,657,224	1,612,866	1,551,147	1,491,419	1,369,347	1,238,646	1,131,092	1,075,066	1,059,267	1,085,923	970,843	1,325,789
1926	1,006,087	1,026,937	1,028,559	1,016,256	1,173,079	1,408,994	1,363,977	1,259,034	1,147,670	1,110,180	1,090,672	1,093,233	1,143,723
1927	1,112,308	1,121,760	1,110,798	1,089,960	1,176,658	1,256,479	1,299,866	1,238,411	1,210,055	1,325,327	1,355,888	1,372,016	1,222,461
1928	1,401,859	1,418,723	1,403,741	1,332,825	1,356,110	1,435,850	1,301,433	1,160,474	1,057,731	990,567	974,731	974,988	1,234,086
1929	991,545	997,297	978,654	930,541	948,104	1,101,871	1,020,404	1,084,753	1,195,256	1,419,646	1,481,165	1,525,893	1,139,594
1930	1,553,960	1,573,137	1,572,366	1,551,150	1,616,811	1,581,901	1,467,992	1,443,418	1,332,472	1,267,177	1,251,443	1,263,329	1,456,263
1931	1,288,813	1,322,164	1,322,159	1,251,973	1,246,585	1,160,657	1,038,244	930,756	842,745	874,129	883,451	905,895	1,088,964
1932	945,357	980,399	1,023,182	1,086,211	1,293,752	1,566,525	1,615,050	1,515,739	1,434,354	1,382,277	1,376,389	1,384,520	1,300,313
1933	1,413,233	1,429,905	1,422,982	1,332,649	1,222,132	1,274,378	1,345,164	1,248,040	1,145,973	1,112,170	1,104,566	1,113,337	1,263,711
1934	1,147,508	1,157,996	1,131,726	1,044,865	951,711	832,774	704,608	568,294	504,807	493,580	493,216	497,139	794,019
1935	488,897	518,907	528,116	470,143	440,503	595,737	638,584	570,410	582,520	595,119	615,487	653,174	558,133
1936	692,874	723,693	736,932	714,330	853,555	831,987	718,219	609,816	547,620	578,884	614,470	649,171	689,296
1937	683,994	721,750	789,228	826,237	1,071,800	1,373,973	1,385,984	1,258,635	1,172,520	1,167,823	1,170,273	1,176,529	1,066,562
1938	1,206,184	1,222,171	1,204,239	1,113,487	1,172,397	1,262,783	1,310,135	1,225,397	1,209,440	1,215,139	1,226,823	1,177,123	1,212,110
1939	1,190,635	1,217,725	1,265,139	1,344,500	1,299,300	1,218,067	1,082,900	977,986	866,723	786,619	787,757	806,768	1,070,343
1940	839,200	874,700	886,700	789,700	732,700	625,400	522,300	451,000	429,900	447,500	470,100	488,500	629,808
1941	485,500	501,600	534,000	595,700	1,390,600	1,850,200	1,924,000	1,863,800	1,855,100	1,968,600	1,949,700	1,937,700	1,404,708
1942	1,906,900	1,875,000	1,885,000	2,116,700	2,235,900	2,252,900	2,055,300	1,968,600	1,930,900	1,878,300	1,814,200	1,780,500	1,975,017
1943	1,755,100	1,731,900	1,693,500	1,653,100	1,623,900	1,565,400	1,523,700	1,454,400	1,394,300	1,329,300	1,276,700	1,250,600	1,520,992
1944	1,219,500	1,199,800	1,173,000	1,141,400	1,339,000	1,511,600	1,503,800	1,450,500	1,393,000	1,364,500	1,323,400	1,290,600	1,325,842
1945	1,272,100	1,257,400	1,223,900	1,209,600	1,484,600	1,496,700	1,423,200	1,351,200	1,272,100	1,221,700	1,167,700	1,130,100	1,292,525

Rio Grande Project Data

Total Monthly

1903 - 2017

Elephant Butte Reservoir - EOM Storage (af)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1946	1,100,600	1,071,700	1,030,900	968,400	898,100	830,000	760,100	680,700	625,400	570,700	544,300	584,300	805,433
1947	557,300	537,600	507,400	446,100	461,300	405,600	341,100	324,900	316,900	309,900	366,400	435,500	417,500
1948	435,600	417,300	395,200	409,300	484,300	761,800	673,500	588,600	542,900	506,800	493,300	492,000	516,717
1949	496,100	517,300	530,500	508,300	570,700	709,900	793,300	746,800	714,000	663,900	639,800	621,000	625,967
1950	607,500	650,600	655,900	616,600	541,500	457,500	397,900	354,500	333,400	329,500	323,200	335,400	466,958
1951	303,900	293,200	248,800	192,200	166,400	106,600	53,200	27,700	19,400	22,900	26,700	36,500	124,792
1952	36,500	17,300	18,900	59,300	259,000	421,200	390,700	385,700	360,900	357,200	355,300	376,900	253,242
1953	351,600	311,800	277,400	232,300	228,700	209,200	162,800	109,600	88,500	90,600	93,900	110,600	188,917
1954	137,200	166,800	138,500	87,000	90,600	59,600	13,800	32,900	55,600	76,100	80,800	97,600	86,375
1955	125,100	150,300	141,100	121,100	131,900	97,600	73,000	120,800	112,300	122,800	130,400	155,000	123,450
1956	169,900	200,600	166,600	146,400	160,200	108,900	63,300	38,400	24,200	26,100	28,700	32,900	97,183
1957	47,300	68,400	64,300	50,200	160,600	267,400	381,000	509,300	556,100	635,900	731,500	776,100	354,008
1958	773,100	753,300	705,900	776,300	1,097,900	1,209,300	1,093,300	977,600	951,200	925,000	954,300	988,800	933,833
1959	977,100	943,700	890,900	844,500	808,500	741,300	621,800	576,400	532,800	517,500	549,300	586,400	715,850
1960	587,800	587,800	554,300	594,500	565,700	547,100	476,400	410,100	385,100	396,200	419,200	439,600	496,983
1961	452,200	409,500	335,700	321,900	371,800	334,700	249,700	185,600	201,600	208,000	285,800	360,900	309,783
1962	403,200	405,000	339,700	385,600	451,200	363,500	283,900	229,400	226,800	237,700	298,600	390,300	334,575
1963	432,800	420,500	392,400	338,600	268,400	217,200	130,200	66,500	78,800	80,200	93,500	112,000	219,258
1964	134,500	160,600	153,300	119,700	135,400	126,900	94,500	63,300	48,600	50,100	64,700	87,300	103,242
1965	125,800	159,000	144,800	154,600	288,700	366,900	337,800	287,800	298,300	327,600	412,900	517,200	285,117
1966	572,900	529,500	492,500	472,400	440,500	376,400	304,800	261,300	262,300	262,200	302,800	344,000	385,133
1967	363,400	347,800	268,200	215,200	180,700	179,800	134,100	160,200	188,500	190,200	227,500	267,100	226,892
1968	304,600	343,500	283,800	216,800	201,200	190,900	136,800	224,000	229,900	236,000	295,400	333,600	249,708
1969	382,100	406,200	364,000	352,200	435,100	467,400	363,000	253,800	274,000	346,800	443,800	528,200	384,717
1970	531,700	531,100	487,300	436,000	442,800	396,900	290,400	188,700	179,100	199,400	271,000	324,500	356,575
1971	367,800	361,100	316,500	289,000	221,200	154,000	98,400	47,300	35,400	64,500	128,000	177,000	188,350
1972	223,400	239,100	200,900	171,600	167,600	145,000	82,800	71,300	128,400	191,700	256,900	301,600	181,692
1973	343,400	384,400	366,100	386,700	551,900	675,900	699,100	705,300	663,800	671,800	706,600	794,200	579,100
1974	839,100	846,600	755,300	687,300	595,000	473,900	375,000	333,500	320,900	343,600	370,500	402,500	528,600
1975	427,800	463,700	425,800	371,300	434,800	468,800	479,700	411,900	462,100	463,700	528,500	617,200	462,942
1976	688,700	722,200	644,000	565,500	534,000	444,000	361,200	312,200	299,500	309,800	330,400	315,800	460,608
1977	317,100	342,000	350,900	347,800	304,500	219,500	136,100	120,900	123,600	127,800	148,300	181,400	226,658
1978	215,400	245,000	230,900	196,900	282,600	262,100	185,700	95,800	92,200	94,400	136,300	182,600	184,992
1979	228,600	280,000	295,800	310,600	494,700	691,600	840,400	844,400	839,400	834,300	907,900	943,500	625,933
1980	935,800	932,300	969,100	937,800	1,118,700	1,277,400	1,244,000	1,164,000	1,174,100	1,158,200	1,207,700	1,222,200	1,111,775
1981	1,205,200	1,183,900	1,201,300	1,115,800	990,700	872,800	799,500	765,900	754,000	758,000	745,700	725,300	926,508
1982	758,300	783,800	776,700	758,700	809,300	834,600	782,400	751,700	799,800	826,800	882,300	916,700	806,758
1983	942,200	932,600	1,015,700	968,400	1,092,300	1,293,700	1,337,300	1,271,700	1,236,400	1,251,800	1,269,900	1,322,700	1,161,225
1984	1,324,200	1,315,000	1,321,600	1,329,000	1,472,900	1,577,900	1,510,600	1,510,600	1,467,700	1,492,300	1,548,400	1,610,500	1,456,725
1985	1,619,500	1,607,100	1,665,400	1,838,000	1,965,600	2,010,900	1,983,400	1,892,000	1,846,900	1,909,400	1,930,300	1,955,700	1,852,017
1986	2,066,300	2,061,200	2,071,800	2,089,700	2,058,600	2,063,400	2,064,800	2,076,100	2,054,300	2,046,600	2,097,800	2,090,100	2,070,058
1987	2,045,900	2,082,400	2,087,100	2,063,000	2,069,200	2,052,100	2,065,600	2,017,800	1,961,000	1,957,500	1,995,200	2,043,400	2,036,683
1988	2,092,600	2,091,200	2,075,400	2,069,200	2,066,600	2,011,600	1,951,100	1,912,900	1,983,000	1,985,200	2,009,100	2,034,700	2,023,550

Rio Grande Project Data
Total Monthly
1903 - 2017
Elephant Butte Reservoir - EOM Storage (af)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1989	2,023,900	2,020,300	1,953,300	1,983,700	1,934,300	1,837,900	1,751,500	1,688,200	1,642,700	1,639,600	1,643,900	1,675,300	1,816,217
1990	1,709,400	1,738,600	1,653,200	1,592,500	1,534,800	1,428,900	1,342,700	1,303,500	1,254,400	1,274,900	1,327,200	1,369,600	1,460,808
1991	1,416,200	1,443,000	1,414,300	1,416,700	1,462,500	1,524,400	1,522,600	1,574,000	1,573,400	1,551,500	1,618,200	1,713,900	1,519,225
1992	1,770,100	1,803,100	1,758,400	1,850,700	2,004,800	1,984,400	1,881,400	1,821,800	1,776,000	1,778,000	1,807,100	1,855,100	1,840,908
1993	1,921,400	1,913,100	1,881,400	1,890,600	1,967,000	2,011,300	1,915,200	1,818,100	1,767,800	1,777,000	1,836,900	1,907,500	1,883,942
1994	1,954,700	1,990,500	2,003,000	2,026,800	2,019,200	2,019,600	1,985,900	1,984,800	1,986,200	1,974,500	2,019,900	2,038,700	2,000,317
1995	2,040,200	2,038,000	2,005,200	1,955,000	2,016,700	2,017,400	2,014,200	1,981,200	1,957,100	1,931,900	1,987,600	2,040,200	1,998,725
1996	2,033,300	2,042,000	2,004,500	1,946,200	1,858,200	1,763,900	1,686,600	1,642,700	1,646,100	1,655,100	1,687,000	1,718,100	1,806,975
1997	1,753,200	1,734,100	1,687,600	1,660,100	1,744,100	1,860,500	1,747,000	1,709,400	1,710,400	1,777,700	1,861,200	1,926,600	1,764,325
1998	1,974,500	1,976,300	1,925,900	1,886,800	1,933,300	1,847,000	1,744,100	1,650,700	1,598,800	1,599,700	1,658,800	1,698,000	1,791,158
1999	1,739,300	1,737,300	1,667,500	1,592,200	1,609,100	1,629,800	1,585,000	1,650,400	1,635,600	1,622,200	1,666,300	1,708,200	1,653,575
2000	1,738,300	1,678,500	1,623,400	1,565,700	1,516,000	1,429,700	1,351,700	1,264,200	1,198,900	1,207,700	1,246,600	1,285,000	1,425,475
2001	1,306,100	1,251,000	1,199,400	1,142,000	1,111,800	1,047,600	946,000	877,400	853,700	849,300	874,300	897,600	1,029,683
2002	915,100	893,800	824,800	742,500	647,900	541,800	436,900	344,600	305,300	289,500	315,700	350,100	550,667
2003	384,200	405,100	395,700	369,400	340,800	268,900	217,700	158,600	154,300	163,100	179,000	210,500	270,608
2004	244,000	272,100	223,800	279,500	322,900	246,500	144,300	111,800	96,400	109,000	139,700	193,200	198,600
2005	241,700	297,700	310,300	318,400	452,900	558,700	466,800	403,000	342,500	349,500	386,000	428,700	379,683
2006	468,800	498,900	452,900	385,800	305,100	218,000	189,000	331,600	351,800	397,500	460,300	514,000	381,142
2007	558,400	598,500	609,100	556,000	601,300	571,400	461,300	396,600	357,600	325,600	352,000	408,800	483,050
2008	454,700	481,900	495,300	535,900	614,500	625,500	626,100	573,100	590,200	582,300	606,900	648,800	569,600
2009	682,100	681,000	622,000	580,400	665,900	634,400	548,400	466,300	448,200	454,500	483,800	519,700	565,558
2010	561,500	567,100	540,600	542,500	600,100	530,400	444,300	383,100	365,900	372,500	392,900	437,200	478,175
2011	474,200	504,300	466,400	383,700	359,300	283,100	223,000	202,200	201,000	208,100	241,000	294,500	320,067
2012	331,900	367,000	385,800	372,200	366,100	266,400	177,400	111,800	113,100	114,200	123,000	161,100	240,833
2013	183,100	207,100	220,200	223,100	193,800	80,600	74,500	90,900	163,600	192,500	236,200	279,100	178,725
2014	312,279	340,567	361,672	363,603	363,174	225,985	133,865	154,007	172,132	183,553	212,607	256,371	256,651
2015	291,047	328,717	368,452	393,277	399,509	342,023	283,123	185,445	168,427	183,134	232,406	322,516	291,506
2016	361,137	401,906	407,188	334,873	310,490	298,204	189,470	132,194	132,016	128,708	160,745	202,454	254,949
2017	250,968	295,292	312,777	395,649	501,124	469,917	366,940	285,213	227,210	297,912	354,744	425,083	348,569
Avg	892,788	902,228	884,762	862,226	913,623	939,619	892,919	844,181	817,779	816,741	840,073	867,494	10,474,436

Appendix 4A
Example Water Distribution Reports
1950 and 1993

Form 7-322 (May 1937)

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

MONTHLY WATER DISTRIBUTION

Project Rincon Unit Area Irrigated 17651 Year 1950

QUANTITIES IN ACRE-FEET

MONTH	Diverted from Stream[1]	INFLOW FROM— Reservoirs[2]	INFLOW FROM— Other Sources	Delivered to Reservoirs[2]	Net Supply[3]	Total Waste	Total Losses	Delivered to Laterals[4]	Lateral Waste	Lateral Losses	DELIVERED TO FARMS[5] Total	DELIVERED TO FARMS[5] Per Acre
January,	0					0	0					
February,	(2,190)					(560)	--					
March,	(14,220)					(2,960)	7,011				5,879	.33
April,	11,870					2,270	2,202				7,398	.42
May,	13,050					2,280	4,258				6,512	.37
June,	12,380					1,940	3,937				6,503	.37
July,	7,570					1,440	993				5,137	.29
August,	20,180					2,150	8,168				9,862	.56
September,	7,880					950	183				6,747	.38
October,	0					0	0				0	
November,	0					0	0				0	
December,	0					0	0				0	
Total,	89,340					14,550	26,752				48,038	2.72
Acre ft. per acre,	5.06					0.82	1.52				2.72	
Per cent Net Supply,	100					16	30				54	

[1] Diversion amount exclusive of waste at head gates for sand sluicing, etc.
[2] Reservoirs connected with distributing system only.
[3] Diversions plus inflow from reservoirs and other sources less delivery to reservoirs.
[4] Measured at
[5] Measured at

Form 7-322 (May 1937)

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

MONTHLY WATER DISTRIBUTION

Revised 11-21-51

Project Leasburg Unit Area Irrigated 30,548 Year 1950

QUANTITIES IN ACRE-FEET

MONTH	Diverted from Stream[1]	INFLOW FROM— Reservoirs[2]	INFLOW FROM— Other Sources	Delivered to Reservoirs[2]	Net Supply[3]	Main Canal Waste	Total ~~Main Canal~~ Losses	Delivered to ~~Laterals~~[4] E. Side Canal	Total ~~Lateral~~ Waste	Lateral Losses	DELIVERED TO FARMS[5] Total	DELIVERED TO FARMS[5] Per Acre
January,	0					0	0	0	0			
February,	(3,250)					2,110	0	70	(2,180)			
March,	(28,150)					2,200	15,530	870	(3,070)		10,620	.35
April,	21,220					1,980	3,289	680	2,660		14,571	.48
May,	25,290					1,990	9,173	650	2,640		13,477	.44
June,	22,350					1,810	10,522	600	2,410		9,418	.31
July,	26,560					2,560	6,681	1,010	3,570		16,309	.53
August,	35,030					1,550	12,599	570	2,120		20,311	.66
September,	20,275					1,780	3,382	610	2,390		14,503	.48
October,	4,020					470	3,122	30	500		398	.01
November,	2,270					290	1,563	--	290		417	.01
December,	1,040					140	494	140	280		266	.01
Total,	189,455					16,880	67,055	5,230	22,110		100,290	3.28
Acre ft. per acre,	6.20					0.55	2.20	0.17	0.72		3.28	
Per cent Net Supply,	100					9	35	3	12		53	

[1] Diversion amount exclusive of waste at head gates for sand sluicing, etc.
[2] Reservoirs connected with distributing system only.
[3] Diversions plus inflow from reservoirs and other sources less delivery to reservoirs.

[4] Measured at

[5] Measured at

US_MSJ_00002512

Form 7-322 (May 1937)

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

MONTHLY WATER DISTRIBUTION

Project Mesilla Unit
Eastside and Westside Canals

Area Irrigated 54,019

Year 1950

QUANTITIES IN ACRE-FEET

MONTH	Diverted from Stream [1]	INFLOW FROM— Reservoirs [2]	Other Sources	From Leasburg Canal	Total Supply	Total Waste	Total Losses	Delivered to Laterals [4]	Lateral Waste	Lateral Losses	DELIVERED TO FARMS [5] Total	Per Acre
January,	0			0	0	0						
February,	1,320			70	(1,390)	(330)						
March,	42,910			870	(43,780)	(4,920)	20,614				19,306	.36
April,	33,450			680	34,130	3,870	5,360				24,900	.46
May,	36,060			650	36,710	3,700	10,971				22,039	.41
June,	35,200			600	35,800	3,650	17,032				15,118	.28
July,	42,250			1010	43,260	8,030	8,692				26,538	.49
August,	51,020			570	51,590	3,850	19,683				28,057	.52
September,	26,830			610	27,440	2,690	2,476				22,274	.41
October,	3,940			30	3,970	1,710	1,864				396	.01
November,	204			—	204	—	161				43	
December,	0			140	140	0	120				20	
Total,	273,184			5230	278,414	32,750	86,973				158,691	2.94
Acre ft. per acre,	5.06			0.10	5.15	0.61	1.61				2.94	
Per cent Net Supply,	98			2	100	12	31				57	

[1] Diversion amount exclusive of waste at head gates for sand sluicing, etc.
[2] Reservoirs connected with distributing system only.
[3] Diversions plus inflow from reservoirs and other sources less delivery to reservoirs.

[4] Measured at

[5] Measured at

Form 7-329 (May 1937)

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

MONTHLY WATER DISTRIBUTION

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Project Total Mesilla Valley Leasburg, Eastside and Westside Canals Area Irrigated 84,567 Year 1950

QUANTITIES IN ACRE-FEET

MONTH	Diverted from Stream[1]	Inflow from— Reservoirs[2]	Inflow from— Other Sources	Delivered to Reservoirs[2]	Net Supply[3]	Total Waste to River	Total Losses	Delivered to Laterals[4]	Lateral Waste	Lateral Losses	Delivered to Farms[5] Total	Delivered to Farms[5] Per Acre
January,	(0)					(0)	0				–	–
February,	(4,570)					(2,440)	0				–	–
March,	71,060					7,120	36,144				29,926	.35
April,	54,670					5,850	9,349				39,471	.47
May,	61,350					5,690	20,144				35,516	.42
June,	57,550					5,460	27,554				24,536	.29
July,	68,810					10,590	15,373				42,847	.51
August,	86,050					5,400	32,282				48,368	.57
September,	47,105					4,470	5,858				36,777	.43
October,	7,960					2,180	4,986				794	.01
November,	2,474					290	1,724				460	.01
December,	1,040					140	614				286	
Total,	462,639					49,630	154,028				258,981	3.06
Acre ft. per acre,	5.47					0.59	1.82				3.06	
Per cent Net Supply,	100					11	33				56	

[1] Diversion amount exclusive of waste at head gates for sand sluicing, etc.
[2] Reservoirs connected with distributing system only.
[3] Diversions plus inflow from reservoirs and other sources less delivery to reservoirs.

[4] Measured at

[5] Measured at

Form 7-32... (ay 1937)

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

MONTHLY WATER DISTRIBUTION

Project El Paso Valley Unit (Ysleta Division) Area Irrigated 56,486) 64) 56,550 Year 1950

QUANTITIES IN ACRE-FEET

MONTH	Diverted from Stream [1]	INFLOW FROM— Reservoirs [2]	Other Sources	Delivered to Reservoirs [2]	Net Supply [3]	Total Waste	Total Losses	Delivered to Laterals [4]	Lateral Waste	Lateral Losses	DELIVERED TO FARMS [5] Total	Per Acre
January,	0					0						
February,	(5,518)					(1,543)	--					
March,	(44,976)					(5,240)	26,506				17,205	.30
April,	50,600					6,315	8,661				35,624	.62
May,	39,116					5,382	9,922				23,812	.42
June,	43,662					4,475	14,880				24,307	.43
July,	43,578					8,885	11,641				23,052	.41
August,	51,564					3,674	15,614				32,276	.57
September,	27,919					7,458	1,962				18,499	.33
October,	12,789					5,055	4,515				3,219	.06
November,	9,177					4,952	2,614				1,611	.03
December,	6,530					3,062	2,069				1,399	.03
Total,	335,429					56,041	98,384				181,004	3.20
Acre ft. per acre,	5.93					0.99	1.74				3.20	
Per cent Net Supply,	100					17	29				54	

[1] Diversion amount exclusive of waste at head gates for sand sluicing, etc.
[2] Reservoirs connected with distributing system only.
[3] Diversions plus inflow from reservoirs and other sources less delivery to reservoirs.

[4] Measured at

[5] Measured at

Note: Tabulation does not include water delivered to City of El Paso Water Plant.

(Over)

US_MSJ_00002515

Form 7-322 (May 1937)

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Revised Jan. 2, 1952

MONTHLY WATER DISTRIBUTION

Project Rio Grande, New Mexico-Texas　　Area Irrigated 158,704) 64) 158,783 15)　　Year 1950

QUANTITIES IN ACRE-FEET

MONTH	Diverted from Stream [1]	INFLOW FROM— Reservoirs [2]	INFLOW FROM— Other Sources	Delivered to Reservoirs [2]	Net Supply [3]	Total Waste	Total Losses	Delivered to El Paso Water Plant	Lateral Waste	*Total Delivered	DELIVERED TO FARMS [4] Total	DELIVERED TO FARMS [4] Per Acre Irrigated
January,	0					0	–	0		0	–	–
February,	(12,278)					(4,543)	–	0		0	–	–
March,	(130,256)					(15,320)	69,661	117		53,127	53,010	.33
April,	117,140					14,435	20,212	855		83,348	82,493	.52
May,	113,516					13,352	34,324	961		66,801	65,840	.41
June,	113,592					11,375	46,371	1,094		56,440	55,346	.35
July,	119,958					20,915	28,007	871		71,907	71,03[illegible]	.45
August,	157,794					11,224	56,064	1,129		91,635	90,506	.57
September,	82,904					12,878	8,003	939		62,962	62,023	.39
October,	20,749					7,235	9,501	915		4,928	4,013	.03
November,	11,651					5,242	4,338	790		2,861	2,071	.01
December,	7,570					3,202	2,683	953		2,638	1,685	.01
Total,	887,408					120,221	279,164	8,624		496,647	488,023	3.07
Acre ft. per acre,	5.59					0.76	1.70	0.05		3.13	3.07	
Per cent Net Supply,	100					14	30	1		56	55	

[1] Diversion amount exclusive of waste at head gates for sand sluicing, etc.
[2] Reservoirs connected with distributing system only.
[3] Diversions plus inflow from reservoirs and other sources less delivery to reservoirs.
[4] Measured at
[5] Measured at

*Total delivered - charged to farms plus delivered to City of El Paso Water Treatment Plant (Over)
Revised May 13, 1954
Total losses computed on basis of farm deliveries instead of total deliveries.

US_MSJ_00002516

ID CODE 406000
FULL CROP PRODUCTION AND WATER UTILIZATION EBID 1994 RVMV94C

	MONTH	NET SUPPLY	OPERATIONAL SPILLS	TRANSPORTATION LOSSES	NONAGRICULTURAL DELIVERIES MUNICIPAL	MISCELLANEOUS	DELIVERED TO FARMS	ACRE FEET PER ACRE
	PART E			PROJECT WATER (Acre Feet)				
201	January							
202	February	27,765	8,428	9,889			9,448	0.32
203	March	65,770	11,283	18,852			35,635	0.92
204	April	56,233	13,614	14,318			28,301	0.81
205	May	56,454	15,031	12,144			29,279	0.86
206	June	84,403	15,810	23,659			44,934	1.18
207	July	91,864	20,017	21,955			49,892	1.22
208	August	79,692	18,629	22,288			38,775	0.99
209	September	55,663	15,066	16,307			24,290	0.61
210	October	31,450	12,586	5,393			13,471	0.34
211	Novermber							
212	December							
213	TOTAL PART	549,294	130,464	144,805			274,025	3.56
214	M & I POPULATION							
	PART F			NONPROJECT WATER (Acre Feet)				
216	Annual Data							
217	TOTAL E & F							

PART G ANNUAL OPERATION, MAINTENANCE AND REPLACEMENT COSTS (Whole Dollars)

	WORKS OPERATED BY	AGRICULTURAL (13-21)	MUNICIPAL & INDUSTRIAL (22-30)	OTHER (31-39)	TOTAL ALL FUNCTIONS
221	Bureau	155,626			155,626
222	Water Users	4,013,906			4,013,906
223	TOTAL COSTS	4,169,532			4,169,532

ID CODE 406020
FULL CROP PRODUCTION AND WATER UTILIZATION EPCWID#1 1994 EP94C

	MONTH	NET SUPPLY	OPERATIONAL SPILLS	TRANSPORTATION LOSSES	NONAGRICULTURAL DELIVERIES MUNICIPAL	MISCELLANEOUS	DELIVERED TO FARMS	ACRE FEET PER ACRE
	PART E			PROJECT WATER (Acre Feet)				
201	January	6,837	329	4,492			2,016	0.04
202	February	17,098	2,045	11,789	892		3,264	0.06
203	March	46,374	6,246	14,568	4,499		25,560	0.47
204	April	29,952	8,864	7,163	6,483		13,925	0.26
205	May	30,119	3,271	12,622	7,883		14,226	0.26
206	June	49,421	14,259	6,224	8,157		28,938	0.54
207	July	60,204	9,414	17,827	7,303		32,963	0.61
208	August	53,764	4,169	18,789	7,505		30,806	0.57
209	September	37,989	7,842	13,105	6,350		17,042	0.32
210	October	33,061	20,650	9,461	6,647		2,950	0.05
211	November							
212	December							
213	TOTAL PART	364,819	77,089	116,040	55,719		171,690	3.18
214	M & I POPULATION SERVED				520,000			
	PART F			NONPROJECT WATER (Acre Feet)				
216	Annual Data							
217	TOTAL E & F							

PART G ANNUAL OPERATION, MAINTENANCE AND REPLACEMENT COSTS (Whole Dollars)

	WORKS OPERATED BY	AGRICULTURAL (13-21)	MUNICIPLE & INDUSTRIAL (22-30)	OTHER (31-39)	TOTAL ALL FUNCTIONS
221	Bureau	125,036			125,036
222	Water Users	166,610			166,610
223	TOTAL COSTS	291,646			291,646

D CODE 406030
UPP CROP PRODUCTION & WATER UTILIZATION HUDSPETH COUNTY HC94C

	MONTH	NET SUPPLY +	OPERATIONAL SPILLS	TRANSPORTATION LOSSES *	NONAGRICULTURAL DELIVERIES MUNICIPAL	MISCELLANEOUS	DELIVERED TO FARMS	ACRE FEET PER ACRE
	PART E			PROJECT WATER (Acre Feet)				
201	January	5,312		5,312				
202	February	9,788		7,628			2,160	0.13
203	March	16,155		7,184			8,971	0.53
204	April	15,620		11,822			3,738	0.22
205	May	11,282		8,390			2,892	0.17
206	June	16,455		6,547			9,908	0.58
207	July	18,978		5,818			13,160	0.77
208	August	15,374		1,694			13,680	0.80
209	September	16,790		11,640			5,150	0.30
210	October	12,928		12,928				
211	Novermber							
212	December	-						
213	TOTAL PART	138,682		78,963			59,659	3.49
214	M & I POPULATION							
	PART F			NONPROJECT WATER (Acre Feet)				
216	Annual Data							
217	TOTAL E & F							

PART G ANNUAL OPERATION, MAINTENANCE AND REPLACEMENT COSTS (Whole Dollars)

	WORKS OPERATED BY	AGRICULTURAL (13-21)	MUNICIPAL & INDUSTRIAL (22-30)	OTHER (31-39)	TOTAL ALL FUNCTIONS
221	Bureau				
222	Water Users	662,000			662,000
223	TOTAL COSTS	662,000			662,000

* THIS COLUMN INCLUDES OPERATIONAL SPILLS FOR WHICH NO DATA IS AVAILABLE
\+ THIS COLUMN INCLUDES FLOWS THRU RECORDER STATIONS AND ESTIMATED DIVERSIONS FROM RIVER

Appendix 4B
El Paso Valley Unit
Diversions and Waste Notes from Water Distribution Reports

Appendix 4B
El Paso Valley Unit
Diversions and Waste Notes from Water Distribution Reports

1919:

[1]Measured at *1 [2]Measured at [3]Measured at Measured at

REMARKS: *1 Monthly deliveries to farms per acre apply to areas irrigated each month; No estimate for March; Apr. - 15,240 acres; May 15,588; June 18,114; July 14,926; Aug. 17,195; Sept. 8,226; Oct. 220; Nov. 1,198; During last months of year the irrigated acreage was reported each month by ditchriders. *2. This flow includes wasteways: - Montoyo, Escarate, River, Clint Lateral, Salatral Lateral, San Elizario Wasteways No. 2, 3 and 4. Of this flow that of the Montoyo and Escarate Wasteways join the flow that is available for diversion to the El Paso Valley system. The remainder is available for diversion to the Independent Tornillo Irrigation District.

Remarks: Under acre feet tabulation apply here.

1920:

[1]Measured at Montoya Headgate, Mexican Dam, San Elizario Headgate [2]Measured at Lateral Headgates [3]Measured at Farm Tap Boxes Measured at

REMARKS: *5 Some wasted into the Rio Grande above Canal intakes, the rest wasted past the end of the Project.
*7 Areas irrigated per month as follows:

Jan.	201	ac.	Apr.	16,548	ac.	July	21,192	ac.	Oct.	4,989	ac.
Feb.	724	"	May	19,270	"	Aug.	15,508	"	Nov.	687	"
Mar.	8,555	"	June	16,052	"	Sept.	10,891	"	Dec.	1,146	"

*8 Not including Tornillo, Ft Hancock nor uncontracted part of Island

1921:

Remarks: *1 To Project only

[1] Measured at River intakes of canals [2] Measured at Lateral Headings [3] Measured at Farm Tap Boxes and Community Ditch Headings Measured at

REMARKS:

1923:

[1] Measured at Headgates [2] Measured at [3] Measured at Farm tap boxes Measured at

REMARKS: Island extension, Hanson and Tornillo included in 1923 report, increased portion of project.

1931:

[1] Diversion amount exclusive of waste at head gates for sand sluicing, etc.
[2] Reservoirs connected with distributing system only.
[3] Diversions plus inflow from reservoirs and other sources less delivery to reservoirs.

[4] Measured at
[5] Measured at

* Includes 4357 leaching water.
** Figures expressed three significant figures.

1933:

[1] Diversion amount exclusive of waste at head gates for sand sluicing, etc.
[2] Reservoirs connected with distributing system only.
[3] Diversions plus inflow from reservoirs and other sources less delivery to reservoirs.

[4] Measured at
[5] Measured at

*Acre-feet delivered to farms include 4055 acre-feet of leaching water.
Diversion does not include 79,500 acre-feet diverted at Fabens to make delivery to Hudspeth Canal of 67091 acre feet (The difference of the two figures representing canal loss)

1934:

[1] Diversion amount exclusive of waste at head gates for sand sluicing, etc.
[2] Reservoirs connected with distributing system only.
[3] Diversions plus inflow from reservoirs and other sources less delivery to reservoirs.

[4] Measured at
[5] Measured at

GOVERNMENT PRINTING OFFICE 6—7283

Note: Above diversion does not include water diverted at Fabens in Tornillo Canal for delivery to Hudspeth Canal.

1937:

GOVERNMENT PRINTING OFFICE 6--7283

Waste water diverted at Fabens to deliver water to Hudspeth Canal is not included in above diversions.

1938:

Diversions:
Franklin
Riverside

Wasteways:
Acequia te
Riverside 1 & 2

Lateral
Point to

and Tornillo

1939:

Diversion
Riverside)
Franklin)
Plus drain water diverted) Mimus Hudspeth

River and to waste channel below Fabens
Waste channel below Tornillo Canal less dr.flo
Waste to drains on Island and Tornillo Dist.

1940:

Diversions:
Franklin ✓)
Riverside ✓) Mimus Hudspeth
Drain Water in) .85
Tornillo Canal

Waste: To River above Island Station
To River and to Waste Channel below Waste Channel Station
Waste Channel below Tornillo Canal less drain flow
Waste to Drains on Island and Tornillo Dist.

1941:

* Diversions plus inflow from reservoirs and other sources less delivery to reservoirs.

Diversions:
Franklin) Less sluicing
Riverside) waste at
Riverside 1 & 2

Waste: Acequia te
Total from Island
Total below Island
Hudspeth Canal

To Waste Channel from Tornillo Canal

1942:

* Diversions plus inflow from reservoirs and other sources less delivery to reservoirs.

Diversions
Franklin) Less sluicing waste at
Riverside) Riverside 1 & 2

Waste: Acequia te
Total from Island
Total below Island

Hudspeth Canal
To Waste Channel from
Tornillo Canal to drains
above Fabens

1943:

Diversions:

GOVERNMENT PRINTING OFFICE

Franklin Canal
Riverside Canal Less Riverside W. W. 1&2

1944:

* Diversions plus inflow from reservoirs and other sources less delivery to reservoirs.

GOVERNMENT PRINTING OFFICE 6—7283

Waste
Waste Above Island T-216
Hudspeth Canal T-520
End Tornillo Canal T-1
Waste from Island Waste in W. Channel

* Measured at

Diversions: Franklin and Riverside Canals less Riverside W. W. 1&2 (Sluiceways)

1945:

Diversions: Franklin and Riverside Canals less Riverside W. W. 1&2 (Sluice Ways)

GOVERNMENT PRINTING

1946:

Diversions: Franklin and Riverside Canals plus Riverdrain to canal at Fabens less Riverside W. W. 1 and 2 (Sluceways)

1947:

GOVERNMENT PRINTING OFFICE 6—7283

*Figures in this column are based on measurements, others are estimates.

Diversions: Franklin & Riverside Canals plus drain to Canal at Fabens less Riverside W.W. 1 & 2 (Sluiceways)

Wasteways . . . .

Ascarate
Total from Island
Residual Waste Fabens
Tornillo No. 1
Tornillo No. 2 (Tornillo Canal at Alamo Alto after May 20, 1947)
Hudspeth Canal (Hudspeth Feeder No. 1 after May 20, 1947)
T-520
T-216

Residual Waste equals Waste Channel minus Waste Drains above Fabens
(On basis of daily data)

1948:

*Figures do not include water delivered to El Paso water treatment plant.

1949:

Note: Figures do not include water delivered to El Paso Water Treatment Plant. This water to the city is pumped from canal above diversion for irrigation.

1950:

Note: Tabulation does not include water delivered to City of El Paso Water Plant.

1951:

[1] Diversion amount exclusive of waste at head gates for sand sluicing, etc.
[2] Reservoirs connected with distributing system only.
[3] Diversions plus inflow from reservoirs and other sources less delivery to reservoirs.
[4] Measured at ___

NOTE: TABULATION DOES NOT INCLUDE WATER DELIVERED TO CITY OF EL PASO WATER TREATMENT PLANT.
(OVER)

1953:

1/ Does not include "Pumped from Drains".
Revised May 13, 1954

1954:

1/ Does not include watdr pumped from drains.

1964:

1/ Does not include water pumped from drains.

1965:

1/ No water pumped from drains during 1965.

Note: River operation in no manner is reflected in this tabulation. All figures are the result of summations of operating records of the Rincon, Leasburg, Mesilla and Ysleta Units of the Project and in no manner do any of the figures represent loss from the river.

The only measured quantities on this tabulation are the "Diverted from Stream" and "City of El Paso Water Treatment Plant." All other data estimated except "Charged to Farms" which is based on spot current measurements and individual farm deliveries.

The City of El Paso owns 2,000 acres of water right land on the Project and also obtains the water rights of land classified under the contract between the City and the El Paso County Water Improvement District No. 1 of December 20, 1962, No. 14-06-500-762. This land is withdrawn from Project irrigation, and water deliveries are made to the City of El Paso Water Treatment Plant.

1966:

[illegible] drains [illegible]

Note: River operation in no manner is reflected in this tabulation. All figures are the result of summations of operating records of the Rincon, Leasburg, Mesilla and Ysleta Units of the Project and in no manner do any of the figures represent loss from the river.

The only measured quantities on this tabulation are the "Diverted from Stream" and "City of El Paso Water Treatment Plant." All other data estimated except "Charged to Farms" which is based on spot current measurements and individual farm deliveries.

The City of El Paso owns 2,000 acres of water right land on the Project, and also obtains the water rights of land classified under contract between the City and the El Paso County Water Improvement District No. 1 of December 20, 1962, No. 14-06-500-762. This land is withdrawn from Project Irrigation, and water deliveries are made to the City of El Paso Water Treatment Plant.

1967:

1/ No water pumped from drains during 1967.

1968:

1 Diversion amount exclusive of waste at head gates for sand sluicing, etc.
2 Reservoirs connected with distributing system only.
3 Diversions plus inflow from reservoirs and other sources less delivery to reservoirs.
4 Do not include power.

a Measured at ______

b Measured at ______

GPO 840834

1/ No water pumped from drains during 1968

NOTE: River operation in no manner is reflected in this tabulation. All figures are the result of summations of operating records of the Rincon, Leasburg, Mesilla and Ysleta Units of the Project and in no manner do any of the figures represent loss from the river.

The only measured quantities on this tabulation are the "Diverted from Stream" and "City of El Paso Water Treatment Plant." All other data estimated except "Charged to Farms" which is based on spot current measurements and individual farm deliveries.

The City of El Paso owns 2,000 acres of water right land on the Project, and also obtains the water rights of land classified under contract between the City and the El Paso County Water Improvement District No. 1 of December 20, 1962, No. 14-06-500-762. This land is withdrawn from Project Irrigation, and water deliveries are made to the City of El Paso Water Treatment Plant.

1969:

1 Diversion amount exclusive of waste at head gates for sand sluicing, etc.
2 Reservoirs connected with distributing system only.
3 Diversions plus inflow from reservoirs and other sources less delivery to reservoirs.
4 Do not include power.

a Measured at ______

b Measured at ______

GPO 840534

1/ No water was pumped from drains during 1969.

1970:

1 Diversion amount exclusive of waste at head gates for sand sluicing, etc.
2 Reservoirs connected with distributing system only.
3 Diversions plus inflow from reservoirs and other sources less delivery to reservoirs.
4 Do not include power.

1/ No water pumped from drains during 1970

1971:

1 Diversion amount exclusive of waste at head gates for sand sluicing, etc.
2 Reservoirs connected with distributing system only.
3 Diversions plus inflow from reservoirs and other sources less delivery to reservoirs.
4 Do not include power.

1/ No water pumped from drains during 1971.

1972:

1 Diversion amount exclusive of waste at head gates for sand sluicing, etc.
2 Reservoirs connected with distributing system only.
3 Diversions plus inflow from reservoirs and other sources less delivery to reservoirs.
4 Do not include power.
1/ No water pumped from drains during 1972.

1973:

1 Diversion amount exclusive of waste at head gates for sand sluicing, etc.
2 Reservoirs connected with distributing system only.
3 Diversions plus inflow from reservoirs and other sources less delivery to reservoirs.
4 Do not include power.

a Measured at ______
b Measured at ______

☆ U.S. GOVERNMENT PRINTING OFFICE: 1972 782 100/167 REGION NO. 8

1/ No water pumped from drains during 1973

1974:

1 Diversion amount exclusive of waste at head gates for sand sluicing, etc.
2 Reservoirs connected with distributing system only.
3 Diversions plus inflow from reservoirs and other sources less delivery to reservoirs.
4 Do not include power.

a Measured at ______
b Measured at ______

☆ U.S. GOVERNMENT PRINTING OFFICE: 1972 782 100/167 REGION NO. 8

*Less than 0.01
1/ No water pumped from drains during 1974.

1975:

1 Diversion amount exclusive of waste at head gates for sand sluicing, etc.
2 Reservoirs connected with distributing system only.
3 Diversions plus inflow from reservoirs and other sources less delivery to reservoirs.
4 Do not include power.

a Measured at ______
b Measured at ______

GPO 840534

1/ No water pumped from drains during 1975.

1976:

1 Diversion amount exclusive of waste at head gates for sand sluicing, etc.
2 Reservoirs connected with distributing system only.
3 Diversions plus inflow from reservoirs and other sources less delivery to reservoirs.
4 Do not include power.

a Measured at ______
b Measured at ______

1/ No water pumped from drains during 1976.

1977:

1 Diversion amount exclusive of waste at head gates for sand sluicing, etc.
2 Reservoirs connected with distributing system only.
3 Diversions plus inflow from reservoirs and other sources less delivery to reservoirs.
4 Do not include power.

1/ No water pumped from drains during 1977

1978:

1 Diversion amount exclusive of waste at head gates for sand sluicing, etc.
2 Reservoirs connected with distributing system only.
3 Diversions plus inflow from reservoirs and other sources less delivery to reservoirs.
4 Do not include power.

a Measured at ______
b Measured at ______

☆ U.S. GOVERNMENT PRINTING OFFICE: 1972 782 100/167 REGION NO. 8

* Less than 0.01

1/ No water pumped from drains during 1978.

There are no notes for the years not listed (1918, 1922, 1924 – 1930, 1932, 1935 – 1936, 1952, and 1955 – 1963).

Appendix 4C
Example Allotment and Allocation Records
Various Years 1951 – 2015

from US BOR Presentation TCEQ_BOR_121103.ppt, obtained from Bert Cortez in 2004

WTreers
05/01/02

RIO GRANDE PROJECT
ALLOCATION OF PROJECT WATER SUPPLY

YEAR	INITIAL ALLOTMENT TO PROJECT LANDS (acre-foot/acre)	FINAL ALLOTMENT TO PROJECT LANDS (acre-foot/acre)	INITIAL ALLOTMENT TO PROJECT CANAL HEADINGS (acre-feet)	FINAL ALLOTMENT TO PROJECT CANAL HEADINGS (acre-feet)	MEXICO DIVERSION AT ACEQUIA MADRE HEADING (acre-feet) *	INITIAL RELEASE DATE FROM CABALLO DAM
1951	1.00	1.75			33,059	03/06
1952	0.21	2.50			49,890	03/20
1953	1.00	1.90			37,760	03/10
1954	0.42	0.50			10,147	03/20
1955	0.21	0.42			8,185	03/20
1956	0.33	0.39			7,864	03/18
1957	0.10	1.17			23,290	03/20
1958	1.75	**4.00**			60,050	03/01
1959	3.00	**3.50**			60,110	03/02
1960	2.25	**3.25**			60,320	03/02
1961	1.25	2.45			48,610	03/10
1962	1.75	**3.25**			60,057	03/05
1963	1.85	2.00			39,693	03/05
1964	0.25	0.33			6,653	03/15
1965	0.17	1.85			36,658	03/20
1966	1.75	2.50			49,618	03/05
1967	1.25	1.50			29,829	02/27
1968	1.00	2.00			39,677	02/27
1969	1.25	**3.00**			59,884	02/27
1970	2.00	**3.00**			60,065	02/23
1971	1.50	1.75			34,847	02/26
1972	0.60	0.80			16,077	03/01
1973	1.00	**3.00**			60,000	03/09
1974	3.00	**3.00**			60,050	03/02
1975	1.00	**3.00**			60,052	01/24
1976	2.50	**3.00**			60,172	01/16
1977	1.00	1.25			24,824	03/03
1978	0.25	0.75			14,903	03/10
1979	0.67	**3.00**		**790,000**	60,055	03/08
1980	0.67	**3.00**		**790,000**	60,033	01/17
1981	3.00	**3.00**	**750,650**	**750,650**	60,262	02/04
1982	3.00	**3.00**	**790,000**	**790,000**	59,257	01/27
1983	3.00	**3.00**	**790,000**	**790,000**	60,621	02/03
1984	3.00	**3.00**	**902,000**	**902,000**	58,588	02/09
1985			**902,000**	**902,000**	60,276	02/20
1986			**902,000**	**902,000**	66,163	04/01
1987			**902,000**	**902,000**	65,866	02/03
1988			**902,000**	**902,000**	61,935	01/20
1989			**890,900**	**890,900**	58,854	02/13
1990			**931,841**	**931,841**	58,353	02/12
1991			**931,841**	**931,841**	59,242	02/19
1992			**931,841**	**931,841**	58,080	01/09
1993			**931,841**	**931,841**	63,763	01/12
1994			**931,841**	**931,841**	60,167	01/11
1995			**931,841**	**931,841**	63,618	01/17
1996			**931,841**	**931,841**	60,063	01/12
1997			**931,841**	**931,841**	59,442	01/21
1998			**931,841**	**931,841**	60,628	01/16
1999			**931,841**	**931,841**	58,308	01/27
2000			**931,841**	**931,841**	60,611	01/20
2001			**931,841**	**931,841**	61,037	02/02
2002			738,139	**931,841**		02/19

bold number means full irrigation supply for Rio Grande Project water users.

* derived from International Boundary & Water Commission (IBWC) - U. S. Section, Yearly Flow Data Publications.

From US BOR Presentation mtg_200902Mexico_IBWC_EBID_EP1.pdf page 50

WTreers
03/05/2008

RIO GRANDE PROJECT HISTORICAL ALLOCATION OF PROJECT WATER SUPPLY

YEAR	EO FEB. TOTAL RIO GRANDE PROJECT STORAGE (acre-feet)	SAN MARCIAL SPRING RUNOFF (Mar-Jul) (acre-feet)	INITIAL ALLOTMENT TO PROJECT LANDS (acre-foot/acre)	FINAL ALLOTMENT TO PROJECT LANDS (acre-foot/acre)	INITIAL ALLOTMENT TO PROJECT CANAL HEADINGS (acre-feet)	FINAL ALLOTMENT TO PROJECT CANAL HEADINGS (acre-feet)	EO OCT. TOTAL RIO GRANDE PROJECT STORAGE (acre-feet)	MEXICO DIVERSION AT ACEQUIA MADRE HEADING (acre-feet) *	INITIAL RELEASE DATE FROM CABALLO DAM	CABALLO DAM TOTAL YEARLY RELEASE (acre-feet)
1951	452,730	17,877	1.00	1.75			32,900	33,059	03/06	469,450
1952	103,920	832,160	0.21	2.50			370,950	49,890	03/20	543,975
1953	468,600	143,170	1.00	1.90			99,990	37,760	03/10	528,628
1954	184,460	76,720	0.42	0.50			91,480	10,147	03/20	244,165
1955	169,850	68,920	0.21	0.42			129,700	8,185	03/20	219,157
1956	212,180	59,885	0.33	0.39			31,040	7,864	03/18	246,140
1957	77,130	600,680	0.10	1.17			645,760	23,290	03/20	397,103
1958	857,510	988,030	1.75	**4.00**			1,007,170	60,050	03/01	737,125
1959	1,185,120	72,590	3.00	**3.50**			575,670	60,110	03/02	687,414
1960	713,550	410,900	2.25	**3.25**			405,820	60,320	03/02	705,162
1961	492,870	269,550	1.25	2.45			223,080	48,610	03/10	561,697
1962	486,570	448,250	1.75	**3.25**			269,580	60,057	03/05	651,941
1963	513,170	116,765	1.85	2.00			109,440	39,693	03/05	517,172
1964	194,790	67,930	0.25	0.33			58,670	6,653	03/15	206,085
1965	172,340	598,290	0.17	1.85			340,940	36,658	03/20	505,598
1966	627,430	328,380	1.75	2.50			312,910	49,618	03/05	610,341
1967	454,710	74,090	1.25	1.50			223,340	29,829	02/27	456,517
1968	386,860	238,560	1.00	2.00			277,530	39,677	02/27	505,691
1969	466,970	358,710	1.25	**3.00**			387,410	59,884	02/27	667,669
1970	614,620	257,960	2.00	**3.00**			223,870	60,065	02/23	661,125
1971	435,640	112,837	1.50	1.75			75,540	34,847	02/26	498,375
1972	283,380	77,630	0.60	0.80			258,910	16,077	03/01	260,911
1973	457,960	914,090	1.00	**3.00**			707,340	60,000	03/09	617,461
1974	915,650	95,430	3.00	**3.00**			376,650	60,050	03/02	640,843
1975	507,700	617,850	1.00	**3.00**			534,490	60,052	01/24	580,617
1976	762,230	204,260	2.50	**3.00**			353,910	60,172	01/16	679,676
1977	482,460	43,374	1.00	1.25			140,460	24,824	03/03	416,498
1978	268,220	248,610	0.25	0.75			112,160	14,903	03/10	356,167
1979	328,690	1,148,880	0.67	**3.00**		**790,000**	855,640	60,055	03/08	568,687
1980	1,080,400	861,894	3.00	**3.00**		**790,000**	1,178,400	60,033	01/17	658,688
1981	1,339,860	54,256	3.00	**3.00**	**750,650**	**750,650**	774,380	60,262	02/04	608,166
1982	878,660	548,573	3.00	**3.00**	**790,000**	**790,000**	866,140	59,257	01/27	635,642
1983	1,070,130	920,545	3.00	**3.00**	**790,000**	**790,000**	1,289,750	60,621	02/03	648,386
1984	1,424,200	831,291	3.00	**3.00**	**902,000**	**902,000**	1,515,500	58,588	02/09	653,150
1985	1,747,700	1,133,599			**902,000**	**902,000**	2,121,600	60,276	02/20	677,398
1986	2,322,200	812,686			**902,000**	**902,000**	2,290,800	66,163	04/01	1,396,165
1987	2,336,900	1,003,319			**902,000**	**902,000**	2,168,400	65,866	02/03	1,376,099
1988	2,383,900	419,098			**902,000**	**902,000**	2,060,100	61,935	01/20	838,008
1989	2,151,900	378,144			**890,900**	**890,900**	1,705,300	58,854	02/13	736,866
1990	1,801,000	159,213			**931,841**	**931,841**	1,319,400	58,353	02/12	680,107
1991	1,509,680	656,638			**931,841**	**931,841**	1,580,080	59,242	02/19	625,956
1992	1,830,380	745,950			**931,841**	**931,841**	1,802,720	58,080	01/09	734,982
1993	1,980,230	742,508			**931,841**	**931,841**	1,978,640	63,763	01/12	823,263
1994	2,155,890	852,845			**931,841**	**931,841**	2,003,860	60,167	01/11	893,384
1995	2,203,730	991,736			**931,841**	**931,841**	2,083,050	63,618	01/17	1,096,146
1996	2,263,420	131,980			**931,841**	**931,841**	1,689,550	60,063	01/12	774,335
1997	1,814,910	600,686			**931,841**	**931,841**	1,814,980	59,442	01/21	798,621
1998	2,036,000	447,172			**931,841**	**931,841**	1,636,860	60,628	01/16	808,661
1999	1,803,410	384,225			**931,841**	**931,841**	1,658,810	58,308	01/27	735,467
2000	1,804,980	159,000			**931,841**	**931,841**	1,243,900	60,611	01/20	751,373
2001	1,359,370	241,000			**931,841**	**931,841**	856,910	61,037	02/02	786,549
2002	974,610	61,095			738,139	**931,841**	323,190	60,324	02/19	801,147
2003	456,140	62,029			74,860	317,495	170,490	26,948	03/17	364,528
2004	288,480	240,367			43,667	353,944	128,010	27,613	03/12	398,612
2005	331,000	738,095			138,549	**931,841**	362,060	58,091	03/09	676,031
2006	517,170	92,621			351,560	472,426	436,950	27,112	03/08	434,228
2007	644,990	316,979			369,466	760,391	346,170	51,245	03/07	636,730

bold number means full irrigation supply for Rio Grande Project water users.

From USBR "Annual Operating Plan 1984 Operations, 1985 Outlook"

United States Department of the Interior

BUREAU OF RECLAMATION

RIO GRANDE PROJECT
109 N. OREGON STREET P.O. DRAWER P
EL PASO, TEXAS 79952-0002

IN REPLY REFER TO: 410

DEC 19 1984

Mr. Bill Saad, Treasurer-Manager
Elephant Butte Irrigation District
PO Drawer A
Las Cruces, NM 88001

Dear Mr. Saad:

The allocation of Rio Grande Project water for 1985 is 100%.

The following amounts have been determined available for diversion at the headings:

Mexico	60,000 AF
EBID	478,037 AF
EPCWID	363,963 AF

Sincerely,

Roger K. Patterson
Project Superintendent

cc: IBWC

From USBR "Annual Operating Plan 1984 Operations, 1985 Outlook"

D. Crop Production and Water Utilization

1. Project

a. The initial release of water from Caballo Reservoir for the irrigation season was made on February 9, 1984. A full allotment of 902,000 AF was declared available for Mexico and the U.S. Districts on February 4, 1984. A total amount of 653,153 AF was released from storage during 1984 to satisfy water user orders. A gross amount of 761,141 AF was delivered at the diversion points within the project. The Caballo Dam was closed on October 3, 1984 ending the irrigation season.

b. Of the 159,650 acres of water right land for the U.S. Districts, 90,640 acres are allocated to the EBID and 69,010 acres are allocated to the EPCWID. A total acreage of 126,395 acres were in production for an overall crop value of $111,679,417. An average crop value for all crops grown by the U.S. Districts amounted to $884 per acre. (Crop value information is from preliminary data.)

2. EBID

a. Of the EBID 90,640 acres of water right land, 79,201 acres were irrigated during 1984. The district had 1305 full time and 1071 part time farms operating during the year. The district utilized a gross total of 411,128 AF of their allocated 478,037 AF of irrigation water during the year.

b. Crop production realized in the Rincon and Mesilla Valleys, for all crops, amounted to $81,121,835 (estimated), not including multiple crops. The average crop value was $1,024 per acre.

c. The major crops grown in Rincon and Mesilla Valley were:

(1) Vegetables (17,260 acres) (peppers, onions and lettuce)	$40,908,329
(2) Pecans (13,160 acres)	$17,849,734
(3) Forage (24,355 acres) (alfalfa and silage)	$11,973,014
(4) Field Crops (18,510 acres) (cotton)	$ 9,789,041 (Estimate)

3. EPCWID

a. Of the 69,010 acres of water right land, 47,194 acres were irrigated during 1984. The district had 705 full time and 1202 part time farms operating during the year. The district utilized a gross total of 289,976 AF of their allocated 363,963 AF of irrigation water during 1984.

b. Crop production realized in the El Paso Valley and Upper Valley (Texas), for all crops, amounted to $30,557,582 not including multiple crops. The average crop value was $647 per acre.

c. The major crops grown were:

(1) Field crops (23,105 acres) (cotton)	$17,514,415
(2) Pecans (5,031 acres)	4,851,142
(3) Forage (11,003 acres) (alfalfa, pasture and silage)	4,168,411
(4) Cereals (10,082 acres) (wheat, sorghums, oats, corn and barley)	3,640,520

mtg_200709Mexico_IBWC_EBID_EP1.pdf

2007 Rio Grande Project Allocation

Updated Allocation - End of August, 2007

(letter issued September 18, 2007)

Mexico	58,769 AF
Elephant Butte Irrigation District	311,517 AF
El Paso County Water Improvement District # 1	390,105 AF
[81.60% of a full supply]	760,391 AF *

* Project water supply available for diversion at the authorized canal headings.

2006 Rio Grande Project Allocation

Final Allocation - End of October, 2006

(letter issued November 21, 2006)

Mexico	33,895 AF
Elephant Butte Irrigation District	211,385 AF
El Paso County Water Improvement District # 1	227,146 AF
[50.70% of a full supply]	472,426 AF *

* Project water supply available for diversion at the authorized canal headings.

2004 Allocation Letter

United States Department of the Interior

BUREAU OF RECLAMATION
EL PASO FIELD DIVISION
700 E. SAN ANTONIO AVENUE, SUITE 710
EL PASO, TEXAS 79901-7020

IN REPLY REFER TO:
EP-431

1 8 AUG 2004

Mr. Gary Esslinger
Manager-Treasurer
Elephant Butte Irrigation District
PO Drawer 1509
Las Cruces, NM 88004-1509

Mr. Jesus Reyes
General Manager
El Paso County Water
Improvement District No. 1
294 Candelaria
El Paso, TX 79907-5599

Commissioner Arturo Duran
International Boundary and Water Commission
U. S. Section
The Commons, Bldg. C, Suite 310
4171 N. Mesa St.
El Paso, TX 79902

SUBJECT: **Final Allocation** of the 2004 Rio Grande Project Water Supply Based on End of July Data

Dear Gentlemen:

The combined total Rio Grande Project water storage at Elephant Butte and Caballo Reservoirs for **July 31, 2004 was 210,365 acre-feet (AF).** We have released 275,793 AF of storage water for irrigation from March 12 to July 31, 2004.

Nearly all of the combined Rio Grande Project (Project) storage in Elephant Butte and Caballo Reservoirs is available for allocation. The only waters that cannot be allocated are: 1,050 AF of Rio Grande Compact credit waters; and 6,315 AF of San Juan-Chama water, both in Elephant Butte Reservoir.

We have gained only 16,118 AF in the net supply available for allocation from July 1 through July 31, 2004. Further, comparing actual deliveries of Project supply to the canal headings and Caballo Dam releases during March through July of 2004 has resulted in a slight increase in the delivery efficiency to 0.704 (or a 29.6% loss rate). The last update of the allocation (for end of June data) indicated a river efficiency of 0.6875 (31.25% losses). The river losses for the present net supply available for allocation have decreased by 2,852 AF since last month's allocation update. However, this decrease in river losses (2,852 AF) and increase in net supply (16,118 AF) totaling 18,970 AF still is less than the increase in river losses last month (44,537 AF). Therefore, Reclamation will not increase the allocation due to continuing decreased river efficiency of delivering Project supply to the Project canal headings. As agreed in our meeting with Elephant Butte Irrigation District, El Paso County Water Improvement District No. 1, the International Boundary & Water Commission, and Mexico on July 30, 2004, **Reclamation declares the allocation of last month's update as the final allocation for the 2004 irrigation season**. The following is the final allocation:

ACRE-FEET

Mexico..	27,197
Elephant Butte Irrigation District..................................	185,507
El Paso County Water Improvement District No. 1......	141,240
TOTAL:	353,944

This final allocation represents only 37.98% of a full irrigation season supply for the entire Project. Last month's updated allocation was the same.

Please find enclosed:

- Enclosure No. 1 which summarizes modifications in the allocation procedures.
- Enclosure No. 2 which provides the details of the calculations for this month's allocation.
- Enclosure No. 3 which details the estimated Rio Grande Compact credit waters and San Juan-Chama water, both in Elephant Butte Reservoir.
- Enclosure No. 4 which summarizes the 2004 allocations to date.

Actual provisional flow data at the San Marcial gauging stations indicate that the flow for the 2004 spring runoff (March – July) was approximately 240,390 AF (41.95% of the 30-year average flow). Since 1996, we have

now had 8 years with below normal runoff into Elephant Butte Reservoir. The only year with above normal runoff was 1997. Enclosed is Reclamation's latest Project reservoirs operational plan with projections of the reservoirs' storage levels for the remainder of 2004. Elephant Butte Reservoir's low point is projected to be 48,450 AF on September 29th.
See Enclosure No. 5.

Sincerely,

for Norma A. Sosa

Filiberto Cortez
Manager, El Paso Field Division

Enclosures (5)

mtg_200709Mexico_IBWC_EBID_EP1.pdf

Final Allocation (November 21, 2006):

	(AF)	Utilization of Allocation (AF)		
MEXICO	33,895	27,112		
EBID	211,385	210,139		
EP#1	227,146	170,586	0	*
TOTAL	472,426	407,837		
% of Full Supply	50.70%			

Final Allocation (September 12, 2005):

	(AF)	Utilization of Allocation (AF)		
MEXICO	60,000	58,091		
EBID	494,979	356,689		
EP#1	376,862	247,607	0	*
TOTAL	931,841	662,387		
% of Full Supply	100.00%			

Final Allocation (August 18, 2004):

	(AF)	Utilization of Allocation (AF)	
MEXICO	27,197	27,613	
EBID	185,507	165,693	preliminary
EP#1	141,240	141,240	3,743
TOTAL	353,944	334,546	
% of Full Supply	37.98%		

Final Allocation (August 21, 2003):

	(AF)	Utilization of Allocation (AF)	
MEXICO	26,616	26,948	
EBID	165,144	164,741	
EP#1	125,735	125,122	12,127
TOTAL	317,495	316,811	
% of Full Supply	34.07%		

1	Rio Grande Project Allocation for 2015 (Data as of June 30, 2015)	ac-ft	
2	Elephant Butte Reservoir Storage	342,023	^
3	Caballo Reservoir Storage	17,310	^
4	Total Rio Grande Project Storage	359,333	
5	Estimated Rio Grande Compact Credit Waters	-15,760	*
6	Estimated San Juan-Chama Water	-3,363	**
7	Water Released from Storage	175,756	
8	Total Usable Water Available for Release	515,966	
9	Carryover Obligation using Estimated Diversion Ratio	15,530	
10	Estimate End-of-Season Adjustment of Project Water for Reservoir Evaporation/Dead storage	-15,000	/
11	Total Usable Water Available for Current Year Allocation	485,436	
12	EBID Allocation Balance (Previous Year)	8,652	-
13	EPCWID Allocation Balance (Previous Year)	2,685	-
14	EBID Allocation Balance (End-of-Year)	0	
15	EPCWID Allocation Balance (End-of-Year)	0	
16	Storage for EBID and EPCWID Allocation Balance (End-of-Year)	0	
17	Current Usable Water	500,966	
18	End-of-Year Release for Diversion Ratio	500,966	
19	D1 Delivery	311,540	
20	Mexico's Current Diversion Allocation	35,355	
21	Multiyear Extreme Drought D2 Correction Factor	0.83	//
22	Gross D2 Diversion Allocation	464,340	
23	EPCWID ACE Conservation Credit (evaluation postponed until EOY)	0	
24	Net D2 Current Year Diversion Allocation for EBID and EPCWID	428,985	
25	D2 Current Year Diversion Allocation for EPCWID	185,432	
26	Total EPCWID Diversion Allocation (w/o Conservation Credit)	188,117	
27	EPCWID Diversion (w/o Conservation Credit or 67/155ths of Row 30)	188,117	
28	Diversion Ratio	0.730	+
29	Diversion Ratio Adjustment	-135,261	
30	Sum of Release and Diversion Ratio Adjustment	365,705	
31	EBID D2 Current Year Diversion Allocation	243,553	
32	Difference between EBID Diversion Ratio Allocation and D2 Diversion Allocation	0	
33	EBID Diversion Ratio Allocation	133,581	
34	EBID Diversion Allocation	133,581	
35	Total EBID Diversion Allocation (includes 88/155th of Value in Row 30)	142,233	
36	Total EPCWID Allocation (includes Row 21 and 67/155th of Value in Row 30)	188,117	
37	District to District Allocation Transfer (OA 1.11 Excess Carryover Balance)	0	
38	Total EBID Diversion Allocation (After Transfer)	142,233	
39	Total EPCWID Allocation (After Transfer)	188,117	
40	Total EBID, EPCWID, and Mexico Allocation	365,705	

^ Figures Current as of April 30, 2015

* Estimated per URGWOM Model - NM Credit = 9,998 AF CO Credit = 5,762 AF July 6,. 2015

** Estimated San Juan Chama water as of July 6, 2015

+ 2014 Weighted Diversion Ratio

// Figure Based on MultiYear Drought Analysis

ENCLOSURE NO. 1

Status Check of 1906 Treaty Obligation to Deliver Proportionately the Same Amount of Water Supply to the U. S. Lands & Mexico's Canal Heading

U. S. Districts Proportional Delivery to Lands

Water Supply to U. S. Irrigation Districts' Lands = 311,540 - 35,355 = 276,184

Current Allotments as Percentage of Full Supply Allotments to U. S. Lands =

276,184	/	155,000	=	1.78183	AF/acre
1.78183	/	3.024	=	**58.92%**	

Mexico's Proportional Diversion at Its Canal Heading

Mexico's Acequia Madre Heading Allotment = 35,355

Current Allotment as Percentage of Full Supply Allotment to Canal Heading =

35,355	/	60,000	=	**58.93%**

Appendix 4D
Example Accounting Records
1979, 1995, and 2015

SN-144

E.B.I.D. Diversions

1979 Irrigation Season

Acre - Feet

Diversion Point	Total Diversion	Less Delivered to Texas	Net Delivered to EBID
*Arrey Canal	73,492	-----	73,492
*Leasburg Canal	98,945	-----	98,945
Eastside Canal	56,053	3,530	52,523
Westside Canal	145,010	29,022	115,988
Percha Lateral	649	-----	649
Del Rio Lateral	2,907	-----	2,907
Pumped from River	101	-----	101
Total	377,157	32,552	344,605
Authorized Waste Credited to EBID			794
		Total Delivery to EBID	343,811 A.F.

*Irrigations above the metering station have been included as part of this diversion.

Water Allocation Charges to the
El Paso County Water Improvement District No. 1
1983 Irrigation Season
Acre-Feet

	September 1 through October 7 Deliveries	Total Deliveries To Date
Charges for Initial Release (Our letter dated March 2, 1983)		8,259
Deliveries to Mesilla Valley, Texas by both Districts	6,954	37,965
City of El Paso	2,300	17,475
Franklin Canal	13,120	82,807
Riverside Canal	27,340	155,633
Less Ascarate Wasteway	6,160	38,290
Total Deliveries	43,554	263,849
*Socorro Ponds into Riverside Canal	0	- 3,480
Gross Allocation Charge	43,554	260,369
Credited Waste to District	- 2,690	- 4,335
Net Allocation Charge	40,864	256,034
Allocation		315,548
Balance		59,514

*This figure is to be deducted as this was previously charged as allocated waters and included 409 A.F. charged as part of the initial release.

RIO GRANDE PROJECT
ELEPHANT BUTTE IRRIGATION DISTRICT
WATER ALLOTMENT CHARGES
OCTOBER 1995(R)

	GROSS DIVERSIONS OCTOBER	TO DATE	DELIVERIES TO TEXAS OCTOBER	TO DATE	NET DELIVERIES OCTOBER	TO DATE
ARREY CANAL	7581	87896			7581	87896
PERCHA LAT.	89	857			89	857
LEASBURG CANAL	10005	116184			10005	116184
CALIF. EXT.	174	493			174	493
EASTSIDE CANAL	5550	64530	666	7744	4884	56787
DEL RIO LAT.	131	2154			131	2154
WESTSIDE CANAL	14015	167472	4518	53282	9498	114190
PUMPED FROM RIVER	55	351			55	351
GROSS TOTALS	37600	439937	5184	61026	32416	378911
CHARGES AT RIVER BELOW CABALLO					0	0
TOTAL CHARGES					32416	378911
CREDIT TO DISTRICT (-)	(ARREY CANAL BYPASS)				0	11391
NET ALLOTMENT CHARGE					32416	367520
DISTRICT ALLOTMENT						494979
DISTRICT BALANCE						127459

** GREENWOOD AND DURAN RIVER PUMPS (EBID DATA)

LA UNION EAST
OCTOBER (R)

DAY	N.M. ORDER	TEXAS ORDER	TOTAL ORDER	% N.M.	% TEX	L.U.EAST TOTAL DELIVERY	W.W.32	NET DELIVERY	N.M. CHARGE % OF NET	TEXAS CHARGE % OF NET
1	10	50	60	17%	83%	121	99	22	4	18
2	10	50	60	17%	83%	119	61	58	10	48
3	10	50	60	17%	83%	115	57	58	10	48
4	10	50	60	17%	83%	116	58	58	10	48
5	10	20	30	33%	67%	116	54	62	21	41
6	10	20	30	33%	67%	118	83	35	12	23
7	10	20	30	33%	67%	130	109	21	7	14
8	30	10	40	75%	25%	125	94	31	23	8
9	30	10	40	75%	25%	97	54	43	32	11
10	30	10	40	75%	25%	97	48	49	37	12
11	30	10	40	75%	25%	95	60	35	26	9
12	10	30	40	25%	75%	113	46	67	17	50
13	10	30	40	25%	75%	115	40	75	19	56
14	10	30	40	25%	75%	113	77	36	9	27
15	30	50	80	38%	63%	108	98	10	4	6
16	30	50	80	38%	63%	105	41	64	24	40
17	30	50	80	38%	63%	104	44	60	23	38
18	30	50	80	38%	63%	103	19	84	32	53
19	40	40	80	50%	50%	102	33	69	35	35
20	40	40	80	50%	50%	117	52	65	33	33
21	40	40	80	0%	0%	94	59	35	0	0
22	0	0	0	0%	0%	0	0	0	0	0
23	0	0	0	0%	0%	0	0	0	0	0
24	0	0	0	0%	0%	0	0	0	0	0
25	0	0	0	0%	0%	0	0	0	0	0
26	0	0	0	0%	0%	0	0	0	0	0
27	0	0	0	0%	0%	0	0	0	0	0
28	0	0	0	0%	0%	0	0	0	0	0
29	0	0	0	0%	0%	0	0	0	0	0
30	0	0	0	0%	0%	0	0	0	0	0
31	0	0	0	0%	0%	0	0	0	0	0
SFD	460	710	1170			2323	1286	1037	384	618
AF	912	1408	2321			4608	2551	2057	761	1226

LA UNION WEST
OCTOBER (R)

DAY	N.M. ORDER	TEXAS ORDER	TOTAL ORDER	% N.M.	% TEX	TOTAL DELIVERY	N.M. CHARGE	TEXAS CHARGE
1	30	10	40	75%	25%	44	33	11
2	30	10	40	75%	25%	50	38	13
3	30	10	40	75%	25%	48	36	12
4	30	10	40	75%	25%	58	44	15
5	50	10	60	83%	17%	50	42	8
6	50	10	60	83%	17%	50	42	8
7	50	10	60	83%	17%	48	40	8
8	40	10	50	80%	20%	45	36	9
9	40	10	50	80%	20%	48	38	10
10	40	10	50	80%	20%	55	44	11
11	40	10	50	80%	20%	62	50	12
12	20	15	35	57%	43%	66	38	28
13	20	15	35	57%	43%	65	37	28
14	20	15	35	57%	43%	63	36	27
15	70	10	80	88%	13%	58	51	7
16	70	10	80	88%	13%	59	52	7
17	70	10	80	88%	13%	68	60	9
18	70	10	80	88%	13%	84	74	11
19	70	10	80	88%	13%	85	74	11
20	70	10	80	0%	0%	94	0	0
21	70	10	80	0%	0%	65	0	0
22	0	0	0	0%	0%	1	0	0
23	0	0	0	0%	0%	0	0	0
24	0	0	0	0%	0%	0	0	0
25	0	0	0	0%	0%	0	0	0
26	0	0	0	0%	0%	0	0	0
27	0	0	0	0%	0%	0	0	0
28	0	0	0	0%	0%	0	0	0
29	0	0	0	0%	0%	0	0	0
30	0	0	0	0%	0%	0	0	0
31	0	0	0	0%	0%	0	0	0
SFD	980	225	1205			1266	862	244
AF	1944	446	2390			2511	1710	484

WESTSIDE CANAL DELIVERIES
OCTOBER 95 (R)

DAY	WESTSIDE HEADING (1)	LUE & LUW TX-CHRGE (2)	115% OF TX-CHRG(2) (3)	W.W. 32 (4)	EBID WATER (1)-(3+4)
1	330	29	34	99	197
2	342	61	70	61	211
3	340	60	69	57	214
4	330	63	72	58	200
5	314	50	57	54	203
6	312	32	36	83	193
7	326	22	25	109	192
8	310	17	19	94	197
9	301	20	23	54	224
10	303	23	27	48	228
11	348	21	24	60	264
12	371	79	90	46	235
13	388	84	97	40	251
14	398	54	62	77	259
15	380	14	16	98	266
16	400	47	54	41	305
17	399	46	53	44	302
18	403	63	72	19	312
19	371	45	52	33	286
20	312	33	37	52	223
21	88	0	0	59	29
22	0	0	0	0	0
23	0	0	0	0	0
24	0	0	0	0	0
25	0	0	0	0	0
26	0	0	0	0	0
27	0	0	0	0	0
28	0	0	0	0	0
29	0	0	0	0	0
30	0	0	0	0	0
31	0	0	0	0	0
SFD	7066	862	992	1286	4788
AF	14015	1710	1967	2551	9498

THREE SAINTS DELIVERIES
OCTOBER 95 (R)

DAY	N.M. ORDER	TEXAS ORDER	TOTAL ORDER	% N.M.	% TEX	TOTAL DELIVERY (1)	N.M. CHARGE	TEXAS CHARGE (2)	120% OF (2)
1	90	10	100	90%	10%	100	90	10	12
2	90	10	100	90%	10%	100	90	10	12
3	90	10	100	90%	10%	100	90	10	12
4	108	12	120	90%	10%	112	101	11	13
5	108	12	120	90%	10%	124	112	12	15
6	108	12	120	90%	10%	123	111	12	15
7	117	13	130	90%	10%	116	104	12	14
8	117	13	130	90%	10%	120	108	12	14
9	117	13	130	90%	10%	123	111	12	15
10	117	13	130	90%	10%	133	120	13	16
11	167	19	185	90%	10%	138	124	14	17
12	167	19	185	90%	10%	158	142	16	19
13	167	19	185	90%	10%	155	140	16	19
14	189	21	210	90%	10%	156	140	16	19
15	189	21	210	90%	10%	157	141	16	19
16	189	21	210	90%	10%	158	142	16	19
17	189	21	210	90%	10%	159	143	16	19
18	221	25	245	90%	10%	185	167	19	22
19	221	25	245	90%	10%	202	182	20	24
20	221	25	245	90%	10%	179	161	18	21
21	0	0	0	90%	10%	0	0	0	0
22	0	0	0	90%	10%	0	0	0	0
23	0	0	0	90%	10%	0	0	0	0
24	0	0	0	90%	10%	0	0	0	0
25	0	0	0	90%	10%	0	0	0	0
26	0	0	0	90%	10%	0	0	0	0
27	0	0	0	90%	10%	0	0	0	0
28	0	0	0	90%	10%	0	0	0	0
29	0	0	0	90%	10%	0	0	0	0
30	0	0	0	90%	10%	0	0	0	0
31	0	0	0	90%	10%	0	0	0	0
SFD	2979	331	3310			2798	2518	280	336
AF	5909	657	6565			5550	4995	555	666

RIO GRANDE PROJECT
ELEPHANT BUTTE IRRIGATION DISTRICT
WATER ALLOTMENT CHARGES
OCTOBER 95 (R)

DATE	ARREY	PERCHA	LEASBURG	EASTSIDE	DEL RIO	WESTSIDE	L.U.WEST	L.U.EAST	W.W.32
1	142	0	211	100	3	330	44	121	99
2	94	0	211	100	0	342	50	119	61
3	125	1	211	100	0	340	48	115	57
4	139	6	214	112	0	330	58	116	58
5	146	10	214	124	0	314	50	116	54
6	143	6	214	123	5	312	50	118	83
7	149	1	210	116	0	326	48	130	109
8	149	1	210	120	0	310	45	125	94
9	151	1	210	123	0	301	48	97	54
10	150	6	210	133	0	303	55	97	48
11	155	5	286	138	0	348	62	95	60
12	157	3	286	158	15	371	66	113	46
13	229	5	286	155	18	388	65	115	40
14	279	0	280	156	0	398	63	113	77
15	278	0	280	157	0	380	58	108	98
16	275	0	280	158	15	400	59	105	41
17	311	0	280	159	0	399	68	104	44
18	325	0	317	185	0	403	84	103	19
19	323	0	317	202	10	371	85	102	33
20	102	0	317	179	0	312	94	117	52
21	0	0	0	0	0	88	65	94	59
22	0	0	0	0	0	0	1	0	0
23	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0
SFD	3822	45	5044	2798	66	7066	1266	2323	1286
AF	7581	89	10005	5550	131	14015	2511	4608	2551

RIO GRANDE PROJECT
EL PASO COUNTY WATER IMPROVEMENT DISTRICT NO. 1
WATER ALLOTMENT CHARGES
OCTOBER 1995

ACRE-FEET

		DELIVERIES FOR MONTH	TOTAL DELIVERIES TO DATE
DELIVERIES TO MESILLA VALLEY TEXAS BY BOTH DISTRICTS		2,177	48,514
L.U.E. & L.U.W. (TX)	1,686		
THREE SAINTS LATERAL	575		
CITY OF EL PASO		5,660	56,041
FRANKLIN CANAL		3,467	97,241
LESS ASCARATE WASTEWAY		0	20,164
RIVERSIDE CANAL		21,925	279,455
CABALLO DAM RELEASE		0	3,068
GROSS TOTAL		33,229	464,156
CREDIT TO DISTRICT		4,520	82,356
NET ALLOTMENT CHARGE		28,709	279,723
DISTRICT ALLOTMENT			376,862
DISTRICT BALANCE			97,139

** See water charges for June thru August credits due to excess releases.

RIO GRANDE PROJECT
COMPUTED DELIVERIES
LA UNION EAST
EL PASO COUNTY WATER IMPROVEMENT DISTRICT NO. 1
OCTOBER 1995

DAY	N.M. ORDER	TEXAS ORDER	TOTAL ORDER	% N.M.	% TEX	TOTAL DELIV.	BYPASS WW #32	WATER PASS 32	N.M. CHARGE	TEXAS CHARGE
1	10	50	60	0.17	0.83	121	99	22	4	18
2	10	50	60	0.17	0.83	119	61	58	10	48
3	10	50	60	0.17	0.83	115	57	58	10	48
4	10	20	30	0.33	0.67	116	58	58	19	39
5	10	20	30	0.33	0.67	116	54	62	21	41
6	10	20	30	0.33	0.67	118	83	35	12	23
7	30	10	40	0.75	0.25	130	109	21	16	5
8	30	10	40	0.75	0.25	125	94	31	23	8
9	30	10	40	0.75	0.25	97	54	43	32	11
10	30	10	40	0.75	0.25	97	48	49	37	12
11	10	30	40	0.25	0.75	95	60	35	9	26
12	10	30	40	0.25	0.75	113	46	67	17	50
13	10	30	40	0.25	0.75	115	40	75	19	56
14	30	50	80	0.38	0.63	113	77	36	14	23
15	30	50	80	0.38	0.63	108	98	10	4	6
16	30	50	80	0.38	0.63	105	41	64	24	40
17	30	50	80	0.38	0.63	104	44	60	23	38
18	40	40	80	0.50	0.50	103	19	84	42	42
19	40	40	80	0.50	0.50	102	33	69	35	35
20	40	40	80	0.50	0.50	117	52	65	33	33
21	0	0	0	0.00	0.00	94	59	35	0	0
22	0	0	0	0.00	0.00	0	0	0	0	0
23	0	0	0	0.00	0.00	0	0	0	0	0
24	0	0	0	0.00	0.00	0	0	0	0	0
25	0	0	0	0.00	0.00	0	0	0	0	0
26	0	0	0	0.00	0.00	0	0	0	0	0
27	0	0	0	0.00	0.00	0	0	0	0	0
28	0	0	0	0.00	0.00	0	0	0	0	0
29	0	0	0	0.00	0.00	0	0	0	0	0
30	0	0	0	0.00	0.00	0	0	0	0	0
31	0	0	0	0.00	0.00	0	0	0		
SFD	450	660	1110	0.41	0.59	2323	1286	1037	400	602
AF	893	1309	2202			4608	2551	2057	793	1195

TOTAL CHARGES FOR OCT. : 23049

FOR 1995 - 274063

RIO GRANDE PROJECT
COMPUTED DELIVERIES
LA UNION WEST
EL PASO COUNTY WATER IMPROVEMENT DISTRICT NO. 1
OCTOBER 1995

DAY	N.M. ORDER	TEXAS ORDER	TOTAL ORDER	% N.M.	% TEX	TOTAL DELIVERY	N.M. CHARGE	TEXAS CHARGE
1	30	10	40	0.75	0.25	44	33	11
2	30	10	40	0.75	0.25	50	38	13
3	30	10	40	0.75	0.25	48	36	12
4	50	10	60	0.83	0.17	58	48	10
5	50	10	60	0.83	0.17	50	42	8
6	50	10	60	0.83	0.17	50	42	8
7	40	10	50	0.80	0.20	48	38	10
8	40	10	50	0.80	0.20	45	36	9
9	40	10	50	0.80	0.20	48	38	10
10	40	10	50	0.80	0.20	55	44	11
11	20	15	35	0.57	0.43	62	35	27
12	20	15	35	0.57	0.43	66	38	28
13	20	15	35	0.57	0.43	65	37	28
14	70	10	80	0.88	0.13	63	55	8
15	70	10	80	0.88	0.13	58	51	7
16	70	10	80	0.88	0.13	59	52	7
17	70	10	80	0.88	0.13	68	60	9
18	70	10	80	0.88	0.13	84	74	11
19	70	10	80	0.88	0.13	85	74	11
20	70	10	80	0.88	0.13	94	82	12
21	0	0	0	0.00	0.00	65	0	0
22	0	0	0	0.00	0.00	1	0	0
23	0	0	0	0.00	0.00	0	0	0
24	0	0	0	0.00	0.00	0	0	0
25	0	0	0	0.00	0.00	0	0	0
26	0	0	0	0.00	0.00	0	0	0
27	0	0	0	0.00	0.00	0	0	0
28	0	0	0	0.00	0.00	0	0	0
29	0	0	0	0.00	0.00	0	0	0
30	0	0	0	0.00	0.00	0	0	0
31	0	0		0.00	0.00	0		
SFD	950	215	1165	0.82	0.18	1266	952.4	248
AF	1884	426	2311			2511	1889	491

RIO GRANDE PROJECT
COMPUTED DELIVERIES
THREE SAINTS LATERAL
EL PASO COUNTY WATER IMPROVEMENT DISTRICT NO. 1
OCTOBER 1995

DAY	3 SAINTS Q (1)	WW23A Q (2)	(1)-(2) (3)	3 SAINTS ORDER FOR TEXAS	EPCWID#1 WATER CHARGED
1	5	5	0	10	5
2	4	4	0	10	4
3	7	5	2	10	7
4	9	4	5	11	9
5	22	8	14	12	14
6	21	5	16	12	16
7	22	9	13	12	13
8	26	15	11	12	12
9	27	17	10	12	12
10	23	11	12	13	13
11	24	11	13	14	14
12	24	8	16	16	16
13	27	12	15	16	16
14	20	13	7	16	16
15	22	18	4	16	16
16	24	10	14	16	16
17	26	0	26	16	26
18	24	0	24	19	24
19	26	6	20	20	20
20	30	13	17	18	18
21	23	19	4	0	4
22	4	4	0	0	0
23	0	0	0	0	0
24	0	0	0	0	0
25	0	0	0	0	0
26	0	0	0	0	0
27	0	0	0	0	0
28	0	0	0	0	0
29	0	0	0	0	0
30	0	0	0	0	0
31	0	0		0	
TOTAL SF	440	197	243	280	290
TOTAL AF	873	391	482	555	575

RIO GRANDE PROJECT
EL PASO COUNTY WATER IMPROVEMENT DISTRICT NO. 1
WATER ALLOTMENT CHARGES
OCTOBER 1995

FLOW IN SFD

DAY	FRANKLIN	ASCARATE	RIVERSIDE	TOTAL DELIVERY
1	44	0	365	409
2	43	0	354	397
3	41	0	372	413
4	41	0	368	409
5	43	0	363	406
6	42	0	355	397
7	44	0	347	391
8	45	0	355	400
9	55	0	382	437
10	65	0	401	466
11	64	0	388	452
12	64	0	386	450
13	55	0	332	387
14	44	0	280	324
15	43	0	283	326
16	42	0	371	413
17	58	0	380	438
18	58	0	380	438
19	56	0	379	435
20	56	0	322	378
21	53	0	268	321
22	50	0	269	319
23	55	0	404	459
24	74	0	379	453
25	86	0	375	461
26	91	0	398	489
27	74	0	377	451
28	64	0	339	403
29	67	0	339	406
30	66	0	396	462
31	65	0	347	412
SFD	1748	0	11054	12802
AF	3467	0	21925	25392

RIO GRANDE PROJECT
EL PASO COUNTY WATER IMPROVEMENT DISTRICT #1
CREDIT SUMMARY
OCTOBER 1995

DAY	TOTAL DIVERT.	ORDER	DIFF. +/-	R.S.H. WASTE	SYSTEM WASTE	EPCWID CHARGE	TOTAL WASTE	USBR/ EBID WASTE	EPCWID WASTE	EPCWID CREDIT
1	409	390	19	232	289	390	521	19	274	19
2	397	390	7	266	246	390	512	7	240	7
3	413	390	23	236	223	390	459	23	205	23
4	409	390	19	209	206	390	415	19	191	0
5	406	446	-40	164	172	446	336	-40	336	0
6	397	446	-49	124	217	446	341	-49	341	0
7	391	446	-55	106	374	446	480	-55	480	0
8	400	390	10	136	316	390	452	10	308	10
9	437	390	47	128	248	390	376	47	210	47
10	466	390	76	70	85	390	155	76	24	76
11	452	390	62	16	127	390	143	62	77	62
12	450	295	155	15	88	331	103	119	0	119
13	387	295	92	99	340	295	439	92	266	92
14	324	295	29	186	433	295	619	29	410	29
15	326	250	76	259	412	250	671	76	351	76
16	413	250	163	117	114	266	231	147	0	147
17	438	250	188	85	163	250	248	188	13	0
18	438	250	188	99	210	250	309	188	60	188
19	435	253	182	89	339	253	428	182	193	182
20	378	253	125	218	431	253	649	125	331	125
21	321	350	-29	442	415	350	857	-29	857	0
22	319	350	-31	473	407	350	880	-31	880	0
23	459	350	109	169	248	350	417	109	161	109
24	453	350	103	55	271	350	326	103	189	103
25	461	350	111	22	282	350	304	111	193	111
26	489	350	139	22	330	350	352	139	219	139
27	451	350	101	92	460	350	552	101	379	101
28	403	350	53	132	432	350	564	53	390	53
29	406	350	56	99	410	350	509	56	365	56
30	462	0	462	7	313	57	320	405	0	405
31	412	0		7	0					
SFD	12,802	9,999	2,391	4,374	8,601	10,108	12,968	2,282	7,943	2,279
AF	25,393	19,833	4,743	8,676	17,060	20,049	25,722	4,526	15,755	4,520

ELEPHANT BUTTE IRRIGATION DISTRICT

WATER ALLOTMENT CHARGES

October-13

SUBJECT TO REVISION

	GROSS DIVERSIONS (AC-FT)		DIVERTED TO TEXAS (AC-FT)		NET DIVERSIONS (AC-FT)	
		TO DATE		TO DATE		TO DATE
ARREY CANAL	0	31,634			0	31,634
PERCHA LATERAL	0	104			0	104
LEASBURG CANAL	0	34,812			0	34,812
CALIFORNIA EXTENTION	0	243			0	243
EASTSIDE CANAL	0	27,628	0	-1,319	0	26,309
DEL RIO LATERAL	0	1,884			0	1,884
WESTSIDE CANAL	0	76,752	0	-26,714	0	50,038
PUMPED FROM RIVER**	0	25			0	25
GROSS TOTAL	0	173,083	0	-28,033	0	145,050

	NET DIVERSION	TO DATE
TOTAL CHARGES (AC-FT)	0	145,050
CREDIT AT ARREY (-)	0	0
CREDIT AT LEASBURG (-)	0	0
ADJUSTMENT FOR CHARGE AT HEADING (+)	**0**	**3,926**
NET ALLOTMENT CHARGE	**0**	**148,976**
DISTRICT ALLOTMENT		**0**
2009 Carryover Transfer		**0**
DISTRICT BALANCE		**-148,976**

** GREENWOOD AND DURAN RIVER PUMPS (EBID DATA)

DRAFT - EPCWID Diversion Allocation Charges for September 2015

Diversion Location	Metered Volume	Adjustment for Conveyance Losses for NM Deliveries	Normal Diversion Allocation Charges for Month	Beginning-of-Month Totals	End-of-Month Totals
	ac-ft	ac-ft	ac-ft	ac-ft	ac-ft
L U E Canal - TX	3,207	100%	3,207	10,962	14,169
L U W Canal - TX	1,886	100%	1,886	3,156	5,042
Three Saints Lateral	317	100%	317	654	971
Total Mesilla Valley (Texas)			5,411	14,771	20,182
Umbenhauer/Robertson Water Treatment Plant	3,008	100%	3,008	9,936	12,944
Franklin Canal	4,973	100%	4,973	16,735	21,707
United States - Ysleta del Sur Agreement	0	100%	0	107	107
United States Section - IBWC (Construction Water)	0	100%	0	0	0
Jonathan W. Rogers Water Treatment Plant	5,353	100%	5,353	14,685	20,038
Riverside Canal	14,565	100%	14,565	55,592	70,156
Haskell R. Street WWTP Effluent	-1,428	100%	-1,428	-4,032	-5,461
Credit for Diversions greater than Orders (El Paso Valley)	0	100%	0	-1,438	-1,438
August Allocation Charges for ACE Credit Calculation			36,917		
Total Diversions for ACE Credit Calculation			31,882	115,433	147,314
Net Charges for Release from Caballo (Aug 23 @ 1100)	44,791	100%	44,791	15,016	**59,807**
Total Allotment Diversions Charges				**106,065**	**165,872**
Diversion Allocation				188,117	188,117
Est. Annual Conservation Credit Diversion Allocation					11,651
Accrued Conservation Credit Diversion Allocation					11,651
Total Diversion Allocation					199,768
District Allotment Balance					22,245
EOY Allocation Balance					**33,896**

Appendix 6A
Inputs for Hueco Annual CFB Models
1903 – 1937

1. Introduction

The CFB Models contain canal and farm budget calculations on an annual time-step for units overlying the Hueco ground water basin, including El Paso Valley (EPCWID), HCCRD, and JID Units 1 – 3. The annual Hueco CFB Models are from 1903 – 1937. This appendix describes the inputs used in the annual Hueco CFB Models.

2. Annual Hueco CFB Model Inputs

2.1 Surface Water Supplies

Surface water supplies were input into the CFB Models using flow data from the surface water dataset ("SWDataSet") prepared by SWE. The following table summarizes the annual surface water supplies used in the Hueco CFB Models for the 1903 – 1937 period.

Irrigation Unit	Surface Water Supplies (1903 – 1937)
El Paso Valley (EPCWID)	Franklin Canal (1903 – 1937) - Ascarate Wasteway (1916 – 1937) + Riverside Canal (1928 – 1937)
HCCRD	1915 – 1924: Calculated (irrigated acres x 4 feet) 1925 – 1937: Tornillo Canal Waste End + Tornillo Drain
JID Unit 1 JID Unit 2 JID Unit 3	Acequia Madre (1903 – 1937) + Cuidad Juarez Sewage (1926 – 1937) + River Diversions (1930 – 1937); split proportionally between units using irrigated acreage

Available surface water flows from 1903 – 1937 have been compiled, but there are significant data gaps during this period. SWE coordinated with MMA to estimate the missing 1903 – 1937 annual data. The start dates for different canals, wasteways, and drains were provided by MMA. These estimates are described in detail below.

<u>El Paso Valley 1903 – 1937</u>

Annual data for the Franklin Canal date back to 1914 (missing data in 1917). Prior to the construction of the American Dam in 1938, the Franklin Canal diverted at the International Dam. Franklin Canal diversion data from 1903 – 1913 and 1917 were estimated using an annual 1918 – 1938 regression with streamflows for the Rio Grande at El Paso gage. The Franklin Canal diversions were estimated as the minimum of the computed canal flow using the regression and the estimated capacity of the canal (320 cubic feet per second ["cfs"]). The Franklin Canal diversions were also limited to an irrigation season of March to November.

The Ascarate Wasteway was constructed around 1916, but annual flow records are only available after 1938. Annual Ascarate Wasteway flows from 1916 – 1937 were estimated using a 1938 – 1949 annual regression with the Franklin Canal.

The Riverside Canal was constructed around 1928 and the annual records for the Riverside Canal from 1928 – 1937 are complete.

<u>Hudspeth County 1903 – 1937</u>

Irrigation in HCCRD commenced around 1915 with the construction of ditches that diverted water from the Rio Grande and HCCRD was organized in 1924 (Reclamation, 2013). The HCCRD flows were measured starting in the 1920s. Measurement of the Tornillo Drain flows began in 1923 and measurement of the Hudspeth Canal (Tornillo End) began in 1925. The total flow to HCCRD was assumed to be the sum of the Tornillo Drain and the Hudspeth Canal (Tornillo End). According to the HCCRD water supply schematic (see report **Figure 6-4)**, the Hudspeth Canal (Tornillo End) began in 1925. There are no Hudspeth Canal (Tornillo End) flow records from 1925 – 1934. The Hudspeth Canal (Tornillo End) flows are estimated from 1925 – 1934 using a water balance approach, calculated as the Tornillo Canal heading flow minus an assumed seepage loss minus farm headgate demands for the Tornillo acres minus Tornillo Waste.

Various regression equations to estimate diversions for the Tornillo Drain and Hudspeth Canal (Tornillo End) from 1915 – 1924 were tested and did not yield good fits. Therefore, the diversions from 1915 – 1924 were estimated as the total irrigated acres multiplied by four feet.

<u>Juarez Units 1903 – 1937</u>

Diversion records for Acequia Madre are available from 1924 – 1925 and 1930 – 1936. Missing data for 1903 – 1923, 1926 – 1929, and 1937 were estimated using an annual 1930 – 1936 regression with the Rio Grande at El Paso gaged flows. The Acequia Madre diversions were estimated as the minimum of the computed canal flow using the regression and the estimated capacity of the canal (300 cfs). The Acequia Madre diversions were also limited to an irrigation season of March to November. A water balance calculation was conducted to check that the estimated combined diversions at Franklin Canal and Acequia Madre did not exceed the total Rio Grande flow at El Paso gage.

The Sewage Flow from 1926 – 1937 was estimated to be 49 percent of the Cuidad Juarez (“JMAS”) pumping using methodology described in the report. There are no data for JMAS pumping prior to 1926, although the annual JMAS pumping was less than 500 af in the late 1920s. Because of the lack of data and the small magnitude of the JMAS pumping, no Sewage Flows were computed to include in the surface water supply to Juarez prior to 1926. Sewage Flow available to the farms from 1926 – 1937 was limited to the irrigation season of March – October.

Annual estimates of River Diversions from 1930 – 1936 from the 1938 Rio Grande Joint Investigation (“RGJI”) were used in the CFB Models (USNRC, 1938). Due to similar hydrological conditions, annual data for 1937 was assumed to be equal to 1936. The extent of the River Diversions prior to 1930 is unknown and there are little flow data to estimate these diversions. The River Diversions prior to 1930 were not included in the surface water supply to Juarez.

The total JID water supplies from 1903 – 1937 were distributed to the JID units based on the irrigated area in each unit. This distribution of water is consistent with the water distribution used during this period in Carreno (1957), except in the drought years 1903 – 1906 in which water was assumed to only be available to JID Unit 1.

2.2 Irrigated Area

Available irrigated area data from 1903 – 1937 were compiled for use in the CFB Models of the Hueco area irrigation units. There are no data on primary acres in Texas and Mexico and all irrigated lands for these areas are assumed to be supplemental acres.

Irrigated area in Texas (El Paso Valley and HCCRD) from 1903 – 1937 are from the 1938 RGJI. The 1938 RGJI records are not complete from 1903 – 1937, and missing irrigated area data were estimated using interpolation/extrapolation of the years with data. The reported and estimated irrigated acreage data used in the CFB Models are shown in the table below.

The irrigated area data for JID was obtained from various reports for use in the Hueco GW Model (USNRC, 1938 and IBWC, 1989). Similar to El Paso Valley and HCCRD, the irrigated acreage for years of no data were interpolated between the available reported acreage. The total acreage was distributed into the three JID units primarily using the reported distribution from Carreno (1957), except from 1903 – 1906, it was assumed that during low flows all diversions would go to JID Unit 1. In 1904, it was assumed that there were zero irrigated acres since there were no flows at the Rio Grande at El Paso gage that year from March – July.

The irrigated area used in the annual Hueco CFB Models is summarized in the table below.

District	**Supplemental Acres 1903 – 1937**
El Paso Valley (EPCWID)	1903 – 1906: Set equal to 1907 acreage from RGJI (USNRC, 1938) 1907, 1914, and 1920 – 1937: Acreage from RGJI (USNRC, 1938) 1915 – 1916: Set equal to 1914 acreage from RGJI (USNRC, 1938) 1918 – 1919 and 1936 – 1937: Reclamation Water Distribution Reports (Accounting DataSet) 1908 – 1913: Linear interpolation between 1907 and 1914 acreage from RGJI (USNRC, 1938)
HCCRD	1903 – 1914: Assumed zero irrigated acres (MMA) 1915 – 1919: Linear interpolation between zero acres in 1914 to 1920 acreage from RGJI (USNRC, 1938) 1920 – 1937: Acreage from RGJI (USNRC, 1938)
JID	1903, 1905, 1908 – 1914, 1916 – 1922, 1927 – 1929, and 1931 – 1937: Acreage interpolated from IBWC (1989) and RGJI (USNRC, 1938), data provided by MMA 1904, 1906, 1915, and 1930 – 1949: Acreage from IBWC (1989) 1907 and 1923 – 1926: Acreage from RGJII (USNRC, 1938)

2.3 Crop Irrigation Requirement and Excess Effective Precipitation

For the 1903 – 1937 annual Hueco CFB Models, the CIR is the average annual 1936 – 1937 CIR from DE reduced by 5 percent. There is no assumed excess effective precipitation simulated in the 1903 – 1937 annual CFB Models.

2.4 Conveyance and Other Losses

The total canal loss and wasteway flows loss is a user-specified percent of the total diversions for each annual CFB Model. These percentages do not vary from year-to-year. The total canal loss is set to 40% for all irrigation units from 1903 – 1937. The wasteway flow percentage is set to 10% for the El Paso Valley irrigation unit and 0% for the other irrigation units.

2.4.1 Incidental Canal Loss and Canal Seepage

The incidental canal loss is computed based on a user specified a percentage of the total canal loss and is set at 6%.

2.5 Maximum On-Farm Irrigation Efficiency ("MFE")

The MFE is a user-specified percent for each annual CFB Model. The MFE does not vary from year-to year. The MFE is currently set at 68% for all irrigation units.

2.6 On-Farm Loss Split

The surface runoff percentage is a user-specified percent for each annual CFB Model that does not vary from year-to year. The surface runoff percentage is currently set at the 6%for all irrigation units. The deep percolation percent is computed as one minus the surface runoff percent (94%).

2.7 Soil Moisture Reservoir

The soil moisture reservoir (inches) for the annual Hueco CFB Models are set equal to the values used in the monthly CFB Models.

2.8 Ground Water Pumping

There is no ground water pumping for irrigation supply on the Hueco lands from 1903 – 1937. However, the structure to simulate the supplemental and primary pumping has been added to the annual Hueco CFB Models.

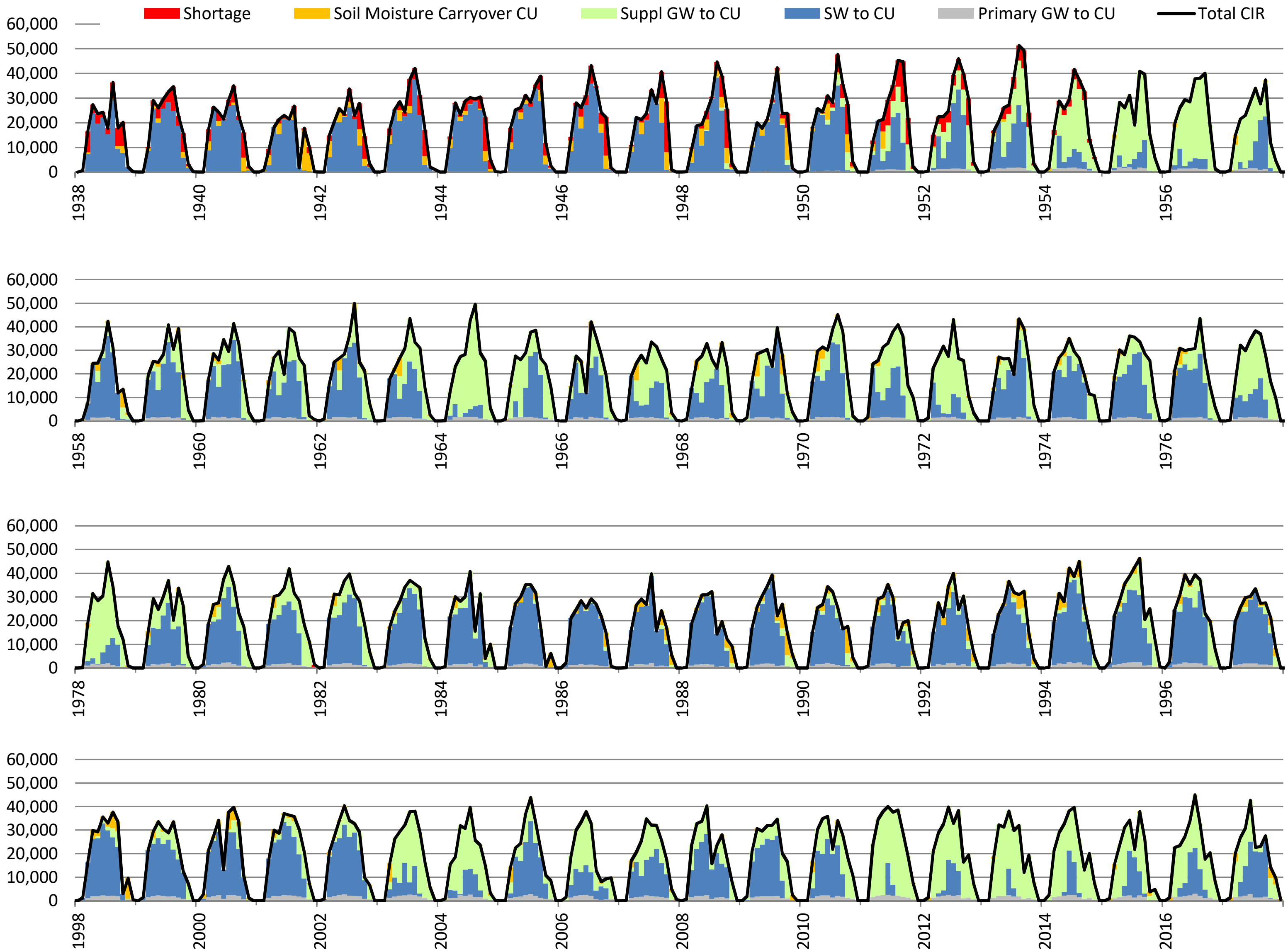
Appendix 6B
District-Wide Summaries of CFB Model Outputs
1938 – 2017

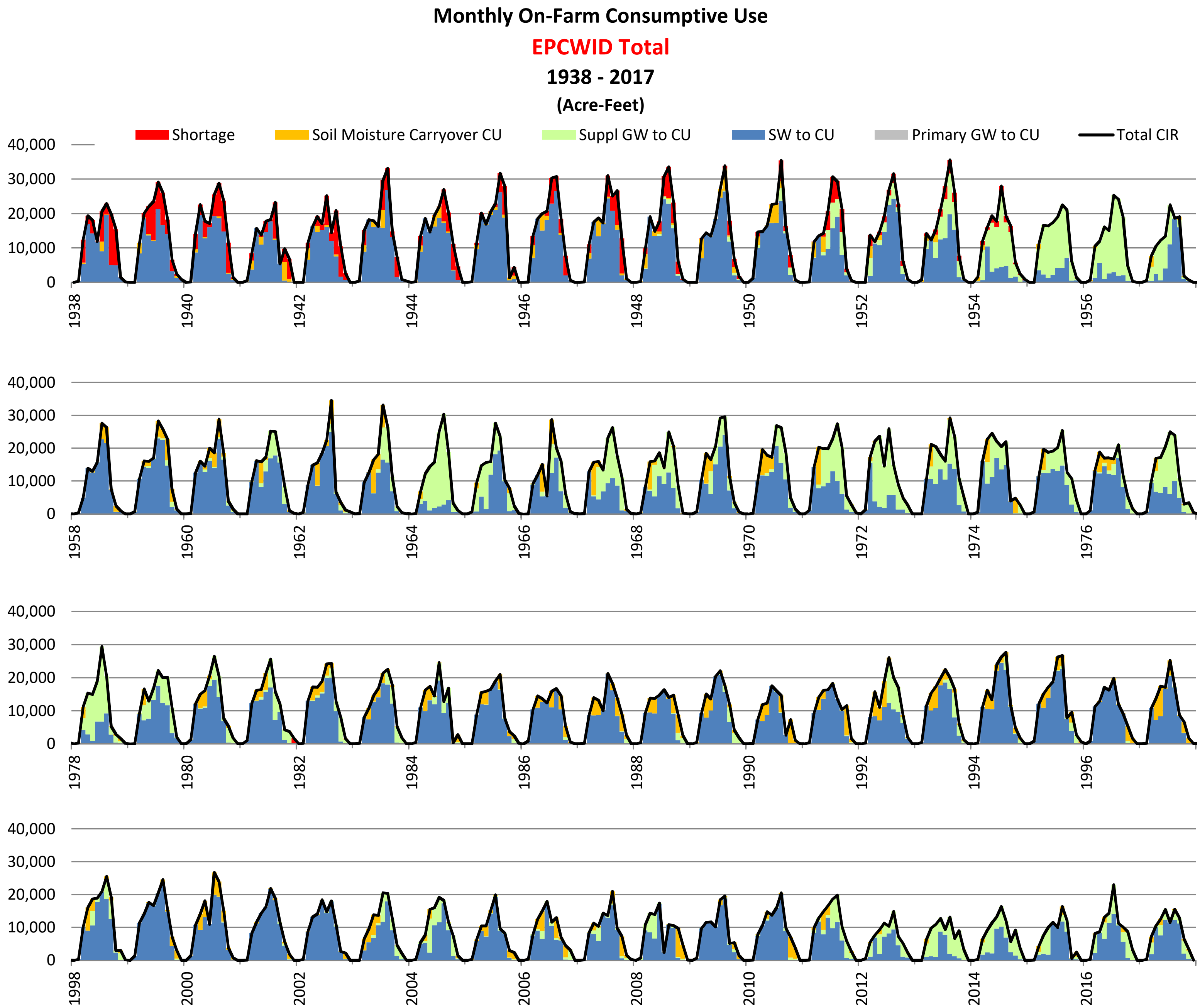
Monthly On-Farm Consumptive Use

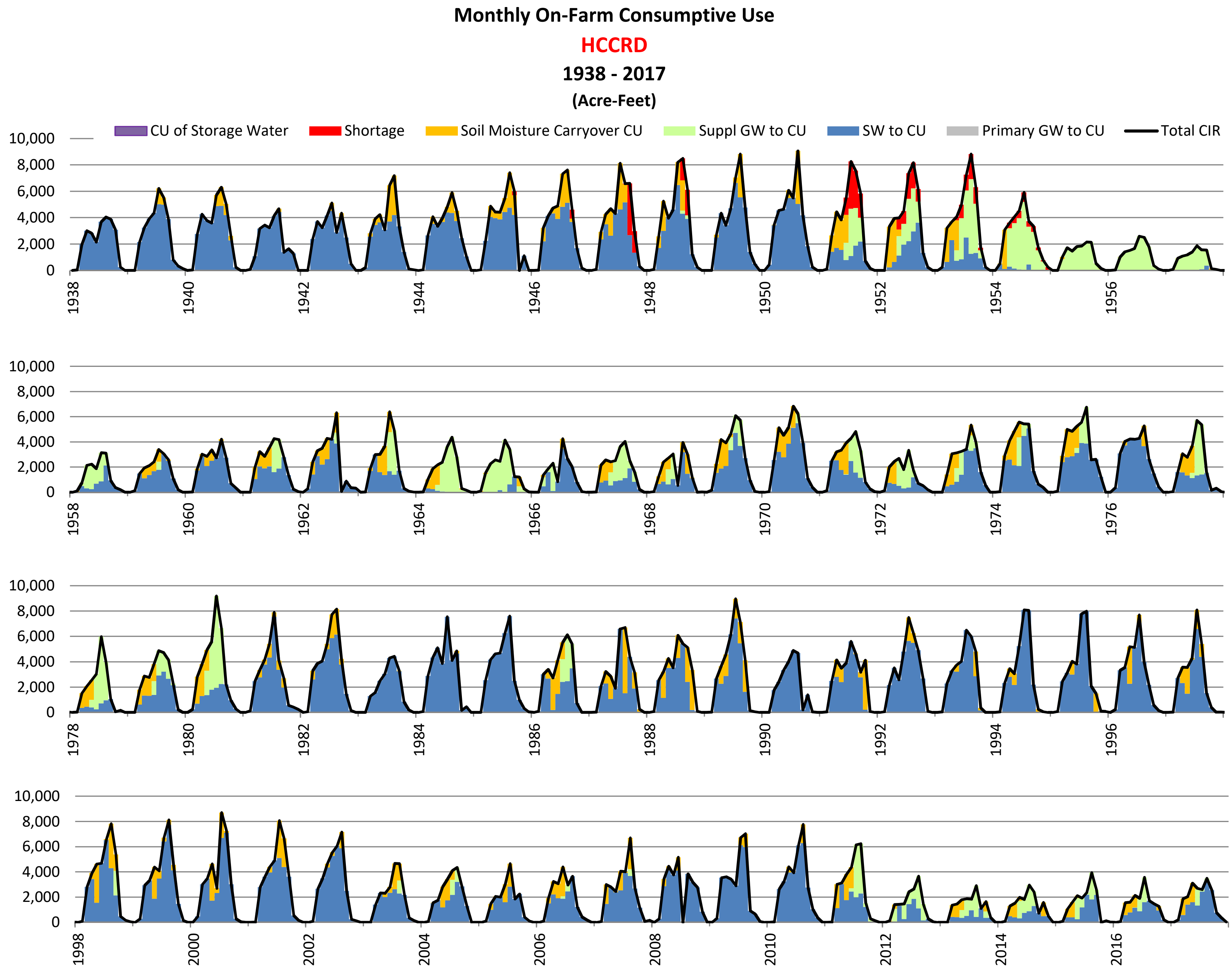
EBID Total

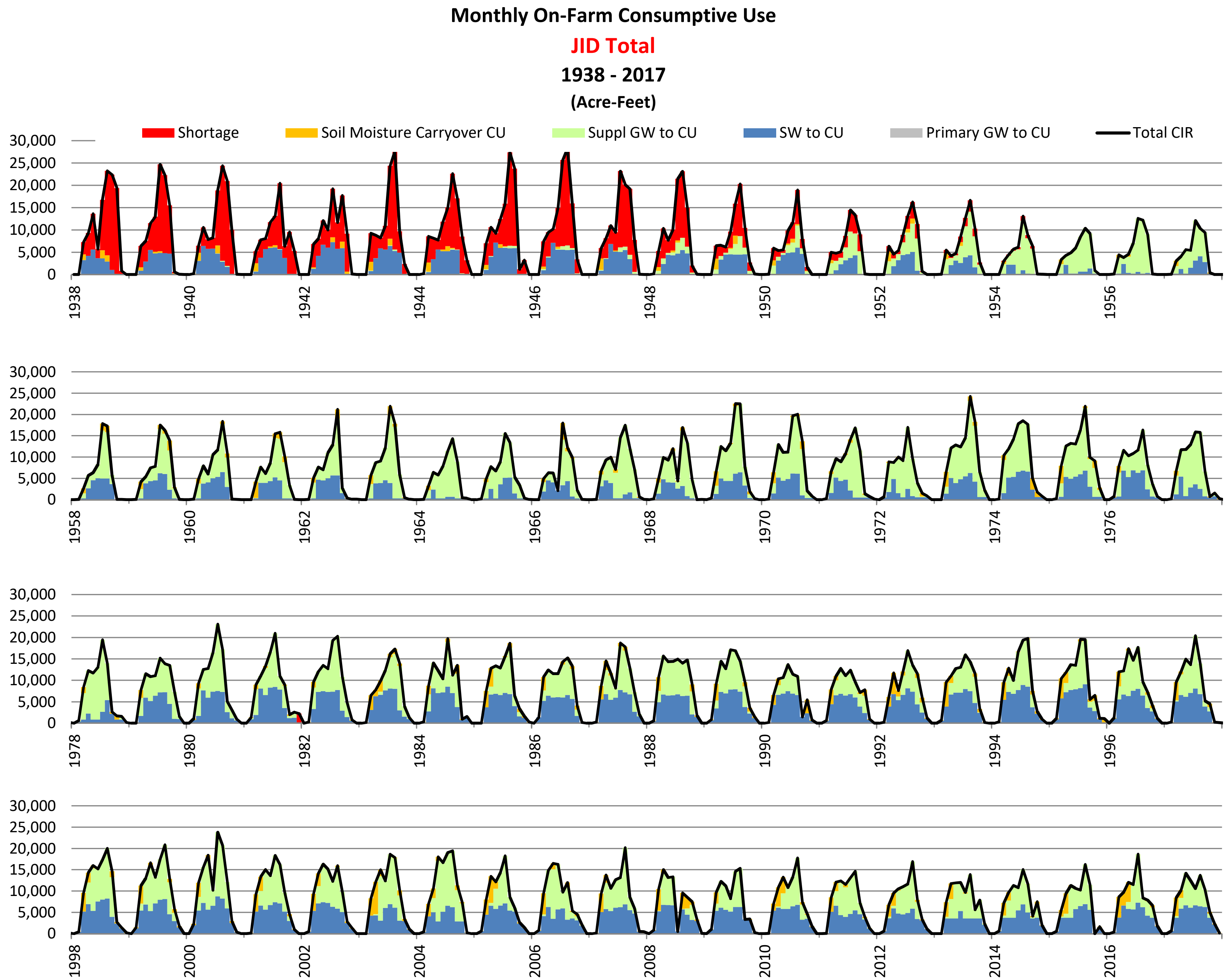
1938 - 2017

(Acre-Feet)




Monthly On-Farm Consumptive Use
EPCWID Total
1938 - 2017
(Acre-Feet)
Shortage
Soil Moisture Carryover CU
Suppl GW to CU
SW to CU
Primary GW to CU
Total CIR
40,000
30,000
20,000
10,000
0
1938
1940
1942
1944
1946
1948
1950
1952
1954
1956
1958
1960
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016


Monthly On-Farm Consumptive Use
HCCRD
1938 - 2017
(Acre-Feet)
CU of Storage Water
Shortage
Soil Moisture Carryover CU
Suppl GW to CU
SW to CU
Primary GW to CU
Total CIR
10,000
8,000
6,000
4,000
2,000
0
1938
1940
1942
1944
1946
1948
1950
1952
1954
1956
1958
1960
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016


Monthly On-Farm Consumptive Use
JID Total
1938 - 2017
(Acre-Feet)
Shortage
Soil Moisture Carryover CU
Suppl GW to CU
SW to CU
Primary GW to CU
Total CIR

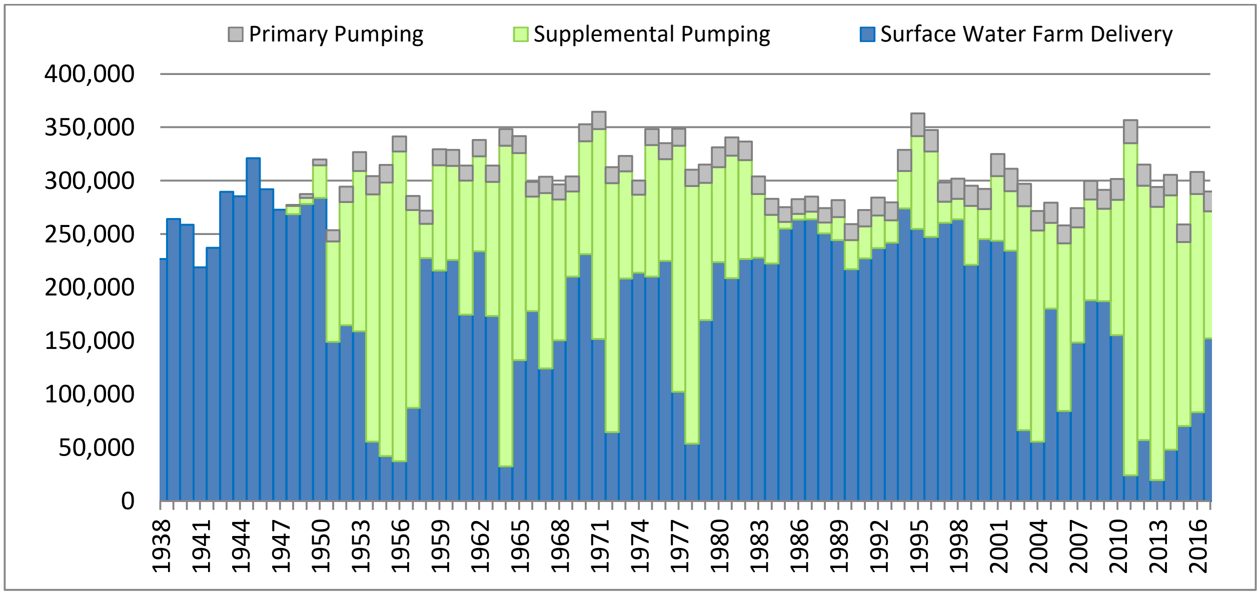
Canal and Farm Water Budget

EBID Total

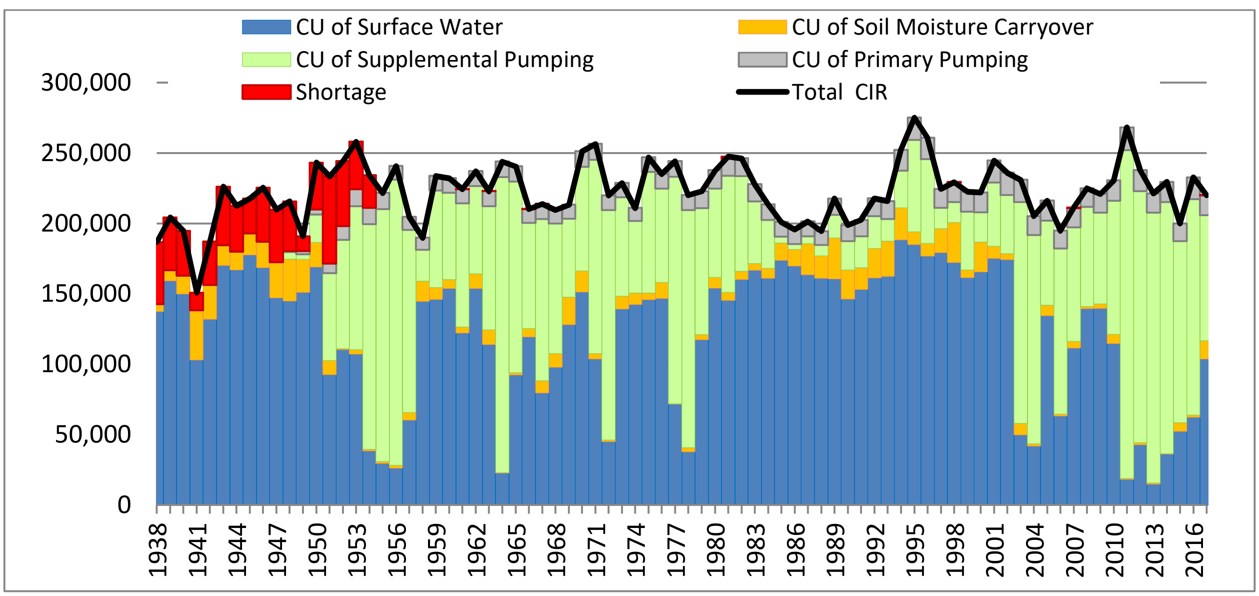
1938 - 2017

Annual Values

Annual Farm Deliveries (Acre-Feet)



Annual CIR and Consumptive Use (Acre-Feet)



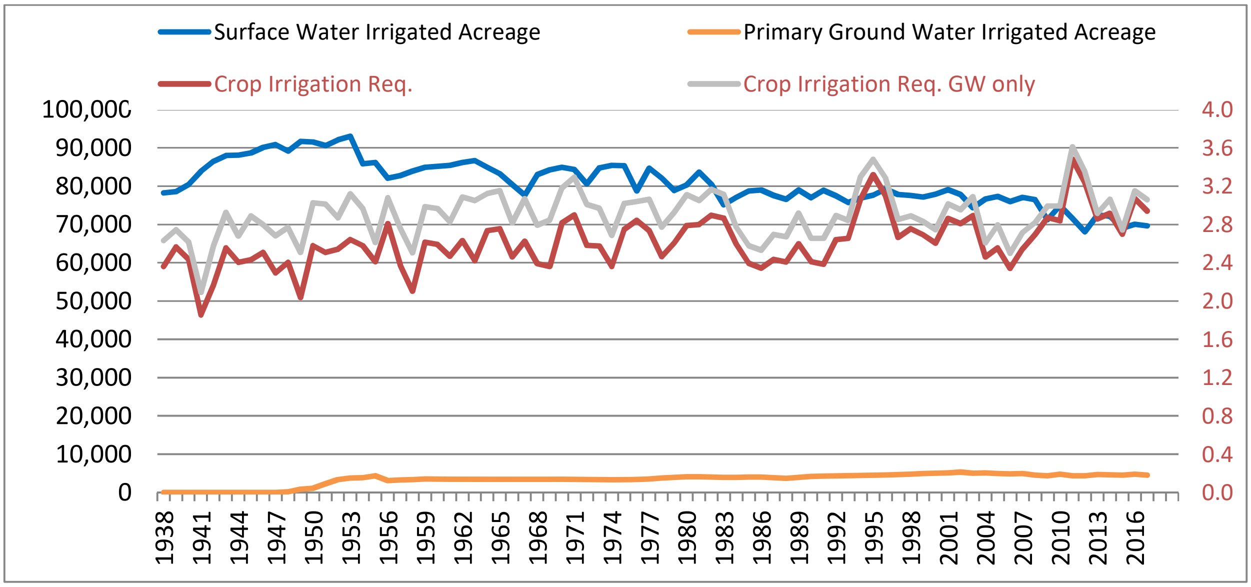
Canal and Farm Water Budget

EBID Total

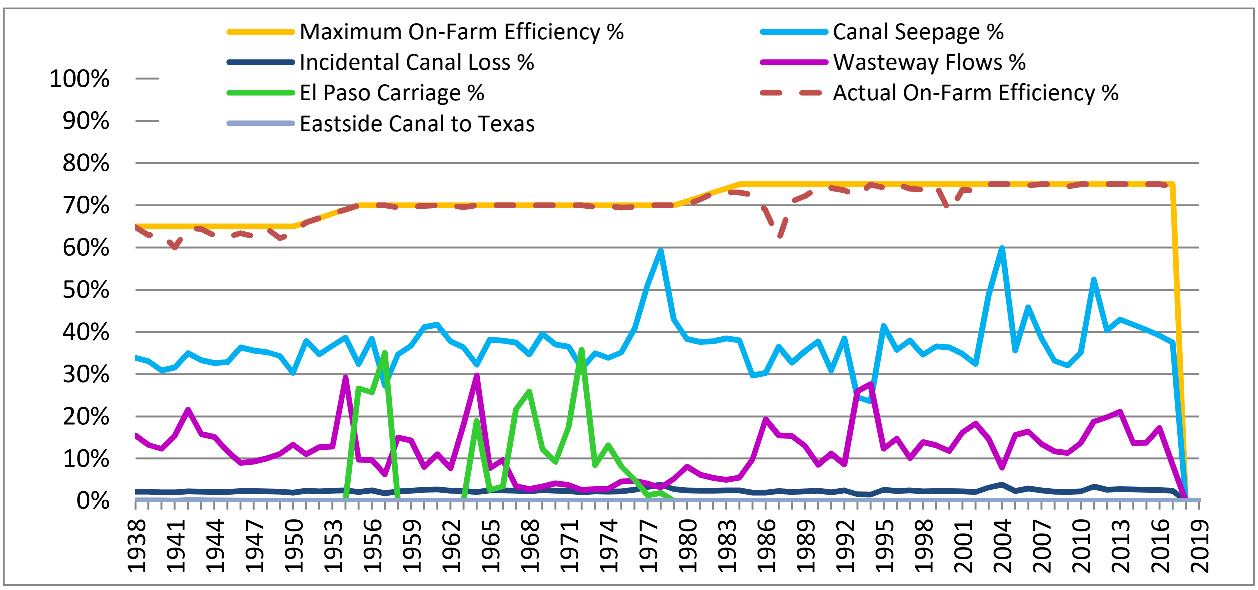
1938 - 2017

Annual Values

Irrigated Area (Acres) and Unit CIR (feet)



Loss and Efficiency Percentages



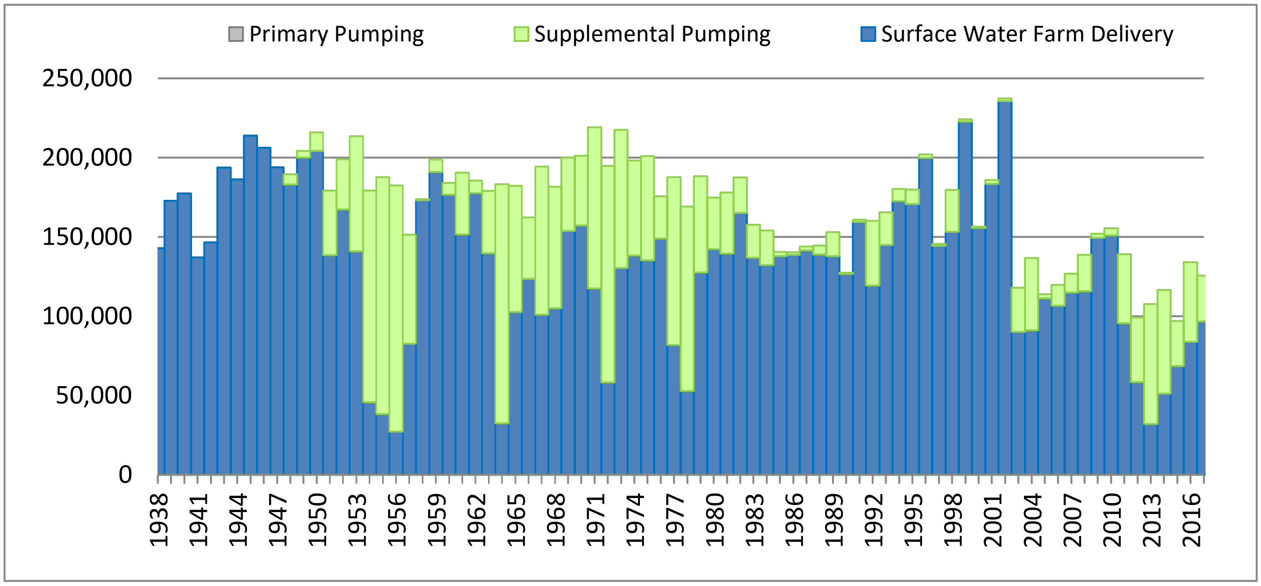
Canal and Farm Water Budget

EPCWID Total

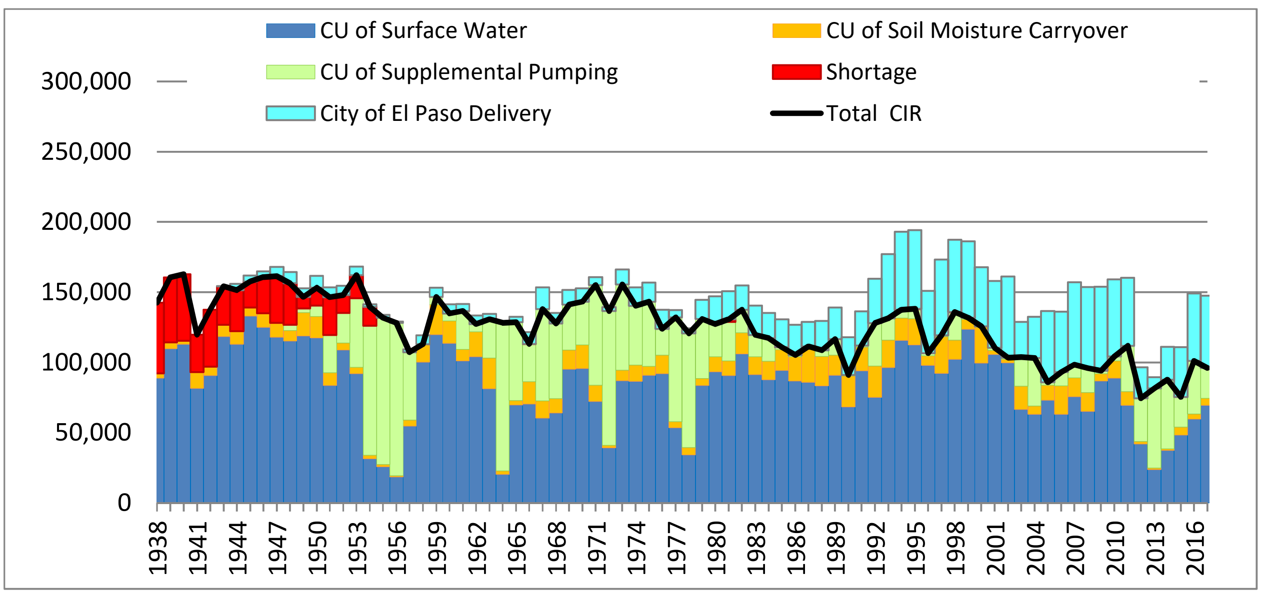
1938 - 2017

Annual Values

Annual Farm Deliveries (Acre-Feet)



Annual CIR, Consumptive Use, and Municipal Diversions (Acre-Feet)



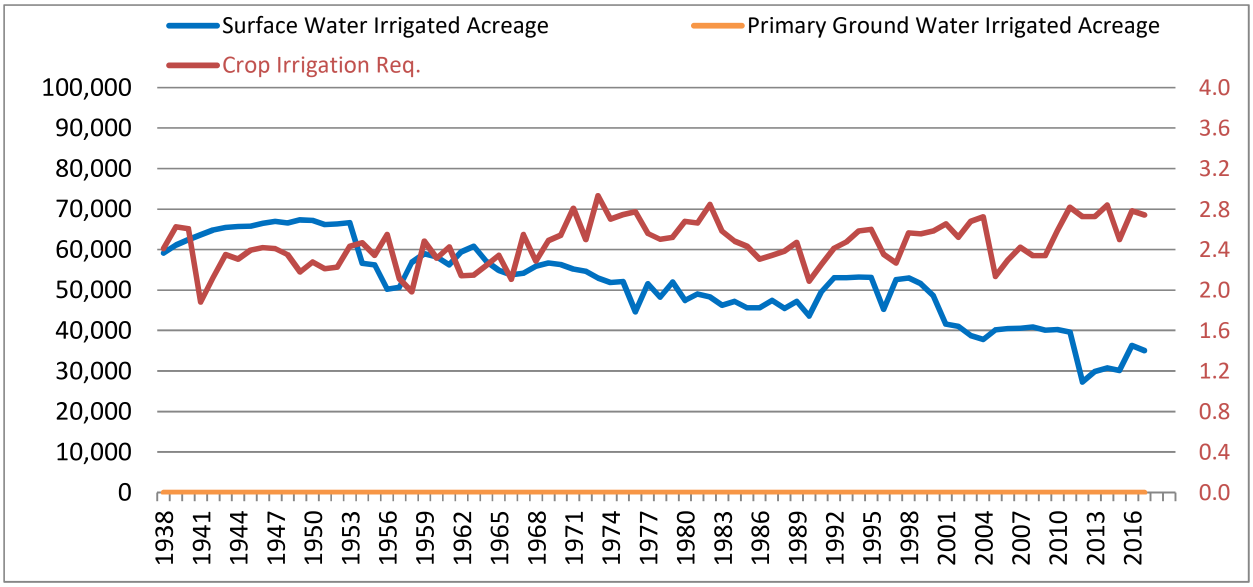
Canal and Farm Water Budget

EPCWID Total

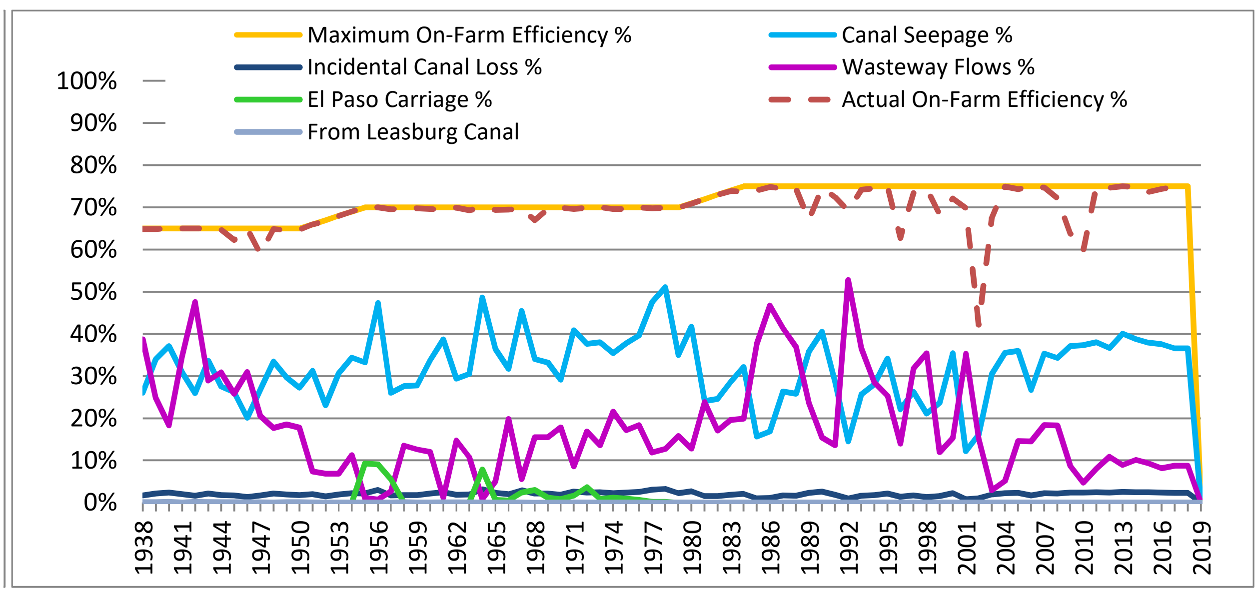
1938 - 2017

Annual Values

Irrigated Area (Acres) and Unit CIR (feet)



Loss and Efficiency Percentages



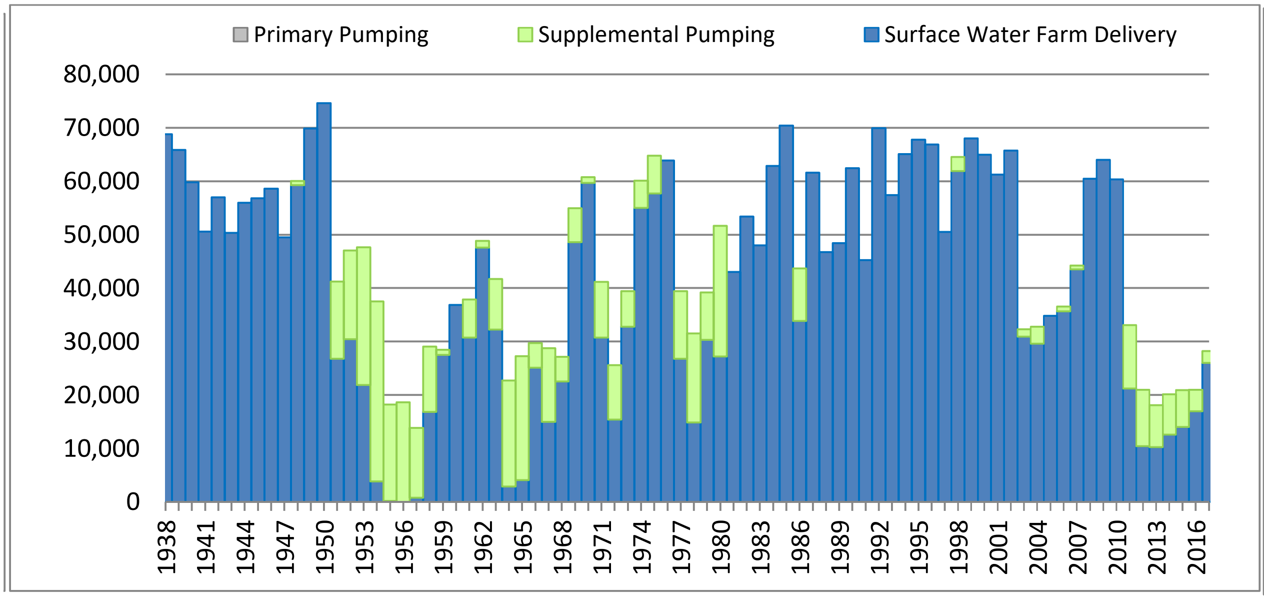
Canal and Farm Water Budget

HCCRD

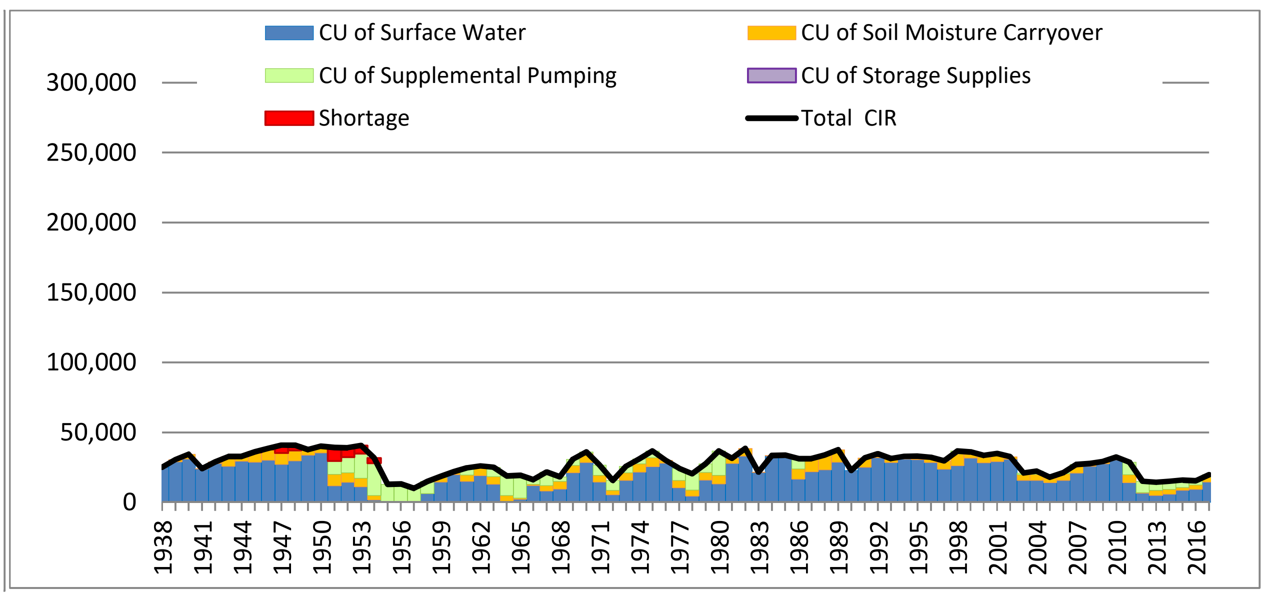
1938 - 2017

Annual Values

Annual Farm Deliveries (Acre-Feet)



Annual CIR and Consumptive Use (Acre-Feet)



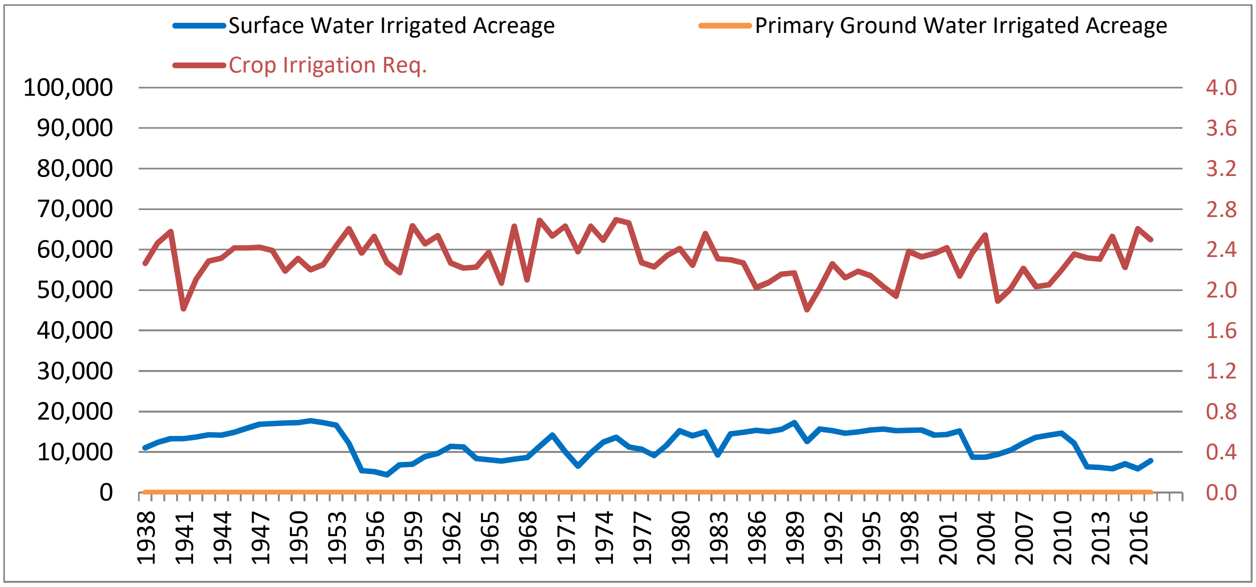
Canal and Farm Water Budget

HCCRD

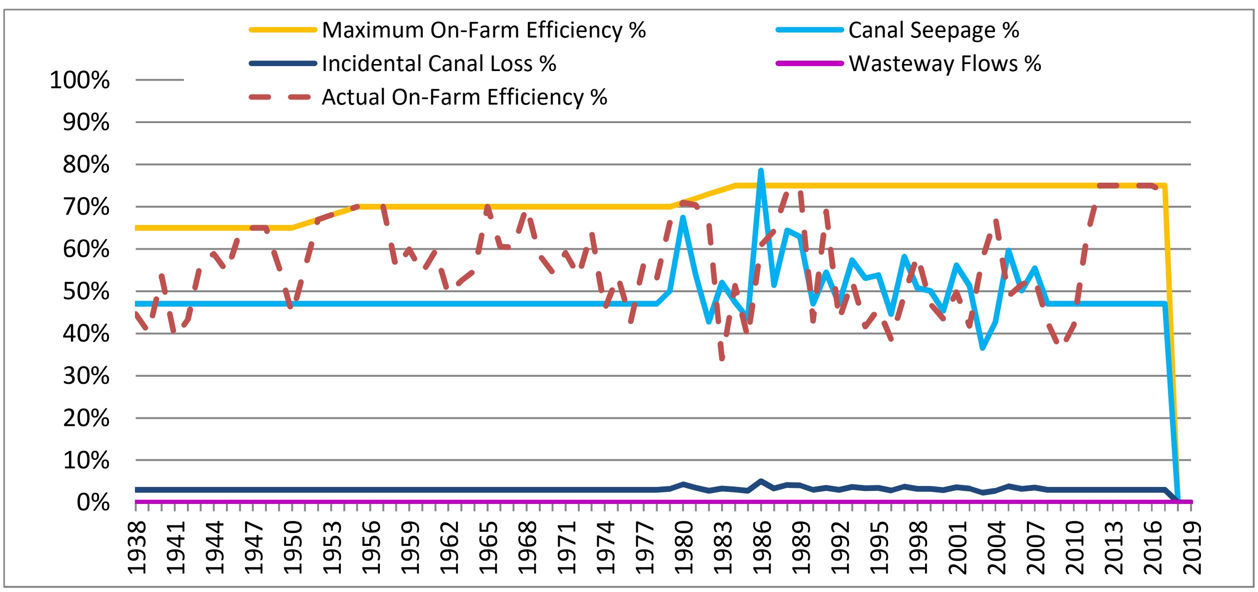
1938 - 2017

Annual Values

Irrigated Area (Acres) and Unit CIR (feet)



Loss and Efficiency Percentages



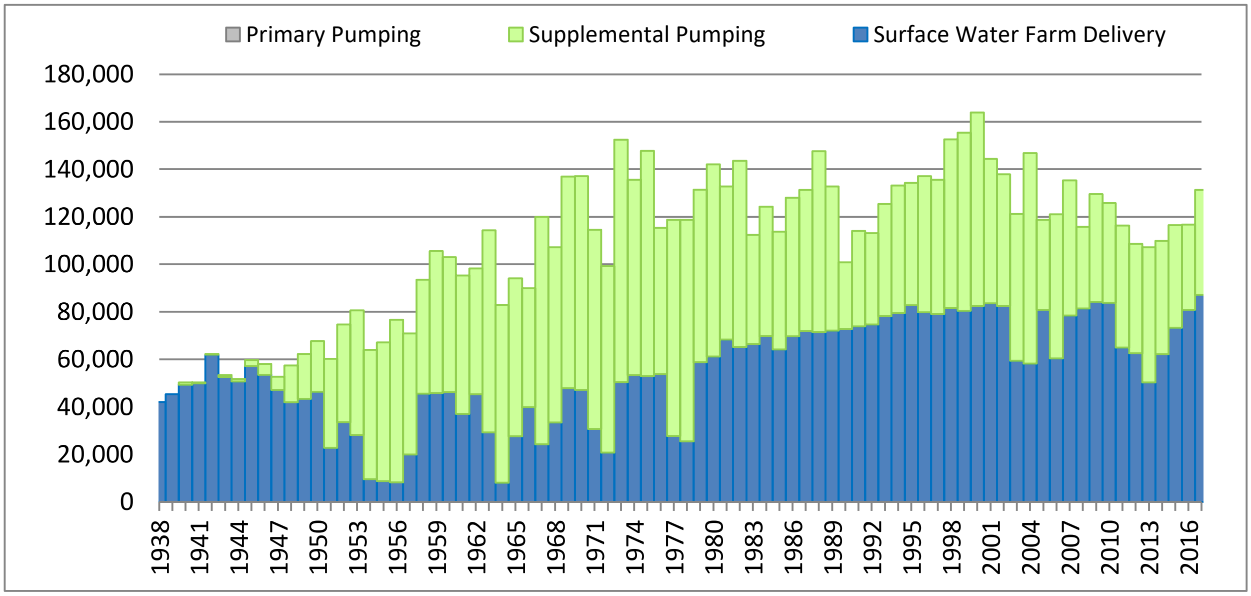
Canal and Farm Water Budget

JID Total

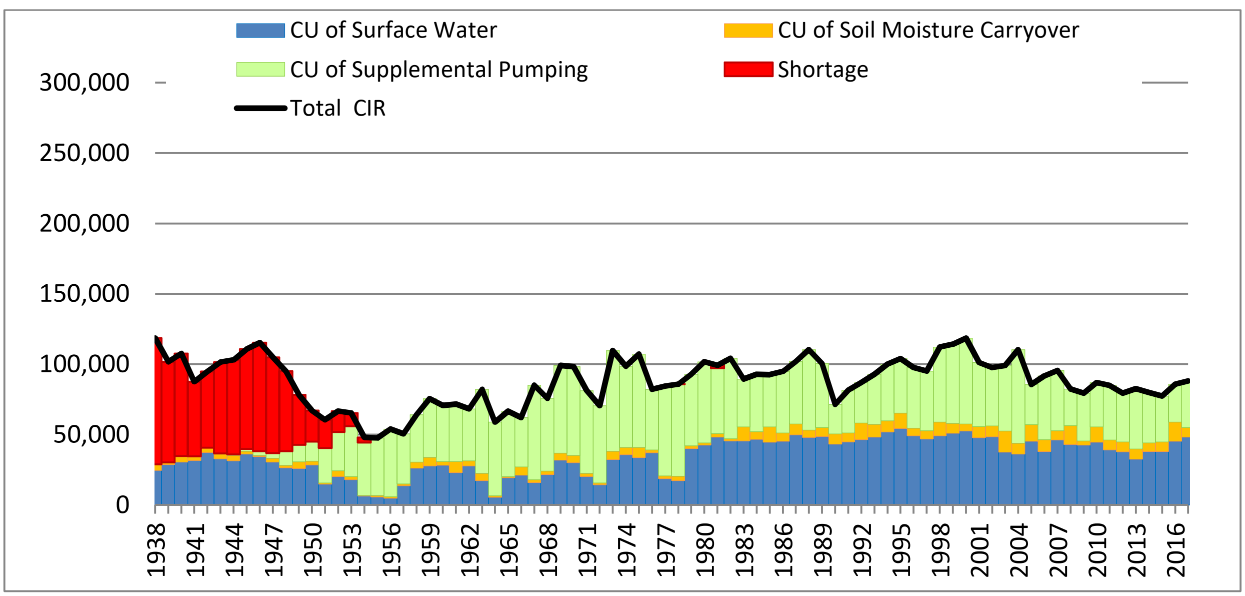
1938 - 2017

Annual Values

Annual Farm Deliveries (Acre-Feet)



Annual CIR and Consumptive Use (Acre-Feet)



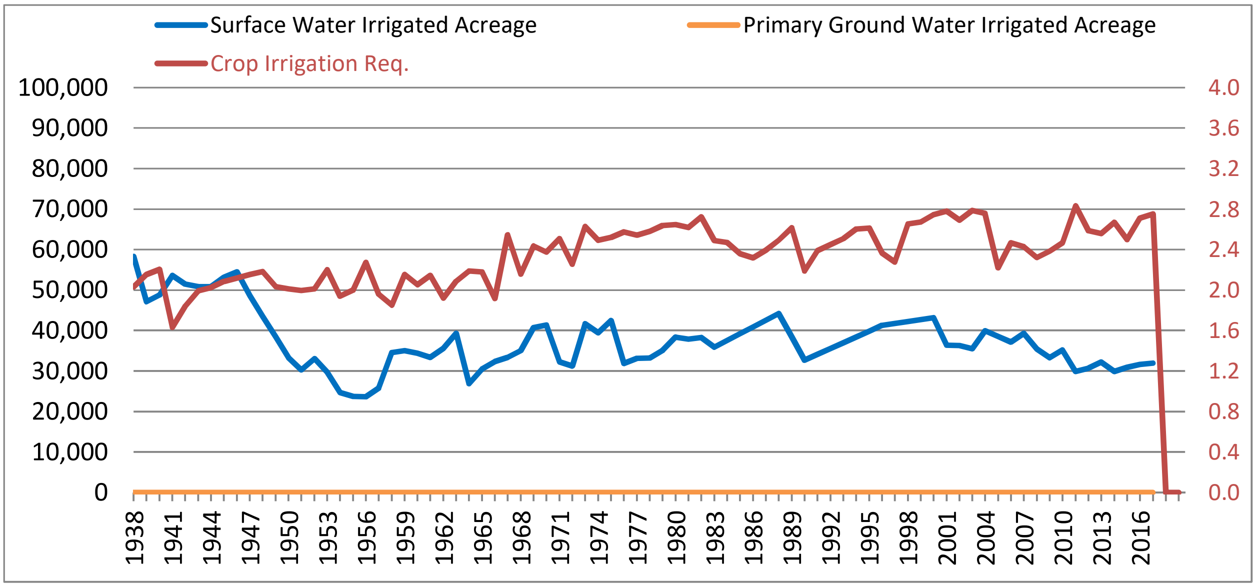
Canal and Farm Water Budget

JID Total

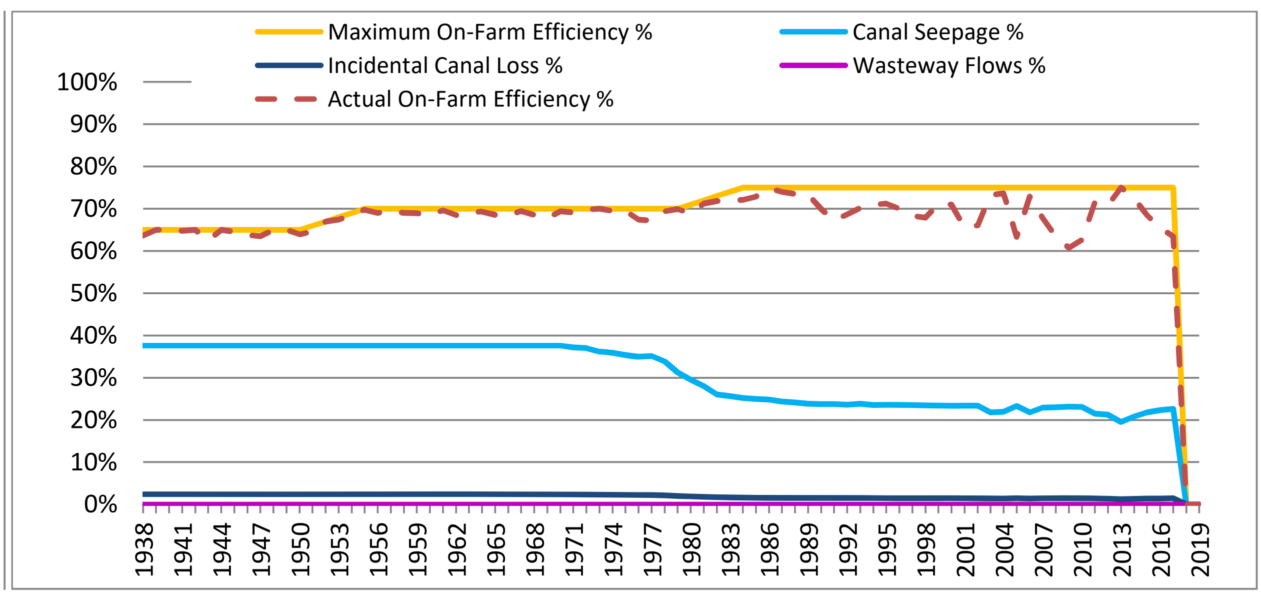
1938 - 2017

Annual Values

Irrigated Area (Acres) and Unit CIR (feet)

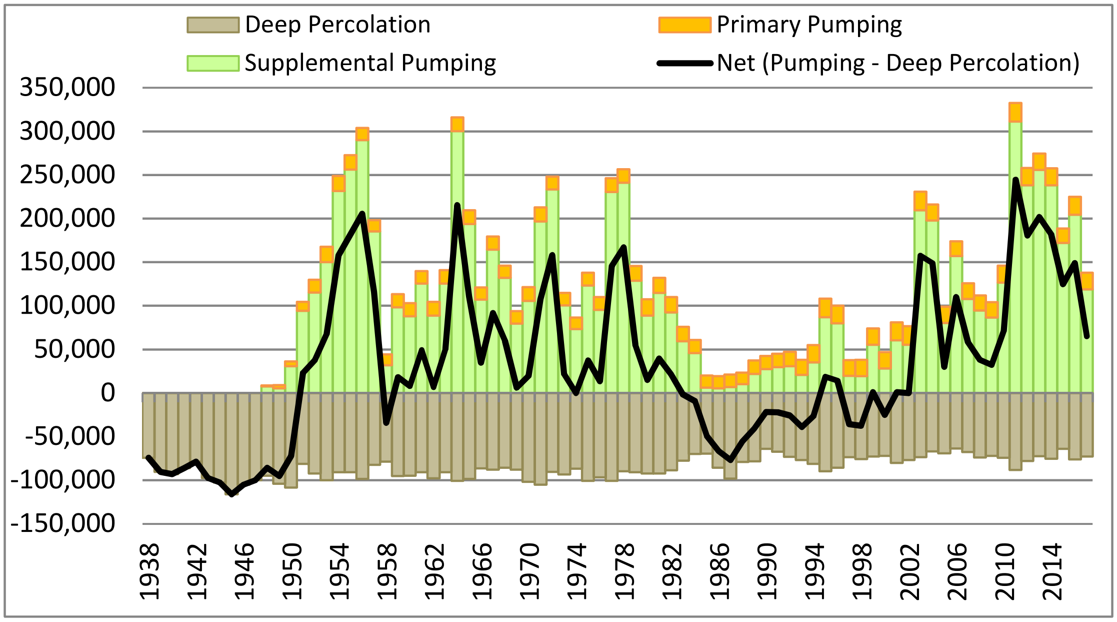


Loss and Efficiency Percentages

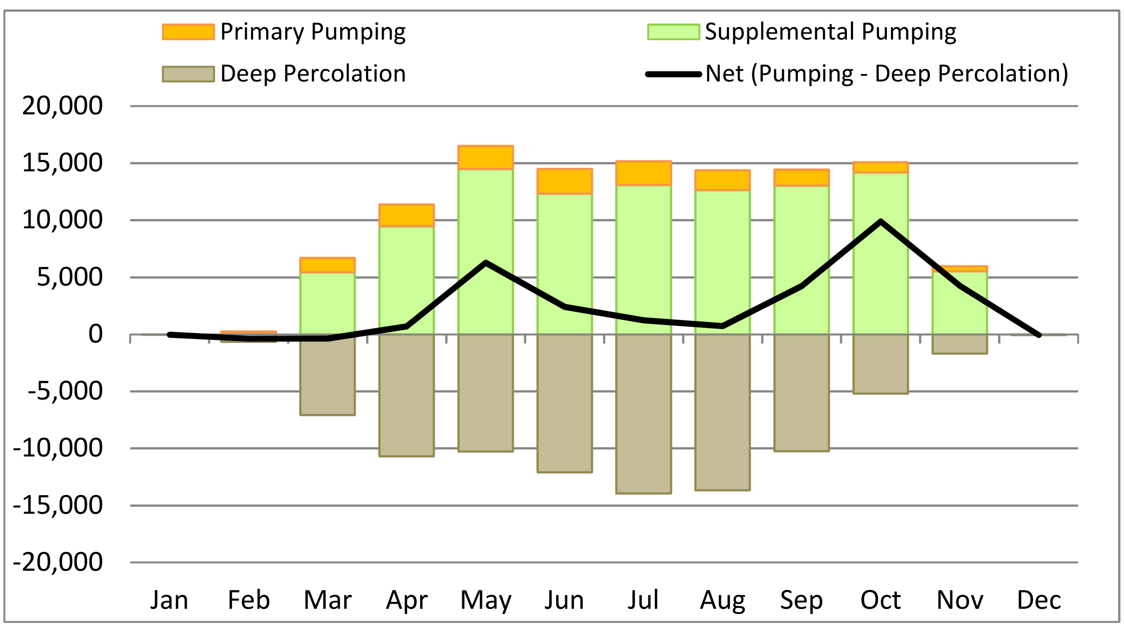


Canal and Farm Water Budget
EBID Total
1938 - 2017

Annual Pumping and Deep Percolation (Acre-Feet)

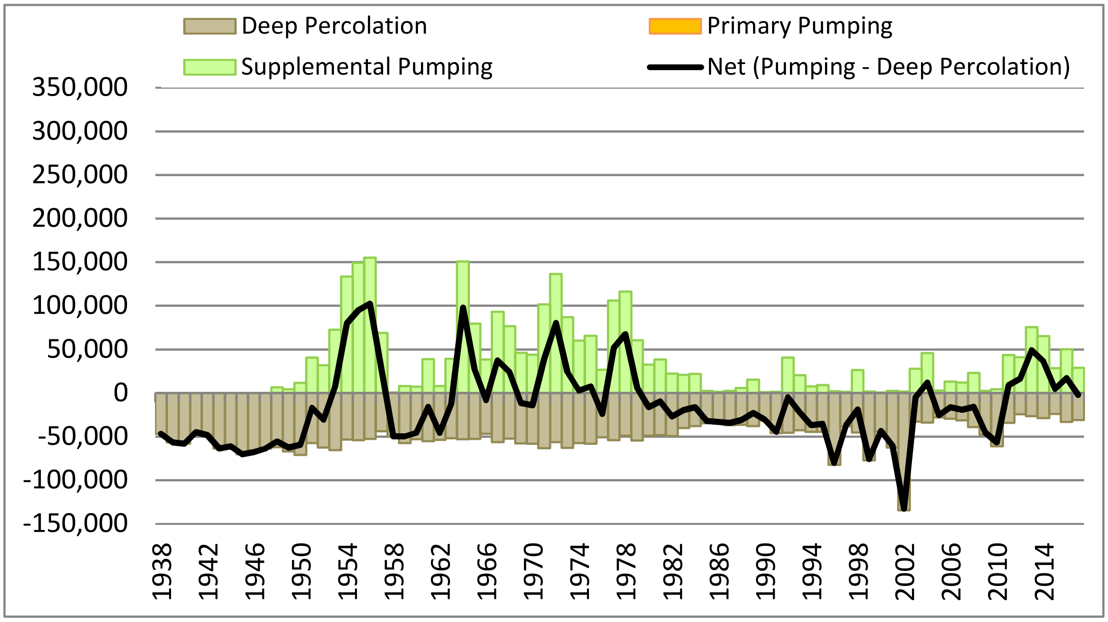


Average Monthly Pumping and Deep Percolation (Acre-Feet)

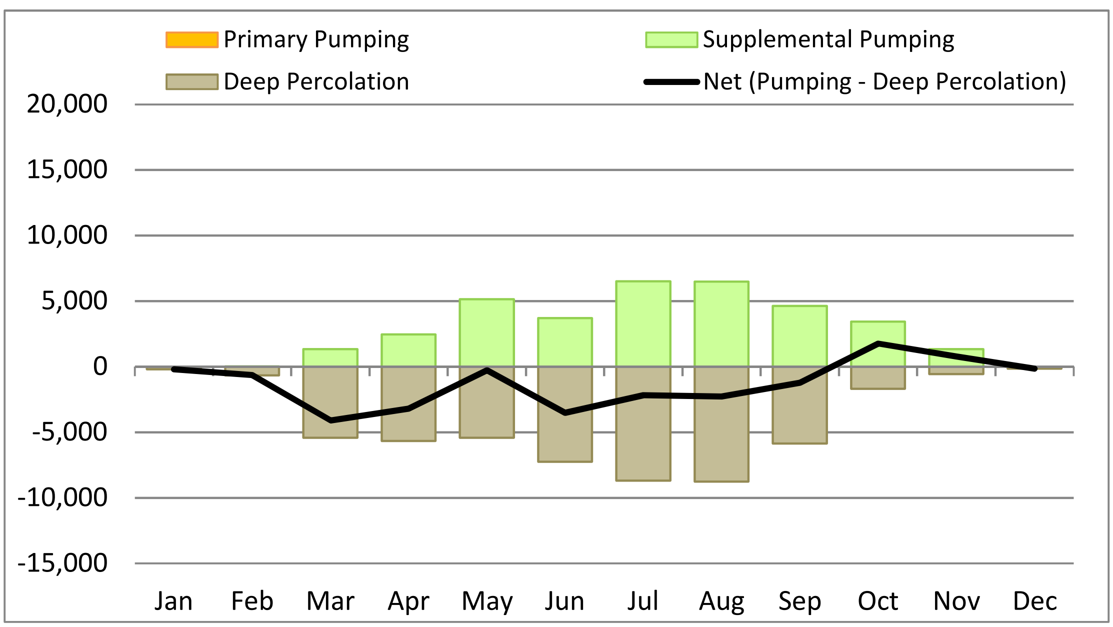


Canal and Farm Water Budget
EPCWID Total
1938 - 2017

Annual Pumping and Deep Percolation (Acre-Feet)

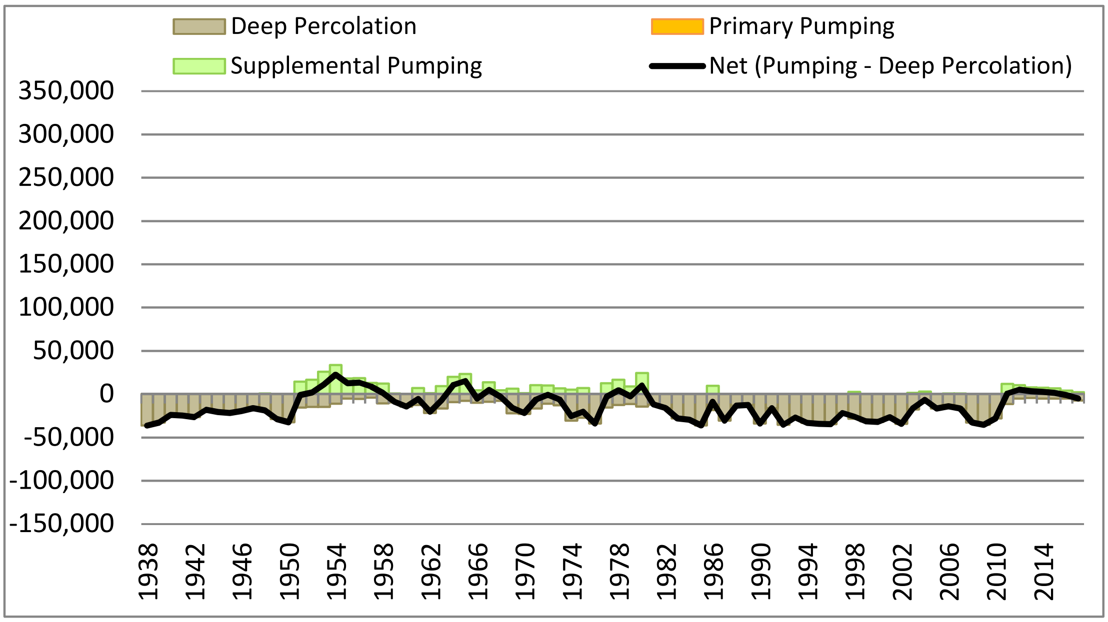


Average Monthly Pumping and Deep Percolation (Acre-Feet)

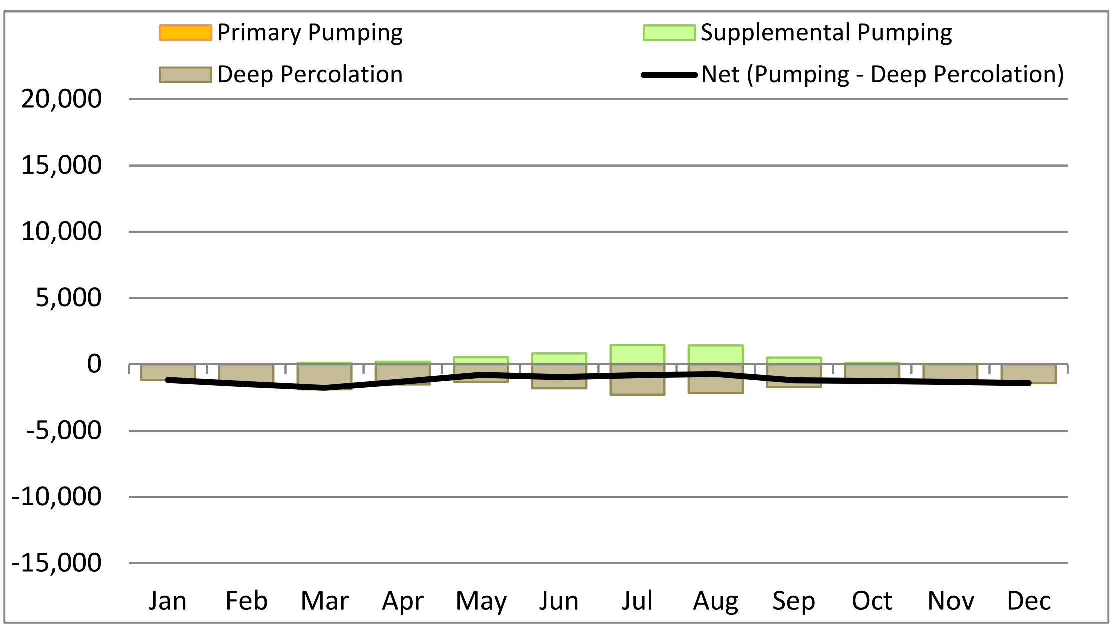


Canal and Farm Water Budget
HCCRD
1938 - 2017

Annual Pumping and Deep Percolation (Acre-Feet)

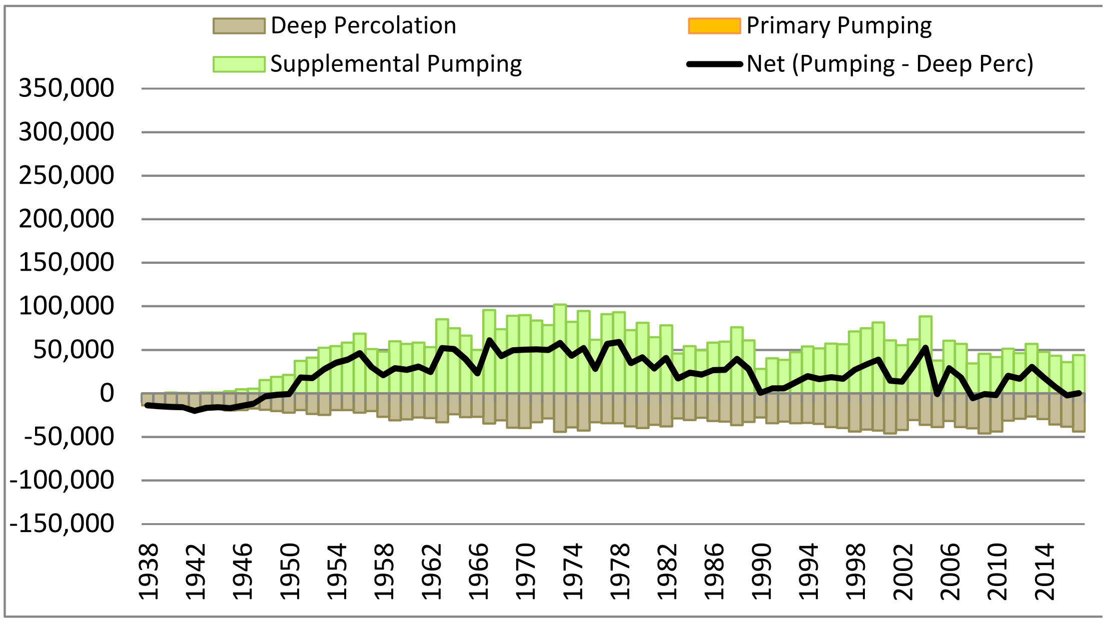


Average Monthly Pumping and Deep Percolation (Acre-Feet)

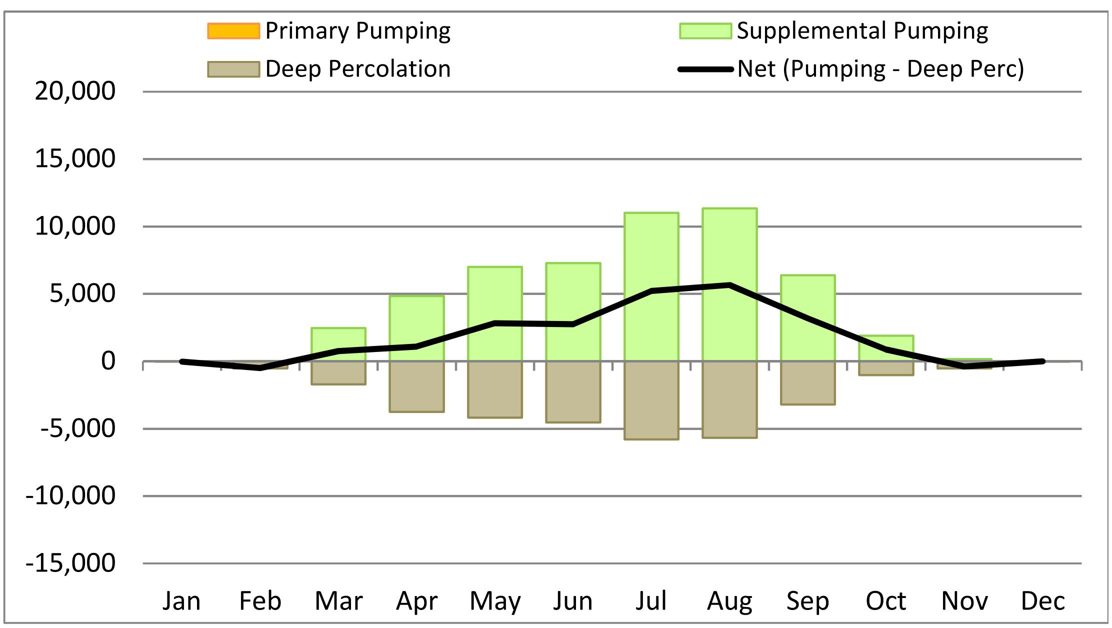


Canal and Farm Water Budget
JID Total
1938 - 2017

Annual Pumping and Deep Percolation (Acre-Feet)



Average Monthly Pumping and Deep Percolation (Acre-Feet)



Canal and Farm Water Budget

EBID Total

1938 - 2017

Monthly Averages (Acre-Feet)

	Water User/Supply	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
	Surface Water Supply (AF)													
(1)	Surface Water Diversion	893	6,753	43,273	49,503	46,206	62,578	68,270	63,932	40,999	9,681	1,699	1,241	395,029
(2)	Total Canal Loss	451	2,818	19,072	15,218	18,682	26,469	26,480	23,306	12,883	3,821	927	649	150,777
(3)	Wasteway Flows	268	2,025	4,762	5,901	5,686	5,782	6,617	6,809	5,665	2,016	465	405	46,399
(4)	Eastside Canal to Texas	2	5	17	17	16	17	20	20	18	10	3	4	149
(5)	El Paso Valley Carriage	25	146	889	2,072	1,437	1,629	1,889	1,399	982	15	0	0	10,482
(6)	SW Farm Delivery (1)-(2)-(3)-(5)	146	1,759	18,533	26,296	20,385	28,680	33,264	32,399	21,451	3,819	303	184	187,221
	Ground Water Supply (AF)													
(7)	Suppl Ground Water Pumping	0	174	5,431	9,478	14,509	12,329	13,092	12,637	13,025	14,180	5,514	0	100,368
(8)	Primary Ground Water Pumping	0	81	1,255	1,898	2,016	2,181	2,086	1,755	1,425	895	444	0	14,036
(9)	Total Ground Water Pumping (7)+(8)	0	255	6,685	11,375	16,525	14,510	15,178	14,392	14,451	15,075	5,958	0	114,403
	On-Farm Water Budget (AF)													
(10)	Total Farm Deliveries (6)+(9)	146	2,014	25,219	37,671	36,910	43,190	48,442	46,791	35,902	18,894	6,261	184	301,624
(11)	BOM Soil Moisture	3,626	4,127	4,821	5,807	5,860	4,503	4,582	4,882	4,855	4,103	2,691	3,054	
(12)	CU of Surface Water	0	243	10,893	16,715	14,253	19,661	22,359	21,671	14,617	2,590	193	8	123,205
(13)	CU of Soil Moisture Carryover	0	238	1,211	1,581	1,523	507	416	714	1,145	1,893	937	39	10,205
(14)	CU of Supplemental Pumping	0	126	3,944	6,864	10,442	8,862	9,406	9,090	9,334	10,135	4,001	0	72,205
(15)	CU of Primary Pumping	0	59	913	1,377	1,467	1,587	1,517	1,275	1,035	652	324	0	10,205
(16)	Total CU (12)+(13)+(14)+(15)	0	667	16,962	26,537	27,684	30,618	33,698	32,750	26,131	15,269	5,454	47	215,819
(17)	EOM Soil Moisture	3,726	4,821	5,807	5,860	4,499	4,582	4,882	4,739	4,023	2,386	1,760	3,117	
(18)	Surface Runoff	1	16	209	391	329	399	498	506	368	160	49	4	2,930
(19)	Deep Percolation	45	637	7,061	10,690	10,258	12,095	13,945	13,678	10,234	5,181	1,690	69	85,584
(20)	Total On-Farm Loss (18)+(19)	47	653	7,270	11,081	10,587	12,494	14,443	14,185	10,602	5,341	1,738	73	88,514
(21)	Balance (10)-(16)-(20)-((17)-(11))	0	0	0	0	0	0	0	0	0	0	0	0	0
(22)	Shortage	0	1	499	169	580	647	781	904	1,332	2,065	226	39	7,242
(23)	On-Farm Efficiency	70%	66%	70%	70%	70%	71%	70%	70%	70%	70%	67%	66%	

Canal and Farm Water Budget

EP#1 Total

1938 - 2017

Monthly Averages (Acre-Feet)

	Water User/Supply	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
	Surface Water Supply (AF)													
(1)	Surface Water Diversion	3,007	7,923	34,935	30,789	29,263	40,699	46,799	44,415	30,641	13,471	6,682	4,254	292,877
(2)	Total Canal Loss	1,029	2,731	12,666	7,951	9,997	14,722	16,158	13,880	7,911	4,519	2,289	1,218	95,070
(3)	Wasteway Flows	1,319	3,186	5,156	5,804	5,489	5,423	7,506	7,480	8,095	6,444	3,733	2,588	62,223
(4)	From Leasburg Canal	2	5	17	17	16	17	20	20	18	10	3	4	149
(5)	El Paso Valley Carriage	2	7	54	182	120	137	156	123	85	1	0	0	867
(6)	SW Farm Delivery (1)-(2)-(3)-(5)+(4)	659	2,004	17,076	16,869	13,673	20,435	22,999	22,951	14,569	2,518	664	452	134,867
	Ground Water Supply (AF)													
(7)	Suppl Ground Water Pumping	0	20	1,335	2,466	5,160	3,720	6,511	6,495	4,628	3,447	1,330	0	35,112
(8)	Primary Ground Water Pumping	0	0	0	0	0	0	0	0	0	0	0	0	0
(9)	Total Ground Water Pumping (7)+(8)	0	20	1,335	2,466	5,160	3,720	6,511	6,495	4,628	3,447	1,330	0	35,112
	On-Farm Water Budget (AF)													
(10)	Total Farm Deliveries (6)+(9)	659	2,024	18,411	19,335	18,832	24,155	29,510	29,447	19,197	5,964	1,994	452	169,979
(11)	BOM Soil Moisture	3,210	3,902	4,842	7,812	6,501	4,398	4,524	3,899	3,183	3,307	2,298	2,656	
(12)	CU of Surface Water	0	334	8,022	10,580	9,389	13,190	15,409	15,615	9,286	1,691	384	37	83,938
(13)	CU of Soil Moisture Carryover	0	68	876	2,427	2,258	735	1,138	897	501	1,292	527	20	10,739
(14)	CU of Supplemental Pumping	0	15	949	1,752	3,668	2,620	4,602	4,596	3,285	2,470	966	0	24,923
(15)	CU of Primary Pumping	0	0	0	0	0	0	0	0	0	0	0	0	0
(16)	Total CU (12)+(13)+(14)+(15)	0	417	9,847	14,760	15,315	16,545	21,149	21,108	13,072	5,453	1,877	57	119,601
(17)	EOM Soil Moisture	3,667	4,842	7,812	6,501	4,398	4,522	3,899	3,151	3,245	2,078	1,844	2,906	
(18)	Surface Runoff	5	19	163	229	198	241	302	315	203	56	19	6	1,758
(19)	Deep Percolation	197	648	5,430	5,657	5,422	7,245	8,683	8,772	5,861	1,685	552	139	50,290
(20)	Total On-Farm Loss (18)+(19)	202	667	5,594	5,887	5,620	7,486	8,985	9,086	6,064	1,741	571	146	52,047
(21)	Balance (10)-(16)-(20)-((17)-(11))	0	0	0	0	0	0	0	0	0	0	0	0	0
(22)	Shortage	0	0	448	103	323	416	964	1,180	1,176	982	214	37	5,842
(23)	On-Farm Efficiency	73%	66%	69%	71%	71%	70%	70%	70%	69%	70%	69%	66%	

Canal and Farm Water Budget

HCCRD

1938 - 2017

Monthly Averages (Acre-Feet)

	Water User/Supply	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
	Surface Water Supply (AF)													
(1)	Surface Water Diversion	3,598	4,106	7,048	8,516	8,008	8,867	11,017	11,131	10,619	7,561	5,041	4,255	89,766
(2)	Diversion to Storage	0	0	0	0	0	0	0	0	0	0	0	0	0
(3)	Diversion from Storage	0	0	0	0	0	0	0	0	0	0	0	0	0
(4)	Canal Loss on SW	2,094	2,250	3,254	4,654	4,645	4,410	5,310	5,635	6,090	4,542	2,849	2,396	48,128
(5)	Canal Loss on Storage	0	0	0	0	0	0	0	0	0	0	0	0	0
(6)	Wasteway Flows	0	0	0	0	0	0	0	0	0	0	0	0	0
(7)	Farm Delivery (1)+(3)-(2)-(4)-(5)-(6)	1,504	1,856	3,794	3,862	3,362	4,458	5,707	5,495	4,529	3,019	2,192	1,859	41,638
(8)	Suppl Ground Water Pumping	0	0	109	208	532	824	1,458	1,443	516	95	25	0	5,211
(9)	Primary Ground Water Pumping	0	0	0	0	0	0	0	0	0	0	0	0	0
(10)	Total Ground Water Pumping (8)+(9)	0	0	109	208	532	824	1,458	1,443	516	95	25	0	5,211
	On-Farm Water Budget (AF)													
(11)	Total Farm Deliveries (7)+(10)	1,504	1,856	3,904	4,070	3,894	5,282	7,165	6,938	5,045	3,114	2,217	1,859	46,849
(12)	BOM Soil Moisture	4,544	4,897	5,121	4,852	4,185	3,344	3,084	2,656	2,163	2,616	3,321	4,143	
(13)	CU of Surface Water	0	91	1,711	2,341	2,138	2,654	3,696	3,548	2,354	894	246	17	19,688
(14)	CU of Soil Moisture Carryover	0	6	467	700	860	474	521	666	202	173	5	0	4,074
(15)	CU of Storage Supplies	0	0	0	0	0	0	0	0	0	0	0	0	0
(16)	CU of Supplemental Pumping	0	0	77	145	375	579	1,026	1,020	362	67	17	0	3,669
(17)	CU of Primary Pumping	0	0	0	0	0	0	0	0	0	0	0	0	0
(18)	Total CU	0	97	2,255	3,187	3,373	3,707	5,244	5,233	2,918	1,134	269	17	27,432
(19)	EOM Soil Moisture	4,830	5,121	4,852	4,185	3,344	3,067	2,656	2,119	2,521	3,204	3,892	4,514	
(20)	Surface Runoff	37	42	46	49	51	59	73	70	57	42	43	51	620
(21)	Deep Percolation	1,181	1,493	1,873	1,501	1,311	1,792	2,275	2,173	1,712	1,350	1,335	1,420	19,416
(22)	Total On-Farm Loss (20)+(21)	1,218	1,535	1,919	1,550	1,362	1,852	2,348	2,243	1,769	1,392	1,377	1,471	20,036
(23)	Balance (11)-(18)-(22)-((19)-(12))	0	0	0	0	0	0	0	0	0	0	0	0	0
(24)	Shortage	0	0	0	5	20	48	93	110	141	26	1	3	447
(25)	On-Farm Efficiency	39%	29%	60%	66%	68%	67%	68%	69%	67%	61%	47%	34%	

Canal and Farm Water Budget

JID Total

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Monthly Averages (Acre-Feet)

	Water User/Supply	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
	Surface Water Supply (AF)													
(1)	Surface Water Diversion	25	2,602	5,030	11,800	11,390	12,082	12,687	12,046	7,093	2,616	2,508	0	79,879
(2)	Total Canal Loss	7	614	1,399	3,777	3,747	3,895	4,079	3,877	2,219	621	587	0	24,822
(3)	Wasteway Flows	0	0	0	0	0	0	0	0	0	0	0	0	0
(4)	SW Farm Delivery (1)-(2)-(3)	18	1,988	3,631	8,023	7,644	8,186	8,608	8,168	4,874	1,995	1,921	0	55,057
	Ground Water Supply (AF)													
(5)	Suppl Ground Water Pumping	0	13	2,457	4,832	7,003	7,291	11,012	11,337	6,385	1,901	158	0	52,389
(6)	Primary Ground Water Pumping	0	0	0	0	0	0	0	0	0	0	0	0	0
(7)	Total Ground Water Pumping (5)+(6)	0	13	2,457	4,832	7,003	7,291	11,012	11,337	6,385	1,901	158	0	52,389
	On-Farm Water Budget (AF)													
(8)	Total Farm Deliveries (4)+(7)	18	2,001	6,088	12,855	14,646	15,477	19,620	19,505	11,258	3,896	2,080	0	107,446
(9)	BOM Soil Moisture	2,672	2,850	3,976	1,635	1,176	1,299	1,571	1,348	1,163	1,087	1,190	2,544	
(10)	CU of Surface Water	0	286	2,545	5,032	4,815	5,182	5,594	5,457	3,292	1,358	632	0	34,192
(11)	CU of Soil Moisture Carryover	0	56	2,402	932	304	103	356	288	376	363	96	42	5,317
(12)	CU of Supplemental Pumping	0	9	1,736	3,494	5,104	5,285	7,943	8,159	4,580	1,371	112	0	37,793
(13)	CU of Primary Pumping	0	0	0	0	0	0	0	0	0	0	0	0	0
(14)	Total CU (10)+(11)+(12)+(13)	0	351	6,683	9,458	10,223	10,569	13,893	13,904	8,247	3,092	839	42	77,303
(15)	EOM Soil Moisture	2,672	3,976	1,635	1,176	1,299	1,539	1,348	1,103	863	834	1,888	2,501	
(16)	Surface Runoff	0	9	47	105	123	129	165	167	100	24	10	0	879
(17)	Deep Percolation	18	515	1,699	3,752	4,177	4,539	5,785	5,680	3,211	1,033	532	0	30,941
(18)	Total On-Farm Loss (16)+(17)	18	524	1,747	3,857	4,300	4,669	5,950	5,847	3,311	1,057	541	0	31,820
(19)	Balance (8)-(14)-(18)-((15)-(9))	0	0	0	0	0	0	0	0	0	0	0	0	0
(20)	Shortage	0	0	689	773	569	862	2,084	2,740	1,836	925	154	27	10,659
(21)	On-Farm Efficiency	75%	68%	70%	67%	69%	68%	67%	68%	70%	70%	68%	0%	

Canal and Farm Water Budget

EBID Total

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Annual Totals (Acre-Feet)

Year	SW Acres	Primary GW Acres	Total CIR	Excess Effective Precip	Surface Water Divers	Total Canal Loss	Wasteway Flows	Eastside Canal to Texas	El Paso Valley Carriage	SW Farm Delivery	Suppl Ground Water Pumping	Primary Ground Water Pumping	Total Ground Water Pumping	CU of Surface Water	CU of SM Carryover	CU of Suppl GW Pumping	CU of Primary GW Pumping	Total CU	Surface Runoff	Deep Perc	Change in Soil Moisture	Shortage
1938	78,237	0	186,810	860	468,254	168,755	72,487	453	0	226,559	0	0	0	137,344	5,359	0	0	142,703	4,956	74,340	380	44,107
1939	78,533	0	204,202	772	512,935	180,490	67,856	492	0	264,098	0	0	0	159,167	7,501	0	0	166,668	6,036	90,538	71	37,534
1940	80,379	0	194,781	1,469	472,715	155,000	58,233	632	0	258,851	0	0	0	149,793	13,012	0	0	162,805	6,204	93,057	-268	31,976
1941	83,944	0	150,766	11,240	428,114	143,523	65,540	275	0	218,775	0	0	0	103,104	35,236	0	0	138,340	5,732	85,976	-939	12,425
1942	86,482	0	187,104	3,236	575,274	213,633	123,681	918	0	237,042	0	0	0	131,939	24,260	0	0	156,198	5,248	78,724	-261	30,906
1943	88,035	0	226,199	2,369	594,190	210,322	93,683	722	0	289,464	0	0	0	170,067	14,358	0	0	184,424	6,503	97,550	82	41,774
1944	88,116	0	212,450	163	570,079	197,829	86,137	618	0	285,496	0	0	0	166,841	13,123	0	0	179,964	6,841	102,620	-327	32,486
1945	88,714	0	217,788	313	602,349	210,411	70,351	449	0	321,139	0	0	0	177,711	15,258	0	0	192,969	7,746	116,195	352	24,819
1946	90,099	0	225,511	2,186	558,552	216,027	50,136	291	0	292,098	0	0	0	168,434	18,429	0	0	186,863	7,007	105,110	-573	38,648
1947	90,829	0	209,674	4,068	516,168	195,324	47,712	242	0	272,890	0	0	0	147,133	25,318	0	0	172,450	6,669	100,036	-522	37,224
1948	89,162	258	215,686	8,977	511,646	191,588	51,190	257	0	268,610	7,744	1,107	8,851	144,776	29,939	5,034	719	180,468	6,311	94,662	-332	35,235
1949	91,701	928	190,840	4,013	530,898	193,479	58,748	303	0	278,368	5,425	3,607	9,031	151,023	23,441	3,526	2,344	180,334	6,940	104,093	-331	10,578
1950	91,521	1,168	243,180	44	521,122	167,954	69,083	278	0	283,807	30,751	5,439	36,190	169,030	17,390	19,988	3,535	209,944	7,225	108,382	-463	33,314
1951	90,608	2,292	233,413	2,738	306,343	123,298	33,842	146	0	149,057	94,060	10,452	104,512	92,662	9,887	62,079	6,899	171,527	4,850	81,364	-348	62,079
1952	92,109	3,389	244,203	466	326,705	120,519	41,474	89	0	164,623	115,297	14,557	129,854	110,226	814	77,249	9,753	198,042	4,859	92,319	-62	46,350
1953	93,045	3,859	257,980	2,830	330,476	128,998	42,461	63	0	158,954	149,987	17,728	167,715	107,110	3,134	101,991	12,055	224,291	4,573	99,961	-180	33,997
1954	85,834	3,930	234,020	66	187,831	77,265	54,856	13	0	55,696	231,648	17,007	248,656	38,430	1,177	159,837	11,735	211,179	3,538	90,811	-98	23,087
1955	86,153	4,378	221,602	1,422	144,314	49,730	13,993	9	38,488	42,095	256,194	16,462	272,656	29,466	1,422	179,336	11,524	221,748	3,541	90,884	-119	0
1956	82,110	3,192	240,757	3,469	156,405	63,810	15,106	3	40,130	37,357	289,988	14,026	304,014	26,150	1,933	202,992	9,818	240,893	3,840	98,571	-161	0
1957	82,740	3,309	204,405	3,105	294,134	85,347	18,273	30	103,079	87,406	185,182	13,129	198,311	60,346	5,479	129,628	9,190	204,642	3,214	82,501	-387	0
1958	83,923	3,425	189,775	2,912	472,955	174,390	70,592	250	0	227,723	31,794	12,405	44,199	144,581	14,473	22,256	8,683	189,992	3,059	78,517	29	0
1959	84,920	3,542	233,718	807	462,929	180,744	66,072	98	0	216,016	98,319	15,144	113,462	146,124	8,385	68,823	10,601	233,933	3,707	95,137	-275	0
1960	85,162	3,535	232,100	4,920	467,868	204,752	37,212	143	0	225,761	88,063	14,956	103,019	153,871	6,323	61,644	10,469	232,307	3,699	94,935	-180	0
1961	85,388	3,527	224,359	771	391,130	173,436	43,152	74	0	174,468	125,495	14,271	139,767	122,038	4,394	87,847	9,990	224,269	3,535	90,735	-359	230
1962	86,191	3,520	237,089	1,556	448,492	179,997	34,403	247	0	233,845	88,897	15,536	104,433	153,672	10,586	62,228	10,875	237,361	3,806	97,678	-47	0
1963	86,669	3,513	222,613	2,109	400,866	154,809	72,683	109	0	173,265	125,541	15,252	140,793	113,877	10,484	87,879	10,676	222,916	3,533	90,684	-256	27
1964	84,881	3,505	243,808	1,332	189,234	64,917	56,139	23	35,721	32,434	300,222	15,756	315,979	22,674	193	210,156	11,029	244,051	3,920	100,604	-14	0
1965	83,259	3,498	240,467	781	268,540	108,901	20,669	35	6,894	132,041	193,859	15,717	209,577	92,429	1,530	135,702	11,002	240,663	3,843	98,642	-128	0
1966	80,402	3,490	210,263	477	381,033	153,727	36,712	21	12,730	177,845	107,181	13,966	121,147	119,401	6,011	75,027	9,776	210,214	3,364	86,334	-77	159
1967	77,675	3,483	213,868	1,199	354,625	141,415	12,103	30	76,884	124,193	164,335	15,208	179,543	79,667	8,466	115,035	10,645	213,814	3,417	87,704	-100	273
1968	82,959	3,476	209,507	2,128	437,441	161,389	12,169	0	113,347	150,536	131,982	13,885	145,867	97,832	9,672	92,388	9,720	209,611	3,335	85,587	-177	105
1969	84,211	3,468	213,079	4,872	497,059	208,849	16,725	27	61,202	210,257	79,509	14,264	93,773	128,069	19,642	55,656	9,985	213,353	3,420	87,789	-44	0
1970	84,948	3,461	251,077	1,325	489,786	192,963	20,334	45	45,208	231,236	105,709	15,746	121,455	151,355	14,909	73,996	11,022	251,282	3,968	101,840	-366	0
1971	84,363	3,454	256,390	373	378,566	146,923	14,256	33	65,697	151,657	196,598	16,228	212,827	103,711	3,906	137,619	11,360	256,596	4,100	105,245	-121	0
1972	80,598	3,446	219,667	1,508	228,424	76,337	5,938	39	81,681	64,430	233,421	14,805	248,226	45,101	1,038	163,395	10,363	219,897	3,517	90,279	-86	0
1973	84,757	3,439	228,502	1,780	403,624	150,012	11,220	85	34,019	208,289	100,415	14,566	114,981	139,188	9,046	70,290	10,196	228,721	3,637	93,344	-203	0
1974	85,380	3,432	210,891	3,968	444,941	159,973	12,569	90	58,615	213,694	73,282	13,186	86,468	142,362	8,190	51,298	9,230	211,079	3,377	86,672	-80	0
1975	85,346	3,424	246,888	635	421,494	157,430	19,313	68	34,393	210,290	123,095	14,862	137,957	145,869	4,599	86,167	10,404	247,038	3,918	100,557	-272	0
1976	78,721	3,417	235,062	251	479,793	207,947	22,775	225	23,969	224,878	95,372	14,820	110,193	146,602	11,436	66,761	10,374	235,173	3,770	96,751	-52	0
1977	84,682	3,611	244,075	1,015	255,660	139,416	10,401	106	3,372	102,364	230,500	15,910	246,410	71,655	154	161,350	11,137	244,296	3,924	100,709	-13	0
1978	82,112	3,805	220,045	4,322	168,907	106,564	5,291	39	3,146	53,867	241,202	15,254	256,456	37,707	2,989	168,842	10,678	220,215	3,491	89,606	-249	0
1979	78,877	3,999	222,627	2,573	344,644	157,227	17,894	137	0	169,386	128,651	16,946	145,596	117,361	3,553	90,055	11,862	222,830	3,544	90,951	-195	0
1980	80,285	4,191	237,585	340	437,718	178,502	35,296	165	0	223,756	88,867	18,495	107,362	153,984	7,647	63,095	13,132	237,858	3,601	92,423	-230	0
1981	83,655	4,118	247,510	855	387,881	155,193	23,916	134	0	208,639	114,857	17,082	131,939	145,384	5,691	82,697	12,299	246,072	2,980	92,382	-71	1,420
1982	80,489	4,045	246,191	2,688	417,387	167,820	22,705	146	0	226,717	92,509	17,521	110,030	160,026	6,033	67,532	12,790	246,380	2,273	88,648	-46	0
1983	75,177	3,973	227,707	1,263	421,218	172,322	20,767	153	0	227,976	59,415	16,632	76,047	166,624	4,969	43,967	12,308	227,867	1,482	77,564	-241	0
1984	77,047	4,017	213,423	8,931	411,371	166,272	22,524	149	0	222,425	45,721	14,934	60,655	160,929	7,115	34,291	11,201	213,536	885	69,885	-102	0
1985	78,697	4,062	200,951	4,982	435,425	137,345	42,719	146	0	255,215	6,095	13,932	20,027	173,864	12,161	4,571	10,449	201,046	878	69,382	328	0
1986	79,017	4,107	195,695	9,589	542,723	174,519	104,435	186	0	263,583	5,349	13,825	19,174	169,719	11,705	4,012	10,369	195,805	1,086	85,816	4	0

Canal and Farm Water Budget

EBID Total

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Annual Totals (Acre-Feet)

Year	SW Acres	Primary GW Acres	Total CIR	Excess Effective Precip	Surface Water Divers	Total Canal Loss	Wasteway Flows	Eastside Canal to Texas	El Paso Valley Carriage	SW Farm Delivery	Suppl Ground Water Pumping	Primary Ground Water Pumping	Total Ground Water Pumping	CU of Surface Water	CU of SM Carryover	CU of Suppl GW Pumping	CU of Primary GW Pumping	Total CU	Surface Runoff	Deep Perc	Change in Soil Moisture	Shortage
1987	77,597	3,913	201,349	1,600	578,161	224,439	89,603	213	0	263,906	7,036	14,125	21,161	163,541	22,082	5,277	10,594	201,494	1,241	98,010	-1,307	0
1988	76,536	3,718	194,394	2,198	502,474	174,654	76,963	183	0	250,674	10,287	13,234	23,521	161,113	15,770	7,715	9,926	194,524	999	78,931	-22	0
1989	78,962	3,991	217,571	5,823	495,146	186,509	64,145	166	0	244,326	21,759	15,625	37,384	160,556	29,143	16,319	11,719	217,737	989	78,157	-1,264	0
1990	76,997	4,264	198,746	406	423,642	170,308	36,197	127	0	217,010	27,269	15,200	42,469	146,359	20,652	20,452	11,400	198,863	811	64,059	-355	0
1991	78,899	4,322	202,338	9,411	406,711	133,599	45,566	143	0	227,403	29,770	15,377	45,148	152,969	15,635	22,328	11,533	202,465	852	67,286	162	0
1992	77,522	4,380	217,715	8,104	469,534	192,048	40,391	168	0	236,927	30,570	16,847	47,417	161,261	21,012	22,927	12,635	217,836	928	73,338	-647	0
1993	75,743	4,438	215,787	5,805	504,268	131,490	130,705	181	0	241,891	20,973	16,931	37,904	162,425	25,033	15,730	12,699	215,887	971	76,747	-1,151	0
1994	76,909	4,496	252,168	2,556	579,107	144,805	160,076	201	0	274,025	35,043	19,901	54,944	188,271	22,822	26,282	14,926	252,300	1,028	81,214	-464	0
1995	77,620	4,554	275,090	746	583,589	256,903	71,638	200	0	254,849	87,001	21,196	108,197	184,872	9,113	65,251	15,897	275,133	1,135	89,627	-237	0
1996	79,246	4,612	260,741	189	523,547	198,764	77,276	135	0	247,373	80,010	20,139	100,149	176,799	8,930	60,008	15,104	260,841	1,086	85,794	-17	0
1997	77,795	4,732	224,473	4,418	526,669	212,810	53,196	132	0	260,531	19,692	18,117	37,808	179,175	17,052	14,769	13,587	224,583	932	73,653	-69	0
1998	77,550	4,852	229,379	1,476	535,351	197,039	74,450	137	0	263,725	19,418	18,779	38,197	172,141	28,543	14,563	14,084	229,332	958	75,713	-340	107
1999	77,150	4,972	222,360	2,449	461,886	179,696	60,818	117	0	221,255	55,186	18,788	73,974	161,500	5,475	41,389	14,091	222,455	923	72,885	-86	0
2000	77,933	5,091	221,979	990	494,468	190,938	58,132	115	0	245,283	28,099	18,879	46,978	165,537	21,306	21,074	14,159	222,077	913	72,152	-240	0
2001	79,061	5,140	244,538	491	522,126	193,555	84,596	84	0	243,890	60,336	20,845	81,182	175,126	8,660	45,252	15,634	244,672	1,016	80,252	-72	0
2002	77,782	5,350	235,859	6,793	497,064	171,315	91,074	57	0	234,618	55,472	21,224	76,695	174,144	4,342	41,604	15,918	236,008	973	76,855	-210	0
2003	74,377	5,096	230,822	3,847	198,434	102,893	29,033	17	0	66,490	209,601	21,035	230,637	49,868	8,173	157,201	15,777	231,019	929	73,353	-681	0
2004	76,665	5,153	205,134	1,761	195,883	124,802	15,409	28	0	55,645	197,768	18,193	215,961	41,734	1,579	148,326	13,645	205,284	849	67,053	-132	0
2005	77,358	5,008	216,072	6,363	387,238	146,543	60,286	52	0	180,357	80,279	18,910	99,189	134,505	7,380	60,210	14,182	216,277	874	69,013	-551	0
2006	76,019	4,941	194,715	1,445	242,254	118,060	39,685	26	0	84,483	156,896	16,839	173,735	63,188	1,389	117,672	12,629	194,879	807	63,748	-101	0
2007	77,030	4,980	211,197	4,730	326,312	133,838	43,950	33	0	148,492	107,868	18,082	125,950	111,369	4,959	80,901	13,561	210,791	858	67,753	-413	511
2008	76,486	4,574	224,882	161	354,763	125,245	41,582	35	0	187,901	94,442	17,518	111,960	139,345	1,664	70,832	13,138	224,979	937	74,028	-7	0
2009	71,210	4,397	220,937	4,711	342,857	116,881	38,740	27	0	187,208	86,515	17,808	104,323	139,591	3,216	64,886	13,356	221,049	911	71,972	-200	0
2010	74,875	4,794	230,525	2,249	317,854	118,847	43,565	25	0	155,417	126,565	19,536	146,101	114,683	6,442	94,924	14,652	230,701	942	74,437	-380	0
2011	71,592	4,411	268,104	1,352	94,843	52,899	17,790	5	0	24,149	311,145	21,450	332,595	18,112	656	233,359	16,088	268,215	1,115	88,071	-55	0
2012	68,110	4,415	237,777	1,203	153,008	65,700	30,284	10	0	57,014	238,292	19,859	258,152	42,761	1,484	178,719	14,894	237,859	985	77,807	-124	0
2013	72,494	4,706	221,354	687	59,397	27,128	12,554	4	0	19,711	255,945	18,392	274,337	14,783	877	191,959	13,794	221,413	919	72,593	-73	0
2014	72,124	4,646	229,456	576	114,714	50,906	15,664	9	0	48,135	238,214	19,282	257,496	36,101	346	178,660	14,461	229,569	955	75,453	-29	0
2015	69,057	4,559	199,986	6,572	163,111	70,232	22,451	12	0	70,416	172,025	16,750	188,775	52,189	6,243	129,019	12,563	200,014	810	63,988	-468	0
2016	70,031	4,853	232,660	1,161	202,286	84,300	34,869	14	0	83,103	204,422	20,578	225,000	62,327	1,651	153,317	15,433	232,729	963	76,063	-138	0
2017	69,602	4,616	219,917	4,437	295,363	117,643	25,419	22	0	152,280	118,975	18,802	137,778	103,626	12,963	89,232	14,102	219,923	919	72,625	-284	14
Avg	80,856	3,458	222,929	2,735	395,029	150,777	46,399	149	10,482	187,221	100,368	14,036	114,403	123,205	10,205	72,205	10,205	215,819	2,930	85,584	-226	7,242
Max	93,045	5,350	275,090	11,240	602,349	256,903	160,076	918	113,347	321,139	311,145	21,450	332,595	188,271	35,236	233,359	16,088	275,133	7,746	116,195	380	62,079
Min	68,110	0	150,766	44	59,397	27,128	5,291	0	0	19,711	0	0	0	14,783	154	0	0	138,340	807	63,748	-1,307	0
Avg 38-78	85,241	2,443	221,576	2,265	406,143	154,590	42,331	197	20,453	188,573	104,904	10,372	115,276	117,037	10,314	73,074	7,214	207,640	4,590	93,830	-184	14,081
Avg 79-07	77,862	4,501	222,901	3,546	443,180	168,766	58,395	129	0	215,891	64,889	17,505	82,394	149,460	12,342	48,120	13,038	222,960	1,269	77,677	-302	70
Avg 08-17	71,558	4,597	228,560	2,311	209,820	82,978	28,292	16	0	98,533	184,654	18,998	203,652	72,352	3,554	138,491	14,248	228,645	946	74,704	-176	1

Canal and Farm Water Budget
EPCWID Total
1938 - 2017
Annual Totals (Acre-Feet)

Year	SW Acres	Primary GW Acres	Total CIR	Excess Effective Precip	Surface Water Divers	Total Canal Loss	Wasteway Flows	From Leasburg Canal	El Paso Valley Carriage	SW Farm Delivery	Suppl Ground Water Pumping	Primary Ground Water Pumping	Total Ground Water Pumping	CU of Surface Water	CU of SM Carryover	CU of Suppl GW Pumping	CU of Primary GW Pumping	Total CU	Surface Runoff	Deep Perc	Change in Soil Moisture	Shortage
1938	59,117	0	142,413	797	424,658	117,781	164,361	453	0	142,969	0	0	0	88,800	3,472	0	0	92,273	3,127	46,912	55	50,140
1939	61,153	0	160,498	641	441,315	159,875	109,265	492	0	172,667	0	0	0	109,786	4,464	0	0	114,250	3,777	56,656	-168	46,249
1940	62,450	0	162,795	1,247	419,544	165,923	76,830	632	0	177,422	0	0	0	112,982	2,407	0	0	115,389	3,881	58,217	-5	47,406
1941	63,669	0	119,843	3,713	419,841	138,169	144,958	275	0	136,990	0	0	0	81,405	11,697	0	0	93,103	2,997	44,950	-338	26,740
1942	64,816	0	137,561	2,225	588,478	162,510	280,371	918	0	146,515	0	0	0	90,640	6,278	0	0	96,918	3,205	48,075	-140	40,644
1943	65,506	0	154,008	1,335	547,890	196,218	158,706	722	0	193,688	0	0	0	118,310	8,579	0	0	126,889	4,237	63,554	-83	27,119
1944	65,699	0	151,476	200	467,774	137,304	144,770	618	0	186,317	0	0	0	113,003	9,306	0	0	122,309	4,076	61,135	-100	29,167
1945	65,747	0	157,525	289	460,629	128,412	118,843	449	0	213,824	0	0	0	133,027	5,994	0	0	139,020	4,677	70,161	-3	18,504
1946	66,477	0	160,803	1,738	432,302	92,452	133,920	291	0	206,221	0	0	0	124,941	10,115	0	0	135,057	4,511	67,666	-84	25,747
1947	66,992	0	161,404	2,751	380,950	109,076	78,180	242	0	193,937	0	0	0	118,024	10,144	0	0	128,168	4,242	63,636	-176	33,236
1948	66,554	0	156,342	5,998	391,550	139,446	69,333	257	0	183,027	6,469	0	6,469	115,298	7,403	4,205	0	126,906	4,145	62,179	-311	29,436
1949	67,342	0	146,692	2,521	400,305	126,554	74,198	303	0	199,855	4,287	0	4,287	118,772	16,774	2,787	0	138,332	4,466	66,984	-470	8,360
1950	67,183	0	153,093	29	383,232	111,210	68,084	278	0	204,216	11,697	0	11,697	117,384	15,434	7,603	0	140,421	4,723	70,847	-6	12,672
1951	66,166	0	146,328	2,203	233,125	77,529	17,182	146	0	138,561	40,598	0	40,598	83,644	9,095	26,794	0	119,534	3,426	57,488	-107	26,794
1952	66,356	0	147,856	657	243,560	59,806	16,624	89	0	167,220	31,687	0	31,687	108,828	5,060	21,230	0	135,118	3,282	62,357	-154	12,738
1953	66,664	0	162,188	1,864	232,601	75,888	15,865	63	0	140,911	72,508	0	72,508	91,891	4,557	49,305	0	145,753	2,988	65,306	-52	16,435
1954	56,594	0	139,649	6	87,553	31,981	9,881	13	0	45,704	133,519	0	133,519	31,536	2,478	92,128	0	126,142	2,083	53,476	-207	13,507
1955	56,229	0	131,832	976	70,629	24,952	764	9	6,562	38,360	149,275	0	149,275	25,838	1,501	104,493	0	131,832	2,111	54,180	-41	0
1956	50,245	0	128,065	1,406	68,361	34,409	468	3	6,165	27,321	155,143	0	155,143	18,422	1,043	108,600	0	128,065	2,053	52,686	-28	0
1957	50,705	0	107,220	1,807	128,695	35,607	3,354	30	7,185	82,578	68,841	0	68,841	54,725	4,306	48,189	0	107,220	1,703	43,722	-102	0
1958	56,879	0	112,867	1,607	302,957	89,094	41,049	250	0	173,064	621	0	621	100,060	12,372	435	0	112,867	1,954	50,152	726	0
1959	59,023	0	146,499	630	330,004	97,436	41,714	98	0	190,951	7,821	0	7,821	119,814	21,210	5,475	0	146,499	2,236	57,396	-613	0
1960	58,228	0	134,753	3,041	339,424	122,084	40,860	143	0	176,622	7,350	0	7,350	113,610	15,998	5,145	0	134,753	2,070	53,122	-498	0
1961	56,266	0	136,549	1,458	262,805	108,268	3,098	74	0	151,513	38,974	0	38,974	101,042	8,188	27,281	0	136,511	2,143	55,003	-264	38
1962	59,457	0	127,261	937	328,435	102,773	48,334	247	0	177,575	7,823	0	7,823	104,043	17,742	5,476	0	127,261	2,086	53,534	210	0
1963	60,783	0	130,593	1,291	246,101	79,987	26,482	109	0	139,741	39,280	0	39,280	81,383	21,714	27,496	0	130,593	2,014	51,692	-440	0
1964	57,118	0	128,187	1,083	82,130	42,502	688	23	6,429	32,533	150,698	0	150,698	20,309	2,390	105,488	0	128,187	2,061	52,908	6	0
1965	54,868	0	128,565	591	184,583	71,589	9,328	35	1,169	102,532	79,636	0	79,636	69,585	3,235	55,745	0	128,565	2,049	52,601	-87	0
1966	53,753	0	113,199	360	268,564	90,558	53,145	21	1,259	123,623	38,596	0	38,596	70,305	15,867	27,017	0	113,190	1,825	46,841	30	9
1967	54,139	0	138,032	1,044	230,900	111,584	12,785	30	5,500	101,060	93,325	0	93,325	60,294	12,411	65,328	0	138,032	2,187	56,129	-164	0
1968	55,904	0	127,810	812	231,858	83,956	35,970	0	6,983	104,950	76,571	0	76,571	63,873	10,337	53,600	0	127,810	2,042	52,414	-62	0
1969	56,726	0	141,249	3,106	320,514	113,439	49,675	27	3,616	153,810	46,185	0	46,185	95,071	13,848	32,330	0	141,249	2,250	57,749	-104	0
1970	56,291	0	143,159	867	312,140	96,735	55,662	45	2,476	157,313	43,853	0	43,853	95,509	16,954	30,697	0	143,159	2,263	58,087	-195	0
1971	55,192	0	154,968	575	253,641	110,389	21,841	33	4,014	117,430	101,572	0	101,572	72,245	11,623	71,100	0	154,968	2,464	63,237	-139	0
1972	54,636	0	136,562	976	147,544	59,021	24,884	39	5,455	58,222	136,499	0	136,499	39,059	1,954	95,549	0	136,562	2,191	56,226	-21	0
1973	52,995	0	155,398	2,366	288,808	116,749	39,199	85	2,467	130,477	87,061	0	87,061	86,967	7,489	60,943	0	155,398	2,447	62,814	-260	0
1974	51,896	0	140,206	3,619	348,859	131,505	75,192	90	4,055	138,197	59,988	0	59,988	86,477	11,738	41,991	0	140,206	2,230	57,226	-123	0
1975	52,154	0	143,232	757	323,920	130,251	55,519	68	2,971	135,247	65,734	0	65,734	90,757	6,461	46,014	0	143,232	2,261	58,033	-212	0
1976	44,617	0	123,777	236	382,868	161,592	70,253	225	2,333	148,914	26,612	0	26,612	91,980	13,169	18,628	0	123,777	1,975	50,683	-76	0
1977	51,590	0	132,055	874	218,763	110,722	25,963	106	378	81,807	105,936	0	105,936	53,460	4,440	74,155	0	132,055	2,112	54,211	-53	0
1978	48,257	0	120,733	2,455	161,026	87,492	20,397	39	326	52,849	116,214	0	116,214	34,262	5,122	81,349	0	120,733	1,902	48,817	-199	0
1979	51,995	0	131,000	1,624	271,509	101,106	42,965	137	0	127,575	60,615	0	60,615	83,550	5,020	42,431	0	131,000	2,117	54,340	61	0
1980	47,452	0	127,171	467	331,701	147,304	42,312	165	0	142,249	32,432	0	32,432	93,235	10,910	23,026	0	127,171	1,900	48,758	-262	0
1981	49,045	0	130,576	686	275,498	70,554	65,588	134	0	139,490	38,525	0	38,525	90,494	10,657	27,738	0	128,889	1,558	48,287	-60	1,687
1982	48,311	0	137,463	3,004	290,708	76,167	49,615	146	0	165,072	22,423	0	22,423	106,193	14,902	16,368	0	137,463	1,266	49,358	-49	0
1983	46,276	0	119,430	737	273,444	83,039	53,660	153	0	136,897	20,654	0	20,654	91,327	12,819	15,284	0	119,430	768	40,195	-237	0
1984	47,194	0	117,242	5,583	288,535	98,907	57,476	149	0	132,302	21,787	0	21,787	87,578	13,325	16,340	0	117,242	482	38,041	-140	0
1985	45,605	0	110,962	1,895	301,392	50,185	113,438	146	0	137,914	2,580	0	2,580	94,300	14,642	1,935	0	110,877	439	34,685	-459	84
1986	45,606	0	105,211	4,525	392,722	70,437	183,715	186	0	138,756	1,543	0	1,543	86,709	17,345	1,158	0	105,211	438	34,637	1	0

Canal and Farm Water Budget

EPCWID Total

1938 - 2017

Annual Totals (Acre-Feet)

Year	SW Acres	Primary GW Acres	Total CIR	Excess Effective Precip	Surface Water Divers	Total Canal Loss	Wasteway Flows	From Leasburg Canal	El Paso Valley Carriage	SW Farm Delivery	Suppl Ground Water Pumping	Primary Ground Water Pumping	Total Ground Water Pumping	CU of Surface Water	CU of SM Carryover	CU of Suppl GW Pumping	CU of Primary GW Pumping	Total CU	Surface Runoff	Deep Perc	Change in Soil Moisture	Shortage
1987	47,428	0	111,207	983	461,784	129,374	191,174	213	0	141,448	2,562	0	2,562	85,755	23,531	1,922	0	111,207	466	36,812	-373	0
1988	45,492	0	108,549	1,151	389,803	107,183	143,885	183	0	138,918	5,606	0	5,606	83,347	20,997	4,205	0	108,549	463	36,550	-86	0
1989	47,185	0	116,519	3,133	359,635	136,960	84,963	166	0	137,877	15,186	0	15,186	90,883	14,246	11,389	0	116,519	482	38,093	-169	0
1990	43,624	0	91,051	301	305,144	131,673	46,975	127	0	126,623	871	0	871	68,290	22,108	653	0	91,051	398	31,475	381	0
1991	49,637	0	111,989	5,556	284,312	86,246	38,757	143	0	159,453	1,448	0	1,448	93,977	16,926	1,086	0	111,989	583	46,039	191	0
1992	53,048	0	128,025	5,571	375,218	57,923	198,110	168	0	119,354	40,684	0	40,684	75,215	22,296	30,513	0	128,025	576	45,510	-1,173	0
1993	53,044	0	131,357	3,905	400,398	109,288	146,378	181	0	144,913	20,559	0	20,559	96,375	19,563	15,419	0	131,357	538	42,535	-746	0
1994	53,187	0	137,398	2,464	413,793	123,710	117,724	201	0	172,560	7,716	0	7,716	115,716	15,895	5,787	0	137,398	563	44,506	-183	0
1995	53,145	0	138,087	761	444,460	161,404	112,567	200	0	170,689	9,151	0	9,151	112,453	18,558	6,863	0	137,874	562	44,398	-250	213
1996	45,246	0	106,476	232	319,415	75,167	44,711	135	0	199,672	2,231	0	2,231	97,908	6,895	1,673	0	106,476	1,043	82,394	999	0
1997	52,591	0	119,282	2,908	358,232	100,164	113,965	132	0	144,235	1,360	0	1,360	92,238	26,024	1,020	0	119,282	485	38,341	-1,043	0
1998	52,987	0	135,894	244	363,420	81,608	128,752	137	0	153,197	26,369	0	26,369	102,176	13,804	19,776	0	135,756	573	45,273	-170	138
1999	51,594	0	131,822	1,346	353,712	89,038	42,160	117	0	222,631	1,592	0	1,592	123,665	6,963	1,194	0	131,822	979	77,316	1,176	0
2000	48,638	0	125,752	404	331,214	124,895	50,799	115	0	155,636	700	0	700	99,496	25,731	525	0	125,752	558	44,111	-1,174	0
2001	41,579	0	110,389	473	354,055	45,734	124,954	84	0	183,452	2,381	0	2,381	105,537	3,066	1,786	0	110,389	793	62,634	1,001	0
2002	41,024	0	103,410	3,605	347,379	59,395	52,466	57	0	235,575	1,745	0	1,745	99,680	2,420	1,309	0	103,410	1,702	134,422	-184	0
2003	38,763	0	103,878	2,530	139,332	45,253	4,084	17	0	90,013	27,833	0	27,833	66,411	16,593	20,875	0	103,878	413	32,599	-1,587	0
2004	37,860	0	103,096	1,384	159,353	60,155	8,128	28	0	91,097	45,607	0	45,607	63,113	5,777	34,205	0	103,096	427	33,749	-47	0
2005	40,207	0	85,821	2,736	235,712	90,199	34,361	52	0	111,203	2,670	0	2,670	73,109	10,709	2,002	0	85,821	356	28,112	-35	0
2006	40,542	0	93,144	340	186,887	53,183	27,170	26	0	106,560	13,141	0	13,141	63,136	20,153	9,855	0	93,144	374	29,551	-281	0
2007	40,569	0	98,244	2,758	261,060	98,240	48,045	33	0	114,807	11,901	0	11,901	75,496	13,503	8,926	0	97,925	396	31,281	-241	319
2008	40,911	0	95,794	192	255,579	93,151	46,737	35	0	115,726	22,989	0	22,989	65,151	13,401	17,242	0	95,794	494	38,989	286	0
2009	40,142	0	94,008	3,280	288,658	114,029	25,228	27	0	149,428	2,575	0	2,575	86,741	5,336	1,931	0	94,008	606	47,853	795	0
2010	40,306	0	104,285	1,216	271,460	107,704	12,745	25	0	151,035	4,420	0	4,420	88,741	12,229	3,315	0	104,285	773	61,078	-890	0
2011	39,659	0	111,805	981	185,638	75,090	15,031	5	0	95,522	43,464	0	43,464	69,460	9,747	32,598	0	111,805	434	34,312	-630	0
2012	27,307	0	74,406	232	116,600	45,494	12,704	10	0	58,413	40,863	0	40,863	41,874	1,885	30,647	0	74,406	310	24,509	4	0
2013	29,903	0	81,476	265	66,233	28,225	5,910	4	0	32,102	75,462	0	75,462	23,597	1,282	56,597	0	81,476	336	26,555	-67	0
2014	30,822	0	87,552	210	105,263	43,414	10,667	9	0	51,190	65,354	0	65,354	37,411	1,125	49,015	0	87,552	364	28,772	-12	0
2015	30,134	0	75,296	2,669	136,068	54,892	12,645	12	0	68,543	28,455	0	28,455	48,240	5,714	21,341	0	75,296	303	23,947	-212	0
2016	36,308	0	101,078	518	161,482	64,516	13,152	14	0	83,829	50,303	0	50,303	59,681	3,669	37,727	0	101,078	419	33,114	-40	0
2017	35,031	0	96,036	1,992	184,547	71,795	16,093	22	0	96,680	28,821	0	28,821	69,434	4,987	21,616	0	96,036	392	30,983	-159	0
Avg	51,448	0	125,443	1,674	292,877	95,070	62,223	149	867	134,867	35,112	0	35,112	83,938	10,739	24,923	0	119,601	1,758	50,290	-139	5,842
Max	67,342	0	162,795	5,998	588,478	196,218	280,371	918	7,185	235,575	155,143	0	155,143	133,027	26,024	108,600	0	155,398	4,723	134,422	1,176	50,140
Min	27,307	0	74,406	6	66,233	24,952	468	0	0	27,321	0	0	0	18,422	1,043	0	0	74,406	303	23,947	-1,587	0
Avg 38-78	58,694	0	140,079	1,490	302,167	103,484	59,463	197	1,691	137,725	48,887	0	48,887	85,545	9,131	34,063	0	128,739	2,792	56,562	-123	11,340
Avg 79-07	46,858	0	116,222	2,114	319,649	91,879	81,686	129	0	146,213	15,237	0	15,237	90,254	14,668	11,216	0	116,138	748	46,690	-177	84
Avg 08-17	35,052	0	92,173	1,155	177,153	69,831	17,091	16	0	90,247	36,270	0	36,270	59,033	5,937	27,203	0	92,173	443	35,011	-93	0

Canal and Farm Water Budget

HCCRD

1938 - 2017

Annual Totals (Acre-Feet)

Year	SW Acres	Primary GW Acres	Total CIR	Excess Effective Precip	Surface Water Divers	Excess Diversions to Storage	Diversion from Storage	Canal Loss from SW Supplies	Canal Loss from Storage Supplies	Wasteway Flows	SW Farm Delivery	From Storage Farm Delivery	Suppl Ground Water Pumping	Primary Ground Water Pumping	Total Ground Water Pumping	CU of Surface Water	CU of SM Carryover	CU of Storage Supplies	CU of Suppl GW Pumping	Total CU	Surface Runoff	Deep Perc	Change in Soil Moisture	Shortage
1938	11,033	0	24,976	416	137,564	0	0	68,782	0	0	68,782	0	0	0	0	24,976	0	0	0	24,976	2,420	36,303	424	0
1939	12,400	0	30,601	403	131,689	0	0	65,845	0	0	65,845	0	0	0	0	28,869	1,732	0	0	30,601	2,188	32,815	20	0
1940	13,347	0	34,384	474	119,587	0	0	59,794	0	0	59,794	0	0	0	0	30,937	3,447	0	0	34,384	1,592	23,879	-5	0
1941	13,312	0	24,173	38	101,087	0	0	50,544	0	0	50,544	0	0	0	0	23,916	257	0	0	24,173	1,649	24,741	-2	0
1942	13,710	0	28,823	504	113,985	0	0	56,993	0	0	56,993	0	0	0	0	27,742	1,081	0	0	28,823	1,780	26,705	-26	0
1943	14,316	0	32,761	494	100,613	0	0	50,307	0	0	50,307	0	0	0	0	25,703	7,059	0	0	32,761	1,209	18,140	-150	0
1944	14,187	0	32,859	285	111,882	0	0	55,941	0	0	55,941	0	0	0	0	29,309	3,550	0	0	32,859	1,365	20,469	104	0
1945	14,905	0	36,010	320	113,660	0	0	56,830	0	0	56,830	0	0	0	0	28,700	7,023	0	0	35,723	1,441	21,617	-163	286
1946	15,917	0	38,451	871	117,160	0	0	58,580	0	0	58,580	0	0	0	0	30,086	7,681	0	0	37,766	1,296	19,439	7	685
1947	16,882	0	40,893	299	98,978	0	0	49,489	0	0	49,489	0	0	0	0	26,999	8,292	0	0	35,290	1,083	16,239	-260	5,602
1948	17,060	0	40,798	441	118,480	0	0	59,240	0	0	59,240	0	788	0	788	29,513	7,189	0	512	37,214	1,313	19,697	150	3,585
1949	17,224	0	37,713	1,270	139,761	0	0	69,881	0	0	69,881	0	0	0	0	33,813	3,901	0	0	37,713	1,922	28,824	118	0
1950	17,318	0	40,022	0	149,175	0	0	74,588	0	0	74,588	0	0	0	0	35,350	4,671	0	0	40,022	2,158	32,364	4	0
1951	17,752	0	39,108	978	53,574	0	0	26,787	0	0	26,787	0	14,462	0	14,462	11,654	8,365	0	9,545	29,563	927	15,561	-400	9,545
1952	17,318	0	38,998	788	60,898	0	0	30,449	0	0	30,449	0	16,606	0	16,606	14,325	6,872	0	11,126	32,322	776	14,752	-66	6,675
1953	16,675	0	40,613	229	43,802	0	0	21,901	0	0	21,901	0	25,722	0	25,722	11,033	6,259	0	17,491	34,783	667	14,573	-200	5,830
1954	12,127	0	31,590	0	7,638	0	0	3,819	0	0	3,819	0	33,707	0	33,707	1,735	3,058	0	23,258	28,051	436	11,197	-180	3,538
1955	5,455	0	12,900	151	447	0	0	224	0	0	224	0	17,991	0	17,991	112	194	0	12,594	12,900	205	5,259	-12	0
1956	5,180	0	13,103	143	4	0	0	2	0	0	2	0	18,623	0	18,623	0	67	0	13,036	13,103	210	5,378	-5	0
1957	4,378	0	9,937	158	1,587	0	0	794	0	0	794	0	13,064	0	13,064	555	236	0	9,145	9,937	156	4,001	-20	0
1958	6,844	0	14,868	181	33,692	0	0	16,846	0	0	16,846	0	12,210	0	12,210	6,195	126	0	8,547	14,868	418	10,726	254	0
1959	6,992	0	18,426	131	55,067	0	0	27,534	0	0	27,534	0	912	0	912	14,400	3,388	0	639	18,426	378	9,703	-5	0
1960	8,907	0	21,889	731	73,763	0	0	36,882	0	0	36,882	0	0	0	0	19,743	2,146	0	0	21,889	556	14,265	14	0
1961	9,661	0	24,500	151	61,456	0	0	30,728	0	0	30,728	0	7,140	0	7,140	14,949	4,552	0	4,998	24,500	494	12,671	17	0
1962	11,429	0	25,907	343	95,171	0	0	47,586	0	0	47,586	0	1,239	0	1,239	19,087	5,953	0	867	25,907	841	21,586	41	0
1963	11,268	0	24,988	251	64,477	0	0	32,239	0	0	32,239	0	9,462	0	9,462	12,835	5,529	0	6,624	24,988	639	16,401	-27	0
1964	8,421	0	18,760	229	5,730	0	0	2,865	0	0	2,865	0	19,877	0	19,877	796	4,050	0	13,914	18,760	352	9,023	-449	0
1965	8,123	0	19,268	198	8,123	0	0	4,062	0	0	4,062	0	23,212	0	23,212	2,098	922	0	16,248	19,268	307	7,875	-15	0
1966	7,815	0	16,175	107	50,286	0	0	25,143	0	0	25,143	0	4,588	0	4,588	11,973	991	0	3,211	16,175	381	9,768	284	0
1967	8,244	0	21,687	223	30,011	0	0	15,006	0	0	15,006	0	13,766	0	13,766	8,166	3,885	0	9,636	21,687	350	8,985	-188	0
1968	8,649	0	18,179	1,040	45,116	0	0	22,558	0	0	22,558	0	4,584	0	4,584	9,506	5,463	0	3,209	18,179	305	7,837	68	0
1969	11,432	0	30,729	550	97,210	0	0	48,605	0	0	48,605	0	6,352	0	6,352	21,131	5,151	0	4,446	30,729	859	22,048	110	0
1970	14,177	0	35,897	149	119,369	0	0	59,685	0	0	59,685	0	1,075	0	1,075	28,464	6,680	0	752	35,897	889	22,828	95	0
1971	10,115	0	26,612	312	61,503	0	0	30,752	0	0	30,752	0	10,390	0	10,390	14,573	4,766	0	7,273	26,612	644	16,529	-220	0
1972	6,546	0	15,575	151	30,779	0	0	15,390	0	0	15,390	0	10,198	0	10,198	5,352	3,085	0	7,138	15,575	428	10,998	-118	0
1973	9,785	0	25,758	1,132	65,512	0	0	32,756	0	0	32,756	0	6,655	0	6,655	15,655	5,445	0	4,658	25,758	502	12,878	23	0
1974	12,446	0	31,019	4,187	110,025	0	0	55,013	0	0	55,013	0	5,073	0	5,073	21,603	5,865	0	3,551	31,019	1,195	30,682	-234	0
1975	13,662	0	36,798	1,023	115,457	0	0	57,729	0	0	57,729	0	7,056	0	7,056	25,421	6,438	0	4,939	36,798	1,066	27,370	-37	0
1976	11,268	0	30,010	306	127,756	0	0	63,878	0	0	63,878	0	0	0	0	28,048	1,963	0	0	30,010	1,324	33,978	-120	0
1977	10,740	0	24,384	791	53,599	0	0	26,800	0	0	26,800	0	12,646	0	12,646	10,471	5,061	0	8,852	24,384	604	15,497	-87	0
1978	9,175	0	20,454	1,031	29,691	0	0	14,846	0	0	14,846	0	16,657	0	16,657	4,471	4,323	0	11,660	20,454	481	12,336	-147	0
1979	11,768	0	27,554	509	64,844	0	0	34,547	0	0	30,297	0	8,867	0	8,867	15,802	5,545	0	6,207	27,554	449	11,530	-31	0
1980	15,237	0	36,715	410	96,113	0	0	68,914	0	0	27,199	0	24,480	0	24,480	13,051	6,283	0	17,381	36,715	562	14,425	-2	0
1981	14,028	0	31,484	547	100,744	0	0	57,706	0	0	43,038	0	0	0	0	27,660	3,824	0	0	31,484	387	12,004	-70	0
1982	15,030	0	38,442	3,211	97,967	0	0	44,575	0	0	53,392	0	0	0	0	32,986	5,456	0	0	38,442	415	16,192	-138	0
1983	9,316	0	21,503	220	107,419	0	0	59,441	0	0	47,978	0	0	0	0	21,471	32	0	0	21,503	533	27,887	-162	0
1984	14,546	0	33,433	3,077	126,709	0	0	63,877	0	0	62,832	0	0	0	0	33,227	206	0	0	33,433	375	29,637	-51	0
1985	14,880	0	33,761	144	131,174	0	0	60,804	0	0	70,370	0	0	0	0	33,761	0	0	0	33,761	457	36,138	1	0
1986	15,379	0	31,158	1,163	206,103	0	0	172,235	0	0	33,868	0	9,815	0	9,815	16,549	7,247	0	7,361	31,158	234	18,466	-514	0

Canal and Farm Water Budget

HCCRD

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Annual Totals (Acre-Feet)

Year	SW Acres	Primary GW Acres	Total CIR	Excess Effective Precip	Surface Water Divers	Excess Diversions to Storage	Diversion from Storage	Canal Loss from SW Supplies	Canal Loss from Storage Supplies	Wasteway Flows	SW Farm Delivery	From Storage Farm Delivery	Suppl Ground Water Pumping	Primary Ground Water Pumping	Total Ground Water Pumping	CU of Surface Water	CU of SM Carryover	CU of Storage Supplies	CU of Suppl GW Pumping	Total CU	Surface Runoff	Deep Perc	Change in Soil Moisture	Shortage
1987	15,043	0	31,213	582	136,058	0	0	74,472	0	0	61,586	0	0	0	0	21,763	9,450	0	0	31,213	387	30,577	-49	0
1988	15,640	0	33,740	271	148,399	0	0	101,685	0	0	46,714	0	0	0	0	23,258	10,481	0	0	33,740	168	13,234	-36	0
1989	17,309	0	37,547	443	146,093	0	0	97,687	0	0	48,406	0	0	0	0	28,714	8,833	0	0	37,547	157	12,422	-143	0
1990	12,599	0	22,763	215	124,916	0	0	62,458	0	0	62,458	0	0	0	0	22,763	0	0	0	22,763	432	34,101	430	0
1991	15,717	0	31,755	2,553	107,563	0	0	62,311	0	0	45,252	0	0	0	0	24,915	6,840	0	0	31,755	206	16,253	-247	0
1992	15,296	0	34,563	2,040	139,804	0	0	69,902	0	0	69,902	0	0	0	0	31,943	2,620	0	0	34,563	446	35,253	-30	0
1993	14,667	0	31,120	757	147,145	0	0	89,770	0	0	57,376	0	0	0	0	28,460	2,660	0	0	31,120	341	26,967	-88	0
1994	14,978	0	32,757	1,307	149,478	0	0	84,421	0	0	65,058	0	0	0	0	30,961	1,796	0	0	32,757	418	33,044	-97	0
1995	15,430	0	33,064	371	158,687	0	0	90,925	0	0	67,762	0	0	0	0	30,506	2,558	0	0	33,064	436	34,420	-13	0
1996	15,734	0	32,039	300	127,198	0	0	60,333	0	0	66,866	0	0	0	0	28,462	3,577	0	0	32,039	437	34,546	-13	0
1997	15,278	0	29,608	815	132,605	0	0	82,097	0	0	50,508	0	0	0	0	23,644	5,964	0	0	29,608	274	21,656	-86	0
1998	15,385	0	36,620	507	134,468	0	0	72,552	0	0	61,917	0	2,588	0	2,588	26,196	8,482	0	1,941	36,620	360	28,472	-79	0
1999	15,462	0	35,993	313	145,571	0	0	77,549	0	0	68,023	0	0	0	0	31,731	4,261	0	0	35,993	398	31,418	18	0
2000	14,192	0	33,532	576	125,418	0	0	60,478	0	0	64,940	0	0	0	0	28,108	5,424	0	0	33,532	407	32,176	-98	0
2001	14,379	0	34,750	471	151,892	0	0	90,681	0	0	61,211	0	0	0	0	29,056	5,694	0	0	34,750	336	26,509	-32	0
2002	15,189	0	32,501	2,044	144,560	0	0	78,849	0	0	65,712	0	0	0	0	30,635	1,866	0	0	32,501	436	34,437	-139	0
2003	8,769	0	20,816	1,181	50,563	0	0	19,656	0	0	30,907	0	1,395	0	1,395	15,637	4,132	0	1,047	20,816	222	17,533	-522	0
2004	8,740	0	22,226	1,493	54,317	0	0	24,685	0	0	29,632	0	3,132	0	3,132	15,752	4,125	0	2,349	22,226	125	9,858	46	0
2005	9,467	0	17,898	280	95,206	0	0	60,412	0	0	34,793	0	0	0	0	14,101	3,798	0	0	17,898	210	16,623	5	0
2006	10,517	0	21,174	125	76,380	0	0	40,747	0	0	35,633	0	900	0	900	15,544	4,956	0	675	21,174	187	14,801	31	0
2007	12,257	0	27,152	1,109	106,027	0	0	62,546	0	0	43,481	0	719	0	719	20,837	5,776	0	539	27,152	217	17,120	-24	0
2008	13,623	0	27,732	1,239	120,887	0	0	60,443	0	0	60,443	0	0	0	0	25,805	1,927	0	0	27,732	416	32,890	-50	0
2009	14,206	0	29,178	1,313	127,955	0	0	63,977	0	0	63,977	0	0	0	0	27,491	1,687	0	0	29,178	448	35,390	-87	0
2010	14,700	0	32,266	426	120,704	0	0	60,352	0	0	60,352	0	0	0	0	30,324	1,942	0	0	32,266	353	27,926	-16	0
2011	12,154	0	28,649	377	42,403	0	0	21,202	0	0	21,202	0	11,849	0	11,849	13,962	5,800	0	8,886	28,649	142	11,221	-580	0
2012	6,419	0	14,880	58	20,846	0	0	10,423	0	0	10,423	0	10,556	0	10,556	6,554	408	0	7,917	14,880	66	5,179	71	0
2013	6,227	0	14,358	80	20,508	0	0	10,254	0	0	10,254	0	7,830	0	7,830	4,880	3,606	0	5,872	14,358	57	4,464	-66	0
2014	5,868	0	14,855	46	25,158	0	0	12,579	0	0	12,579	0	7,536	0	7,536	5,891	3,311	0	5,652	14,855	63	4,966	19	0
2015	7,097	0	15,787	1,259	28,113	0	0	14,056	0	0	14,056	0	6,857	0	6,857	8,587	2,058	0	5,143	15,787	65	5,163	-9	0
2016	5,919	0	15,433	133	33,944	0	0	16,972	0	0	16,972	0	4,035	0	4,035	9,331	3,076	0	3,026	15,433	66	5,186	27	0
2017	7,891	0	19,717	129	51,986	0	0	25,993	0	0	25,993	0	2,249	0	2,249	14,494	3,536	0	1,687	19,717	92	7,273	97	0
Avg	12,157	0	27,879	670	89,766	0	0	48,128	0	0	41,638	0	5,211	0	5,211	19,688	4,074	0	3,669	27,432	620	19,416	-52	447
Max	17,752	0	40,893	4,187	206,103	0	0	172,235	0	0	74,588	0	33,707	0	33,707	35,350	10,481	0	23,258	40,022	2,420	36,303	430	9,545
Min	4,378	0	9,937	0	4	0	0	2	0	0	2	0	0	0	0	0	0	0	0	9,937	57	4,001	-580	0
Avg 38-78	11,615	0	27,576	524	74,521	0	0	37,261	0	0	37,261	0	7,660	0	7,660	17,324	4,066	0	5,314	26,704	922	17,706	-34	872
Avg 79-07	13,870	0	30,582	932	121,842	0	0	69,873	0	0	51,969	0	1,790	0	1,790	24,741	4,548	0	1,293	30,582	345	23,714	-74	0
Avg 08-17	9,410	0	21,285	506	59,250	0	0	29,625	0	0	29,625	0	5,091	0	5,091	14,732	2,735	0	3,818	21,285	177	13,966	-59	0

Canal and Farm Water Budget

JID Total

1938 - 2017

Annual Totals (Acre-Feet)

Year	SW Acres	Primary GW Acres	Total CIR	Excess Effective Precip	Surface Water Divers	Total Canal Loss	Wasteway Flows	SW Farm Delivery	Suppl Ground Water Pumping	Primary Ground Water Pumping	Total Ground Water Pumping	CU of Surface Water	CU of SM Carryover	CU of Suppl GW Pumping	CU of Primary GW Pumping	Total CU	Surface Runoff	Deep Perc	Change in Soil Moisture	Shortage
1938	58,300	0	118,395	2,308	70,136	28,054	0	42,082	0	0	0	24,441	4,517	0	0	28,958	921	13,808	-134	89,437
1939	47,137	0	101,559	2,085	75,397	30,159	0	45,238	0	0	0	28,600	1,659	0	0	30,259	990	14,844	-71	71,300
1940	48,785	0	107,507	2,023	82,344	32,938	0	49,406	912	0	912	30,347	3,868	593	0	34,808	1,101	16,511	-175	72,699
1941	53,640	0	87,546	158	83,156	33,262	0	49,894	453	0	453	31,514	2,772	294	0	34,580	1,101	16,520	-155	52,966
1942	51,497	0	94,828	2,053	103,331	41,332	0	61,999	278	0	278	37,264	3,278	180	0	40,723	1,362	20,434	-20	54,105
1943	50,884	0	101,465	2,196	87,658	35,063	0	52,595	841	0	841	32,665	3,489	547	0	36,700	1,169	17,534	-164	64,765
1944	50,881	0	102,962	936	84,568	33,827	0	50,741	1,075	0	1,075	31,334	3,844	699	0	35,877	1,133	17,002	-183	67,085
1945	53,118	0	110,706	19	95,275	38,110	0	57,165	2,579	0	2,579	36,159	1,953	1,676	0	39,788	1,307	19,603	-80	70,918
1946	54,460	0	115,420	3,019	89,247	35,699	0	53,548	4,619	0	4,619	34,253	1,013	3,002	0	38,269	1,272	19,086	-38	77,151
1947	48,642	0	104,851	1,002	78,696	31,478	0	47,218	5,490	0	5,490	30,455	2,818	3,569	0	36,841	1,153	17,295	-215	68,010
1948	43,545	0	95,049	1,129	69,931	27,972	0	41,959	15,425	0	15,425	26,364	1,850	10,026	0	38,239	1,255	18,829	-78	56,809
1949	38,448	0	78,226	2,334	72,371	28,948	0	43,423	18,835	0	18,835	25,995	4,583	12,243	0	42,821	1,362	20,428	-196	35,405
1950	33,350	0	67,067	0	77,361	30,944	0	46,417	21,308	0	21,308	28,300	2,935	13,850	0	45,085	1,481	22,222	-89	21,982
1951	30,320	0	60,505	1,687	37,918	15,167	0	22,751	37,499	0	37,499	14,845	771	24,749	0	40,366	1,152	19,333	-50	20,139
1952	33,110	0	66,659	1,753	56,040	22,416	0	33,624	41,090	0	41,090	20,300	4,107	27,530	0	51,937	1,233	23,423	-157	14,722
1953	29,650	0	65,301	434	46,886	18,754	0	28,132	52,419	0	52,419	17,982	2,250	35,645	0	55,878	1,128	24,649	-92	9,424
1954	24,700	0	47,875	0	16,042	6,417	0	9,625	54,343	0	54,343	6,254	537	37,497	0	44,288	744	19,087	-12	3,587
1955	23,770	0	47,530	844	14,645	5,858	0	8,787	58,298	0	58,298	5,708	1,014	40,809	0	47,530	755	19,371	-48	0
1956	23,670	0	53,871	471	13,729	5,492	0	8,237	68,484	0	68,484	4,659	1,273	47,939	0	53,871	863	22,153	-14	0
1957	25,800	0	50,557	616	33,334	13,334	0	20,000	50,885	0	50,885	13,560	1,377	35,620	0	50,557	797	20,468	-78	0
1958	34,620	0	64,089	438	75,964	30,386	0	45,578	48,023	0	48,023	26,149	4,325	33,616	0	64,089	1,053	27,027	119	0
1959	35,090	0	75,584	681	76,462	30,585	0	45,877	59,706	0	59,706	27,826	5,964	41,794	0	75,584	1,204	30,910	-176	0
1960	34,400	0	70,645	2,741	77,032	30,813	0	46,219	56,774	0	56,774	28,157	2,747	39,742	0	70,645	1,159	29,739	121	0
1961	33,360	0	71,552	585	61,829	24,732	0	37,097	58,174	0	58,174	22,960	7,870	40,722	0	71,552	1,072	27,510	-405	0
1962	35,570	0	68,334	730	75,409	30,164	0	45,245	52,945	0	52,945	27,732	3,540	37,061	0	68,334	1,105	28,352	33	0
1963	39,290	0	82,047	937	48,772	19,509	0	29,263	85,023	0	85,023	17,322	5,208	59,516	0	82,047	1,286	33,000	-171	0
1964	26,930	0	58,935	783	13,591	5,436	0	8,155	74,728	0	74,728	5,388	1,238	52,309	0	58,935	932	23,932	-76	0
1965	30,560	0	66,638	549	46,119	18,448	0	27,671	66,453	0	66,453	19,220	901	46,517	0	66,638	1,059	27,178	-63	0
1966	32,370	0	62,037	390	66,505	26,602	0	39,903	49,962	0	49,962	21,237	5,826	34,974	0	62,037	1,053	27,015	-20	0
1967	33,390	0	85,016	905	40,496	16,198	0	24,298	95,675	0	95,675	15,783	2,260	66,972	0	85,016	1,350	34,642	-86	0
1968	35,080	0	75,732	3,582	55,702	22,281	0	33,421	73,671	0	73,671	21,515	2,647	51,570	0	75,732	1,205	30,923	-64	0
1969	40,770	0	99,251	2,270	79,714	31,886	0	47,828	89,144	0	89,144	31,855	4,994	62,401	0	99,251	1,541	39,551	-281	0
1970	41,370	0	98,291	198	78,534	31,414	0	47,120	89,952	0	89,952	30,101	5,224	62,966	0	98,291	1,542	39,580	-195	0
1971	32,330	0	81,121	1,065	50,939	20,143	0	30,796	83,737	0	83,737	20,168	2,337	58,616	0	81,121	1,288	33,071	-79	0
1972	31,270	0	70,527	917	34,323	13,515	0	20,808	78,427	0	78,427	14,332	1,296	54,899	0	70,527	1,116	28,654	-89	0
1973	41,730	0	109,649	2,836	82,036	31,614	0	50,422	102,053	0	102,053	32,295	5,918	71,437	0	109,649	1,715	44,027	-243	0
1974	39,470	0	98,383	7,027	86,379	32,950	0	53,429	82,191	0	82,191	35,711	5,138	57,534	0	98,383	1,526	39,160	-287	0
1975	42,520	0	107,235	1,710	84,866	31,944	0	52,922	94,789	0	94,789	33,708	7,175	66,352	0	107,235	1,662	42,651	-320	0
1976	31,887	0	82,127	300	85,570	31,821	0	53,749	61,613	0	61,613	36,983	2,015	43,129	0	82,127	1,298	33,311	-114	0
1977	33,154	0	84,309	1,706	44,460	16,626	0	27,834	90,912	0	90,912	18,565	2,106	63,638	0	84,309	1,336	34,288	-99	0
1978	33,231	0	85,767	2,452	39,789	14,323	0	25,466	93,325	0	93,325	17,316	3,113	65,328	0	85,756	1,336	34,301	-217	11
1979	35,159	0	92,791	755	87,994	29,239	0	58,755	72,619	0	72,619	40,090	1,868	50,833	0	92,791	1,478	37,934	-69	0
1980	38,392	0	101,614	605	89,215	28,047	0	61,168	80,866	0	80,866	42,612	1,588	57,415	0	101,614	1,545	39,645	-64	0
1981	37,885	0	99,187	920	97,312	28,976	0	68,337	64,424	0	64,424	48,200	2,427	46,385	0	97,013	1,162	36,011	-119	2,174
1982	38,277	0	104,240	6,307	90,199	24,994	0	65,205	78,272	0	78,272	45,557	1,545	57,138	0	104,240	968	37,770	41	0
1983	35,931	0	89,452	246	91,344	24,904	0	66,440	45,953	0	45,953	45,402	10,045	34,005	0	89,452	548	28,674	-523	0
1984	37,594	0	92,824	6,452	95,404	25,549	0	69,855	54,355	0	54,355	46,706	5,352	40,767	0	92,824	388	30,664	28	0
1985	39,257	0	92,620	169	87,352	23,236	0	64,116	49,576	0	49,576	44,573	10,865	37,182	0	92,620	355	28,068	-613	0
1986	40,920	0	94,940	2,364	94,574	24,933	0	69,641	58,388	0	58,388	45,168	5,982	43,791	0	94,940	400	31,607	90	0

Canal and Farm Water Budget

JID Total

1938 - 2017

Annual Totals (Acre-Feet)

Year	SW Acres	Primary GW Acres	Total CIR	Excess Effective Precip	Surface Water Divers	Total Canal Loss	Wasteway Flows	SW Farm Delivery	Suppl Ground Water Pumping	Primary Ground Water Pumping	Total Ground Water Pumping	CU of Surface Water	CU of SM Carryover	CU of Suppl GW Pumping	CU of Primary GW Pumping	Total CU	Surface Runoff	Deep Perc	Change in Soil Moisture	Shortage
1987	42,583	0	101,989	1,557	97,175	25,223	0	71,952	59,305	0	59,305	49,878	7,632	44,479	0	101,989	410	32,404	-296	0
1988	44,246	0	110,245	622	96,182	24,689	0	71,493	76,046	0	76,046	48,030	5,180	57,035	0	110,245	461	36,424	34	0
1989	38,448	0	100,596	826	96,585	24,513	0	72,072	60,707	0	60,707	48,767	6,299	45,531	0	100,596	415	32,780	-84	0
1990	32,650	0	71,493	546	97,349	24,624	0	72,725	28,132	0	28,132	43,248	7,145	21,099	0	71,493	350	27,630	115	0
1991	34,086	0	81,417	5,240	98,821	24,999	0	73,822	40,205	0	40,205	44,719	6,543	30,154	0	81,417	434	34,309	-178	0
1992	35,522	0	86,981	4,602	99,787	25,095	0	74,692	38,370	0	38,370	46,361	11,843	28,777	0	86,981	411	32,444	-564	0
1993	36,958	0	92,738	2,033	104,771	26,583	0	78,188	47,099	0	47,099	48,246	9,168	35,324	0	92,738	434	34,269	-179	0
1994	38,394	0	99,981	3,204	106,025	26,535	0	79,490	53,717	0	53,717	51,834	7,859	40,288	0	99,981	431	34,057	-105	0
1995	39,830	0	104,003	851	110,412	27,701	0	82,711	51,562	0	51,562	54,318	11,014	38,671	0	104,003	443	35,025	-433	0
1996	41,267	0	97,611	548	106,403	26,601	0	79,802	57,284	0	57,284	49,117	5,531	42,963	0	97,611	489	38,647	28	0
1997	41,752	0	95,121	1,961	105,541	26,375	0	79,166	56,359	0	56,359	46,835	6,016	42,269	0	95,121	503	39,745	13	0
1998	42,237	0	112,043	1,235	108,771	27,128	0	81,643	70,937	0	70,937	49,154	9,686	53,203	0	112,043	554	43,784	-317	0
1999	42,721	0	114,199	943	107,014	26,579	0	80,435	74,946	0	74,946	50,868	7,121	56,209	0	114,199	527	41,613	-80	0
2000	43,205	0	118,548	1,056	109,852	27,347	0	82,505	81,343	0	81,343	52,448	5,092	61,008	0	118,548	540	42,653	176	0
2001	36,411	0	101,179	1,041	111,273	27,671	0	83,602	60,705	0	60,705	47,685	7,965	45,529	0	101,179	585	46,177	-303	0
2002	36,298	0	97,643	4,808	109,800	27,311	0	82,489	55,416	0	55,416	48,393	7,688	41,562	0	97,643	529	41,785	-171	0
2003	35,535	0	98,967	4,303	77,386	17,938	0	59,448	61,779	0	61,779	37,438	15,195	46,334	0	98,967	385	30,418	-712	0
2004	39,968	0	110,218	5,425	76,011	17,716	0	58,295	88,507	0	88,507	36,211	7,626	66,380	0	110,218	459	36,242	-10	0
2005	38,518	0	85,565	1,802	107,613	26,681	0	80,932	37,866	0	37,866	45,274	11,892	28,400	0	85,565	488	38,561	-485	0
2006	37,170	0	91,715	431	78,591	18,197	0	60,394	60,596	0	60,596	37,916	8,351	45,447	0	91,715	402	31,745	-239	0
2007	39,311	0	95,447	3,308	103,789	25,330	0	78,459	56,792	0	56,792	46,162	6,691	42,594	0	95,447	488	38,584	61	0
2008	35,459	0	82,304	2,569	107,725	26,333	0	81,392	34,400	0	34,400	42,945	13,559	25,800	0	82,304	507	40,090	-592	0
2009	33,300	0	79,446	2,157	111,751	27,484	0	84,267	45,281	0	45,281	42,525	2,960	33,961	0	79,446	582	45,980	295	0
2010	35,220	0	86,940	1,618	111,152	27,269	0	83,883	41,860	0	41,860	44,662	10,884	31,395	0	86,940	557	43,972	-477	0
2011	29,953	0	84,804	806	84,120	19,199	0	64,921	51,441	0	51,441	39,152	7,071	38,580	0	84,804	396	31,254	-8	0
2012	30,719	0	79,453	383	80,889	18,322	0	62,567	46,124	0	46,124	37,687	7,173	34,593	0	79,453	370	29,256	-32	0
2013	32,209	0	82,454	653	63,496	13,175	0	50,321	56,887	0	56,887	32,410	7,379	42,665	0	82,454	335	26,467	-171	0
2014	29,917	0	79,881	280	79,760	17,660	0	62,100	47,717	0	47,717	38,041	6,052	35,788	0	79,881	373	29,478	7	0
2015	30,918	0	77,213	4,753	95,412	22,132	0	73,280	43,149	0	43,149	37,950	6,902	32,361	0	77,213	452	35,724	253	0
2016	31,677	0	85,826	780	105,964	25,143	0	80,821	35,903	0	35,903	45,334	13,565	26,927	0	85,826	483	38,190	-648	0
2017	32,014	0	88,074	629	114,941	27,702	0	87,240	44,083	0	44,083	48,150	6,862	33,062	0	88,074	554	43,769	-90	0
Avg	37,550	0	87,961	1,708	79,879	24,822	0	55,057	52,389	0	52,389	34,192	5,317	37,793	0	77,303	879	30,941	-140	10,659
Max	58,300	0	118,548	7,027	114,941	41,332	0	87,240	102,053	0	102,053	54,318	15,195	71,437	0	118,548	1,715	46,177	295	89,437
Min	23,670	0	47,530	0	13,591	5,436	0	8,155	0	0	0	4,659	537	0	0	28,958	335	13,808	-712	0
Avg 38-78	38,100	0	82,321	1,411	63,233	25,039	0	38,194	49,320	0	49,320	24,032	3,213	34,331	0	61,576	1,198	26,132	-116	20,744
Avg 79-07	38,639	0	97,771	2,212	98,019	25,335	0	72,684	59,384	0	59,384	46,249	7,283	44,165	0	97,696	572	35,851	-171	75
Avg 08-17	32,139	0	82,640	1,463	95,521	22,442	0	73,079	44,684	0	44,684	40,886	8,241	33,513	0	82,640	461	36,418	-146	0

Appendix 10A

Comparison of Model Runs
Integrated LRG Model

Table 10A-2a
Comparison of Integrated LRG Model Runs
All Pumping Off v. Historical Base Run
1985 - 2016 Annual Average
(1,000 acre-feet)

Run No.	1	2	2 - 1		
Simulated Input or Output	Historical Base Run	All Pumping Off	All Pumping Off minus Historical Base Run		
CHANGE IN PUMPING STRESS					
Irrigation Pumping	202.7	0.0	-202.7		
Non-Irrigation Pumping	240.0	0.0	-240.0		
WWTP Flows	125.6	20.5	-105.1		
Urban Deep Percolation	17.4	4.8	-12.7		
Total Change in Stress	299.6	-25.3	-324.9		
	Change in stress is pumping minus returns				
EFFECTS OF CHANGE IN PUMPING STRESS					
FHG Deliveries (Mar - Oct)				*% ΔStress*	*% Diff.*
EBID	179.3	210.1	30.8	*9%*	*17%*
EPCWID (incl. EPW)	153.1	161.3	8.2	*3%*	*5%*
HCCRD	36.5	36.8	0.3	*0%*	*1%*
Total	369.0	408.2	39.2	*12%*	*11%*
FHG Deliveries (Nov - Feb)					
EBID	0.0	0.1	0.1	*0%*	*782%*
EPCWID (incl. EPW)	8.6	8.5	-0.1	*0%*	*-1%*
HCCRD	0.8	0.7	-0.1	*0%*	*-7%*
Total	9.4	9.3	-0.1	*0%*	*-1%*
Irrigation Pumping					
EBID	123.0	0.0	-123.0		
EPCWID (Mesilla Valley)	2.8	0.0	-2.8		
EPCWID (El Paso Valley)	17.1	0.0	-17.1		
HCCRD	0.6	0.0	-0.6		
Total					
	Pumping turned off.	*Other values are simulated responses and are totaled.*			
Other Inflows/Outflows					
Reservoir Evaporation	174.9	183.1	8.1	*3%*	*5%*
Riparian ET	65.6	74.1	8.5	*3%*	*13%*
River Evaporation + Incidental Canal Loss	30.1	31.3	1.3	*0%*	*4%*
Total	270.6	288.6	17.9	*6%*	*7%*
Rio Grande at Fort Quitman					
Reservoir Spills	74.7	113.0	38.3	*12%*	*51%*
Nov-Feb Flows	30.4	56.7	26.3	*8%*	*87%*
Mar - Oct Flows	59.1	99.3	40.2	*12%*	*68%*
Underflow (GW Model)	0.3	0.3	0.0	*0%*	*7%*
Total	164.5	269.3	104.8	*32%*	*64%*

Table 10A-2a
Comparison of Integrated LRG Model Runs
All Pumping Off v. Historical Base Run
1985 - 2016 Annual Average
(1,000 acre-feet)

Run No.	1	2	2 - 1		
Simulated Input or Output	Historical Base Run	All Pumping Off	All Pumping Off minus Historical Base Run		
EFFECTS OF CHANGE IN PUMPING STRESS continued					
Change in Storage				*% ΔStress*	*% Diff.*
Reservoir Storage	-32.5	-43.3	-10.8	*-3%*	*33%*
Alluvial GW Storage (RW Model)	-34.8	-1.8	33.0	*10%*	*-95%*
Non-alluvial GW Storage (GW Models)	-117.5	-1.9	115.6	*36%*	*-98%*
Soil Moisture Storage	0.1	-0.1	-0.2	*0%*	*-249%*
Total	-184.7	-47.2	137.6	*42%*	*-74%*
Summary of Effects					
FHG Deliveries (Mar-Oct)	369.0	408.2	39.2	*12%*	*11%*
FHG Deliveries (Nov-Feb)	9.4	9.3	-0.1	*0%*	*-1%*
Irrigation Pumping	0.0	0.0	0.0	*0%*	*0%*
Riparian ET + Evaporation	270.6	288.6	17.9	*6%*	*7%*
Fort Quitman Flow	164.5	269.3	104.8	*32%*	*64%*
Change in Storage	-184.7	-47.2	137.6	*42%*	*-74%*
Total	628.7	928.2	299.5	*92%*	*48%*
OTHER EFFECTS OF CHANGE IN PUMPING STRESS					
Rio Grande at El Paso				*% ΔStress*	*% Diff.*
Reservoir Spills	107.6	149.9	42.3	*13%*	*39%*
Nov-Feb Flows	26.1	50.8	24.7	*8%*	*94%*
Mar - Oct Flows	262.7	288.4	25.7	*8%*	*10%*
Total	396.5	489.1	92.6	*28%*	*23%*
Surface Water Diversions (Mar - Oct)					
EBID	396.1	441.0	45.0	*14%*	*11%*
EPCWID (incl. EPW)	279.2	299.8	20.7	*6%*	*7%*
HCCRD	65.0	83.5	18.5	*6%*	*28%*
Total	740.2	824.4	84.2	*26%*	*11%*
Surface Water Diversions (Nov - Feb)					
EBID	0.0	0.0	0.0	*0%*	*0%*
EPCWID (incl. EPW)	21.8	24.5	2.8	*1%*	*13%*
HCCRD	18.6	26.3	7.7	*2%*	*42%*
Total	40.4	50.9	10.5	*3%*	*26%*

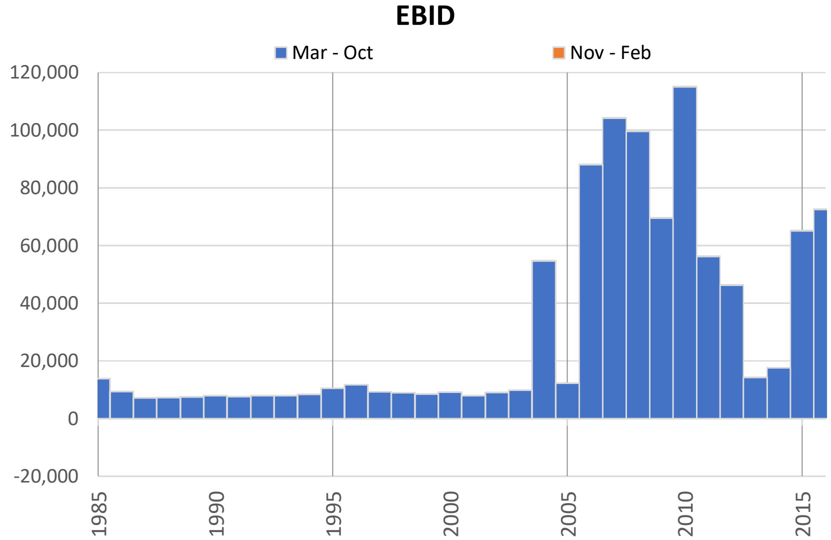
Table 10A-2b
Simulated Annual Differences in Integrated LRG Model Outputs
All Pumping Off minus Historical Base Run
1985 - 2016 (acre-feet)

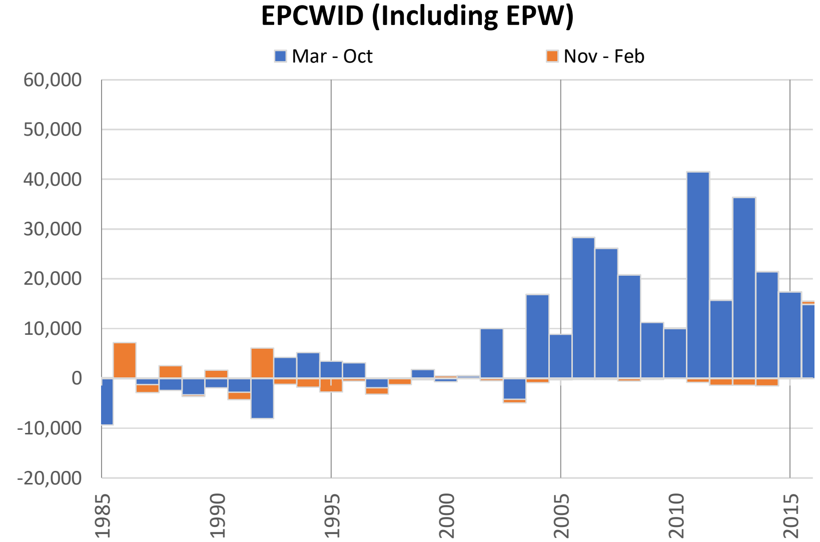
	Farm Headgate Deliveries						Other			Flows	
	EBID		EPCWID (incl. EPW)		HCCRD						
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Net Reservoir Evaporation	Riparian ET	River Evaporation + Incidental Canal Loss	Rio Grande at El Paso	Rio Grande at Fort Quitman
1985	13,752	13,796	-9,318	-9,133	0	0	35,434	2,243	-2,769	-25,189	8,157
1986	9,364	9,449	-88	7,116	0	0	17,383	12,511	3,361	532,967	529,303
1987	7,183	7,255	-1,222	-2,846	0	0	-1	4,714	-598	61,174	112,749
1988	7,203	7,276	-2,401	188	0	0	841	4,721	-1,389	46,853	79,494
1989	7,530	7,585	-3,324	-3,623	0	0	1,061	5,912	-211	45,363	67,938
1990	7,865	7,927	-1,884	-245	0	0	2,873	5,256	-620	35,628	49,623
1991	7,562	7,628	-2,799	-4,238	0	0	3,299	4,150	-231	32,665	41,318
1992	7,890	7,971	-8,039	-1,966	0	0	885	6,013	324	112,218	125,300
1993	7,964	8,050	4,255	3,109	0	0	352	4,952	-954	74,439	99,426
1994	8,397	8,483	5,220	3,466	0	0	841	4,829	-794	81,777	109,177
1995	10,519	10,592	3,479	768	0	0	370	5,638	-482	115,357	149,653
1996	11,642	11,718	3,157	2,630	0	0	3,036	5,048	-1,125	51,341	68,452
1997	9,206	9,270	-1,879	-3,166	0	0	7,264	4,273	457	102,655	103,741
1998	8,864	8,941	134	-1,116	0	0	3,913	4,619	8	70,173	105,984
1999	8,471	8,527	1,782	1,501	0	0	7,773	5,183	-398	44,120	80,030
2000	9,098	9,150	-682	-160	0	0	7,514	6,892	-112	66,797	100,536
2001	7,883	7,921	517	530	0	0	9,947	7,541	-752	44,496	75,060
2002	8,989	9,018	10,021	9,567	0	0	18,020	6,649	-1,009	41,845	68,195
2003	9,834	9,918	-4,210	-4,884	0	0	23,645	7,959	-727	43,535	64,348
2004	54,665	54,783	16,825	16,007	0	0	23,607	9,902	1,196	109,421	94,140
2005	12,211	12,285	8,878	8,593	0	0	138	8,827	576	55,601	81,468
2006	88,100	88,148	28,289	28,112	0	0	22,941	9,442	1,911	114,014	88,824
2007	104,114	104,166	26,145	25,937	0	0	12,268	9,838	3,167	131,371	132,870
2008	99,615	99,663	20,764	20,263	0	0	4,278	11,044	3,726	126,154	144,529
2009	69,582	69,645	11,232	11,037	0	0	6,832	8,393	1,676	75,337	97,958
2010	115,017	115,112	10,030	10,163	0	0	5,136	8,219	2,502	75,430	98,316
2011	56,257	56,297	41,516	40,750	-1,113	-3,642	-1,172	17,941	5,950	194,312	169,622
2012	46,187	46,215	15,681	14,308	-1,272	-2,772	3,774	15,700	5,538	106,930	86,047
2013	14,200	14,227	36,357	35,005	4,177	4,675	6,076	15,182	6,300	129,345	65,762
2014	17,546	17,564	21,438	19,921	8,764	9,643	9,399	18,031	5,258	94,295	70,140
2015	65,141	65,167	17,379	17,281	-1,579	-766	10,340	15,400	5,571	96,945	102,146
2016	72,563	72,588	14,861	15,509	0	0	12,425	16,196	4,861	75,244	84,770
Avg 85-05	11,243	11,312	877	1,052	0	0	8,009	6,087	-297	83,011	105,433
Avg 85-16	30,763	30,823	8,191	8,137	281	223	8,140	8,538	1,257	92,582	104,846

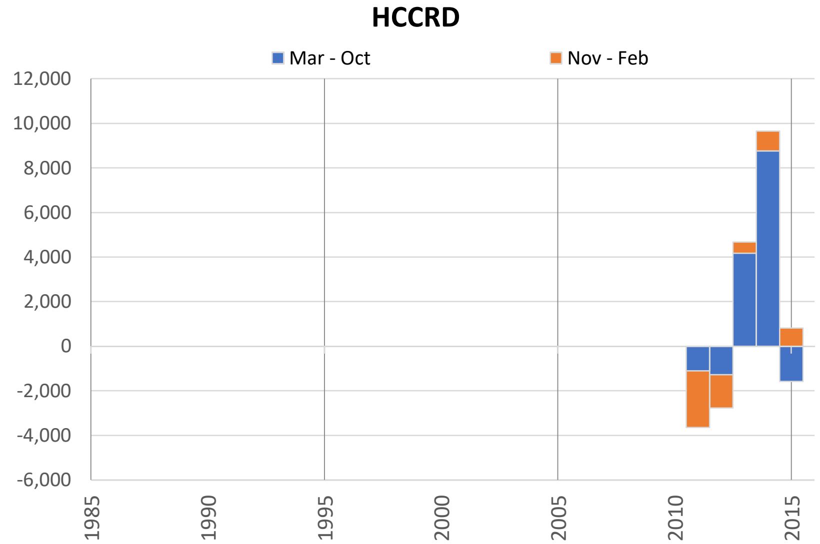
Figure 10A-2

Simulated Annual Differences in Integrated LRG Model Outputs
All Pumping Off minus Historical Base Run
1985 - 2016 (acre-feet)

Farm Headgate Deliveries







*Note different scales.

10/27/2019

Table 10A-3a
Comparison of Integrated LRG Model Runs
NM Pumping Off v. Historical Base Run
1985 - 2016 Annual Average
(1,000 acre-feet)

Run No.	1	3	3 - 1		
Simulated Input or Output	Historical Base Run	NM Pump Off	NM Pump Off minus Historical Base Run		
CHANGE IN PUMPING STRESS					
Irrigation Pumping	123.0	0.0	-123.0		
Non-Irrigation Pumping	240.0	204.4	-35.6		
WWTP Flows	125.6	114.8	-10.8		
Urban Deep Percolation	17.4	13.4	-4.1		
Total Change in Stress	219.9	76.2	-143.7		
	Change in stress is pumping minus returns				
EFFECTS OF CHANGE IN PUMPING STRESS					
FHG Deliveries (Mar - Oct)				*% ΔStress*	*% Diff.*
EBID	179.3	205.5	26.2	*18%*	*15%*
EPCWID (incl. EPW)	153.1	161.3	8.2	*6%*	*5%*
HCCRD	36.5	36.8	0.3	*0%*	*1%*
Total	369.0	403.6	34.6	*24%*	*9%*
FHG Deliveries (Nov - Feb)					
EBID	0.0	0.1	0.1	*0%*	*750%*
EPCWID (incl. EPW)	8.6	9.1	0.6	*0%*	*7%*
HCCRD	0.8	0.7	-0.1	*0%*	*-7%*
Total	9.4	9.9	0.6	*0%*	*6%*
Irrigation Pumping					
EBID	123.0	0.0	-123.0		
EPCWID (Mesilla Valley)	2.8	1.8	-1.0	*-1%*	*-37%*
EPCWID (El Paso Valley)	17.1	13.0	-4.1	*-3%*	*-24%*
HCCRD	0.6	0.0	-0.6	*0%*	*-100%*
Total	20.5	14.8	-5.7	*-4%*	*-28%*
Other Inflows/Outflows					
Net Reservoir Evaporation	174.9	182.0	7.0	*5%*	*4%*
Riparian ET	65.6	68.5	2.9	*2%*	*4%*
River Evaporation + Incidental Canal Loss	30.1	31.7	1.6	*1%*	*5%*
Total	270.6	282.2	11.6	*8%*	*4%*
Rio Grande at Fort Quitman					
Reservoir Spills	74.7	104.8	30.1	*21%*	*40%*
Nov-Feb Flows	30.4	49.6	19.2	*13%*	*63%*
Mar - Oct Flows	59.1	76.4	17.3	*12%*	*29%*
Underflow (GW Model)	0.3	0.3	0.0	*0%*	*5%*
Total	164.5	231.0	66.6	*46%*	*40%*

Table 10A-3a
Comparison of Integrated LRG Model Runs
NM Pumping Off v. Historical Base Run
1985 - 2016 Annual Average
(1,000 acre-feet)

Run No.	1	3	3 - 1		
Simulated Input or Output	Historical Base Run	NM Pump Off	NM Pump Off minus Historical Base Run		
EFFECTS OF CHANGE IN PUMPING STRESS continued					
Change in Storage				*% ΔStress*	*% Diff.*
Reservoir Storage	-32.5	-42.8	-10.3	*-7%*	*32%*
Alluvial GW Storage (RW Model)	-34.8	-24.3	10.5	*7%*	*-30%*
Non-alluvial GW Storage (GW Models)	-117.5	-105.4	12.1	*8%*	*-10%*
Soil Moisture Storage	0.1	0.1	0.0	*0%*	*-23%*
Total	-184.7	-172.4	12.4	*9%*	*-7%*
Summary of Effects					
FHG Deliveries (Mar-Oct)	369.0	403.6	34.6	*24%*	*9%*
FHG Deliveries (Nov-Feb)	9.4	9.9	0.6	*0%*	*6%*
Irrigation Pumping	20.5	14.8	-5.7	*-4%*	*-28%*
Riparian ET + Evaporation	270.6	282.2	11.6	*8%*	*4%*
Fort Quitman Flow	164.5	231.0	66.6	*46%*	*40%*
Change in Storage	-184.7	-172.4	12.4	*9%*	*-7%*
Total	649.2	769.2	120.0	*84%*	*18%*
OTHER EFFECTS OF CHANGE IN PUMPING STRESS					
Rio Grande at El Paso				*% ΔStress*	*% Diff.*
Reservoir Spills	107.6	145.1	37.5	*26%*	*35%*
Nov-Feb Flows	26.1	46.5	20.3	*14%*	*78%*
Mar - Oct Flows	262.7	279.4	16.6	*12%*	*6%*
Total	396.5	470.9	74.4	*52%*	*19%*
Surface Water Diversions (Mar - Oct)					
EBID	396.1	436.1	40.0	*28%*	*10%*
EPCWID (incl. EPW)	279.2	296.9	17.7	*12%*	*6%*
HCCRD	65.0	73.4	8.4	*6%*	*13%*
Total	740.2	806.3	66.1	*46%*	*9%*
Surface Water Diversions (Nov - Feb)					
EBID	0.0	0.0	0.0	*0%*	*0%*
EPCWID (incl. EPW)	21.8	25.1	3.3	*2%*	*15%*
HCCRD	18.6	22.0	3.5	*2%*	*19%*
Total	40.4	47.1	6.8	*5%*	*17%*

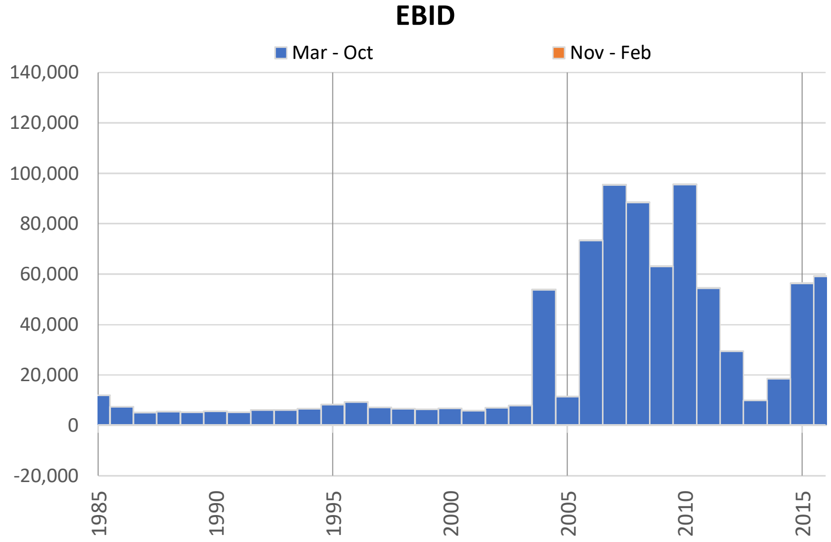
Table 10A-3b
Simulated Annual Differences in Integrated LRG Model Outputs
NM Pumping Off minus Historical Base Run
1985 - 2016 (acre-feet)

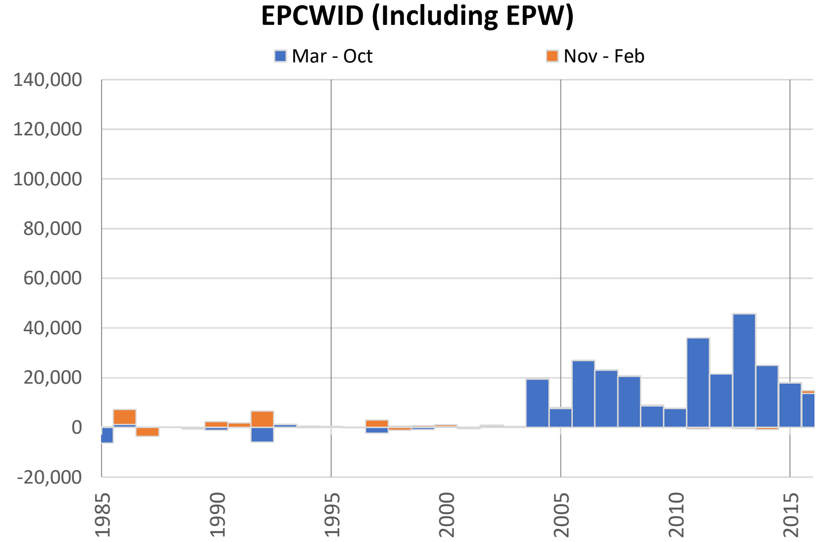
	Farm Headgate Deliveries						Other			Flows	
	EBID		EPCWID (incl. EPW)		HCCRD						
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Net Reservoir Evaporation	Riparian ET	River Evaporation + Incidental Canal Loss	Rio Grande at El Paso	Rio Grande at Fort Quitman
1985	11,970	12,010	-6,223	-5,882	0	0	33,973	-2,140	-2,495	-55,902	-30,870
1986	7,325	7,408	1,225	7,272	0	0	17,383	8,793	4,001	509,451	469,021
1987	5,057	5,128	80	-3,443	0	0	-1	1,159	-93	43,904	58,974
1988	5,476	5,547	53	70	0	0	650	828	-709	29,921	33,695
1989	5,207	5,261	-525	-626	0	0	896	1,326	72	30,469	31,395
1990	5,523	5,585	-1,186	1,175	0	0	2,786	915	71	18,065	24,719
1991	5,217	5,280	-75	1,694	0	0	3,386	644	8	16,483	21,113
1992	6,084	6,162	-5,839	811	0	0	772	2,492	632	97,000	93,981
1993	6,125	6,209	1,214	1,271	0	0	265	1,234	-617	56,720	59,337
1994	6,565	6,649	488	481	0	0	612	988	-630	64,809	60,918
1995	8,215	8,288	288	404	0	0	367	1,692	-68	92,826	94,862
1996	9,201	9,277	96	-15	0	0	2,378	1,038	-661	40,526	39,373
1997	7,067	7,128	-2,322	636	0	0	6,324	657	290	73,271	60,864
1998	6,518	6,595	539	-554	0	0	3,459	881	121	53,408	64,796
1999	6,389	6,444	-939	-302	0	0	6,906	682	99	25,375	28,731
2000	6,727	6,778	335	1,038	0	0	6,852	1,300	0	46,328	46,182
2001	5,844	5,882	-542	-396	0	0	8,558	1,082	-90	32,874	31,869
2002	6,997	7,025	653	888	0	0	15,041	883	-112	31,801	32,589
2003	7,883	7,964	182	363	0	0	20,361	788	-38	19,509	22,951
2004	53,797	53,915	19,421	19,644	0	0	20,799	2,810	1,756	91,069	52,067
2005	11,389	11,463	7,603	8,005	0	0	-2,742	2,268	1,286	41,286	40,784
2006	73,271	73,316	26,933	27,098	0	0	19,664	2,692	2,147	93,256	51,239
2007	95,434	95,482	23,061	23,163	0	0	10,395	4,473	3,303	115,589	93,808
2008	88,439	88,485	20,672	20,796	0	0	2,697	5,311	3,662	114,999	105,010
2009	62,979	63,039	8,652	9,025	0	0	4,575	2,546	1,733	63,029	56,240
2010	95,463	95,534	7,575	7,677	0	0	3,532	2,450	2,951	68,341	61,784
2011	54,436	54,473	36,060	35,381	-1,113	-3,642	-4,396	9,540	6,011	166,876	129,972
2012	29,389	29,415	21,487	21,392	-1,272	-2,772	3,015	6,295	5,988	82,153	67,778
2013	9,862	9,887	45,684	45,132	4,177	4,675	6,115	8,281	7,331	103,992	53,190
2014	18,558	18,576	25,007	24,189	8,764	9,643	8,910	9,371	5,791	70,352	45,520
2015	56,256	56,281	17,947	17,971	-1,579	-766	9,988	6,525	5,810	78,733	73,844
2016	59,047	59,070	13,697	14,830	0	0	11,837	5,573	4,902	64,351	54,773
Avg 85-05	9,266	9,333	692	1,549	0	0	7,097	1,444	134	64,723	63,683
Avg 85-16	26,178	26,236	8,166	8,725	281	223	7,042	2,918	1,639	74,402	66,579

Figure 10A-3

Simulated Annual Differences in Integrated LRG Model Outputs
NM Pumping Off minus Historical Base Run
1985 - 2016 (acre-feet)

Farm Headgate Deliveries





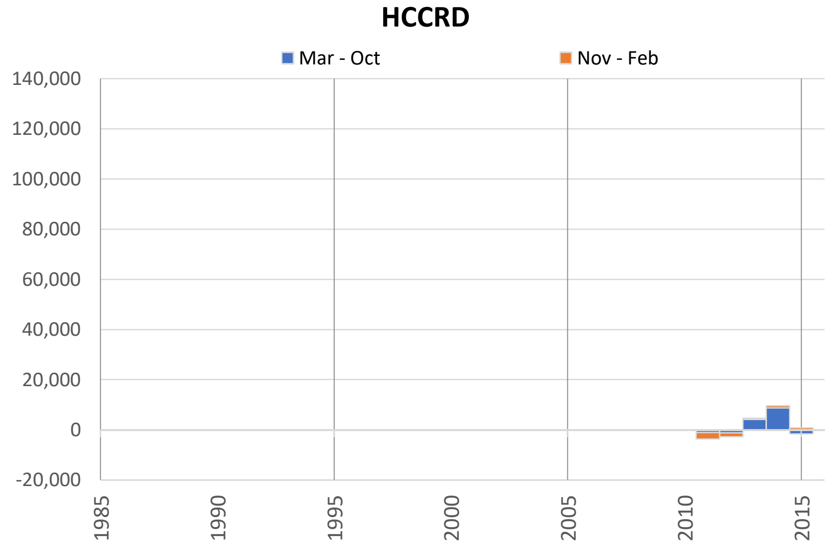


Table 10A-4a
Comparison of Integrated LRG Model Runs
TX Pumping Off v. Historical Base Run
1985 - 2016 Annual Average
(1,000 acre-feet)

Run No.	1	4	4 - 1		
Simulated Input or Output	Historical Base Run	TX Pump Off	TX Pump Off minus Historical Base Run		
CHANGE IN PUMPING STRESS					
Irrigation Pumping	20.5	0.0	-20.5		
Non-Irrigation Pumping	240.0	151.1	-88.9		
WWTP Flows	125.6	88.6	-37.0		
Urban Deep Percolation	17.4	8.8	-8.6		
Total Change in Stress	117.5	53.6	-63.8		
	Change in stress is pumping minus returns				
EFFECTS OF CHANGE IN PUMPING STRESS					
FHG Deliveries (Mar - Oct)				*% ΔStress*	*% Diff.*
EBID	179.3	184.5	5.1	*8%*	*3%*
EPCWID (incl. EPW)	153.1	153.0	-0.1	*0%*	*0%*
HCCRD	36.5	36.9	0.4	*1%*	*1%*
Total	369.0	374.4	5.4	*8%*	*1%*
FHG Deliveries (Nov - Feb)					
EBID	0.0	0.0	0.0	*0%*	*6%*
EPCWID (incl. EPW)	8.6	7.6	-1.0	*-2%*	*-11%*
HCCRD	0.8	0.8	0.0	*0%*	*1%*
Total	9.4	8.4	-1.0	*-2%*	*-10%*
Irrigation Pumping					
EBID	123.0	118.0	-5.0	*-8%*	*-4%*
EPCWID (Mesilla Valley)	2.8	0.0	-2.8		
EPCWID (El Paso Valley)	17.1	0.0	-17.1		
HCCRD	0.6	0.0	-0.6		
Total	123.0	118.0	-5.0	*-8%*	*-4%*
	Pumping turned off.	*Other values are simulated responses and are totaled.*			
Other Inflows/Outflows					
Reservoir Evaporation	174.9	175.5	0.6	*1%*	*0%*
Riparian ET	65.6	67.5	1.9	*3%*	*3%*
River Evaporation + Incidental Canal Loss	30.1	29.6	-0.5	*-1%*	*-2%*
Total	270.6	272.6	2.0	*3%*	*1%*
Rio Grande at Fort Quitman					
Reservoir Spills	74.7	74.0	-0.7	*-1%*	*-1%*
Nov-Feb Flows	30.4	29.3	-1.1	*-2%*	*-4%*
Mar - Oct Flows	59.1	64.4	5.3	*8%*	*9%*
Underflow (GW Model)	0.3	0.3	0.0	*0%*	*3%*
Total	164.5	168.0	3.5	*6%*	*2%*

Table 10A-4a
Comparison of Integrated LRG Model Runs
TX Pumping Off v. Historical Base Run
1985 - 2016 Annual Average
(1,000 acre-feet)

Run No.	1	4	4 - 1		
Simulated Input or Output	Historical Base Run	TX Pump Off	TX Pump Off minus Historical Base Run		
EFFECTS OF CHANGE IN PUMPING STRESS continued					
Change in Storage				*% ΔStress*	*% Diff.*
Reservoir Storage	-32.5	-32.9	-0.3	*0%*	*1%*
Alluvial GW Storage (RW Model)	-34.8	-30.6	4.2	*7%*	*-12%*
Non-alluvial GW Storage (GW Models)	-117.5	-72.4	45.1	*71%*	*-38%*
Soil Moisture Storage	0.1	0.1	0.0	*0%*	*34%*
Total	-184.7	-135.8	49.0	*77%*	*-27%*
Summary of Effects					
FHG Deliveries (Mar-Oct)	369.0	374.4	5.4	*8%*	*1%*
FHG Deliveries (Nov-Feb)	9.4	8.4	-1.0	*-2%*	*-10%*
Irrigation Pumping	123.0	118.0	-5.0	*-8%*	*-4%*
Riparian ET + Evaporation	270.6	272.6	2.0	*3%*	*1%*
Fort Quitman Flow	164.5	168.0	3.5	*6%*	*2%*
Change in Storage	-184.7	-135.8	49.0	*77%*	*-27%*
Total	751.6	805.6	53.9	*84%*	*7%*
OTHER EFFECTS OF CHANGE IN PUMPING STRESS					
Rio Grande at El Paso				*% ΔStress*	*% Diff.*
Reservoir Spills	107.6	109.6	2.0	*3%*	*2%*
Nov-Feb Flows	26.1	30.6	4.5	*7%*	*17%*
Mar - Oct Flows	262.7	275.0	12.3	*19%*	*5%*
Total	396.5	415.2	18.7	*29%*	*5%*
Surface Water Diversions (Mar - Oct)					
EBID	396.1	403.4	7.3	*11%*	*2%*
EPCWID (incl. EPW)	279.2	284.4	5.2	*8%*	*2%*
HCCRD	65.0	69.4	4.5	*7%*	*7%*
Total	740.2	757.2	17.0	*27%*	*2%*
Surface Water Diversions (Nov - Feb)					
EBID	0.0	0.0	0.0	*0%*	*0%*
EPCWID (incl. EPW)	21.8	21.0	-0.8	*-1%*	*-4%*
HCCRD	18.6	19.4	0.9	*1%*	*5%*
Total	40.4	40.4	0.0	*0%*	*0%*

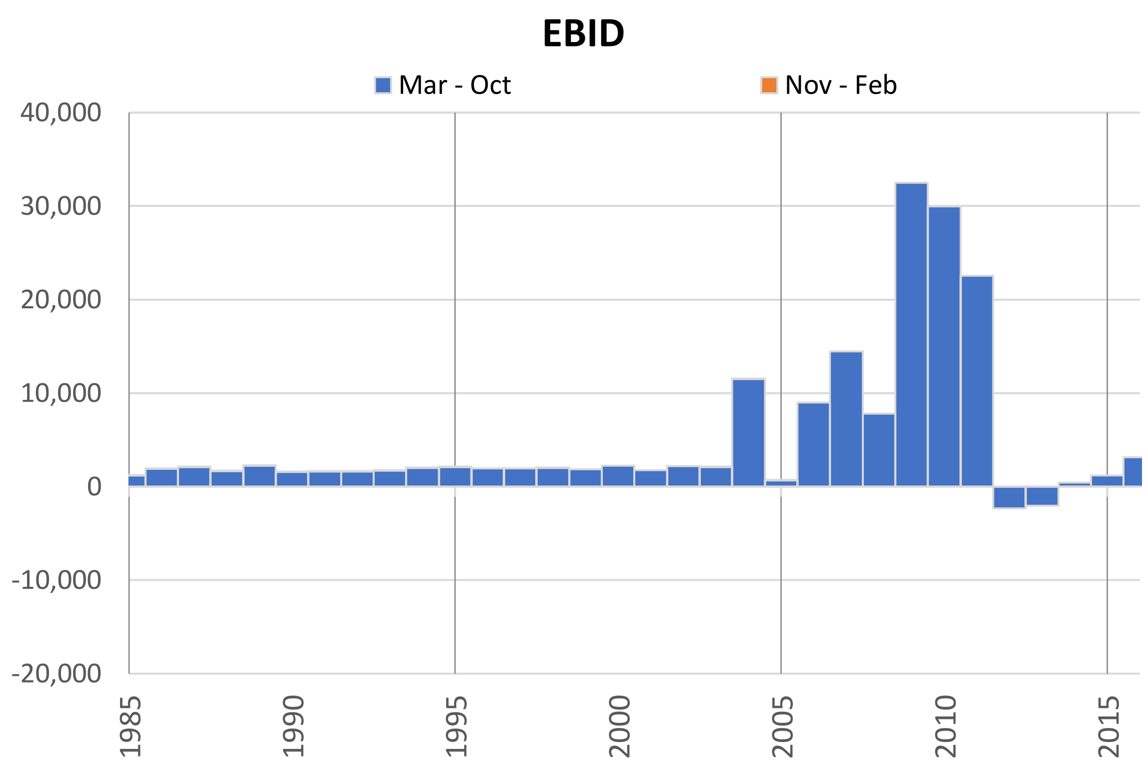
Table 10A-4b
Simulated Annual Differences in Integrated LRG Model Outputs
TX Pumping Off minus Historical Base Run
1985 - 2016 (acre-feet)

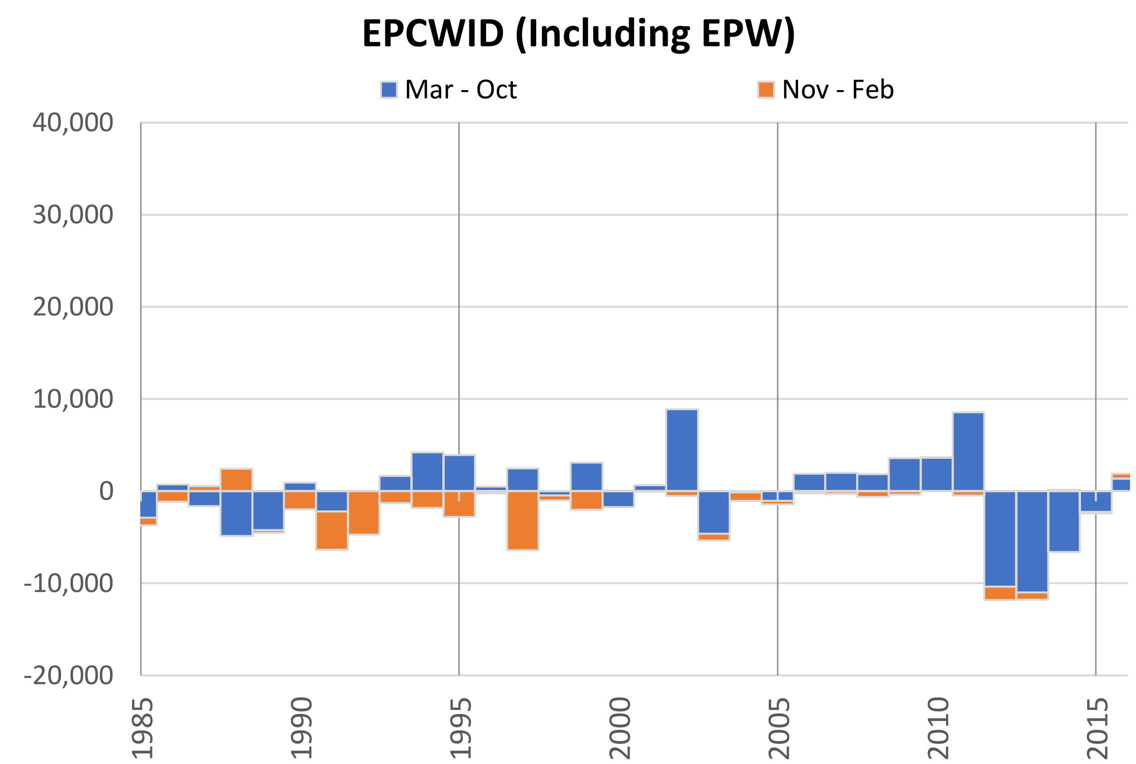
	Farm Headgate Deliveries						Other			Flows	
	EBID		EPCWID (incl. EPW)		HCCRD						
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Net Reservoir Evaporation	Riparian ET	River Evaporation + Incidental Canal Loss	Rio Grande at El Paso	Rio Grande at Fort Quitman
1985	1,183	1,184	-2,907	-3,705	0	0	462	1,213	-251	22,752	-4,508
1986	1,919	1,921	733	-413	0	0	240	945	-203	25,240	-1,982
1987	2,095	2,097	-1,620	-1,072	0	0	0	747	-415	18,383	-4,595
1988	1,690	1,691	-4,861	-2,430	0	0	-38	812	-168	19,096	-2,619
1989	2,220	2,221	-4,225	-4,536	0	0	-211	1,097	-304	19,331	-3,241
1990	1,567	1,568	935	-1,024	0	0	-457	1,326	-198	27,640	-2,546
1991	1,608	1,609	-2,201	-6,351	0	0	-956	950	-227	24,636	-3,154
1992	1,601	1,602	-4	-4,734	0	0	-473	353	-795	2,962	-16,112
1993	1,726	1,726	1,667	367	0	0	-7	933	-550	14,180	-7,052
1994	2,009	2,010	4,218	2,413	0	0	99	1,024	-994	18,342	5,163
1995	2,085	2,086	3,919	1,127	0	0	-43	1,171	-392	23,132	4,438
1996	1,973	1,973	517	277	0	0	544	621	-732	11,911	-9,992
1997	1,943	1,943	2,467	-3,952	0	0	223	1,062	-491	30,664	1,114
1998	2,002	2,003	-457	-981	0	0	134	1,008	-160	24,746	-52
1999	1,852	1,852	3,083	1,086	0	0	10	1,182	-315	23,329	9,838
2000	2,225	2,225	-1,736	-1,719	0	0	766	1,196	-550	13,554	4,274
2001	1,761	1,761	615	563	0	0	1,658	1,405	-784	10,699	1,300
2002	2,185	2,185	8,908	8,389	0	0	3,675	1,175	-970	9,006	-2,859
2003	2,098	2,100	-4,609	-5,362	0	0	4,356	1,937	-977	23,672	6,113
2004	11,520	11,520	-149	-1,056	0	0	2,788	2,526	-44	36,474	12,975
2005	651	652	-1,075	-1,433	0	0	804	1,870	-365	13,606	6,110
2006	8,988	8,988	1,876	1,630	0	0	2,224	1,732	-385	20,605	1,488
2007	14,490	14,490	1,998	1,700	0	0	1,325	1,685	-86	13,168	4,396
2008	7,799	7,799	1,856	1,250	0	0	2,707	2,017	306	11,216	9,110
2009	32,504	32,504	3,576	3,222	0	0	2,405	1,781	137	15,978	10,490
2010	29,954	29,954	3,631	3,651	0	0	2,756	1,612	422	11,784	7,274
2011	22,542	22,542	8,553	8,065	-1,113	-3,642	-6,411	6,731	-407	65,167	58,292
2012	-2,321	-2,321	-10,362	-11,827	-1,272	-2,772	-2,459	2,593	-2,113	6,797	3,600
2013	-2,031	-2,031	-10,994	-11,754	4,019	4,740	1,095	1,730	-1,245	9,421	-3,282
2014	409	409	-6,581	-6,445	8,101	10,238	1,322	5,110	-856	9,725	4,050
2015	1,183	1,183	-2,259	-2,390	2,544	3,938	-56	5,313	-572	11,786	15,021
2016	3,167	3,167	1,357	1,892	0	0	146	5,122	-559	9,543	9,520
Avg 85-05	2,282	2,282	153	-1,169	0	0	646	1,169	-471	19,684	-352
Avg 85-16	5,144	5,144	-129	-1,111	384	391	582	1,874	-476	18,705	3,518

Figure 10A-4

Simulated Annual Differences in Integrated LRG Model Outputs
TX Pumping Off minus Historical Base Run
1985 - 2016 (acre-feet)

Farm Headgate Deliveries





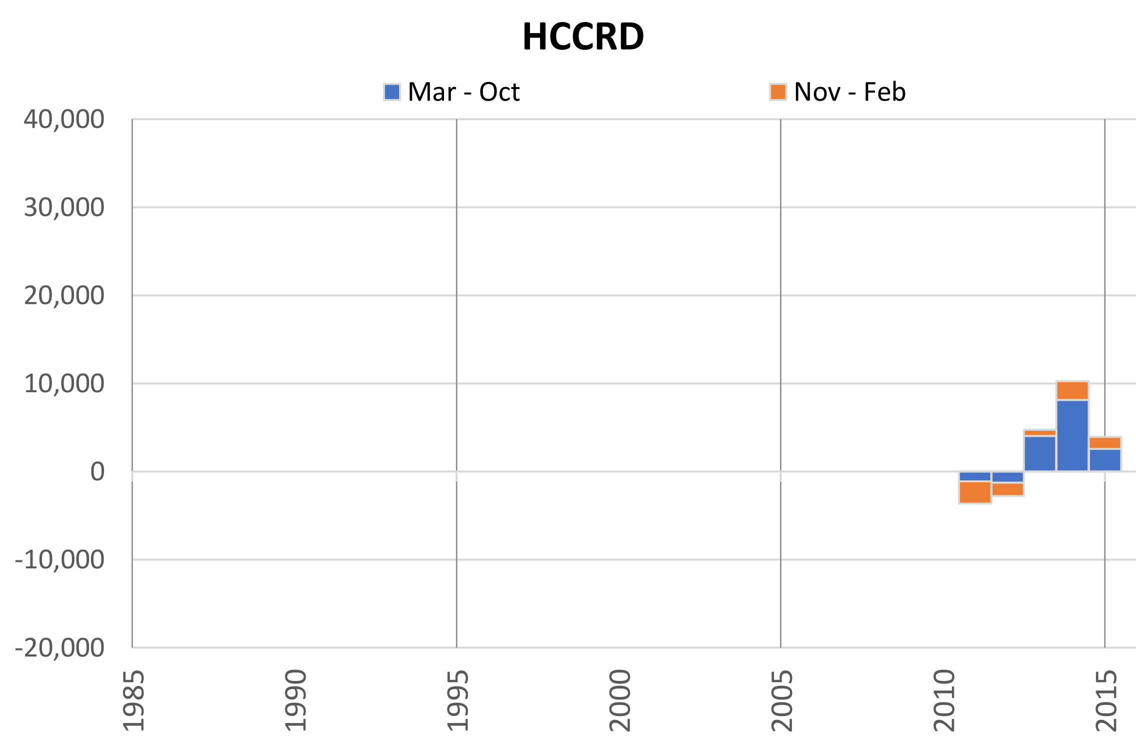


Table 10A-5a
Comparison of Integrated LRG Model Runs
MX Pumping Off v. Historical Base Run
1985 - 2016 Annual Average
(1,000 acre-feet)

Run No.	1	5	5 - 1		
Simulated Input or Output	Historical Base Run	MX Pump Off	MX Pump Off minus Historical Base Run		
CHANGE IN PUMPING STRESS					
Irrigation Pumping	59.2	0.0	-59.2		
Non-Irrigation Pumping	240.0	125.1	-115.0		
WWTP Flows	125.6	68.3	-57.3		
Urban Deep Percolation	17.4	17.4	0.0		
Total Change in Stress	156.2	39.3	-116.9		
	Change in stress is pumping minus returns				
EFFECTS OF CHANGE IN PUMPING STRESS					
FHG Deliveries (Mar - Oct)				*% ΔStress*	*% Diff.*
EBID	179.3	179.8	0.5	*0%*	*0%*
EPCWID (incl. EPW)	153.1	153.9	0.8	*1%*	*1%*
HCCRD	36.5	36.9	0.4	*0%*	*1%*
Total	369.0	370.7	1.7	*1%*	*0%*
FHG Deliveries (Nov - Feb)					
EBID	0.0	0.0	0.0	*0%*	*0%*
EPCWID (incl. EPW)	8.6	8.6	0.1	*0%*	*1%*
HCCRD	0.8	0.8	0.0	*0%*	*-2%*
Total	9.4	9.4	0.0	*0%*	*0%*
Irrigation Pumping					
EBID	123.0	122.4	-0.5	*0%*	*0%*
EPCWID (Mesilla Valley)	2.8	2.8	0.0	*0%*	*-1%*
EPCWID (El Paso Valley)	17.1	16.4	-0.7	*-1%*	*-4%*
HCCRD	0.6	0.2	-0.4	*0%*	*-69%*
Total	143.5	141.8	-1.6	*-1%*	*-1%*
Other Inflows/Outflows					
Reservoir Evaporation	174.9	175.2	0.2	*0%*	*0%*
Riparian ET	65.6	70.1	4.5	*4%*	*7%*
River Evaporation + Incidental Canal Loss	30.1	30.2	0.1	*0%*	*0%*
Total	270.6	275.4	4.8	*4%*	*2%*
Rio Grande at Fort Quitman					
Reservoir Spills	74.7	79.3	4.6	*4%*	*6%*
Nov-Feb Flows	30.4	38.7	8.3	*7%*	*27%*
Mar - Oct Flows	59.1	76.8	17.7	*15%*	*30%*
Underflow (GW Model)	0.3	0.3	0.0	*0%*	*3%*
Total	164.5	195.0	30.6	*26%*	*19%*

Table 10A-5a
Comparison of Integrated LRG Model Runs
MX Pumping Off v. Historical Base Run
1985 - 2016 Annual Average
(1,000 acre-feet)

Run No.	1	5	5 - 1		
Simulated Input or Output	Historical Base Run	MX Pump Off	MX Pump Off minus Historical Base Run		
EFFECTS OF CHANGE IN PUMPING STRESS continued					
Change in Storage				*% ΔStress*	*% Diff.*
Reservoir Storage	-32.5	-32.8	-0.3	*0%*	*1%*
Alluvial GW Storage (RW Model)	-34.8	-14.2	20.6	*18%*	*-59%*
Non-alluvial GW Storage (GW Models)	-117.5	-48.9	68.6	*59%*	*-58%*
Soil Moisture Storage	0.1	-0.1	-0.2	*0%*	*-199%*
Total	-184.7	-96.0	88.7	*76%*	*-48%*
Summary of Effects					
FHG Deliveries (Mar-Oct)	369.0	370.7	1.7	*1%*	*0%*
FHG Deliveries (Nov-Feb)	9.4	9.4	0.0	*0%*	*0%*
Irrigation Pumping	143.5	141.8	-1.6	*-1%*	*-1%*
Riparian ET + Evaporation	270.6	275.4	4.8	*4%*	*2%*
Fort Quitman Flow	164.5	195.0	30.6	*26%*	*19%*
Change in Storage	-184.7	-96.0	88.7	*76%*	*-48%*
Total	772.2	896.3	124.1	*106%*	*16%*
OTHER EFFECTS OF CHANGE IN PUMPING STRESS					
Rio Grande at El Paso				*% ΔStress*	*% Diff.*
Reservoir Spills	107.6	107.8	0.2	*0%*	*0%*
Nov-Feb Flows	26.1	26.3	0.1	*0%*	*1%*
Mar - Oct Flows	262.7	262.3	-0.4	*0%*	*0%*
Total	396.5	396.4	-0.1	*0%*	*0%*
Surface Water Diversions (Mar - Oct)					
EBID	396.1	397.0	1.0	*1%*	*0%*
EPCWID (incl. EPW)	279.2	279.0	-0.2	*0%*	*0%*
HCCRD	65.0	72.6	7.6	*7%*	*12%*
Total	740.2	748.6	8.4	*7%*	*1%*
Surface Water Diversions (Nov - Feb)					
EBID	0.0	0.0	0.0	*0%*	*0%*
EPCWID (incl. EPW)	21.8	21.7	-0.1	*0%*	*0%*
HCCRD	18.6	22.3	3.8	*3%*	*20%*
Total	40.4	44.0	3.7	*3%*	*9%*

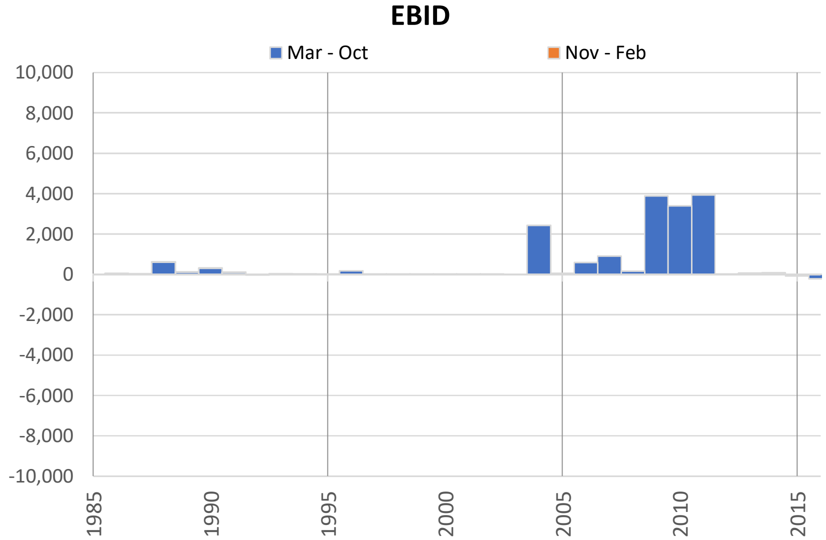
Table 10A-5b
Simulated Annual Differences in Integrated LRG Model Outputs
MX Pumping Off minus Historical Base Run
1985 - 2016 (acre-feet)

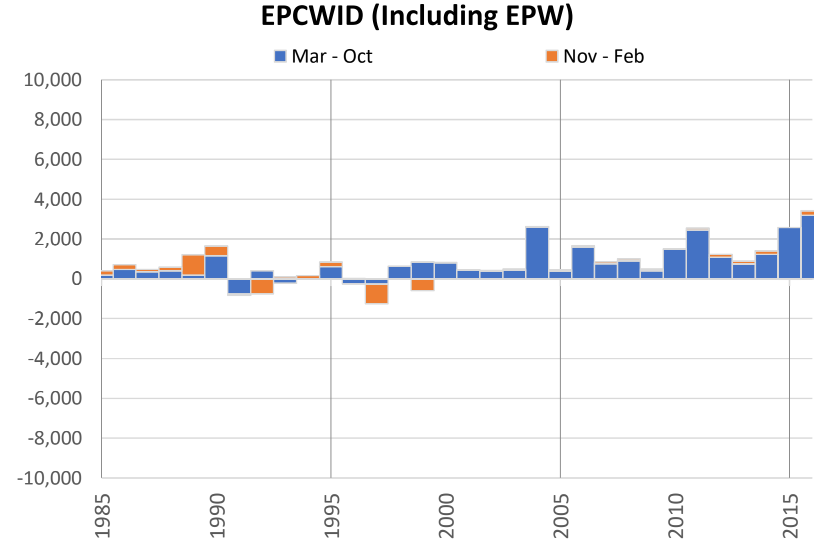
	Farm Headgate Deliveries						Other			Flows	
	EBID		EPCWID (incl. EPW)		HCCRD						
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Net Reservoir Evaporation	Riparian ET	River Evaporation + Incidental Canal Loss	Rio Grande at El Paso	Rio Grande at Fort Quitman
1985	-3	-3	173	403	0	0	679	3,706	-474	-1,466	34,341
1986	34	34	469	712	0	0	1,071	3,406	-302	9,928	46,096
1987	14	14	349	465	0	0	0	3,181	-79	289	52,456
1988	599	599	405	582	0	0	-29	3,559	-203	170	42,418
1989	108	108	179	1,203	0	0	-65	4,162	48	763	34,502
1990	295	295	1,153	1,635	0	0	-164	3,973	111	1,600	31,607
1991	86	86	-774	-838	0	0	-214	3,196	297	1,739	27,963
1992	-23	-23	411	-339	0	0	-25	2,775	137	-5,488	22,408
1993	12	12	-226	-130	0	0	-15	3,068	106	2,154	33,323
1994	4	4	9	158	0	0	7	3,108	256	-349	33,358
1995	-3	-3	612	832	0	0	-71	3,041	-4	460	40,803
1996	171	171	-251	-240	0	0	-101	3,728	305	298	36,422
1997	10	10	-271	-1,257	0	0	-127	2,860	457	262	32,805
1998	15	15	634	630	0	0	-305	3,190	261	1,064	36,945
1999	1	1	835	239	0	0	-153	3,528	41	-1,311	39,188
2000	1	1	798	802	0	0	100	4,240	-63	-2,027	37,781
2001	0	0	436	460	0	0	215	5,164	-10	-1,598	36,372
2002	0	0	378	427	0	0	666	4,747	-33	-1,554	34,157
2003	-1	-1	418	477	0	0	787	5,657	-62	-2,213	31,367
2004	2,421	2,421	2,588	2,624	0	0	514	5,345	177	5,777	36,197
2005	33	33	394	444	0	0	-162	4,648	26	-937	33,597
2006	590	590	1,588	1,656	0	0	113	5,532	234	241	36,719
2007	900	900	765	860	0	0	-37	4,562	23	-2,306	30,300
2008	159	159	907	992	0	0	944	4,982	76	-1,781	31,713
2009	3,876	3,876	403	491	0	0	424	4,927	159	-3,939	32,804
2010	3,389	3,389	1,477	1,483	0	0	536	4,852	109	-3,840	33,316
2011	3,934	3,934	2,448	2,543	-1,113	-3,642	1,933	6,432	308	3,184	20,104
2012	14	14	1,074	1,230	-1,272	-2,772	114	6,285	178	-47	11,960
2013	55	55	738	893	2,581	3,168	159	3,449	106	-453	3,014
2014	83	83	1,219	1,398	7,509	9,363	233	6,811	75	-162	-2,022
2015	-76	-76	2,570	2,535	5,218	6,413	3	7,290	-71	-1,678	6,913
2016	-231	-231	3,181	3,412	0	0	44	7,886	-166	173	19,528
Avg 85-05	180	180	415	442	0	0	124	3,823	47	360	35,910
Avg 85-16	515	515	784	837	404	392	221	4,478	63	-95	30,577

Figure 10A-5

Simulated Annual Differences in Integrated LRG Model Outputs
MX Pumping Off minus Historical Base Run
1985 - 2016 (acre-feet)

Farm Headgate Deliveries





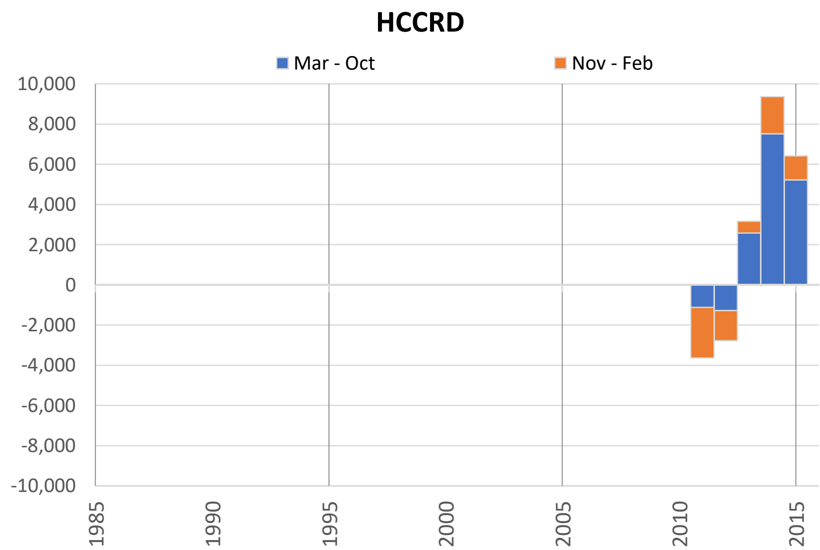


Table 10A-6a
Comparison of Integrated LRG Model Runs
RM Pumping Off v. Historical Base Run
1985 - 2016 Annual Average
(1,000 acre-feet)

Run No.	1	6	6 - 1		
Simulated Input or Output	Historical Base Run	RM Pump Off	RM Pump Off minus Historical Base Run		
CHANGE IN PUMPING STRESS					
Irrigation Pumping	125.8	0.0	-125.8		
Non-Irrigation Pumping	240.0	175.1	-64.9		
WWTP Flows	125.6	104.0	-21.7		
Urban Deep Percolation	17.4	11.0	-6.4		
Total Change in Stress	222.7	60.2	-162.6		
	Change in stress is pumping minus returns				
EFFECTS OF CHANGE IN PUMPING STRESS					
FHG Deliveries (Mar - Oct)				*% ΔStress*	*% Diff.*
EBID	179.3	209.7	30.4	*19%*	*17%*
EPCWID (incl. EPW)	153.1	161.7	8.6	*5%*	*6%*
HCCRD	36.5	36.8	0.3	*0%*	*1%*
Total	369.0	408.2	39.2	*24%*	*11%*
FHG Deliveries (Nov - Feb)					
EBID	0.0	0.1	0.1	*0%*	*778%*
EPCWID (incl. EPW)	8.6	9.2	0.6	*0%*	*7%*
HCCRD	0.8	0.7	-0.1	*0%*	*-7%*
Total	9.4	9.9	0.6	*0%*	*6%*
Irrigation Pumping					
EBID	123.0	0.0	-123.0		
EPCWID (Mesilla Valley)	2.8	0.0	-2.8		
EPCWID (El Paso Valley)	17.1	13.3	-3.9	*-2%*	*-23%*
HCCRD	0.6	0.0	-0.6	*0%*	*-100%*
Total	17.7	13.3	-4.4	*-3%*	*-25%*
	Pumping turned off.	*Other values are simulated responses and are totaled.*			
Other Inflows/Outflows					
Reservoir Evaporation	174.9	183.2	8.3	*5%*	*5%*
Riparian ET	65.6	68.9	3.3	*2%*	*5%*
River Evaporation + Incidental Canal Loss	30.1	31.7	1.6	*1%*	*5%*
Total	270.6	283.9	13.2	*8%*	*5%*
Rio Grande at Fort Quitman					
Reservoir Spills	74.7	109.4	34.7	*21%*	*46%*
Nov-Feb Flows	30.4	51.8	21.4	*13%*	*70%*
Mar - Oct Flows	59.1	77.8	18.7	*12%*	*32%*
Underflow (GW Model)	0.3	0.3	0.0	*0%*	*6%*
Total	164.5	239.3	74.8	*46%*	*45%*

Table 10A-6a
Comparison of Integrated LRG Model Runs
RM Pumping Off v. Historical Base Run
1985 - 2016 Annual Average
(1,000 acre-feet)

Run No.	1	6	6 - 1		
Simulated Input or Output	Historical Base Run	RM Pump Off	RM Pump Off minus Historical Base Run		
EFFECTS OF CHANGE IN PUMPING STRESS continued					
Change in Storage				*% ΔStress*	*% Diff.*
Reservoir Storage	-32.5	-44.5	-12.0	*-7%*	*37%*
Alluvial GW Storage (RW Model)	-34.8	-24.0	10.7	*7%*	*-31%*
Non-alluvial GW Storage (GW Models)	-117.5	-99.2	18.3	*11%*	*-16%*
Soil Moisture Storage	0.1	0.1	0.0	*0%*	*-39%*
Total	-184.7	-167.7	17.0	*10%*	*-9%*
Summary of Effects					
FHG Deliveries (Mar-Oct)	369.0	408.2	39.2	*24%*	*11%*
FHG Deliveries (Nov-Feb)	9.4	9.9	0.6	*0%*	*6%*
Irrigation Pumping	17.7	13.3	-4.4	*-3%*	*-25%*
Riparian ET + Evaporation	270.6	283.9	13.2	*8%*	*5%*
Fort Quitman Flow	164.5	239.3	74.8	*46%*	*45%*
Change in Storage	-184.7	-167.7	17.0	*10%*	*-9%*
Total	646.4	786.8	140.5	*86%*	*22%*
OTHER EFFECTS OF CHANGE IN PUMPING STRESS					
Rio Grande at El Paso				*% ΔStress*	*% Diff.*
Reservoir Spills	107.6	151.4	43.8	*27%*	*41%*
Nov-Feb Flows	26.1	51.5	25.4	*16%*	*97%*
Mar - Oct Flows	262.7	287.5	24.8	*15%*	*9%*
Total	396.5	490.4	93.9	*58%*	*24%*
Surface Water Diversions (Mar - Oct)					
EBID	396.1	440.3	44.2	*27%*	*11%*
EPCWID (incl. EPW)	279.2	299.3	20.1	*12%*	*7%*
HCCRD	65.0	73.1	8.2	*5%*	*13%*
Total	740.2	812.7	72.5	*45%*	*10%*
Surface Water Diversions (Nov - Feb)					
EBID	0.0	0.0	0.0	*0%*	*0%*
EPCWID (incl. EPW)	21.8	25.3	3.6	*2%*	*16%*
HCCRD	18.6	21.9	3.3	*2%*	*18%*
Total	40.4	47.3	6.9	*4%*	*17%*

Table 10A-6b
Simulated Annual Differences in Integrated LRG Model Outputs
RM Pumping Off minus Historical Base Run
1985 - 2016 (acre-feet)

	Farm Headgate Deliveries						Other			Flows	
	EBID		EPCWID (incl. EPW)		HCCRD						
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Net Reservoir Evaporation	Riparian ET	River Evaporation + Incidental Canal Loss	Rio Grande at El Paso	Rio Grande at Fort Quitman
1985	13,721	13,768	-6,117	-6,155	0	0	38,127	-1,470	-1,805	1,037	7,848
1986	9,453	9,539	914	7,086	0	0	17,383	9,487	4,005	537,762	496,593
1987	7,194	7,266	166	-3,037	0	0	-1	1,532	-195	61,487	69,208
1988	7,224	7,297	-85	67	0	0	904	1,128	-1,589	47,122	43,107
1989	7,317	7,372	-299	372	0	0	1,127	1,767	49	45,714	37,156
1990	7,528	7,590	-1,352	1,857	0	0	3,521	1,130	-214	27,592	25,965
1991	6,830	6,895	-217	2,142	0	0	4,265	792	-86	26,483	23,079
1992	7,947	8,029	-5,709	924	0	0	846	3,064	640	127,046	116,185
1993	7,931	8,016	1,305	1,119	0	0	314	1,640	-709	72,355	67,736
1994	8,412	8,496	992	792	0	0	747	1,358	-749	82,606	68,960
1995	10,506	10,579	312	426	0	0	439	2,213	-181	114,460	105,108
1996	11,676	11,752	871	750	0	0	2,840	1,335	-855	56,598	42,151
1997	9,163	9,228	-3,711	-818	0	0	7,422	1,005	439	97,171	71,968
1998	8,847	8,925	-350	-1,592	0	0	4,257	1,176	1	69,376	70,078
1999	8,423	8,479	-1,556	-980	0	0	8,508	938	-65	37,763	30,831
2000	9,130	9,183	18	923	0	0	7,608	1,882	193	73,647	60,656
2001	7,895	7,933	-1,254	-1,120	0	0	9,845	1,415	-195	47,263	35,362
2002	9,002	9,031	175	281	0	0	17,475	1,127	-399	45,339	34,772
2003	9,796	9,880	-799	-794	0	0	23,722	1,054	-174	33,571	25,526
2004	54,678	54,795	19,735	19,856	0	0	24,292	3,092	1,614	108,128	53,049
2005	12,199	12,272	7,319	7,672	0	0	687	2,582	668	54,436	42,335
2006	88,662	88,710	29,379	29,367	0	0	23,295	3,183	2,452	119,246	57,969
2007	104,873	104,925	24,174	24,218	0	0	12,108	4,899	3,507	133,394	100,188
2008	99,977	100,025	19,450	19,500	0	0	3,819	5,632	3,996	128,779	109,028
2009	66,443	66,506	9,207	9,436	0	0	6,131	2,909	1,746	80,538	62,705
2010	109,412	109,494	8,842	8,964	0	0	4,493	2,785	2,656	83,035	65,600
2011	55,107	55,146	39,488	38,810	-1,113	-3,642	-2,384	10,252	6,232	192,714	139,820
2012	44,558	44,585	21,876	21,661	-1,272	-2,772	3,675	6,962	5,973	102,308	74,194
2013	13,949	13,975	50,451	49,840	4,177	4,675	6,434	8,874	7,035	128,050	60,389
2014	18,039	18,056	29,180	28,265	8,764	9,643	9,745	10,064	5,993	94,589	53,303
2015	65,470	65,495	17,832	17,904	-1,579	-766	10,739	6,927	6,191	95,902	83,408
2016	71,007	71,032	13,606	14,723	0	0	12,409	6,028	5,278	79,592	59,600
Avg 85-05	11,184	11,254	493	1,418	0	0	8,301	1,821	19	84,141	72,746
Avg 85-16	30,386	30,446	8,558	9,139	281	223	8,275	3,336	1,608	93,910	74,809

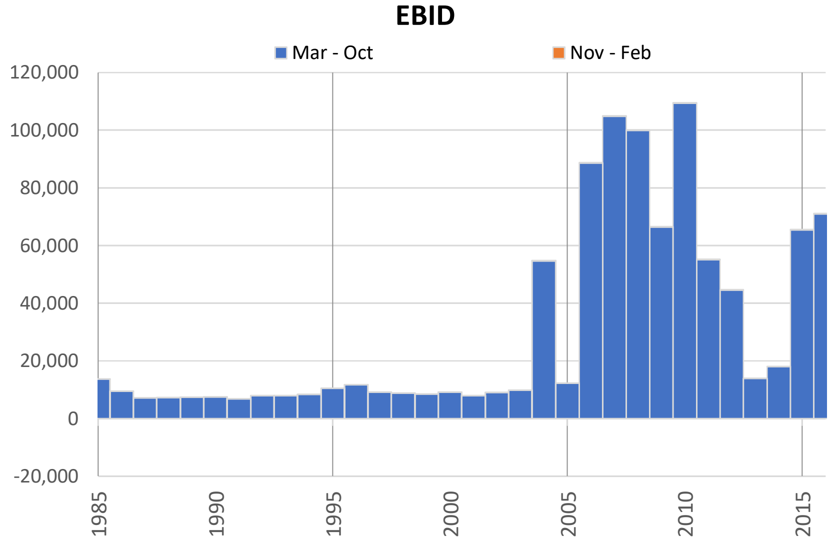
Figure 10A-6

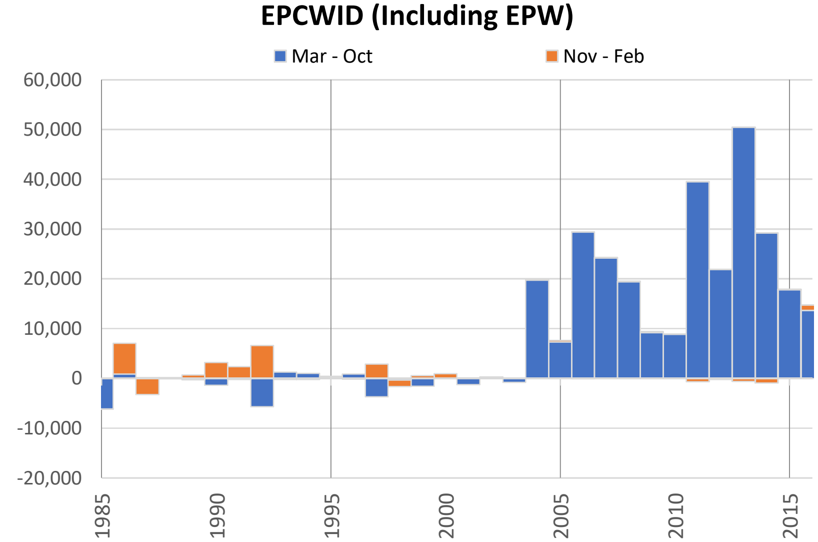
Simulated Annual Differences in Integrated LRG Model Outputs

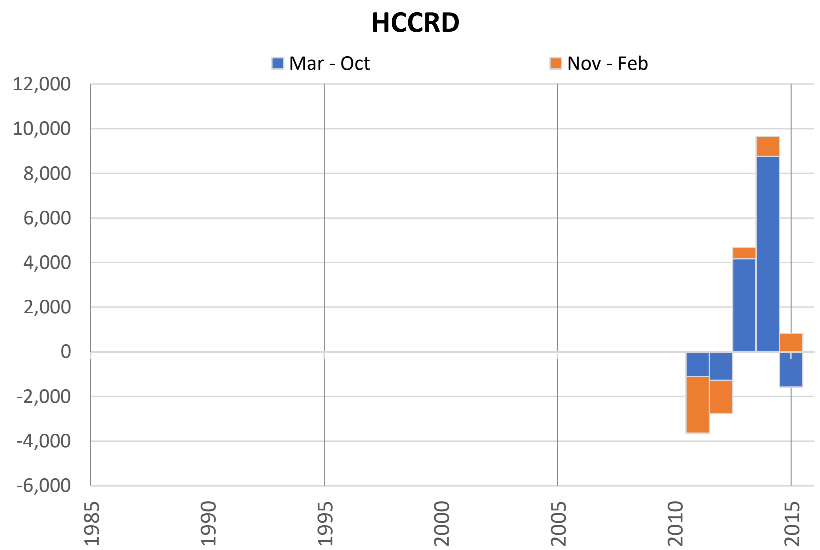
RM Pumping Off minus Historical Base Run

1985 - 2016 (acre-feet)

Farm Headgate Deliveries







*Note different scales.

Table 10A-7a
Comparison of Integrated LRG Model Runs
TX Mesilla Pumping Off v. Historical Base Run
1985 - 2016 Annual Average
(1,000 acre-feet)

Run No.	1	7	7 - 1		
Simulated Input or Output	Historical Base Run	TX Mesilla Pump Off	TX Mesilla Pump Off minus Historical Base Run		
CHANGE IN PUMPING STRESS					
Irrigation Pumping	2.8	0.0	-2.8		
Non-Irrigation Pumping	240.0	215.9	-24.1		
WWTP Flows	125.6	114.8	-10.8		
Urban Deep Percolation	17.4	15.1	-2.4		
Total Change in Stress	99.8	86.0	-13.8		
	Change in stress is pumping minus returns				
EFFECTS OF CHANGE IN PUMPING STRESS					
FHG Deliveries (Mar - Oct)				*% ΔStress*	*% Diff.*
EBID	179.3	184.7	5.4	*39%*	*3%*
EPCWID (incl. EPW)	153.1	153.2	0.1	*1%*	*0%*
HCCRD	36.5	36.4	-0.1	*-1%*	*0%*
Total	369.0	374.4	5.4	*39%*	*1%*
FHG Deliveries (Nov - Feb)					
EBID	0.0	0.0	0.0	*0%*	*7%*
EPCWID (incl. EPW)	8.6	8.7	0.2	*1%*	*2%*
HCCRD	0.8	0.7	-0.1	*-1%*	*-15%*
Total	9.4	9.4	0.0	*0%*	*0%*
Irrigation Pumping					
EBID	123.0	117.7	-5.2	*-38%*	*-4%*
EPCWID (Mesilla Valley)	2.8	0.0	-2.8		
EPCWID (El Paso Valley)	17.1	17.4	0.3	*2%*	*2%*
HCCRD	0.6	0.6	0.0	*0%*	*7%*
Total	140.6	135.8	-4.9	*-35%*	*-3%*
	Pumping turned off.	*Other values are simulated responses and are totaled.*			
Other Inflows/Outflows					
Reservoir Evaporation	174.9	176.6	1.7	*12%*	*1%*
Riparian ET	65.6	66.1	0.4	*3%*	*1%*
River Evaporation + Incidental Canal Loss	30.1	30.3	0.2	*1%*	*1%*
Total	270.6	272.9	2.3	*17%*	*1%*
Rio Grande at Fort Quitman					
Reservoir Spills	74.7	80.7	6.0	*43%*	*8%*
Nov-Feb Flows	30.4	32.6	2.2	*16%*	*7%*
Mar - Oct Flows	59.1	59.9	0.8	*6%*	*1%*
Underflow (GW Model)	0.3	0.3	0.0	*0%*	*1%*
Total	164.5	173.4	9.0	*65%*	*5%*

Table 10A-7a
Comparison of Integrated LRG Model Runs
TX Mesilla Pumping Off v. Historical Base Run
1985 - 2016 Annual Average
(1,000 acre-feet)

Run No.	1	7	7 - 1		
Simulated Input or Output	Historical Base Run	TX Mesilla Pump Off	TX Mesilla Pump Off minus Historical Base Run		
EFFECTS OF CHANGE IN PUMPING STRESS continued					
Change in Storage				*% ΔStress*	*% Diff.*
Reservoir Storage	-32.5	-36.0	-3.4	*-25%*	*10%*
Alluvial GW Storage (RW Model)	-34.8	-31.8	3.0	*22%*	*-9%*
Non-alluvial GW Storage (GW Models)	-117.5	-115.4	2.1	*16%*	*-2%*
Soil Moisture Storage	0.1	0.1	0.0	*0%*	*22%*
Total	-184.7	-183.0	1.7	*13%*	*-1%*
Summary of Effects					
FHG Deliveries (Mar-Oct)	369.0	374.4	5.4	*39%*	*1%*
FHG Deliveries (Nov-Feb)	9.4	9.4	0.0	*0%*	*0%*
Irrigation Pumping	140.6	135.8	-4.9	*-35%*	*-3%*
Riparian ET + Evaporation	270.6	272.9	2.3	*17%*	*1%*
Fort Quitman Flow	164.5	173.4	9.0	*65%*	*5%*
Change in Storage	-184.7	-183.0	1.7	*13%*	*-1%*
Total	769.3	782.9	13.6	*99%*	*2%*
OTHER EFFECTS OF CHANGE IN PUMPING STRESS					
Rio Grande at El Paso				*% ΔStress*	*% Diff.*
Reservoir Spills	107.6	117.1	9.5	*69%*	*9%*
Nov-Feb Flows	26.1	31.3	5.2	*38%*	*20%*
Mar - Oct Flows	262.7	267.9	5.1	*37%*	*2%*
Total	396.5	416.3	19.8	*144%*	*5%*
Surface Water Diversions (Mar - Oct)					
EBID	396.1	403.8	7.7	*56%*	*2%*
EPCWID (incl. EPW)	279.2	281.3	2.1	*15%*	*1%*
HCCRD	65.0	64.9	0.0	*0%*	*0%*
Total	740.2	750.0	9.8	*71%*	*1%*
Surface Water Diversions (Nov - Feb)					
EBID	0.0	0.0	0.0	*0%*	*0%*
EPCWID (incl. EPW)	21.8	22.3	0.5	*4%*	*2%*
HCCRD	18.6	18.6	0.0	*0%*	*0%*
Total	40.4	40.8	0.5	*3%*	*1%*

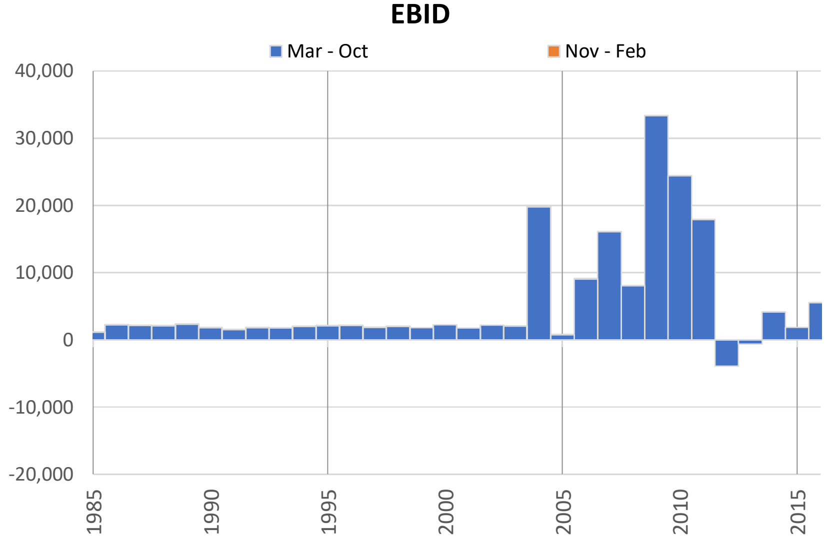
Table 10A-7b
Simulated Annual Differences in Integrated LRG Model Outputs
TX Mesilla Pumping Off minus Historical Base Run
1985 - 2016 (acre-feet)

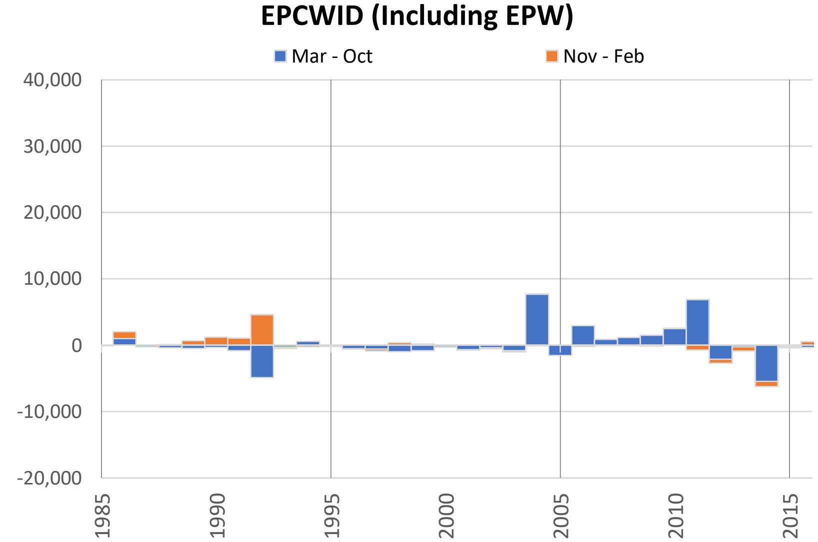
	Farm Headgate Deliveries						Other			Flows	
	EBID		EPCWID (incl. EPW)		HCCRD						
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Net Reservoir Evaporation	Riparian ET	River Evaporation + Incidental Canal Loss	Rio Grande at El Paso	Rio Grande at Fort Quitman
1985	1,129	1,130	-85	-72	0	0	7,083	242	-6	9,951	2,953
1986	2,225	2,228	1,012	2,032	0	0	8,371	1,866	806	112,493	96,507
1987	2,137	2,139	45	-180	0	0	0	518	-71	20,207	15,830
1988	2,081	2,083	-387	-265	0	0	257	354	-308	18,228	10,398
1989	2,317	2,317	-452	240	0	0	452	426	61	13,091	4,447
1990	1,834	1,835	-326	888	0	0	964	240	-78	9,555	1,643
1991	1,523	1,523	-799	279	0	0	1,177	155	-80	9,070	1,915
1992	1,819	1,820	-4,865	-253	0	0	408	1,066	545	33,612	25,763
1993	1,769	1,770	-286	-482	0	0	87	457	-280	19,342	12,064
1994	2,020	2,021	573	360	0	0	176	306	-699	18,865	9,194
1995	2,089	2,089	-188	-136	0	0	86	573	-69	22,992	11,733
1996	2,143	2,143	-525	-577	0	0	602	219	-220	12,112	727
1997	1,874	1,874	-544	-845	0	0	1,339	253	-256	17,672	3,489
1998	1,999	2,000	-977	-599	0	0	1,222	320	-20	24,517	13,314
1999	1,793	1,793	-819	-617	0	0	2,198	249	-73	12,246	2,527
2000	2,251	2,251	-220	-222	0	0	2,715	258	-302	13,516	2,464
2001	1,766	1,766	-677	-714	0	0	3,172	248	-52	11,990	1,579
2002	2,192	2,192	-379	-534	0	0	5,139	161	-133	10,967	-26
2003	2,038	2,040	-815	-1,020	0	0	6,627	231	-345	12,886	1,324
2004	19,801	19,801	7,688	7,584	0	0	4,814	1,254	949	49,534	21,828
2005	763	764	-1,521	-1,506	0	0	121	439	226	17,636	9,644
2006	9,031	9,031	2,940	2,779	0	0	2,124	573	295	20,959	5,172
2007	16,104	16,104	898	875	0	0	1,121	503	486	16,053	1,630
2008	8,068	8,068	1,194	1,165	-17	-17	1,597	452	822	14,384	1,817
2009	33,374	33,374	1,504	1,389	0	0	1,452	628	554	22,622	9,971
2010	24,407	24,407	2,525	2,543	0	0	1,298	516	767	19,152	8,789
2011	17,878	17,878	6,847	6,120	217	-1,987	22	1,536	1,081	33,902	10,886
2012	-3,900	-3,900	-2,092	-2,712	-1,272	-2,772	-1,221	-130	-338	8,563	4,721
2013	-634	-634	-224	-871	-150	-150	431	244	-88	10,331	707
2014	4,152	4,152	-5,423	-6,201	-388	-388	706	-244	1,670	-3,537	-1,124
2015	1,839	1,839	-168	-381	-1,644	-1,722	-325	58	67	10,366	-2,921
2016	5,538	5,538	-348	171	0	0	-502	256	338	11,108	-1,562
Avg 85-05	2,741	2,742	-217	160	0	0	2,239	468	-19	22,404	11,872
Avg 85-16	5,419	5,420	97	257	-102	-220	1,679	445	164	19,825	8,981

Figure 10A-7

Simulated Annual Differences in Integrated LRG Model Outputs
TX Mesilla Pumping Off minus Historical Base Run
1985 - 2016 (acre-feet)

Farm Headgate Deliveries





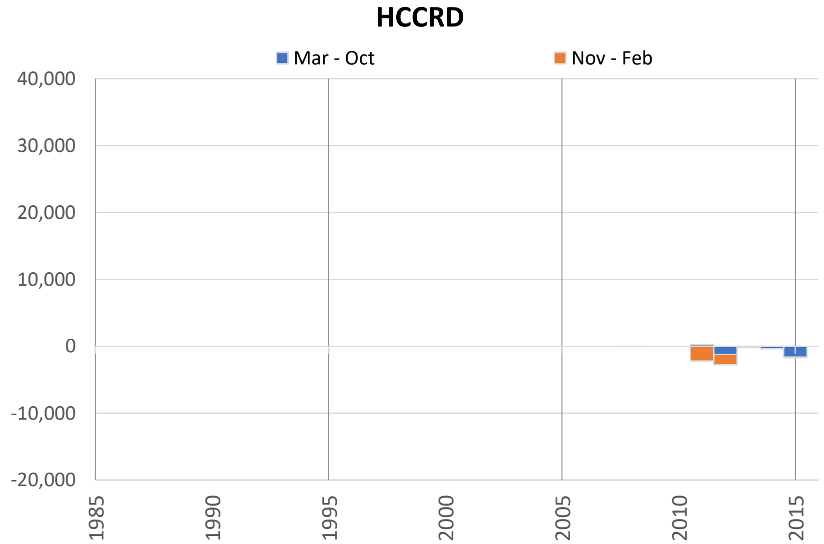


Table 10A-8a
Comparison of Integrated LRG Model Runs
TX Non-Irrigation Pumping Off v. Historical Base Run
1985 - 2016 Annual Average
(1,000 acre-feet)

Run No.	1	8	8 - 1		
Simulated Input or Output	Historical Base Run	TX Non-Irrigation Pump Off	TX Non-Irrigation Pump Off minus Historical Base Run		
CHANGE IN PUMPING STRESS					
Non-Irrigation Pumping	240.0	151.1	-88.9		
WWTP Flows	125.6	88.6	-37.0		
Urban Deep Percolation	17.4	8.8	-8.6		
Total Change in Stress	96.9	53.6	-43.3		
	Change in stress is pumping minus returns				
EFFECTS OF CHANGE IN PUMPING STRESS					
FHG Deliveries (Mar - Oct)				*% ΔStress*	*% Diff.*
EBID	179.3	183.6	4.3	*10%*	*2%*
EPCWID (incl. EPW)	153.1	151.8	-1.4	*-3%*	*-1%*
HCCRD	36.5	35.6	-0.9	*-2%*	*-2%*
Total	369.0	371.0	2.0	*5%*	*1%*
FHG Deliveries (Nov - Feb)					
EBID	0.0	0.0	0.0	*0%*	*5%*
EPCWID (incl. EPW)	8.6	7.5	-1.1	*-3%*	*-13%*
HCCRD	0.8	0.7	-0.1	*0%*	*-12%*
Total	9.4	8.2	-1.2	*-3%*	*-13%*
Irrigation Pumping					
EBID	123.0	118.8	-4.1	*-10%*	*-3%*
EPCWID (Mesilla Valley)	2.8	2.7	-0.2	*0%*	*-6%*
EPCWID (El Paso Valley)	17.1	19.7	2.6	*6%*	*15%*
HCCRD	0.6	1.4	0.8	*2%*	*143%*
Total	143.5	142.6	-0.9	*-2%*	*-1%*
Other Inflows/Outflows					
Reservoir Evaporation	174.9	175.1	0.2	*0%*	*0%*
Riparian ET	65.6	66.0	0.4	*1%*	*1%*
River Evaporation + Incidental Canal Loss	30.1	29.7	-0.4	*-1%*	*-1%*
Total	270.6	270.8	0.2	*0%*	*0%*
Rio Grande at Fort Quitman					
Reservoir Spills	74.7	71.6	-3.1	*-7%*	*-4%*
Nov-Feb Flows	30.4	24.9	-5.5	*-13%*	*-18%*
Mar - Oct Flows	59.1	56.2	-2.9	*-7%*	*-5%*
Underflow (GW Model)	0.3	0.3	0.0	*0%*	*-1%*
Total	164.5	153.0	-11.5	*-27%*	*-7%*

Table 10A-8a
Comparison of Integrated LRG Model Runs
TX Non-Irrigation Pumping Off v. Historical Base Run
1985 - 2016 Annual Average
(1,000 acre-feet)

Run No.	1	8	8 - 1		
Simulated Input or Output	Historical Base Run	TX Non-Irrigation Pump Off	TX Non-Irrigation Pump Off minus Historical Base Run		
EFFECTS OF CHANGE IN PUMPING STRESS continued					
Change in Storage				*% ΔStress*	*% Diff.*
Reservoir Storage	-32.5	-32.0	0.6	*1%*	*-2%*
Alluvial GW Storage (RW Model)	-34.8	-30.7	4.0	*9%*	*-12%*
Non-alluvial GW Storage (GW Models)	-117.5	-72.1	45.4	*105%*	*-39%*
Soil Moisture Storage	0.1	0.1	0.0	*0%*	*12%*
Total	-184.7	-134.7	50.0	*115%*	*-27%*
Summary of Effects					
FHG Deliveries (Mar-Oct)	369.0	371.0	2.0	*5%*	*1%*
FHG Deliveries (Nov-Feb)	9.4	8.2	-1.2	*-3%*	*-13%*
Irrigation Pumping	143.5	142.6	-0.9	*-2%*	*-1%*
Riparian ET + Evaporation	270.6	270.8	0.2	*0%*	*0%*
Fort Quitman Flow	164.5	153.0	-11.5	*-27%*	*-7%*
Change in Storage	-184.7	-134.7	50.0	*115%*	*-27%*
Total	772.2	810.8	38.7	*89%*	*5%*
OTHER EFFECTS OF CHANGE IN PUMPING STRESS					
Rio Grande at El Paso				*% ΔStress*	*% Diff.*
Reservoir Spills	107.6	106.5	-1.1	*-3%*	*-1%*
Nov-Feb Flows	26.1	30.0	3.9	*9%*	*15%*
Mar - Oct Flows	262.7	275.6	12.8	*30%*	*5%*
Total	396.5	412.1	15.7	*36%*	*4%*
Surface Water Diversions (Mar - Oct)					
EBID	396.1	402.0	5.9	*14%*	*2%*
EPCWID (incl. EPW)	279.2	283.5	4.3	*10%*	*2%*
HCCRD	65.0	62.5	-2.4	*-6%*	*-4%*
JID	52.0	52.2	0.2	*0%*	*0%*
Total	792.2	800.2	8.0	*19%*	*1%*
Surface Water Diversions (Nov - Feb)					
EBID	0.0	0.0	0.0	*0%*	*0%*
EPCWID (incl. EPW)	21.8	20.8	-1.0	*-2%*	*-4%*
HCCRD	18.6	16.3	-2.3	*-5%*	*-12%*
Total	40.4	37.1	-3.2	*-7%*	*-8%*

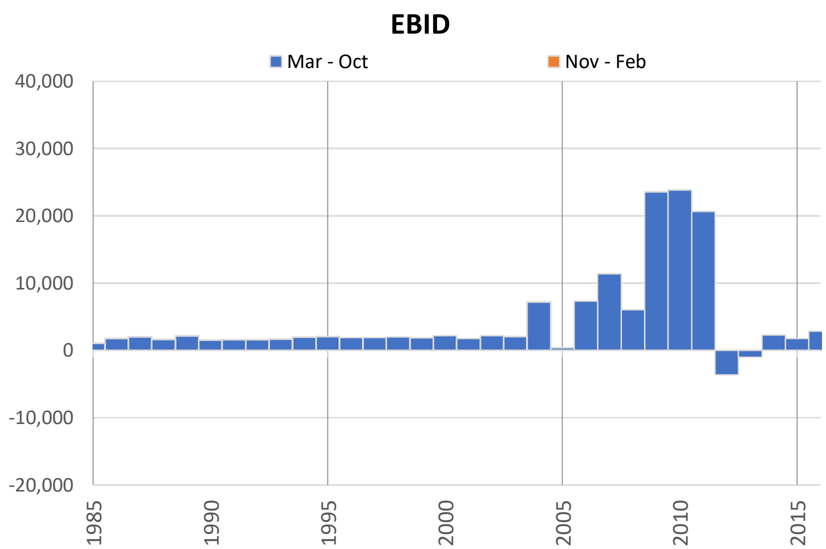
Table 10A-8b
Simulated Annual Differences in Integrated LRG Model Outputs
TX Non-Irrigation Pumping Off minus Historical Base Run
1985 - 2016 (acre-feet)

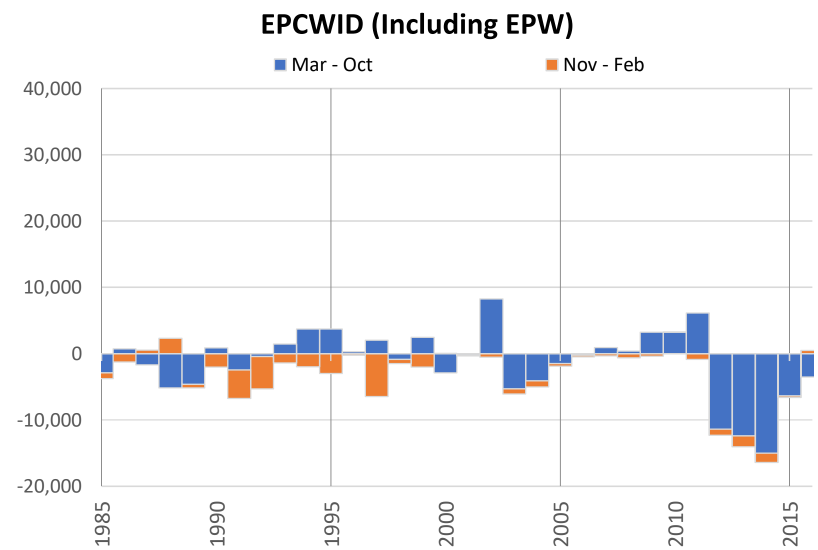
	Farm Headgate Deliveries						Other			Flows	
	EBID		EPCWID (incl. EPW)		HCCRD						
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Net Reservoir Evaporation	Riparian ET	River Evaporation + Incidental Canal Loss	Rio Grande at El Paso	Rio Grande at Fort Quitman
1985	1,039	1,040	-2,889	-3,767	0	0	-1,747	648	-83	24,127	-12,528
1986	1,756	1,757	735	-487	0	0	-2,450	2	-335	-4,177	-37,763
1987	1,993	1,994	-1,661	-1,124	0	0	0	385	-386	17,047	-13,952
1988	1,605	1,607	-5,147	-2,839	0	0	-70	397	-103	18,681	-12,881
1989	2,146	2,146	-4,617	-5,146	0	0	-455	439	-233	20,266	-15,028
1990	1,522	1,523	878	-1,142	0	0	-615	679	-137	28,581	-12,082
1991	1,581	1,582	-2,467	-6,736	0	0	-1,138	423	-138	25,576	-12,682
1992	1,555	1,555	-416	-5,295	0	0	-609	-115	-746	9	-28,655
1993	1,680	1,681	1,457	89	0	0	-34	547	-419	13,189	-17,422
1994	1,972	1,973	3,745	1,787	0	0	45	628	-919	18,121	-5,861
1995	2,052	2,052	3,722	755	0	0	-67	778	-318	22,515	-7,883
1996	1,926	1,926	304	97	0	0	500	248	-691	12,342	-15,572
1997	1,920	1,920	2,045	-4,429	0	0	99	798	-410	31,718	-5,429
1998	1,983	1,983	-835	-1,502	0	0	11	694	-112	24,240	-10,078
1999	1,841	1,841	2,471	439	0	0	-305	755	-245	25,443	-4,294
2000	2,195	2,195	-2,893	-2,891	0	0	269	500	-389	16,352	-14,300
2001	1,756	1,756	-247	-312	0	0	1,005	514	-698	12,903	-14,489
2002	2,183	2,183	8,245	7,714	0	0	2,558	377	-891	11,060	-16,553
2003	2,059	2,061	-5,286	-6,049	0	0	2,982	1,135	-880	25,653	-5,310
2004	7,193	7,193	-4,100	-5,023	0	0	2,001	918	-199	26,572	-12,804
2005	361	362	-1,504	-1,877	0	0	942	766	-363	14,192	-9,855
2006	7,334	7,334	-233	-489	0	0	1,716	1,019	-495	17,269	-7,816
2007	11,394	11,394	908	598	0	0	1,157	977	-101	12,959	-8,126
2008	6,029	6,029	393	-226	1,074	1,174	1,262	1,210	222	11,385	-4,161
2009	23,568	23,568	3,251	2,884	0	0	1,874	1,270	-110	12,825	2,132
2010	23,829	23,829	3,227	3,238	0	0	2,618	1,261	185	10,156	2,152
2011	20,632	20,632	6,118	5,245	351	-1,810	1,102	3,190	359	32,176	2,941
2012	-3,633	-3,633	-11,367	-12,324	-1,272	-2,772	-1,753	701	-1,857	6,611	-8,903
2013	-1,011	-1,011	-12,399	-14,035	-8,931	-8,931	-1,342	-2,459	-1,433	6,396	-12,247
2014	2,287	2,287	-14,986	-16,410	-8,970	-8,960	535	-4,026	1,326	-5,820	-5,100
2015	1,747	1,747	-6,379	-6,608	-10,527	-10,356	-2,202	-2,121	-617	7,220	-9,361
2016	2,881	2,881	-3,514	-3,016	-824	-424	-2,779	496	-507	5,268	-34,182
Avg 85-05	2,015	2,016	-403	-1,797	0	0	139	548	-414	18,305	-13,591
Avg 85-16	4,293	4,293	-1,358	-2,465	-909	-1,002	160	407	-366	15,652	-11,503

Figure 10A-8

Simulated Annual Differences in Integrated LRG Model Outputs
TX Non-Irrigation Pumping Off minus Historical Base Run
1985 - 2016 (acre-feet)

Farm Headgate Deliveries





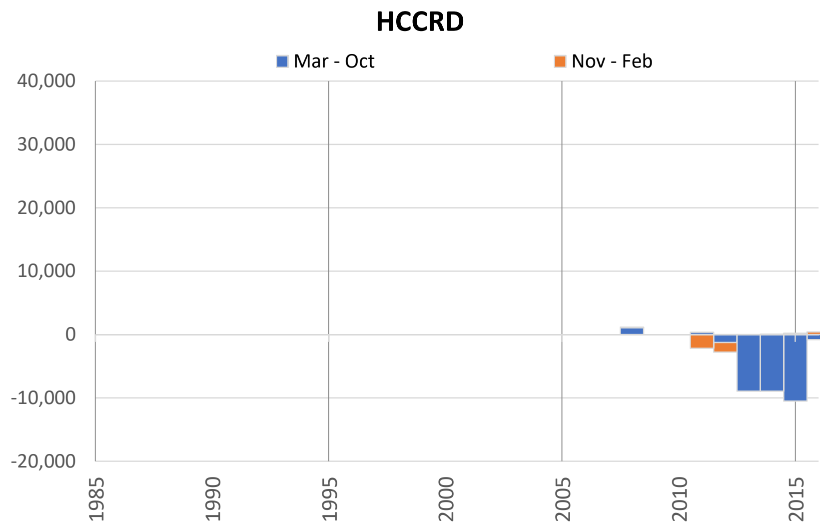


Table 10A-12a
Comparison of Integrated LRG Model Runs
D3 + Carryover v. D1/D2
1948 - 2017 Annual Average
(1,000 acre-feet)

Run No.	11	12	12 - 11	
Simulated Input or Output	D1/D2	D3 + Carryover	D3 + Carryover minus D1/D2	
EFFECTS OF CHANGE IN PROJECT ALLOCATION PROCEDURES				
FHG Deliveries (Mar - Oct)				*% Diff.*
EBID	175.5	133.4	-42.1	-24%
EPCWID (incl. EPW)	138.8	154.9	16.1	12%
HCCRD	33.8	35.1	1.3	4%
Total	348.2	323.4	-24.8	-7%
FHG Deliveries (Nov - Feb)				
EBID	0.0	0.0	0.0	143%
EPCWID (incl. EPW)	7.5	6.1	-1.4	-18%
HCCRD	1.7	1.1	-0.6	-37%
Total	9.1	7.2	-2.0	-22%
Irrigation Pumping				
EBID	134.6	176.6	42.0	31%
EPCWID (Mesilla Valley)	4.7	5.2	0.5	11%
EPCWID (El Paso Valley)	36.0	31.0	-5.1	-14%
HCCRD	4.5	2.7	-1.8	-41%
Total	179.8	215.4	35.6	20%
Other Inflows/Outflows				
Reservoir Evaporation	121.6	116.0	-5.6	-5%
Riparian ET	72.9	73.7	0.8	1%
River Evaporation + Incidental Canal Loss	30.3	28.9	-1.5	-5%
Total	224.8	218.5	-6.3	-3%
Rio Grande at Fort Quitman				
Reservoir Spills	34.2	25.4	-8.7	-26%
Nov-Feb Flows	24.1	26.9	2.7	11%
Mar - Oct Flows	44.6	53.4	8.8	20%
Underflow (GW Model)	0.2	0.3	0.0	5%
Total	103.1	106.0	2.9	3%
Change in Storage				
Reservoir Storage	-2.2	-0.3	1.8	-85%
Alluvial GW Storage (RW Model)	-20.4	-24.5	-4.0	20%
Non-alluvial GW Storage (GW Models)	-92.2	-95.6	-3.4	4%
Soil Moisture Storage	-0.1	0.1	0.1	-174%
Total	-114.9	-120.4	-5.5	5%

Table 10A-12a
Comparison of Integrated LRG Model Runs
D3 + Carryover v. D1/D2
1948 - 2017 Annual Average
(1,000 acre-feet)

Run No.	11	12	12 - 11	
Simulated Input or Output	**D1/D2**	**D3 + Carryover**	**D3 + Carryover minus D1/D2**	
EFFECTS OF CHANGE IN PROJECT ALLOCATION PROCEDURES continued				
Summary of Effects				***% Diff.***
FHG Deliveries (Mar-Oct)	348.2	323.4	-24.8	*-7%*
FHG Deliveries (Nov-Feb)	9.1	7.2	-2.0	*-22%*
Irrigation Pumping	179.8	215.4	35.6	*20%*
Riparian ET + Evaporation	224.8	218.5	-6.3	*-3%*
Fort Quitman Flow	103.1	106.0	2.9	*3%*
Change in Storage	-114.9	-120.4	-5.5	*5%*
Total	750.1	750.1	0.0	*0%*
OTHER EFFECTS OF CHANGE IN PROJECT ALLOCATION PROCEDURES				
Rio Grande at El Paso				***% Diff.***
Reservoir Spills	49.2	37.9	-11.3	*-23%*
Nov-Feb Flows	27.0	23.7	-3.2	*-12%*
Mar - Oct Flows	265.4	294.1	28.7	*11%*
Total	341.6	355.8	14.2	*4%*
Surface Water Diversions (Mar - Oct)				
EBID	404.8	331.8	-73.0	*-18%*
EPCWID (incl. EPW)	251.0	286.6	35.6	*14%*
HCCRD	55.8	63.4	7.6	*14%*
Total	711.6	681.8	-29.8	*-4%*
Surface Water Diversions (Nov - Feb)				
EBID	0.0	0.0	0.0	*0%*
EPCWID (incl. EPW)	21.6	18.0	-3.6	*-17%*
HCCRD	15.6	15.6	0.0	*0%*
Total	37.3	33.6	-3.7	*-10%*

Table 10A-12b
Simulated Annual Differences in Integrated LRG Model Outputs
D3 + Carryover minus D1/D2
1948 - 2017 (acre-feet)

	Farm Headgate Deliveries						Other			Flows	
	EBID		EPCWID (incl. EPW)		HCCRD						
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Net Reservoir Evaporation	Riparian ET	River Evaporation + Incidental Canal Loss	Rio Grande at El Paso	Rio Grande at Fort Quitman
1948	-53,269	-53,289	-6,447	-7,316	0	0	3,256	-729	-1,907	-37,071	-28,748
1949	-38,688	-38,709	6,412	6,288	0	0	6,941	-126	-469	-7,848	-12,604
1950	-44,126	-44,139	5,551	4,367	0	0	9,214	73	-399	4,819	1,801
1951	6,340	6,338	59,094	56,504	9,118	3,734	-3,425	7,955	5,225	176,840	101,533
1952	-66,508	-66,544	12,801	14,180	-7,718	-15,284	-10,546	-452	-1,326	-13,610	14,254
1953	-1,976	-1,983	57,863	57,604	15,076	12,822	-26,832	6,329	2,582	113,625	50,945
1954	-19,190	-19,190	-16,746	-15,753	8,534	5,588	-19,955	464	-2,914	-39,968	12,221
1955	18,233	18,233	5,447	5,069	-43	-24	-15,991	607	-1,844	5,243	15
1956	12,008	12,008	1,729	1,866	1,204	1,235	-11,858	280	-2,886	2,193	12
1957	-45,543	-45,543	-192	-29	-3,874	-3,773	-1,683	606	5,333	-9,687	-2,980
1958	-136,446	-136,446	10,989	9,399	2,378	2,813	-248	195	-3,906	22,178	13,216
1959	-92,660	-92,660	23,099	19,065	-4,791	-4,509	2,399	1,244	-36	48,614	29,336
1960	-75,069	-75,069	18,631	17,610	0	0	154	2,311	446	41,196	33,187
1961	-130,196	-130,199	3,577	2,719	0	0	-5,097	3,900	-1,410	18,105	26,946
1962	-82,034	-82,037	2,646	-229	0	0	-3,214	-788	-1,631	-4,210	6,483
1963	-43,304	-43,304	36,534	34,121	4,951	3,355	-13,988	2,606	-299	60,956	30,966
1964	-2,376	-2,376	-7,923	-8,076	4,766	2,206	-21,139	90	-3,958	-24,108	6,351
1965	-109,599	-109,599	13,353	11,901	2,441	2,473	-5,181	1,293	-749	22,078	5,209
1966	-158,807	-158,807	8,585	6,462	-2,856	-3,250	10,126	3,970	-3,404	14,753	1,625
1967	-2,840	-2,840	42,598	39,174	8,357	7,666	-7,544	3,693	-2,932	53,136	5,585
1968	-76,746	-76,746	29,109	27,669	13,479	11,233	-5,525	5,443	-2,481	53,390	25,086
1969	-116,604	-116,611	18,341	17,675	-3,934	-10,682	-11,248	2,349	-2,786	17,815	41,408
1970	-137,793	-137,795	8,692	2,378	-1,836	-3,844	-10,358	1,282	-2,995	33,861	37,029
1971	-33,335	-33,335	10,533	7,065	2,566	2,395	-12,144	637	-3,478	5,872	2,132
1972	-5,717	-5,717	-1,333	-1,098	5,409	5,592	-8,905	-644	-6,986	-18,559	29
1973	-128,938	-128,939	13,334	12,588	2,262	1,856	-1,361	792	-3,324	40,734	14,026
1974	-123,524	-123,525	19,914	17,299	-7,626	-10,545	2,923	-36	-1,727	40,090	39,215
1975	-127,276	-127,281	15,770	11,091	4,396	92	-7,430	650	-3,549	16,621	28,978
1976	-91,521	-91,521	9,329	3,136	-872	-3,144	-6,245	-1,736	-3,302	-3,236	10,440
1977	-17,834	-17,834	-2,025	-4,823	1,538	2,083	-7,570	-1,773	-5,933	-21,542	844
1978	-37,863	-37,863	6,189	6,332	-1,537	-664	-2,049	-46	1,117	9,288	-2,308
1979	-143,287	-143,296	21,277	19,678	3,753	4,286	176	59	-4,170	-5,813	-3,546
1980	-102,950	-102,951	7,417	129	40	133	3,412	-1,231	-3,032	1,747	3,717
1981	-97,318	-97,318	12,332	7,823	0	0	1,437	-728	-2,399	11,543	544
1982	-108,268	-108,291	16,595	12,834	0	0	-200	638	-3,537	-5,050	3,796
1983	-88,016	-88,017	17,951	11,383	0	0	-10,644	-784	-2,840	5,490	-5,118
1984	-71,505	-71,523	13,082	9,793	0	0	682	-1,185	-3,206	-30,352	-35,381
1985	-36,708	-36,734	16,171	11,475	0	0	-1,743	-538	-689	-13,216	-28,697
1986	58,993	59,012	19,331	17,023	0	0	676	-1,396	1,335	-64,978	-76,390
1987	36,003	36,059	13,289	13,508	0	0	-925	-127	1,292	-27,948	-34,783
1988	20,023	20,074	12,216	12,261	0	0	-2,781	1,315	1,856	49,394	24,807

Table 10A-12b
Simulated Annual Differences in Integrated LRG Model Outputs
D3 + Carryover minus D1/D2
1948 - 2017 (acre-feet)

	Farm Headgate Deliveries						Other			Flows	
	EBID		EPCWID (incl. EPW)		HCCRD						
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Net Reservoir Evaporation	Riparian ET	River Evaporation + Incidental Canal Loss	Rio Grande at El Paso	Rio Grande at Fort Quitman
1989	60,891	60,969	22,924	15,665	0	0	-7,933	650	1,850	42,321	11,875
1990	34,525	34,601	15,659	18,712	0	0	-10,868	1,097	1,915	52,432	32,358
1991	23,316	23,389	12,067	14,482	0	0	-11,686	965	2,118	50,618	31,726
1992	42,597	42,690	10,800	12,563	0	0	-13,676	-2,540	-276	-113,337	-121,874
1993	45,926	46,007	32,450	26,281	0	0	-4,993	-1,509	-911	-88,045	-97,794
1994	80,609	80,709	35,057	35,692	0	0	-3,288	1,049	1,829	43,045	-4,989
1995	100,408	100,538	39,567	32,273	0	0	-3,131	-1,289	-97	-121,341	-139,094
1996	107,962	108,084	29,837	31,517	0	0	-3,194	1,837	2,828	97,594	38,746
1997	58,846	58,949	22,937	27,047	0	0	-12,419	1,200	2,406	78,990	42,698
1998	61,532	61,576	34,328	29,174	0	0	-18,051	509	1,124	27,585	-5,472
1999	59,441	59,509	26,625	27,358	0	0	-31,349	1,177	2,241	75,916	41,045
2000	61,786	61,846	21,891	22,123	0	0	-31,890	1,481	1,754	78,573	48,056
2001	-24,681	-24,669	33,194	33,570	0	0	-24,898	4,015	1,685	154,077	112,277
2002	-62,682	-62,682	40,993	41,144	0	0	-44,805	3,152	71	107,884	74,023
2003	-177,539	-177,551	-33,226	-32,832	0	0	-41,437	-5,698	-7,246	-140,658	-79,547
2004	-93,798	-93,799	-15,809	-16,164	0	0	-12,093	-4,566	-6,924	-73,326	-44,912
2005	-81,097	-81,113	5,891	5,549	0	0	-15,750	-1,772	-3,145	-35,425	-43,008
2006	-81,531	-81,531	25,966	25,513	0	0	2,284	1,932	-4,346	56,186	20,632
2007	-109,048	-109,061	-5,274	-5,430	0	0	6,705	-2,227	-5,390	-53,236	-40,140
2008	-98,509	-98,532	14,057	13,666	-3,203	-3,687	17,442	-954	-3,478	-27,837	-33,157
2009	-154,153	-154,176	9,386	9,166	-82	-181	15,572	-2,426	-5,472	-43,212	-50,193
2010	-85,756	-85,777	22,182	22,101	0	0	7,411	565	-3,183	16,190	-7,015
2011	-11,070	-11,070	78,887	79,372	24,044	26,539	10,124	9,229	-2,252	115,619	7,148
2012	-22,300	-22,300	5,483	5,591	774	1,241	11,616	2,365	-1,884	13,301	23,044
2013	22,333	22,333	38,459	38,499	8,525	8,043	-14,505	7,224	4,935	68,216	14,301
2014	-39,983	-39,983	-32,279	-31,442	2,024	1,374	-3,466	-2,123	-6,899	-69,367	-3,985
2015	-26,607	-26,607	19,158	19,359	2,057	263	10,515	431	-3,196	39,189	3,321
2016	-49,388	-49,388	31,398	30,875	-1,431	-2,143	15,178	2,671	-2,966	59,507	16,663
2017	-94,759	-94,767	26,473	26,619	2,396	2,194	13,739	3,488	-2,708	40,182	13,141
Avg 48-17	-42,128	-42,116	16,060	14,688	1,290	678	-5,618	806	-1,470	14,200	2,872
Avg 85-16	-8,739	-8,707	18,863	18,303	1,022	983	-6,792	491	-910	11,085	-8,385

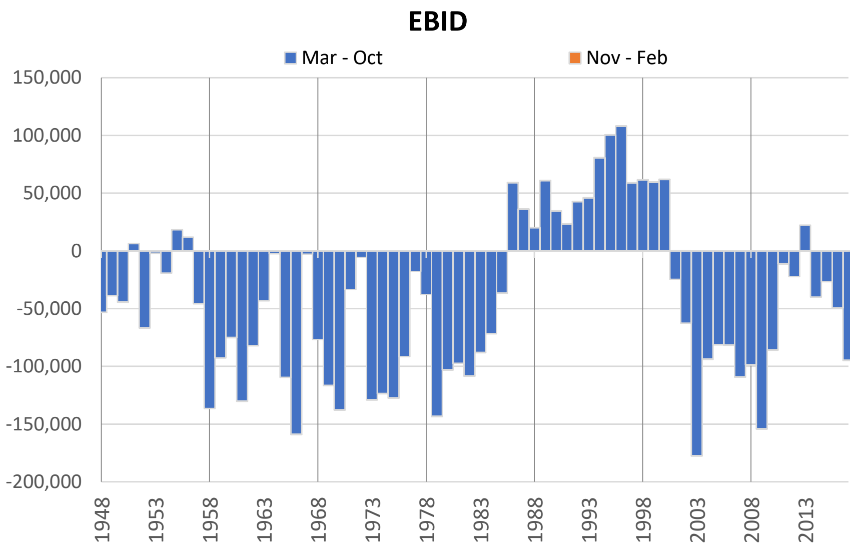
Figure 10A-12

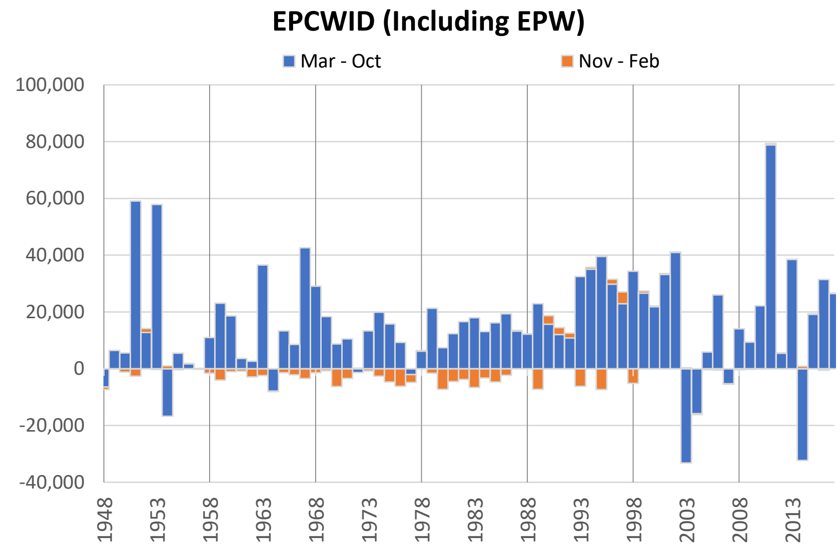
Simulated Annual Differences in Integrated LRG Model Outputs

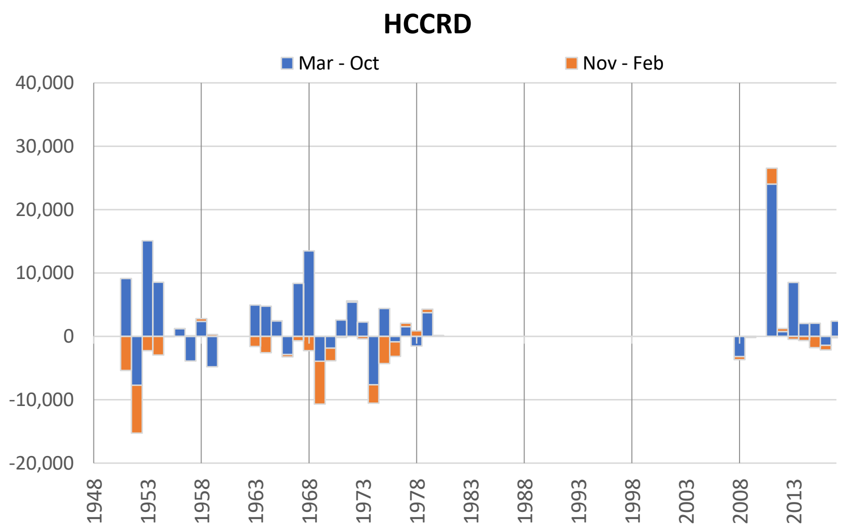
D3 + Carryover minus D1/D2

1948 - 2017 (acre-feet)

Farm Headgate Deliveries







*Note different scales.

10/29/2019

Table 10A-13
Comparison of Integrated LRG Model Runs
Reduced Waste Run v. Historical Base Run
1985 - 2016 Annual Average
(1,000 acre-feet)

Run No.	1	13	13 - 1	
Simulated Input or Output	**Historical Base Run**	**Reduced Waste**	**Reduced Waste minus Historical Base Run**	
EFFECTS OF REDUCED WASTE (Limit Waste to 10%)				
FHG Deliveries (Mar - Oct)				***% Diff.***
EBID	179.3	207.9	28.6	*16%*
EPCWID (incl. EPW)	153.1	165.9	12.7	*8%*
HCCRD	36.5	35.5	-1.1	*-3%*
Total	369.0	409.3	40.3	*11%*
FHG Deliveries (Nov - Feb)				
EBID	0.0	0.0	0.0	*0%*
EPCWID (incl. EPW)	8.6	7.0	-1.6	*-18%*
HCCRD	0.8	3.1	2.3	*296%*
Total	9.4	10.1	0.7	*8%*
Irrigation Pumping				
EBID	123.0	98.6	-24.4	*-20%*
EPCWID (Mesilla Valley)	2.8	2.0	-0.8	*-29%*
EPCWID (El Paso Valley)	17.1	9.0	-8.1	*-48%*
HCCRD	0.6	2.7	2.2	*378%*
Total	143.5	112.3	-31.2	*-22%*
Other Inflows/Outflows				
Reservoir Evaporation	174.9	179.8	4.9	*3%*
Riparian ET	65.6	65.4	-0.2	*0%*
River Evaporation + Incidental Canal Loss	30.1	30.0	-0.1	*0%*
Total	270.6	275.2	4.6	*2%*
Rio Grande at Fort Quitman				
Reservoir Spills	74.7	87.2	12.5	*17%*
Nov-Feb Flows	30.4	36.1	5.7	*19%*
Mar - Oct Flows	59.1	34.0	-25.0	*-42%*
Underflow (GW Model)	0.3	0.3	0.0	*-1%*
Total	164.5	157.6	-6.8	*-4%*
Change in Storage				
Reservoir Storage	-32.5	-40.4	-7.9	*24%*
Alluvial GW Storage (RW Model)	-34.8	-29.7	5.1	*-15%*
Non-alluvial GW Storage (GW Models)	-117.5	-114.1	3.4	*-3%*
Soil Moisture Storage	0.1	-0.2	-0.3	*-303%*
Total	-184.7	-184.4	0.3	*0%*

Table 10A-13
Comparison of Integrated LRG Model Runs
Reduced Waste Run v. Historical Base Run
1985 - 2016 Annual Average
(1,000 acre-feet)

Run No.	1	13	13 - 1	
Simulated Input or Output	**Historical Base Run**	**Reduced Waste**	**Reduced Waste minus Historical Base Run**	
EFFECTS OF REDUCED WASTE (Limit Waste to 10%) continued				
Summary of Effects				***% Diff.***
FHG Deliveries (Mar-Oct)	369.0	409.3	40.3	*11%*
FHG Deliveries (Nov-Feb)	9.4	10.1	0.7	*8%*
Irrigation Pumping	143.5	112.3	-31.2	*-22%*
Riparian ET + Evaporation	270.6	275.2	4.6	*2%*
Fort Quitman Flow	164.5	157.6	-6.8	*-4%*
Change in Storage	-184.7	-184.4	0.3	*0%*
Total	772.2	780.1	8.0	*1%*
OTHER EFFECTS OF REDUCED WASTE (Limit Waste to 10%)				
Rio Grande at El Paso				***% Diff.***
Reservoir Spills	107.6	128.6	21.0	*20%*
Nov-Feb Flows	26.1	33.9	7.8	*30%*
Mar - Oct Flows	262.7	231.3	-31.5	*-12%*
Total	396.5	393.8	-2.7	*-1%*
Surface Water Diversions (Mar - Oct)				
EBID	396.1	416.2	20.1	*5%*
EPCWID (incl. EPW)	279.2	249.8	-29.3	*-11%*
HCCRD	65.0	44.1	-20.9	*-32%*
Total	740.2	710.1	-30.1	*-4%*
Surface Water Diversions (Nov - Feb)				
EBID	0.0	0.0	0.0	*0%*
EPCWID (incl. EPW)	21.8	23.6	1.9	*9%*
HCCRD	18.6	24.1	5.5	*30%*
Total	40.4	47.8	7.4	*18%*

Appendix 10B

Comparison of Historical Base Run to No New Mexico Pumping Run
Integrated LRG Model

Figure 10B-1

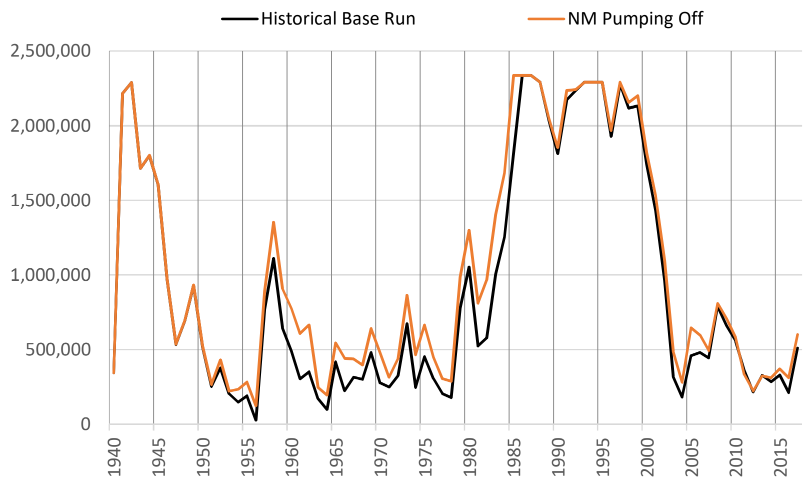
NM Pumping Off v. Historical Base Run

Integrated LRG Model

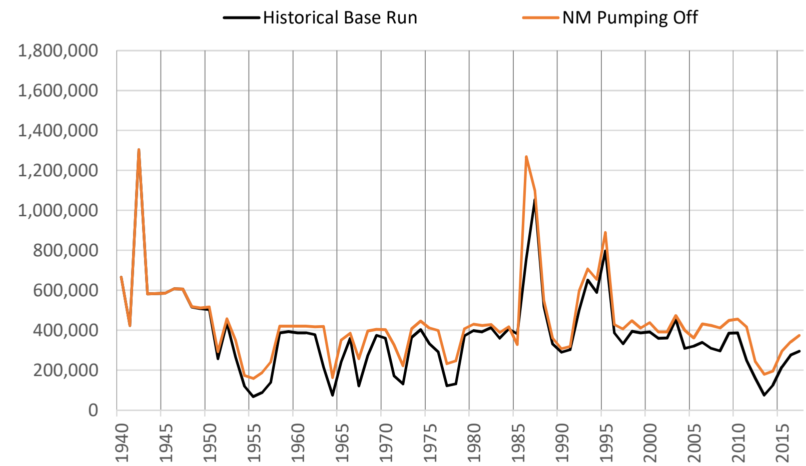
Annual Summary of Project Storage and Rio Grande Flows

1940 - 2017 (acre-feet)

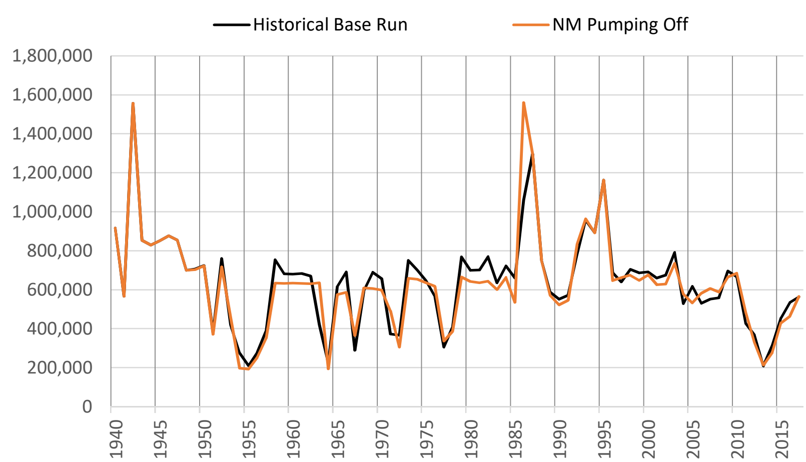
Total Year-End Project Reservoir Storage



Rio Grande at El Paso



Rio Grande Below Caballo



Rio Grande at Fort Quitman

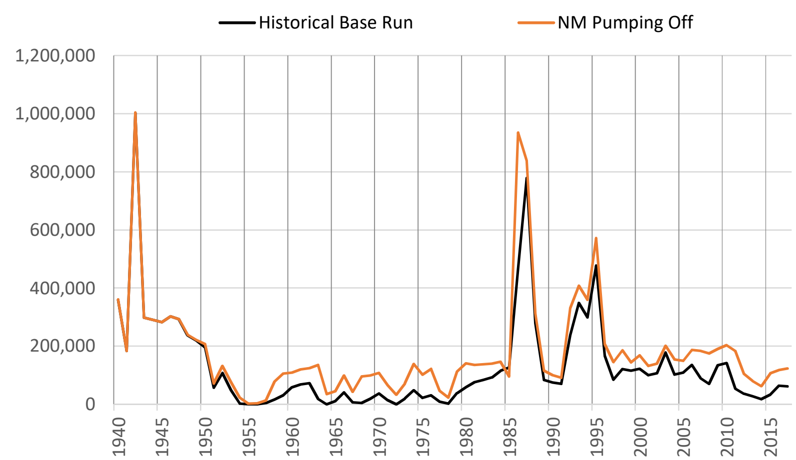
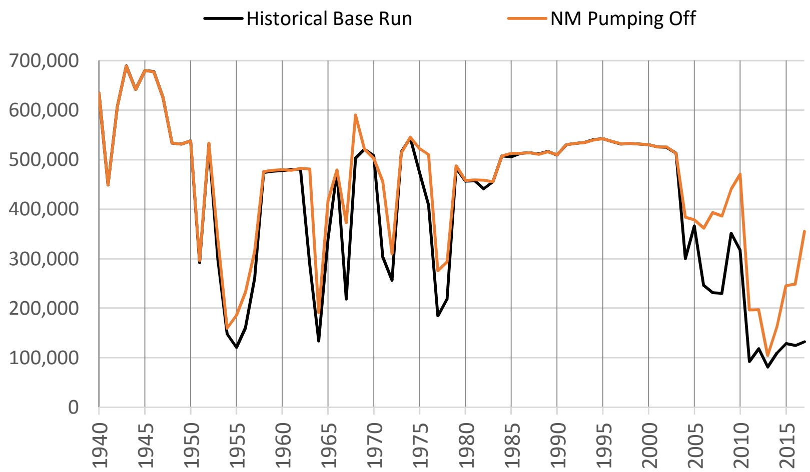


Figure 10B-2

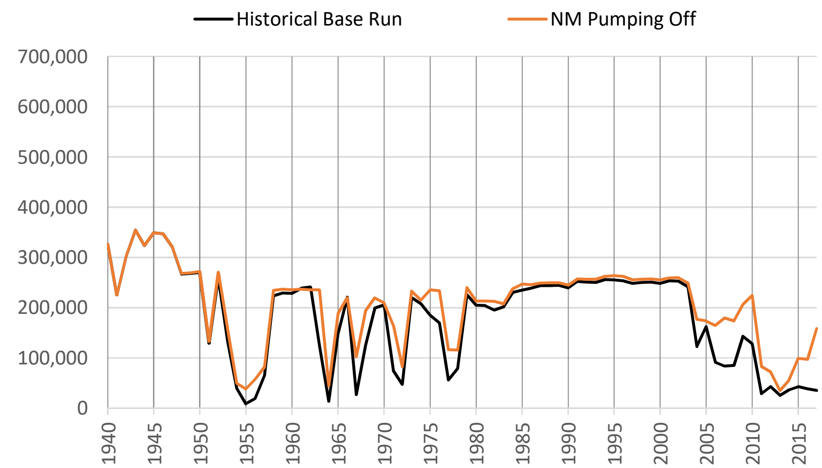
NM Pumping Off v. Historical Base Run
Integrated LRG Model
Annual Summary of Irrigation Operations
1940 - 2017 (acre-feet)

EBID Total

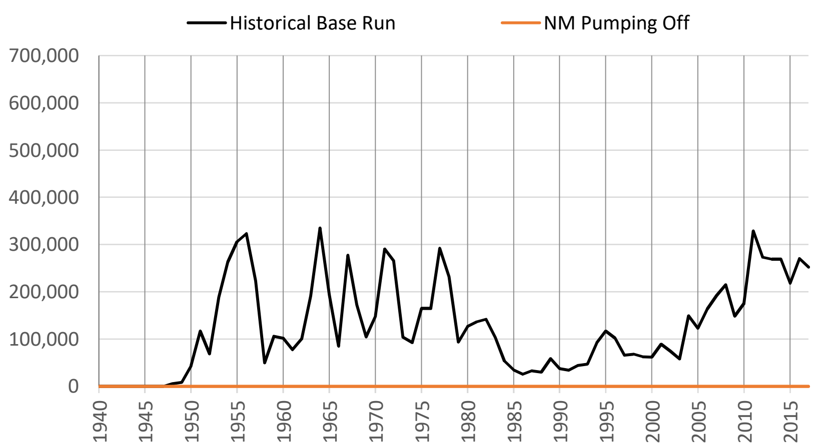
River Headgate Diversions



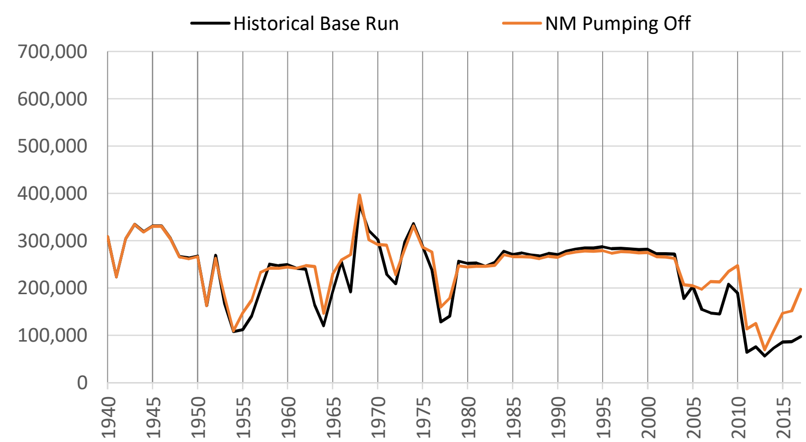
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries



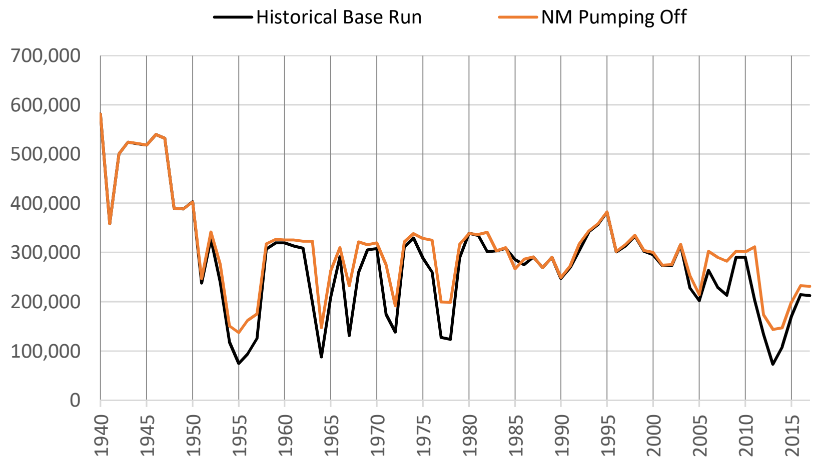
Supplemental and Primary

Figure 10B-3

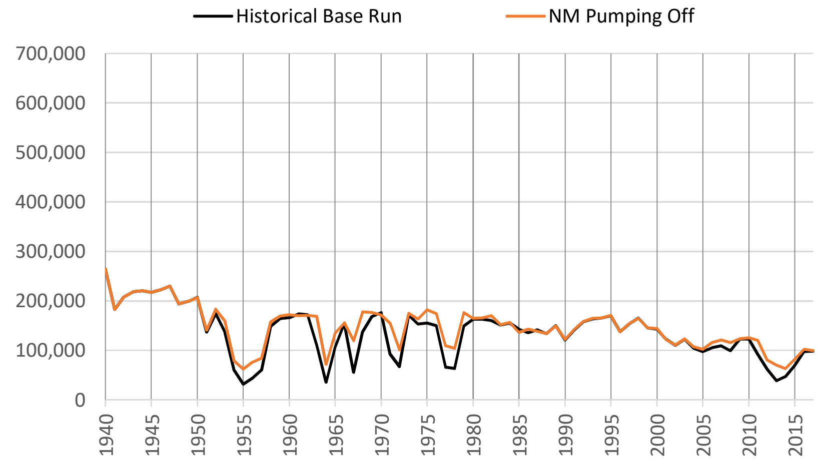
NM Pumping Off v. Historical Base Run
Integrated LRG Model
Annual Summary of Irrigation Operations
1940 - 2017 (acre-feet)

EPCWID Total

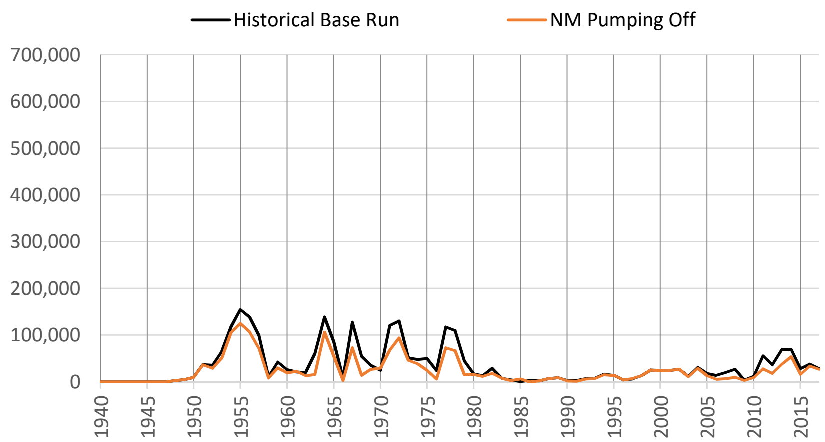
River Headgate Diversions



Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries

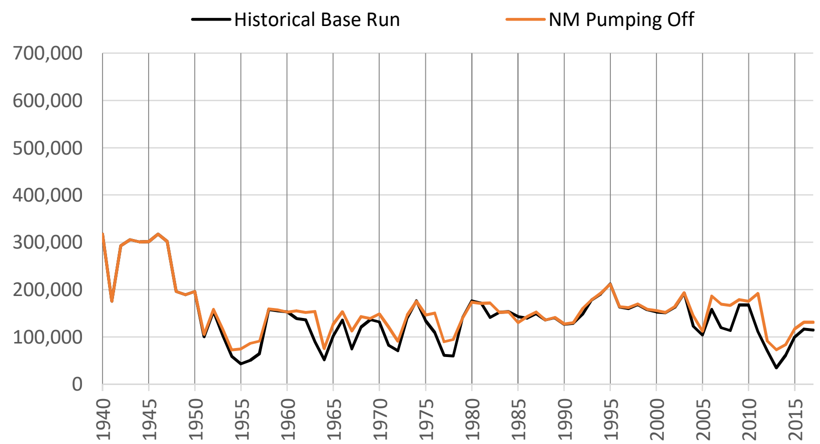


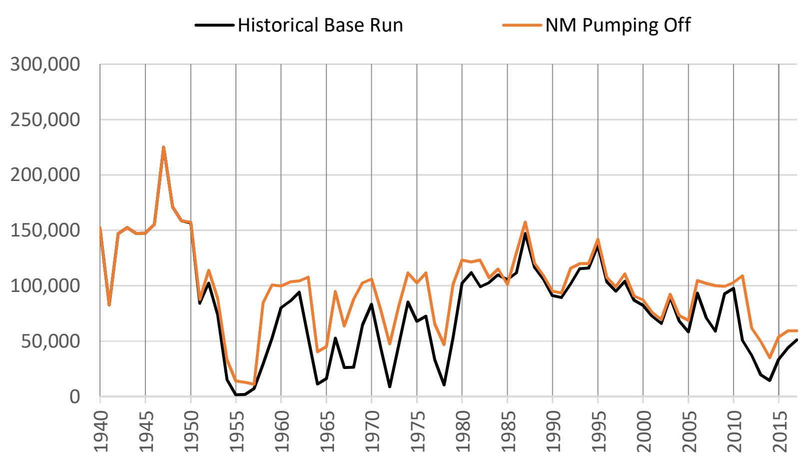
Figure 10B-4

4

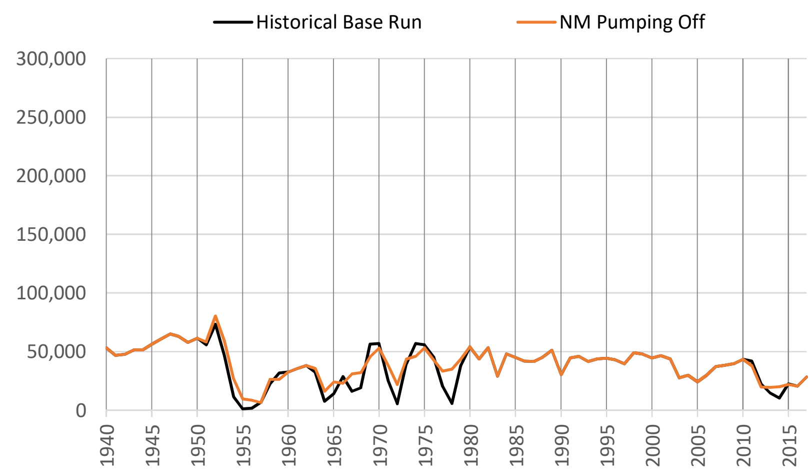
NM Pumping Off v. Historical Base Run
Integrated LRG Model
Annual Summary of Irrigation Operations
1940 - 2017 (acre-feet)

HCCRD Total

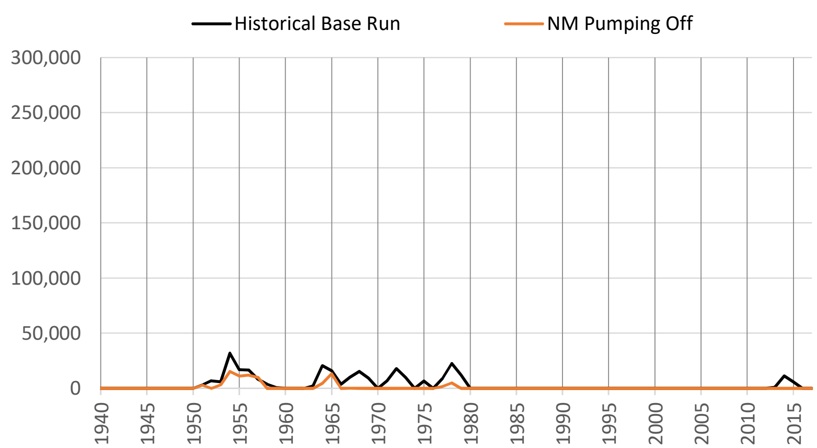
River Headgate Diversions



Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries

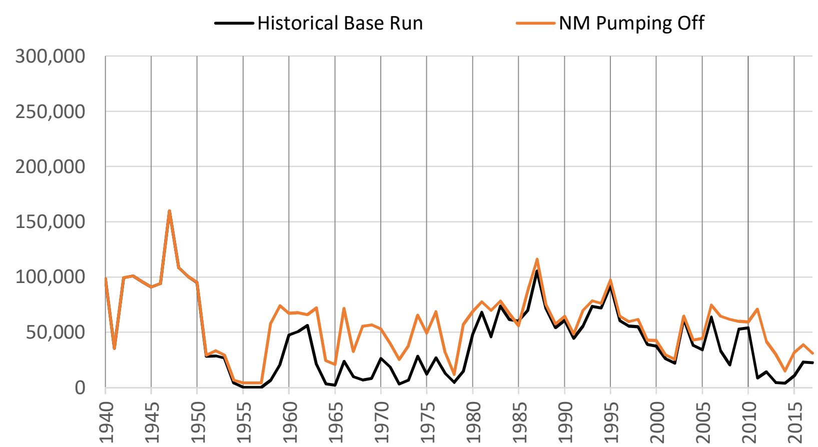


Figure 10B-5

NM Pumping Off v. Historical Base Run

Integrated LRG Model

Monthly RHG Diversions

1940 - 2017 (acre-feet)

EBID Total

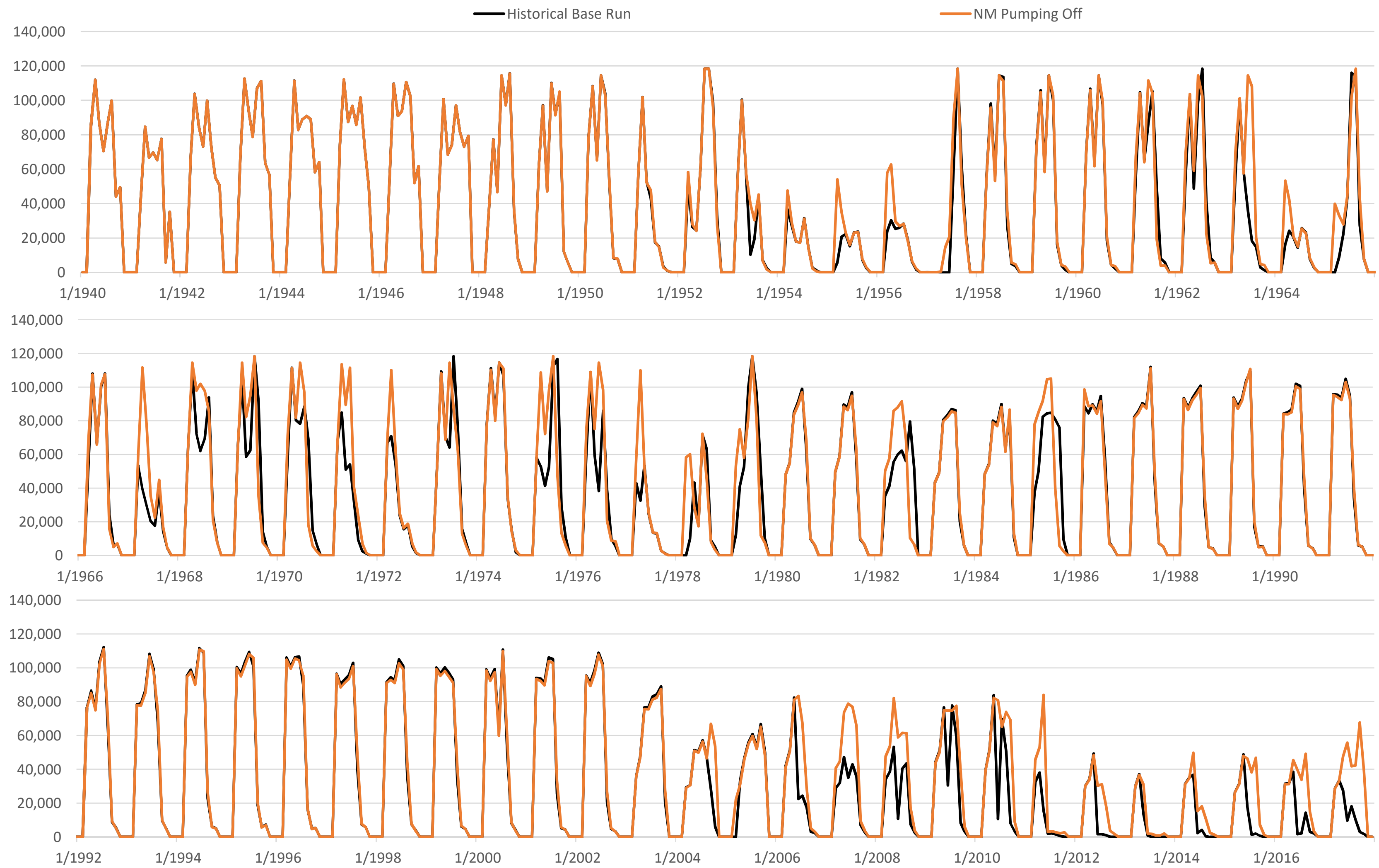


Figure 10B-6
NM Pumping Off v. Historical Base Run
Integrated LRG Model
Monthly RHG Diversions
1940 - 2017 (acre-feet)

EPCWID Total

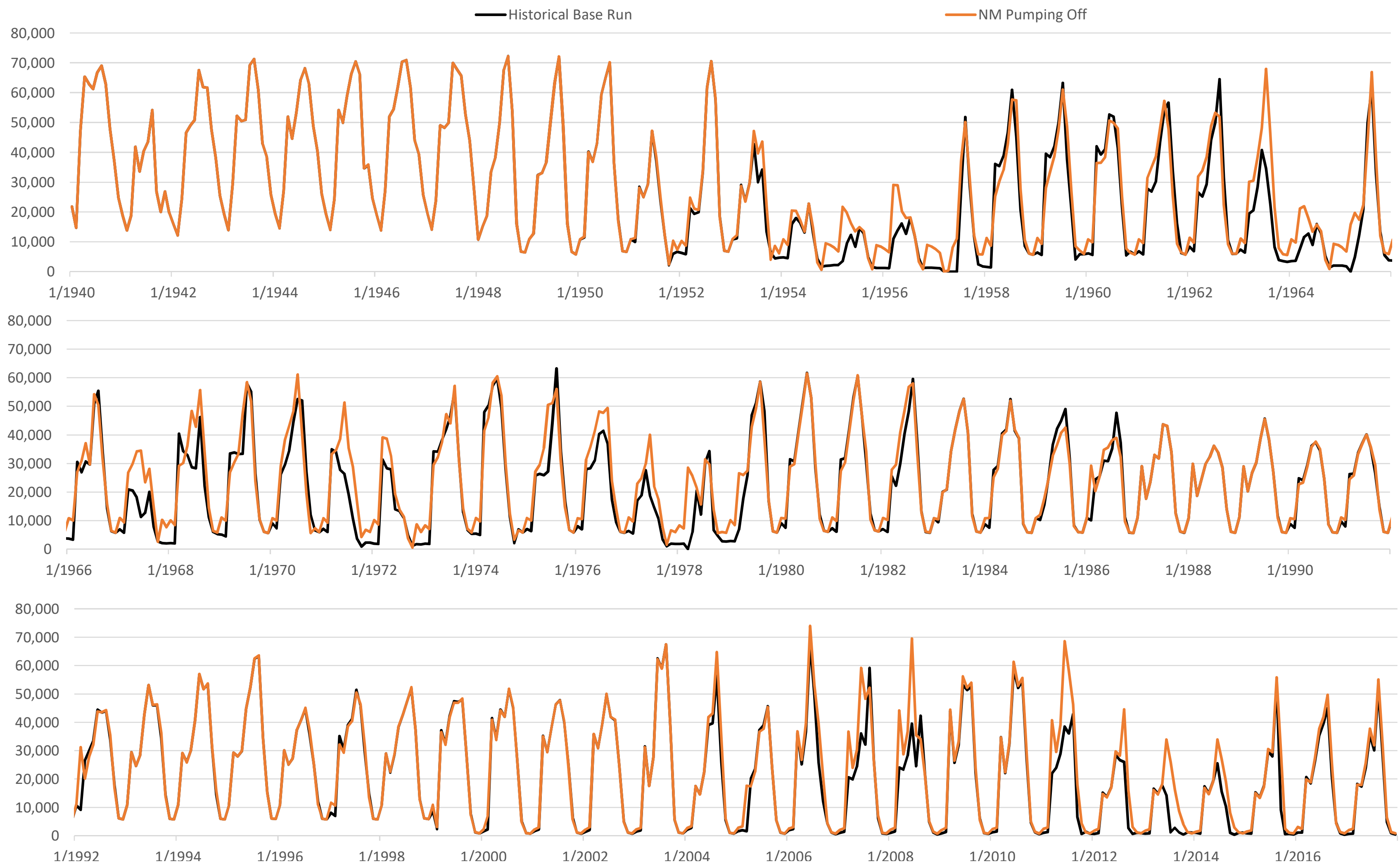


Figure 10B-7

NM Pumping Off v. Historical Base Run

Integrated LRG Model

Monthly RHG Diversions

1940 - 2017 (acre-feet)

HCCRD Total

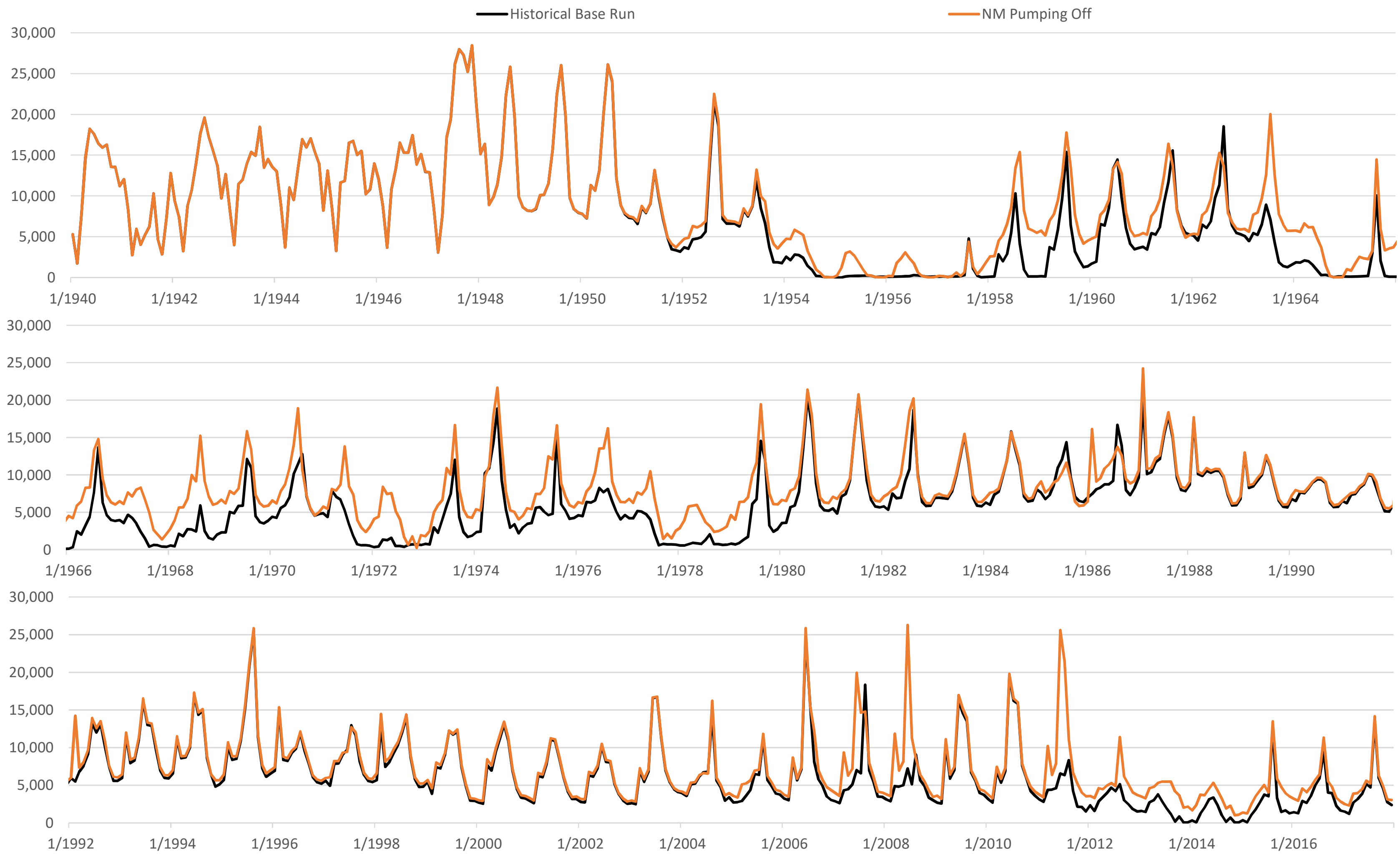


Figure 10B-8
NM Pumping Off v. Historical Base Run
Integrated LRG Model
Monthly FHG Deliveries
1940 - 2017 (acre-feet)
EBID Total

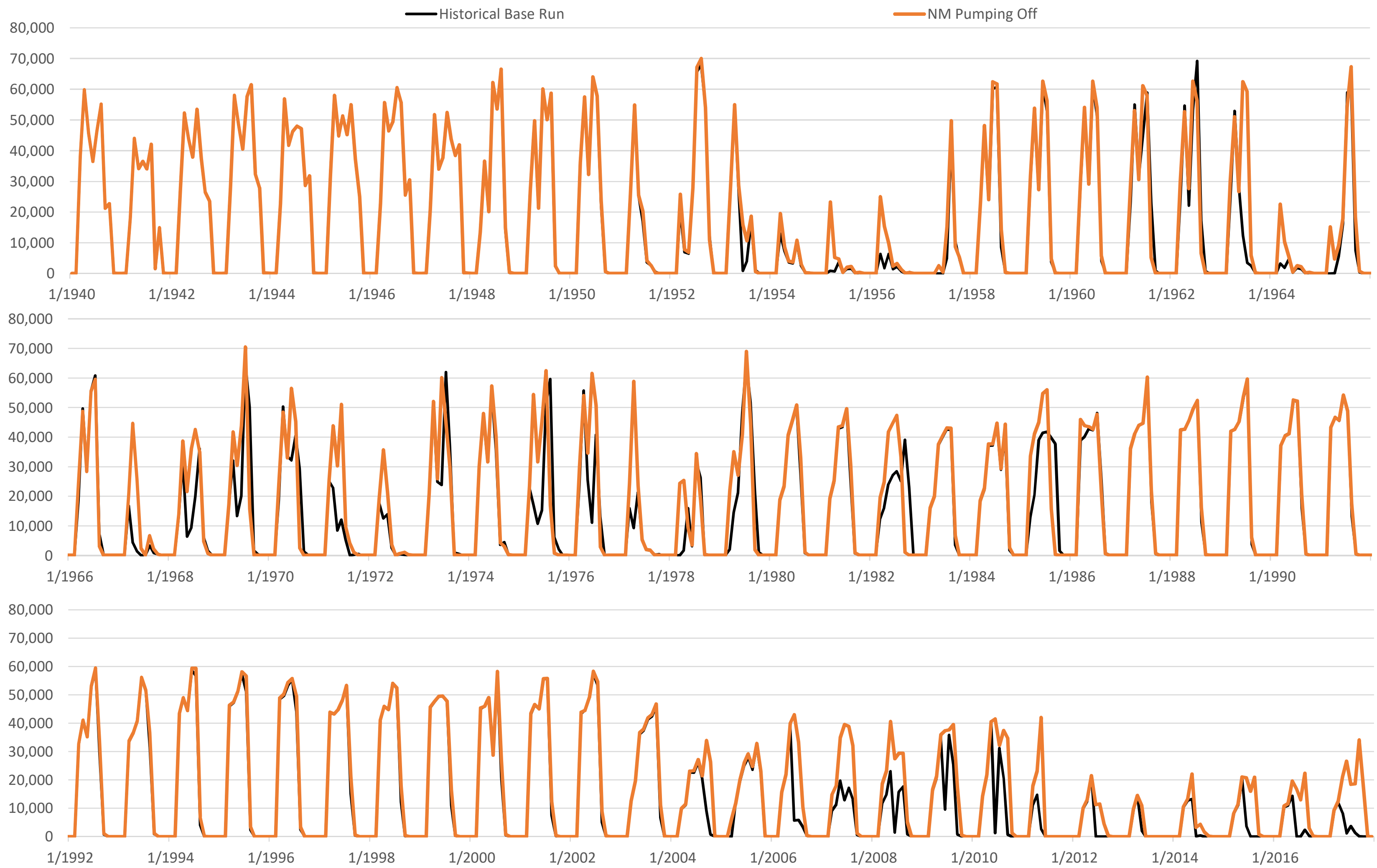


Figure 10B-9
NM Pumping Off v. Historical Base Run
Integrated LRG Model
Monthly FHG Deliveries
1940 - 2017 (acre-feet)
EPCWID Total

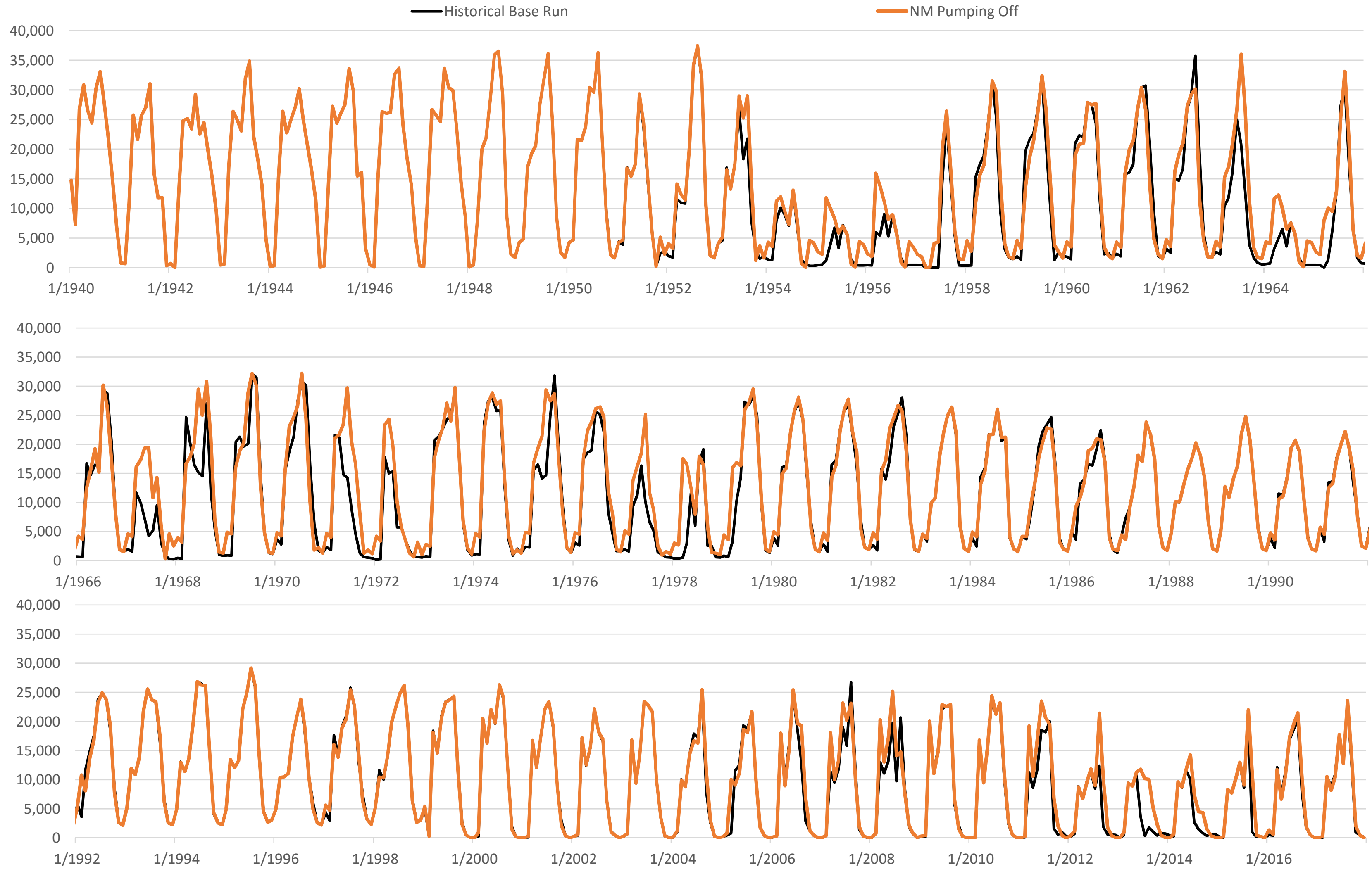


Figure 10B-10
NM Pumping Off v. Historical Base Run
Integrated LRG Model
Monthly FHG Deliveries
1940 - 2017 (acre-feet)
HCCRD Total

Figure 10B-11
NM Pumping Off v. Historical Base Run
Integrated LRG Model
Monthly Irrigation Supplemental Pumping
1940 - 2017 (acre-feet)

EBID Total

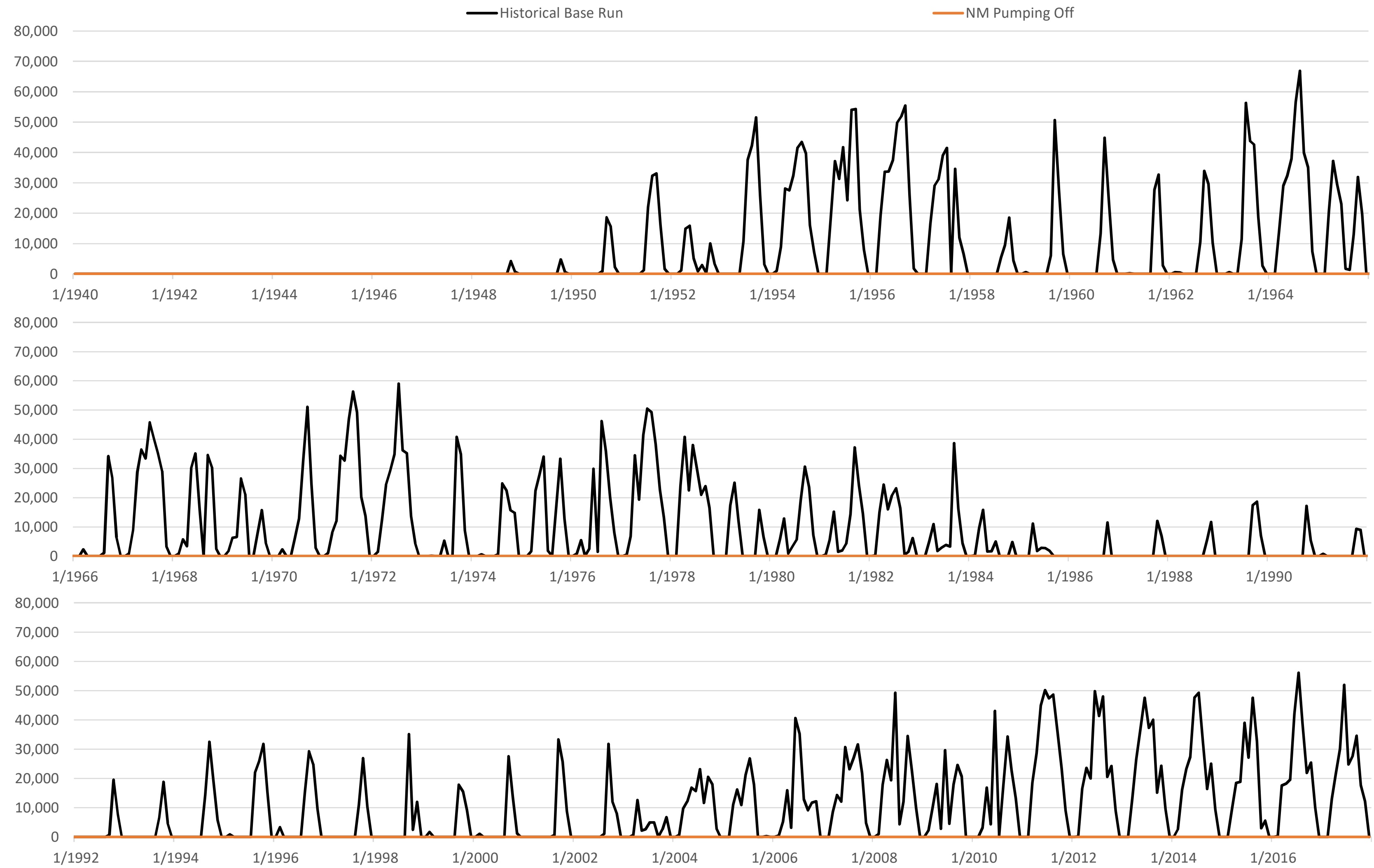


Figure 10B-12
NM Pumping Off v. Historical Base Run
Integrated LRG Model
Monthly Irrigation Supplemental Pumping
1940 - 2017 (acre-feet)
EPCWID Total

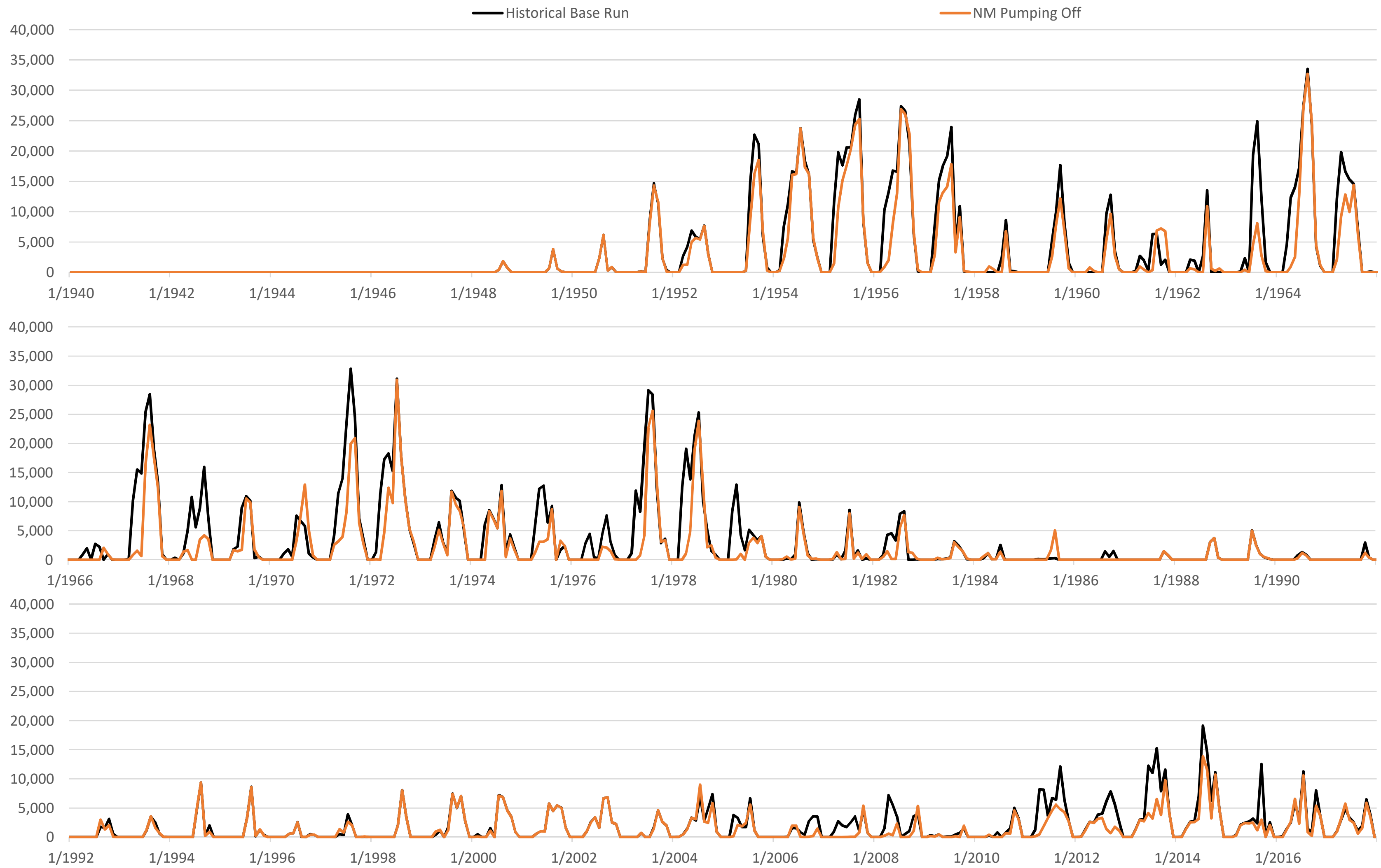


Figure 10B-13
NM Pumping Off v. Historical Base Run
Integrated LRG Model
Monthly Irrigation Supplemental Pumping
1940 - 2017 (acre-feet)
HCCRD Total

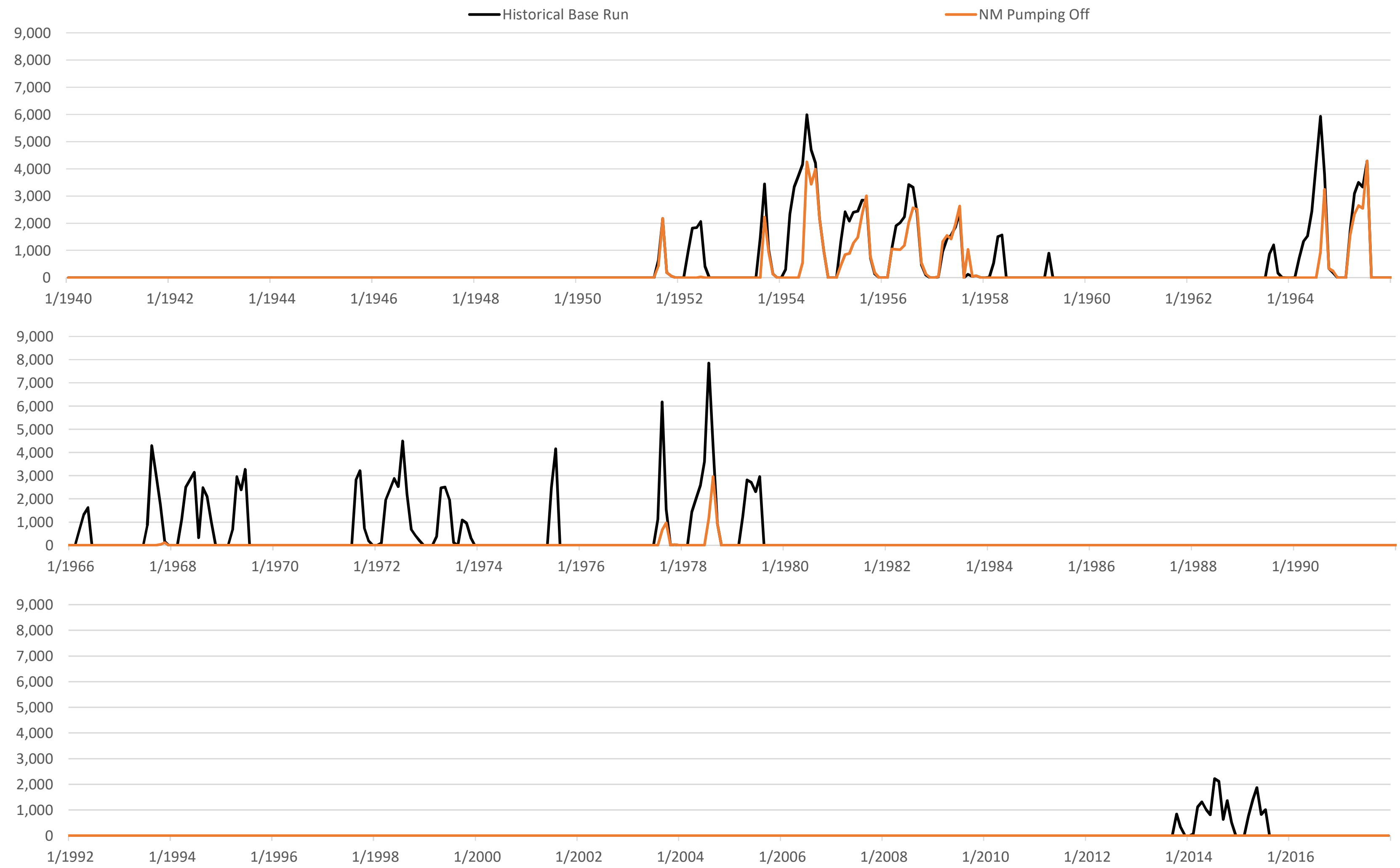


Figure 10B-14
NM Pumping Off v. Historical Base Run
Integrated LRG Model
End of Month Reservoir Storage (Elephant Butte + Caballo)
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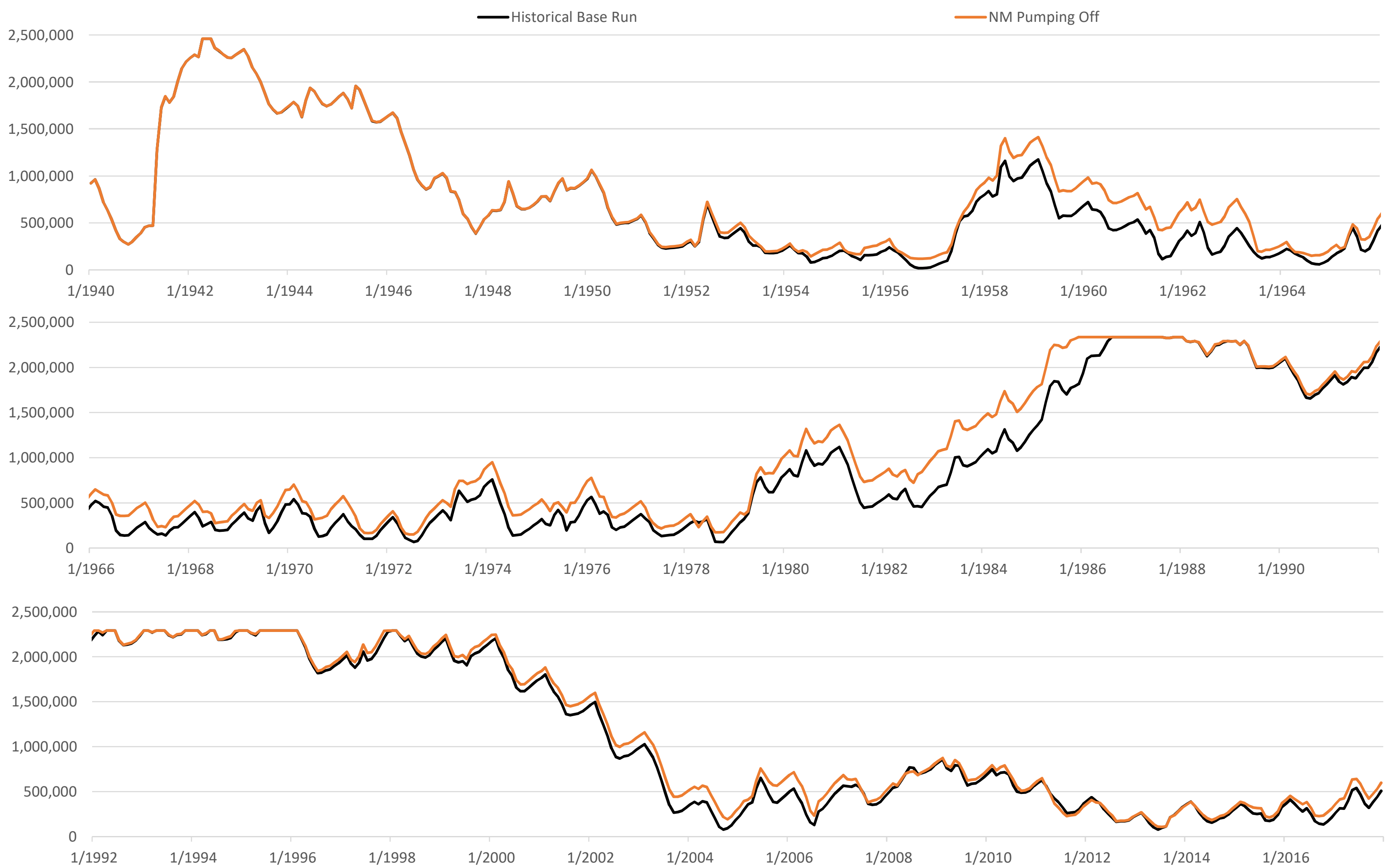


Figure 10B-15
NM Pumping Off v. Historical Base Run
Integrated LRG Model
Monthly Rio Grande Flow Below Caballo
1940 - 2017 (acre-feet)

Figure 10B-16
NM Pumping Off v. Historical Base Run
Integrated LRG Model
Monthly Rio Grande Flow at El Paso
1940 - 2017 (acre-feet)

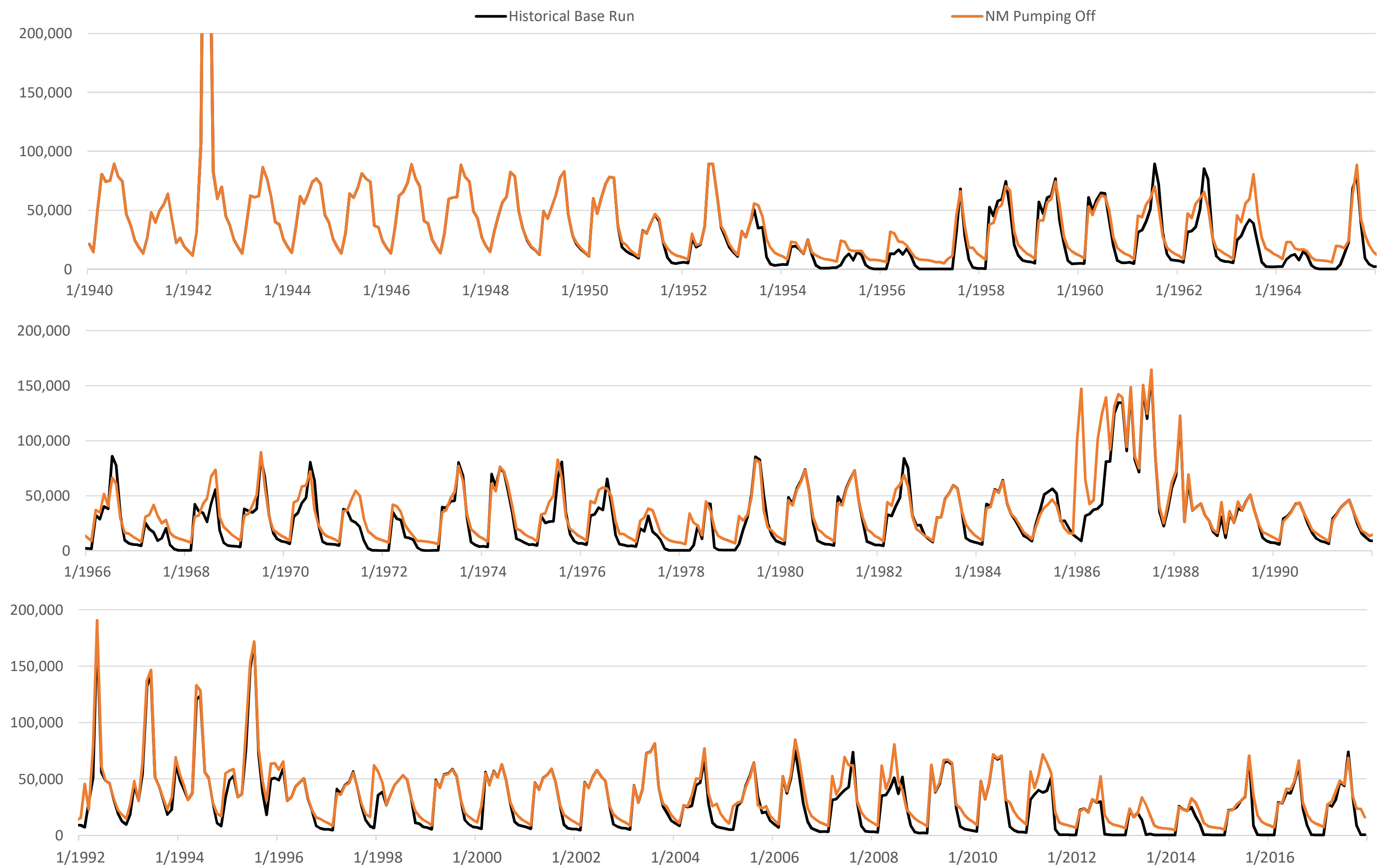
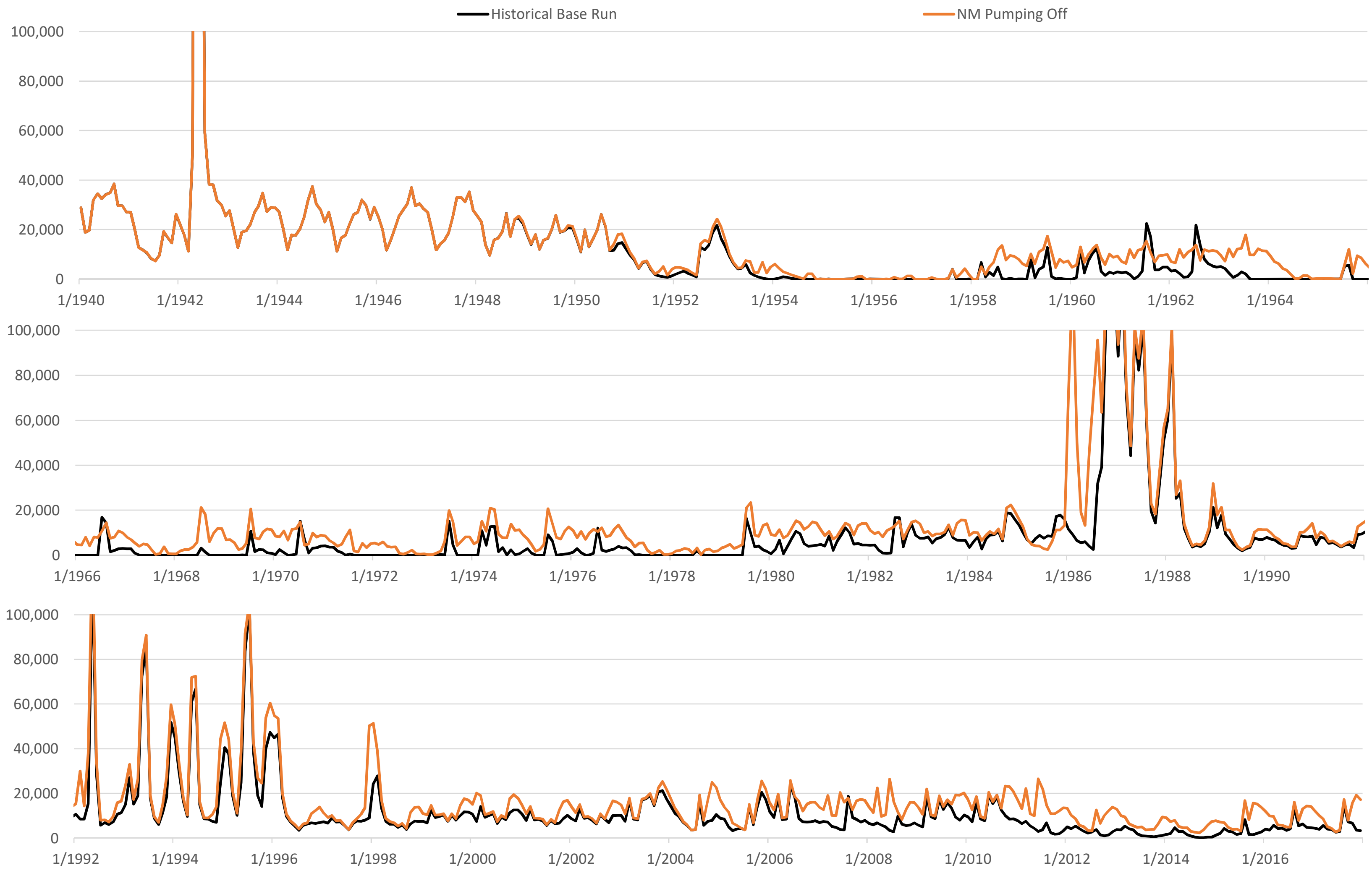


Figure 10B-17
NM Pumping Off v. Historical Base Run
Integrated LRG Model
Monthly Rio Grande Flow at Fort Quitman
1940 - 2017 (acre-feet)



No. 141, Original

IN THE

SUPREME COURT OF THE UNITED STATES

TEXAS V. NEW MEXICO AND COLORADO

REBUTTAL EXPERT REPORT OF
GREGORY K. SULLIVAN, P.E.
AND
HEIDI M. WELSH

Second Edition

Prepared for:

STATE OF NEW MEXICO

Prepared by:

GREGORY KEVIN SULLIVAN
NEW MEXICO
22620
9/15/20
PROFESSIONAL ENGINEER

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Gregory K. Sullivan, P.E. **Heidi M. Welsh**

July 15, 2020

(Revised September 15, 2020)

Spronk Water Engineers, Inc.

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LIST OF ABBREVIATIONS

2008 OA	2008 Operating Agreement
ACE	American Canal Extension
AF	Acre-feet
Reclamation	Bureau of Reclamation
BIAS	Mean Error
CFB Model	Canal and Farm Budget Model prepared by SWE
cfs	Cubic feet per second
CIR	Crop irrigation requirement
cms	Cubic meters per second
Compact	Rio Grande Compact
d	Index of Agreement
D1/D2	Procedure for allocating and accounting of Project water from 1979-2005 based on 1951-1978 Project operation data
D3	Procedure for allocating and accounting of Project water from 2006-present under the 2008 Operating Agreement
DCMI	Domestic, commercial, municipal, and industrial
DE	David's Engineering
DP	Deep percolation
EBID	Elephant Butte Irrigation District
EPA	Environmental Protection Agency
EPCWID	El Paso County Water Improvement District No. 1
EPW	El Paso Water
ET	Evapotranspiration
FHG	Farm headgate
Ft. Quitman	Fort Quitman, Texas
gpm	Gallons per minute
GPS	Global positioning system
HCCRD	Hudspeth County Conservation and Reclamation District No. 1
Hueco Model	Hueco Ground Water Model
Hydros	Hydros Consulting
IBWC	International Boundary and Water Commission
ILRG Model	Integrated Lower Rio Grande Model
JID	Juarez Irrigation District
JMAS	Junta Municipal de Aqua y Saneamiento (water utility for Ciudad Juarez)
Log-NSE	Logarithmic Nash-Sutcliffe Efficiency
LRG	Lower Rio Grande
LRG Area	Area of irrigation and non-irrigation water use in the Rincon, Mesilla, El Paso, and Juarez Valleys between Caballo Reservoir and Ft. Quitman Texas
M&A	Montgomery & Associates
M&I	Municipal and Industrial
MAD	Management allowable depletion

MAE	Mean Absolute Error
MFE	Maximum farm irrigation efficiency
MMA	McDonald-Morrisey Associates, LLC
MX-IBWC	Mexican section of the International Boundary and Water Commission
NMAGO	New Mexico Office of the Attorney General
NMISC	New Mexico Interstate Stream Commission
NMOSE	New Mexico Office of the State Engineer
NMR-M Model	New Mexico Rincon-Mesilla Ground Water Model
NPDES	National Pollutant Discharge Elimination System
NSE	Nash-Sutcliffe Efficiency
PBIAS	Percent Bias
PET	Potential evapotranspiration
PMAE	Percent Mean Absolute Error
QA/QC	Quality assurance and quality control
R^2	Coefficient of Determination
RGCC	Rio Grande Compact Commission
RGJI	Rio Grande Joint Investigation
RiverWare	RiverWare simulation model
RHG	River headgate
RMSE	Root Mean Squared Error
RSR	RMSE – Observed Standard Deviation Ratio
SSPA	S.S. Papadopulos & Associates
SWDataSet	Surface Water Dataset prepared by SWE
SWE	Spronk Water Engineers, Inc.
URGWOM	Upper Rio Grande Water Operations Model
USGS	United States Geological Survey
US-IBWC	United States section of the International Boundary and Water Commission
WDR	Water Distribution Report
WTP	Water Treatment Plant
WWTP	Wastewater Treatment Plant

17.0 SUMMARY OF OPINIONS

17.1 Introduction

The Case Management Order in Texas v. New Mexico and Colorado set forth a schedule for alternating the exchange of expert reports by parties to the case and the following reports have been submitted to date:

- Opening expert reports for Texas and the United States were submitted on May 31, 2019.
- Expert reports for New Mexico supporting the New Mexico counterclaims and responding to the original reports of Texas and the United States were submitted on October 31, 2019.
- Rebuttal expert reports for Texas and the United States responding to the New Mexico reports were submitted on December 30, 2019.
- Supplemental expert reports were submitted by several of the experts for Texas and United States after the deadlines in the case management orders. These included a May 2020 Coors Supplemental Report, a September 2019 Moran Supplemental Report, and a May 2020 Moran Second Supplemental Report. In addition, updated information and analysis was provided by certain of the Texas experts that was not documented in any expert reports.
- Rebuttal expert reports for New Mexico were originally scheduled for submittal on March 27, 2020, but this deadline was postponed to June 15, 2020 for non-modeling experts and July 15, 2020 for modeling experts as a result of the Covid-19 situation and other factors, including allowance of time to respond to the late-disclosed supplemental reports from Texas and the Unites States.
- Also, on July 15, 2020, the New Mexico experts submitted revised or second editions of their opening expert reports.

Among the opening New Mexico reports submitted on October 31, 2019 was the Expert Report of Gregory K. Sullivan, P.E., and Adelheid (Heidi) M. Welsh ("SWE Report"). The topics covered in the SWE Report generally consisted of the following:

- Hydrologic and Rio Grande Project data,
- Summaries of historical water supply and water uses,
- Canal and farm budget modeling,
- Review of the New Mexico Integrated LRG Model ("ILRG Model"),

- Results from ILRG Model simulations, and
- Responses to certain of the Texas expert reports.

This Rebuttal Expert Report by Gregory K. Sullivan, P.E. and Heidi M. Welsh was prepared to respond to certain of the rebuttal expert reports and supplemental expert reports submitted by the Texas and United States experts ("SWE Rebuttal Report").

Due to changes in the analyses performed by the Texas experts and updates to the ILRG Model runs, certain of the results that were reported in the text, tables, figures, and appendices in the SWE Report have changed. Revised figures and tables from the SWE Report are provided with this report. **Appendix 18** contains updates of the figures and tables for which the presentation format did not change. The format for certain of the figures, tables, and appendices that presented results of the ILRG Model have been updated. For these, rather than updating the original attachments in their original format, revised figures, tables, and appendices in the new format are attached to this rebuttal report and are described in Sections 28.0 – 30.0.

To avoid confusion with the numbering of the sections and attachments in the SWE Report, the section numbering in this rebuttal report picks up where the prior report left off with Section 17. All figures, tables, and appendices are identified with a prefix of the section number followed by numbers that are sequenced in the order described in the report text.

A second edition of the SWE Rebuttal Report was prepared to describe corrections and improvements that have been made to the ILRG Model, to report the results of the model re-tuning, and to present the results of the updated Base Run (Run 1) and alternative scenario runs (Runs 2 – 18). This second edition report also corrects typographical errors in the original SWE Rebuttal Report. A new Appendix 17 is attached that contains an errata list for Sections 17-29 and 31, a redline depiction of the changes to Section 30, and a list of the figures, tables, and appendices revised for this second edition.

17.2 Assignments

Our assignments for this rebuttal report were developed in discussions with legal counsel for the State of New Mexico. We were asked by legal counsel to develop analyses and expert opinions in the following areas:

- Review of rebuttal reports and supplemental report and supporting data, analyses, and modeling submitted by experts for the Texas and the United States,
- Updates to the CFB Models of the major irrigation users between Elephant Butte Reservoir and Fort Quitman Texas,

- Coordination of the updates to and use of the ILRG Model,
- Analysis of the effects of changes in Project operations and accounting in the El Paso Valley portion of EPCWID compared to those that existed in the past, and
- Evaluation of conjunctive use of ground water and surface water under alternative conditions, including limiting pumping to D1/D2 amounts, limiting M&I pumping to pre-compact levels, and/or limiting pumping to crop demands on authorized Project acres.

Summaries of the opinions that were developed by Ms. Welsh and Mr. Sullivan for this case follow. The numbering of the opinions picks up where the numbering in the SWE Report left off.

17.3 Summary of Opinions of Heidi M. Welsh

Ms. Welsh updated the SWDataSet as described in Section 26.0 and prepared an update to the annual CFB Model of the Hueco Bolson area that is described in Section 27.0. and summarized below. In addition, she continued to be involved in disseminating data for use in the New Mexico models, and in post-processing the model output files into summary tables and graphs.

Section 26.0 – Lower Rio Grande Data

47. Additional data for the Socorro WWTP and monthly drain water diverted at Fabens were added to the SWDataSet. The updated SWDataSet was used to supply data inputs to the revised ILRG Model.

Section 27.0 – Lower Rio Grande Canal and Farm Budget Models

48. The annual CFB Models that simulate irrigation operations in the portions of the Texas and Mexico irrigation districts that overlie the Hueco Bolson during 1903 - 1937 were revised to incorporate new FHG delivery data and to include a switch to turn off Juarez sewage discharge to canals when Mexico pumping is turned off. The revised CFB Model was used to prepare certain input data used in the early 1903 – 1939 annual warm-up simulation in the Hueco Model.

17.4 Summary of Opinions of Gregory K. Sullivan

Mr. Sullivan prepared Sections 18.0 – 25.0, and Sections 28.0 – 31.0 and is responsible for the opinions presented in those sections, which are summarized below.

Section 18.0 – Response to Revised Texas Analyses Submitted Without a Rebuttal Report

Based on review of the revised Texas analyses that were submitted without a rebuttal report, I developed the responses and opinions that are presented in Section 18.0, some of which are summarized below.

49. Corrections to the M&A Farm Budget analysis of EPCWID reduced the magnitude of the differences in results compared to the SWE CFB analysis, however substantial differences remain, including M&A's unrealistically high estimates of crop evapotranspiration and supplemental pumping.

50. Dr. Dorrance updated her analysis that translates impacts on Rio Grande at El Paso flow from New Mexico pumping computed by the Texas Model into estimated impacts on deliveries to Texas water users. The revised analysis remains flawed and inappropriate for the reasons described in the original SWE Report.

Section 19.0 – Response to Ferguson Rebuttal Report

Based on review of the rebuttal report by Dr. Ian Ferguson (U.S. expert), his backup files and references, and attending his deposition, I developed the responses and opinions that are presented in Section 19.0, some of which are summarized below.

51. Annual Texas Mesilla pumping occasionally exceeded 20% of the total pumping in the Rincon and Mesilla Valleys. (Figure 19-1). Simulated depletions of El Paso flow caused by Texas Mesilla pumping, on the other hand, were often much greater than 20% of the total depletions from all pumping in the Rincon and Mesilla Valleys. (Figure 19-2).

52. Pumping from the Hueco Bolson, including pumping by wells in Texas, depletes river flows, canal and lateral flows, and drain flows in and around the EPCWID service area. These depletions increase EPCWID calls for Project releases, reduce farm headgate deliveries of Project water, and reduce the surface flows leaving EPCWID that supply HCCRD. The impacts of Texas Hueco pumping on Project operations impact diversions and FHG deliveries of Project water to EBID. These impacts are reflected in the ILRG Model Runs that are discussed in Section 30.0.

53. The effects of Texas Hueco pumping have been partially offset by Texas WWTP discharges and urban deep percolation return flows. In order to minimize the impacts of Texas Hueco pumping, EPW WWTP discharges must continue to be a part of the irrigation supply used by EPCWID farmers. If EPW WWTP discharges were to become unavailable, the effects of Texas Hueco pumping on EBID would increase.

54. Total New Mexico pumping during 1979-2005, when the D1/D2 accounting was in use, averaged 109,600 AF/y, which is less than the total New Mexico pumping during the D1/D2 source data period of 1951-1978, when it averaged 179,100 AF/y. (Figure 19-5).

55. New Mexico Irrigation pumping since the 2008 OA has been in effect (2006-2017) is marginally greater than the average irrigation pumping during the 1951-1978 D1/D2 period. The increased recent pumping is due to severe drought conditions and the effect of the 2008 OA that has substantially reduced the allocation of Project water to EBID. (Figure 19-7).

56. New Mexico M&I pumping has increased by approximately 20,000 AF since the end of the D1/D2 period (1978), but a portion of the impacts of the increased pumping has been offset by urban return flows. (Figure 19-7).

57. Total beneficial consumptive use for irrigation and non-irrigation uses in New Mexico has increased relatively little over the last 60 years, with the 10-year average ending in 2017 only 20,000 AF greater than it was in 1960. (Figure 19-9).

58. EPCWID's unused allocation has exceeded 50,000 AF in 20 years since 1978, more than half of all the years, and these years tend to correspond with years of little or no irrigation pumping to meet unmet demand, thus confirming that EPCWID's unused allocation generally occurs in years when EPCWID irrigation demands are met (Figure 19-12).

59. Historical records show that annual EPWCID use of drain flows for irrigation declined from almost 30,000 AF in the late 1940s to zero in the early 1980s. Use of drain flows throughout the Project has been an integral part of Project operation throughout the history of the Project and the cessation of use of return flows arising within the EPCWID service area has impacted Project operations to the detriment of EBID. (Figure 19-16).

60. Analysis of historical records confirms that the increase in reported EPCWID waste that occurred after EPWCID took over distribution of water within its service area from the BOR in about 1980 was unreasonable compared to the more efficient operation that occurred prior to that time. (Figures 19-17 – Figure 19-20).

61. Analysis of historical records of Project operation clearly shows that releases from Project storage vary inversely with the amount of net gains between the Caballo Reservoir outlet and American Dam in order to meet Project water demands. Reservoir releases are higher in dry years with more losses and lower in years with

more gains. Since pumping affects Rio Grande gains and losses, changes in pumping result in changes in reservoir releases (Figure 19-23).

Section 20.0 - Response to George Rebuttal Report

Based on review of the rebuttal report by Mr. Jonathan D. George (Texas expert), his backup files and references, and reviewing his deposition transcript, I developed the responses and opinions that are presented in Section 20.0 and summarized below.

62. Increases in average crop evapotranspiration in the Rincon and Mesilla Valleys during 1985-2016 compared to 1938-1950 can be explained mostly by differences in weather and crop selection as opposed to well pumping. (Figure 20-1).

Section 21.0 - Response to Hornberger Rebuttal Report

Based on review of the rebuttal report by Dr. George M. Hornberger (Texas expert), his backup files and references, and viewing his deposition, I developed the responses and opinions that are presented in Section 21.0, some of which are summarized below.

63. The Texas Model fails to meet the stated Texas objective of showing how New Mexico pumping affects Rio Grande at El Paso flows because the Texas model (a) does not simulate the dynamic response of Project operations to changes in flows that would occur without pumping, (b) does not simulate the area downstream of the El Paso gage and thus cannot simulate the feedback response from those areas to changes in Project operations, and (c) uses annual stress periods that prevent distinguishing impacts that occur during the irrigation season from impacts that occur during the non-irrigation season.

64. The effects of pumping from the Hueco Bolson can propagate upstream of El Paso through Project operation mechanisms. Because the Project is operated as a unit, depletions of surface flows that affect deliveries to EPCWID users can result in increased releases of Project water to meet EPCWID demands, which in turn reduces the supply available for allocation to EBID. The impacts to EBID from Hueco Bolson pumping are magnified under the D3 accounting in the 2008 OA.

65. Simulation of Project operations is essential in modeling impacts of pumping on deliveries to LRG water users. The key aspects of Project operation are well understood and amenable to simulation, and there is a rich trove of historical data to validate the model simulation processes.

Section 22.0 - Response to Coors Rebuttal Report

Based on review of the rebuttal report by Mr. Adolph (Shane) Coors V (Texas expert), his backup files and references, and attending his deposition, I developed the responses and opinions that are presented in Section 22.0, one of which is summarized below.

66. Average deviations between simulated and observed data in the historical run of the ILRG Model do not represent uncertainty of the ILRG Model in simulating impacts of pumping or changes in operating practices. These impacts are quantified based on differences between model runs, and any model imperfections tend to cancel out when computing these differences.

Section 23.0 - Response to Coors Supplemental Report

Based on review of the supplemental report by Mr. Coors, his backup files and references, and viewing his deposition, I developed the responses and opinions that are presented in Section 23.0, some of which are summarized below.

67. Development and refinement of the ILRG Model by the New Mexico experts occurred over many years based on extensive discussion, testing, and evaluation of the simulated processes and model outputs. Additional simulation capabilities were added incrementally when they were shown to improve the functionality of the model and improve its performance. The result is a model that captures the essential elements of the reservoir and irrigation system operations in the LRG Basin. The robust and sophisticated operation of the ILRG Model is supported by the rich and extensive record of historical Project operation.

68. The complexity and detail included in the ILRG Model is consistent with the complexity of the Rio Grande Project and the LRG irrigation systems, and this complexity and detail is needed to answer and address the complex questions and issues raised in this case.

69. Project operation responses to impacts from pumping vary depending on several factors including the allocation procedure that is in effect (D1/D2 vs. D3+Carryover) and whether there is a full or partial allocation to the Districts. The Project operation responses that are simulated in the ILRG Model reflect the real-world responses to changes in surface water supply resulting from variations in pumping and other factors.

70. The monthly timestep of the ILRG Model is consistent with the monthly scale of the generally extensive historical data that document the historical Project operation,

and allow the model to importantly distinguish impacts on surface flows that occur within the irrigation season from those that occur during the non-irrigation season.

71. While there are numerous statistics and graphical methods that can be used to evaluate model calibration, there are no universally accepted guidelines for calibration assessment in the scientific community. Assessment of model calibration should be focused on how the model is being used.

72. The calibration statistics proposed by Mr. Coors for evaluation of model calibration are partially consistent with the statistics that were used by the New Mexico experts to evaluate performance of the ILRG Model. However, these statistics were computed using irrigation season or annual flows consistent with the temporal scale of the questions that the ILRG Model is being used to answer.

73. The statistics and graphical methods used to evaluate the calibration of the ILRG Model are based, in part, on performance measures and performance evaluation criteria recommended by Moriasi et.al. (2015) on behalf of the American Society of Agricultural and Biological Engineers ("ASABE").

74. The Log NSE statistic proposed by Mr. Coors is inappropriate for use in evaluating the ILRG Model because of its emphasis on differences in low flows. The claims and counterclaims by the states implicate Project operations and deliveries at all levels of flows. In addition, the highly regulated nature of the Rio Grande Project insulates it from the extreme flow variations and extreme low flows that are typical of unregulated river basins that may be more suited to evaluation using the Log NSE statistic.

75. The locations selected by Mr. Coors for evaluation of the calibration of the ILRG Model reflect an indiscriminate selection based on available data rather than locations that are important to the essential model functions and intended uses of the model. The individual and aggregated locations selected by the New Mexico experts for evaluating model calibration reflect thoughtful consideration of the interaction of the simulated model components and the questions that the model is being used to answer in this case.

76. Calibration of the ILRG Model should not be assessed using statistics computed from monthly data for several reasons. First, Project water is allocated to the Districts and to farmers as irrigation season volumes that they can take delivery of at their discretion. Second, releases from Project storage can buffer the monthly variability of stream depletions caused by pumping. Third, the availability of wells to

supplement surface supplies can smooth out monthly water supply variations caused by the pumping of others.

77. There is no widespread consensus in the scientific community for excluding a portion of the historical data period for use in validating a simulation model calibrated using data from a different period. In this case, since the ILRG Model is being used mostly to analyze the past, it is logical to use the entire simulation period for calibration.

78. It is common in modeling alternative irrigation scenarios using historical data to leave the irrigated acreage and cropping pattern at the historical values. This is reasonable because when the water supply to a farm is reduced in the absence of supplemental pumping, consumptive use will be limited by the available surface water supply and the maximum irrigation efficiency rather than crop water demand.

79. The dynamics of the Rio Grande Project operation and management are evident in the extensive historical records that have been analyzed and used in developing and calibrating the ILRG Model. The remarkable calibration performance of the ILRG Model is clear evidence that the system can be reasonably simulated.

80. Quantification of impacts on streamflows, diversions, and deliveries is not dependent on precise replication of historical conditions in calibration. Indeed, no simulation models of heterogeneous real-world systems could meet such an impossible standard. Rather, good model simulations are ensured using a model with reasonable and rational simulation processes that is calibrated to reasonably match the magnitude and patterns of the historical data. In this case, since model results are largely being evaluated based on differences between model runs, the cancelling of errors that occurs when differencing model results further enhances the reliability of model results.

81. It is illogical and inappropriate to use the results of the All Pumping Off (Run 2) scenario of the ILRG Model to evaluate the impacts of New Mexico pumping on Project operations, surface water flows, and ground water storage because pumping in the Texas portion of the Mesilla Valley and all pumping from the Hueco Bolson is turned off. There is no way to distinguish the impacts of New Mexico pumping from the impacts caused by the other pumping.

82. Due to non-linearities in the ILRG Model, differences between results of the All Pumping Off (Run 2) and Rincon-Mesilla Pumping Off (Run 6) should not be used to assess the impacts of Hueco Bolson pumping on Project operations. These impacts can be assessed by turning off the Hueco pumping and the associated return flows

in isolation and simulating the results as was done in Run 14 and several variants that are described in Section 30.0.

Section 24.0 - Response to Moran Supplemental Report

Based on review of the supplemental report by Ms. Jean Moran (U.S. expert), her backup files and references, and reviewing her deposition transcript, I developed the responses and opinions that are presented in Section 24.0, some of which are summarized below.

83. The results of the simulations of impacts of New Mexico pumping performed by Ms. Moran using the Texas Model are unreliable because of the serious flaws in that model which include the lack of simulation of the dynamic response of Project facilities and irrigation systems to changes in supply, the coarse annual stress periods, and the limited model domain that ends at the El Paso gage.

84. The crude redistribution of simulated increases in flow at the El Paso gage that result from turning off New Mexico pumping performed through iterative post-processing by Ms. Moran fail to incorporate many essential processes that affect Project operations and deliveries and therefore the results of these analyses are unreliable. Notwithstanding, the redistribution that was attempted by Ms. Moran recognizes the crucial point that Project operations, including reservoir releases, diversions, and deliveries, would have been different if pumping had been reduced.

85. In addition to the limitations of the Texas Model and the crudeness of her redistribution attempt, the estimates of the impacts of New Mexico pumping that were simulated by Ms. Moran are inflated because (a) all pumping in the Rincon and Mesilla Valleys was turned off, including the irrigation and M&I pumping in the Texas portion of the Mesilla Valley, and (b) WWTP discharges were not turned off which precluded simulation of the offset these discharges provide to depletions from pumping.

Section 25.0 - Response to Moran Second Supplemental Report

Based on review of the second supplemental report by Ms. Moran, her backup files and references, and reviewing her deposition transcript, I developed the responses and opinions that are presented in Section 25.0, some of which are summarized below.

86. The differences in ILRG Model performance before and after 1985 are insignificant and have not been shown to affect the results of the ILRG Model simulations. The average percent differences between modeled and measured values of Caballo releases and Rio Grande at El Paso flows fall within the "Very Good" evaluation

criteria proposed by Moriasi et. al, (2015). The performance of the updated ILRG Model is improved compared to the version of the model evaluated by Ms. Moran.

87. The other criticisms of ILRG Model performance made by Ms. Moran are not significant in the context of the overall calibration performance that is described in detail in Section 28.0. Moreover, Ms. Moran has not analyzed whether the alleged imperfections in the ILRG Model simulation of the Historical Base Run would affect the differences in the simulated results of alternative scenarios, given the cancelling of errors that occurs with such comparisons.

88. The calibration of the Rio Grande at El Paso flow in the ILRG Model is very good. The purportedly perfect calibration of the Texas Model at El Paso is achieved through inappropriate overparameterizing of conductance values and canal spills to drains in every stress period.

89. The comparisons of ILRG Model results of Run 2 (All Pumping Off) with Run 6 (R-M Pumping Off) are not reliable indications for the effect of Hueco pumping for the same reasons described in the opinions for Section 23.0.

90. When evaluating the effects of New Mexico pumping, WWTP returns from use of Las Cruces' Jornada Wells should be turned off to compute an appropriate credit for water imported to the basin.

91. Differences between simulated impacts of Rincon-Mesilla pumping computed by the Texas Model compared to the ILRG Model have not been demonstrated by Ms. Moran to be within the range of uncertainty of the models. Moreover, as described at length in this report and the SWE Report, the ILRG Model is far superior to the Texas Model due to its more sophisticated and robust processes and first-rate calibration.

Section 28.0 - Overview and Assessment of Updated ILRG Model

92. Changes to the RiverWare operating rules along with updated tuning have improved the ILRG Model simulation of historical Project operations. Substantive changes included modifications to reservoir operations to improve model performance when Project storage is near full or spilling. In addition, refinements were made to EPCWID operations to more evenly distribute water within the EPCWID service area and to make the simulated RHG demands more responsive to changes in irrigation use of WWTP discharges and local drain flows.

93. The improvements to the ILRG Model are reflected in the updated and expanded calibration summaries that demonstrate the outstanding performance of the ILRG Model in replicating historical operation of the Project and the associated LRG irrigation systems.

94. A wide range of statistical performance measures were employed to characterize the statistical performance of the ILRG Model in simulating the reservoir operations, streamflows, RHG diversions, FHG deliveries, supplemental pumping, and drain flows in the study area. These included a standard regression measure (R^2), dimensionless statistics (NSE, d), and error indices (BIAS, PBIAS, MAE, PMAE, RMSE, RSR).

95. The statistical performance measures were evaluated in comparison to performance evaluation criteria recommended by the ASABE and contained in a peer-reviewed journal article by Moriasi et. al. (2015) based on synthesis and meta-data analysis of numerous published articles describing calibration performance of various watershed models.

96. In addition, graphical performance measures were utilized to visually assess the goodness of fit of ILRG Model results, including monthly and annual time series graphs, cumulative residual graphs, scatter plots, and flow duration curves.

97. All statistical performance measures and graphical performance depictions were applied to a set of individual and aggregated locations that were thoughtfully selected as representative of model performance in relation to the intended uses of the ILRG Model results to answer the questions posed in this case.

98. The results of the application of the statistical performance measures to the ILRG Model Historical Base Run (Run 1) are summarized in Table 28-1. The results demonstrate acceptable to remarkable performance of the ILRG model in simulating Project operations, diversions and deliveries to LRG water users, and Rio Grande streamflows.

99. Graphical depictions of the ILRG Model performance are presented in Figure 28-1 through Figure 28-21. The graphs confirm and illustrate the ability of the ILRG Model to reasonably replicate the monthly, seasonal, annual, and decadal variations in streamflows, RHG diversions, FHG deliveries, supplemental pumping and drain flows throughout the LRG Basin.

100. The calibration performance of the ILRG Model is generally excellent considering the complexity and scale of the Rio Grande Project, the associated irrigation systems,

and the M&I water uses in the LRG Basin. The model achieves this excellent performance by reasonable and rational simulation of the physical and management processes that control the movement and interaction of surface water and ground water throughout the study area.

Section 29.0 – Historical Base Run of ILRG Model

101. The revised ILRG Model (v116) was used to prepare a new Historical Base Run (Run 1) generally according to the procedures described in the original SWE Report. Project water allocations were simulated using the D1/D2 allocation procedure from 1950-2005, the D3 allocation procedure without carryover in 2006 and 2007, and the D3+Carryover procedure in the 2008 OA from 2008-2017. Irrigation pumping coverage in EBID, EPCWID, HCCRD, and JID Units 2 and 3 was specified to increase linearly from 0% in 1947 to 100% in 1955, and in JID Unit 1 from 0% in 1939 to 100% in 1954. Non-irrigation pumping and return flows were specified and simulated based on historical records and estimates.

102. In addition to the statistics and graphs illustrating the calibration of the Historical Base Run in Section 28.0, numerous graphs were prepared to illustrate Project reservoir water budgets, canal and farm water budgets, river water budgets, and river point flows over the 1940-2017 simulation period. These results demonstrate that the ILRG Model reasonably and sensibly simulates the operation of the Rio Grande Project over the range of hydrologic conditions that occurred during the historical study period.

103. The excellent calibration of the ILRG Model achieved using rules that facilitate dynamic response of the essential Project and irrigation system functions make the model the best available tool and a reliable tool for answering the complex questions presented in this case through simulation of alternative scenarios and computing the differences between model runs.

Section 30.0 - Alternative Runs of ILRG Model

104. The revised ILRG Model was used to simulate "what-if" scenarios over the historical period to assess the impacts on reservoir operations, reservoir releases, RHG diversions, FHG deliveries, and Rio Grande flows resulting from cessation or reduction in historical pumping and/or changes in operating practices. Changes in model inputs cause dynamic responses of all simulated processes as the changed conditions ripple spatially and temporally through the model, just as they would in the real world. For the most part, the results from the what-if scenarios were compared to the Historical Base Run (Run 1) and changes in model outputs were

computed and summarized using a consistent set of tables and graphs that facilitate comparison of results between the various model runs.

105. The thirteen original runs described in the original SWE Report were repeated using the revised ILRG Model. These include the previously described Historical Base Run (Run 1), nine no-pumping runs (Runs 2 - 10), and three alternative operations scenarios (Runs 11 - 13) (Table 30-1).

106. Fourteen new runs were made in response to issues raised by experts for Texas and United States in rebuttal and supplemental expert reports, and in response to issues raised by legal counsel for Texas and the United States in their questioning of the New Mexico experts in depositions. These included five scenarios of reduced pumping from the Hueco Bolson in Texas and Mexico (Runs 14 – 14d), four scenarios with EPCWID operations modified to be consistent with earlier practices (Runs 15 – 15c), and five alternative conjunctive use scenarios (Runs 16, 16a, 17, 17a, and 18) (Table 30-2).

107. In the no-pumping runs, all pumping or just non-irrigation pumping was turned off in all areas (Run 2) or in certain geographic areas (Runs 3 – 10, 14, 14a, 14b, 14d, 15c). When non-irrigation pumping was turned off or reduced, so were the associated wastewater treatment plant discharges and urban deep percolation (except 14d). Because the Project is operated as a single system, any effects of pumping on surface water supplies that occur upstream of points of water delivery affect Project operations. The model results show that pumping in Texas and Mexico affects Project water deliveries to EBID water users in New Mexico.

108. The updated results for the original no pumping scenarios (Runs 2-10) are generally similar to the results for these scenarios that were presented and described in the original SWE Report. Keep in mind that the updated results for Runs 2-10 report differences in net RHG diversions as opposed to the differences in gross RHG diversions that were presented in the results for the original simulations of these scenarios.

109. Several runs were made to analyze the effects of Hueco Bolson pumping on Project operations and water supplies. These included turning off all Hueco pumping (Run 14), Texas Hueco pumping (Run 14a), and Mexico Hueco pumping (Run 14b). To further analyze the effect of Texas Hueco pumping, two additional runs were made. A run was made in which the Texas Hueco pumping was turned off, but the return flows from Texas M&I pumping were left on (Run 14d), to show the effect of Texas Hueco pumping without M&I return flow offsets. Another run was made in which all discharges from Texas WWTPs were turned off (Run 14c). The results from these

simulations show that pumping from the Hueco Bolson affects Project operations including deliveries to EBID and EPCWID as well as the total supply of water available to HCCRD. The results also show that without the offsetting effects of Texas WWTP discharges, impacts from Hueco pumping would be greater.

110. The updated results for the original runs that were made to evaluate the effect of the 2008 OA on Project operations (Runs 11 and 12) are similar to the results presented in the original SWE Report. The updated results show that since the new Project water allocation procedures in the 2008 OA were enacted beginning in 2006, the new procedures have caused a profoundly negative impact on the allocation and delivery of Project water to EBID that far outweighs the impacts of New Mexico pumping. Comparison of Runs 11 and 12 over the 1951-2017 period show that the negative impacts of the 2008 OA on EBID allocations and deliveries during average and dry years when water is most needed far outweigh the increased allocations and deliveries in wet years when water supplies are more plentiful.

111. The updated simulation of Project operations in which operational waste in EBID and EPCWID is limited to no more than 10 percent of the simulated diversions (Run 13) results that are similar to the original run described in the original SWE expert report. Limiting Project operational waste would substantially increase allocations and deliveries of Project water to both EBID and EPCWID.

112. Four runs of the ILRG Model were made to evaluate the effects on Project operations that would result from a return to EPCWID operations that are consistent with how the Project operated in the past (Runs 15, 15a, 15b, and 15c). The simulated changes in EPCWID operations generally consisted of increased use of drain flows for irrigation and charging EPCWID for all of the water that it uses. The results of these runs show that EBID allocations and deliveries would increase in average and dry years.

113. Based on discussion with New Mexico representatives and legal counsel, several ILRG Model runs were made to simulate various conjunctive use scenarios (Runs 16, 16a, 17, 17a, and 18). The results for Runs 16 and 16a are described in detail in the supplemental rebuttal expert report of Ms. Barroll (2020b), and the results for Runs 17, 17a, and 18 are detailed in the supplemental rebuttal expert report of Mr. Lopez (2020b).

Section 31.0 - Sensitivity Analyses of ILRG Model

114. Alternative runs of the updated ILRG Model were made to test the sensitivity of the model results to changes in certain input parameters and input data. The

sensitivities of model results were evaluated based on differences in alternative simulations of Run 3 (No New Mexico Pumping) and Run 1 (Historical Base Run). The results of the sensitivity analyses showed the simulated effects of pumping were most sensitive to changes in crop irrigation requirements. The results showed moderate sensitivity to changes in canal bed conductance, and minor sensitivity to changes in river bed conductance, drain bed conductance, and alluvial aquifer hydraulic conductivity.

18.0 RESPONSE TO REVISED TEXAS ANALYSES SUBMITTED WITHOUT A REBUTTAL REPORT

Certain of the analyses prepared by Texas experts, M&A and Dr. Dorrance, were updated to address some of the criticisms of the New Mexico experts. Neither M&A nor Dr. Dorrance submitted a rebuttal report or a supplemental report describing their updated analyses. Rather, the revised analyses were submitted as part of the materials relied upon by Texas expert Dr. Sunding for his rebuttal report. Upon learning of these revised analyses, legal counsel requested backup for the analyses and provided this information to SWE.

The SWE Report contained comparisons of results from simulations of the ILRG Model performed by the New Mexico experts to runs of the Texas Model performed by Dr. Hutchison. While Dr. Hutchison did not submit any new runs of the Texas Model, it was necessary to revise the comparisons of the model results to incorporate the results of the simulations made using the updated ILRG Model that are described in Section 30.0.

Discussion of the revised M&A Farm Budget analysis for EPCWID (El Paso Valley), the revised Dorrance analysis, and the updates to the comparisons of the ILRG Model and Texas Model results is provided below, and updated figures and tables relevant to these topics are included in **Appendix 18**.

18.1 Revised M&A Farm Budget Analysis

The May 31, 2019 expert report from M&A included a water budget analysis of irrigation operations by EPCWID and HCCRD in the El Paso Valley that was used in analysis of alleged damages to Texas from water quality impacts caused by New Mexico pumping during the period from 1985 – 2016. A revision to the M&A water budget analysis of EPCWID (El Paso Valley) was used in the updated damages analysis by Dr. Sunding.

The Goldsim Model input and output files and associated Excel spreadsheets that comprised the revised M&A Farm Budget Model and output for the revised analysis of EPCWID operations in the El Paso Valley were provided to SWE for review. The following is a summary of the changes to the M&A farm budget analysis of EPCWID (El Paso Valley) and our responses.

- <u>On-Farm Conveyance Efficiency</u> – The on-farm conveyance loss in the revised M&A Farm Budget Model of EPCWID (El Paso Valley) was changed from 10% to 2%. The basis for the revised on-farm conveyance loss was not provided in the Texas rebuttal materials. Nor was any basis provided as to why it is appropriate to change the on-farm conveyance loss for EPCWID (El Paso Valley), but leave the on-farm conveyance loss in the other M&A Farm Budget Models of the Rincon basin, the Mesilla basin, and HCCRD at 10%. As a sensitivity analysis, the M&A Farm Budget Models for Rincon basin and Mesilla basin were rerun by adjusting the on-farm conveyance loss (FCE) in the M&A input file from 10% to 2%, and the average annual simulated supplemental pumping in the Rincon and Mesilla basins declined by a combined total of 12,500 AF during 1985 - 2016.

- 2010 FHG Delivery Data – As described in the SWE Report, it appeared that the BOR FHG delivery data used by M&A for EPCWID (El Paso Valley) in 2010 were in error. While this error was corrected in the revised M&A farm budget analysis, disagreement with the method that M&A used to estimate EPCWID (El Paso Valley) FHG deliveries after 2008 remains.

- EPCWID Irrigated Area – The New Mexico experts criticized the irrigated area data used in the original M&A Farm Budget Model of EPCWID (El Paso Valley) because prior to 2011 it appeared to include the irrigated area for the Texas portion of the Mesilla Valley. The pre-2011 irrigated area values in the revised M&A farm budget analysis for EPCWID (El Paso Valley) were reduced, but the basis for the reduced values was not described in the rebuttal materials provided by Texas, and it was not clear if the reduction was to correct for the apparent error or for other reasons.

The results for the M&A Farm Budget Model of EPCWID (El Paso Valley) were compared to the results from the SWE CFB Model in **Figure 12-12** – **Figure 12-14** of the SWE Report. Updated versions of these figures with the results from the revised M&A Farm Budget Model are provided in **Appendix 18**. The following are comparisons of the 1985-2016 annual averages from the SWE CFB Model to the outputs from original and revised M&A Farm Budget Models.

Comparison of 1985-2016 Annual Averages
SWE CFB Model vs. M&A Farm Budget Model
EPCWID (El Paso Valley)

Quantity	SWE	M&A Original	M&A Revised	M&A Rev minus SWE	% Diff
Irrigated Area (ac)	37,900	43,200	38,800	+900	+2.3%
FHG Deliveries (AF)	116,800	104,400	100,100	-16,700	-14.3%
Unit ET (ft)	2.48	3.18	3.17	+0.69	+28.0%
ET Volume (AF)	93,400	137,200	122,700	+29,300	+31.4%
Irrigation Pumping (AF)	14,300	78,900	58,000	+43,800	+306.9%

The corrections to the irrigated area closed the gap in average annual irrigated area, but the revised M&A value remains 2.3% greater than the SWE value.

The correction to the 2010 FHG deliveries further increased the difference in average annual FHG deliveries, with the M&A value being 14.3% less than the SWE value. As described in the SWE Report, the difference between the M&A and SWE FHG deliveries appears to be due to differences in how the reported total EPCWID FHG deliveries were disaggregated between the Texas Mesilla and the El Paso Valley, with the M&A method providing unrealistically low results for the El Paso Valley FHG deliveries in many years.

The change to the M&A weighted average unit ET was minimal, and it remains 28% greater than the weighted average value in the SWE farm budget during the 1985-2016 period. This difference is due to differences in ET values for individual crops and differences in the annual crop mix.

The difference in ET Volume has decreased, but the average in the M&A Farm Budget Model is 31.4% greater than in the SWE CFB Model of EPCWID (El Paso Valley).

The revisions to the irrigated area, FHG deliveries, and the on-farm loss narrowed the difference in the computed pumping in EPCWID (El Paso Valley). However, the average annual pumping in the M&A Farm Budget analysis of 58,000 AF is still much greater than the 14,300 AF average in the SWE CFB Model.

While the revisions to the M&A farm budget analysis have reduced the differences between the pumping for EPCWID (El Paso Valley) computed by M&A and SWE, the opinions and criticisms of the M&A farm budget analysis that were originally presented in the SWE Report remain valid, most notably the unrealistically high M&A estimates of consumptive use and pumping.

18.2 Revised Comparisons to Texas Model Results

Dr. Hutchison has not submitted additional or revised runs of the Texas Model. However, because of the updates to the ILRG Model and the revised ILRG Model runs described in Section 30.0, it was necessary to update **Figure 13-1** and **Figure 13-2** from the SWE Report to reflect the revised ILRG Model results. These updated figures are included **Appendix 18**. The revisions to these figures did not change the overall conclusions and opinions regarding the Hutchison Report that were presented in the SWE Report.

18.3 Revised Dorrance Analyses

The May 31, 2019 expert report from Dr. Dorrance included analyses that translated simulated changes in the annual flows for the Rio Grande at El Paso computed using the Texas Model into estimated changes in monthly surface water deliveries to EPCWID farmers, HCCRD farmers, and EPW municipal water users. The Dorrance Report also describes the effect that changes in the monthly surface water deliveries would have on the salinity of the mixed surface water and ground water supplies of farmers and municipal water users.

While Dr. Dorrance did not submit a rebuttal report on behalf of Texas, she did prepare a revised analysis to translate the depletions of the Rio Grande at El Paso caused by New Mexico pumping from the Texas Model into effects on deliveries to Texas farmers, HCCRD farmers, and to EPW for M&I use. The analysis was revised to incorporate the results of the updated farm budget analysis of EPCWID (El Paso Valley) that was prepared by M&A as described Section 18.1. An Excel spreadsheet containing the revised Dorrance analysis was provided to SWE for review.

The additional available flow from the simulated reduction in New Mexico pumping used by Dorrance did not change because there were no new runs of the Texas Model submitted with the Texas rebuttal reports. However, the increases in deliveries to Texas water users and reductions in simulated pumping computed by Dorrance did change as a result of the corrected 2010 FHG deliveries and the reduced pumping provided as part of the revised M&A farm budget analysis of EPCWID (El Paso Valley). Updated versions of

Figure 14-1 – **Figure 14-3** from the SWE Report reflecting the updated Dorrance analysis are provided in **Appendix 18**.

The results from the updated Dorrance analysis were also used to prepare revised comparisons between her estimates of the increased deliveries to Texas water users that would occur with a reduction in New Mexico pumping to the increased deliveries to Texas users in the ILRG Model simulation of no New Mexico pumping (Run 3). These updated comparisons are provided in the revised **Figure 14-4** – **Figure 14-7** that are included in **Appendix 18**.

The revisions to the Dorrance analysis described above do not change the overall conclusions and opinions regarding the Dorrance Report that were originally presented in the SWE Report.

18.4 Revised Sunding Analyses

The May 31, 2019 expert report from Dr. Sunding computed alleged damages to Texas resulting from the increased Texas pumping for irrigation and M&I uses due to the effects of pumping by New Mexico computed by the Texas experts. According to Dr. Sunding, the increased pumping in Texas caused by New Mexico pumping increased the salinity of the mixed surface water and ground water supply used in Texas for irrigation (in EPCWID and HCCRD) and M&I uses resulting in economic damages that were quantified during 1985 – 2016.

Dr. Sunding used the revised Dorrance analysis described above to recompute the damages to Texas generally in accordance with the procedures set forth in the original Sunding Report.

The responses to the Sunding Report contained in the SWE Report did not rely on ILRG Model runs or any other analyses by the New Mexico experts that were updated since the original expert reports were prepared. As a result, it was unnecessary to update any of the responses to the Sunding opinions, and all responses and associated data, information, summaries contained in Section 15.0 of the SWE Report remain valid.

19.0 RESPONSE TO FERGUSON REBUTTAL REPORT

Ian M. Ferguson, Ph.D., P.E. prepared a December 30, 2019 rebuttal expert report on behalf of the United States ("Ferguson Rebuttal Report") that describes his rebuttal opinions to expert reports prepared on behalf of New Mexico by Margaret Barroll, Estevan Lopez, Gregory K. Sullivan and Heidi M. Welsh (SWE Report), and John C. Carron and Steven T. Setzer.

SWE was asked by legal counsel for New Mexico to review the Ferguson Rebuttal Report and to prepare expert opinions to respond the opinions of Dr. Ferguson. A lack of response regarding a particular issue should not be interpreted as tacit agreement with the Ferguson opinions on that issue.

Ferguson Opinion 1 – *Estimates of groundwater pumping provided in the expert report of Sullivan and Welsh indicate that more than 80% of the total groundwater pumping in the Rincon and Mesilla Valleys occurs in New Mexico and less than 20% occurs in Texas; similar estimates are provided in the expert report of Hutchinson. While the relative amount of annual pumping in each state varies from year to year, these studies indicates that the relative amount of cumulative pumping has remained consistent since the late 1960s. (page 3).*

Response:

Contrary to Dr. Ferguson's assertion, the relative amounts of New Mexico and Texas annual pumping in the Rincon and Mesilla Valleys have not remained constant since the late 1960s. The upper chart in **Figure 19-1** shows that total annual New Mexico pumping (sum of irrigation and M&I pumping) as blue bars and the total annual Texas Mesilla pumping as orange bars from 1940 – 2017. The annual New Mexico and Texas pumping as percentages of the total pumping in the Rincon and Mesilla Valleys are shown as blue and orange lines, respectively in the lower chart in **Figure 19-1**. The graph shows that the Texas pumping percentage exceeded 20% in 16 years between 1974 and 2000.

As shown in **Figure 19-1**, the Texas pumping as a percentage of the total pumping in the Rincon and Mesilla Valleys has declined in recent years due to the increase in New Mexico pumping that has occurred in large part due to the effect of the 2008 OA that significantly reduced New Mexico's allocation of Project water, resulting in a significant increase in unmet irrigation demand that was met by pumping.

Ferguson Opinion 2 – *Model simulation results presented in the expert report of Sullivan and Welsh and the expert report of Hutchinson further suggest that the depletion of Project surface water supplies is roughly proportional to the cumulative amount of* *pumping, with approximately 80% of the total depletion of Project supplies in the Rincon and Mesilla Valleys resulting from groundwater pumping in New Mexico and approximately 20% resulting from groundwater pumping in Texas. (page 3).*

Response:

The relative impact of New Mexico pumping and Texas Mesilla pumping on Rio Grande at El Paso flows was computed using results from the ILRG Model runs described in Section 30.0. Annual depletions to El Paso flow were computed based on differences in simulated El Paso flow between no pumping runs and the Historical Base Run (Run 1). Annual depletions from 1950 - 2017 for New Mexico pumping (Run 3 minus Run 1), Texas Mesilla pumping (Run 7 minus Run 1), and all Rincon-Mesilla pumping (Run 6 minus Run 1) are shown in the upper chart in **Figure 19-2**.

Annual depletions from New Mexico pumping and Texas Mesilla pumping as percentages of the depletions from all Rincon-Mesilla pumping are shown in the lower chart in **Figure 19-2**. The relative effects of Texas Mesilla pumping on Rio Grande at El Paso flows are often much greater 20%.

Ferguson Opinion 3 – *With respect to groundwater pumping in the El Paso Valley (Hueco Bolson aquifer), model simulation results presented in the expert report of Sullivan and Welsh indicate that the effects of groundwater pumping in the El Paso Valley on historical Project diversions and deliveries to Elephant Butte Irrigation District ("EBID") are negligible. Groundwater pumping in El Paso Valley no longer impacts Project deliveries in El Paso Valley due to the construction of the American Canal Extension ("ACE"), which eliminates the effects of groundwater/surface-water interactions on Project deliveries in the El Paso Valley. (page 3).*

Response:

Prior to construction of the ACE, depletions of the Rio Grande upstream of Riverside Dam affected Project deliveries to the Riverside Canal, requiring more releases from Project storage to the Riverside Canal than would be necessary without pumping from the Hueco Bolson in the El Paso Valley ("Hueco").

Depletions to the Rio Grande downstream of American Dam affect deliveries of 1906 Treaty water to Mexico at the Acequia Madre. In addition, depletions to river flows downstream of American Dam would affect downstream diversions from the river (if any) by HCCRD at the structure that can supply the Hudspeth Feeder Canal.

Hueco pumping also increases seepage from EPCWID canals and laterals (MMA, 2019). The increased seepage losses in the EPCWID service area require additional Project releases to deliver orders for Project water to EPCWID farmers. The increased seepage losses also reduce the amount of waste and drain flows from EPCWID that can be delivered to the headgates of HCCRD farmers.

Finally, Hueco pumping also depletes EPCWID drain flows that accumulate in the Fabens Waste Drain and the Tornillo Drain. Historical BOR records show EPCWID diverted water from the Fabens Waste Drain until the early 1980s for irrigation in the Tornillo area. Therefore, Hueco pumping reduced the drain supply that comprised a portion of the irrigation supply delivered to Tornillo area farmers until the early 1980s, and would still be depleting that supply if EPCWID had not ceased diverting from the Fabens Waste Drain.

Depletions of drain flows that reach the Fabens Waste Drain as well as depletions of Tornillo Drain flows reduce the supply leaving the EPCWID service area that is the primary source of supply to HCCRD farmers. The effect of Texas Hueco irrigation pumping on drain flows is illustrated in **Figure 19-3** which compares the monthly net recharge from the SWE CFB Model (orange line; defined as canal seepage plus deep percolation minus irrigation pumping) to the sum of the Fabens Waste Drain and the Tornillo Drain (blue line). Comparison of the lines in **Figure 19-3** shows that the simulated drain flows fluctuate up and down with the fluctuation in net recharge. During extended drought periods such as the mid-1950s, the net recharge declined due in large part to pumping, becoming negative at times (pumping exceeded the sum of canal seepage and deep percolation), and this resulted in the drain flows declining substantially and even drying up. The accumulated effect of the negative recharge during the 1950s drought is seen in the slow recovery of the drains after the drought, when it took two or three years for the drains to recover.

The impacts of Hueco pumping on surface water flows are ongoing and are reflected in the ILRG Model results for Runs 4, 5, 8, 10, 14, 14a, and 15c that are discussed in Section 30.0.

While Hueco pumping has impacted and continues to impact EPCWID and HCCRD water supplies, these impacts have been partially offset by increases in EPW WWTP discharges from pumping. The offsetting effects of the EPW WWTP discharges from pumping are immediate and concentrated in the EPCWID service area as opposed to the depletive effects of Hueco pumping, particularly the M&I pumping by EPW and Juarez, that are significantly lagged in time and distributed geographically throughout the El Paso Valley.

The combined effect of Texas Hueco pumping and Texas WWTP offsets is reflected in Run 14a of the ILRG Model that is described in Section 30.0. In this run, all Texas Hueco irrigation and non-irrigation pumping was turned off as well as the WWTP returns and urban deep percolation returns from the non-irrigation pumping. Differencing the results from Run 14a and Run 1 (Historical Base Run) reflects the net effect of Texas Hueco pumping and Texas Hueco returns. The following is a summary of the differences in EBID diversions and FHG deliveries averaged over two periods of time:

Average Annual Change in EBID Supply
from Turning Off Texas Hueco Pumping and Return Flows
(Run 14a minus Run 1)
(acre-feet)

Output	1951-1978	2006-2017
Diversions	-600	-7,800
FHG Deliveries	-300	-4,000

The impacts of Texas Hueco pumping are relatively small due in part to the offsetting effect of the Texas WWTP discharges (although there are some years with larger impacts). To illustrate this, a Run of the ILRG Model was made in which all Texas Hueco pumping was turned off, but leaving on the Texas WWTP returns at the historical levels (Run 14d). Comparison of Run 14d to Run 1 shows the effect of Texas Hueco pumping without the Texas WWTP offset. The following is a summary of the average changes in EBID diversions and FHG deliveries that would be caused by Texas Hueco pumping without the Texas WWTP offset:

Average Annual Change in EBID Supply
from Turning Off Texas Hueco Pumping without WWTP Offset
(Run 14d minus Run 1)
(acre-feet)

Output	1951-1978	2006-2017
Diversions	8,200	3,400
FHG Deliveries	5,000	2,000

Another run of the ILRG Model was made to isolate the effect of the Texas WWTP offsets. In this run, all Texas WWTP discharges were turned off, but all of the Texas pumping (irrigation and EPW pumping) was left on (Run 14c). The results show that without the Texas WWTP offsets, EBID diversions and FHG deliveries would decrease by the following average volumes:

Average Annual Change in EBID Supply from Turning Off Texas WWTP Discharges (Run 14c minus Run 1) (acre-feet)

Output	1951-1978	2006-2017
Diversions	-15,200	-25,000
FHG Deliveries	-8,200	-11,700

The above comparisons clearly show that Texas Hueco pumping would have a greater impact on deliveries to EBID without the offsetting effect of the Texas WWTP discharges. In order to minimize the effect of Texas Hueco pumping on Project operations going forward it is essential that the Texas WWTP offsets continue and are a part of a future EPCWID compliance requirement. This means that the EPW WWTP discharges to the EPCWID canal system must continue to be part of the irrigation supply that is used by EPCWID farmers. If EPW found another use for its WWTP discharges (e.g., nonpotable reuse or sale to others), the effects of Texas Hueco pumping on EBID would increase.

Ferguson Opinion 4 *– Estimates of groundwater pumping in the Rincon Valley and the New Mexico portion of the Mesilla Valley provided in the expert report of Sullivan and Welsh show that groundwater pumping in New Mexico increased from 1985 to 2002, despite full diversion allocations to EBID through this period. Pumping in New Mexico continued to increase from 2003 to 2005, prior to the implementation of the "D3 Method" allocation procedure. (page 5).*

Response:

Dr. Ferguson's observation about increases in EBID ground water pumping during the full allocation years of 1985 – 2002 ignores that pumping during this period was generally lower than the EBID pumping in the full allocation years of 1979 – 1984. The upper chart in **Figure 19-4** shows the simulated annual EBID supplemental irrigation pumping from 1948 – 2017. The lower chart in **Figure 19-4** shows the annual EBID supplemental irrigation pumping during 1979 – 2017 along with the reported annual EBID allocations and delivery charges.

The simulated annual volume of EBID supplemental ground water pumping varies based on the unmet demand which is a function of the irrigation demand and the surface water supply. The irrigation demand is affected by the irrigated area, crop mix, weather conditions, and irrigation efficiency. Surface water supply is affected by the Project water allocation and how much Project water is called for and delivered to the farms. Given all of the factors that contribute to variations in pumping to meet unmet demand, the simulated variability in supplemental pumping during the full supply years from 1979 – 2005 is not surprising, and it has not been shown to be indicative of any upward or downward trend in supplemental pumping. As described in the Barroll Rebuttal Report (2020a), over the long term, to the extent there has been a shift to higher water consuming crops in EBID, this has been offset by overall reductions in irrigated area.

Ferguson Opinion 5 *– Increases in groundwater pumping in New Mexico occurred prior to the OA due to increases in water demands for supplemental irrigation within EBID, increases in water demands for irrigation of groundwater-only lands outside of EBID, and increases in water demands for domestic, municipal, industrial, and commercial uses. Current demands within EBID exceed the historical full-supply delivery of 3.024 AF per acre. (page 5).*

Response:

Dr. Ferguson appears to assert that EBID pumping increased during the time that the D1/D2 allocation procedure was in effect from 1979 – 2005 before it was replaced by the 2008 OA accounting that commenced in 2006. **Figure 19-5** is a stacked bar chart showing the annual pumping in New Mexico comprised of supplemental pumping in EBID, primary ground water pumping outside of EBID, and total M&I pumping. **Figure 19-5** shows that the total pumping in New Mexico actually decreased from an average of 179,100 AF/y during 1951 – 1978 (period used to develop the D1 and D2 Curves) to an average of 109,600 AF/y in 1979 – 2005 (period of D1/D2 accounting).

The normal or full supply delivery of 3.024 AF/ac was computed by the BOR based on analysis of actual Project water deliveries during 1946 – 1950 (Friedkin and Resch 1956). This represents the water supply that the BOR determined was sufficient in the late 1940s to meet average annual irrigation water demands. This unit full supply delivery was multiplied by the authorized Project acres in EBID (90,640 acres) and EPCWID (69,010 acres) to compute the average annual full supply delivery volume for the authorized Project acres. The actual annual FHG delivery demands for EBID and EPCWID were computed as the crop-weighted CIR multiplied by the reported annual irrigated acres divided by the estimated farm irrigation efficiency used in the CFB Models (increased from 65% before 1950 to 75% after 1984). The historical EPW diversions were added to the computed EPCWID FHG demands.

Figure 19-6 compares the average annual full supply delivery determined by the BOR for the authorized Project acres (dashed lines) to the computed annual FHG delivery demands in EBID and EPCWID (solid lines) for the period from 1940 – 2017. This comparison shows that the EBID FHG delivery demand consistently exceeded the BOR estimate during most years from 1951-1978. Since that time, the demand has remained above the BOR estimate in most years, but as shown in the inset table in **Figure 19-6**, the average FHG demand has declined since the D1/D2 period by an average of 27,900 AF. The annual EPCWID FHG demand (plus EPW Project water deliveries) was above the BOR estimate in the 1940s and 1950s, fluctuated above and below the estimate during the 1960s and 1970s, and has been generally less than the BOR estimate since then.

Ferguson Opinion 6 *– Increased groundwater pumping to meet these demands, and the corresponding impacts on Project surface-water supplies, was a major driver in negotiation of the OA. The reduction in EBID's annual diversion allocation under the "D3 Method" was negotiated as a means to offset these impacts. Under the "D3 Method," EBID foregoes a portion of its annual diversion allocation to offset the impacts of groundwater pumping in New Mexico on Project allocations and deliveries to EPCWID. (page 5).*

Response:

As discussed in Section 11.0 of the SWE Report, the D1 and D2 curves implicitly grandfathered in the effects of pumping during 1951 – 1978 by New Mexico, Texas, and Mexico on Project performance and Project deliveries. Contrary to Dr. Ferguson's assertion, the 2008 OA does not include any explicit statements that its purpose was to address only increases in pumping impacts after the D1/D2 period.

Historical pumping data and information from the SWE CFB Models were compiled to characterize and compare surface water and ground water use during and after the 1951 – 1978 D1/D2 period. The results are presented in **Figure 19-7** through **Figure 19-11** which are described below.

<u>Pumping</u>

Figure 19-7 shows the annual New Mexico pumping from 1940 – 2017. The upper chart shows the EBID irrigation pumping (blue bars). The maximum annual pumping during the D1/D2 period is shown as a horizontal black line and the average annual pumping during

that period is shown as a horizontal blue line. Since the D1/D2 period there has been only one year (2011) with irrigation pumping that exceeded the D1/D2 period maximum. The running 10-year average pumping (red line) has only exceeded the D1/D2 average during the dry years from 2012 – 2017 when the 2008 OA was in effect. Therefore, Dr. Ferguson is wrong to imply that implementation of the 2008 OA was to address increased irrigation pumping in New Mexico after the D1/D2 period.

The lower chart in **Figure 19-7** shows the New Mexico M&I pumping from 1940 – 2017. The maximum annual pumping during the D1/D2 period is shown as a horizontal black line and the average annual pumping during that period is shown as a horizontal blue line. The New Mexico M&I pumping steadily increased after the D1/D2 period through about 2000 and has since leveled off. The annual New Mexico M&I pumping following the D1/D2 period has been above the D1/D2 maximum during most years. However, a portion of the impacts of the New Mexico M&I pumping is offset by WWTP discharges and urban deep percolation return flows. As is shown in the results for Run 9 described in Section 30.0, the impacts of New Mexico M&I pumping on EPCWID FHG deliveries averaged less than 1,500 AF/y during 1985-2017.

Figure 19-8 shows the annual Texas pumping from 1940 – 2017. The upper chart shows the sum of EPCWID and HCCRD irrigation pumping from 1940 – 2017 in the same format as **Figure 19-7**. Since the D1/D2 period there have not been any years that the irrigation pumping exceeded the D1/D2 maximum. The running 10-year average pumping (red line) exceeded the D1/D2 average during 1979 and 1980.

The lower chart in **Figure 19-8** shows the Texas M&I pumping from 1940 – 2017 in the same format as **Figure 19-7**. The Texas M&I pumping increased steadily throughout the D1/D2 period, leveled out during the 1980s, and then declined through the 1990s and 2000s. The annual M&I pumping then rose during the 2010s and has declined again during recent years. The annual Texas M&I pumping since 1978 has not exceeded the maximum during the D1/D2 period, however the running 10-year average pumping exceeded the D1/D2 average until the 2008 and since that time it has hovered near the D1/D2 average.

<u>Consumptive Use</u>

Figure 19-9 shows the annual New Mexico consumptive use comprised of surface water (grey bars) and pumping (irrigation and M&I) (light blue bars). The annual average total consumptive use during the D1/D2 period is plotted as a horizontal blue line and the 10-year running average total consumptive use is plotted as a red line. The running 10-year average consumptive use has remained slightly above the D1/D2 average since until the mid-1990s, and is currently about 21,000 AF above the D1/D2 average.

Figure 19-10 shows the annual Texas consumptive use of surface water (orange bars) and pumping (irrigation and M&I) (yellow bars). The annual average total consumptive use during the D1/D2 period is plotted as a horizontal blue line and the 10-year running average total consumptive use is plotted as a red line. The running 10-year average consumptive use remained slightly above the D1/D2 average until the early 2000s, after which it declined and is currently about 30,000 AF below the D1/D2 average.

Figure 19-11 shows the annual Texas plus Mexico consumptive use comprised of Texas surface water (orange bars), Texas pumping (irrigation and M&I) (yellow bars), Mexico surface water (dark green bars), and Mexico pumping (irrigation and M&I) (light green bars). The annual average total consumptive use during the D1/D2 period is plotted as a horizontal blue line and the 10-year running average total consumptive use is plotted as a red line. The running 10-year average consumptive use rose steadily above the D1/D2 average until the early 2000s. Since that time, the 10-year average consumptive has declined, but currently remains about 44,000 AF above the D1/D2 average.

Ferguson Opinion 7 *– Model simulation results presented in the expert report of Sullivan and Welsh indicate that the effects of groundwater pumping in El Paso Valley, including pumping in Texas and Mexico, on historical Project deliveries is negligible. (page 11).*

Response:

See response to Ferguson Opinion 2.

Ferguson Opinion 8 *– Reclamation ensures that diversion allocations do not exceed the amount of water that can be physically delivered to Project diversion points and accounted for under Project water accounting procedures. Allocations are constrained by the available Project supply, including return flows, as accounted for under Project water accounting procedures. Water orders by EBID, EPCWID, and US-IBWC on behalf of Mexico are subsequently constrained by each entity's allocation. Reclamation will not allocate water that cannot be delivered, and will not accept a delivery order that cannot be met. Therefore, the fact that all delivery orders were met cannot be interpreted as all demands being met. (page 12).*

Response:

Figure 19-12 was prepared to summarize EPCWID's historical use of Project water, irrigation pumping to meet unmet demand determined in the CFB Model, and unused allocation from 1940 – 2017. The annual EPCWID FHG demand is shown as a black line and was computed as the EPCWID FHG deliveries plus EPCWID irrigation pumping plus the historical deliveries of Project water to EPW. The historical FHG deliveries of Project water for irrigation are depicted as grey bars, the historical deliveries of Project water to EPW are shown as light blue bars, and the pumping to meeting unmet irrigation demand is shown as dark blue bars. The unused allocation for EPCWID was computed for the period 1979 – 2017 as the final allocation minus the reported delivery charges and is shown as orange bars.

The summary in **Figure 19-12** shows that there was substantial unused allocation in many years during 1979 – 2017. The unused allocation exceeded 30,000 AF in 26 years (67%), 50,000 AF in 20 years (51%), and 70,000 AF in 14 years (36%). The years with substantial unused allocation generally coincide with years of little or no supplemental irrigation pumping, thus confirming that the unused EPCWID allocation generally occurs in years when the EPCWID irrigation demands are met.

Ferguson Opinion 9 *– Increased operational waste from EPCWID in El Paso Valley from 1979-2002 was primarily the result of extremely wet hydrologic conditions throughout this period. As shown in the expert report of Sullivan and Welsh, operational waste from El Paso Valley was generally greater than 15% of total diversions from 1938-1950, generally less than 10% from 1951-1978, and generally greater than 15% from 1979-2002. Fluctuation in operational waste are consistent with fluctuations in hydrologic conditions: the period 1938-1950 was dominated by extremely wet hydrologic conditions; the period from 1951-1978 was dominated by dry and normal conditions; and the period from 1979-2002 was again dominated by extremely wet conditions. Operational waste increased during wet hydrologic conditions due to increases in storm runoff and greater than anticipated bypass and return flows from the Rincon and Mesilla Valleys. In addition, operational waste during the 1980s and 1990s included large amounts of water ordered by EBID but not diverted. Increased operational waste during this period did not result from negligence or improper operations by EPCWID or Reclamation. (page 19).*

Response:

While operational waste can fluctuate based on water supply conditions with more waste in wet years and less waste in dry years, Project records show that there was an increase in EPCWID waste after EPCWID took over operation from the BOR in 1979 that cannot be attributed solely to changes in water supply conditions. Additional analysis of the available water supply in the El Paso Valley was performed to further assess the reported increases in operational waste that occurred in EPCWID after the BOR relinquished operation of the EPCWID system.

The Rio Grande Project was conceived and initially operated to use all available water supplies to meet Project water deliveries. This included use of all available return flows between the Caballo Reservoir outlet and the last diversion from the river at Tornillo that supplied the Tornillo Canal.

The Rio Grande Rectification project in the late 1930s changed the surface water plumbing in the El Paso Valley so that most of the flows were conveyed through the EPCWID service area to EPCWID farmers using the canal system (including the part of the Rio Grande that was converted to an extension of the Riverside Canal), and from EPWCID to the HCCRD more in drains and less in the relocated Rio Grande channel.

As a result of the replumbing of the system in the Fabens area, return flows that previously were conveyed in the river and diverted to supply the lower portion of the EPCWID service area in the river instead were conveyed using canals and drains. Regardless of the conveyance mechanism, WWTP discharges and drain flows in the Fabens area have always been a portion of the supply available for use within the EPCWID service area.

Consistent with the Project planning described in the RGJI, it is reasonable to expect that WWTP discharges and drain flows that arise within the EPCWID system should be efficiently used by EPCWID farmers in order to reduce unnecessary releases from Project storage that could be saved and conserved for subsequent allocation and use.

Historical records of flows available for use in the El Paso Valley portion of EPCWID were tabulated and analyzed to determine how efficiently the available flows have been used and whether the records provide additional information as to the reasons for the increases in reported EPCWID operational waste that were described in the SWE Report.

A schematic diagram prepared by MMA that illustrates the EPCWID water distribution and drainage system is provided in **Figure 19-13**. Canals and laterals are shown as blue lines, wasteways as black lines, and drains as red lines. Long-term flow measurement locations are depicted as triangles.

The surface water supply available for use in the El Paso Valley portion of EPCWID has historically been comprised of (a) Rio Grande diversions at American Canal, (b) drain flows, and (c) discharges from EPW WWTPs.

Discharges from EPW WWTPs have long been a part of the supply used by EPCWID farmers. These include discharges to the Riverside Canal from the Socorro WWTP (1967-1992) and later from the Bustamante WWTP (1991 – present), discharges to the Rio Grande upstream of the Riverside Canal heading from the Haskell WWTP (until 1999), and discharges to the ACE from the Haskell WWTP (1999-2017). A chart illustrating the WWTP discharges to EPCWID canals from 1967 – 2017 is shown in **Figure 19-14**. Total irrigation season discharges to the EPCWID canal system have increased from about 5,000 AF/y in the mid-1960s to approximately 30,000 AF/y in recent years. These WWTP discharges comingle with other supplies in the EPCWID distribution system and comprise a portion of the available irrigation supply.

Drain flows collected in the Fabens area are another supply that is available and has historically been used for irrigation by EPCWID farmers. There are daily records of diversions from the River Drain to the Riverside Canal Extension from 1945 – 1983. This is labeled as "Drain to Canal" in **Figure 19-13**. A chart summarizing the historical drain diversion data is provided in **Figure 19-15**. The blue line depicts the monthly average diverted flow and the orange line presents the daily maximum diversion in each month. The chart shows that monthly average drain flow diversions often exceeded 50 cfs in the 1940s and early 1950s while maximum diversions often exceeded 100 cfs. The maximum reported monthly diversion volume was 5,700 AF in July 1946.

Historical records of Fabens area irrigation season drain flows from 1940 – 2017 are summarized in **Figure 19-16**. Until 1983 the drain flow records include measurements at five drains that collected in the Fabens Waste Drain. The blue bars depict the flows of the River Drain and Middle Drain that flow into the River Drain upstream of the point where the diversions to the Riverside Canal Extension occurred until 1983. These are referred to as the "Usable Drains." The other three bars represent flows in the Fabens Intercepting Drain, the Mesa Drain, and the Cuadrilla Drain that accrue to the Fabens Waste Drain downstream of where drain flows were diverted into the Riverside Canal Extension. These are referred to as the "Other Drains."

Beginning in 1984, the Fabens area drain records are limited to measurements of the Fabens Waste Drain upstream of where it discharges into the Fabens Waste Channel. These records are plotted as the green bars in **Figure 19-16**. The drain flows measured at this location represent the accumulation of the flows contributed by all five drains that were separately measured until 1983. Therefore, the irrigation season totals depicted by the green bars from 1984 – 2017 are comparable to the sum of the flows of the five drains that were separately measured prior to 1984. On average during 1945 – 1983 when there are records of diversions from the River Drain to the Riverside Canal Extension, the average flow of the Usable Drains comprised approximately 70% of the total Fabens Drain flows during the irrigation season.

Figure 19-17 shows the total supply available to EPCWID users in the El Paso Valley from 1940 – 2017. The blue bars represent the historical EPCWID diversions[1] less the reported and estimated conveyance losses from the CFB Model, the yellow bars represent the total EPW discharges to the canal system, and the grey bars represent the usable Fabens drain flows[2]. The black line represents the total Project water deliveries to EPCWID users including deliveries to irrigation users and deliveries to EPW. The reported total supply to HCCRD is shown for comparison as the negative light blue bars. EPCWID flows in excess of EPCWID deliveries are represented by the portion of the stacked bars that project above the black line. These excess flows generally correspond to the total flows to HCCRD. The data presented in **Figure 19-17** shows that the EPCWID system was generally operated efficiently during most years from 1951 – 1979 with modest amounts of excess flow going to HCCRD.

Figure 19-18 presents a more detailed analysis of the excess flows (portion of bars above the black line) in **Figure 19-17**. Superimposed on the excess flow bars are lines depicting the unadjusted reported EPCWID waste in the WDR's (black line) and EPCWID waste adjusted to fill in missing data and to make other mass balance adjustments (red line). The data plotted in **Figure 19-18** show that the reported EPCWID waste generally corresponds with the sum of the excess EPCWID diversions and EPW WWTP discharges, but does not include the unused Fabens drain flows.

Additional insight on the flow exiting the EPCWID service is gained by analysis of the historical water supply for HCCRD. **Figure 19-19** is a stacked bar chart illustrating the historical irrigation season flows to HCCRD that are comprised of water tailing out of the Tornillo Canal at Alamo Alto (dark blue bars), the Tornillo Drain (grey bars) and the Hudspeth Feeder Canal (yellow bars). Also shown in **Figure 19-19** is a red line computed as 10% of the EPCWID diversions, which represents a reasonable upper limit of the waste that should be exiting the EPCWID service area. Comparison of the sum of the Tornillo Canal at Alamo Alto and non-drain flows in the Hudspeth Feeder Canal shows this sum is similar to the red line until 1980.

Table 19-1 contains a summary of the irrigation season totals depicted in **Figure 19-19**. The total waste exceeding a reasonable upper limit of 10% of the EPCWID supply is summarized in column 12. During 1980 – 2002, the waste to HCCRD in excess of 10% of the EPCWID supply averaged approximately 16,700 AF. Had the deliveries to EPCWID

[1] Franklin Canal plus Riverside Canal minus Ascarate Wasteway plus EPW diversions.

[2] Sum of reported Middle Drain and River Drain flows from 1940 – 1983 and 70% of the reported Fabens Waste Drain flows from 1984 – 2017.

been managed more carefully to reduce the excess waste that flowed to HCCRD, additional water would have been conserved in Project storage that would have increased allocations to EBID and EPCWID in later years with less than full allocations.

The dramatic increase in supply to HCCRD that occurred after EPCWID took over operation is remarked upon in a report by Dr. Phillip King (2003) containing analyses of irrigation operations in the LRG Basin:

> *In his evaluation of the District Kirby (1978) presented a rather gloomy outlook for the District, understandable considering the 28 years of drought that preceded his investigation: "It would appear that the Hudspeth (sic) District may continue marginal agricultural operations at about current levels for perhaps another twenty years. At the end of that time, the district most probably will begin dissolution with only those few water users blessed with good soil drainage and reasonably good groundwater surviving as independent farmers."*
>
> *Ironically, the water supply began its wet cycle the very next year, and HCCRD has enjoyed three to nine feet of inflow per water righted acre ever since. If the current drought proves to be anything like the period of 1951-1978, Kirby (1978) may prove to be prophetic, but ahead of his time.*

***Ferguson Opinion 10** – Sullivan's and Welsh's use of correlation or regression analysis to fill missing data does not account for the effects of hydrologic conditions on Project operations. For example, operational waste from EPCWID in El Paso Valley was estimated based on correlations over the period 1951-2002. The early part of this period (1951-1978) is characterized by normal to extremely dry hydrologic conditions; the latter part of this period (1979-2002) is characterized by extremely wet hydrologic conditions. These conditions affect Project operations, including operational waste. Use of correlations based in part on extremely wet conditions (1979-2002) to estimate operational waste during recent years characterized by normal to extremely dry hydrologic conditions (2003-2018) results in a significant over estimation of recent operational waste. (page 21).*

Response:

Contrary to Dr. Ferguson's statement, the regression analyses that were used to fill missing data in the SWDataSet did account for variations in hydrologic conditions. The regression relationships were developed using the available historical data which typically included wet, average, and dry years. Note that there was significant missing data that needed to be estimated for the pre-1940 period for use in the Hueco ground water model. Considering the data needs and time period, these pre-1940 regressions were largely performed using data from the 1930s and 1940s that would have been more representative of the looser operational practices that existed before the BOR tightened up operations with the onset of the drought in the early 1950s.

Dr. Ferguson goes on to complain that estimates of operational waste from EPCWID in the El Paso Valley for 2003 – 2017 are too high because they were based on a regression analysis of historical data from 1951 – 2002 that included a wet period from 1979 – 2002. His comments imply that the 1979 – 2002 historical data should have been excluded from the regression analysis.

EPCWID operational waste estimates from 2003 – 2017 were computed using a correlation with the total flows to HCCRD using historical data from 1951 – 2002 (excluding spill years) that included dry, average, and wet years. The data from this period generally show that EPCWID operational waste and HCCRD total diversions are lower in dry years and higher in wet years.

In order to assess Dr. Ferguson's contention that the 1979 – 2002 data influenced the regression relationship, the historical irrigation season (March – October) EPCWID waste data from 1951 – 2002 that were used in the regression analysis were plotted against irrigation season Caballo Reservoir releases in the scatter diagram in **Figure 19-20**. The blue dots in represent data for 1951 – 1978 and the orange dots show data for 1979 – 2002. While comparison of the blue dots and the orange dots indicates that reservoir releases were generally lower during 1951 – 1978 than during 1979 – 2002, the data also show that EPCWID waste was significantly greater after 1978 for similar reservoir releases. Therefore, it would be inappropriate to exclude the 1979 – 2002 data from the regression relationship because only using the blue dots would result in a regression relationship that would ignore the apparent change in operational practices that resulted in increases in operational waste for similar hydrologic conditions. If anything, it may be more appropriate to use only the data after 1978 since it would reflect the change in operational practices that is apparent in the data.

Ferguson Opinion 11 *– As shown in Figures 5-10, 5-12, and 5-14, FHG deliveries of Project water were not "relatively steady from the 1950s-1970s." Rather, FHG deliveries during this period varied from less than 0.5 acre-feet per acre to more than 2.5 acre-feet per acre (Figures 5-12 and 5-14). In addition, it should be clarified that FHG deliveries declined in the early 2000s relative to the wet period during the 1980s and 1990s, not relative to the 1950s-1970s. Recent FHG deliveries since 2003 are comparable to FHG deliveries during the 1950s-1970s; FHG deliveries during both of these periods reflect severe drought conditions. (page 22).*

Response:

Dr. Ferguson implies that the SWE report mischaracterized the changes in EBID FHG deliveries. However, the partially quoted language from the SWE Report accurately stated that "average annual farm headgate deliveries remained relatively steady from the 1950s – 1970s." This is indicated by the running 10-year average line in Figure 5-10. Further, the decline in FHG deliveries during the recent drought is described as a decline "since then" with "then" referring to the "1980s and 1990s."

Ferguson Opinion 12 *– Figure 5-15 indicates that the total applied water in EBID during the period 2008-2016 is slightly greater than the total applied water during the period 1984-1993. Figure 5-19 indicates that the total applied water in EPCWID, including deliveries to EPW, declined slightly during the 1980s, increased during the 1990s, and has generally declined since 2003. (page 22).*

Response:

As shown in Figure 5-15 of the SWE Report, the 10-year average total applied water for EBID declined from approximately 300,000 AF in the early 1980s to about 270,000 AF in recent years

Ferguson Opinion 13 *– Operational waste in during the period 1979-2002 is greater than during the period 1951-1978 due to extremely wet hydrologic conditions during this period. Operational waste during this period includes large amounts of water diverted in excess of district water orders, including storm runoff, greater than anticipated bypass and return flows from the Rincon and Mesilla Valleys, and water ordered by EBID and not diverted. Operational waste during this period is consistent with operational waste during the 1940s, which were also characterized by extremely wet hydrologic conditions. (page 22).*

Response:

As described in the response to Ferguson Opinion 9 and as shown in **Figure 19-20**, the reported EPCWID waste is greater after 1978 than before that time for years of similar releases from Project storage.

Irrigation season operational waste during the 1940s (excluding the 1942 spill year) averaged 87,400 AF which is much greater than the average of 67,400 AF during 1979 – 2002 (excluding spill years 1986, 1987, and 1995).

Ferguson Opinion 14 *– In addition, as noted above, the correlation analysis used to estimate operational waste for the period 2003-2016 incorrectly over-estimates* *operational waste. Lack of accounting for hydrologic conditions in estimating recent operational waste contributes to the incorrect conclusion that operational waste from 2003-2016 is excessive compared to operational waste from 1951-1978. (page 23).*

Response:

See the response to Ferguson Opinion 9.

Ferguson Opinion 15 *– This conclusion incorrectly implies or assumes that metering of pumping results in reduction of pumping, or that lack of metering of pumping results in an increase in pumping. The fact that groundwater pumping in New Mexico is metered has no bearing on the fact that groundwater pumping in New Mexico depletes Project water supplies. In addition, this conclusion incorrectly implies that recent increases in groundwater pumping in New Mexico are the result of reduced allocations to EBID under the OA; to the contrary, increased groundwater pumping in New Mexico and corresponding impacts on Project water supplies began decades before the Operating Agreement was adopted. Lastly, this conclusion fails to acknowledge that increased groundwater pumping in New Mexico, and the corresponding impacts on Project surface-water supplies, was a major driver in negotiation of the OA and that the reduction in EBID's annual diversion allocation under the "D3 Method" was negotiated as a means to offset these impacts. (page 23).*

Response:

Dr. Ferguson's statement that metering has no effect on pumping is contrary to statements in a report by Texas expert, Dr. Phillip King (2003) that analyzed irrigation water use in the Rio Grande Project. In a section of that report describing Farm Delivery Metering, Dr. King states the following:

> *It has been noted by several researchers that the very act of metering reduces the amount of water people use, though it is difficult to prove because there is no pre-metering baseline to which metered water usage can be compared. Newly installed meters often show an initial drop in use with time as water users adjust their management practices in response to the new information provided by the meters. Fipps (1999) suggested that metering is a necessary part of a water conservation program. The fact that farmers have quantitative metrics to guide their management can, in itself, significantly reduce water use by as much as 20 percent. (p. 108).*

While Dr. King's report was referring to metering of farm deliveries of surface water, the same logic would apply to ground water pumping. It costs money to pump ground water. If farmers have knowledge of how much water their crops require and how much their surface water and ground water sources supply, they can employ management practices such as irrigation scheduling to optimize their water use, minimize their operational costs, and maximize their profits.

Dr. Ferguson's assertion that increased New Mexico pumping is not the result of reduced allocations to EBID under the 2008 OA is illogical. **Figure 19-21** is a scatter plot of annual EBID supplemental pumping from the SWE CFB Model versus the annual EBID Project water allocation for 1979 – 2017. The blue dots represent data for the years that EBID's allocation was determined using the D1/D2 procedure (1979 – 2005) and the orange dots are data for the years that the D3 procedure under the 2008 OA was in effect (2006 – 2017). The chart shows clearly that as the EBID allocation declines, EBID supplemental pumping increases. Since 1979, the lowest annual EBID allocations have occurred under the 2008 OA resulting in the greatest annual supplemental pumping in 2011.

Simulations of the ILRG Model demonstrate that EBID supplemental pumping is greater under the 2008 OA than under D1/D2 accounting. Annual EBID pumping under Run 11 with D1/D2 allocation simulated in all years starting in 1950 averages 129,600 AF during 1951 – 2017. This compares to an average of 154,200 AF during the same period under the D3 + Carryover accounting of the 2008 OA. The results for these ILRG Model runs are presented and discussed in Section 30.0.

Ferguson Opinion 16 *– This conclusion incorrectly implies that the impact of groundwater pumping on the Project is proportionate to the volume of pumping, without consideration as to the location where pumping occurs. Modeling results provided with the expert report of Sullivan and Welsh demonstrate that groundwater pumping in New Mexico results in significant depletion of Project deliveries to EBID and EPCWID. These modeling results also demonstrate that groundwater pumping in the Texas portion of the Mesilla Valley results in much smaller depletions of Project deliveries to EBID and EPCWID (less than 25% of the depletion caused by pumping in New Mexico). In addition, these modeling results demonstrate that groundwater pumping in the Conejos-Médanos Basin (i.e., the Mexican portion of the Mesilla Valley aquifer) and in the Hueco Bolson have negligible impact on Project deliveries to EBID and EPCWID. (page 24).*

Response:

The Rio Grande Project is operated as an integrated system. Releases from storage are made to deliver orders for Project water, and the release amounts are varied in consideration of the gains and losses in the river system and the canal system. For any particular aggregate Project water demand, when net downstream gains increase, storage releases are reduced to meet that demand. Conversely, when downstream gains decrease, storage releases must be increased to meet the same demand.

Historical monthly records of reservoir releases, diversions, and Rio Grande flows were analyzed to assess the relationship between reservoir releases and downstream gains. These records included the following:

- Caballo Reservoir releases
- Arrey Dam diversions (Rincon)
- Leasburg Dam diversions
- Mesilla Dam diversions
- American Dam diversions
- Rio Grande Below American Dam flows
- Acequia Madre diversions

Except during periods of high flow and spills, the flow past American Dam is generally limited to the flow necessary to deliver the Mexico order at the Acequia Madre including river conveyance losses. This is illustrated in the scatter plot in **Figure 19-22** that shows the monthly Rio Grande below American Dam flow vs. the monthly Acequia Madre diversions from 1940 – 2017.

The total gain/loss between the Caballo outlet and American Dam was computed as the sum of the Rio Grande below American Dam plus diversions at American Dam plus all upstream river diversions minus the Caballo releases. **Figure 19-23** shows the historical monthly releases from Project storage, the gains and losses, and the total diversions between the Caballo Dam and American Dam. The graphs on the left side of **Figure 19-23** show the monthly Caballo Dam to American Dam diversions (black line), the monthly release (blue bars) and the monthly gain (+) or loss (-) (orange bars).

On the right side of **Figure 19-23** is a plot of the normalized monthly gain (+) or loss (-) against the normalized monthly Caballo release (both values normalized by the sum of the monthly Caballo to American Dam diversions). The results, which all plot along a straight line, show empirically that as monthly gain increases the reservoir release needed to meet the diversion decreases, and as the monthly gain decreases the reservoir release increases.

There is no disagreement that pumping in the Rincon and Mesilla Valleys affects the gains and losses between the Caballo Outlet and American Dam. Therefore, by logical extension to the gain/loss – reservoir release relationship shown in **Figure 19-23**, pumping affects reservoir releases. When more water needs to be released from storage to meet demands, this leaves less water in storage for subsequent use, and thus creates or exacerbates shortages in non-full supply years. Return flows from irrigation pumping and M&I pumping within the Rincon and Mesilla Valleys offset a portion of the impacts of pumping.

As with the impacts of pumping in the Rincon and Mesilla Valleys, there is a similar relationship among pumping, gains/losses, and reservoir releases within EPCWID. The BOR should be operating the Project to release only enough water from storage to meet the EPWICD demands with a minimum of waste, and net of the gain/loss within the EPCWID system. Since Hueco pumping increases the losses between American Dam and Riverside Dam (before 1999), increases conveyances losses through the EPCWID distribution system, and reduces the drain flows available for irrigation use, this requires increased releases from Project storage to meet EPCWID demands. This is how Hueco pumping affects upstream Project operations.

Under current Project operation and accounting, discharges from EPW WWTPs to EPCWID canals provide an offset to the negative effects on Project operations caused by Hueco pumping. Just as Hueco pumping increases the reservoir releases needed to meet EPCWID demands, WWTP discharges to the EPCWID canal system that are used by EPCWID farmers reduce the reservoir releases needed to meet demands.

What is dissimilar between the WWTP offsets in the Rincon and Mesilla Valley versus the WWTP offsets in the El Paso Valley is that EPCWID either receives a credit or is not charged for its use of EPW WWTP discharges while EBID is charged for all water that it uses and receives no credit for New Mexico WWTP discharges.

20.0 RESPONSE TO GEORGE REBUTTAL REPORT

Jonathan D. George, P.E. prepared a December 30, 2019 rebuttal expert report on behalf of Texas ("George Rebuttal Report") that describes his rebuttal to opinions of the New Mexico experts related to crop consumptive use in the LRG Basin.

SWE was asked by legal counsel for New Mexico to review certain opinions in the George Rebuttal Report and to prepare expert opinions to respond those opinions of Mr. George.

George Opinion 1 *– [Based] on the October 2019 NM SWE Report, the SWE Farm Budget average actual evapotranspiration in the Rincon and Mesilla valleys increased from a pre-well development average of 188,830 acre-feet per year during the 1938 through 1950 period to a post-well development average of 236,916 acre-feet per year during the 1985-2016 period, an increase in average actual evapotranspiration of 48,085 acre-feet per year or 25.5%, and the M&A Farm Budget average actual evapotranspiration in the Rincon and Mesilla valleys increased from a pre-well development average of 201,183 acre-feet per year during the 1938 through 1950 period to a post-well development average of 257,364 acre-feet per year during the 1985-2016 period, an increase in average actual evapotranspiration of 56,181 acre-feet per year or 27.9%. The percentage increase in average actual evapotranspiration between the SWE Farm Budget and M&A Farm Budget (25.5% vs. 27.9%, respectively), as reported in the October 2019 NM SWE Report, are very similar and the increase can largely be attributed to use of wells. (p. 10).*

Response:

While it is true that a portion of the increase in consumptive use in the SWE Farm Budget analysis of the Rincon and Mesilla Valleys is due to the development of ground water pumping for irrigation, differences in weather conditions and changes in crops also are reasons that the consumptive use during 1985-2016 is greater than the consumptive use during 1938-1950.

The effect of weather and crop selection on consumptive use are integrated in the crop-weighted average CIR input to the SWE CFB Model. Therefore, differences in crop-weighted CIR between one period and another reflect differences in weather effects on Reference ET, difference in effective precipitation, and differences in crop selection between the two periods. Based on inputs to the SWE CFB Model, the crop-weighted average CIR in the Rincon and Mesilla Valleys was 2.74 and 2.78 inches per year ("in/yr") during 1985-2016, which is 116% and 117% greater than the average of 2.35 and 2.36 in/yr during 1938-1950.

In order to test the effect of differences in weather and crop selection on differences in the consumptive use in the Rincon and Mesilla Valleys between 1938-1950 and 1985-2016, a test run of the SWE CFB Model was made in which the crop-weighted average inputs to the model during 1985-2016 were scaled by the ratio of the 1938-1950 average CIR to the 1985-2016 average CIR (i.e., ratio for Rincon = 0.86). The results of this analysis showed that the annual consumptive use in the Rincon and Mesilla Valleys during 1985-2016 computed using the adjusted CIR values averaged 203,763 AF. This is an average of 33,153 AF/y less than the average of 236,916 AF/y computed with the original unadjusted CIR values. These results show that 69% of the 48,095 AF/y difference in average consumptive use in the SWE CFB Model for the Rincon and Mesilla Valleys between 1985-2016 and 1938-1950 can be explained by differences in weather and crop selection between the two periods.

The upper graph in **Figure 20-1** shows annual crop-weighted average CIR from 1938-2017, and averages for 1938-1950 and 1985-2016. The lower graph in **Figure 20-1** shows the annual consumptive use of applied water for the same period with annual average for 1938-1950 and 1985-2016. The 1985-2016 adjusted CIR and consumptive use volumes are also shown in the two graphs. This analysis shows that Mr. George is incorrect in his assertion that differences in average annual consumptive use in the Rincon and Mesilla Valleys between 1938-1950 and 1985-2016 "can largely be attributed to wells."

21.0 RESPONSE TO HORNBERGER REBUTTAL REPORT

George M. Hornberger, Ph.D. prepared a December 30, 2019 rebuttal expert report on behalf of Texas ("Hornberger Rebuttal Report") that describes his rebuttal to opinions of the New Mexico modeling experts regarding the Texas Model.

SWE was asked by legal counsel for New Mexico to review the Hornberger Rebuttal Report and to prepare expert opinions to respond the opinions of Dr. Hornberger. A lack of response regarding a particular issue should not be interpreted as tacit agreement with the Hornberger opinions on that issue.

Hornberger Opinion 1 *- The critiques of the groundwater modeling approach (hereinafter Texas model") taken by Hutchison (2019) from experts for New Mexico lack specificity. The Texas groundwater model focuses on modeling the impact of pumping groundwater in the Rincon and Mesilla Valleys on flow in the Rio Grande at El Paso using annual stress periods. In contrast, the models produced by New Mexico include a river flow routing model using RiverWare, include groundwater models of the Hueco Bolson in addition to the Rincon-Mesilla Valleys, use monthly stress periods, and use hypothetical reservoir releases in place of historical observations. The argument that these "improvements" to the model are necessary without presentation of any justification of what purpose is served by adding complexity, is completely opaque. Without justification in terms of the specific objectives stated for the model, such criticism is meaningless.*

Response:

The assertion by Dr. Hornberger that so-called "improvements" were made to the ILRG Model by the New Mexico experts without presentation of any justification for the purpose of the improvements is blatantly false, and confirms Dr. Hornberger's statement in the Introduction section of his report that "he only scanned the reports produced by the experts for New Mexico." During his deposition, Dr. Hornberger admitted to only spending two hours reviewing the New Mexico expert reports.

The New Mexico experts provided ample description and support for the monthly stress periods, spatial scale, and rule-based processes for simulating Project operations that are essential bedrock elements of the ILRG Model. This is discussed at length in the SWE Report, and in the responses to the Coors Supplemental Report in Section 23.0.

By comparison, the coarse annual stress periods, limited geographic scope, and absence of dynamic processes for simulating Project operations render the Texas Model woefully inadequate for analyzing the claims and counterclaims in this case.

Hornberger Opinion 2 *- The objectives set forth for the Texas model by Hutchison (2019) are stated clearly and are straightforward. The goal is to show how groundwater pumping in the Rincon and Mesilla Valleys affects the amount of water that flows to Texas at the gage at El Paso. This is the key issue that needs to be addressed both to demonstrate the impact of pumping in New Mexico on water deliveries to Texas and to provide a simple and straightforward method to explore counterfactuals related to what deliveries would have been if pumping had been curtailed over the period of record.*

Response:

The Texas Model fails to meet the stated Texas objective "to show how groundwater pumping in the Rincon and Mesilla Valleys affects the amount of water that flows to Texas at El Paso" for several reasons.

- The Texas Model lacks simulation of the dynamic responses of Project operations to changes in surface water flows that would occur under no pumping or reduced pumping scenarios.
- The limited geographic scope of the Texas Model from the Caballo Reservoir outlet to the Rio Grande at El Paso gage precludes simulation and analysis of the response of upstream reservoir operations to changes in pumping, and the effects of irrigation and non-irrigation pumping in the Hueco Bolson on deliveries to EBID, EPCWID, and HCCRD.
- The annual stress periods of the Texas Model are too coarse to distinguish the effects of pumping on surface water supplies and Project deliveries that occur within the irrigation season versus the effects on surface flows during the non-irrigation season.

In addition, the stated Texas objective is an incomplete statement of the questions that need to be answered to fully analyze the claims and counterclaims in this case. Other questions that need to be answered include how pumping throughout the Project affects Project deliveries to New Mexico and Texas water users, and how changes in Project operations (e.g., enactment of the 2008 OA) have affected deliveries.

Hornberger Opinion 3 *- The vast majority of Project deliveries to Texas are diverted at the American Dam, a short distance downstream from the El Paso gage. Because the clearly stated objective of the Texas model is to determine the impact of groundwater pumping on deliveries to Texas, the only possible reason to include the use of water between El Paso and Ft. Quitman in the model would be if pumping from the Hueco Bolson significantly influenced flow in the Rio Grande above El Paso. The only groundwater links between the*

Mesilla and the Hueco are at Fillmore Pass and at the Narrows. The connecting strata are thin, however, so the underflows from the Mesilla to the Hueco are quite limited (Slichter 1905). Hutchison's estimates of about 400 to 1200 AF/year (Hutchison 2019) are somewhat higher than other estimates (e.g., Heywood and Yager 2003) but nevertheless a small fraction of annual groundwater pumping by New Mexico above El Paso. Pumping from the Hueco aquifer can have very little effect on the Rio Grande flows at the El Paso gage and thus on deliveries to Texas; therefore, adding complexity to the Texas model on this account is unnecessary to address the objectives stated. The criticism leveled at the Texas model has no merit.

Response:

Due to an apparent lack of understanding of Project operations, Dr. Hornberger mistakenly assumes that the only way for impacts of Hueco pumping to propagate upstream is through changes in ground water flow either at Fillmore Pass or at the El Paso Narrows. Rather than through ground water flow changes, Hueco pumping impacts propagate upstream through changes in Project operations caused by such pumping.

The mechanism for Hueco pumping impacts to propagate upstream is rooted in the long-standing practice of operating the Rio Grande Project as a single unit, and that changes in flows anywhere within the system have the potential to affect deliveries to all Project water users, including users located upstream of where the pumping occurs. Upstream impacts from Hueco pumping occur when the pumping depletes delivery of Project water to EPCWID water users, thus necessitating increased releases of Project water to meet EPCWID demands. Depletions of Project water deliveries by Hueco pumping occur through mechanisms that vary based on the location:

- Prior to construction of the ACE, depletions of the Rio Grande upstream of Riverside Dam caused by Hueco pumping required increased releases from Project storage to meet demands for Riverside Canal users.

- Depletions to the Rio Grande downstream of American Dam caused by Hueco pumping increase the reservoir releases needed to deliver 1906 Treaty water to Mexico at the Acequia Madre.

- Hueco pumping also increases seepage from EPCWID canals and laterals (MMA, 2019). The increased seepage losses in the EPCWID service area require additional Project storage releases to deliver orders for Project water to EPCWID farmers.

Any of the above effects of Hueco pumping that require increases in Project storage releases reduce the unused supply of water left in Project storage at the end of the year.

Under the accounting that existed prior to the 2008 OA, these reductions in unused supply would have reduced the supply available for allocation to the Districts in the following year.

Under the 2008 OA, the above effects of Hueco pumping reduce the computed Diversion Ratio, and this negatively impacts deliveries of Project water to EBID in the current year in accordance with the D3 allocation procedure. In addition, the increased reservoir releases to deliver EPCWID orders for Project water increase the amount of "paper water" in EPCWID's carryover storage account that must be filled by inflows in the next year, thus reducing the supply available for allocation to EBID in the next year.

In addition to the effects on Project water deliveries described above, Hueco pumping also affects the supply of water to HCCRD through the following mechanisms:

- Hueco pumping depletes the Tornillo Canal at Alamo Alto and the flows of the Tornillo Drain and Fabens Waste Channel that comprise the HCCRD supply.

- Hueco pumping increases seepage losses in the HCCRD canals and laterals, reducing the supply available for delivery to the headgates of HCCRD farmers.

The ILRG Model is the only model in this case that is capable of analyzing and quantifying the effects of Hueco pumping on EBID, EPCWID, and HCCRD.

Hornberger Opinion 4 *- Hutchison (2019) stated no objective about exploring how management decisions in the future might affect Project deliveries. Rather, he focused on the physical response because that is the central question related to the Compact. Any institutional or management changes would involve several stakeholders to determine how much of a given flow increase would be retained in storage and how much would flow to the Narrows. Information about such management is unknowable before any negotiations are completed so any such simulation would be highly speculative and counterproductive given the objectives stated by Hutchison.*

Response:

It is naïve to state that impacts in this case would somehow be limited to impacts that manifest solely through physical processes. Given the dominant effect that Project operations have on the water supply of the LRG area, both directly and indirectly, virtually all impacts from pumping or other actions that affect the available water supply are likely to be filtered through the Project water allocation and delivery mechanisms. The key elements of the allocation and delivery processes are well established and well understood. For example, the water available for allocation in the current year is generally based on the water available in storage, and releases from storage are based on the aggregation of downstream demands adjusted for gains and losses between the reservoir outlet and the points of delivery.

The effects of pumping are implicit in the gains and losses to surface flows throughout the LRG area. During periods of high pumping, net surface water gains (gains minus losses) decrease and more water must be released to meet certain demands. Conversely, during periods of low pumping, net surface water gains increase and less water needs to be released to meet the same demands. The specific effects of pumping generally cannot be discerned by observation or measurement from other processes that affect the gains and losses. Nor do such pumping impacts need to be specifically discerned in order to determine reservoir releases that are needed to meet demands. Reservoir releases are made in consideration of the downstream gains and losses regardless of what causes those gains and losses.

It is not necessary to speculate how the Project would operate with reduced pumping because the records of operations during the 1940s, 1980s, and 1990s already provide ample empirical evidence.

Hornberger Opinion 5 *- The intent of the Hutchison report was to determine to what extent groundwater pumping by New Mexico depletes deliveries to Texas from the Rio Grande Project. This is the key question and the answer does not depend on a distinction between the irrigation and non- irrigation seasons. Changes in pumping over time influence short-term conditions near the well being pumped but impacts on river flow are manifested in the long term. The point is that at some distance from the river the effects of an intermittent or cyclic pumping pattern "become indistinguishable from a constant pumping pattern at a cycle (or long-term) average pumping rate" (Barlow and Leake 2012). The long-term impact of pumping and associated consumptive use of the water through irrigation on the regional water budget is captured by use of an annual stress period in calculations. The important question is not about potential monthly fluctuations but about long-term average impacts.*

Response:

As discussed in the response to the Coors Supplemental Report, responses of surface water flows (canals, drains, and Rio Grande) to irrigation pumping typically occur within months but can persist for longer durations during extended drought periods. See the response to Coors Opinion 6 for a detailed discussion of this subject.

The annual stress periods of the Texas Model are too coarse to evaluate the monthly and seasonal effects of pumping on LRG surface water supplies. Quantification of the portion of the surface water depletions caused by pumping is of significant importance because of the seasonal nature of Project operations and deliveries. Depletions to surface water flows during the non-irrigation season from pumping are less significant in this case than depletions during the irrigation season. Uses of surface water during the non-irrigation season are minimal, and none of the impacts claimed by Texas are due to depletions of non-irrigation season surface water flows caused by New Mexico pumping.

22.0 RESPONSE TO COORS REBUTTAL REPORT

Mr. Coors prepared a December 30, 2019 rebuttal expert report on behalf of Texas ("Coors Rebuttal Report") that describes his rebuttal opinions and criticisms of New Mexico's ILRG Model.

SWE was asked by legal counsel for New Mexico to review the Coors Rebuttal Report and to prepare expert opinions to respond to the opinions of Mr. Coors. A lack of response regarding a particular issue should not be interpreted as tacit agreement with the Coors opinions on that issue.

Although the deadline for Mr. Coors to submit his report was in December 2019, he much later substantially expanded on his initial rebuttal opinions and added new rebuttal opinions in a supplemental report that was submitted on May 5, 2020. In some instances, my responses to Mr. Coors' initial and supplemental opinions are consolidated in the responses to his supplemental report in Section 23.0. The opinion numbering system in the following discussion is independent of the opinion numbering in the Coors Rebuttal Report.

Coors Opinion 1 *- The Lower Rio Grande (LRG) system itself is complex and the data used to develop the models comprising the ILRG is limited, so determining if the model produces meaningful results is something that warrants further analysis. A sensitivity analysis of the ILRG system is in order to determine the reliability of the model results and the level of uncertainty present in them. There is no indication in the NM experts' reports that a sensitivity analysis of the ILRG was performed. (page 4).*

Response:

Sensitivity analyses of the ILRG Model were performed to test the sensitivity of the model results (differences between runs) to changes in selected input parameters and input data. The results of the sensitivity analyses are reported in Section 31.0.

Coors Opinion 2 *- The impacts on flows in the river at El Paso are determined by longer time scale effects that may not warrant the shorter timestep and highly uncertain modeling that has been performed by the NM experts on a monthly timestep. (page 5).*

Response:

See the responses to Mr. Coors' supplemental report.

Coors Opinion 3 *- The uncertainty present in the ILRG model due to insufficient data, unknowable historical practices in irrigation and Project operations may make the model results unreliable or require that the modeled domain be further aggregated either spatially or temporally in order to reduce the uncertainty present in the results to an acceptable level for quantifying impacts. (page 5).*

Response:

See the responses to Mr. Coors' supplemental report.

Coors Opinion 4 *- I also generated a timeseries of annual differences between the Run 1 and Run 0 variables. If the model was a perfect replica of the LRG system, each of the 78 annual difference values (1940-2017) for each variable would be zero acre-feet. The average deviation of each of these timeseries provides a simple measure of the level of uncertainty in values produced by the model for each variable. It is important to note that five of the six calculated impacts of pumping in New Mexico and Texas are smaller than this uncertainty metric in the model as indicated by the Run 1 to Run 0 comparison across the three modeled variables. This is further indication that a sensitivity analysis of the model is needed to determine if the level of uncertainty in the ILRG model results is problematic for answering the questions it is being used to answer.*

> *12.1 For Project water storage the average deviation of the Run 1 – Run 0 values is 152,156 acre-ft. The differences in the no New Mexico and no Texas pumping run combinations are 104,802 acre-ft and 9,386 acre-ft respectively.*
>
> *12.2 For the annual volume of flow at El Paso the average deviation of the Run 1 – Run 0 values is 121,572 acre-ft. The differences in the no New Mexico and no Texas pumping runs are 121,939 acre-ft and 30,850 acre-ft respectively.*
>
> *12.3 For the annual diversion at the American Canal, the average deviation of the Run 1 – Run 0 values is 110,040 acre-ft. The differences in the no New Mexico and no Texas pumping runs are 56,375 acre-ft and 20,419 acre-ft respectively. (page 6).*

Response:

Like all simulation models, the ILRG Model does not perfectly replicate historical observed flows in the Historical Base Run (Run 1). However, as is described in Section 28.0, the ILRG Model is well calibrated to give reliable results, and is the best model available for analyzing the claims and counterclaims in this case.

The analyses of the ILRG Model presented by Mr. Coors are not useful measures of the uncertainty of the ILRG Model in analysis of the impacts of pumping or other actions in this case. This is because such impacts are analyzed by differences between model runs. For example, the effects of New Mexico pumping can be assessed by comparing the result of Run 3 (No New Mexico Pumping) and Run 1 (Historical Base Run). When computing the differences between model runs, the model imperfections that are present in both runs cancel out. Therefore, differences between model runs can be more accurate than simulated values in a single model run. See additional discussion of canceling of errors in the responses to Coors' supplemental report and in Section 28.0.

Coors Opinion 5 *- It is my opinion that characterizing the results [based on differences between runs] is not necessarily accurate and that a more thorough model validation process would need to be conducted in order to make this claim. If the Run 1 model is not a sufficiently accurate representation of the basin and all of the water dynamics, then the differences between any of the Scenario Runs and Run 1 do not give a reliable approximation of what would have happened historically if pumping in any particular region of the basin did not occur. (page 7).*

Response:

See the response to Coors Opinion 4.

23.0 RESPONSE TO COORS SUPPLEMENTAL REPORT

Mr. Coors prepared a May 5, 2020 supplemental rebuttal expert report on behalf of Texas ("Coors Supplemental Report") that greatly expanded on and added to the rebuttal opinions provided in the Coors Rebuttal Report. The topic of both Coors reports is criticism of New Mexico's ILRG Model.

SWE was asked by legal counsel for New Mexico to review the Coors Supplemental Report and to prepare expert opinions to respond to the opinions of Mr. Coors. A lack of response regarding a particular issue should not be interpreted as tacit agreement with the Coors opinions on that issue.

The opinion numbering in this section picks up where the opinion numbering in the responses to the Coors Rebuttal Report left off.

Coors Opinion 6 *- So, the Compact was intended to fix the existing apportionment of the LRG water supply among the two states and Mexico at the time of the Compact, which included a recognition of the influence of groundwater on surface water. With this as one of the fundamental objectives of the Compact, in order to substantiate its Complaint, Texas developed the Texas Model to simply demonstrate that New Mexico's ongoing use of groundwater throughout the years since the signing of the Compact represents an inappropriate overuse of the original apportionment of the limited water supply to the Project. The Texas model was designed specifically to substantiate this claim and as was concluded by Dr. Hornberger in his report:*

> *"These questions supplied a clear purpose for developing a parsimonious model…I conclude that Hutchison (2019) indeed followed appropriate modeling guidelines and produced a model that meets the stated objectives, clearly showing the impacts of groundwater pumping by New Mexico on Rio Grande water deliveries to Texas." (Hornberger Rebuttal at p. 10.)*

New Mexico experts, Spronk Water Engineers (Spronk) and Hydros Consulting (Hydros) state repeatedly in their expert reports that the LRG system is highly complex and includes many dynamics that occur on a monthly scale, namely Project operations. While this is true it does not ipso facto justify a model that attempts to model all known dynamics in the system. A justification tied specifically to the Texas Complaint that drives the decision to include a very ambitious level of detail in on-farm processes throughout the project, a monthly timestep, and an attempt to capture in rules historical Project operations is not clearly given. (page 4).

Response:

The Supreme Court has essentially stated that the Rio Grande Project has been the mechanism for effecting the allocation of water under the Rio Grande Compact between New Mexico and Texas downstream of Elephant Butte Reservoir, and implicit in this recognition was the necessity to ensure successful operation of the Rio Grande Project (Lopez, 2019). Consistent with this, the BOR, New Mexico, and Texas encouraged the development of ground water pumping to supplement Project water deliveries in dry years when it became evident that the Project supply was inadequate to provide a full irrigation water supply (Barroll, 2019). Conjunctive use of surface water and ground water ensured the continued successful operation of the Rio Grande Project in all hydrologic conditions, including during extended drought periods, which had not been experienced in the LRG Basin between 1915, when Elephant Butte Reservoir began delivering Project water, and 1939, when the Compact was enacted.

Notwithstanding the encouragement and embrace of ground water pumping by the BOR, New Mexico, and Texas, Mr. Coors and Dr. Hornberger continue to support the overly simplistic Texas objective of the of the Texas Model to answer the question, "Did New Mexico's pumping deplete streamflows at El Paso on an annual basis?" The scope of this case is not limited to this very simplistic question. Rather, to determine impacts to Project deliveries it is necessary to develop a simulation model that includes simulation of Project operations to answer the correct questions.

New Mexico and its experts understood from the outset that the issues in this case were more complex than portrayed by Mr. Coors and Dr. Hornberger. This case involves <u>quantifying</u> the amount and timing of impacts from pumping and changes in Project operations on deliveries to water users in New Mexico and Texas. Quantification of these impacts needs to consider how pumping and other actions affect the Project operations that dominate how the highly variable Rio Grande inflows to Project storage are managed and delivered to New Mexico and Texas water users.

As was described at length in the opening expert reports of the New Mexico experts and further expounded upon in their rebuttal reports, the Texas Model, with its limited geographic scope, coarse annual stress periods, and lack of dynamic simulation of Project operations, is woefully inadequate and inappropriate for answering the complex technical questions posed in this case, including the quantification of impacts from pumping and other actions.

The level of detail included in the ILRG Model developed by the New Mexico experts was developed over many years of model testing, evaluation, and refinement. The simulations of Project operations and on-farm processes were developed and refined to capture essential elements of these processes. Additional simulation capabilities were added when detailed review of model output revealed that simulation of historical conditions could be improved. Potential model improvements were identified, discussed, and tested in the model. Proposed model changes were implemented if (a) they reasonably reflected physical processes or rational operating procedures and (b) resulted in significant improvement in model performance. Proposed changes were not implemented and if they did not meet these criteria. The following are examples of improvements that were made to the ILRG Model through the years:

- Extension of the model south to Fort Quitman and incorporation of full simulations of irrigation operations in the El Paso Valley and Juarez Valley as well as M&I pumping and returns.
- Development of the Hueco Ground Water Model as a component of the ILRG.
- Subdivision of the spatial scale of the simulated water user and ground water components in the RiverWare Model into smaller subareas,
- Linking of the ground water models to the RiverWare Model to provide a dynamic exchange of data between the models, including the RiverWare inputs for canal seepage, riparian ET, and flux between the shallow and deep aquifers,
- Simulation of WWTP discharges and urban deep percolation from M&I pumping,
- Implementation of a soil moisture simulation algorithm in the farm budget kernel of the RiverWare model,
- Refinement of rules for allocating Project water under D1/D2 accounting and D3+Carryover accounting, and
- Refinement of operational rules for simulating farm headgate and river headgate demands considering crop water demands, conveyance losses, and other irrigation supplies (i.e., WWTP flows and drain flows).

Development of the ILRG Model employed the principle of parsimony in the sense that additional detail was added to the simulation processes only as necessary to capture essential elements of the system operation. The robust and sophisticated functionality of the ILRG Model is supported by the rich and extensive record of historical Project operations.

Coors Opinion 7 *- The ILRG model became a monumental undertaking that is not appropriate for, or successful in, refuting the Texas Complaint or supporting New Mexico's criticisms of the Texas Model for reasons surveyed in the remainder of this report. What is most interesting is that once the ILRG model was completed and a set of runs were made* *by New Mexico experts, the results support Texas's claims, confirm the Texas experts' findings both from modeling and historical analysis, and refute New Mexico's Counterclaim 1. (page 5).*

Response:

What Mr. Coors' portrays as a monumental undertaking was instead incremental and rational development of a model appropriate for simulating the complex Project operations, irrigation system operations, and ground water and surface interactions in the LRG Basin. The effort and care in developing the ILRG Model reflect the necessary attention that New Mexico and its experts are giving to this case.

The objectives for developing the ILRG Model were not limited to refuting the Texas complaint. Rather, the ILRG Model was also developed to gain insight into and understanding of the effects of various actions on Project operations and deliveries to the U.S. Districts and Mexico, and to analyze New Mexico's counterclaims. This includes identifying and quantifying how past or proposed changes in Project operations and water use practices have affected surface flows, reservoir storage, ground water storage, Project water allocations and deliveries, and consumptive use since the Compact became effective in 1939.

The Texas Model is wholly inadequate to meet the foregoing objectives because it does not extend downstream beyond the El Paso gage, it employs annual stress periods that cannot distinguish between Project operations during the irrigation season and non-Project operations during the non-irrigation season, and it does not simulate the Project operation and accounting that determine deliveries of surface water for irrigation and non-irrigation uses in the Project area.

Coors Opinion 8 *- The nature of Texas's Complaint against New Mexico is that groundwater pumping in New Mexico has resulted in New Mexico consistently using more than its share of water annually as defined by the Compact to the injury of the Texas water users. The effects of groundwater pumping are slow and are not realized within a single year. As Dr. Hornberger stated in his rebuttal report:*

"The long-term impact of pumping and associated consumptive use of the water through irrigation on the regional water budget is captured by use of an annual stress period in calculations. The important question is not about potential monthly fluctuations but about long-term average impacts." (Hornberger Rebuttal, Criticism 3 at p. 9.)

New Mexico experts describe the complexity of the effects of GW pumping within a given year. (See Spronk Report at pp. 71-72) The sequence of effects given in this section *qualitatively describe how the system would be affected by a reduction in pumping in the Project. While effects in this sequence might be accurate, this is put forth as one of the justifications for the ILRG model and its complex representation of the system. This sequence of effects generally takes place within a single year and does not describe the sequence of events (mechanism) that gives rise to the Texas Complaint. (page 5).*

Response:

The Compact has no explicit definition of how water delivered into Elephant Butte Reservoir is divided among downstream water users in New Mexico and Texas. Instead, the inflows are allocated and delivered to downstream water users in accordance with the operating practices of the Rio Grande Project, which have long incorporated the conjunctive use of ground water and surface water to ensure successful operation during drought periods.

Mr. Coors and Dr. Hornberger are wrong in their assertions that the effects of ground water pumping are slow and not realized within a single year. Irrigation wells in the LRG area are generally less than 250 feet deep and less than one-half mile from the drains that control the alluvial ground water levels. This results in a relatively rapid response (within months) of surface flows to pumping during non-drought periods when the ground water table is hydraulically connected to surface water flows (canals, drains, and the Rio Grande). During drought periods, the combination of a lack of recharge from surface water use and increased ground water pumping can cause the ground water table to become disconnected from the surface water flows in some areas. When this happens, the drains can cease flowing, and seepage from rivers and canals will stabilize and not be affected by short-term variation in pumping. Therefore, the effects of pumping during drought periods can persist for longer periods than during non-drought periods.

The rapid response of the LRG area drains is illustrated in **Figure 23-1** for the Rincon Valley and **Figure 23-2** for the Mesilla Valley for 1938 - 2005[3]. Each graph compares the monthly net recharge (orange line; defined as canal seepage plus deep percolation minus irrigation pumping) to the aggregate recorded monthly drain flows (blue line). Close inspection of the Rincon Valley and Mesilla Valley graphs shows that the drain flows respond rapidly and typically lag the net recharge by only one to three months.

During drought periods such as the mid-1950s, net recharge declined, becoming negative at times (pumping exceeded the sum of canal seepage and deep percolation), and this

[3] Some drain data are not available from 1984-2005, and limited drain data are available after 2005.

resulted in the drain flows declining substantially and even drying up. The accumulated effect of the negative recharge during the drought is seen in the slow recovery of the drains after the drought, when it took two or three years for the drains to recover.

The ILRG Model, with its monthly stress periods, is capable of simulating the monthly, seasonal, and long-term responses of surface water flows to pumping as well as the Project operation responses to the changing surface flows. While the ILRG Model results reported by New Mexico generally rely on seasonal stress periods, the granularity of monthly stress periods is helpful in simulation of the following processes:

- Monthly inflows to Project storage and the resulting increases in Project water allocations through the early portions of the irrigation season (typically through July) and reserving later inflows for carryover to the next year.
- Characteristic monthly variability in LRG irrigation operations including planting dates, crop irrigation demands, diversions and deliveries, soil moisture carryover, and irrigation pumping,
- Monthly or sub-seasonal lagged impacts from recharge and pumping on surface flows (e.g., canal, drain, and river flows),
- Monthly M&I pumping volumes and WWTP returns based on historical monthly data, and associated estimates of monthly urban deep percolation,
- Bunching of reservoir releases into shorter delivery periods during non-full supply years.

The Texas Model, with its annual stress periods and lack of Project operating rules, is incapable of simulating many of the real-world responses described in Section 7.0 of the SWE Report (2019), including their monthly and seasonal variability.

Coors Opinion 9 *- When there is not a full allocation, Project operations do not provide a mechanism to compensate for the reduced flows that occur at El Paso due to pumping in New Mexico. Then, in subsequent years of full allocation, the groundwater elevation remains lower than it would have been without New Mexico pumping. So even if Texas receives a full allocation in a full allocation year, the depleted groundwater condition in New Mexico continues depleting additional water from the river and the injury to Texas continues. (page 6).*

Response:

The description of the Project response to the impacts of pumping described by Mr. Coors is overly simplistic and incomplete. Under D1/D2 accounting, pumping impacts during a year with less than a full allocation can potentially result in (a) more water having to be released from storage to deliver the allocations or (b) insufficient water being available to deliver the allocations. In the latter case, pumping can reduce deliveries in the current year. In both cases, the supply available for allocation in the next year can be reduced. In a full supply year, the effects of pumping can result in more water needing to be released to deliver the orders for irrigation water, which can result in less water available for allocation in the next year.

Under the D3 accounting in the 2008 OA, mechanisms for pumping to impact deliveries to EPCWID are generally similar to the mechanisms described above for the D1/D2 accounting. However, pumping (or other actions) can also affect EBID in the current year due to changes in the diversion ratio.

The ILRG Model, with its dynamic rules for simulating Project operations, is capable of reasonably simulating the foregoing real-world responses to changes in surface water supply caused by pumping in New Mexico and Texas in full supply and non-full supply years as well as the effects on future Project water allocations and deliveries.

Coors Opinion 10 *- The ILRG runs on a monthly timestep. For the questions raised by the Texas Complaint and New Mexico's Counterclaim, the most appropriate timestep is an annual one. By selecting a monthly timestep, simulating Project operations, including on-farm processes, reservoir operations, and canal operations and drain flows becomes significantly more complex and uncertain. Data needs to support modeling at this time scale also become greater. Due to a lack of much important historical data, a significant data development effort needed to be undertaken that introduces significant uncertainty to the model. Just because there are dynamics in the Project that occur on a monthly or seasonal level, does not mean that a monthly timestep is the appropriate one. The objective of the model is better served by an annual timestep which reduces the uncertainty present in the model results and more effectively captures the effects of a depleted groundwater condition on the surface water in the Rio Grande and in the Project over the course of years. (page 7).*

Response:

Contrary to Mr. Coors' statements, simulating the monthly operations of the Rio Grande Project and the LRG irrigation systems is not significantly more complex than simulating these operations using an annual timestep. Most of the LRG data needed for modeling are recorded and tabulated as monthly if not daily values. There is no significant "lack of important historical data" that limits the monthly simulation of the ILRG Model as asserted by Mr. Coors, and he did not specifically identify any data alleged to be lacking.

The monthly time-step of the ILRG Model allows it to simulate and distinguish the effects of pumping and other actions on Project water deliveries during the irrigation season from less important impacts on surface flows during the non-irrigation season. This capability is extremely important for analysis of the issues in this case.

Coors Opinion 11 *- Hydros applied three statistical metrics to quantify the effectiveness of the calibration of the Historical Base Run. For a short list of locations, they analyzed all the differences between the Run 1 simulated values and the observed values. The difference between an observed value and a modeled value is called the residual. Residuals from the Historical Base Run were analyzed by the following three statistics:*

1. *Monthly Mean Error*
2. *Mean Error as Percentage of Monthly Average*
3. *Nash-Sutcliffe Efficiency.*

The statistical methods selected are inadequate and inappropriate, and the locations at which they were applied are inadequate for determining the quality of the calibration of the Historical Base Run. (page 8).

Response:

While use of calibration statistics to evaluate the calibration of hydrologic models is commonplace, there are no universally accepted guidelines for calibration assessment in the scientific community (Moriasi et al., 2012). There are numerous statistical performance measures that have been developed to assess the goodness of fit of modeled values to measured values, and the choice of statistics is generally left in the hands of the modeler based on professional judgment. In addition, there are numerous graphical performance measures to evaluate model calibration, and most modelers use some combination of statistical and graphical performance measures to assess calibration of hydrologic models.

Coors Opinion 12 *- The third statistical parameter reported in the New Mexico experts' reports is the Nash Sutcliffe Efficiency (NSE) parameter, Eq (2). This parameter characterizes the goodness-of-fit between a modeled quantity and the observed. The value ranges from - ∞ to 1.0. A value of 1.0 represents a perfect fit. Negative values indicate the observed mean is a better representation of the timeseries than the model results. "Performance Evaluation of Hydrological Models: Statistical Significance for Reducing Subjectivity in Goodness-of-Fit Assessments" by Ritter, Axel, and Rafael Muñoz-Carpena (2013) provides performance ratings for NSE values. This performance rating system is given in Table 1. (page 9).*

NSE Category	*Value Range*
Unsatisfactory	*< 0.65*
Acceptable	*0.65 – 0.80*
Good	*0.80 – 0.90*
Very Good	*0.90 – 1.00*

Response:

The NSE has become a widely used statistic for evaluating the calibration of hydrologic models because it more appropriately measures the goodness of fit than does the coefficient of determination (R^2) statistic that previously was the standard regression statistic used to evaluate model performance (Harmel et al., 2010; Legates, 1999; Moriasi et al., 2007). However, there are no universally accepted performance criteria in the scientific community for evaluating NSE scores, and performance criteria used by Mr. Coors are proposed criteria included in Ritter (2013).

A widely cited journal article by Moriasi et al. (2007) included performance evaluation criteria for the NSE statistic that are less stringent than the criteria advocated by Mr. Coors. A subsequent article by Moriasi et al. (2015) describes an in-depth review and analysis of statistical and graphical performance measures and performance evaluation criteria in the hydrologic modeling literature. The following criteria were recommended for the NSE, coefficient of determination (R^2), Index of Agreement (d), and the Percent Bias (PBIAS) by Moriasi et al. (2015) on behalf of the American Society of Agricultural and Biological Engineers ("ASABE"):

Recommended Performance Evaluation Criteria
ASABE (2015)

Performance Evaluation Criteria	Nash-Sutcliff Efficiency (NSE)	Coefficient of Determination (R^2)	Index of Agreement (d)	Percent Bias (PBIAS)
Very Good	> 0.80	> 0.85	> 0.90	< 5%
Good	0.70 – 0.80	0.75 – 0.85	0.85 – 0.90	±5% – ±10%
Satisfactory	0.50 – 0.70	0.60 – 0.75	0.75 – 0.85	±10% – ±15%
Unsatisfactory	0.0 - 0.50	0.18 - 0.60	0.60 - 0.75	±15% - ±30%
Unacceptable	≤ 0.0	≤ 0.18	≤ 0.60	≥ ±30%

Note also that the NSE equation presented in the Coors Report on page 9 is incorrect. The opening parentheses in the numerator and denominator should be placed after, rather than before, the summation character.

Coors Opinion 13 *– [T]he NSE methodology fails to accurately evaluate model calibration across the whole range of values in the dataset. Krause, et al. (2005) asserts,*

> *"the Nash-Sutcliffe is not very sensitive to systematic model over- or underprediction especially during low flow periods."*

The NSE metric overemphasizes a model's ability to match higher values and underemphasizes the ability to match lower values. For model output intended to represent the surface water conditions of the Rio Grande Project, matching low flows is particularly important as it is during the low flow times when surface water is limited that the impacts of groundwater pumping are realized. It is more important that the model be effective at capturing the low flow periods to address the issues at hand. The NSE is more a measure of how well a model represents the higher values than the lower ones, which is not appropriate for determining the effectiveness of the ILRG model in replicating Project operations. (page 9).

Response:

The criticism by Mr. Coors of use of the NSE methodology for evaluating calibration of the ILRG Model because it underemphasizes low flows is misplaced for several reasons. First, the LRG system is different from more typical unregulated flow systems. Except for rare spills from Project storage, the irrigation season surface water flows in the LRG area are highly regulated by Project operations, resulting in streamflow and diversion rates that generally fall within a relatively narrow range of flows. This is much different than unregulated basins in the West in which streamflows may routinely vary widely between snowmelt or rainfall runoff in the spring and baseflows in the fall.

Second, reported monthly flow volumes (streamflows and diversions) in the LRG area are often very low in shoulder season months because the Caballo Reservoir releases commence late in a spring month or cease early in a fall month. These low flow volumes should not be treated in the statistics as if they are significant extreme values when they represent typical regulated flow rates occurring over a limited number of days in the month. Zero flows are typically rare in unregulated watersheds and of great interest to engineers and planners. However, zero flows in the LRG Basin are routine because of reservoir and canal operations.

Finally, the claims and counterclaims in this case need to be evaluated at all levels of flow conditions and not just in low flow years.

Coors Opinion 14 *- There are three additional metrics that are needed for a more complete assessment of the quality of the Run 1 calibration (tuning). The first is the Mean Absolute Error (MAE), shown in Eq (3). By taking the absolute value of the residual before applying the average, positive and negative residuals do not cancel each other out and the formula produces a statistic that meaningfully quantifies the predictive capability of a model. Note this metric does not have a "squared" term in its formulation which prevents large deviations from dominating the calculation. In hydrology, large flows generally exhibit larger deviations and so, unlike the NSE, this metric characterizes the model's ability to represent a full range of flows, not just high flows which are not nearly as important for the questions being addressed in this case. Additionally, this metric has units of flow and provides an intuitive value that simply represents the average absolute size of the model residual. (page 10).*

Response:

The MAE is a commonly used statistic for evaluating the range of the differences between simulated and observed values without the cancelation of positive and negative differences that occurs in the mean error statistic. The New Mexico experts informally reviewed the MAE in calibrating their models but did not publish this statistic in their prior reports. The MAE statistic is included in the calibration and tuning results for the ILRG Model that are presented in Section 28.0.

Mr. Coors again misplaces his criticism of the NSE statistic. Unlike other hydrologic models that may be focused more exclusively on drought periods, the modeling required for the LRG area needs to more equally consider and weigh conditions in dry, wet, and average periods because the claims and counterclaims in this case have the potential to affect Project operations in all types of hydrologic conditions.

Coors Opinion 15 *- The second is simply the MAE divided by the observed monthly mean. This calculates the relative size of the MAE to the mean of the observed quantity through the run period. (page 10).*

Response:

The MAE divided by the observed mean ("PMAE") statistic is included in the calibration and tuning results for the ILRG Model that are presented in Section 28.0. As with any relative statistic, care must be given in reviewing the computed values of the PMAE and PBIAS statistics because a simulated output with small mean can result in deceivingly high computed values for these statistics (i.e., a large percentage of a small value).

Coors Opinion 16 *- The third additional metric to apply is the Log NSE. Applying a log transformation to values in the NSE formula, shown in Eq (4), reduces parameter sensitivity to extreme high values and increases sensitivity to low flow conditions. (page10).*

Response:

As discussed in the response to Coors Opinions 13 and 14, the LRG modeling in this case should not be focused on drought conditions or low flow conditions because the claims and counterclaims by the states implicate Project operations and deliveries at all levels of supply, and in any event, the low monthly streamflows and diversions are typically the result of (a) normal partial month operations rather than dry conditions, or (b) months with no reservoir releases, typically in the non-irrigation season. In addition, the highly regulated nature of the Rio Grande Project insulates it from the more extreme flow variations that typically characterize unregulated river basins in the west. While the Log NSE can be useful in emphasizing the match of low flows, this is not necessary and indeed is undesirable in evaluating the LRG modeling for the aforementioned reasons.

In reviewing the implementation of the Log NSE statistic in the backup spreadsheets disclosed by Mr. Coors, it was discovered that he did not adjust his computations to consider a common issue associated with log transforming very small numbers. The equation for computing the Log NSE is shown below.

$$Log\ NSE = 1 - \frac{\sum_{i=1}^{n}(logx_{io} - logx_i)^2}{\sum_{i=1}^{n}(logx_{io} - log\bar{x}_o)^2}$$

n = number of stress periods
$x_i = modeled\ value$
$x_{io} = observed\ value$
$\bar{x}_o = mean\ of\ observed\ values$

The numerator of the above equation computes the sum of the squared differences between the log of the observed value and the log of the modeled value. The log of zero is negative infinity and the log of a small number approaching zero becomes a very large negative number. Therefore, the computed value of the numerator in the Log NSE equation can become inappropriately dominated by a few very small flows. This is what happens in Mr. Coors' application of the Log NSE equation to the simulated results of Run 1 of the ILRG Model. The RiverWare Model, like other computer models, sometimes computes a very small number for what is effectively a zero flow. When the log of that very small number is computed in the Coors spreadsheet, the result is a relatively large negative number that dominates the numerator in the Log NSE equation when squared[4]. In order to avoid this issue, it is typical in computing log transformed values to either (a) exclude flows lower than a certain threshold from the computations, or (b) to add a nominal amount to all flows (e.g., 100 AF) to avoid the computational issues described above. As described above, Mr. Coors did not make this important adjustment when computing the Log NSE statistics that he presented in his report.

It was also noted that the Log NSE equation presented in the Coors Report is incorrect. As shown in the above equation, the opening parentheses in the numerator and denominator should be placed after, rather than before, the summation character.

Coors Opinion 17 *- The three metrics used by the New Mexico experts and the three additional metrics described above are applied at 26 locations in the model. These provide*

[4] For example, the flow computed by the RiverWare Model in Run 1 (v106) for the Acequia Madre in October 1956 is 2.095 x 10^{-29}. The log of this value is approximately -29 and when squared, the result is 841.

a much more robust and representative set of locations to assess how well the model represents Project operations throughout the basin on a monthly basis. (page 11).

Response:

An important consideration for determining the locations for evaluating model calibration is whether the simulated flows at those distinct locations are important to the functioning and proposed uses of the model. In reviewing the locations selected by Mr. Coors for evaluating the calibration of the ILRG Model, it appears that many of the locations were selected just because there were historical data available to compare to the modeled values. In particular, eleven of the locations selected by Mr. Coors are drain flow sites. Drains are important features in the ILRG Model because they are significant areas for the interaction of ground water and surface water. The effects of surface water irrigation and ground water pumping are realized, in part, in the model by impacts on drain flows that in turn affect Rio Grande flows. However, when evaluating the drain flows from a particular area (for example the Mesilla Valley) it is more important to assess the combined flow of all drains rather than the flow of the individual drains. As long as the combined drain flow is reasonably simulated, it is not so important that one drain is simulated too high and another is simulated too low. By evaluating the calibration of flows at individual drains, Mr. Coors' calibration statistics give the appearance of very poor drain flow calibration. The calibration performance improves when the drain flows are reasonably aggregated.

In addition, the flows at several of the Rio Grande gages evaluated by Mr. Coors are relatively unimportant to the model functioning and uses. These include the flows at the gages below Leasburg Dam and below Mesilla Dam. The streamflows at these two gages typically are not a limitation on diversions because of the additional flows that are being delivered past the gages downstream to Texas and Mexico. Also, the Rio Grande at Island Station gage is not of great importance because the flow at this gage does not limit any of the simulated water uses. Most of the surface water in this area is moving through the irrigation systems of EPCWID and JID and not in the Rio Grande.

Finally, the spatial scale of the data for use in modeling the LRG Basin is also important. **Table 23-1** summarizes the spatial scale of the major input data for the ILRG Model.

After reviewing the list of 26 locations evaluated by Mr. Coors and considering the model processes and intended model uses, the following individual and combined locations for evaluating the calibration and tuning of the updated ILRG Model were used:

River Gages
Caballo Reservoir Outflow
Rio Grande at El Paso
Rio Grande at Fort Quitman

Drains
Rincon Valley Drains
Mesilla Valley Drains
El Paso Valley Drains

FHG Deliveries and Pumping
EBID
EPCWID
HCCRD

Diversions
Rincon Dam
Leasburg Dam
Eastside Canal
Westside Canal
American Canal
Riverside Canal
Franklin Canal
Acequia Madre
Total HCCRD Supply

The above individual and aggregated locations represent thoughtful consideration of the extent to which historical and simulated flows are effectively aggregated in their simulated interactions, as summarized below:

- Rio Grande Flows – Releases from Caballo Reservoir and the flows at the El Paso and Fort Quitman gages are most important. The flows at the Rio Grande gages between the Caballo outlet and El Paso are less important because the river typically does not dry up at these locations, and therefore the simulated flow at these gages does not limit diversions of Project water. The flow at the Rio Grande gages between El Paso and Ft. Quitman is of less significance because most of the surface water is delivered through EPCWID and JID irrigation systems rather than the Rio Grande in this area.
- Diversions – Diversions are assessed at each of the major river headgates in the study area and at the Franklin and Riverside Canal gages in EPCWID.
- FHG Deliveries and Pumping – FHG deliveries are assessed for each District, consistent with the scale that the historical FHG delivery data are available. Because pumping is simulated to meet unmet demands after the FHG deliveries, pumping is also evaluated on a consistent District-wide basis. Note that irrigation pumping data is not available in the LRG Basin except for pumping in New Mexico starting in 2009. As result, simulated pumping in the Historical Base Run (Run 1) was compared to the simulated pumping in the Historical Calibration Run (Run 0).
- Drains – The flow of individual drains is generally less important than the aggregate flow of drains that collect flow from the major valleys. It is the aggregate total drain flow that contributes flow to the downstream users, and the

particular drain in which the flow arises is of little importance to the model simulation. Aggregated drain flows were assessed for the Rincon Valley, the Mesilla Valley, and the El Paso Valley.

The claim by Mr. Coors that the ILRG Model is poorly calibrated is based on his assessment of calibration using statistics that compare monthly modeled and observed data. This assessment does not consider whether matching of monthly flows is necessary given how the Project operates and how the results from ILRG Model will be used in this case.

Project water is allocated to the Districts and allotted to the farmers as irrigation season volumes that they can take delivery at their discretion. In general, it is reasonable to assume that water users took delivery of water to meet the needs of their crops, but they also likely considered bunching releases to minimize transit losses, prioritizing irrigation of certain crops at the expense of other crops, whether late season reservoir inflows were better saved for use in the next year, and other factors. It is generally not possible to develop simulation rules that exactly match the variable water ordering and reservoir release practices that existed during the simulation period. Fortunately, accurate matching of historical monthly releases and deliveries is not necessary in the ILRG Model because simulating too much delivery early and not enough delivery late, or vice-versa, just redistributes a similar seasonal volume of deliveries and similarly redistributes a similar seasonal volume of pumping to meet unmet demand.

The existence of stored Project water in Elephant Butte and Caballo Reservoirs is another important consideration in assessing the need for close matching of modeled and observed values on a monthly basis in the ILRG Model. This stored water is by far the largest source of surface water supply in the LRG Basin. The availability of stored water to the Project users has a buffering effect on the impacts of pumping and other actions on Project water supplies. This means, for example, that monthly depletions to surface flows from pumping can be buffered in the short-term by greater releases from storage to meet delivery demands until the available storage supply is exhausted (either the physical supply or the annual allocations). It would be unreasonable to use the model to compute injurious impacts on a monthly basis without consideration of whether water remained in the water user's account. The availability of supplemental wells can buffer the effect of monthly variations in Project supply

The foregoing considerations invite use of the ILRG Model to evaluate impacts on a seasonal basis rather than a monthly basis. This recognizes the important fungible nature of the timing of Project water use within the irrigation season. While aggregation of monthly model results to irrigation season totals is appropriate for analysis of impacts from pumping or other actions, aggregating model results into annual totals is generally not appropriate for evaluating diversions and deliveries of irrigation water supplies. Less usable flows occurring during the non-irrigation season are not a substitute for more useable flows during the irrigation season. This is consistent with Project accounting that is based on irrigation season allocations and deliveries, and water used outside of the irrigation season when the reservoir is not releasing is not considered or charged as Project water.

Given how the Project operates based on seasonal allocations, allotments, and releases as described above, it is appropriate to evaluate the ILRG Model calibration of diversions, FHG deliveries, and pumping using irrigation season totals. Reasonable matching of diversions goes hand in hand with reasonable simulation of river flows during the irrigation season. If there is not enough water is in the river, then the diversions can't be met, and if there is too much water in the river, then there will be too much water passing the American and International Dams. Therefore, the calibration of river flows was evaluated using annual totals to verify the model was reasonably matching the entire volume of the simulated flows that typically includes both reservoir releases and return flows in the irrigation season and return flows only during the non-irrigation season. Drain flows were also evaluated using annual totals.

Coors Opinion 18 *- It would be ideal to include model locations that were not used as calibration targets to assess the quality of the calibration process, but all of the locations that have observation data were used as calibration targets. It would have been more appropriate for the New Mexico experts to either leave some portion of every location's data for validation or some portion of the locations for validation, but this does not appear to have been done. (page 11).*

Response:

There is no broad consensus in the scientific community for excluding a portion of the historical study period from the model calibration, and to use the excluded data to validate the calibration. Some advocate that validation is useful and a good test of a model. Others argue that using all available information for calibration produces a better model (Konikow and Bredehoeft, 1992).

In this case, the ILRG Model is being used mostly to analyze the past, so it makes sense to use all available historical data to calibrate the model. Further, the historical data contain a representative variety of hydrologic conditions ranging from full supply years with relatively little pumping demand to low supply drought periods requiring large pumping volumes. The range of conditions during the historical calibration period generally encompasses the range of conditions that would be expected to occur in any of the conditions that are simulated in alternative scenarios. Therefore, it is reasonable to use all available data to calibrate the ILRG Model.

Coors Opinion 19 *- The results from the statistical analysis demonstrate that the Historical Base Run fails to accurately model historic Rio Grande Project conditions throughout the basin. The more robust and appropriate statistical parameters and list of locations introduced in this report provide a more accurate assessment of the quality of the Run 1 calibration process, and how well Run 1 simulates historical Project operations. (page 12).*

Response:

For the reasons described above, including the use of monthly calibration statistics applied to needlessly disaggregated locations, the calibration assessment presented by Mr. Coors is not appropriate for evaluating the utility of the ILRG Model for assessing the claims and counterclaims in this case.

The calibration and tuning assessment presented in Section 28.0, which includes calibration statistics computed using irrigation season and annual flows, and visual comparisons of simulated and observed values, is more representative of the capabilities of the ILRG Model in simulating conditions during the historical study period than the assessment presented by Mr. Coors. The calibration evaluation described in Section 28.0 provides confidence that the ILRG Model simulations of alternative scenarios are reasonable and can be relied upon in analyzing the claims and counterclaims in this case.

Coors Opinion 20 *- The ME parameter and the ME as Percent of Monthly Mean values reported by New Mexico experts give the appearance of a good fit. However, this metric only characterizes bias in modeled values at calibration target locations. When this metric is applied to a more comprehensive and representative set of locations, a significant bias in modeled values is shown. The average absolute value for the ME as Percent of Monthly Mean is 19% with values for four drains being nearly 50% and higher. The Rio Grande at Island Station gage shows a 55.1% value. This indicates an unacceptable level of bias throughout the model. (page 12).*

Response:

As discussed in more detail in Section 28.0 and shown in **Table 28-1**, the Mean Error and PBIAS statistics applied to a more representative set of locations or aggregated locations using irrigation season and annual totals demonstrate much better performance of the ILRG Model than indicated by the assessment presented by Mr. Coors. The PBIAS is less than 5% at the Caballo outlet and the Rio Grande at El Paso (very good), less than 10% at the canal gages (good to very good), and 16% or less for the aggregated drains (not satisfactory to very good).

***Coors Opinion 21** - The MAE parameter indicates significant uncertainty in the modeled values. The MAE as Percent of Monthly Mean values range from 28% to 121% of the observed monthly mean at the analyzed locations. The average value of this quantity for all 26 locations is 52.7%. This means that on average across all of these locations in the model, the monthly modeled values are over 50% off from observed values at these locations. This indicates an unacceptably high level of uncertainty in the monthly values across the whole model. (page 12).*

Response:

The MAE and PMAE statistics for locations selected by the New Mexico experts show better model performance when computed using irrigation season and annual totals rather than the monthly values used by Mr. Coors. The PMAE for most locations ranges from 6% to 36% with most values less than approximately 20%. This represents reasonable model performance given the size and complexity of the Rio Grande Project and irrigation systems in the LRG Basin. In addition, the graphs in **Figure 28-1** through **Figure 28-21** that are discussed in Section 28.0, demonstrate satisfactory to excellent performance in reproducing the monthly, seasonal, and long-term patterns of the historical data.

***Coors Opinion 22** - According to the NSE rating criteria created by Ritter, Axel, and Rafael Muñoz-Carpena (2013) three of the 26 locations analyzed perform at a satisfactory level. The average NSE value across all locations is 0.41 which is unsatisfactory. There is one location that has a NSE value that is negative. This means that the historical mean value is a better representation than what the model simulates. This also indicates an unacceptably high level of uncertainty in the monthly values across the whole model. (page 12).*

Response:

As discussed in the response to Coors Opinion 12, there is no consensus in the scientific community for what for what constitutes a satisfactory NSE value. However, according to the criteria proposed by the ASABE contained in Moriasi et al. (2015), an NSE greater than 0.50 is considered satisfactory. All but one of the 21 seasonal or annual NSE values shown in **Table 28-1** for the ILRG Model exceed 0.50, and all but seven exceed the 0.65 threshold advocated by Mr. Coors.

The only NSE value less than 0.50 is for the aggregated Rincon Valley drain flows which on average after 1950 flowed less than 15,000 AF/y.

Coors Opinion 23 *- Applying the same performance criteria to the Log NSE parameters only three of the 26 locations perform satisfactorily. Because the Rio Grande at El Paso is one of the calibration targets used during the operational tuning, this location and its associated calibration metrics have limited value in characterizing the quality of the calibration of the model. There are seven locations that have a Log NSE value that is negative including Caballo Reservoir Outflow which is discussed further in section 6.1.2.1, below. This is a clear indication of an unacceptable amount of uncertainty in the model. The fact that the log NSE indicates worse performance than the NSE says that the model does a particularly poor job of representing lower flow values. (page 13).*

Response:

See the response to Coors Opinion 16. While the Log NSE statistic is generally inappropriate for evaluating the ILRG Model performance because there is no need to emphasize performance at low flows, the Log NSE statistics computed for seasonal and annual values shown in **Table 28-1** show satisfactory to good performance for most locations.

Coors Opinion 24 *- Figures showing the calibration results graphically as scatter plots for all locations are found at the end of the report (see Section 9). (page 13).*

Response:

Mr. Coors included residual plots and scatter plots for the 26 locations that he selected for evaluating the calibration of the ILRG Model in Section 9 of his report. However, Mr. Coors did not offer any opinions regarding these graphs and therefore there are no opinions regarding these charts to rebut.

The presentation of the calibration and tuning results for the updated ILRG Model in Section 28.0 includes numerous graphs comparing modeled results against historical observed data. These charts, which are described in Section 28.0, are further evidence of the overall excellent performance of the updated ILRG Model.

Coors Opinion 25 *- The Caballo Outflow calibration metrics are particularly problematic. Caballo releases are arguably the most important Rio Grande Project operation that the model needs to replicate in the Historical Base Run (page 13).*

Response:

The calibration statistics in **Table 28-1** for the Caballo Outflows in the updated LRG Model show a small PBIAS of 0.1% and an excellent NSE value of 0.93. The monthly and annual graphs of modeled and observed values in **Figure 28-1** demonstrate that the simulated releases reasonably match the amounts and patterns in the historical data. This is evidence of excellent functioning of the RiverWare Model rules that simulate historical Project allocations and releases.

Coors Opinion 26 *- For New Mexico's claim that Project operations are reasonably simulated in the model to be true, the model must demonstrate the ability to, with rules, simulate releases of Project water that are a good representation of how the Project is actually operated. The ability of the ILRG model to meaningfully represent Project operations determines its capability to model hypotheticals, which in turn determines its ability to determine impacts. The Log NSE for this parameter is a problem at -.07. A negative Log NSE value means that the historical (observed) mean for the entire run period would be a better representation of monthly releases from Caballo than what RiverWare produced with its rules (Krause, P., et al). The unacceptable performance of the Caballo Outflow parameter in RiverWare means that the "operationally tuned" RiverWare model is not a reliable simulator of Project operations on a monthly scale and cannot be relied upon to provide accurate what-if analyses of hypothetical scenarios. (page 13).*

Response:

As discussed in the response to Coors Opinion 25, the ILRG Model performance in simulating Caballo Outflows is excellent. While the Log NSE statistic is generally inappropriate for evaluating the ILRG Model for the reasons discussed in the response to Coors Opinion 16, the Log NSE statistic was included among the performance measures presented in **Table 28-1** for comparison to the calibration statistics presented in the Coors Supplemental Report. When computed using simulated and observed annual Caballo releases, the Log NSE performance score for Caballo Outflows is very good at 0.93.

Coors Opinion 27 *- Though this figure (and the others like it) is never referenced by Hydros in the Tech Memo 4, presumably it is being presented to demonstrate that EBID project river diversions are being captured adequately by the rules. This is incomplete. These values have been aggregated significantly, both temporally and spatially. The model is monthly and the New Mexico experts assert that the system must be modeled monthly to be viable. The values in the plot are annual. (page 14).*

Response:

As discussed in the response to Coors Opinion 8, while it is important to model the system using monthly stress periods, the performance of the ILRG Model should be assessed primarily based on the degree that it reasonably simulates Project operations, irrigation operations, and surface water flows using irrigation season or annual totals. Visual comparison of model results on a monthly basis confirms that the simulated flows generally follow the monthly patterns in the observed data, particularly during the irrigation season.

Thoughtful spatial aggregation of ILRG model results for assessment of ILRG calibration is appropriate in consideration of how the Rio Grande Project operates and how water is delivered for use. For example, there is little sense in criticizing the model calibration of individual drains when those drain flows join together before the next downstream diversion.

In addition, calibration assessment should also consider the spatial scale of the input data to the ILRG Model. For example, while the model separately simulates the irrigation operations in the EBID subareas of Rincon, Leasburg, Eastside Mesilla, and Westside Mesilla, it is appropriate to evaluate the model performance for certain aspects of EBID using District totals. This is because portions of the EBID data used in the modeling are reported only as EBID totals. Care must be given in judging model results at a spatial scale that is finer than the spatial scale of the input data. A summary of the spatial scale of selected input data for the ILRG Model is shown in **Table 23-1** and discussed in Section 23.0.

Coors Opinion 28 *- A second important indicator of a well calibrated model is low operational bias. The cumulative residual between the modeled values and observed values is an indicator of model bias and should not exhibit noticeable patterns or trends in a well calibrated model. If the model is replicating history (Project operations in this case) objectively the absolute residual should appear random and cumulative residual should display no distinct multiannual trends indicated by significant departures from the zero line. Analysis of the bias in the same 26 locations exhibits the opposite, and the flaw is evident when viewing the residual and cumulative residual trends of the Rio Grande at El Paso, Figure 2. (page 15).*

Response:

The cumulative residual described by Mr. Coors is not the same as operational bias. Operational bias, also known as mean error, is defined as the difference between the computed mean of a simulated output and the computed mean of the observed data over all or a portion of the simulation period. The cumulative residual shows how differences between modeled and observed values accumulate through time during the simulation period. Virtually all models of complex systems will show cumulative residuals of model outputs trending in positive and negative directions over short time periods such as are shown for the Rio Grande at El Paso in Figure 2 of the Coors Supplemental Report. The suggestion by Mr. Coors that the cumulative residual represented by the heavy blue line should hover very closely around zero is an ideal that is rarely achieved in hydrologic modeling of complex systems.

In addition, Figure 2 in the Coors Supplemental Report does not provide context for the amount of the residuals and cumulative residuals. The middle right graph in **Figure 28-2** shows the cumulative residual for the Rio Grande at El Paso gage as a percentage of the cumulative El Paso flow over the 1940 – 2017 study period. This puts the cumulative residual error at the El Paso gage in proper perspective. The maximum cumulative residual ranges from -1.8% to +0.6% which is excellent.

Coors Opinion 29 *- The New Mexico experts fail to create accurate representations of no pumping conditions in their hypothetical scenarios. The hypothetical runs (Runs 2, 3, 4, 5, and 6) simulate scenarios in which groundwater pumping is turned off for regional and basin-wide combinations of water users. New Mexico experts modeled the hypothetical scenarios by simply setting groundwater pumping to zero in the no-pumping areas. Modeling the no-pumping condition in this way fails to adequately represent changes that would occur in on-farm processes resulting from the unavailability of groundwater supply. While the irrigated acreage on the primary groundwater users is properly reduced to zero, the irrigated acreage of supplemental groundwater users is not reduced in response to decreased water supply. The irrigated acreage would decrease or a crop requiring less water would be produced to respond to the decrease in available water, as shown in Eq (6). ILRG modelers selected RiverWare methods on the RiverWare "Water User" objects requiring irrigated acreage and the evapotranspiration (ET) rate be entered as inputs. Historical irrigated acreages and ET rates are also used in all the hypotheticals. Not allowing irrigated acreages or ET rates to change (reduce) for scenarios in which water supply significantly decreases results in unrealistic results because the modeling of monthly on-farm processes through the irrigation season are unreasonable. (page 16).*

Response:

In my experience, it is common in modeling alternative scenarios of historical irrigation to leave the irrigated acreage and cropping pattern at the historical values in simulations of alternative scenarios, including no pumping or reduced pumping scenarios. This is how reduced pumping scenarios were simulated using the H-I Model of the Arkansas River for the Kansas v. Colorado litigation. This procedure is also similar to how engineers in Colorado analyze historical use for changes in irrigation water rights in the Colorado water courts. In these analyses, the irrigated area is typically simulated at the maximum irrigable acres evident in aerial photographs. In each year of the historical simulation, the upper limit of the crop consumptive use is based on the crop-weighted CIR multiplied by the simulated irrigated area. During water short years, the actual crop consumptive use is limited to the historical farm headgate deliveries multiplied by the maximum on-farm irrigation efficiency.

In the no pumping or reduced pumping runs of the ILRG Model, the simulated irrigation supply delivered to the farms will often be less than the irrigation water demand for the historical irrigated area and cropping pattern resulting in irrigation water shortages. In these water short conditions, the simulated irrigation consumptive use is limited to the available supply times the maximum on-farm irrigation efficiency.

While it is true that in the real-world farmers without access to wells may reduce the irrigated area and change their crops to conform to the expected limited surface water supply, it is reasonable to assume that the limited supply would be consumed at the same maximum irrigation efficiency resulting in the same consumptive use of applied surface water. In other words, even if the acres and assumed crops were changed in the alternative runs, the consumptive use would still be the result of the available supply times maximum on-farm irrigation efficiency.

If the simulated consumptive use is the same whether or not the simulated acreage is reduced and the crops are changed, then there is little to be gained by speculating how the farmers would respond to the reduced irrigation supply in terms of the modeling results. Note also that Dr. Hutchison did not reduce the irrigated area is his simulation of reduced pumping scenarios.

Coors Opinion 30 *- This is a standard method to develop reservoir local inflows. However, because estimated evaporation and measurement error are part of the calculated mass balance equation, and bank storage and reservoir seepage are elements in the actual water balance of the reservoir and is not included in the calculated water balance, there are numerous months for which a negative value is calculated for this quantity. This is a common result from a mass-balance approach to developing reservoir inflows. It causes problems for modeling the hypothetical scenarios as the inflow to Caballo Reservoir would be different in the different hypothetical scenarios that have a significant difference in Caballo storage throughout the run, as bank storage and seepage are dependent on reservoir storage levels. The NM experts did not consider that there would be difference in bank storage effects in alternative runs. (page 18).*

Response:

Caballo Reservoir is an operational reservoir that helps to regulate releases for power production from Elephant Butte Reservoir for subsequent downstream delivery to meet Project water demands. It is not expected that the function of Caballo Reservoir as a regulating reservoir would be materially different in alternative scenarios compared to the historical operation over the long term, and therefore any differences in bank storage effects would be positive and negative and largely cancel each other out.

Coors Opinion 31 *- There is a second, more significant problem with this quantity. The RiverWare model introduces erroneous (non-historical) water to the system here by means of an inappropriate "method" being employed on this object. When during the course of a model run, the simulated releases from Elephant Butte are not large enough to compensate for the negative inflows input to the system at the "RGabvCaballo" reach, a negative outflow would result from the reach. This is problematic for the model and must be addressed. Hydros' solution to the problem was to select the "Negative Outflow Unidentified Loss" method which adds any additional flow to the reach necessary to make the outflow zero. This added water is not part of the historical inflow development process and represents water erroneously added to the system at Caballo. (page 18).*

Response:

This issue was described by Mr. Coors in his first deposition in February 2020. The New Mexico experts reviewed this matter and added a rule to the RiverWare simulation of Elephant Butte Reservoir that computes a minimum monthly release equal to the computed unmeasured negative inflow (loss) between Elephant Butte Reservoir and Caballo Reservoir. This additional rule corrected the mass balance issue that was identified by Mr. Coors.

Coors Opinion 32 *- Creating management rules and tuning a set of simplistic operational parameters to accurately simulate the complexity of real historic operations of the Project at a monthly scale is an overly ambitious goal. Physical processes are governed by physical laws that behave consistently. Given the same set of initial conditions, the dynamics of water in a physical system governed by physical laws will always be the same. The same is not true of management processes; management processes like Rio Grande Project operations are governed by legal structures, historical practice, and subjective decision making. Given the same set of initial conditions the dynamics of water governed by management process can vary significantly for a variety of reasons including the political climate, current system operator, one-off conditions, and any number of other factors. This fact makes characterizing historical Project operations with a sufficient degree of accuracy to support impacts analysis using hypotheticals an impossibility. (page 21).*

Response:

I disagree that the dynamics of the Rio Grande Project management processes cannot be modeled with sufficient accuracy. The historical procedures for allocating water and operating the Project reservoirs to release sufficient water to meet water orders are generally well established, understood, and amenable to modeling. The excellent calibration statistics for Caballo Outflows summarized in **Table 28-1** and the graphical comparison of simulated and observed releases shown in **Figure 28-1** are evidence of the efficacy of the RiverWare rules in simulating Project operations.

Coors Opinion 33 - *These unanticipated deviations make "tuning" the model to simulate management processes a highly uncertain exercise with only modest success even possible. When the quantification of pumping impacts is dependent on the model replicating historical conditions precisely, tuning a few simple model parameters to attempt to closes match the intricacies of real-world management processes to a degree suitable for closely matching historical operations is unattainable. (page 21).*

Response:

While there were occasional ad hoc historical deviations from standard Project operating practices, the RiverWare simulation rules produce a well-calibrated model as evidenced by the calibration statistics and graphical comparisons of predicted and observed flows presented in Section 28.0.

The statement that quantification of pumping impacts depends on precise model replication of historical conditions by Mr. Coors is not realistic and sets an impossible standard. A model need not be perfect to be useful and reliable. As discussed in the response to Coors Opinion 34, differences in model outputs from simulated scenarios (e.g., a no pumping run vs. the Historical Base Run) can be more accurate than the model predictions of the individual scenarios because of the cancelling of similar errors that are present in both scenarios.

In order for the differences between scenarios simulated in this case to be reasonable and accurate, the simulation model needs to (a) simulate the entire area from Elephant Butte Reservoir to Fort Quitman, (b) use monthly stress periods that facilitate analysis of the relatively rapid temporal response and interaction between the surface water features and the shallow alluvial aquifers, (c) simulate Project and irrigation system operations using rules that facilitate dynamic response to changing conditions in alternative scenarios, and (d) be calibrated to show a reasonable match between modeled and observed historical flows on a seasonal or annual basis. The updated ILRG Model succeeds in all of these areas.

The relatively simple tuning of the operational rules that produces a good model calibration without overparameterizing the model as demonstrated in tables and charts in Section 28.0.

Coors Opinion 34 *- [Deposition testimony of Michel Estrada-Lopez] characterizes precisely what is described above as a management process. This process is a fundamental aspect of Project operations that are purportedly "well represented" by rules and operational tuning factors. Her description of how the process of determining the annual allocation for the Project actually takes place certainly highlights the subjective and evolutionary nature of this operation. These characteristics make capturing historical Project operations with rules and simple tuning parameters essentially impossible. The failing calibration analysis and operational bias analysis presented above demonstrate what would be expected from a model that attempts to capture with static logic a real-world historical operational process like annual Project allocation as described by Ms. Estrada-Lopez. (page 22).*

Response:

The deposition testimony of Ms. Estrada-Lopez cited by Mr. Coors details the annual process involved in Project accounting. For modeling purposes, it is not necessary to simulate every detail of the Project accounting in order for the model to be reliable in analyzing the claims and counterclaims in this case. Application of the ILRG Model in this case will typically involve computing differences between model runs (e.g., a no pumping run minus the Historical Base Run). When computing these differences, model error resulting from insignificant fine accounting details that are not incorporated in the simulation rules will tend to be present in both of the model runs, and therefore this error will tend to cancel out when the runs are differenced. A consistent set of simulation rules is applied in the ILRG Model simulations of the Historical Base Run and alternative scenarios and this allows the changes in input data or assumptions for different runs to be reflected in the computed differences in model outputs.

This is analogous to ground water models that do not and cannot represent all of the real-world spatial heterogeneity of the simulated ground water system. Instead, ground water modelers represent the aquifer hydrogeology using hydraulic conductivity and storage coefficients that are spatially smoothed and approximate representations of real-world variability. When the ground water models are calibrated to reasonably replicate historical conditions, they are judged ready for use in simulating alternative scenarios.

Ms. Estrada-Lopez's testimony also describes the process for reviewing and potentially updating the Operating Agreement Manual and/or the accounting spreadsheet. The ILRG Model reasonably simulates the processes set forth in the Operations Manual and in the Accounting Spreadsheet. To the extent that the manual or spreadsheet are revised to a substantive degree, relevant ILRG Model rules can be modified accordingly to simulate those changes beginning in the year they are implemented. Historically, most of the accounting refinements that have been implemented are in the category of fine accounting details that need not be represented in the ILRG Model rules. As described above, to the extent the absence of these details contributes to model error, this error will tend to cancel out when differencing model runs.

Coors Opinion 35 *- It is my opinion that based on the calibration results for Run 1 the idealized monthly Project operations in the RiverWare model do not represent historical monthly Project operations to an acceptable degree to model non-historical hypothetical scenarios and how Project operations would change under hypothetical, non-historical conditions on a monthly basis. (page 22).*

Response:

As shown in the tables and figures in Section 28.0, the ILRG Model is well calibrated on a seasonal and annual basis and also generally matches the patterns of the monthly flows during the irrigation season and non-irrigation season. Because the robust performance of the ILRG Model is achieved with rules that facilitate dynamic response to changing conditions, it is my opinion that ILRG Model produces reasonable and reliable results in simulating alternative scenarios.

Coors Opinion 36 *- When results from the New Mexico experts' model runs are temporally aggregated to annual averages and spatially aggregated into large project areas (Rincon, Leasburg, and Mesilla), the uncertainty in the results is reduced. The simplest way to limit uncertainty in data, especially in the case of modeling the LRG system would be to aggregate. When data is aggregated spatially and/or temporally, the uncertainty in its values decreases. (page 22).*

Response:

There is agreement that aggregating results temporally and spatially reduces uncertainty in the ILRG Model results. Such aggregation is reasonable and appropriate in assessing the model calibration, interpreting the model results, and in using the model to evaluate the claims and counterclaims in this case.

Coors Opinion 37 *- Table 5 shows the same set of calibration results as were presented in Section 6.1.1, but model results are aggregated to an annual timestep. When comparing Table 5 to Table 2 (Section 6.1.2, above) it is apparent that the performance improves. Further improvement would be expected by spatially aggregating within the ILRG model as well. The results still show significant problems with the calibration of the model even at the annual level, and thus specific quantitative annual results from the ILRG model are informative, but still not reliable. (page 23).*

Response:

As discussed extensively above, it is reasonable and appropriate to aggregate and assess the ILRG Model results primarily using irrigation season totals. There is also some utility in assessing the model performance in simulating the Rio Grande flows at the El Paso and Fort Quitman gages on the basis of annual totals from an overall mass balance perspective because the simulated flows at these gages integrate all upstream operations.

The annual results presented in Table 5 of the Coors Supplemental Report and all other annual totals presented in the report and in backup spreadsheets are plagued with an arithmetic error. All of the annual totals were computed by Excel formulas based on the sum of the monthly values from one December through the next December. In other words, all annual totals reflect the sum of 13 monthly values. For example, the annual flow for 2010 was computed as the sum of the monthly flows from December 2009 through December 2010.

Coors Opinion 38 *- Considering Run 2 as the baseline or 1938 Compact condition and Run 1 as the historical deviation from the 1938 Compact condition, comparing results from the two runs at an appropriate spatial and temporal scale shows the impacts of groundwater pumping throughout the basin as all other processes that might affect the dynamics of water in the system are the same. Comparing results from these two scenarios isolates the impacts of groundwater pumping on surface water conditions, groundwater conditions, and Project operations. The results clearly substantiate Texas's primary claim. (page 24).*

Response:

It is illogical and inappropriate to use the results from Run 2 of the ILRG Model when all pumping is turned off (New Mexico, Texas, and Mexico) to attempt to substantiate the Texas claim that New Mexico pumping has reduced the supply to Texas. Run 2 does not isolate the effects of New Mexico's pumping on deliveries to Texas. The impacts of pumping by Texas in the Mesilla basin and the Hueco basin contribute to computed differences in the ILRG Model results for Run 2 and Run 1.

Coors Opinion 39 *- Dry periods such as the mid-1950's when pumping in New Mexico was prevalent are evident by the depleted groundwater condition. It is evident too that the duration of depleted groundwater conditions is multiple years, and that the groundwater condition remains somewhat depleted for the remainder of the run after 1950. This is consistent with the Texas claims and illustrates why Texas chose to develop a model with an annual stress period. (page 26).*

Response:

The fact that the ILRG Model simulates multi-year impacts to ground water elevations during dry periods does not mean that a model with annual stress periods is appropriate for use in analyzing the Texas complaint. While impacts to ground water storage are of interest in this case, the impacts to Project surface water supplies are the primary focus. As has been clearly demonstrated through analyses of historical data and through the simulations using the ILRG Model, impacts of pumping, changes in irrigation practices, and changes in Project operations affect surface water deliveries on a monthly or seasonal basis. The typical rapid response of drains to pumping and irrigation recharge is illustrated in **Figure 23-1** and **Figure 23-2** that are discussed in the response to Coors Opinion 8.

Coors Opinion 40 *- Clearly, the seepage out of the Rio Grande in these service areas in New Mexico is significantly greater in the historic scenario, Run 1, than in the no pumping baseline scenario, Run 2. (page 28).*

Response:

It is not appropriate to evaluate the effects on river seepage caused by New Mexico pumping using Run 2 (All Pumping Off). See the response to Coors Opinion 38.

Coors Opinion 41 *- Finally, New Mexico's RiverWare model simulates an idealized version of the determination of the annual allocation for EPCWID for each year of the run. Results show that the EPCWID allocation is negatively impacted by the historical pumping represented in Run 1 compared to the no pumping condition of Run 2. (page 28).*

Response:

It is not appropriate to evaluate the effects on Texas allocations caused by New Mexico pumping using Run 2 (All Pumping Off). See the response to Coors Opinion 38. As discussed in Section 30, New Mexico pumping impacts irrigation season deliveries to EPCWID by an average of 17,800 AF during 2006-2017. This is much less than the impact of the 2008 OA on New Mexico computed in Run 11 that averaged 54,600 AF during the same period.

Coors Opinion 42 *- A comparison of the flows in the river at El Paso between Run 2 and Run 1 of New Mexico's ILRG model clearly indicates that pumping in New Mexico has negatively impacted flows at El Paso. (page 29).*

Response:

It is not appropriate to evaluate the effects on Rio Grande at El Paso flows caused by New Mexico pumping using Run 2 (All Pumping Off). See the response to Coors Opinion 38. In any event, the El Paso gage is not a Compact delivery point and changes in El Paso flows caused by New Mexico pumping are not an appropriate measure of impacts to Texas.

Coors Opinion 43 *- Comparing Run 1 and Run 2 and their results for El Paso flows provides an answer from New Mexico's own model to Spronk and Hydros' repeated contentions that the Texas analysis in general, and Brandes's analysis in particular, is "overly-simplistic" and that the depleted El Paso flows issue is actually much more complex with many possible explanations. Run 1 and Run 2 are formulated to isolate the effects of pumping with <u>all else equal</u>. The Run 2 scenario as conceived by New Mexico experts is very similar in concept to a 1938 Compact condition of the basin. It simulates a condition in which there is no pumping throughout the LRG basin, as was the case during the 1930-1950 period. It is striking how similar the 1930-1950 double mass analysis data and extended trend line from Brandes' report are to the same double mass curve generated from the ILRG model Run 2 results. (page 30).*

Response:

Mr. Coors is incorrect in stating that there was no pumping in the LRG Basin during the 1930-1950 period. Large scale development of supplemental irrigation wells commenced in the late 1940s, and non-irrigation Irrigation pumping for M&I and other uses started earlier, most notably in the El Paso and Juarez areas.

The general long-term agreement between change in El Paso flow shown in the Brandes double-mass curve (as revised by Coors) and the ILRG Model (Run 2 vs. Run 1) is a validation of the efficacy of the ILRG Model.

Figure 15 in the Coors Supplemental Report compares cumulative <u>annual</u> El Paso flows from the revised Brandes double-mass curve analysis against the ILRG Model results. These comparisons of annual flows do not distinguish changes in flows during the irrigation season from changes in flows during the non-irrigation season. As described above, it is the changes in irrigation season flows that are most important in this case, with changes in irrigation season deliveries to the end users being the relevant measure of impacts, not changes in flow at the El Paso gage.

When all of the pumping in the Rincon and Mesilla Valleys is turned off in the Texas Model, far too much water shows up at El Paso, more than shown by the Brandes double-mass curve analysis because of the lack of re-operation in the Texas Model. This is clear evidence of the failure of the Texas Model to produce reasonable and believable results.

Coors Opinion 44 *- The New Mexico models corroborate that the observed decrease in flows at El Paso from the time when groundwater pumping began in New Mexico appears to be rightly attributed to this pumping. (page 32).*

Response:

The results from Run 2 cannot be used to attribute the effects of New Mexico pumping because all pumping is turned off in Run 2, including pumping by Texas and Mexico in the Mesilla and Hueco basins. See the response to Coors Opinion 38.

Coors Opinion 45 *- Modeling monthly Project reservoir operations is not necessary to demonstrate the impact of New Mexico groundwater pumping on deliveries to Texas water users, as has been substantiated throughout this report and is demonstrated convincingly in Dr. Hutchinson's report describing the Texas model. However, referencing these results from the New Mexico experts' runs of their own model further refines the narrative of how New Mexico's pumping impacts on Texas water users. (page 32).*

Response:

As discussed extensively in the SWE Report, the Texas Model is unreliable because it includes no capability for dynamic simulation of Project operations. In order to approximately match the historical change in El Paso flow evident in the Brandes double-mass curve analysis, Dr. Hutchison turns off only 60% of the pumping by New Mexico and Texas in the Rincon and Mesilla basins. Because of the lack of reoperation in the Texas Model, turning off all of the pumping in the Rincon and Mesilla basins causes too much water to flow out the bottom of the Texas Model at El Paso.

Notwithstanding the lack of reoperation, the Texas Model runs performed by Dr. Hutchison are not appropriate for attribution of impacts caused by New Mexico pumping because these runs also reflect the effects of pumping by Texas wells in the Mesilla basin.

Coors Opinion 46 *- Table 7 shows that during this 1950-1956 drought period, as a result of groundwater pumping, the impact to groundwater elevations grows, the impact to seepage increases and the allocation to EPCWID is negatively impacted as well. These values are bordered in orange in Table 7. (page 33).*

Response:

The results from Run 2 cannot be used to attribute effect of New Mexico pumping because all pumping is turned off in Run 2, including pumping by Texas and Mexico in the Mesilla and Hueco basins. See the response to Coors Opinion 38.

Coors Opinion 47 *- What is important about this first sequence of years is that it shows that the negative impacts of groundwater pumping continue to accrue even when the basin is no longer in drought and allocations return to full. (page 34).*

Response:

Impacts to ground water storage can reasonably persist even when full supply conditions return. That the ILRG Model simulates this phenomenon shows that the ILRG Model is robust and can simulate both short-term and long-term impacts from pumping. Mr. Coors has not shown how impacts to ground water storage in New Mexico are injurious to Texas.

Coors Opinion 48 *- While there is no realized impact to the allocation during these years, there is a growing deficit in stored water in the reservoirs. This storage differential can be characterized as a growing potential impact to Texas. (page 34).*

Response:

The results from Run 2 cannot be used to attribute effects of New Mexico pumping because all pumping is turned off in Run 2, including pumping by Texas and Mexico in the Mesilla and Hueco basins. See the response to Coors Opinion 38.

Potential impacts are not the same as actual impacts. Depletions to reservoir storage do not translate into impacts on Project deliveries until the storage account(s) empty. Impacts from pumping can accumulate in storage during full allocation years during which time portions of the accumulated impacts are lost to evaporation and seepage. Reservoir spills will also cancel out accumulated storage impacts.

Coors Opinion 49 *- When New Mexico pumps groundwater, it effectively and inappropriately borrows Project water from the future. Some of this borrowed water ends up impacting New Mexico by the same mechanism described above. But because New Mexico water users receive the benefit of the water when it is pumped from the ground, the impact does not represent an injury. They effectively borrowed from their own future water. There is an injury to Texas water users, however, because a significant portion of the Project water New Mexico borrowed through pumping belongs to the Texas as defined* *in the 1938 Rio Grande Compact. This is the essence of the complaint and the source of the injury to Texas water users. (page 35).*

Response:

The results from Run 2 cannot be used to attribute effects of New Mexico pumping because all pumping is turned off in Run 2, including pumping by Texas and Mexico in the Mesilla and Hueco basins. See the response to Coors Opinion 38.

Mr. Coors' assertions about future impacts caused by New Mexico pumping also apply to Texas pumping. The extent to which New Mexico or Texas pumping impacts Project water deliveries in the future depends on whether such pumping causes depletions of surface water flow that when translated through lens of Project operations results in material reductions in deliveries of Project water to the end users in Texas and/or New Mexico. The only way to evaluate such impacts is using the ILRG Model with its capability for dynamic reoperation response to changes to ground water and surface water flows caused by pumping. The Texas Model is incapable of such analysis.

Coors Opinion 50 *- Rather ILRG model results indicate that pumping in the Hueco has no significant impact on releases from Caballo Reservoir or Rio Grande flows at El Paso. (page 35).*

Response:

As described in the response to Ferguson Opinion 3. Hueco pumping does impact upstream Project operations, including Caballo Reservoir releases and El Paso flows. However, in many years some, but not all, of these impacts are offset by EPW WWTP discharges.

Coors Opinion 51 *- The appropriate conclusion from this simple comparison (Run 6 vs. Run 2) is that pumping in the Hueco Bolson basin has essentially no impact on Project operations or flows in the river at El Paso. Pumping in the Hueco Bolson resulted in differences in the releases from Caballo and the flows at El Paso by less than 1% on an absolute basis, and the changes were essentially unbiased, meaning that they were equally often increased as decreased. (page 37).*

Response:

Differencing the results between Run 2 (All Pumping Off) and Run 6 (Rincon-Mesilla Pumping Off) to compute the effects of pumping in the Hueco basin assumes that the ILRG Model is linear, which it is not. A more appropriate way to evaluate the effects of Hueco pumping is to make a run of the ILRG Model with the Hueco pumping turned off and compare the results to Run 1 (All Pumping On). This run and several variants are described in Section 31.0 (Runs 14, 14a, 14b, 14c, and 14d) and also in the response to Ferguson Opinion 3.

Coors Opinion 52 *- In order to make a comparison with Run 1 that isolates Hueco Bolson pumping, Texas legal counsel directed Precision to develop and conduct a run of the ILRG model that was not included in the set of runs disclosed by the New Mexico experts. Precision designed a scenario in which all groundwater pumping in the Hueco Bolson groundwater basin is turned off. This run of the ILRG model is titled "Run A". Comparing Run A back to New Mexico Run 1 provides an estimate of the impact of turning historical Hueco Bolson pumping off while maintaining historical pumping in the Rincon and Mesilla basins. (page 37).*

Response:

While Mr. Coors said that he turned off all ground water pumping in the Hueco in his "Run A" of the ILRG Model, review of the input and output files that he disclosed for this run shows this was not the case. The following are among the errors that were discovered in the configuration of Run A:

- Supplemental irrigation pumping and M&I pumping in Mexico were left on,
- M&I pumping in Texas by entities other than EPW was left on,
- All WWTP discharges (Haskell, Bustamante, Socorro, Juarez, and Fabens) were left on, and
- All urban deep percolation was left on.

Because of these errors, the results from the Run A made by Mr. Coors are not usable.

Coors Opinion 53 *- My conclusion from this comparison, much the same as the first one, is that according to the ILRG model, pumping in the Hueco Bolson basin has virtually no impact on Project operations or flows in the river at El Paso. (page 39).*

Response:

Because of the errors with how Run A was configured, the results from this run are not a reliable indication of the effects of Hueco pumping.

24.0 RESPONSE TO MORAN SUPPLEMENTAL REPORT

Ms. Jean Moran of Stetson Engineers, Inc. prepared a September 17, 2019 supplemental expert report on behalf of the United States ("Moran Supplemental Report") that described further review and analysis using the Texas Model and included two new model runs.

SWE was asked by legal counsel for New Mexico to review the Moran Supplemental Report and to prepare expert opinions to respond the opinions of Ms. Moran. A lack of response regarding a particular issue should not be interpreted as tacit agreement with the Moran opinions on that issue.

All of the criticisms of the Texas Model structure and inputs that are described in the SWE Report and elsewhere in the SWE Rebuttal Report also apply to the Texas Model runs described in the Moran Supplemental Report. The responses described below do not restate these criticisms but rather focus on particulars of the Texas Model runs performed by Ms. Moran.

Moran Opinion 1 *- To assess the impacts of pumping on surface water supplies, the Historical model run3 was modified to account for no pumping in an iterative process. First the MODFLOW WEL package was adjusted to eliminate irrigation, urban, and domestic pumping; in addition, deep infiltration attributed in the Texas Model to groundwater used for irrigation and urban supply was also eliminated. The Texas Model was rerun using these no pumping conditions. The No Pumping model run was compared to the Historical model run to evaluate and quantify changes (increases) in annual streamflow in the Rio Grande at El Paso Narrows that would have been available in the absence of groundwater pumping in New Mexico. These new No Pumping model run results with the final Texas Model update and confirm the model results described in our May 31, 2019 report.*

Response:

The first step in Moran's no-pumping run of the Texas Model was to turn off the irrigation pumping, non-irrigation pumping (urban and domestic), deep percolation from irrigation pumping, and deep percolation from urban pumping. Critically absent from this list of changes was turning off the WWTP discharges from the urban pumping. Without turning off these WWTP discharges, the Moran run does not simulate the offset from WWTP discharges when the results from this run are compared to the historical run. This error inflates the simulated impacts from pumping.

In the Moran no pumping run, all pumping in the Texas Model was turned off, including irrigation and non-irrigation pumping in the Texas portion of the Mesilla Valley. Therefore, the computed differences between the historical run and the no-pumping run reflect impacts caused by New Mexico pumping and Texas pumping.

Moran Opinion 2 *- The analysis for this supplemental report attempts to reasonably distribute the additional surface water made available by eliminating pumping in order to evaluate the sensitivity of the Texas Model to show the effect of no pumping on the surface water supplies for the Project. To make this analysis, adjustments were made to the MODFLOW Stream Flow Routing (SFR) package to distribute the increases in Rio Grande streamflow at El Paso Narrows calculated in the No Pumping model run to upstream diversions and farm deliveries based on historical distribution. The Texas Model was iteratively rerun to account for Project water deliveries and Rio Grande streamflow at El Paso Narrows gage.*

Response:

As has been discussed at length by the New Mexico experts, one of the fundamental flaws of the Texas Model is the absence of mechanisms for simulating the water allocation and delivery processes of the Rio Grande Project. The absence of such mechanisms causes the results from Texas Model runs that were presented in the Hutchison Report to be generally of little use because there is no simulated response of the Project operation to the changes simulated in alternative scenarios (e.g., reduced pumping scenarios). In the alternative scenario runs of the Texas Model runs that were presented by Dr. Hutchison, the reservoir releases and diversions are fixed at historical levels in all runs. Therefore, simulated changes in surface flows simply flow downstream and out of the model domain at the Rio Grande at El Paso gage.

Ms. Moran has attempted to remedy the severe shortcomings of the Texas Model by developing a crude iterative redistribution procedure that redistributes a portion of simulated changes in flow at El Paso to upstream diversions. This is tacit acknowledgement of the shortcomings caused by the lack of reoperation in the Texas Model.

While the redistribution mechanism implemented by Ms. Moran represents some improvement to the Texas Model, it has substantial shortcomings that create unrealistic results, especially in comparison to the more realistic reoperation capability that is inherent in the ILRG Model. The Moran process redistributes on average 84% of the simulated additional annual flow at El Paso to upstream river diversions at the Arrey, Leasburg, Eastside, and Westside Canals in proportion to relative historical annual diversions. The additional flow allocated to each canal is then distributed to terminal diversions (FHG deliveries) within each canal in proportion to the simulated values in the calibration run. This simple proportional redistribution of the additional El Paso flow to the upstream canals assumes a linear redistribution of the additional flow to the upstream canals in a highly nonlinear system. The simplified redistribution process used by Ms. Moran does not consider the following factors that would affect the distribution of additional river flow in no pumping or reduced pumping scenarios.

- Monthly and seasonal distribution of the additional annual El Paso flow,
- Changes in releases from Caballo Reservoir,
- Limits on canal capacity,
- Whether EBID or EPCWID had already used their annual allocations,
- Whether EBID or EPCWID already had sufficient supply to meet their irrigation demand, and
- Effects of the 2008 OA on how pumping impacts are distributed.

A comparison of the results of the crude redistribution performed by Ms. Moran to the results from the ILRG Model for the no Rincon-Mesilla pumping run (Run 6) is included in Section 30.0, and demonstrates the severe limitations of the crude Moran approach.

Moran Opinion 3 *- A second analysis using the Texas Model was made to evaluate the effects of a 60% reduction in total pumping (40% of the amount of pumping contained in the Texas Model's Historical model run) on Rio Grande flow and Project diversions. ("40% Pumping model run"). This model run was conducted with water budget and model files that were not available at the time of Stetson's May 31, 2019 report. The 40% Pumping model run further examines the Texas Model performance by making modifications to the WEL and SFR files, and comparing these results with the Historical and No Pumping model runs. The same methodology of model iterations performed for the No Pumping model run were applied to the 40% Pumping model run.*

Response:

Ms. Moran applied her crude redistribution process to the 40% pumping run of the Texas Model in which pumping was reduced by 60%. All of the criticisms described above for the No Pumping Run also apply to the 40% Pumping Run.

It is also important to point out the conceptual inconsistencies in the results of the 40% Pumping Run presented by Ms. Moran and the 40% Pumping Run presented by Dr. Hutchison.

Dr. Hutchison presented numerous simulations of alternative scenarios using the Texas Model in his May 2019 expert report. Among those runs was the 60% reduced pumping run (i.e., 40% Pumping Run). Dr. Hutchison identified this as a key run because it produced an average of 73,000 AF/y of Rio Grande flow at El Paso during 1951 – 2016 which he claimed was similar to the result of the double-mass curve analysis performed by Dr. Brandes that showed that the Rio Grande at El Paso flow had changed by an average of 79,000 AF/y during the same 1951-2016 period.

When Ms. Moran made a 40% Pumping Run of the Texas Model, she reported that it showed an average increase in Rio Grande flow at El Paso of 61,700 AF/y during 1951 – 2016, which is about 15% less than what Dr. Hutchison presented in his report. Then, when Ms. Moran applied her crude redistribution procedure to the 40% Pumping Run, the revised average annual increase in El Paso flow averaged only 26,800 AF/y. This is 63% less than the result presented by Dr. Hutchison, and 66% less than the result from the Brandes double-mass curve analysis. Notwithstanding all of the flaws in the crude redistribution by Ms. Moran described above, the results of her re-operated 40% Pumping Run appear to undercut the modeling results presented in the Hutchison expert report.

25.0 RESPONSE TO MORAN SECOND SUPPLEMENTAL REPORT

Ms. Jean Moran of Stetson Engineers, Inc. prepare a May 5, 2020 supplemental expert report on behalf of the United States ("Moran Second Supplemental Report") that included analyses and comparisons of the New Mexico ILRG Model and the Texas Model.

SWE was asked by legal counsel for New Mexico to review the Moran Second Supplemental Report and to prepare expert opinions to respond the opinions of Ms. Moran. A lack of response regarding a particular issue should not be interpreted as tacit agreement with the Moran opinions on that issue.

All of the criticisms of the Texas Model structure and inputs that are described in the SWE Report and elsewhere in the SWE Rebuttal Report also apply to the Texas Model runs described in the Moran Second Supplemental Report. The responses described below do not restate these criticisms but rather focus on particulars of the Texas Model runs performed by Ms. Moran.

The opinion numbering in this section picks up where the opinion numbering in the responses to the Moran Supplemental Report left off.

Moran Opinion 4 *- The ILRGM assumptions for the Baseline Run 1 appear to introduce noticeable differences (i.e. a pre/post 1985 bias) when compared to the Calibration Run 0 and gaged data. The assumptions that are part of the 'operational tuning' process should be reviewed to evaluate what causes these differences, and make the necessary improvements to either fix the observed differences or quantify the uncertainty that is introduced. (page 1).*

Response:

Ms. Moran points out differences in the performance of the ILRG Model before and after 1985. In particular, she highlights differences in simulated Caballo Reservoir releases (pre-1985: +2.5%; post-1985 -3.9%) and simulated El Paso flows (pre-1985: +3.6%; post-1985 -2.1%. Her summaries are based on comparison of model bias during 1940-1984 (pre-1985) and 1985-2017 (post-1985).

It is common for simulation models of complex system to vary in performance throughout a long study period. The bias (average % difference between modeled and measured values) for simulated Caballo releases and El Paso flows before and after 1985 fall within the within the "Very Good" performance evaluation criteria for PBIAS that are presented in Moriasi et al. (2015). These criteria are described in more detail in Section 28.0. Moreover, Ms. Moran presented no information or analysis to quantify the impact on model predictions that results from the small differences in average percent error before and after 1985.

Also noteworthy is that the differences between the pre- and post-1985 bias in the ILRG Model have narrowed for the Caballo releases and the Rio Grande at El Paso flows as summarized below.

Comparison of Pre- and Post-1985 PBIAS
Original (v106) and Updated (v116) ILRG Models

Output	ILRG Model (v106)	ILRG Model (v116)
Caballo Release		
Pre-1985 (1940-1984)	+2.5%	-0.9%
Post-1985 (1985-2017)	-3.9%	-0.7%
Total	-0.2%	-0.8%
Rio Grande at El Paso		
Pre-1985 (1940-1984)	+3.6%	-3.0%
Post-1985 (1985-2017)	-2.1%	2.3%
Total	1.2%	-0.6%

Moran Opinion 5 *- The mean absolute error ("MAE") for the annual differences in gaged and Baseline Run 1 simulated releases is 82,160 acre-feet/year (14% of average annual gaged releases). The root mean square error ("RMSE") for Caballo Dam gaged releases and Baseline Run 1 is larger, 110,900 acre-feet/year (18% error), because extra weight is given to larger differences. Both MAE and RMSE average errors indicate that some elements of the system are not captured correctly in the tuning process from Calibration Run 0 to Baseline Run 1. Further evaluation is warranted to determine the effects and uncertainties that are being introduced by the tuning process developed by the New Mexico experts for their Baseline Run 1. (page 7).*

Response:

As summarized in Section 28.0, the MAE and RMSE for annual Caballo releases in the updated ILRG Model are 47,600 AF/y and 58,100 AF/y, respectively. These values are significantly lower than the value that Ms. Moran computed for the prior version of the ILRG Model (version 106). All rule-based simulation models of complex system will produce results that do not exactly match historical values. The excellent overall performance of the updated ILRG Model is discussed at length in Section 28.0.

Moran Opinion 6 *- The RW Model manages the Caballo Reservoir more evenly than historical practices resulting in more spills in the late-1980s to mid-1990s indicated by the upper maximum reached on the monthly graph during this time period. The 'tuned' reservoir management does not appear to capture the historical variations that took place, and may contribute to the differences seen in the Caballo Dam releases (discussed in the previous paragraph). (page 8).*

Response:

Rules were added in the updated ILRG Model to increase reservoir releases and canal diversions in spill years. This improved the model performance during the wetter-than-average period of the 1980s and 1990s.

Moran Opinion 7 *- A comparison of the main canal diversions simulated in Baseline Run 1 (bottom graph, Figure 5) to the Calibration Run 0 (top graph, Figure 5) shows an average annual decrease of about 3% in diversions from 1951 to 2016, a period that coincides with increased groundwater pumping. The RW Model Baseline Run 1 shows an average of 11,800 acre-feet/year lower and the NMR-M Model shows an average of 13,200 acre-feet/year lower than the Calibration Run 0 for canal diversions. The RW Model estimates relatively consistent year-to-year canal diversions from 1984 through 2003 in the Baseline Run 1 that do not capture the variability observed during that same historical Calibration Run 0 time period. The Baseline Run 1 also underestimates the recent canal diversions in 2007-2008 and 2015-2017. The RW Model's 'tuned' Baseline Run 1 manages the canal diversions more evenly than historical practices (Calibration Run 0) resulting in overall decreased canal diversions compared with historical conditions that introduce some uncertainty into the predicted model results. The rule-based Baseline Run 1 underprediction of diversions from the river for the Rincon Mesilla Basins should be evaluated by the New Mexico experts to see if this introduces a bias in the proportioning of available Project water. (page 9).*

Response:

The average under-prediction of Rincon-Mesilla diversions by 11,800 AF/y in the ILRG Model described by Ms. Moran represents 3.0% of the Rincon-Mesilla diversions that average 400,000 AF/y. A 3.0% PBIAS qualifies as Very Good model performance under the criteria presented in Moriasi et al. (2015).

Moran Opinion 8 *- For the Baseline Run 1, on-farm surface water and groundwater required for meeting irrigation water demands are calculated by the RW Model for the ILRGM based on the 'tuned' rule-set developed to simulate historical conditions (Carron* *and Setzer, 2019). On average, the Baseline Run 1 FHG deliveries simulated by the RW Model (Table 4, Attachment B) are within 2,700 acre-feet/year of the FHG deliveries simulated in the Calibration Run 0 for the period 1951-2016. About 17% of the time (13 years),19 there is more than a 25% difference (± 45,000 acre-feet) in FHG deliveries between the Baseline Run 1 and the Calibration Run 0 (Figure 6 bottom graph). The MAE and RMSE for the annual differences between Calibration Run 0 and Baseline Run 1 FHG deliveries are 28,700 and 43,100 acre-feet/year, respectively, corresponding to 14% and 22% of the average annual historical FHG deliveries of 179,700 acre-feet/year. Both MAE and RMSE average errors indicate that that some elements of the system are not captured correctly in the tuning process from Calibration Run 0 to Baseline Run 1. Further evaluation should be undertaken by the New Mexico experts to determine the effects and uncertainties that are being introduced by the tuning process developed for their Baseline Run 1. (page 11).*

Response:

The simulated FHG deliveries in the ILRG Model represent the integration of the simulated Project operations, river operations, and canal system operations. Simulation of seasonal FHG deliveries are bound to be greater than measured in some years and less than measured in other years. The average underprediction in the simulated EBID and EPCWID FHG deliveries in the updated ILRG Model is less than 5% as shown in the results presented in Section 28.0. This qualifies as "Very Good" performance based on the PBIAS criteria presented in Moriasi et al. (2015).

Moran Opinion 9 *- Supplemental groundwater pumping for irrigation was initially estimated by Sullivan and Welsh (2019) for the ILRGM Calibration Run 0. The RW Model simulates about 7.3% (10,300 acre-feet/year) more irrigation pumping than the TX-RG Model (Table 5) during 1951 to 2016. The upper graph of Figure 7 shows the annual FHG deliveries of surface water and the supplemental pumping that make up the applied water simulated by the RW Model Calibration Run 0 and the TX-RG Model Calibration Run. Both the ILRGM and the TX-RG Model develop applied water based on crop irrigation requirements and on-farm efficiency assumptions. Figure 7 (upper graph) shows the annual differences in the two models – the RW Model calculates higher applied water than the TX-RG Model pre-1985, and lower applied water after 1985. (page 12).*

Response:

The pumping in the calibration run (Run 0) of the ILRG Model is computed by the on-farm simulation algorithm in the RiverWare Model. The results are very similar to but not exactly the same as the pumping computed in the SWE CFB Model and reported in the SWE Report.

Differences in the simulated Rincon-Mesilla pumping between the ILRG Model and the Texas Model are due to differences in (a) irrigated area, (b) crop irrigation water requirements, and (c) farm headgate deliveries. These differences are described in Section 12.0 of the SWE Report.

Moran Opinion 10 *- For the Calibration Run 0, the RW Model and NMR-M Model simulate streamflow out of the Mesilla Basin at the USGS streamflow gage 08364000 for Rio Grande at El Paso Narrows (Figure 1). When compared with the USGS gage 08362500 for Rio Grande below Caballo Dam, this streamflow data represents the net effect from hydrologic conditions, Rio Grande Project releases, canal diversions, seepage gains/losses, and return flows to the river within the Rincon and Mesilla Basins. The annual gaged and simulated data for these two USGS gages from 1940 to 2017 (model period) are shown in Figure 2 upper graph. For the Calibration Run 0, the RW Model simulates the long-term average Rio Grande gaged flows at El Paso Narrows almost exactly, and the NMR-M Model matches closely, within 300 acre-feet/year. The annual differences of Rio Grande flow at El Paso Narrows simulated by the RW Model compared with gaged data are shown on the upper graph of Figure 2, ranging from -74,600 acre-feet in 1979 to 96,300 acre-feet in 1948. The TX-RG Model was calibrated to the Rio Grande gaged flows at El Paso Narrows, and matches almost exactly as shown on Figure 2 upper graph. (page 15).*

Response:

The simulated flows in the updated ILRG Model for the Rio Grande at El Paso reasonably match the historical flows. This is reflected in the calibration statistics presented in **Table 28-1**. The exact match of the simulated and observed flows at the El Paso gage in the Texas Model is the result of inappropriate calibration techniques employed by Dr. Hutchison to adjust river bed conductance values and canal spills to drains in every stress-period to reproduce the historical gage flows (Barth, 2019).

Moran Opinion 11 *- New Mexico applied the ILRGM to ten different no-pumping scenarios by turning off groundwater production within different geographical areas (basins, states, country) or different entities (irrigation district, DCMI). The Rio Grande Project's operational criteria and farm processes developed for the Baseline Run 1 were applied to* *these different no-pumping conditions. In the absence of pumping, groundwater levels are higher, there are more gaining reaches in the river (and less river seepage (loss) to the aquifer), canals, and drains. This additional water in the river system becomes available for Project deliveries, affecting canal diversions and Caballo releases. The RW Model accounts for changes and feedback in Project operations and provides a new estimate of the surface water operations for assessing the impacts of pumping on Project supplies. The ILRGM's project re-operation was used to evaluate no-pumping scenarios where additional streamflow in the Rio Grande was allocated to both EBID in New Mexico and EPCWID in New Mexico and Texas based on the operational rules established in Baseline Run 1. (page 16).*

Response:

The changes and feedback in Project operations described by Ms. Moran in simulations of no-pumping scenarios and other scenarios are essential elements of the ILRG Model that simulate the real-world response of the Project operations to changes in conditions. This is one of many reasons that the ILRG Model is superior to Texas Model.

Moran Opinion 12 *- Two of the ILRGM model scenarios addressed no pumping in the Rincon and Mesilla Basins: Run 2 simulated no groundwater pumping in the Rincon, Mesilla, and Hueco Basins; and Run 6 simulated no groundwater pumping in the Rincon and Mesilla Basins with continued pumping in the Hueco Basin. This section of the supplemental report summarizes the effects of pumping in the Rincon and Mesilla Basins; compares the differences between the existing Run 2 and Run 6 simulated by the ILRGM (that also included linking the Hueco Model23); and compares these results with the TX-RG Model no-pumping results. Comparing the differences in Run 2 and Run 6 developed by New Mexico would show the effect of pumping in Hueco Basin on the conditions in the Rincon-Mesilla Basin. (page 16).*

Response:

Because of the non-linearities in the ILRG Model, it is not appropriate to compute the differences between Run 2 (All Pumping Off) and Run 6 (R-M Pumping Off) as a representation of the effects of pumping in the Hueco Bolson. The effects of Hueco pumping are more reasonably and accurately determined in a scenario in which the Hueco pumping is turned off by itself rather than differencing other model runs. See the discussion of the ILRG Model runs in Section 30.0

Moran Opinion 13 *- Stetson conducted an additional analysis using the RW Model and the NMR-M Model to evaluate the predicted effects of 40% pumping (60% reduction in Baseline Run 1 pumping) in the Rincon and Mesilla Basins in order to compare the RW Model predictions with a similar model run by Stetson using the TX-RG Model (Moran, 2019). The 40% R-M Pumping Run further evaluates the performance of the linked models and the ability to predict changes to Rio Grande Project operations (e.g. releases, diversions, deliveries) resulting from reduced pumping in the Rincon and Mesilla Basins. In addition, the changes to Rio Grande streamflow at El Paso Narrows and groundwater in storage are compared with the Baseline Run 1 and the TX-RG Model. (page 18).*

Response:

As discussed in the response to Moran Opinion 3, the 40% Pumping Run performed by Ms. Moran illuminate inconsistencies with the Texas Model runs presented in the Hutchison Report. Based on these inconsistencies, it is unclear what the purpose of the 40% Pumping Run is.

Moran Opinion 14 *- The RW Model input variables for No R-M Pumping Run 6 were adjusted for the 40% R-M Pumping Run. Agricultural and DCMI groundwater pumping variables were adjusted to account for 40% of the Baseline Run 1 pumping in the Rincon and Mesilla Basins. The corresponding variables for urban return flows to groundwater30 and wastewater treatment plan (WWTP) return flow to surface water were also adjusted to evaluate a 60% reduction in groundwater pumping used for the Baseline Run 1. There was one exception, the Las Cruces municipal WWTP return flow was adjusted to account for no changes to 10% of its water supply imported from outside of the basin. (page 19).*

Response:

When evaluating the effects of New Mexico pumping in the Rincon and Mesilla basins, WWTP returns that result from water imported from outside the basin should be turned off in order to compute an appropriate offset from that imported supply against the impacts of in-basin pumping. This includes turning off the return flows from Las Cruces use of imported water from its Jornada wells.

Moran Opinion 15 *- For the 40% R-M Pumping Run, the RW Model and NMR-M Model show about 9,200 acre-feet/year (1.5%) decrease in Project releases from Caballo Dam (Table 3) under reduced pumping conditions (Table 8). The RW Model and NMR-M Model simulated an average increase of Rio Grande streamflow at El Paso Narrows from 1951-2016 of 49,500 acre-feet/year and 49,700 acre-feet/year, respectively. The RW Model predicts a 7.6% (29,400 acre-feet/year) increase in canal diversions and an 11.2% (20,400* *acre-feet/year) increase in FHG deliveries under 40% Pumping Run conditions compared to Baseline Run 1 for 1951 through 2016. Figure 8 upper graph shows the cumulative change in groundwater storage, averaging -8,200 acre-feet/year (Table 9) under 40% pumping conditions. The Rio Grande streamflow at El Paso Narrows for the 40% Pumping Run shows a partial recovery over historical conditions (bottom graph of Figure 10). Stetson was not able to make any adjustments to Caballo releases in the TX-RG Model described in the first supplemental report (September 2019) – resulting in an increase of surface water for the Project. The proportioning method used by Stetson with the TX-RG Model estimated more canal diversions and farm deliveries, resulting in 26,800 acre-feet/year of streamflow at El Paso Narrows (Table 8). (page 21).*

Response:

The inability to adjust the releases from Caballo Reservoir in the 40% R-M Pumping Run of the Texas Model represents a fatal flaw in that model and a serious shortcoming in the crude proportioning method developed and applied by Ms. Moran to reallocate simulated increase in El Paso flows to upstream diversions in the Texas Model.

Moran Opinion 16 *- Both models are able to make predictions and show that pumping in the Rincon and Mesilla Basins impact the Project. Neither New Mexico nor Texas provided an error analyses for their models to give a range of uncertainty of the results. The differences between the models is likely within the uncertainty of the models. Both the New Mexico and Texas models are numerical tools showing that pumping impacts the Project and cutting back pumping would improve Project performance. Both models have uncertainties. (page 23).*

Response:

While both the ILRG Model and the Texas Model can be operated to simulate impacts from pumping in the Rincon and Mesilla Basins, shortcomings in the Texas Model that include (a) use of overly coarse annual stress periods, (b) a limited geographic scope that excludes simulation of the area between El Paso and Fort Quitman, and (c) no ability to reasonably re-operate the Rio Grande Project in response to changes in water supplies in alternative scenarios results in the Texas Model being far inferior to the ILRG Model.

26.0 LOWER RIO GRANDE DATA

26.1 Hydrologic Data

All hydrologic data opinions provided in Section 3.0 (Lower Rio Grande Hydrologic Data) of the SWE Report remain valid.

New Mexico has received limited additional hydrologic and water use data from Texas, the United States, and others since the SWE Report was submitted. These data include annual Socorro WWTP discharge data from 1967-1984 and monthly volumes of drain water diverted at Fabens to Tornillo Canal via the Riverside Canal Extension from 1945-1983. These additional data were added to the SWDataSet. Backup for these additional data are provided with this disclosure. An updated summary of the estimated data in the SWDataSet reflecting replacement of the previously estimated Socorro WWTP discharges with actual data is provided in **Table 26-1.**

The records for Socorro WWTP discharges and drain water diverted at Fabens were used as inputs to the updated ILRG Model.

26.2 Rio Grande Project Data

All Rio Grande Project accounting data, information, summaries, and opinions provided in Section 4.0 (Rio Grande Project Accounting Data) of the SWE Report remain valid.

New Mexico has received limited additional Project accounting data from the United States since the original SWE Report was submitted. These data, which include monthly accounting records 2008 – 2019 and Project allocation records for 2019, are currently under review.

27.0 LOWER RIO GRANDE CANAL AND FARM BUDGET MODELS

All data, information, and summaries provided in Section 6.0 (Lower River Grande Canal and Farm Budget Models) of the SWE Report remain valid, with the exception of the CFB Models for the Hueco area from 1903 – 1937 that were revised and updated. This included the CFB Models for the following geographic areas:

- EPCWID (El Paso Valley),
- HCCRD,
- JID Unit 1,
- JID Unit 2, and
- JID Unit 3.

The revisions to the annual CFB Models of the Hueco area are summarized below, and more detailed descriptions are provided in **Appendix 27**.

- The Water Distribution Report records of diversions and FHG deliveries for the El Paso Valley were used for the years they are available (1920, 1921, 1923, 1927, 1931, 1933, 1934, 1936, and 1937).
- A switch was added to turn off Juarez sewage discharge to canals when the Mexico pumping is turned off.

The revised annual CFB Models for the Hueco area were provided to MMA for generating the FHG delivery and on-farm deep percolation inputs to the Hueco GW Model.

28.0 OVERVIEW AND ASSESSMENT OF UPDATED ILRG MODEL

Several modifications were made by Hydros to improve the RiverWare Model (Hydros 2020). A summary of modifications is provided in Section 28.1 below. The assessments of the ILRG Model in Section 8.0 of the SWE Report remain valid except as modified by the descriptions in Section 28.2.

28.1 Revisions to RiverWare Model (v116)

Hydros made several revisions to the RiverWare Model to correct or improve the model functioning in operational mode when rules are used to simulate operation of the Project and the LRG irrigation systems. Many of the improvements result from responses to comments from the United States and Texas experts, questions during depositions, and further model review prompted by the United States and Texas comments. The following is a brief summary of the revisions:

<u>Model Changes</u>

- <u>Project Allocation Period</u> – Revise the pre-allocation period to end in 1949 and start the pre-D1/D2 period (during which the D1/D2 Rules are simulated) in 1950. While the Project Histories report that 1951 was the first year that an annual allotment was in effect for the entire irrigation season, allotments were issued in prior years that were lifted before the end of the season. Simulating annual allocations beginning in 1950 improved model tuning.

- <u>Maximum Annual Allocations to U.S Districts</u> – Compute time-series inputs of the maximum annual allocations for EBID and EP1 in full supply years using the D2 Curve, the maximum annual Project releases that were previously determined for 1955 – 1993, and a full supply allocation to Mexico of 60,000 AF. Compute the annual allocations to EBID and EP1 in RiverWare during 1955 – 1993 based on the D1/D2 procedure with allocations limited to maximum annual allocations. The annual allocation to Mexico is computed using the D1 Curve and the usable water in Project storage.
- <u>Final Annual Allocation</u> – Compute a final allocation to EBID and EPCWID in October for purposes of computing the amount of carryover when the D3 + Carryover rules are in effect.

- <u>Mexico Allocation</u> – Correct the computation of the annual allocation to Mexico during 1951 – 2017 as 11.3486% of the amount determined from the D1 Curve.

- Diversion Charge when One District Is Diverting – When only one District is diverting Project water, charge that District the maximum of its canal heading diversions or the Caballo Reservoir release minus the diversion by Mexico at the Acequia Madre.

- Project Water Split – Revise the split of Project water to be 57% for EBID and 43% for EPCWID during the period from 1955-1979 rather than the 60%/40% split that was previously used.

- Reservoir Threshold Elevations – Revise the elevations in Elephant Butte Reservoir and Caballo Reservoir above which spills and flood control operations are simulated.

- Reservoir Operations in Spill Years – Increase the EBID and EPCWID waste percentages during reservoir spill years. The added waste is routed through the EBID and EPCWID systems without being charged against their allocations.

- Net Losses in Elephant Butte Reservoir to Caballo Reservoir Reach – Release water from Elephant Butte Reservoir to cover net losses in the Elephant Butte Reservoir to Caballo Reservoir reach.

- Reservoir Evaporation Estimate for D1/D2 Allocation – Revise the estimated monthly evaporation values for Elephant Butte and Caballo Reservoirs used in computing the total usable water in D1/D2 allocation to be the average of years when Project storage is at or below a full supply of approximately 790,000 acre-feet.

- Pre-1950 Caballo Reservoir Winter Releases – Simulate releases from Caballo Reservoir during the winter months before 1950 consistent with historical operation.

- ACE Credit – Revise the application of the ACE credit to be simulated only in the years that it was historically applied.

- EP1 Use of Fabens Drain Flows – Simulate historical use of Fabens drain flows by EP1 based on historical records (1945 - 1983) in historical Base Run and all alternative scenarios (except scenarios with increased use of Fabens drain flows).

- EPCWID Orders – Adjust EPCWID Orders for EPW WWTP discharges and use of Fabens drain flows. Revise the equation for computing EPCWID orders of Project water at American Dam by subtracting the EPW WWTP discharges to canals (Haskell, Bustamante, and Socorro) and the use of Fabens drain flows.

- EPCWID Waste – Revise EPCWID waste to be computed as specified percentages of canal heading diversions rather than bypass of a portion of the deliveries to certain EPCWID subareas.

- EPCWID Diversion Charges – Add the simulated canal loss in the Texas Mesilla from the NMR-M Model to the EP1 Mesilla diversion charges rather than charging EBID for all Mesilla canal losses. Credit EBID for 1.15 x revised EP1 Westside Canal diversion charges and 1.20 x revised Eastside Canal diversion charges.

- EPCWID Diversion Charges Option – Add an option to charge EPCWID for use of drain flows and WWTP discharges. This option is enacted in several of the new alternative scenario runs described in Section 30.0.

- Distribution of Irrigation Water in EPCWID – Improve the distribution of water to EPCWID subareas to be more proportionate to irrigated area instead of distributing water top to bottom based with specified bypass percentages.

- Riverside Waste to Tornillo Drain – Add a rule to compute waste discharge from the Riverside Canal to the Tornillo drain based on monthly percentages computed from historical records.

- Hudspeth Feeder Canal Diversions – Add two rules to manage flows in the Hudspeth Feeder Canal. The first rule routes Fabens Waste Channel flows in excess of the historical Hudspeth Feeder Canal diversions to the Rio Grande. The second rule diverts water from the Rio Grande to the extent the Fabens Waste Channel flows are less than the historical Hudspeth Feeder Canal diversions.

- River Headgate Demand - Rearrange the equation that computes the river headgate demands so that the tuning factor is only applied to the crop, soil moisture, and EPW demands, and not to the conveyance losses and EPCWID use of WWTP discharges and drain flows.

- EPCWID Allocation Limit - Adjust the rule that limits EPCWID diversions when the EPCWID has less remaining allocation than demand.

- EPCWID FHG Deliveries – Add river seepage as an independent term in the equation that computes the EPCWID farm headgate deliveries.

- ACE Credit – Revise the rule that computes the ACE Credit to use the equation that has historically been most frequently used in the Project accounting.

Data Changes

- Haskell WWTP Discharges – Specify the Haskell WWTP discharges to the Franklin Canal and the Rio Grande based on historical records.
- Socorro WWTP Discharges – Use historical Socorro WWTP discharge data that was recently provided by Texas and the United States instead of the estimates of WWTP discharge that were used.
- Hueco WWTP Return Flows Attributed to Project Water – Set the time series input of WWTP discharges attributed to Project water to zero during the non-irrigation season. This avoids simulating WWTP discharges of Project water during the non-irrigation season when Project water deliveries are not simulated.
- EPW Hueco WTP Diversions – Compute monthly EPW water treatment plant diversions computed by multiplying the simulated monthly EPCWID allocations by a time series of monthly percentages input to the model. The monthly time-series percentages were recomputed as historical monthly EPW WTP diversions divided by the simulated monthly EPCWID allocations in Run 1 of the ILRG Model.
- Rincon and Mesilla Valley Canal Capacities – Reduce the simulated capacity of the Rincon, Leasburg, Eastside, and Westside canals to limit the simulated maximum monthly diversions consistent with historical diversion records.

The revisions to the RiverWare Model rules and data described above resulted in some minor changes to the Calibration Run (Run 0), but not enough to require the model to be recalibrated. However, the model changes did necessitate that the model be retuned so that the simulated reservoir operations and deliveries of Project water in the Historical Base Run (Run 1) reasonably matched historical records or in some cases, simulated values in the historical Calibration Run (Run 0) (e.g., simulated irrigation pumping). Comparisons of the revised Historical Base Run (Run 1) against historical data and simulated results from the Historical Calibration Run (Run 0) are presented in the figures and tables that are described below. As evidenced in these figures and tables, the revisions to the RiverWare Model rules and input data described above and the subsequent retuning have improved the ILRG Model and the correspondence between simulated flows in the Historical Base Run (Run 1) and the historical observed data (and in some cases to the simulated outputs from Run 0). This is particularly evident in the simulated reservoir storage, reservoir releases, Project water diversions and FHG deliveries, and El Paso flows. Based on these model enhancements and improved model performance, the revised ILRG Model continues to be the best available tool to simulate the effects of pumping and changes in Project operations on the supplies available to LRG water users.

28.2 Summary of Updated ILRG Model Tuning

In response to criticisms in the rebuttal and supplement expert reports by Texas experts Shane Coors and George Hornberger, additional charts and tables were prepared to present and summarize the calibration and tuning of the updated ILRG Model.

As discussed in the SWE Report, development of the ILRG Model included a physical calibration process in which monthly Caballo releases, diversions, and FHG deliveries were set to historical records (and estimates), and physical parameters in the models including aquifer hydraulic conductivity, river bed conductance, canal bed conductance, and drain bed conductance were adjusted to improve the match between modeled outputs, and observed data for river flows, drain flows, and ground water levels.

After the physical calibration of the ILRG Model, the historical records specifying the Caballo releases, diversions, and FHG deliveries were replaced by operational rules that operate the Project and LRG irrigation systems. The operational rules were tuned to match simulated reservoir releases, diversions, and FHG deliveries to the historical data. The match of historical drain flows and river flows was also reviewed during the tuning process.

After making the changes to the ILRG Model that are discussed in Section 28.0, it was necessary to retune the model. The tuning of the model was evaluated using various statistical and graphical performance measures recommended for use in assessing calibration of hydrological models. Unless otherwise specified, the term “calibration” as used below refers to the goodness of fit between the simulated outputs of the calibrated and tuned ILRG Model and the historical data.

While there is no universal consensus in the scientific community for evaluating the calibration of hydrologic models, a recent article by Moriasi et al. (2015) contains proposed guidelines for model performance evaluation based on meta-data analysis of hydrologic models reported in numerous peer-reviewed journal articles since 1990. This article synthesizes the recent state of the art of model calibration assessment and was used as a general guide for selection of the performance measures used for evaluating the calibration of the updated ILRG Model. The following subsections describe and present these statistical and graphical performance measures.

28.2.1 Statistical Performance Measures

Statistical performance measures provide an objective and reproducible process for evaluating model calibration. Moriasi et al. (2015) recommends use of the following statistics to assess the model calibration performance each of which have advantages and disadvantages, but together provide a reasonable and comprehensive picture of model calibration.

- Coefficient of Determination (R2) – Degree of collinearity between modeled and measured data.
- Nash-Sutcliff Efficiency (NSE, E2) – Relative magnitude of the residual variance compared to the measured data variance.
- Index of Agreement (d2) – Ratio between the mean square error and the potential error represented by the largest value that the squared difference of each measured and observed data pair can attain.
- Root-Mean Squared Error (RMSE) – Square root of the mean square error.
- RMSE-Observed Standard Deviation Ratio (RSR) – RMSE normalized using the standard deviation of the observed data.
- Mean Error or Bias (BIAS) – Average of the positive and negative differences between the modeled and measured data.
- Percent Bias (PBIAS) – Mean error expressed as a percentage of the average of the observed values.
- Mean Absolute Error (MAE) – Average of the absolute value of the differences between modeled and observed values.
- Percent MAE (PMAE) – Mean absolute error expressed as a percentage of the average of the observed values.

Descriptions of the equations, range of possible values, optimal values, and advantages and disadvantages of the above statistics is provided in Table 5 of the Moriasi et al. (2015) article which is included in **Appendix 28**.

In addition to the statistics listed above, **Table 28-1** also includes results for the Log NSE statistic that was advocated by Mr. Coors. As discussed in Section 23.0, the Log NSE statistic is inappropriate for evaluating the calibration of the ILRG Model because of how it inappropriately weights differences in low flows. Nevertheless, the Log NSE statistic is included in **Table 28-1** for comparison to the results presented in the Coors Supplemental Report.

The spatial and temporal scales of the input data, calibration data, model processes, model outputs, and the intended model uses need to be considered in determining how to apply the calibration statistics to the model output. To achieve meaningful results, model performance assessment must focus on the processes and model outputs that are relevant to the model purpose using methods that reflect variation at the appropriate temporal and spatial scales (Baffaut, 2015).

Most of the inputs, outputs, and simulation processes of the ILRG Model are monthly, consistent with the monthly stress periods of the model. However, the model results should generally be assessed as irrigation season or annual totals. For example, when comparing the results of a no pumping run against the Historical Base Run (Run 1), differences between model outputs can be computed at monthly or longer time intervals. However, it makes little sense to evaluate simulated changes in Project water deliveries at monthly intervals because water users generally have wide latitude for ordering and receiving delivery of water most anytime within the irrigation season (subject of course to orders being bunched in water short years to minimize transit losses). Of more significance are the differences between model runs of diversions and deliveries over the entire irrigation season. Consistent with this, it is appropriate that the calibration of the ILRG Model also be evaluated based on irrigation season totals rather than monthly totals.

The spatial resolution of the model calibration assessment should be consistent with the resolution of the input data, calibration targets, modelled processes, and model linkages. As shown in **Table 23-1** in the response to the Coors Supplemental Report in Section 23.0, the spatial resolution of LRG data that are either used in the model or available for calibration assessment include point, valley, district, and basin scale information. The coarse nature of some of the input data (valley, district, basin) result in some level of smoothing of model inputs. Therefore, while farm budget calculations in the model are performed at a sub-area scale to spatially distribute model processes, it is not reasonable to assess certain of the model outputs on a fine spatial scale that is inconsistent with the model inputs. A prime example is the assessment of drain flow calibration. While drain flow data (measurements and estimates) are reported for some individual canals, it is unrealistic to expect the model to calibrate well to individual drains. Further, since the flow of many drains return flows that comingle upstream of where the next downstream diversion occurs it is reasonable to aggregate the flow of such drains for calibration assessment.

The simulation period of the ILRG Model extends from 1940 – 2017. However, widespread irrigation pumping did not commence until the late 1940s and early 1950s. In addition, the 1940s were characterized by greater than average inflows to Elephant Butte Reservoir and plentiful Project storage resulting in little restriction on use of Project water, and water users generally had sufficient supplies to meet demands. Therefore, consistent with the prior calibration and tuning described in the original reports of the New Mexico experts, calibration of the updated ILRG Model was evaluated primarily for the period from 1951 – 2017. The beginning of the calibration assessment period generally coincides with initiation of widespread irrigation pumping in the LRG area and also overlaps the 1951 – 1978 period from which data were used to develop the D1 and D2 curves that were subsequently used for allocation of Project water to the U.S Districts and Mexico.

Statistics summarizing calibration of the ILRG Model over the 1951 – 2017 period are tabulated in **Table 28-1**. Certain of these statistics were evaluated against Performance Evaluation Criteria presented in Moriasi et al. (2015) for R2, NSE, d, and PBIAS. These criteria characterize the model performance based on the value of the computed statistic relative to numerical ranges that define performance as Very Good, Good, Satisfactory, Not Satisfactory, and Unacceptable. The performance ranges for each statistic are listed in the color-coded legend at the bottom of **Table 28-1**. Note that no criteria were reported in Moriasi et al. (2015) for RMSE, RSR, and PMAE.

The ILRG Model performance summarized in **Table 28-1** ranges from satisfactory to very good for most of the calibration statistics when the results are appropriately evaluated using irrigation season totals. The improvements and re-tuning have generally elevated the statistical performance of the updated ILRG Model over that of the ILRG Model (v. 106) that was presented in the original reports of the New Mexico experts.

28.2.2 Graphical Performance Measures

Performance of the ILRG Model in simulating historical conditions was also evaluated using various graphical performance measures including monthly and annual time series plots, cumulative plots, scatter diagrams, and flow duration curves. These graphs facilitate qualitative assessment of the model capability to reproduce historical patterns and trends in the model output in a manner that the statistical measures do not. **Figure 28-1** through **Figure 28-21** present the graphs for each of the individual and aggregated locations for which calibration statistics are presented in **Table 28-1**.

The monthly and yearly time-series graphs show that the ILRG Model generally performs well in matching the monthly, seasonal, annual, and decadal patterns and variability present in the historical data.

- Caballo Release (Figure 28-1) – Monthly and annual releases match very well throughout the study period as evidenced by the monthly and annual time-series plot and the cumulative residual graph. Modeled annual releases match the historical records throughout the range of simulated values as indicated in the scatter plot and flow duration curve.

- Rio Grande at El Paso (Figure 28-2) – Monthly and annual flows match very well throughout the study period as shown in the monthly and annual time-series plot and the cumulative residual graph. The peaks and troughs of the simulated flows agree in most years indicating the supplies delivered during the irrigation season and return flows in the non-irrigation season are well simulated. Modeled annual flows match the historical records throughout the range of simulated values as indicated in the scatter plot and flow duration curve.

- Rio Grande at Fort Quitman (Figure 28-3) – Differences in simulated and measured flows at Fort Quitman represent the accumulation of all imperfections in the model simulation. While the variability of the monthly flows is not well matched, the annual and multi-year trends in flow are well simulated. The cumulative residual graph shows a general overprediction of flows in the 1940s and an underprediction of flows in the 1970s and 1980s. The horizontal slope of the cumulative residual line from about 1950-1970 and after 1990 shows the model replicates the annual flows reasonably well during these periods.

- Rincon and Mesilla Valley Diversions (Figures 28-4 – 28-7) – Irrigation season diversions are generally simulated well throughout the study period, aside from some overprediction for the smaller Rincon and Eastside Canals in the 1940s. The good match is evidenced in the irrigation season time-series graphs and the cumulative residual graphs that are relatively flat after the 1940s. The monthly diversion patterns are reasonably replicated in most years although there is some tendency to overpredict peak month diversions in full supply years.

- El Paso Valley Diversions (Figures 28-8 – 28-12) – Diversions at American Dam, Acequia Madre, Riverside Canal Gage, Franklin Canal Gage, and Total HCCRD Supply are generally simulated well after some underprediction in the 1940s as indicated in the monthly and annual time-series graphs. The cumulative residual graphs show no unreasonable long-term over- or under-predictions of diversions. The patterns of monthly diversions are simulated well, including monthly peak diversions.

- EBID FHG Deliveries (Figure 28-13) – Deliveries are typically simulated well, matching the yearly variability and long-term trends. Peak monthly flows tend to be overpredicted in full supply years, but the overall monthly patterns of deliveries match well.

- <u>EPCWID FHG Deliveries (Figure 28-14)</u> – There is a slight tendency toward underprediction of deliveries, particularly in wet years. The monthly pattern of deliveries is well matched.

- <u>HCCRD FHG Deliveries (Figure 28-15)</u> – The yearly and long-term trends in deliveries are satisfactorily simulated. The cumulative residual charts demonstrate a tendency toward overprediction of deliveries before 1980 and underprediction of deliveries after 1980.

- <u>EBID Pumping (Figure 28-16)</u> – Accurate simulation of supplemental pumping in the ILRG Model reflects a culmination of the successful simulation of the physical and operational processes that ultimately deliver inflows to Project storage to the end users. Given the complex interaction of all of the modeled processes, the replication of the pumping volumes in the yearly time-series plot is outstanding. As is the relatively lack of wavering in the cumulative residual chart and the degree of agreement throughout the range of pumping in the flow duration curve.

- <u>EPCWID Pumping (Figure 28-17)</u> – Supplemental pumping is simulated almost as well as for EBID with some underprediction late in the study period. The flow duration curve demonstrates pumping is generally well matched in all hydrologic conditions.

- <u>HCCRD Pumping (Figure 28-18)</u> – Supplemental pumping tends to be underpredicted in most years.

- <u>Rincon Valley Drains (Figure 28-19)</u> – Good simulation of drain flows is difficult because it requires reasonable simulation of ground water elevations (and surface water elevations) and the processes that conduct and attenuate the drain flow responses to the simulated elevation differences. Given these challenges, the ILRG Model simulates acceptable responses of the Rincon Valley Drains throughout the study period with some underprediction of flows until about 1980. The amplitude of the monthly variations in the simulated drain flows is satisfactory. The historical data for the Rincon drains are substantially incomplete after 2002 and therefore there is no observed data shown in the graphs after that time.

- <u>Mesilla Valley Drains (Figure 28-20)</u> – The Mesilla Valley drains, which transmit roughly five times as much flow as the Rincon Valley Drains are simulated very well in the ILRG Model. The annual flows are well matched throughout the study period as shown in the annual time-series plot, the cumulative residual plot, and the flow duration plot. The seasonal amplitude of the monthly flows is also well matched during most years. The historical data for the Mesilla Valley drains are substantially incomplete after 2013 and therefore there is no observed data shown in the graphs after that time.

- El Paso Valley Drains (Figure 28-21) – El Paso Valley drains are simulated generally well as shown in the annual time-series and cumulative residual plots, except for some underprediction of flows from 1960-1980. The amplitude of the monthly flow variations tends to be underpredicted in most years before 1990, but well matched thereafter.

28.2.3 Summary and Conclusions

Given the complexity of the Rio Grande Project area and the need to simulate the mix of physical and management processes that characterize the Project operations, the overall calibration performance of the ILRG Model is remarkable. In my opinion the superior calibration performance of the ILRG Model that is achieved using rational process-based rules clearly demonstrates that the updated ILRG Model is suitable for use in evaluating the claims and counterclaims in this case.

While the overall calibration performance of the ILRG Model is excellent for a system as complex as the Rio Grande Project and the associated portions of the LRG Basin, the model performance in matching the historical flows in the Historical Base Run (Run 1) is not perfect. It is important to understand that the imperfections in the Historical Base Run do not carry over into computed differences between the Historical Base Run and alternative scenario runs. This is due to the cancelling of errors that occurs when differencing model runs. For example, when the flow at El Paso or the diversion at the American Canal are overpredicted in a particular month in the Historical Base Run, that error will tend to also be present in the alternative run. Therefore, when the differences between model runs are computed, these errors will cancel out. The resulting computed differences then reflect the change in stress or operating rules between the two runs.

Canceling of errors is clearly evident in careful review of the differences between model runs. The simulated changes in flows such as streamflows, diversions and deliveries are reasonable and consistent with differences in the model inputs for the two runs and the simulated processes in the ILRG Model. In detailed review of the model results, there have been no identified differences between runs that could not be attributed to the rational functioning of the model rules. The cancelling of errors is why even relatively small differences between runs are reasonable and rational and are not lost in the noise of random errors that do not cancel out.

The ILRG Model is clearly more capable than the Texas Model of simulating the response of Project operations to changes in conditions simulated in alternative scenarios than is the Texas Model. The serious shortcomings of the Texas Model, which include rudimentary annual stress periods that foreclose the model from distinguishing between irrigation season and non-irrigation season flows, absence of dynamic simulation of Project operations that can respond to changes in flows and stresses in alternative scenarios, and limited geographical scope that excludes simulation of Project operations and water use downstream of the El Paso gage, render the Texas Model of limited or no utility in analyzing the complex issues that are presented in this case.

29.0 HISTORICAL BASE RUN OF ILRG MODEL

As described in Section 28.0, a number of revisions were made to the RiverWare Model to refine the simulated Project operations and water distribution. After these revisions were made the model was retuned and iterated with the ground water models to closure to produce a revised Historical Base Run (Run 1). Various water budget summaries and other outputs for the original Run 1 were presented in figures discussed in Section 9.0 of the SWE Report. Updated versions of those figures for the new Run 1 are included as **Figure 29-1** through **Figure 29-10** and a new **Figure 29-11** as listed below:

- Annual Reservoir Budget Summaries (**Figure 29-1**)
- Annual Project Allocations and Charges (**Figure 29-2**)
- Annual Canal and Farm Budget Summaries (**Figure 29-3** – **Figure 29-6**)
- Annual River Budget Summaries (**Figure 29-7** – **Figure 29-8**)
- Rio Grande Flow Summaries (**Figure 29-9** – **Figure 29-11**)

The illustrations of the Historical Base Run (Run 1) outputs provided **Figure 29-1** – **Figure 29-10** are similar to the comparable figures in Section 9.0 of the SWE Report. The detailed discussions of the Section 9.0 figures in the SWE Report also are applicable to the updated figures in this report. These summaries of the Historical Base Run along with the calibration results described in Section 28.0 show that the ILRG Model reasonably simulates the operations of the Rio Grande Project and the irrigation systems of the LRG Basin.

30.0 ALTERNATIVE RUNS OF ILRG MODEL

The updated ILRG Model (v116) was used to re-run the no-pumping scenarios and operations scenarios that were presented in the SWE Report (Runs 2 – 13). A list of the original model runs is provided in **Table 30-1**.

In addition to re-running the original 13 scenarios, the updated ILRG Model was used to simulate additional no-pumping scenarios and operations scenarios. These included Run 14 and several variants that simulate the effects of pumping in the Hueco and Run 15 and several variants that simulate early EPCWID operations prior to changes in water use practices. In addition, five other scenarios were simulated (Runs 16, 16a, 17, 17a, and 18) to analyze conjunctive use of surface water and ground water. These conjunctive use scenarios are based on either a D1/D2 level of supplemental pumping or a supplemental pumping level up to the crop demands on the authorized Project acres, and were developed in consultation with representatives and legal counsel for New Mexico. A list of the additional model runs is provided in **Table 30-2**. Additional specifications for the model runs are provided in **Appendix 30-A** including details for Runs 15-18 and details for the WWTP discharges and urban deep percolation returns that are turned off or reduced in certain of the alternative scenarios.

The results from the re-running of the original scenarios and simulation of the new scenarios are presented in a consistent format in the tables and graphs in **Appendix 30**. These include tabular and graphical results similar to those presented in the SWE Report as well as several additional tables and graphs. Unless otherwise noted, all of the results presented in **Appendix 30** are comparisons between an alternative scenario and the Historical Base Run (Run 1). There are 22 pages of tables and graphs included in the run comparisons for each scenario. An overview of the format and content of each of these tables and graphs follows:

- <u>Cover Page (p. 1)</u> – Selected input specifications for the two runs being compared.

- <u>Comparison of ILRG Model Runs (p. 2-3)</u> – This two-page table provides a high-level overview of how the ILRG Model distributes the change in inputs (e.g., change in pumping stress or change in operating rules) into changes in model outputs. The first five rows of values are the average annual pumping stresses in each run, which consist of the irrigation pumping that is on in Run 1 and off in the alternative run, and the total non-irrigation pumping and non-irrigation pumping return flows (WWTP discharges and urban deep percolation). The Total Stress is computed as the sum of the irrigation and non-irrigation pumping less the non-irrigation returns flows. The third column of numbers shows the difference in stress between the two runs being compared. The remainder of the table reports the annual averages for selected ILRG Model outputs and the differences in outputs between the two runs. The fourth and fifth columns of numbers express the average annual output differences as percentages of the change in Total Stress and as percentages of the Base Run values. For the alternative runs that simulate differences in operating rules (i.e. Runs 11-13, 15-18), there are no rows in the table listing the stresses, nor is there a column listing the % Change Stress.

- Annual Differences in ILRG Model Outputs (p. 4-5) – This two-page table lists the differences in model outputs for selected model outputs. These include the differences in irrigation season and annual net RHG Diversions and FHG Deliveries, and differences in annual river flows at the Caballo outlet, El Paso, and Fort Quitman. Net RHG Diversions are defined as the simulated gross diversions less the historical El Paso carriage water that was delivered through the Rincon and Mesilla Valley canals and less the simulated flood control releases that were run through the canals in spill years. Reporting of differences in net RHG Diversions in the model results represents a change from the reporting of differences in gross RHG diversions that were presented in model results described in the SWE Report.

- Simulated Differences in ILRG Model Outputs (p. 6-9) – These four pages of graphs and tables show differences in model outputs expressed as either annual or irrigation season totals. There is a bar chart with the yearly differences in model output, an inset line chart showing the annual outputs that are differenced in the bar chart, and a table summarizing the yearly average differences (annual or irrigation season totals). The differences in net RHG diversions and FHG deliveries are shown in line graphs rather than bar charts.

- Annual Allocation and Charges (p. 10) – This chart summarizes for the two compared runs the simulated annual allocation and delivery charges for EBID and EPCWID, as well as the simulated annual Diversion Ratio computed as the sum of the annual diversion charges for EBID, EPCWID, and Mexico divided by the annual Caballo Reservoir releases.

- Annual Summary of Project Storage and Rio Grande Flows (p. 11) – This chart summarizes for the two compared runs the total year-end project storage in Elephant Butte and Caballo Reservoirs and the annual Rio Grande flow at the Caballo Reservoir outlet, at El Paso, and at Fort Quitman.

- Irrigation Season Summary of Irrigation Operations (p. 12-14) – These three pages of charts summarize for the two compared runs the net RHG diversions, FHG deliveries, irrigation pumping, and RHG diversions minus FHG deliveries (conveyance losses). There are separate pages for EBID, EPCWID, and HCCRD.

- Cumulative Change in Ground Water Storage (p. 15) – This chart summarizes for the two compared runs the cumulative year-end change in ground water storage in the alluvial and non-alluvial aquifers in the Rincon and Mesilla valleys and in the Hueco.

- Monthly Net RHG Diversions (p. 16-18) – These three pages of charts show for the two compared runs the simulated monthly net RHG diversions. There are charts showing the total EBID diversions, total EPCWID diversion, and the total flow to HCCRD.

- End of Month Reservoir Storage (Elephant Butte + Caballo) (p. 19) – This chart shows for the two compared runs the combined end-of-month Project storage in Elephant Butte and Caballo Reservoirs. This doesn't include storage of non-Project water.

- Monthly Rio Grande Flows (p. 20-22) – These three pages of charts show for the two compared runs the simulated monthly Rio Grande flows at the Caballo Reservoir outlet, at El Paso, and at Fort Quitman.

Narrative summaries of the ILRG Model simulations of alternative scenarios are provided below to highlight and explain some of the more significant results shown in the tabular and graphical summaries presented in **Appendix 30**. The tables in **Appendix 30** include annual and irrigation season differences in model outputs for all run comparisons. Averages are computed for the following noteworthy ranges of years:

1951-2017: Period with irrigation pumping development commencing with the beginning of the D1/D2 data period (57/43 allocation until 2006).

1951-1978: D1/D2 data period (57/43 allocation).

1979-2005: Post D1/D2 data period prior to the 2008 OA allocation and accounting that commenced in 2006 (57/43 allocation).

2006-2017: Period when the 2008 OA allocation and accounting was in effect (D3 allocation for 2006 and 2007, D3 allocation plus carryover for 2008-2017).

1985-2017: Period for which alleged damages were computed by Texas (1985-2016) plus the last year of the study period (2017).

1985-2005: Portion of the Texas damages period prior to commencement of the 2008 OA allocation and accounting.

Averages for other portions of the study periods can be computed from the data in the run comparison spreadsheets that are being disclosed with this report.

30.1 All Pumping Off (Run 2)

In Run 2, all irrigation and non-irrigation pumping in the study area is turned off, and all non-irrigation returns, including WWTP discharges and urban deep percolation returns, are also turned off. The changes in irrigation returns that result from turning off the irrigation pumping are simulated by the farm budget processes included in the model.

The ILRG Model re-operates the Project and all of the simulated irrigation systems in the absence of pumping. Turning off pumping increases drain flows and reduces river seepage in most years. During full allocation years, this results in water accumulating in storage as less water needs to be released to meet demands. Accumulating water in storage increases allocations and Caballo Reservoir releases in subsequent dry years (e.g., several years in the 1960s, 1970s, and 2000s). Spills are also larger due to the accumulated water in storage.

The increased allocations result in increased diversions and FHG deliveries to EBID in dry years between 1950 and 1978. During the full allocation years from 1979 – 2002, there is little change in EBID diversions, however FHG deliveries increase modestly due to reductions in the simulated canal conveyance losses in the no-pumping run that allowed more of the water that is diverted to be delivered to the farms. When dry conditions return, EBID diversions and FHG deliveries increase again in 2003 and 2004. EBID diversions increase substantially beginning in 2006 due to the effects that pumping has when the 2008 OA is in effect. As is discussed in Barroll (2019), EBID's allocation under the 2008 OA is sensitive to the diversion ratio. When pumping is turned off, the diversion ratio increases resulting in increased allocations and increased deliveries to EBID. On average from 2006 – 2017, EBID's diversions increase by 148,700 AF and FHG deliveries increase by 92,700 AF.

The increase in Project water allocations also results in increased diversions and FHG deliveries to EPCWID in many dry years in the 1950s – 1970s. There are also modest increases in EPCWID diversions during many full allocation years in the 1980s and 1990s because the reduction in EPW WWTP discharges to EPCWID canals results in EPCWID requiring more reservoir releases to meet its demands. Increases in deliveries also occur in several dry years in the 2000s – 2010s although the increases are not near as large under the 2008 OA after 2005 as they are for EBID.

Turning off pumping and the resulting effects on Project operations and deliveries results in increased Rio Grande at El Paso flow in most years averaging 79,000 AF annually during 1951 – 2017. Of this amount, an average of only 33,100 AF occurs during the irrigation season (Mar-Oct) and the remaining 45,900 AF occurs during the non-irrigation season (Nov-Feb) or during reservoirs spill. During the 1985-2005 period, the increase in irrigation season flows, excluding spills, averages 15,700 AF. A portion of the increase is attributable to turning off New Mexico pumping and a portion is due to turning off Texas pumping. Cessation of pumping also produces substantial increases in flow at Fort Quitman averaging 100,300 AF annually during 1951-2017.

30.2 NM Pumping Off (Run 3)

In Run 3, all irrigation pumping and all non-irrigation pumping and returns in New Mexico is turned off. This includes all EBID supplemental irrigation pumping, all primary irrigation pumping in the Rincon Valley and Mesilla Valley, and all non-irrigation pumping and associated WWTP discharges and deep percolation returns in New Mexico.

Many of the simulated effects of turning off New Mexico pumping are similar to but smaller than the effects of turning off all pumping in Run 2. There is a similar pattern of accumulations in Project storage that are released in dry years when the simulated Project allocations increase. The accumulated storage again leads to larger spills.

EBID diversions increase by an average of 46,300 AF during 1951-2017, while FHG deliveries increase by an average of 31,200 AF. When the 2008 OA is in effect during 2006-2017, turning off New Mexico pumping increases EBID diversions by an average of 137,500 AF, and FHG deliveries increase by an average of 83,900 AF.

The impacts of New Mexico pumping on EPCWID supply are less than the impacts on EBID. From 1951 – 2017, EPCWID irrigation season diversions increase by an average of 18,500 AF and FHG deliveries increase by an average of 11,700 AF. After 1984 when Texas is claiming damages, New Mexico pumping impacts EPCWID irrigation season diversions by an average of 17,200 AF and irrigation season FHG deliveries by an average of 9,700 AF (1985-2017). During 1985-2005, prior to implementation of the 2008 OA, EPCWID irrigation season diversions increase by an average of 10,900 AF and irrigation season FHG deliveries increase by an average of 5,100 AF.

Simulated flows in the Rio Grande at El Paso increase when New Mexico pumping is turned off by an average of 61,100 AF annually during 1951-2017, of which an average of 22,900 AF occurs during the irrigation season and 38,200 AF occurs during the non-irrigation season or during spills. Average annual flows at Fort Quitman during 1951-2017 increase by an average of 49,000 AF due largely to return flows from increased surface water deliveries and reduced surface water depletions from pumping. This run shows that the Texas Model without reoperation greatly exaggerates the impacts of New Mexico pumping on El Paso flows.

30.3 TX Pumping Off (Run 4)

In Run 4, all supplemental irrigation pumping in EPCWID and HCCRD is turned off, as is all non-irrigation pumping and associated returns in the Texas portion of the Mesilla Valley and in the El Paso Valley. Deliveries of Project water to EPW and the associated return flows continue to be simulated in Run 4.

When Texas pumping is turned off, annual EBID diversions increase by an average of 5,400 AF/y during 1951-1978, and by an average of 15,500 AF during 2006-2017 when the 2008 OA is in effect. The impacts of Texas pumping are magnified by the sensitivity of changes in the diversion ratio on EBID allocations. The pattern of impacts on EBID FHG deliveries is similar with impacts to diversions that average 4,300 AF during 1951-1978 and 9,600 AF during 2006-2017.

Texas pumping also impacts Project water deliveries to EPCWID. The net effect on EPCWID supply depends on the relative positive effect of reducing depletions from pumping compared to the negative effect of turning off Texas WWTP discharges. During 1951-1978, EPCWID diversions increase by an average of 200 AF, but FHG deliveries increase by an average of 2,600 AF. During the mostly full supply years of 1979-2005, EPCWID diversions increase by an average of 10,200 AF to replace the significant reduction in WWTP discharges to the EPCWID canal system.

The reduction in the Texas WWTP discharges due to turning off the non-irrigation pumping and the concurrent increased deliveries of Project water to EPCWID, along with the reduction in stream depletions caused by Texas Mesilla irrigation pumping results in increased Rio Grande at El Paso flow in many years, particularly in the 1980s and 1990s. During 1985-2005, El Paso flows increase by an average of 27,800 AF during the irrigation season, excluding spills.

30.4 MX Pumping Off (Run 5)

In Run 5, all supplemental pumping in JID and all municipal pumping and associated WWTP discharges in Ciudad Juarez is turned off. Turning off pumping in Mexico has much less effect on Project operations than turning off pumping in New Mexico or Texas.

Turning off Mexico pumping reduces the river and conveyance system losses in delivering Project water to EPCWID farmers. As a result, in full supply years, less water needs to be released from storage to meet EPCWID demands. This results in an accumulation of water in storage that increases allocations and deliveries in later non-full supply years. This is seen in the increased reservoir releases and deliveries in 1955, 1964, 1967, 1977, 1978 and several other years after 2000.

EBID FHG deliveries increase by an average of 2,400 AF during 1951-1978, and 2,400 AF during 2006-2017. EPCWID FHG deliveries increase by similar amounts averaging 1,500 AF during 1951-1978 and 2,100 AF during 2006-2017. The impact of Mexico pumping on the HCCRD supply is larger than on EBID or EPCWID, with the total irrigation season supply to HCCRD increasing by an average of 3,900 AF during 1951-2007.

Mexico pumping also has a large impact on ground water storage in the Hueco. From 1951-2017, Hueco ground water storage is depleted by an average of 59,500 AF/y. The effect of Juarez pumping from the new Conejos-Medanos wellfield is evident in the recent changes in Rincon-Mesilla ground water storage.

30.5 R-M Pumping Off (Run 6)

In Run 6, all irrigation pumping and non-irrigation pumping and associated returns in the Rincon and Mesilla basins is turned off. This includes turning off irrigation and non-irrigation pumping in the Texas portion of the Mesilla basin. The purpose of this run is to simulate a scenario that is directly comparable to the 100% reduced pumping run of the Texas Model described in the Hutchison Report.

As expected, the effect of turning off all Rincon-Mesilla pumping in Run 6 has a larger effect than turning off New Mexico pumping in Run 3, but with a similar pattern. Turning off R-M pumping increases the Project delivery efficiency by increasing drain flows, reducing river losses, and reducing canal seepage. In full allocation years, releases from storage can be reduced while still delivering full allocations to EBID and EPCWID. This accumulates water in storage leading to increased allocations and deliveries in dry years, and greater spills in very wet years.

As discussed in Section 18.0, the comparisons of simulated changes in El Paso flow between the ILRG Model and the Texas Model that were presented in the SWE Report were revised with results from the updated ILRG Model. The revised results are shown in revised **Figures 13-1** and **13-2** in **Appendix 18**.

Additional comparisons of the R-M Pumping Off results to comparable runs of the Texas Model presented in the Hutchison Report and the Second Supplemental Moran Report are presented in **Table 30-3**. These include comparisons of 1951-2016 averages for selected model outputs for the updated ILRG Model (Run 6), the Texas Model without reoperation (Hutchison; 100% R-M Pumping Off), and the Texas Model with crude redistribution (Moran; 100% R-M Pumping Off). The updated ILRG Model results are summarized as annual averages and irrigation season averages. The Texas Model results are annual averages consistent with the annual stress periods in the Texas Model. The table entries for the Texas Model shown as "n/a" and shaded grey indicate outputs that are not simulated in the Texas Model.

Table 30-3 highlights many of the processes simulated in the ILRG Model that are not simulated in the Texas Model. It also contrasts long-term average differences between the models as to simulated changes in Rincon-Mesilla diversions and FHG deliveries, and El Paso flows. During 1951-2016, the average annual change in El Paso flow in the Texas Model is 124,700 AF without reoperation (Hutchison) and 51,700 AF with crude redistribution (Moran). These results compare to the change in flow in the ILRG Model that averages 79,800 AF year-around, and 33,200 AF during the irrigation season, excluding spills. The change in flow goes down to 12,900 AF during the irrigation season from 1985-2005.

30.6 TX Mesilla Pumping Off (Run 7)

In Run 7, all supplemental irrigation pumping and non-irrigation pumping in the Texas portion of the Mesilla basin is turned off. This includes turning off the EPW Canutillo wells and associated M&I return flows. The results of this run show that turning off Texas-Mesilla pumping has, on average over the whole study period, more impact on Project operations than does turning off all Texas pumping in Run 4. This is due to significant WWTP offsets that occur in Run 4.

Similar to many of the runs described above, turning off Texas-Mesilla pumping and returns increases the Project delivery efficiency due to increased drain flows, reduced river seepage, and reduced canal seepage. In turn, this reduces reservoir releases needed to deliver full supply allocations in wet years and the resulting storage accumulations increase allocations and deliveries in dry years.

Turning off Texas-Mesilla pumping causes EBID diversions to increase by an average of 7,200 AF during 1951-1978 and 21,300 AF during 2006-2017. EBID FHG deliveries increase in a similar pattern with average increases of 5,800 AF in 1951-1978 and 12,500 AF in 2006-2017. Impacts during recent years are magnified by the effect of the 2008 OA on EBID allocations.

EPCWID operations are also impacted by Texas-Mesilla pumping. Average irrigation season diversions by EPCWID increase by an average of 4,100 AF during 1951-1978 and 2,600 AF during 2006-2017. EPCWID FHG deliveries during 1951-1978 increase by an average of 2,600 AF and during 2006-2017 by an average of 400 AF.

30.7 TX Non-Irrigation Pumping Off (Run 8)

In Run 8, all Texas non-irrigation pumping and associated urban return flows are turned off. This includes pumping by EPW and other minor pumpers from the Hueco and pumping from EPW's Canutillo wellfield in the Mesilla Valley. Discharges from EPW's WWTPs are turned off except for amounts attributed to EPW's use of Project water which continue to be simulated. All urban deep percolation is also similarly eliminated or reduced.

Turning off the non-irrigation pumping and returns in Texas results in EPCWID ordering more Project water to replace the loss in WWTP discharge supply. This reduces the supply available for allocation in some dry years resulting in reduced diversions and/or deliveries to EBID and EPCWID.

EBID diversions decrease by an average of 2,900 AF during 1951-1978. After the 2008 OA becomes effective, the increases in Project water diversions by EPCWID to replace the reduced WWTP discharge supply increases the computed diversion ratio resulting in EBID diversions increasing by an average of 12,100 AF during 2006-2017. EBID FHG deliveries change by corresponding amounts with an average decrease of 1,000 AF from 1951-1978 and an average increase of 7,600 AF from 2006-2017.

Turning off Texas non-irrigation pumping causes EPCWID to order more Project water to replace the lost WWTP returns. There is a modest increase in diversions during 1951-1978 averaging 2,500 AF/y, which is followed by a much larger increase in diversions during 1979-2005 averaging 14,300 AF/y.

30.8 NM Non-Irrigation Pumping Off (Run 9)

In this scenario, all non-irrigation pumping in New Mexico along with the associated WWTP discharges and urban deep percolation are turned off. The effects are similar in pattern, but much smaller than the effects of turning off all New Mexico pumping in Run 3.

The familiar pattern of accumulated water in Project storage in wet years followed by increases in allocation and releases in dry years is repeated in Run 9. EBID diversions increase by averages of 2,500 AF during 1951-1978 and 23,400 AF during 2006-2017 when the effects of pumping are elevated by interaction with the revised allocation procedure under the 2008 OA. EBID FHG deliveries increase proportionally by an average of 2,000 AF/y during 1951-1978 and 14,100 AF/y during 2006-2017.

EPCWID diversions and FHG deliveries increase by small amounts when the non-irrigation pumping in New Mexico is turned off. On average, irrigation season diversions for

EPCWID increase by 900 AF during 1951-1978 and 4,500 AF during 1985-2017. Irrigation season FHG deliveries to EPCWID increase by 800 AF from 1951-1978 and 2,000 AF during 1985-2017.

The increases in Rio Grande at El Paso flow during the irrigation season are generally limited to times of increased deliveries to EPCWID, and these average 4,000 AF during 1951-2017. The increases in El Paso flow during the non-irrigation season and during spills average 2,100 AF during 1951-2017.

30.9 MX Non-Irrigation Pumping Off (Run 10)

In this scenario, all non-irrigation pumping for Ciudad Juarez in Mexico along with the associated sewage/WWTP returns are turned off. Mexico non-irrigation pumping has a relatively minor effect on Project operations and deliveries to EBID and EPCWID. For the analysis of all Mexico groundwater pumping off, refer to Run 5 in section 30.4 above.

Mexico irrigation pumping increases due to loss of Juarez WWTP discharges. This in turn increases EPCWID conveyance losses resulting in EPCWID having to increase diversions to deliver similar amounts to the farms. EPCWID irrigation season diversions increase by an average of 700 AF/y during 1951-2017, and FHG deliveries increase by an average of 200 AF over the same period. The increase in EBID diversions and FHG over 1951-2017 is minimal averaging 300 AF.

30.10 2008 Operating Agreement Scenarios (Runs 11 and 12)

Two runs of the ILRG Model were made to evaluate the effect of the D3+Carryover accounting in the 2008 OA on Project operations and LRG water supplies. In Run 11, the D1/D2 allocation procedure is simulated to allocate Project water during the entire period from 1950 - 2017 period, and in Run 12 the D3+Carryover accounting is simulated during this 68-year period[5]. Otherwise, both runs employ the same RiverWare simulation rules that are used in the Historical Base Run. Irrigation pumping is computed based on the unmet irrigation demand and the non-irrigation pumping and associated return flows are set at historical levels.

Comparison of the results of Run 11 to Run 1 show the effects of the 2008 OA on Project operations in Run 1 compared to what would have happened had the 2008 OA not been implemented and the D1/D2 allocation procedure been left in place.

[5] The RiverWare rules do not simulate annual allocations during the wet period from 1940 – 1949.

When the D1/D2 allocation procedure is left in place during 2006-2017, the annual allocations to EBID increase substantially in most years during this period resulting in large increases in EBID diversions averaging 94,200 AF and in EBID FHG deliveries averaging 54,600 AF. These impacts on EBID from the 2008 OA are far greater than the impacts of New Mexico pumping on EPCWID irrigation season FHG deliveries that average 17,800 AF during 2006-2017 as shown in the Run 3 results.

Conversely EPCWID diversions decline by an average of 23,000 AF and FHG deliveries decline by an average of 17,200 AF during 2006-2007. The reason for the decline in EPCWID supply is primarily due to the limited amount of Project water in storage. The increases in EBID's allocations and deliveries result in smaller amounts of Project water to allocate between the districts in subsequent years. Another factor is the absence of carryover for the individual districts and this results in more water allocated to EBID and less water available for EPCWID to use.

Comparison of the results of Run 12 to Run 11 allows differences between the D1/D2 and D3+Carryover allocation procedures to be evaluated over the entire 1950-2017 period. The differences between these runs are computed based on Run 12 (D3+CO) minus Run 11 (D1/D2) and therefore reflect the impacts of going from the D1/D2 allocation procedure to the D3+CO allocation procedure.

Comparison of Run 12 and Run 11 shows clearly the effect of the 2008 OA on EBID varies depending on the type of year. In wet years with a relatively high diversion ratio, the annual EBID allocation is greater under the D3+CO method than under D1/D2 method and this results in increased diversions and FHG deliveries during 26 of the 67 years between 1951-2017 period (1951-1952, 1959-1962, 1982-2001). EBID diversions and FHG deliveries were lower in the other 41 years which were generally years of average and below average water supply. On average during 1951-2017, EBID diversions declined by 34,400 AF and FHG deliveries declined by 19,800 AF.

Conversely, the 2008 OA has a positive effect on EPCWID allocations, diversions, and FHG deliveries in most years. During the irrigation season, diversions increased by an average of 13,100 AF and FHG deliveries increased by an average of 8,200 AF. The average increase in EPCWID supply is much less that the average decrease in EBID supply.

The following is a summary of the average annual effect on EBID and EPCWID FHG deliveries in dry, wet, and all years during the 1951-2017 period.

Cumulative Volume Impact of 2008 Operating Agreement on March - October FHG Deliveries In Wet and Dry Periods 1951-2017

Condition	Years	EBID	EPCWID
Dry	1953-1958, 1963-1981, 2002-2017	-2.47 MAF	+0.37 MAF
Wet	1951-1952, 1959-1962, 1982-2001	+1.14 MAF	+0.17 MAF
All	1951-2017	-1.33 MAF	+0.55 MAF

The results in the above table show that the 2008 OA takes away critical surface water in the dry years when EBID has a greater need for water (2.47 MAF) than it gives back to EBID in wet years when the need is less (1.14 MAF) As a result, the 2008 OA forces EBID to pump more ground water in dry years to make up for the reduction in surface water supplies. The increased EBID pumping negatively affects the diversion ratio which contributes to the reduction in water allocated and delivered to EBID in dry years. This was termed a "vicious cycle" by Dr. Barroll (2019, 2020a).

30.11 Reduced Waste (Run 13)

As was described in Section 5.0 of the SWE Report, beginning with the 1950s drought and continuing through the 1970s, Reclamation was able to operate the Project with reported operational waste below 10% during most years. In a few years during the wet periods of the mid-1980s and mid-1990s, the EBID waste increased to approximately 20%. The situation in EPCWID was markedly different than in EBID from the 1980s through the 2000s (after EPCWID took over operations) with the operational waste consistently in the range of 20% to 30%.

A run of the ILRG Model was made to evaluate the benefit to the Project from reducing the operational waste. The RiverWare operational rules were modified so that the operational waste was limited to the lesser of the historical amounts or 10% of the simulated diversions.

Limiting operational waste in both Districts to no more than 10 percent reduces releases from Project storage in full allocation years resulting in increased allocations and deliveries in dry years with less than full allocations. As a result of the more efficient Project operation, FHG deliveries to EBID and EPCWID increase in many years during the

1950s – 1970s, and again after 2002. Increases in FHG deliveries to EBID average 35,300 AF during 1951-1978 and 57,300 AF during 2006-2017. Increases in FHG deliveries to EPCWID average 17,800 AF during 1951-1978 and 18,500 AF during 2006-2017.

30.12 Hueco Pumping Off (Runs 14, 14a, 14b, 14c, and 14d)

In response to questions from Texas legal counsel during depositions of the New Mexico experts, and in response to opinions from Texas and U.S. experts, several runs of the ILRG Model were made in which all or a portion of the pumping in the Hueco was turned off, as well as runs in which pumping was turned off without turning off WWTP discharges and vice-versa. The results from these runs are useful in assessing the effects of the Hueco pumping in isolation from pumping in other areas of the LRG basin and the effect of WWTP discharges in offsetting impacts from Hueco pumping.

The No Hueco Pumping Scenarios is simulated in the same manner as the other no pumping scenarios. The supplemental irrigation pumping from the Hueco in Texas and/or Mexico is turned off. In addition, the non-irrigation pumping in these areas and the corresponding WWTP and urban deep percolation return flows are also turned off. Specifications and summaries of the results of the No Hueco Pumping Scenarios are presented below. Runs 14a, 14b, 14c, and 14d were made to test various components of Run 14.

- All Hueco Pumping Off (Run 14) – In Run 14, all supplemental irrigation pumping and non-irrigation pumping in the Hueco in Texas and Mexico is turned off. In addition, the WWTP discharges by EPW and Ciudad Juarez from their Hueco pumping are turned off, as is the urban deep percolation from EPW[6].

  There are opposing effects within EPCWID from turning off Hueco pumping. Turning off Hueco pumping reduces canal and lateral losses in EPCWID and reduces river seepage between American Dam and Riverside Dam before the ACE was constructed in 1999. These changes can result in reduced Project water orders to deliver the same amount of water to EPCWID farm headgates. On the other hand, the reduction in WWTP discharges to the EPCWID canal system when M&I pumping is turned off reduces the irrigation supply available to deliver to EPCWID farm headgates and increases RHG demands for Project water. These opposing effects can result in net increases or decreases in annual EPCWID FHG deliveries.

[6] No urban deep percolation is simulated for Mexico in the historical Base Run.

The effects within EPCWID from turning off Hueco pumping can propagate upstream and impact reservoir operations and deliveries to EBID depending on whether it is a full allocation year or non-full allocation year. In full allocation years, there is little effect on EBID FHG deliveries because EBID's allocation does not change. In non-full allocation years, accumulated changes in reservoir storage resulting from changes in EPCWID orders of Project water can result in changes in EBID allocations and deliveries.

When Hueco pumping is turned off in Run 14, there are some increases and decreases in EBID FHG deliveries that average to a 1,500 AF increase during 1951-2017 with the increases occurring in dry years.

Turning off Hueco pumping increases EPCWID FHG deliveries by an average of 800 AF during 1951-2017. Turning off Hueco pumping results in a substantial increase in the total HCCRD supply (RHG diversions) averaging 7,500 AF during 1951-2017.

- Texas Hueco Pumping Off (Run 14a) – In Run 14a, all supplemental irrigation pumping and non-irrigation pumping by Texas in the El Paso Valley is turned off, along with the WWTP discharges and urban deep percolation from the EPW Hueco pumping.

  Turning off Texas Hueco pumping reduces EBID FHG deliveries by an average of 1,000 AF during 1951-2017. EBID FHG deliveries decrease by an average of 4,000 AF during 2006-2017 when the 2008 OA is in effect.

  During 1985-2017, Texas Hueco pumping reduces EPCWID FHG deliveries during the irrigation season by an average of 1,400 AF and increases the total flow to HCCRD an average of 2,100 AF.

  Contrary to the claims of the Texas and U.S. experts, the impacts of Texas Hueco pumping on Project operations and surface water supplies to EBID, EPCWID, and HCCRD are not negligible.

- Mexico Hueco Pumping Off (Run 14b) – In Run 14b, all supplemental irrigation pumping and non-irrigation pumping in the Mexico portion of the Hueco is turned off, along with the WWTP discharges from Ciudad Juarez pumping.

  Turning off Mexico pumping reduces canal seepage and river seepage in EPCWID causing reduced Project orders at EPCWID canal headings. This results in accumulation of water in Project storage that increases Project water deliveries to EBID in years with less than a full Project water allocation. Simulated increases in

EBID FHG deliveries average 1,700 AF during 1951-2017, and 3,200 AF during 2006-2017, with increases exceeding 5,000 AF in several years and 10,000 AF in 2010.

Turning off Mexico Hueco pumping has similar effects on EPCWID with FHG deliveries increasing by an average of 1,500 AF during 1951-2017. The increase in total HCCRD supply is greater averaging 3,900 AF during 1951-2017.

- <u>Texas WWTP Discharges Off (Run 14c)</u> – In Run 14c, all discharges from Texas WWTPs are turned off. This includes turning off discharges from the EPW's Northwest, Haskell, Socorro, and Bustamante WWTPs, as well as discharges from the Anthony TX WWTP and the Fabens WWTP. The purpose of this run is to quantify the benefit to the Project operations and LRG water users from the Texas WWTP discharges. Without these discharges, the impacts of Texas Hueco pumping would be much larger.

  When the Texas WWTP returns are turned off, EBID FHG deliveries decrease markedly in numerous years with less than full allocations. This shows the interconnected nature of the Project and how changes in supply at the bottom of the Project area can ripple through the Project and affect operations hundreds of miles upstream. On average during 1951-2017 the reduction in diversions averages 14,600 AF and the reduction in FHG deliveries averages 6,600 AF.

  Turning off Texas WWTP discharges results in increased Project releases and diversions to EPCWID to replace the reduction in irrigation supply to EPCWID farmers from the WWTP discharges. This results in large increases in El Paso flows to deliver additional Project water to EPCWID, particularly during the wet period in the 1980s and 1990s. The increase in El Paso flows during the irrigation season, excluding spills, average 38,300 AF during 1985-2005.

  Without the Texas WWTP discharges, the simulated impacts from Texas pumping would be much larger than the impacts shown in Runs 4, 7, 8, 14, and 14a. The results for Run 14c show the effect of Texas WWTP discharges have in offsetting the impacts of Texas pumping. Without these discharges (for example if EPW reused its WWTP discharges for non-potable uses), the effects of Texas pumping on Project operations, including deliveries to EBID would be much greater.

- <u>Texas Hueco Pumping Off without WWTP Discharges Off (Run 14d)</u> – In Run 14d, Texas Hueco pumping is turned off without turning off the associated Texas WWTP discharges and urban deep percolation. This test run simulates the effect of Texas Hueco pumping without the offsets from Texas M&I return flows.

When the Texas Hueco pumping is turned off without turning off the M&I returns, the simulated impacts on Project operations increase. EBID FHG deliveries increase by an average of 5,000 AF during 1951-1978 and 2,000 AF during 2006-2017. FHG deliveries to EPCWID increase by 4,600 AF during 1951-1978 and 2,000 AF during 2006-2017. Total flows to HCCRD increase by 7,100 AF during 1951-1978 and 3,700 AF during 2006-2017.

30.13 Early EPCWID Ops (Runs 15, 15a, 15b, 15c)

Four scenarios were simulated using the ILRG Model to evaluate the effects on Project operations that would result from a return to EPCWID operations consistent with how the Project was operated in the past. These include simulating increased irrigation use of drain flows in the Fabens area and charging EPCWID for all water that it uses. Runs 15a, 15b, and 15c were made to test various components of Run 15. Descriptions of the four Early EPCWID Ops scenarios are provided below along with the scenario results.

- <u>Early EPCWID Ops (WWTP & Fabens Drains) (Run 15)</u> – In Run 15, simulation of EPCWID operations in the El Paso Valley are modified to simulate irrigation use of all available supplies consistent with how the Project was originally operated in the El Paso Valley. This includes simulation of irrigation use of the usable Fabens drain flows, which are estimated as 70% of the total Fabens drain flows limited to a monthly volume of 6,000 AF, based on available historical data (see response to Ferguson Opinion 9 for more information). In addition, EPCWID is charged for all use of drain flows and WWTP flows, and the ACE Credit and Haskell WWTP discharge credits are disabled. These changes reflect operations consistent with the original concept and implementation of the Project which was to use all available supplies to minimize the amount of storage releases needed to meet Project water demands. Further, since EPCWID is charged for all of its water use including the water that arises within the EPCWID system, it has less unused allocation in many years and uses its entire allocation in more years than in the Historical Base Run (Run 1). The increased use of water arising within the EPCWID system reduces the releases from Project storage to meet EPCWID demands and the accumulated Project storage increases the supply available for allocation and use in subsequent years. When accounting under 2008 OA commences, EPCWID has less unused allocation to carryover to subsequent years. The following is a summary of the effects of the foregoing changes in EPCWID operations:
    - <u>EBID</u> – FHG deliveries increase modestly by an average of 4,300 AF during 1951-1978 and by a much larger amount, averaging 41,900 AF during 2006-2017. The large increases during the recent period result from significant increases in the diversion ratio that result from EPCWID being

charged for all water that it uses, and the positive feedback of increases in the diversion ratio on EBID allocations under D3 accounting.

  - EPCWID – FHG deliveries increase by an average of 1,400 AF during 1951-2017. Simulated EPCWID RHG diversions decrease by an average of 15,100 AF during 1951-2017 as diversions of Project water from the river are eschewed in favor of the supplies arising within EPCWID.

  - HCCRD – The changes in EPCWID operations result in minor reductions in the water flowing to HCCRD. Annual total flow to HCCRD decreases by an average of 3,100 AF during 1951-2017.

- Early EPCWID Ops (WWTP) (Run 15a) – In Run 15a, EPCWID is charged for irrigation use of WWTP flows, and the ACE Credit and Haskell WWTP discharge credits are disabled. However, the simulated use of drain flows is left at the historical levels simulated in Run 1, and EPCWID is not charged for the historical use of the drain flows. The results are similar in pattern to the Run 15 results but smaller in magnitude as follows:

  - EBID – FHG deliveries increase modestly by an average of only 200 AF during 1951-1978, but by much larger amounts averaging 27,200 AF during 2006-2017. Similar to Run 15, the large increases during the recent period result from the effect of an increase in the diversion ratio on EBID allocations under the 2008 OA.

  - EPCWID – FHG deliveries decrease by an average of 1,900 AF during 1951-2017. Simulated EPCWID RHG diversions decrease by an average of 2,900 AF during 1951-2017 with the increased use and charge for supplies arising within EPCWID.

  - HCCRD – Charging EPCWID for use of WWTP flows and elimination of credits against charges reduces the total flow to HCCRD by an average of 500 AF during 1979-2005 and 2,200 AF during 2006-2017

- Early EPCWID Ops (Fabens Drains) (Run 15b) – In Run 15b, the model simulates and charges EPCWID for use of the usable Fabens drain flows as described above in Run 15. However, EPCWID is not charged for use of WWTP flows and is credited for Haskell WWTP discharges and the ACE Credit. The results are similar in pattern to the Run 15 results as follows:

- EBID – FHG deliveries increase modestly by an average of 4,300 AF during 1951-1978, and by an average of 21,800 AF during 2006-2017. Similar to Run 15, the large increases during the recent period result from the effect of an increase in the diversion ratio on EBID allocations under the 2008 OA.

- EPCWID – FHG deliveries increase by an average of 3,100 AF during 1951-2017. Simulated EPCWID RHG diversions decrease by an average of 12,900 AF during 1951-2017 with the simulated increased use and charge for drain flows arising within EPCWID.

- HCCRD – The increased use of drain flows in EPCWID results in a reduction in the total flow to HCCRD averaging 2,600 AF.

- Early EPCWID Ops (TX Hueco Pumping Off) (Run 15c) – In this scenario, the changes to EPCWID operations and accounting from Run 15 were simulated with the Texas Hueco pumping turned off. The effects of Texas Hueco pumping with the modified EPCWID operation were assessed by comparing the results of Run 15c and Run 15. The effects of the Texas Hueco pumping on EBID are mixed due to the opposing effects on EPCWID from pumping and WWTP discharges from pumping.

30.14 Conj Use 1: Hist All Acres D1/D2 (Runs 16 and 16a)

Two scenarios are simulated to evaluate conjunctive use of surface water and ground water within the Rio Grande Project under the D1/D2 allocation procedure with the historical irrigated area that evolved over time (including irrigation of the primary ground water only acres in New Mexico), and with the early EPCWID operations that are simulated in Run 15. In both scenarios, irrigation pumping in EBID and EPCWID is limited based on the irrigation pumping that existed during the 1951-1978 D1/D2 data period. This is implemented by not allowing the 10-year running average pumping after 1978 to exceed the 1951-1978 historical average annual pumping.

- Conj Use 1: Hist All Acres D1/D2 (Hist M&I) (Run 16) – Run 16 essentially combines the early EPCWID operations from Run 15 with the Run 11 continuation of D1/D2 allocation of Project water after 2005 along with a limit on irrigation pumping after 1978. In Run 16, the M&I pumping and returns are set at the historical amounts simulated in Run 1. The results for Run 16 are very similar to Run 15 until 2005. After that time, the differences from Run 1 represent the combination of the early EPCWID operations and continuation of D1/D2 accounting. The following are summaries of the differences between Run 16 and Run 1 after 2005:

  - EBID – FHG deliveries increase by an average 69,000 AF during 2006 -2017 which is much greater than the increase of 41,900 AF in Run 15.
  - EPCWID – FHG deliveries decrease by an average of 14,500 AF during 2006 -2017 with the D1/D2 accounting compared to an average increase of 700 AF in Run 15.
  - HCCRD – Total flows to HCCRD decline by an average of 9,500 AF during 2006-2017, compared to an average decline of 3,800 AF during this same period in Run 15.

- Conj Use 1: Hist All Acres D1/D2 (1978 M&I) (Run 16a) – The conditions simulated in Run 16a are the same as Run 16 except that M&I pumping in New Mexico and Texas after 1978 is limited to the levels that existed in 1978 at the end of the D1/D2 period. This limit has minimal effect on Texas M&I pumping because it exceeded the 1978 amount by only small amounts in a few years after 1978. When the M&I pumping is limited by the 1978 amount, the simulated M&I returns are scaled down proportionally. The results of Run 16a are very similar to Run 16 which reinforces that New Mexico M&I pumping has relatively little impact on Project operations.
  - EBID – FHG deliveries increase by an average of 72,400 AF during 2006-2017 compared to an average increase of 69,000 AF in Run 16.
  - EPCWID – FHG deliveries decrease by an average of 12,600 AF during 2006-2017 compared to a decrease of 14,500 AF in Run 16.
  - HCCRD – Total supply to HCCRD from 2006-2017 decreases by 9,200 AF compared to an average decrease of 9,500 AF in Run 16.

30.15 Conj Use 2: Hist Proj Acres (Runs 17 and 17a)

A second set of conjunctive use scenarios are simulated in Run 17 and Runs 17a under the D1/D2 allocation procedure with irrigation limited to the historical Project acres and no irrigation of the non-Project primary (ground water only) acres in New Mexico. The early EPCWID operations from Run 15 are also a part of these conjunctive use scenarios.

- Conj Use 2: Hist Proj Acres (Hist M&I) (Run 17) – In Run 17, the M&I pumping and returns are set at the historical amounts simulated in Run 1. The results from Run 17 are similar to the results from Run 16 and the differences largely reflect the effect of ground water pumping on primary acres in New Mexico.

- EBID – Annual FHG deliveries increase by an average of 7,500 AF during 1951-1978, and by a much larger average of 75,600 AF following the change to D1/D2 after 2005.

- EPCWID – Annual FHG deliveries increase by an average 5,100 AF during 1951-1978, and decline by 10,700 AF during 2006-2017 due to the change in allocation method from D3 to D1/D2 starting in 2006.

- HCCRD – Total flows to HCCRD decrease by an average of 8,600 AF during 2006-2017.

- Conj Use 2: Hist Proj Acres (Pre-Comp M&I) (Run 17a) – The conditions simulated in Run 17a are the same as Run 17 except that M&I pumping in New Mexico and Texas is set at the pre-Compact amounts that existed in 1938 (736 AF/y in New Mexico and 13,744 AF/y in Texas). M&I returns are scaled down proportionally consistent with the pre-Compact pumping volumes. The differences between Run 17 and Run 17a reflect the effects of the post-compact increases in total M&I pumping throughout the study area on simulated surface water supplies.

  - EBID – Annual FHG deliveries increase by an average of 9,500 AF from 1951 – 1978 and 87,900 AF from 2006-2017. These compare to an increase of 7,500 AF and an increase of 75,600 AF in Run 17, respectively.

  - EPCWID – Annual FHG deliveries increase by an average 6,100 AF during 1951-1978, and decrease by 4,300 AF during 2006-2017 due to the change in allocation method to D1/D2. These compare to a 1951-1978 increase of 5,100 AF and 2006-2017 decrease of 10,700 AF in Run 17.

  - HCCRD – Total supply to HCCRD increases by an average of 1,100 AF during 1951-2017 compared to an average decrease of 2,800 AF in Run 17.

30.16 Conj Use 3: Auth Proj Acres (Pre-Comp M&I) (Run 18)

A third conjunctive use scenario is simulated in Run 18 under the D1/D2 allocation procedure with irrigation of the original authorized Project acres simulated in every year from 1940-2017 (88,000 acres in EBID and 67,000 acres in EPCWID). The irrigated area in HCCRD is set at the reported maximum historical amount of 17,750 acres that occurred in 1951, and the irrigated area in JID is set at historical levels. M&I pumping and returns are limited to the pre-Compact amounts as in Run 17a. The early EPCWID operations are also simulated as in the other conjunctive use scenarios. Finally, because the authorized EPCWID acres are simulated as irrigated in every year, there is no simulation of EPW use of Project water.

- EBID – Annual FHG deliveries decrease by an average of 1,800 AF during 1951-1978, and increase by 51,500 AF during 2006-2017 under D1/D2.
- EPCWID – Annual FHG deliveries increase by an average of 5,600 AF during 1951-1978 and decrease by an average of 35,700 AF during 2006-2017 when allocations revert back to the D1/D2 method.
- HCCRD – Total supply to HCCRD increases by 500 AF during 1951-1978 and decreases by an average of 13,500 AF during 2006-2017.

31.0 SENSITIVITY ANALYSES OF ILRG MODEL

Alternative runs of the ILRG Model were made to test the sensitivity of the results to changes in certain input parameters and input data. Since ILRG Model results are assessed primarily based on differences between runs, the results of the sensitivity runs were also tabulated based on run differences. The No New Mexico Pumping scenario (Run 3) was selected for the sensitivity analysis, along with the differences in model output compared to the Historical Base Run scenario (Run 1).

The following inputs were selected for sensitivity analysis based on discussions among the New Mexico experts:

- Alluvial Aquifer Hydraulic Conductivity
- River Bed Conductance
- Canal Bed Conductance
- Drain Bed Conductance
- Crop Irrigation Requirement (CIR)

Each of the above inputs was separately perturbated by +10% for the sensitivity runs. Since each of the above inputs are represented in the model as spatially varying values, the 10% perturbation involved applying a scaler of 1.1 to each spatially distributed value. Then, fully iterated runs of the ILRG Model were made to closure for Run 3 and Run 1 (identified as Run 3* and Run 1* in the results summaries). The model inputs being tested were perturbated by 10% in both the RiverWare Model and the two ground water models, except for the CIR which is not an input to the ground water models and canal bed conductance which is perturbed only in the ground water models since canal loss is computed in the ground water models and passed to the RiverWare Model.

The model outputs tabulated and compared for the sensitivity analyses are the same outputs that are summarized in the run comparisons for the alternative model runs described in Section 30.0. The differences in outputs between Run 3* and Run 1* are compared to the differences between the original Run 3 and Run 1, and these comparisons are tabulated in several figures and tables for each input that was tested.

Graphs illustrating the sensitivity analysis results are provided in the bar charts in **Figure 31-1** through **Figure 31-5**. The black bars represent the average Run 3 minus Run 1 differences for the original ILRG Model Runs. As described in more detail in Section 30.0

turning off New Mexico pumping generally results in increased Project storage, decreased Caballo releases, increased diversions and FHG deliveries to EBID, EPCWID, and HCCRD, increased Rio Grande flows at El Paso and Fort Quitman, and increased ground water storage. The orange bars depict the average Run 3* minus Run 1* differences for the sensitivity runs of the ILRG Model. Differences between the black and orange bars reflect the sensitivity of the model outputs to the 10% perturbations of the specified inputs. These differences are summarized as average volumes and average percent changes in **Table 31-1** for each of the five inputs that were tested. The sensitivities of each input are summarized below.

- Alluvial Aquifer Hydraulic Conductivity – Increasing the alluvial aquifer hydraulic conductivity by 10% causes relatively small changes in diversions, FHG deliveries, river flows, and storage (4% or less). These changes generally reflect slight speeding of the surface flow responses to pumping and recharge.

- River Bed Conductance – Increasing the river bed conductance by 10% increases the river gain and loss responses to changes in aquifer heads in hydraulically connected reaches. This in turn slightly increases the surface water response to the cessation of New Mexico pumping in Run 3. More of the pumping effects are expressed as changes in surface water flows and less to changes in ground water storage.

- Canal Bed Conductance – Increasing the canal bed conductance by 10% increases the canal seepage response to changes in pumping and recharge. As a result, turning off pumping in New Mexico results in a modest increase in the effects on diversions and FHG deliveries of the districts (0% - 7%). There are also positive changes in the increases in reservoir and ground water storage (3% - 5%) as well as the increases in river flows from turning off New Mexico pumping (3% - 6%).

- Drain Bed Conductance – Increasing the drain bed conductance by 10% has little effect on the model outputs. The effect on the changes in diversions is only 2% or less, and the effect on reservoir and ground water storage changes is less than 1%.

- Crop Irrigation Requirement (CIR) – Increasing the CIR by 10% has a greater effect on model outputs than any of the other inputs that were tested. This is not surprising because an increase in the CIR has a greater effect on the water budget. Increasing the CIR results in an increase in the unmet demand after the surface water deliveries which in turn increases the simulated pumping in Run 1*. Therefore, when New Mexico pumping is turned off in Run 3*, there are larger computed impacts of pumping on surface water flows than in the base runs. The effect of pumping on diversions and FHG deliveries by the U.S. districts increases by 15% - 43%. The effects of pumping on reservoir storage, river flows, and ground water storage are also significantly affected.

The results of the sensitivity analyses demonstrate that the ILRG Model is most sensitive to changes in CIR because of its substantial effect on the water budget and the unmet irrigation demand that is satisfied by pumping. The other tested parameters mainly affect the timing of ground water flow and the interaction of ground water and surface water interaction as opposed to directly affecting the water budget.

32.0 LIST OF REFERENCES

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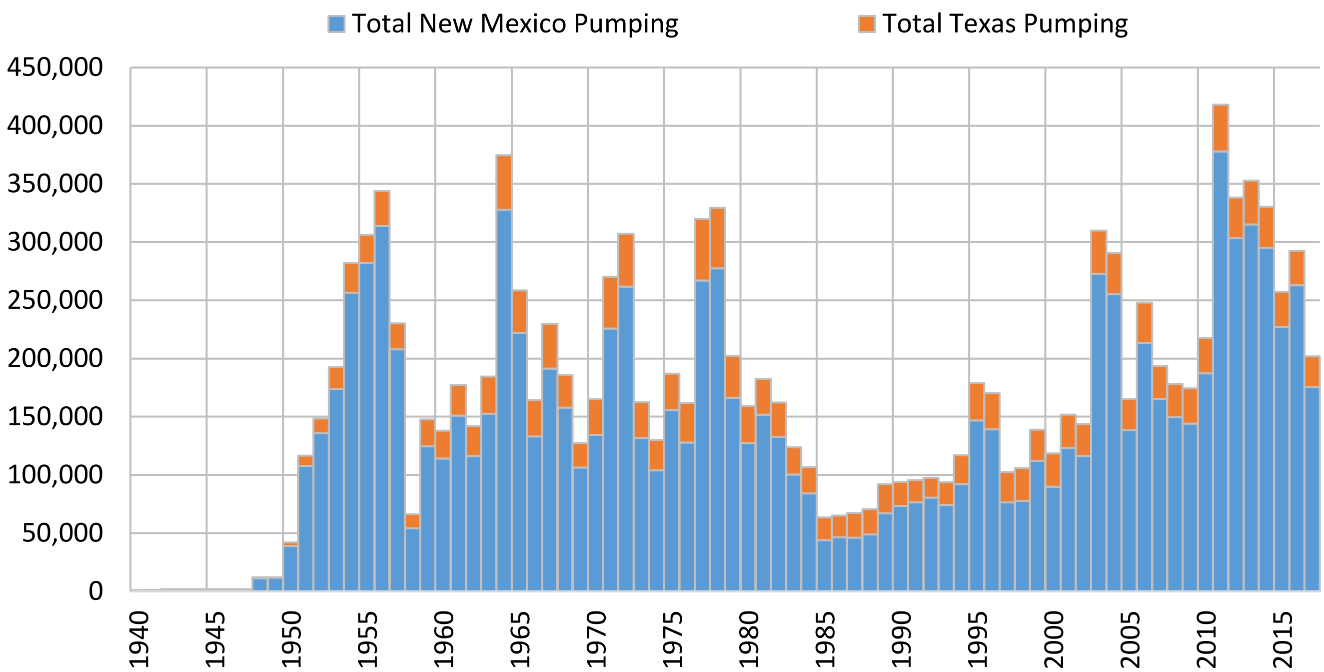
FIGURES

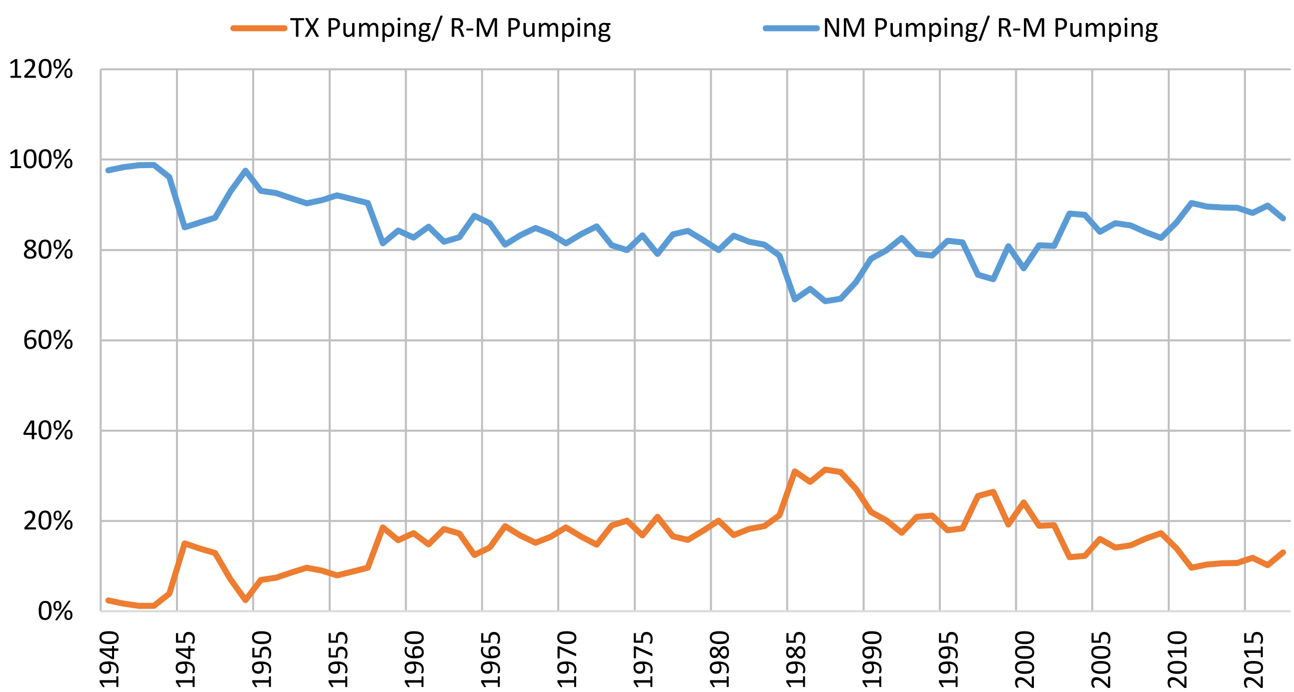
Figure 19-1

Historical Pumping in the Rincon and Mesilla Valleys
1940 - 2017

Annual Pumping (acre-feet)



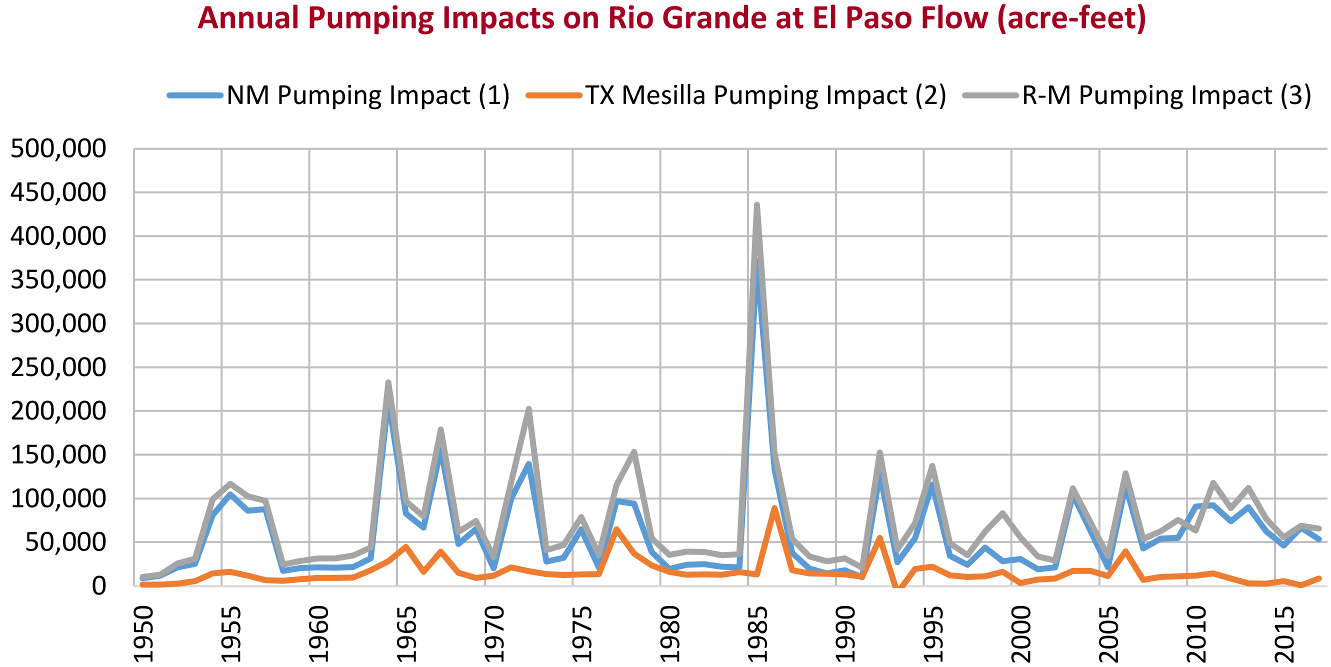
% Total Rincon and Mesilla Valley Pumping

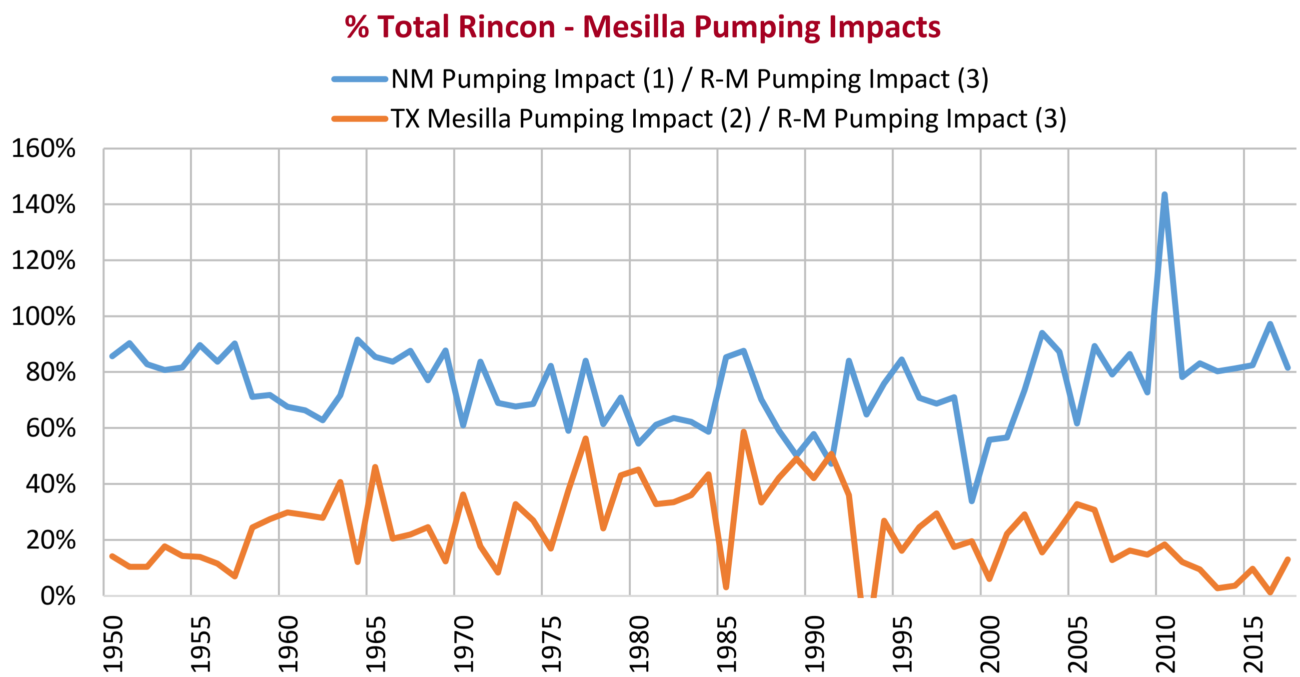


Notes:
(1) All pumping amounts include irrigation (primary and supplemental) plus M&I pumping.
(2) Irrigation pumping amounts from SWE CFB Model.
(3) M&I pumping from the NMR-M Model.

Figure 19-2

Depletion to Rio Grande at El Paso Flow from Pumping in the Rincon and Mesilla Valleys
ILRG Model
1950 - 2017

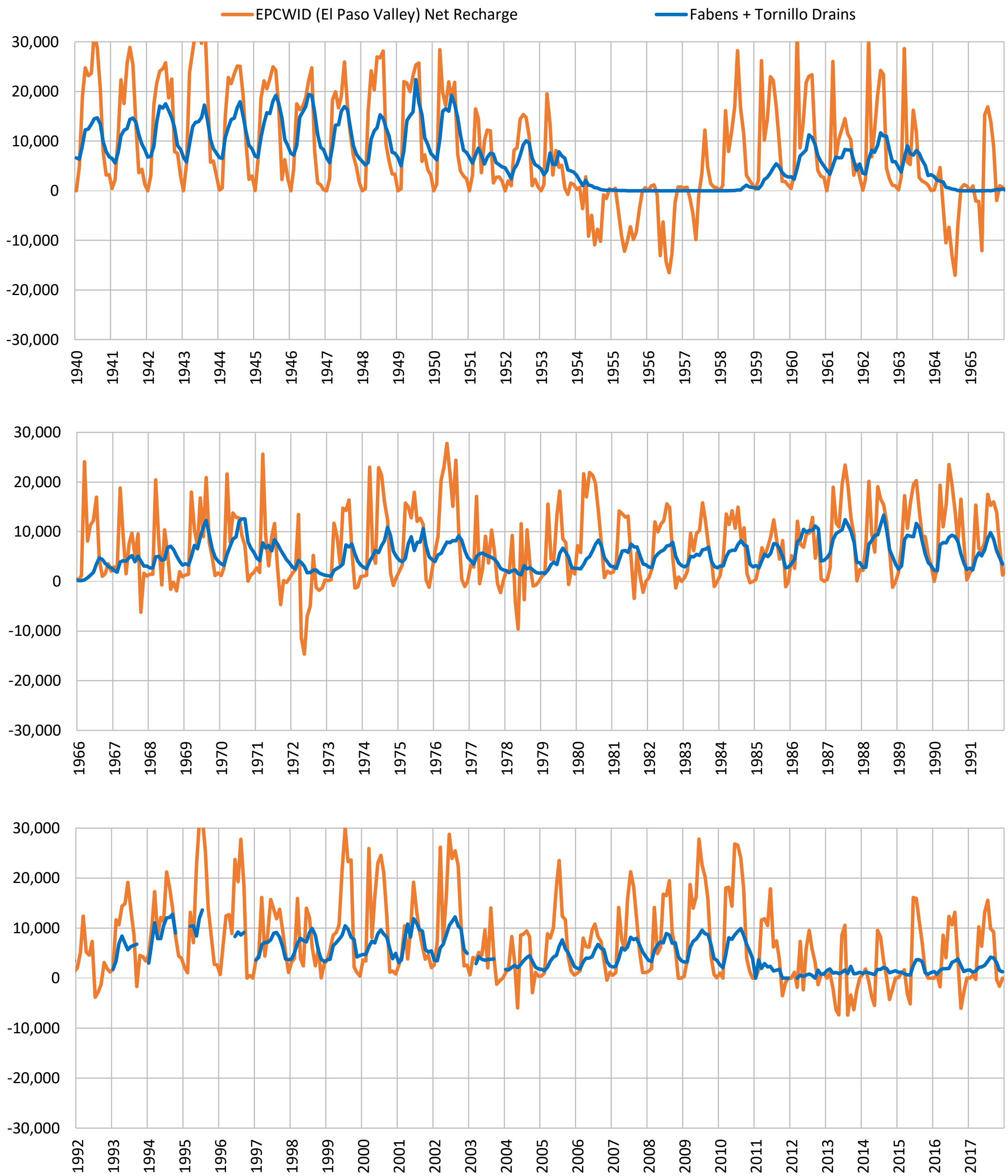




Notes:
(1) NM Pumping Impact computed as El Paso Flow plus Northwest WWTP discharge in Run 3 minus Run 1.
(2) TX Mesilla Pumping Impact computed as El Paso Flow plus Northwest WWTP discharge in Run 7 minus Run 1.
(3) R-M Pumping Impact computed as El Paso Flow plus Northwest WWTP discharge in Run 6 minus Run 1.

Figure 19-3

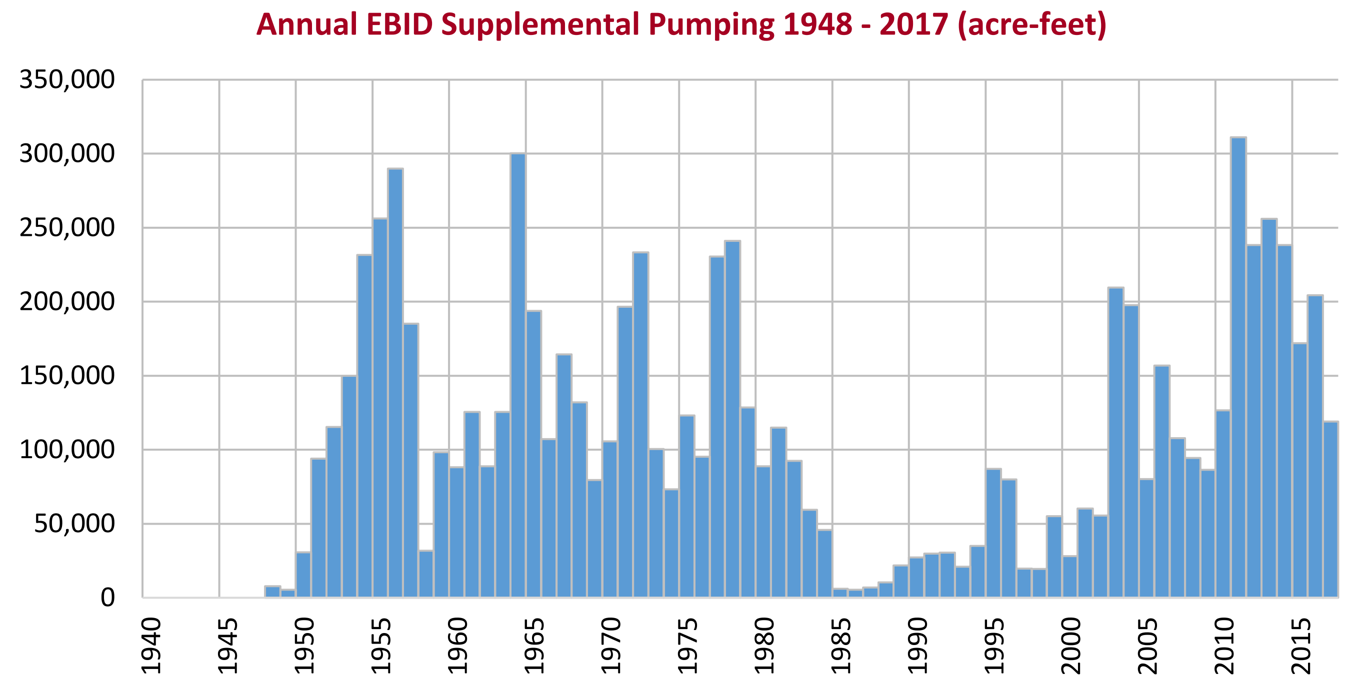
Monthly Net Recharge vs. Drain Flow
EPCWID (El Paso Valley)
1940 - 2017 (acre-feet)

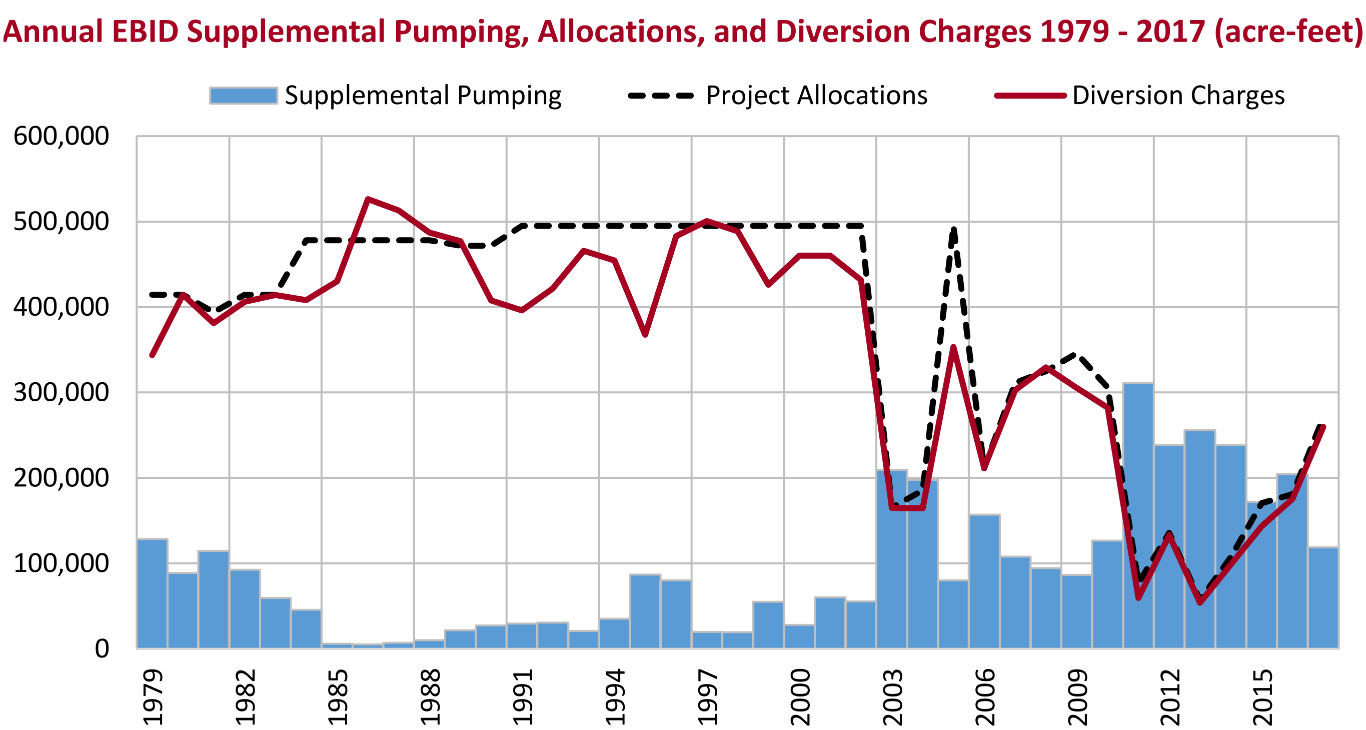


Notes: Net recharge computed as canal seepage plus on farm deep percolation minus pumping from the CFB Model.
Drain flows from SWE SWDataSet. Computed as Tornillo Drain plus Fabens Waste Drain. Fabens Waste Drain flows estimated 1940-1983 as sum of River, Middle, Cuadrilla, Mesa, and Fabens Intercepting drains. Missing Fabens Intercepting Drain flows 1972 - 1983. Missing Fabens Waste Drain flows in 1992, and in certain months in 1993-1996, 2003, and 2012.

Figure 19-4

EBID Pumping, Allocations, and Charges

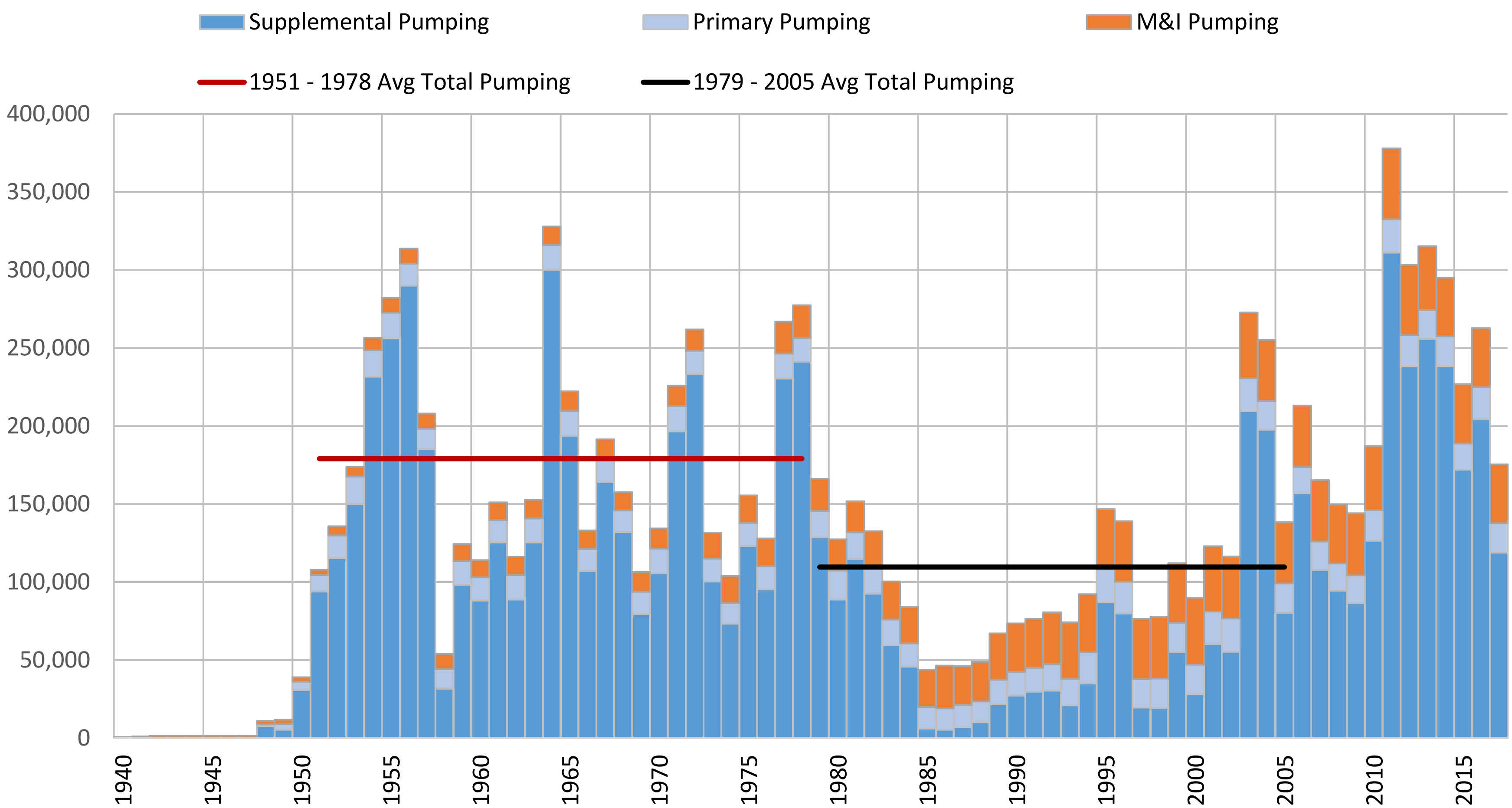




Notes:
(1) Supplemental irrigation pumping from SWE CFB Model.
(2) Annual allocations and diversion charges from SWE Accounting DataSet.

Figure 19-5

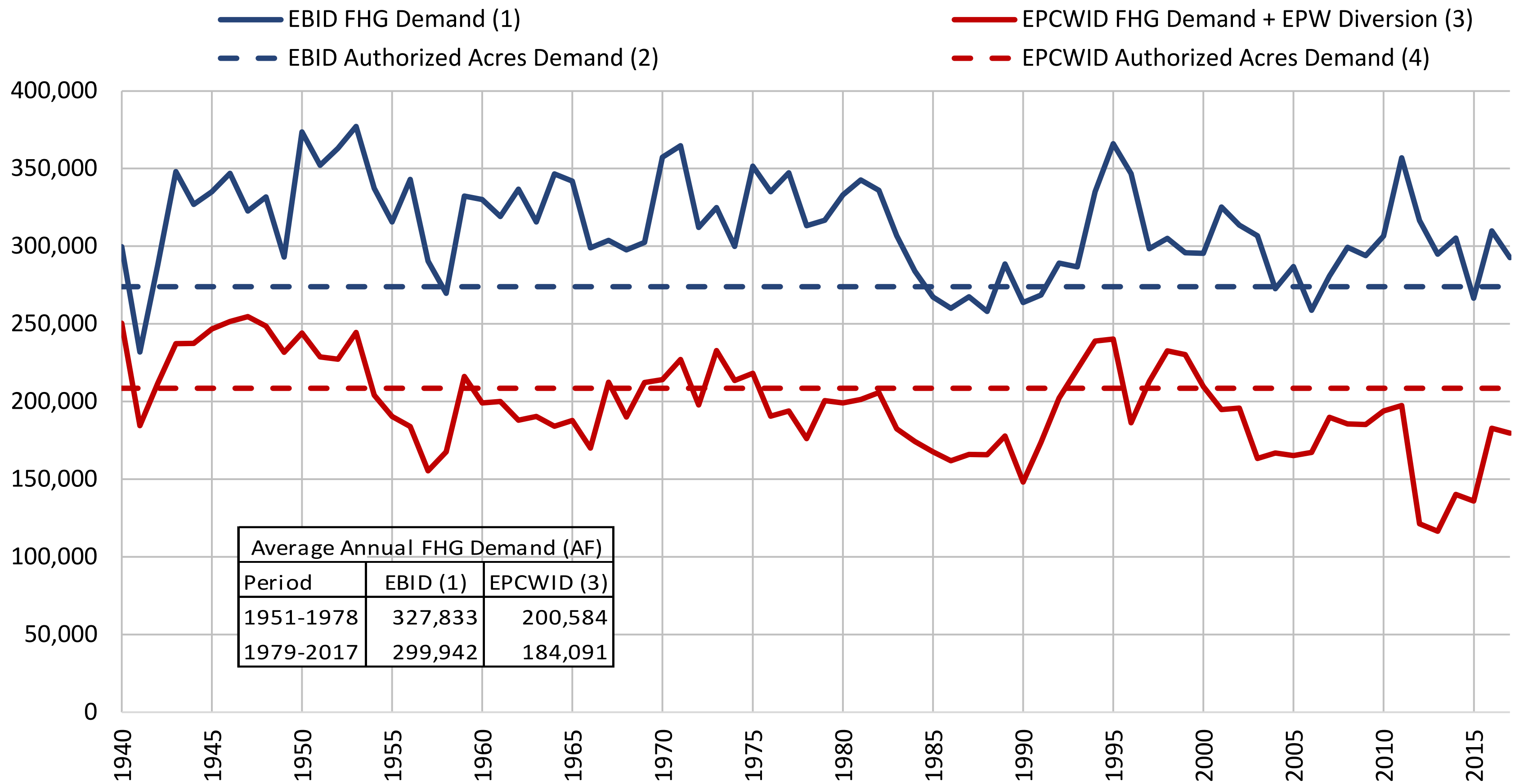
New Mexico Annual Pumping in the Rincon and Mesilla Valleys
1940 - 2017 (acre-feet)



Notes:
(1) New Mexico irrigation pumping from SWE CFB Model.
(2) New Mexico M&I pumping from the NMR-M Model.

Figure 19-6

EBID and EPCWID Annual Farm Headgate Demand
1940 - 2017 (acre-feet)



Average Annual FHG Demand (AF)		
Period	EBID (1)	EPCWID (3)
1951-1978	327,833	200,584
1979-2017	299,942	184,091

Notes:

(1) EBID FHG Demand from SWE CFB Model and computed as weighted supplemental CIR (feet) x irrigated acres /on-farm irrigation efficiency.

(2) EBID Authorized Acres Demand computed as 3.024 AF/acre x EBID authorized acres (90,640).

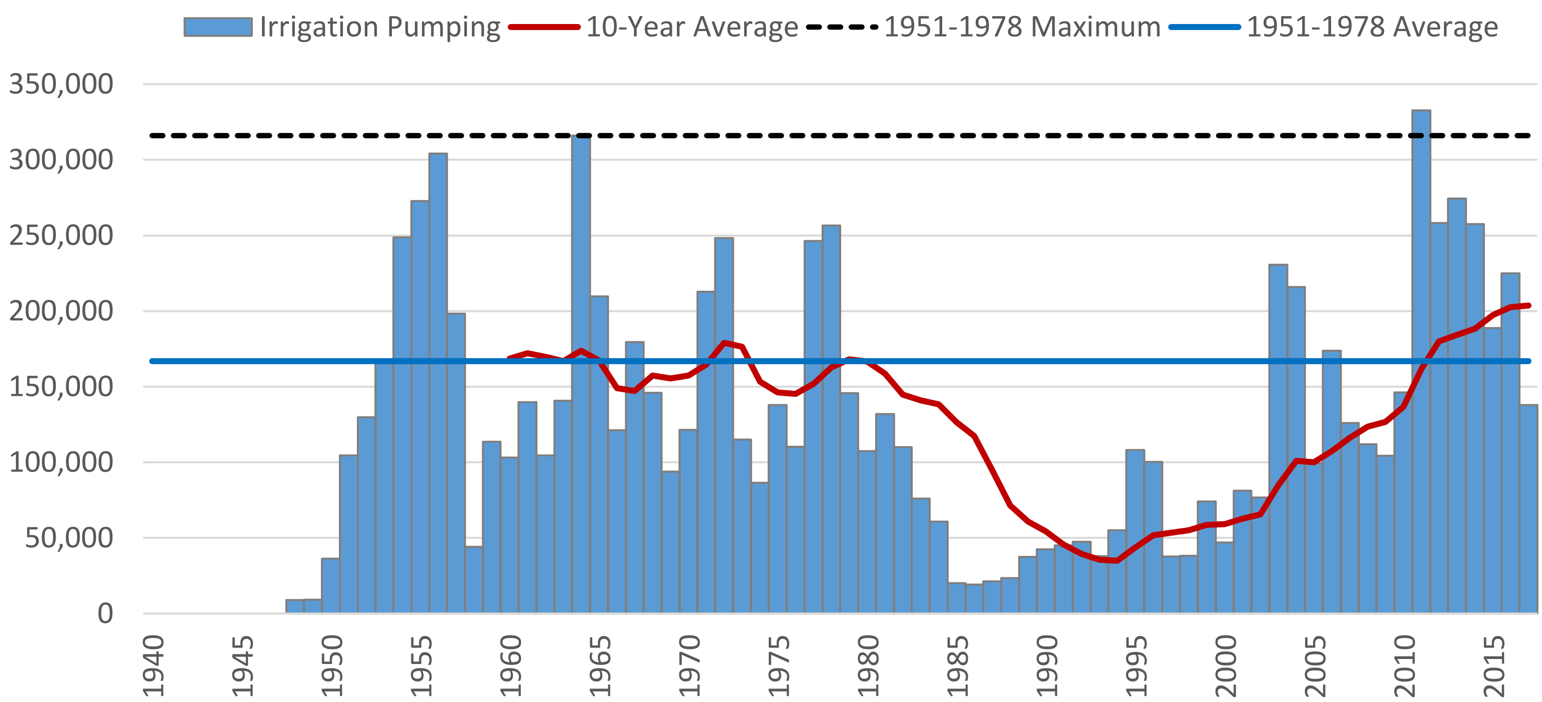
(3) EPCWID FHG Demand from SWE CFB Model and computed as weighted CIR (feet) x irrigated acres /on-farm irrigation efficiency.
EPW Diversion from SWE SWDataSet.

(4) EPCWID Authorized Acres Demand computed as 3.024 AF/acre x EPCWID authorized acres (69,010).

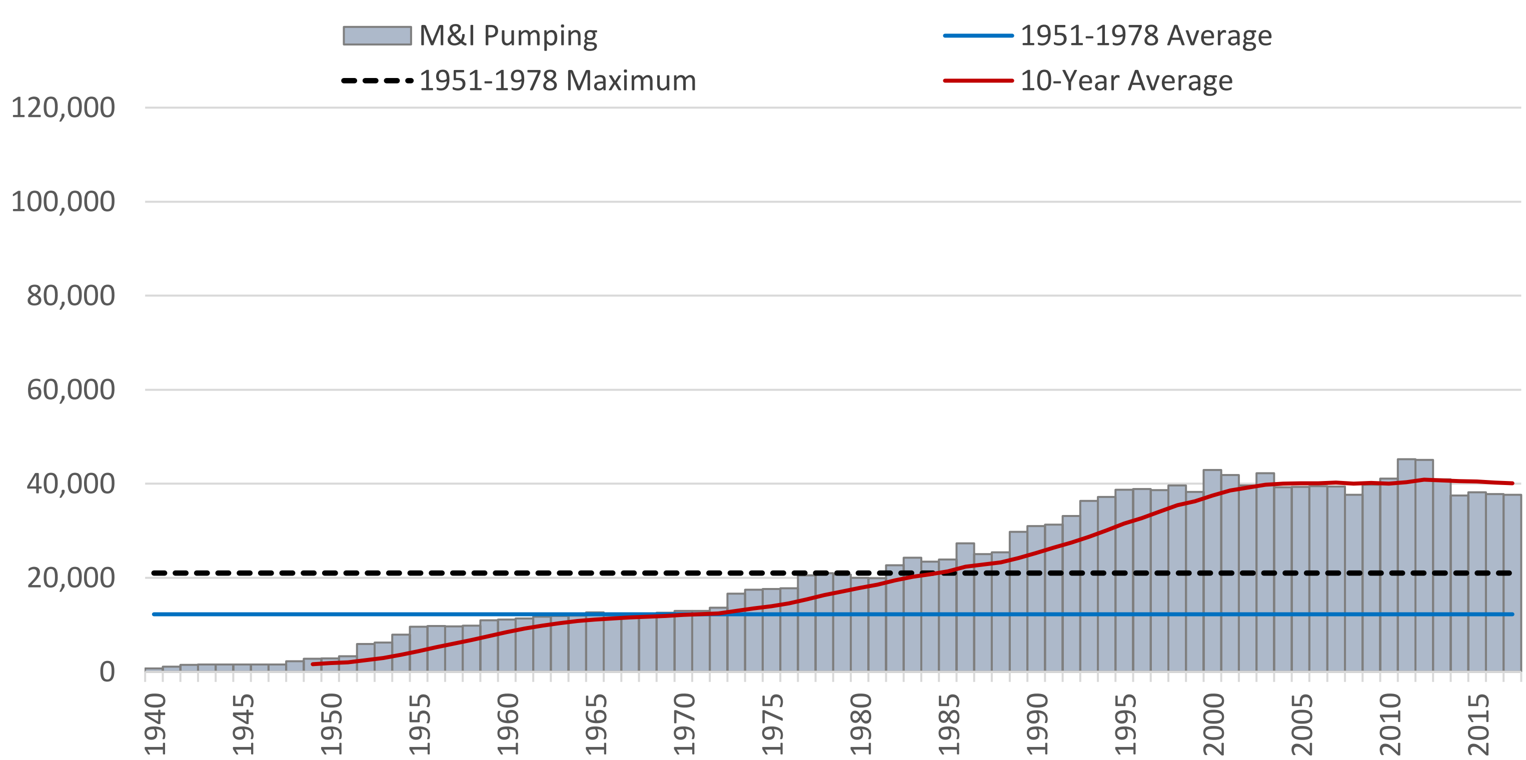
Figure 19-7

Annual New Mexico Pumping
1940 - 2017 (acre-feet)

New Mexico Irrigation Pumping



New Mexico M&I Pumping



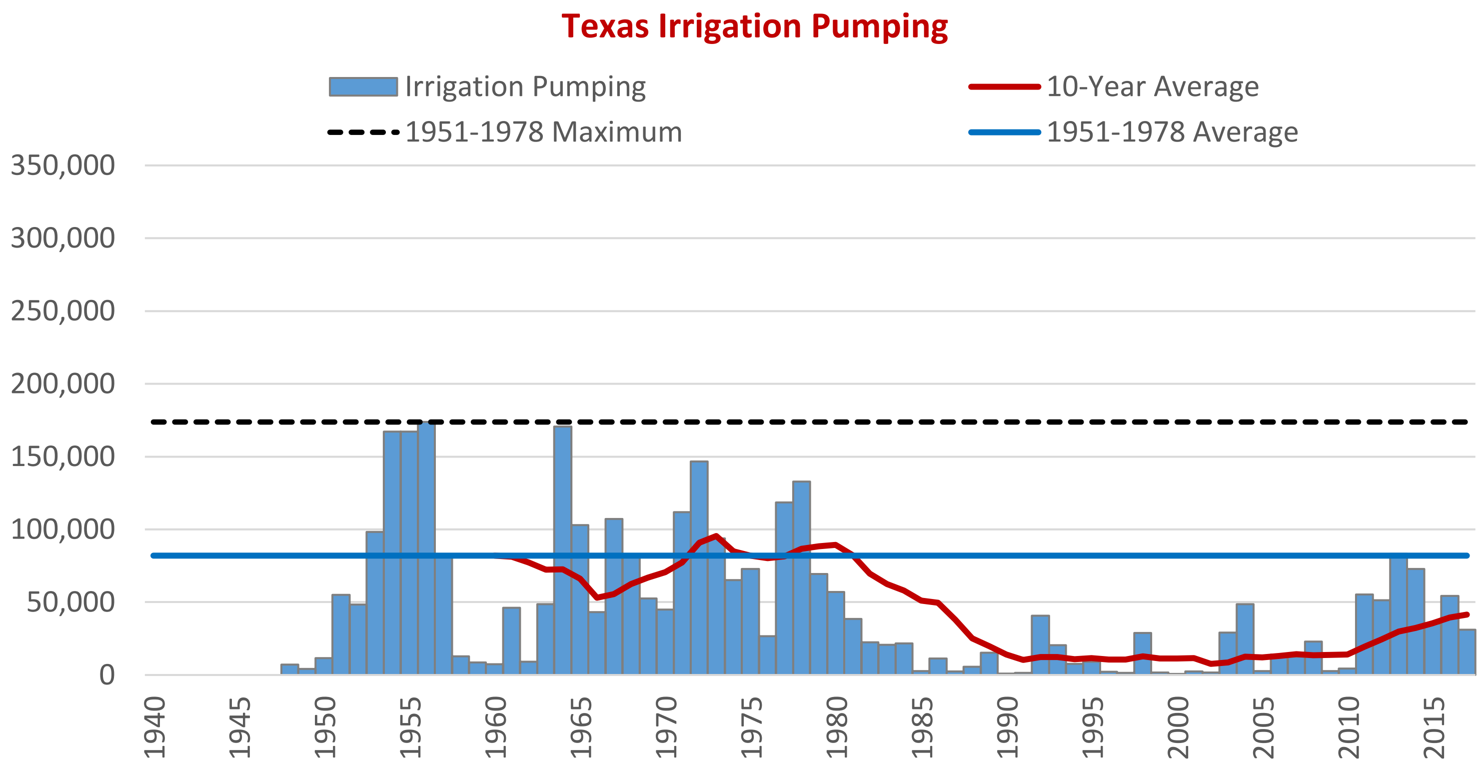
Notes:

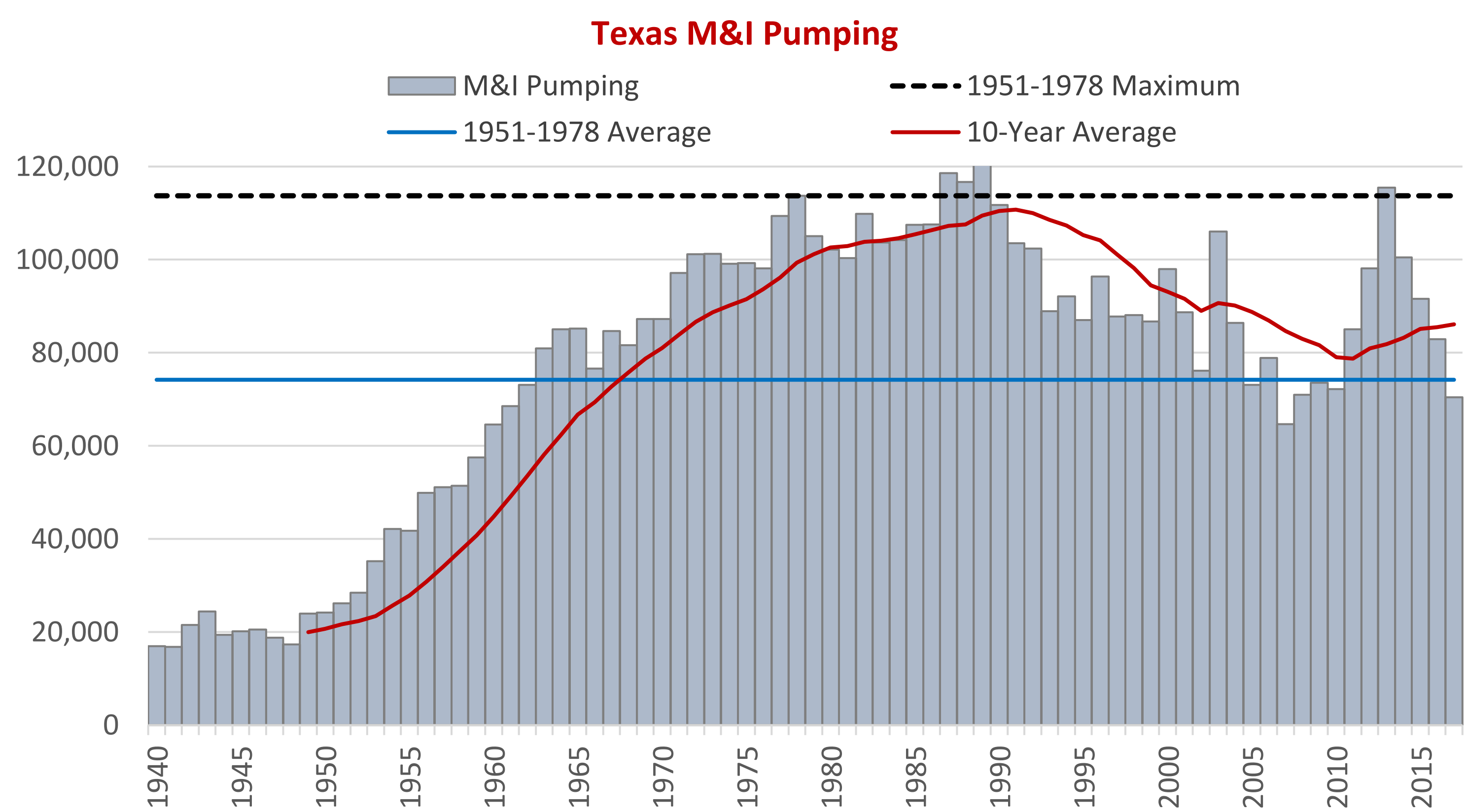
(1) New Mexico irrigation pumping includes EBID supplemental and primary pumping from SWE CFB Model.

(2) New Mexico M&I pumping from NMR-M Model.

Figure 19-8

Annual Texas Pumping
1940 - 2017 (acre-feet)





Notes:

(1) Texas irrigation pumping includes EPCWID and HCCRD pumping from SWE CFB Model.

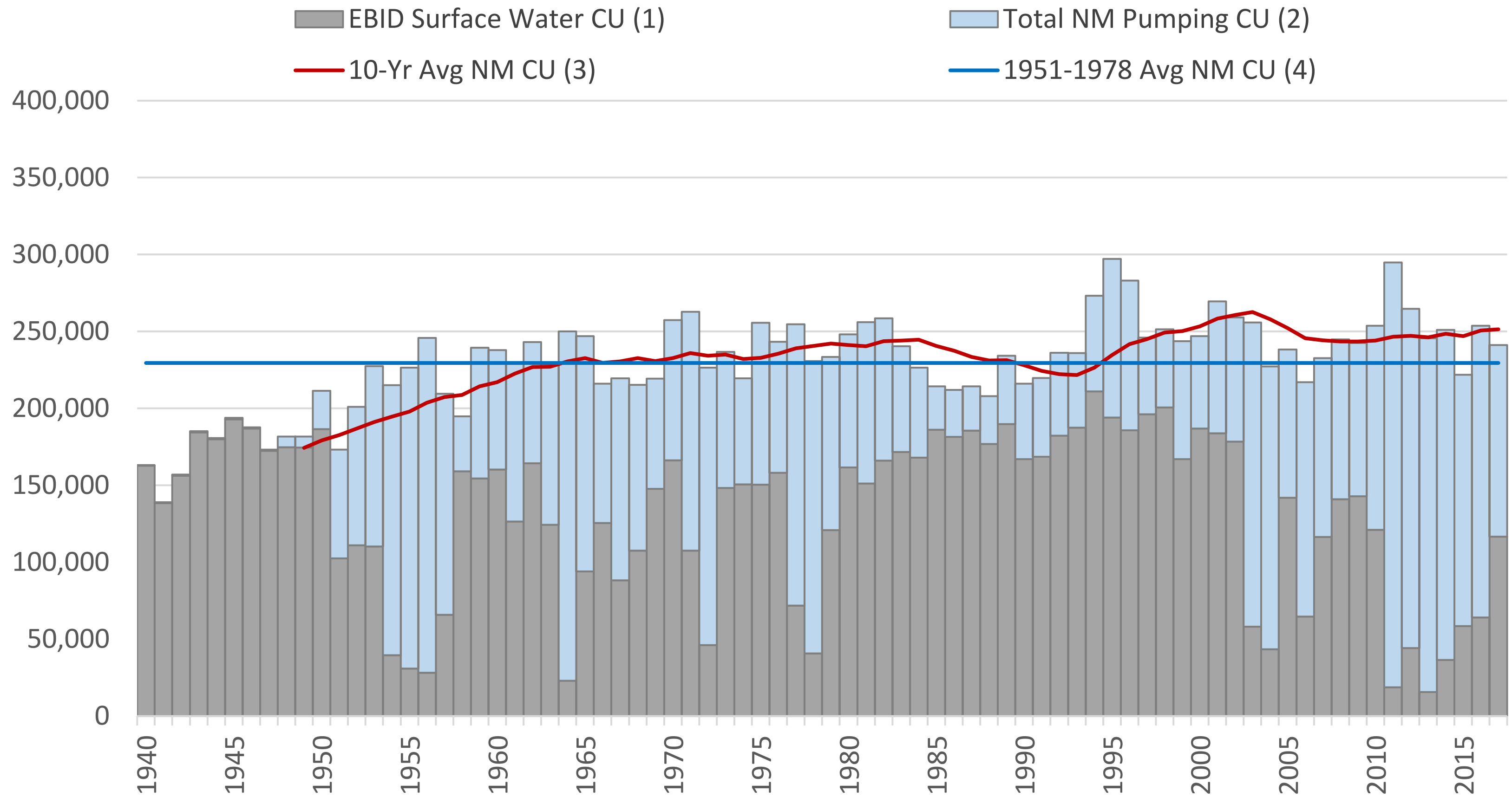
(2) Texas M&I pumping includes EPW and other Texas M&I pumping from NMR-M Model and Hueco Model.

Figure 19-9

Annual Irrigation and M&I Consumptive Use

New Mexico

1940 - 2017 (acre-feet)



Notes:

(1) EBID surface water irrigation consumptive use from SWE CFB Model.

(2) EBID irrigation pumping CU (incl. primary ground water lands) from SWE CFB Model plus New Mexico M&I pumping from NMR-M Model and Hueco Model minus return flows from NMR-M Model and Hueco Model inputs.

(3) 10-year running average of total irrigation and M&I consumptive use (1, 2).

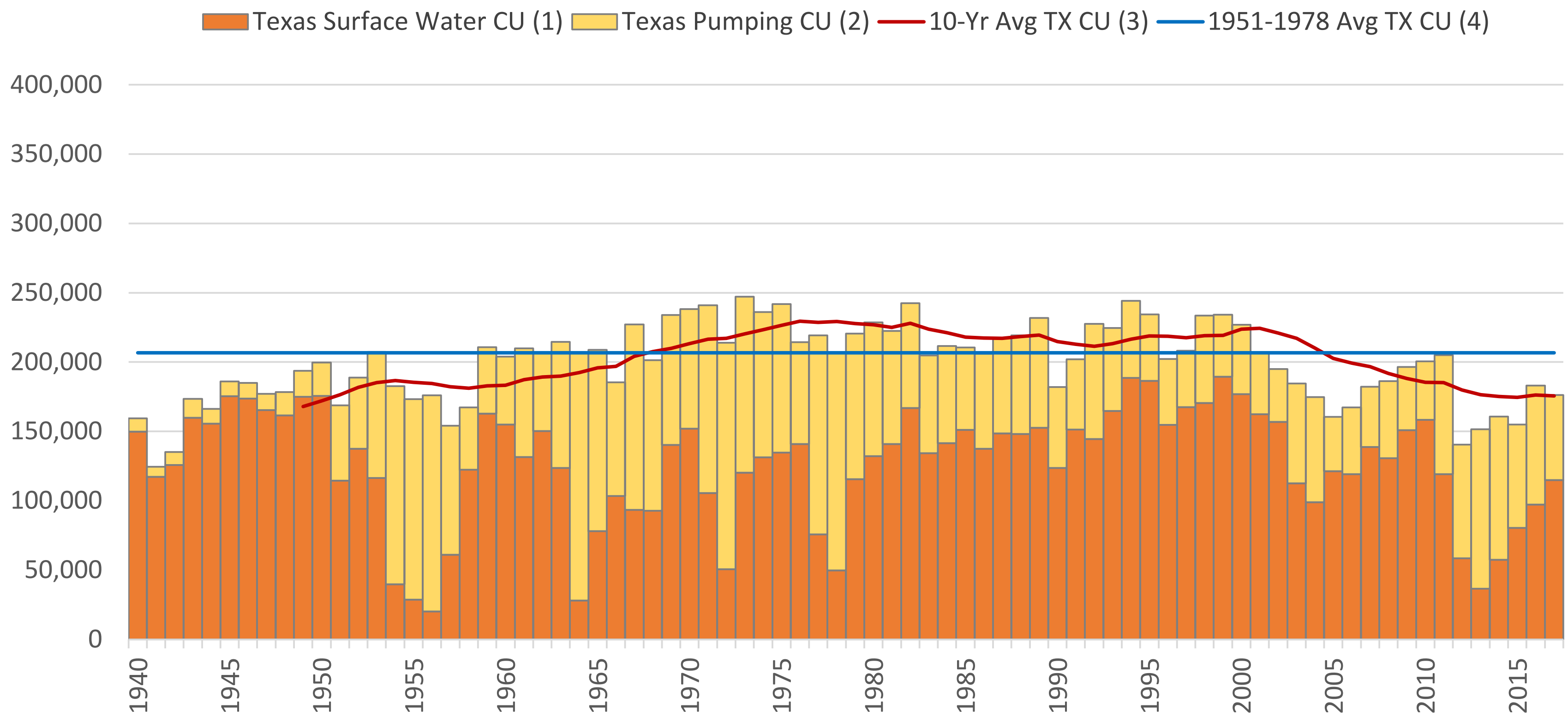
(4) 1951 - 1978 average of total irrigation and M&I consumptive use (1, 2).

Figure 19-10

Annual Irrigation and M&I Consumptive Use

Texas

1940 - 2017 (acre-feet)



Notes:

(1) Sum of EPCWID and HCCRD surface water irrigation consumptive use from SWE CFB Model plus EPW surface water diversions from SWE SWDataSet minus pro-rata return flows based on EPW total use minus total returns. EPW pumping and returns from NMR-M Model and Hueco Model.

(2) Sum of EPCWID and HCCRD irrigation pumping CU from SWE CFB Model plus Texas M&I pumping from NMR-M Model and Hueco Model minus return flows from NMR-M Model and Hueco Model inputs.

(3) 10-year running average of total irrigation and M&I consumptive use (1, 2).

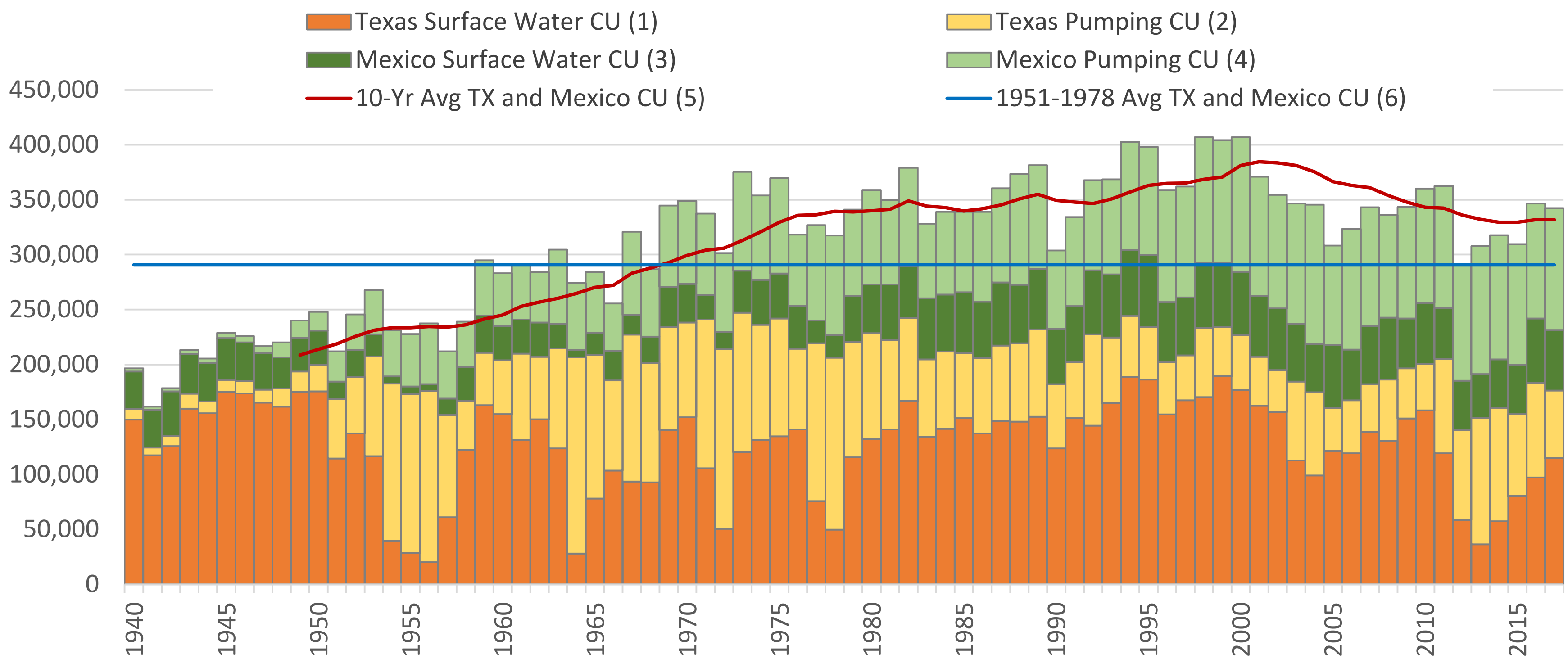
(4) 1951 - 1978 average of total irrigation and M&I consumptive use (1, 2).

Figure 19-11

Annual Irrigation and M&I Consumptive Use

Texas and Mexico

1940 - 2017 (acre-feet)



Notes:

(1) Sum of EPCWID and HCCRD surface water irrigation consumptive use from SWE CFB Model plus EPW surface water diversions from SWE SWDataSet minus pro-rata return flows based on EPW total use minus total returns. EPW pumping and returns from NMR-M Model and Hueco Model.

(2) Sum of EPCWID and HCCRD irrigation pumping CU from SWE CFB Model plus Texas M&I pumping from NMR-M Model and Hueco Model minus return flows from NMR-M Model and Hueco Model inputs.

(3) JID irrigation surface water consumptive use from SWE CFB Model.

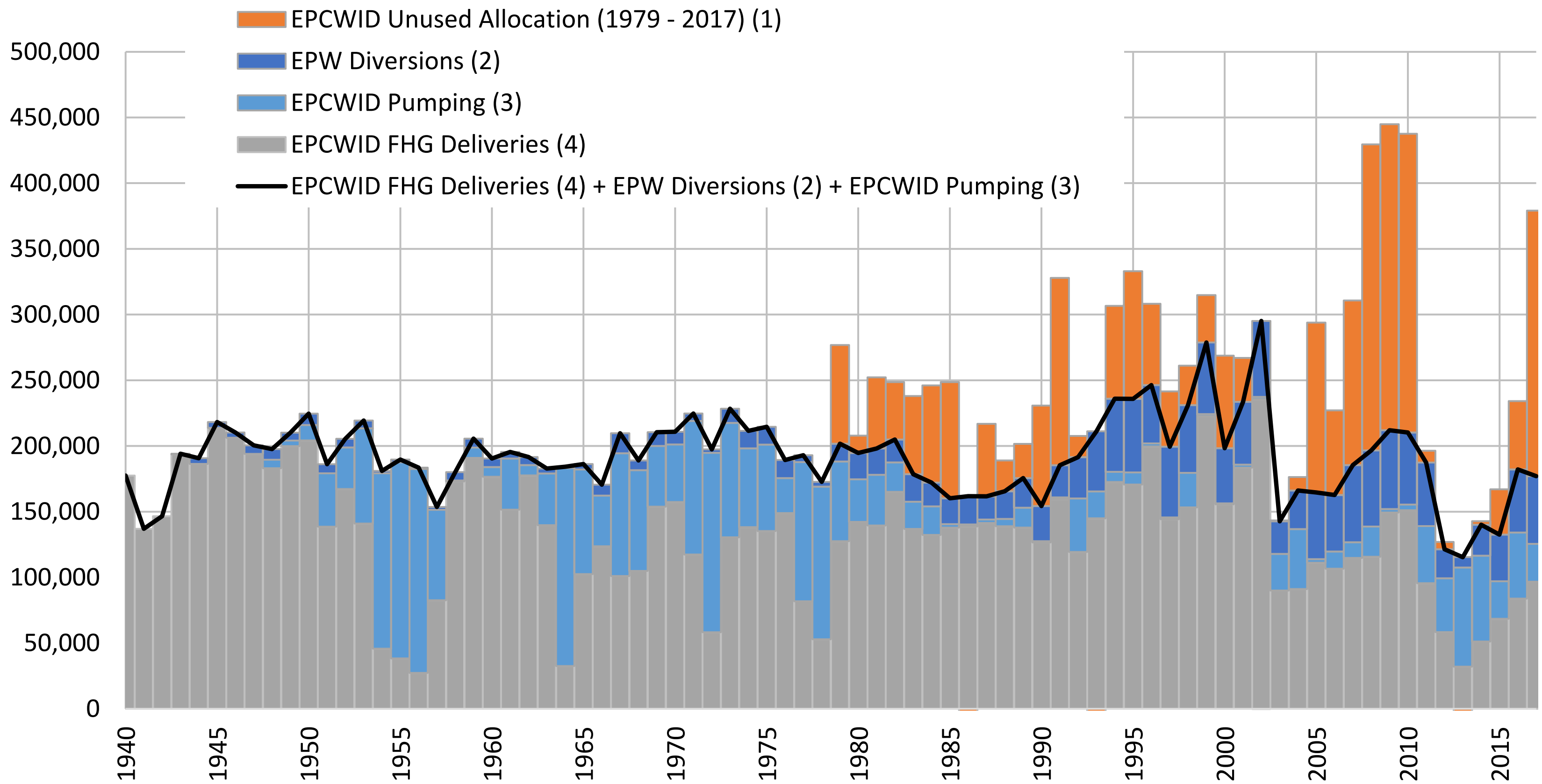
(4) Sum of JID irrigation pumping CU from SWE CFB Model and Ciudad Juarez M&I pumping (not including Conejos-Medanos M&I pumping) minus return flows from Hueco Model.

(5) 10-year running average of total Texas and Mexico consumptive use (1,2,3,4).

(6) 1951 - 1978 average of total Texas and Mexico consumptive use (1,2,3,4).

Figure 19-12

Annual EPCWID FHG Deliveries, Pumping, and Unused Allocation
1940 - 2017 (acre-feet)



Notes:
(1) EPCWID unused allocation from SWE Accounting Dataset and computed as allocations minus diversion charge.
(2) EPW diversions from SWE SWDataSet.
(3) EPCWID pumping from SWE CFB Model.
(4) EPCWID FHG deliveries from SWE CFB Model.

Figure 19-13

Schematic Diagram
EPCWID Distribution and Drainage System and Gages

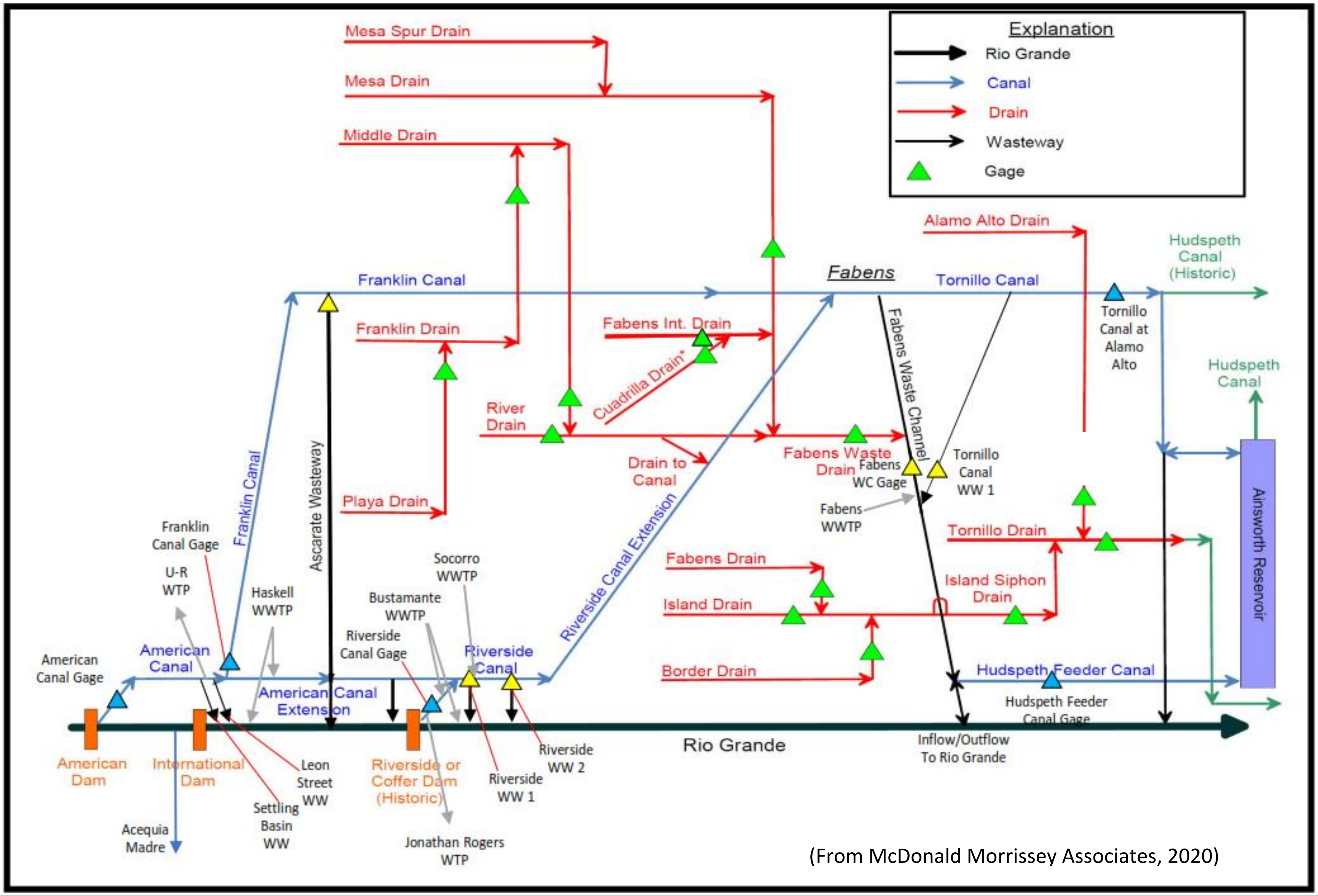
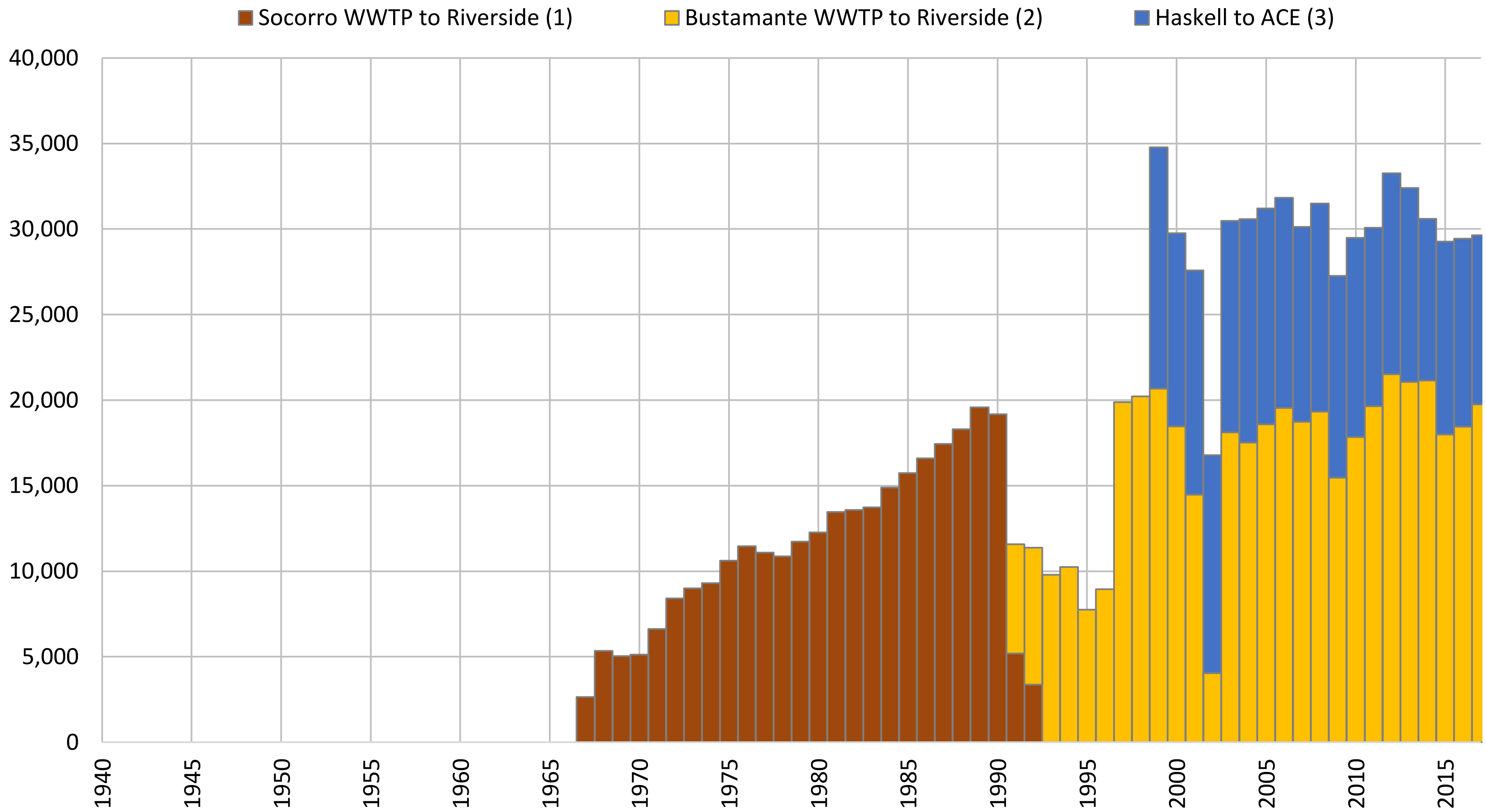


Figure 19-14

WWTP Discharges to Canals (Irrigation Season)
EPCWID (El Paso Valley)
1967 - 2017 (acre-feet)



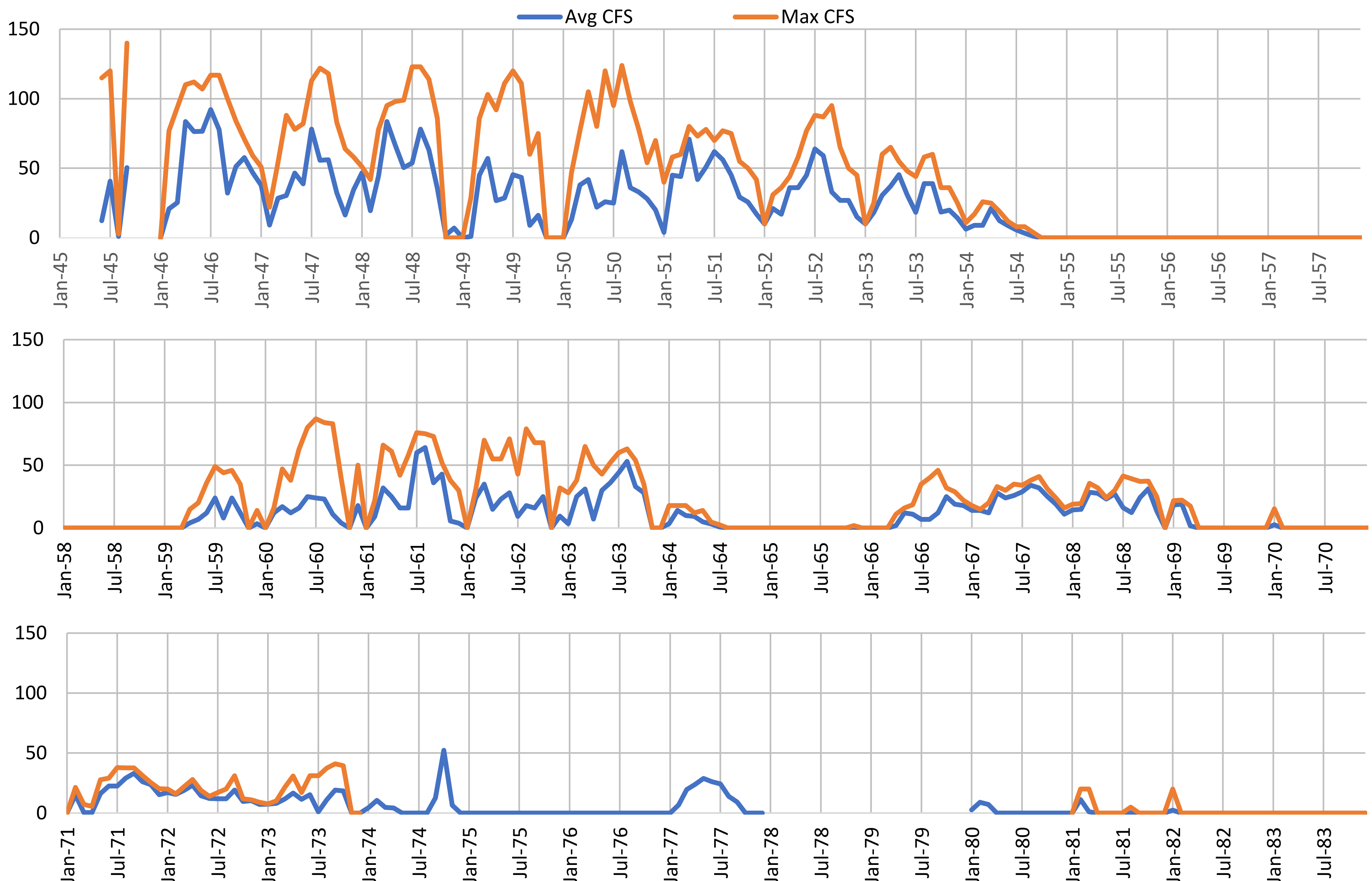
Notes:

(1) Monthly Socorro WWTP discharges estimated 1967 - 1988 from SWE SWDataSet (annual data only 1967 - 1984).
(2) Bustamante WWTP discharges to Riverside Canal estimated 1991 - 1994 from SWE SWDataSet.
(3) Haskell WWTP discharges to the American Canal Extension ("ACE") are included in Riverside Canal gaged flows from SWE SWDataSet.

Figure 19-15

Monthly Drain Flows Pumped at Fabens to Canal

1945 - 1983 (CFS)

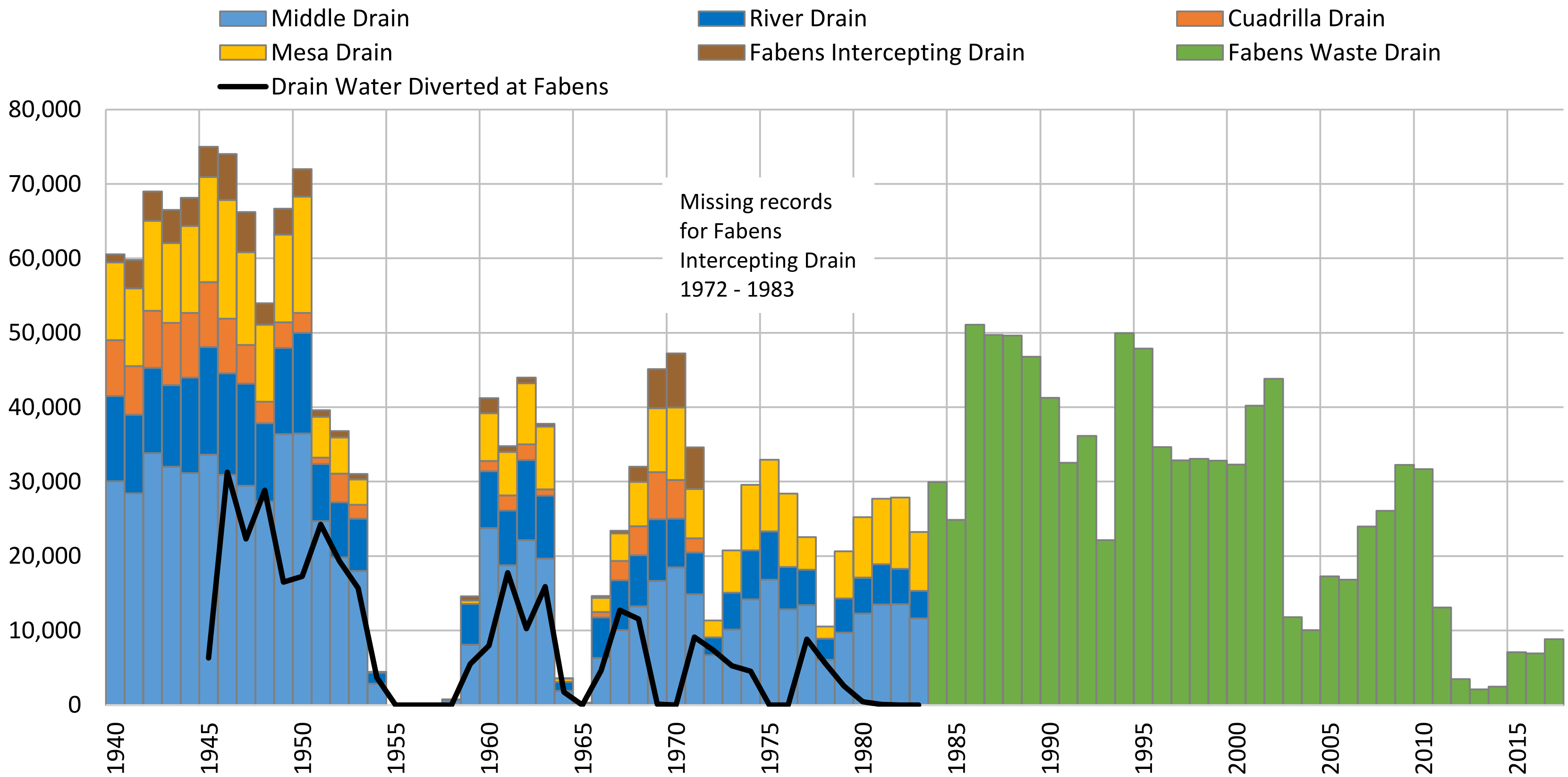


Note:

(1) Monthly average and maximum daily values from USBR daily records ("USBR-Scan-Drain to Canal").

Figure 19-16

Irrigation Season Drain Flows at Fabens
EPCWID (El Paso Valley)
1940 - 2017 (acre-feet)



Notes:

(1) Water pumped from the River Drain and Middle Drain for EPCWID irrigation use.

(2) The Mesa Drain, Cuadrilla Drain, and Fabens Intercepting Drain reportedly were reportedly not used for EPCWID irrigation use. These drain flows accrue to the Fabens Waste Channel and become part of the HCCRD supply along with unused River and Middle Drain flows.

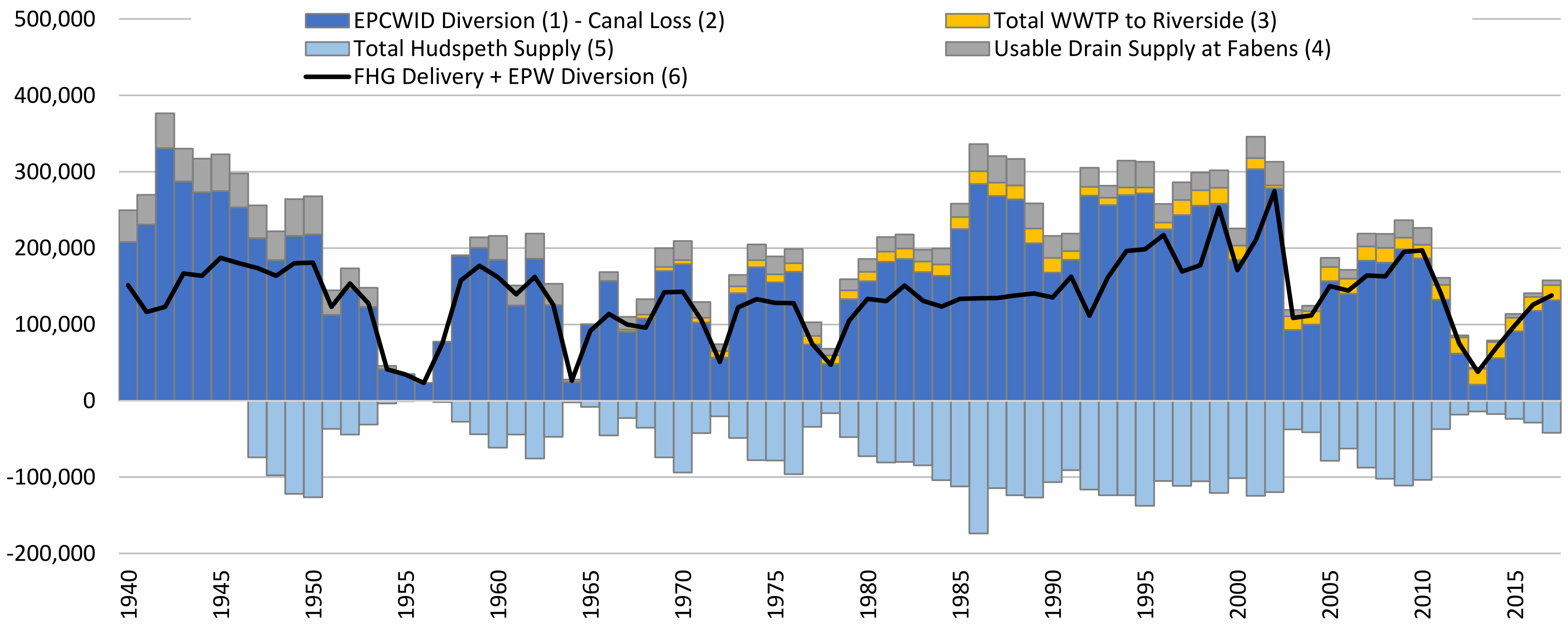
(3) The Fabens Waste Drain collects flow from the River Drain, Middle Drain, Mesa Drain, Cuadrilla Drain, and Fabens Intercepting Drain for delivery into the Fabens Waste Channel.

(4) A schematic diagram illustrating EPCWID drain system is provided in **Figure 19-13**.

(5) Fabens Waste Drain flows were estimated in 1992 and some months in 1993 - 1996, 2003, and 2012.

Figure 19-17

Available FHG Supply vs. FHG Delivery (Irrigation Season)
EPCWID (El Paso Valley)
1940 - 2017 (acre-feet)



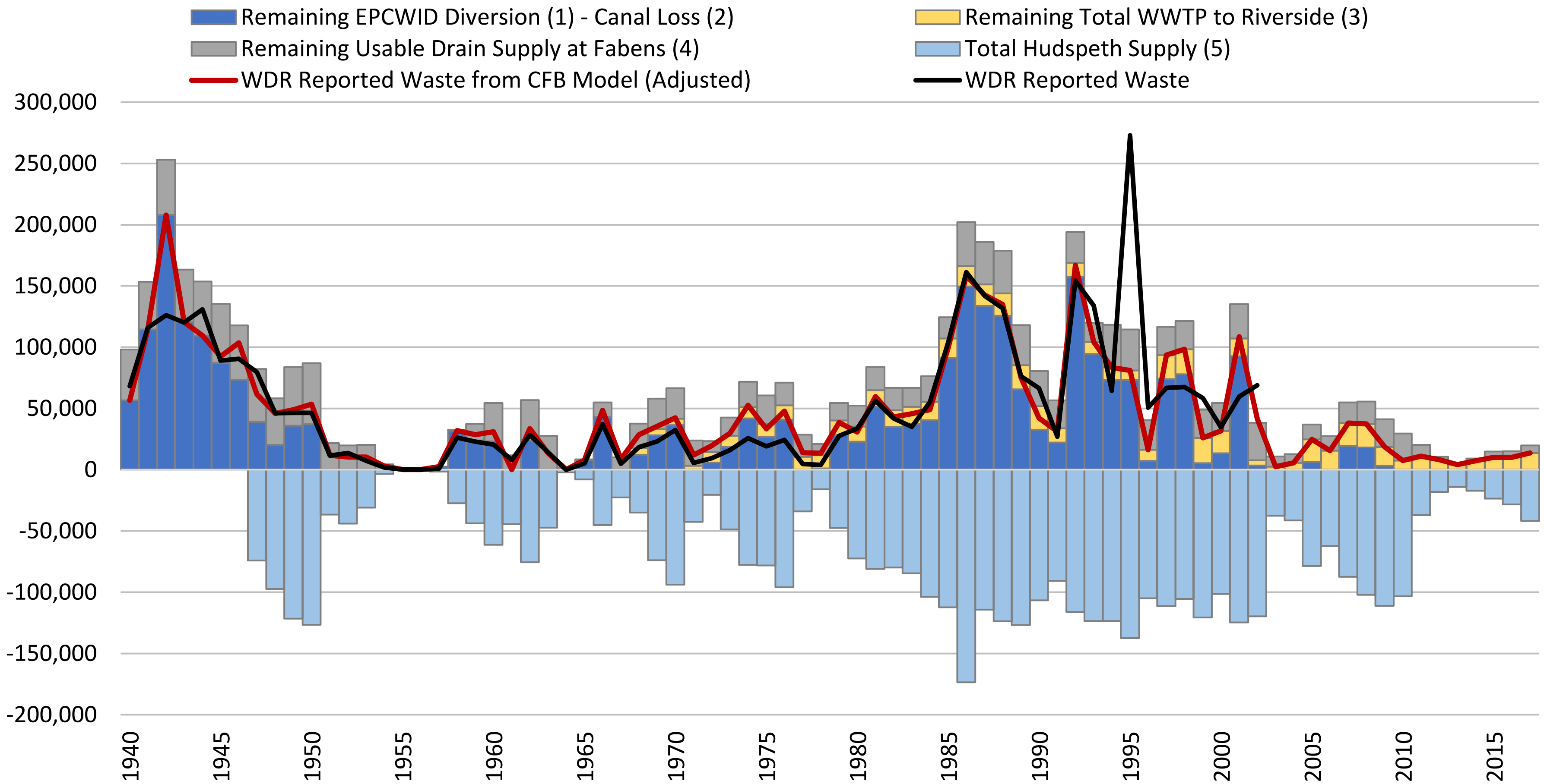
Notes:

All data from SWE SWDataSet unless otherwise noted.

(1) EPCWID (El Paso Valley) Diversions computed as the sum of the Franklin Canal plus Riverside Canal plus EPW diversions minus Ascarate Wasteway.
(2) Canal Loss from SWE CFB Model and are based on records and estimates for years with no records.
(3) Total WWTP to Riverside includes Socorro WWTP and Bustamante WWTP. Flows are estimated for Socorro WWTP from 1985 - 1988 and for Bustamante WWTP from 1991 - 1994.
(4) Usable Drain Supply at Fabens computed as the sum of the River Drain plus Middle Drain (1940 - 1983) and 70% of Fabens Waste Drain (1984 - 2017). Fabens Waste Drain flows were estimated in 1992 and some months in 1993 - 1996, 2003, and 2012.
(5) Total Hudspeth Supply is the sum of Tornillo Drain plus Tornillo Canal at Alamo Alto plus Hudspeth Feeder Canal. Missing records for Tornillo. Canal at Alamo Alto in 1995 - 1996 and Hudspeth Feeder Canal in 2011 - 2012 were estimated. Missing records for Tornillo Drain in 2011 - 2012 were not estimated. Total Hudspeth Supply shown as negative for presentation purposes.
(6) FHG Delivery from SWE CFB Model based on records and estimates for years with no records plus EPW Diversions.

Figure 19-18

Waste Comparison (Irrigation Season)
EPCWID (El Paso Valley)
1940 - 2017 (acre-feet)



Notes:

(1,2,3) The positive bars represent the portion of the available EPCWID supply in excess of the historical EPCWID FHG deliveries (see Figure 19-17).

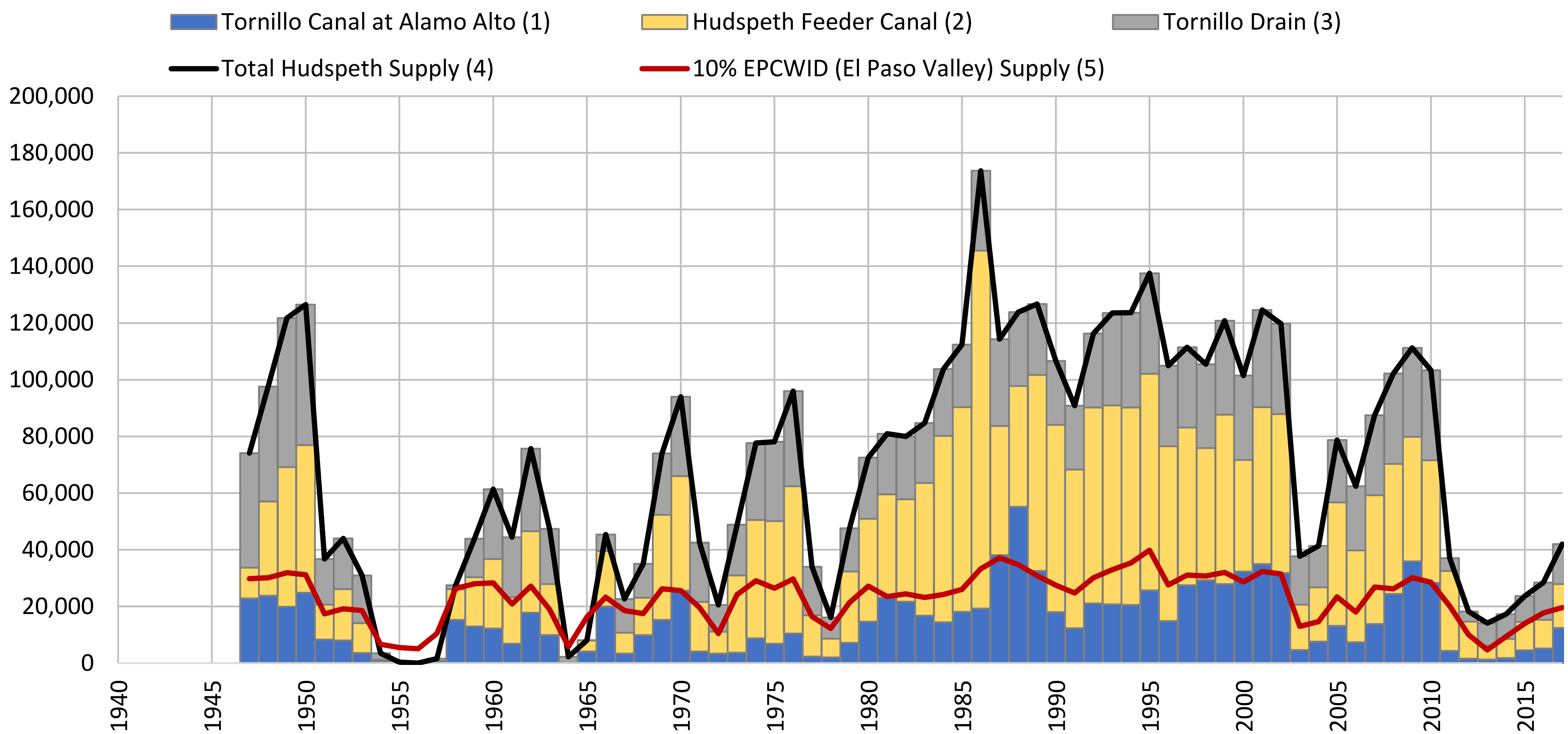
(4) Total Hudspeth Supply is the sum of Tornillo Drain plus Tornillo Canal at Alamo Alto plus Hudspeth Feeder Canal (data from 1947 - 2017 only).

(5) Adjusted WDR Reported Waste is the historical reported waste from the WDRs with mass balance adjustments and estimates of missing data from SWE CFB Models.

(6) WDR Reported Waste (Unadjusted) is the historical reported waste from the SWE Accounting DataSet.

Figure 19-19

Total Water Supply (Irrigation Season)
HCCRD
1947 - 2017 (acre-feet)

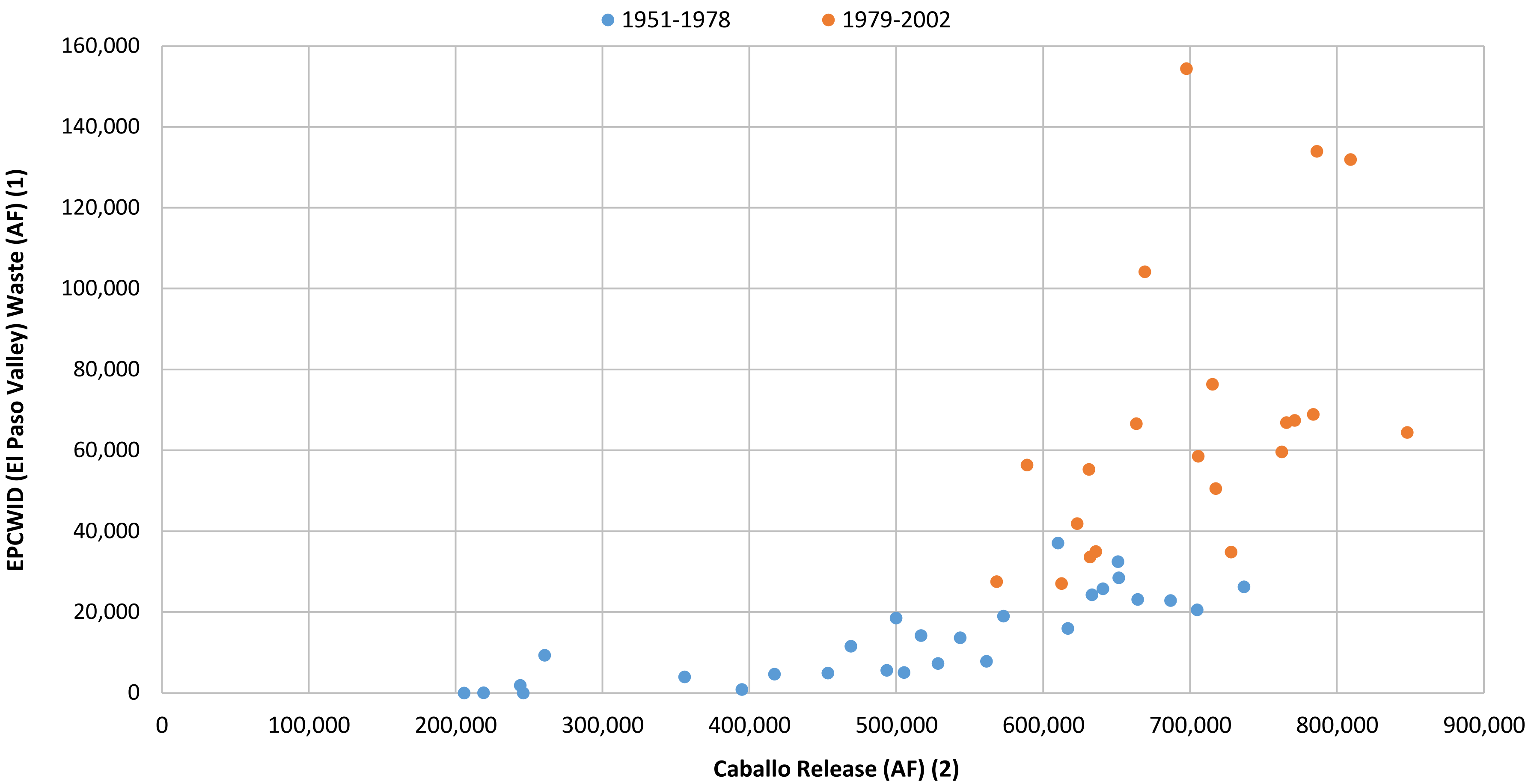


Notes:

Prior to 1947, the Hudspeth Feeder Canal did not exist and there was no Tornillo Canal at Alamo Alto gage.

(1) Tornillo Canal at Alamo Alto flows include estimates for certain months in 1995 and 1996; data and estimates from SWE SWDataSet.
(2) Hudspeth Feeder Canal flows include estimates for certain months in 2011 and 2012; data and estimates from SWE SWDataSet.
(3) Tornillo Drain flows are incomplete for 2011 and 2012; data from SWE SWDataSet and estimates from the SWE CFB Model.
(4) Total Hudspeth Supply is the sum of Tornillo Canal at Alamo Alto (1) plus Hudspeth Feeder Canal (2) plus Tornillo Drain (3) flows.
(5) EPCWID (El Paso Valley) Supply computed as the sum of the Franklin Canal plus Riverside Canal flows plus EPW surface water diversions minus Ascarate Wasteway flows; flows from SWE SWDataSet.

Figure 19-20
Waste vs. Caballo Release (Irrigation Season)
EPCWID (El Paso Valley)
1951 - 2002 (acre-feet)

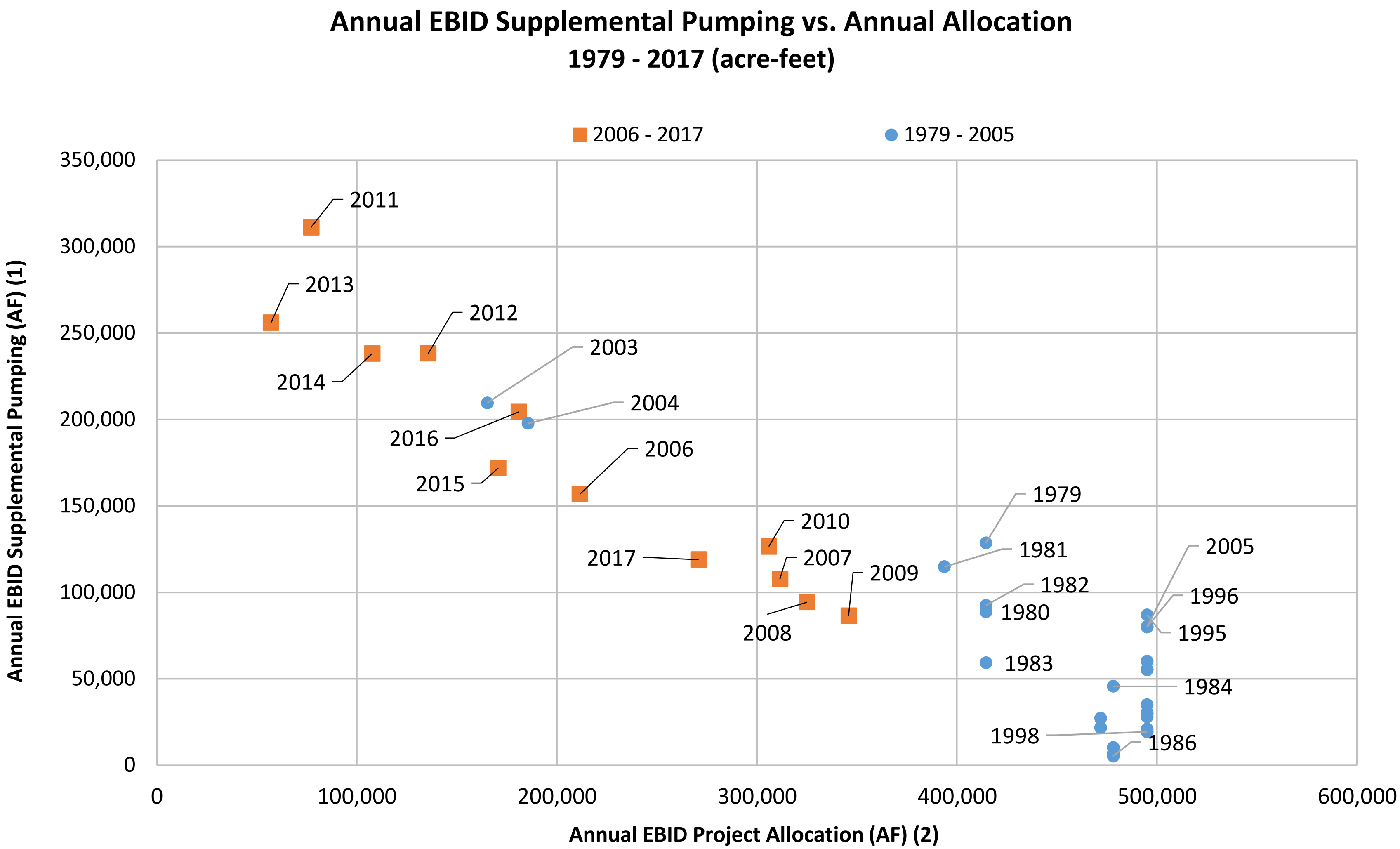


Notes:

(1) EPCWID (El Paso Valley) Waste from Water Distribution Reports in the SWE Accounting DataSet.

(2) Caballo Releases are the Rio Grande below Caballo flows from SWE SWDataSet.

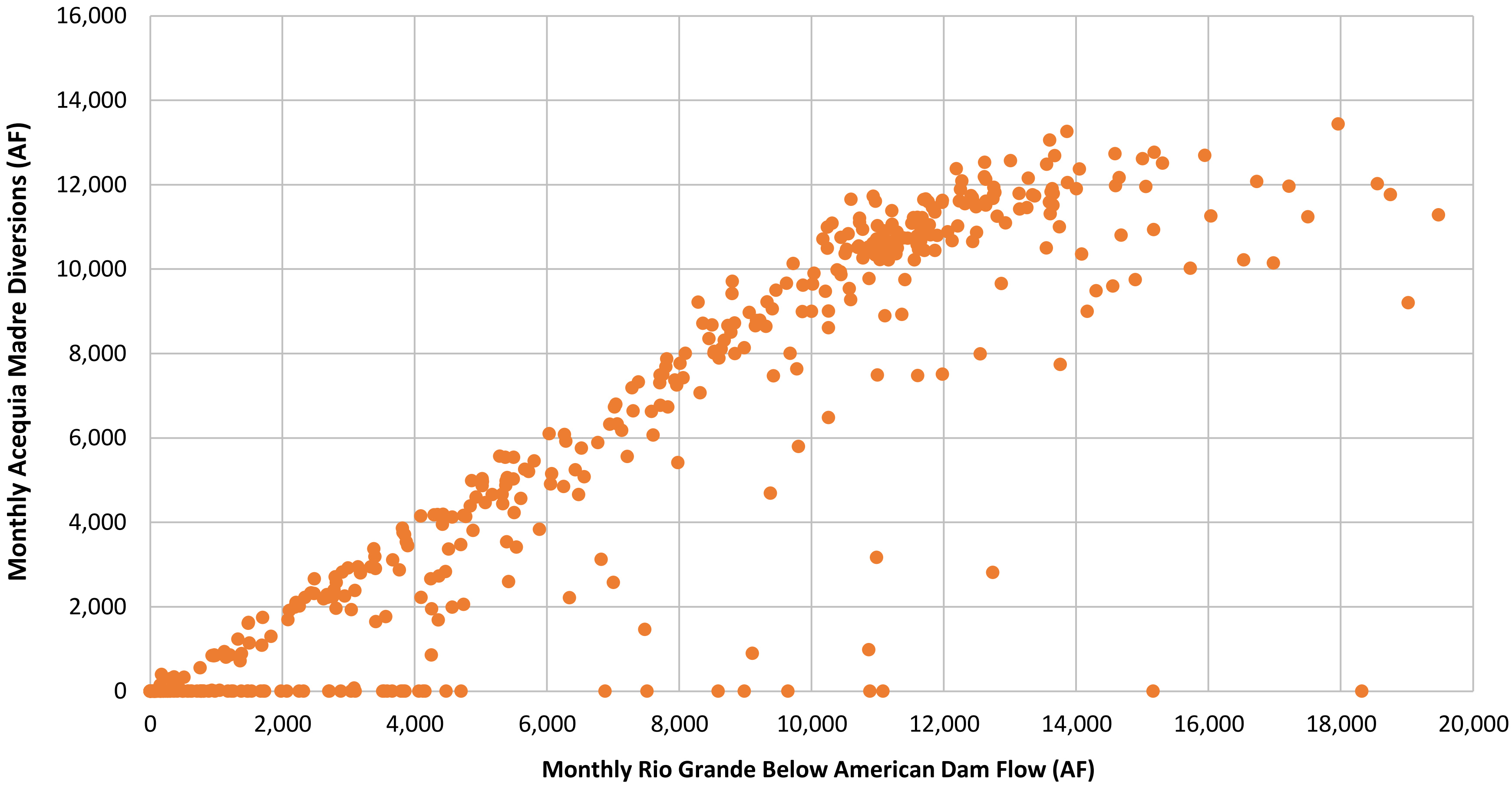
Figure 19-21



Notes:
(1) Supplemental irrigation pumping amounts from SWE CFB Model.
(2) Annual allocations and diversion charges from SWE Accounting DataSet.

Figure 19-22

Monthly Acequia Madre Diversions vs. Monthly Rio Grande Below American Dam Flows
1940 - 2017 (acre-feet)

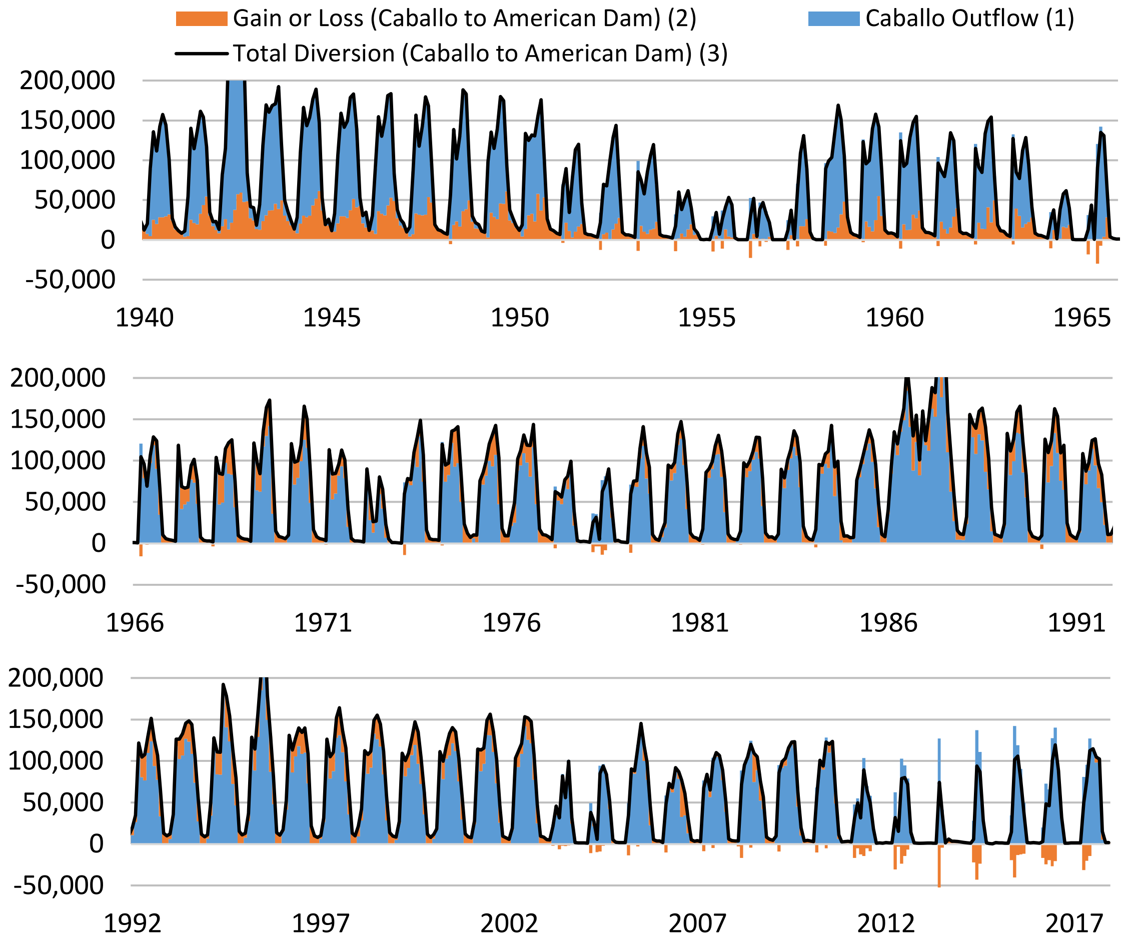


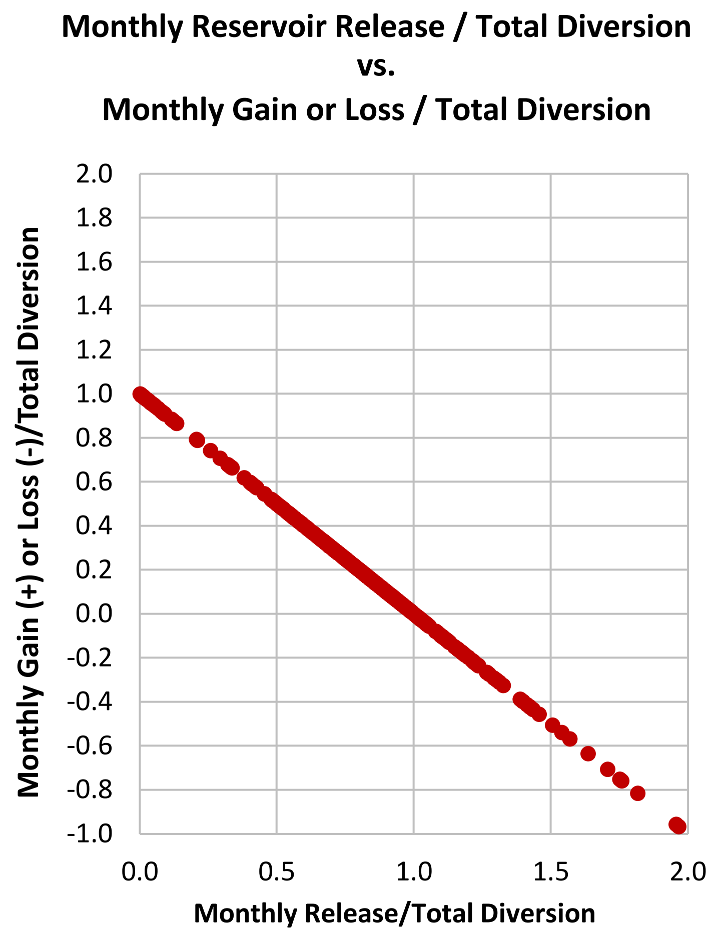
Note:
(1) No monthly data for 2007 (only annual data available).
(2) Monthly flow data from SWE SWDataSet.

7/15/2020

Figure 19-23

Monthly Reservoir Releases, Diversions, and Gains or Losses
Below Caballo Dam to Below American Dam
1940 - 2017 (acre-feet)





Notes:

Monthly flow data from SWE SWDataSet.

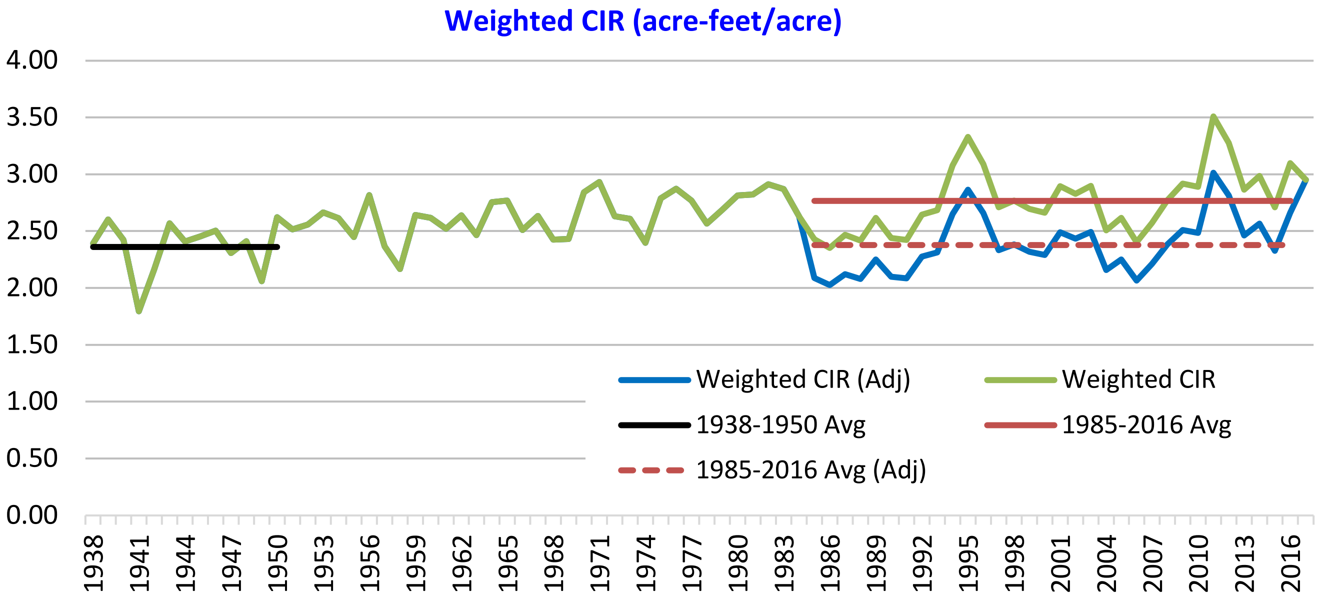
(1) Caballo releases from Rio Grande below Caballo Dam gage.

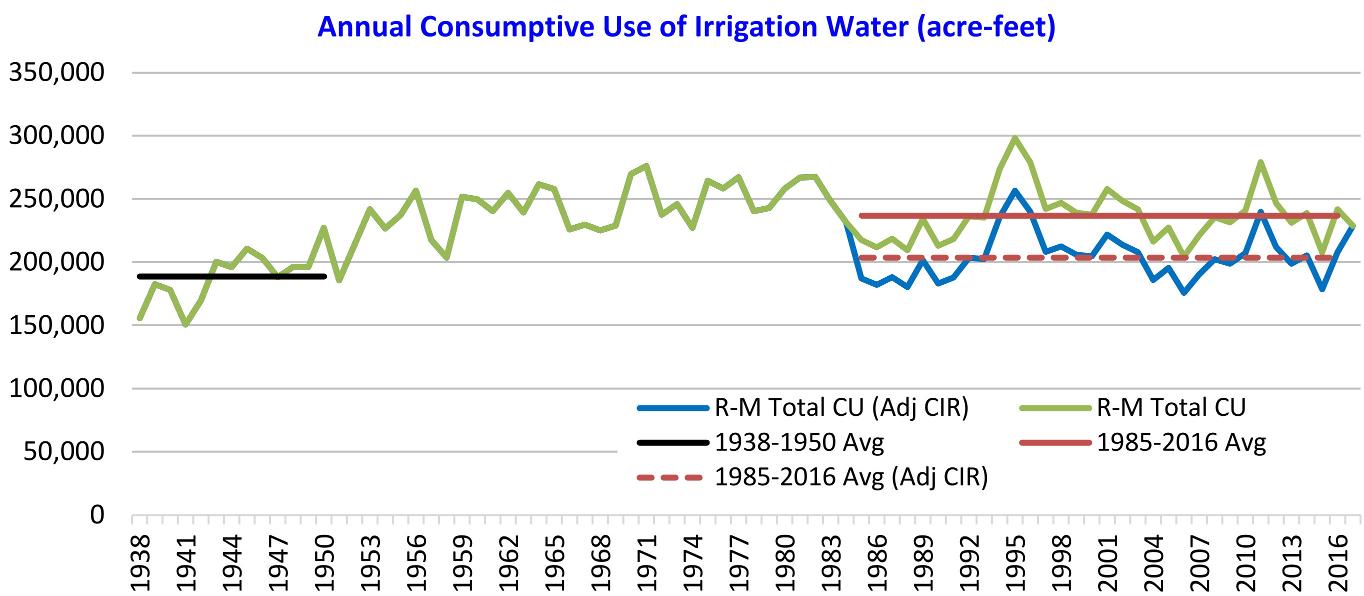
(2) Monthly gain or loss computed as total diversions plus Rio Grande below American Dam flow minus Caballo Reservoir releases.

(3) Total diversions at Arrey Dam (Arrey Canal and Percha Lateral), Leasburg Dam (Leasburg Canal, California Extension, and Pumped from River), Mesilla Dam (Eastside Canal, Westside Canal, and Del Rio Lateral), and American Canal PLUS Rio Grande below American Dam flow.

7/15/2020

Figure 20-1
Total Consumptive Use of Irrigation Water
Rincon and Mesilla Valleys (EBID and EPCWID)
SWE Canal and Farm Budget Model



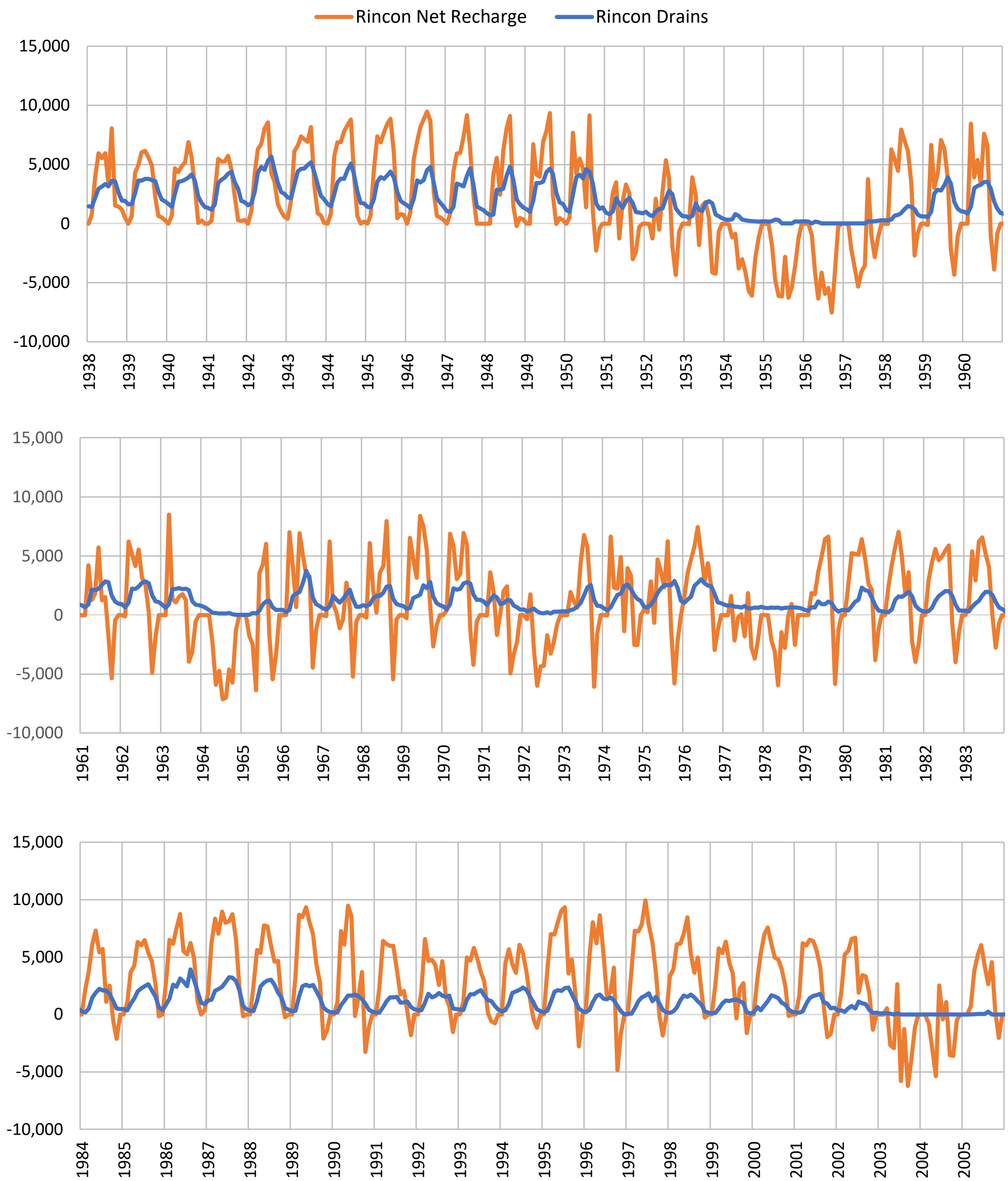


	CIR (acre-feet/acre)					Consumptive Use (acre-feet)		
	EBID Rincon		EBID Mesilla		EPCWID Mesilla	EBID	EPCWID	R-M
Period	Suppl	Primary	Suppl	Primary	Total	Total	Total	Total
(1) 1938-1950	2.35	2.69	2.36	2.71	2.35	173,395	15,436	188,830
(2) 1985-2016	2.74	2.91	2.78	2.95	2.61	223,057	13,858	236,916
(3) 1985-2016 (adj)	2.35	2.69	2.36	2.71	2.35	191,301	12,461	203,763
Ratio (1)/(2)	0.86	0.92	0.85	0.92	0.90			

Notes:
(1,2) CIR and consumptive use of irrigation water from SWE CFB Model.
(3) CU is adjusted for 1985-2016 by multiplying monthly CIR by the ratio of CIR: (1) 1938-1950 average/(2) 1985 - 2016 average.

Figure 23-1

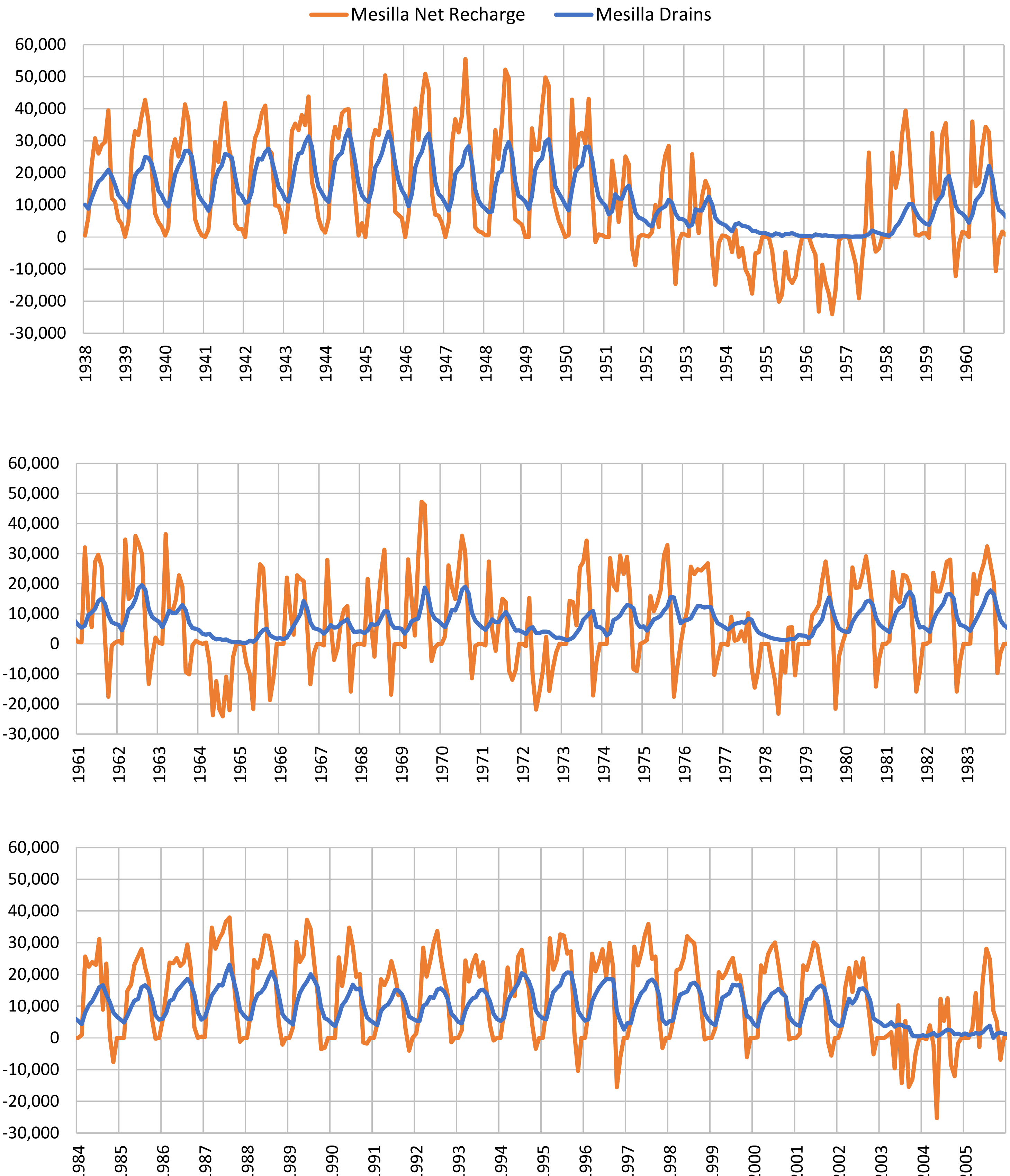
Monthly Net Recharge vs. Drain Flow
Rincon Valley
1938 - 2005 (acre-feet)



Notes: Net recharge computed as canal seepage + on farm deep percolation minus pumping from the SWE Canal and Farm Budget Model of the Rincon Valley.
Drain flows are the sum of the reported flows of the Rincon Valley drains.
Angostrata drain data is unavailable from 1983-2005.
Rincon drain data is unavailable from 2006-2017.

Figure 23-2

Monthly Net Recharge vs. Drain Flow
Mesilla Valley
1938 - 2005 (acre-feet)



Notes: Net recharge computed as canal seepage + on farm deep percolation minus pumping from the SWE Canal and Farm Budget Model of the Leasburg-Mesilla Valley (NM + TX). Drain flows are the sum of the reported flows of the Mesilla Valley drains. Drain data availability varies by drain.

Figure 28-1

Integrated LRG Model Historical Calibration Results

Caballo Release

1940 - 2017

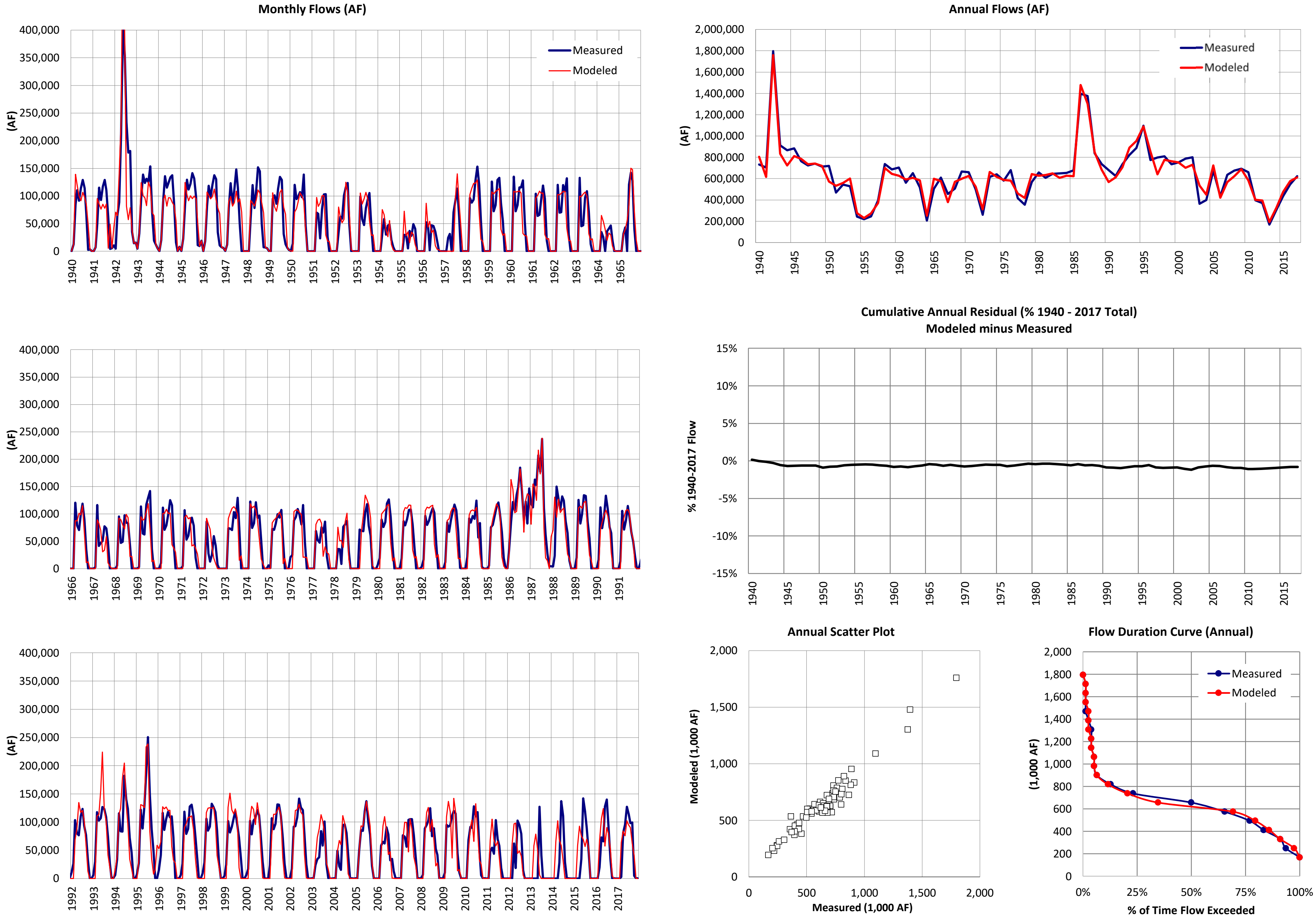


Figure 28-2

Integrated LRG Model Historical Calibration Results

Rio Grande at El Paso

1940 - 2017

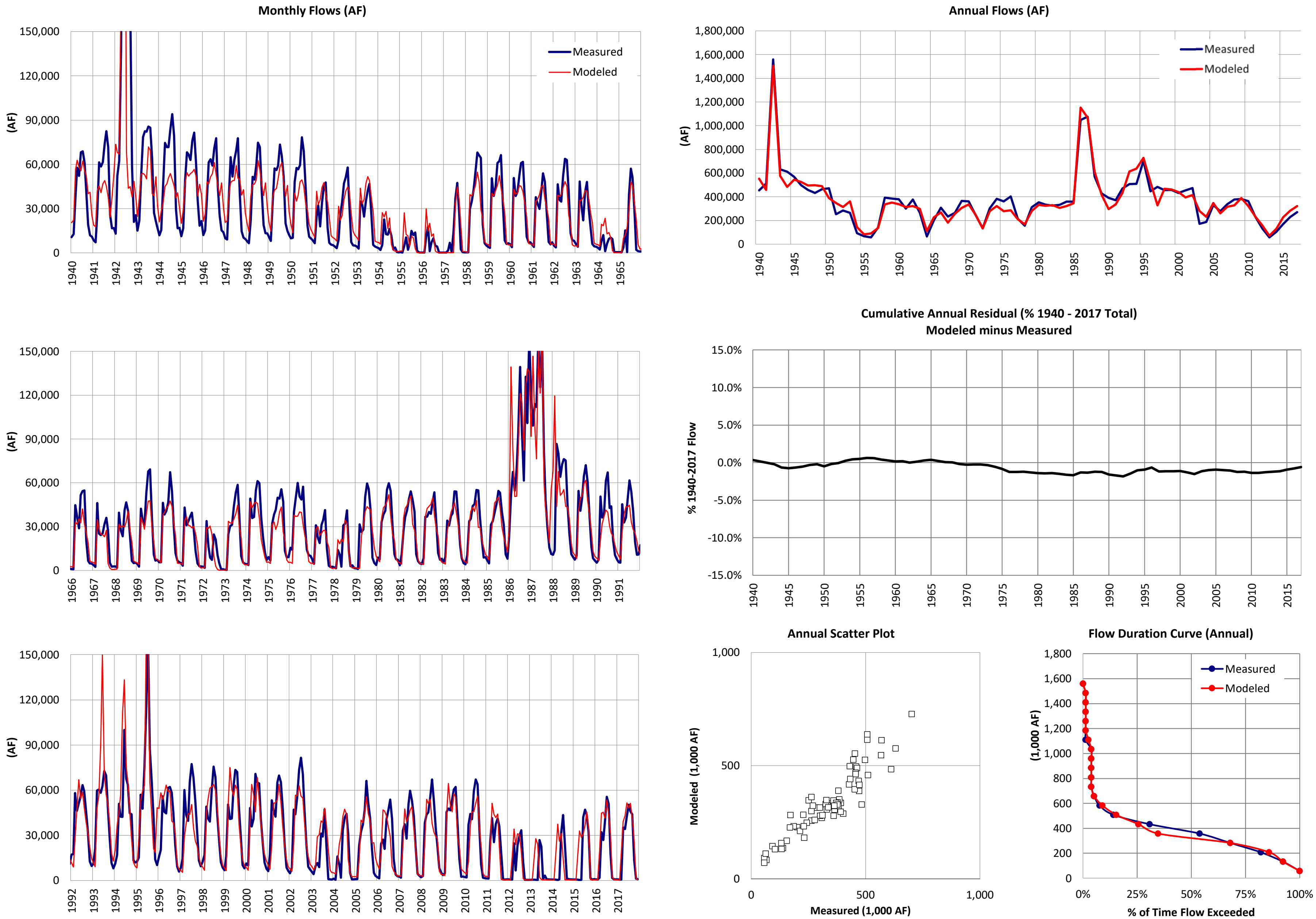


Figure 28-3

Integrated LRG Model Historical Calibration Results

Rio Grande at Fort Quitman

1940 - 2017

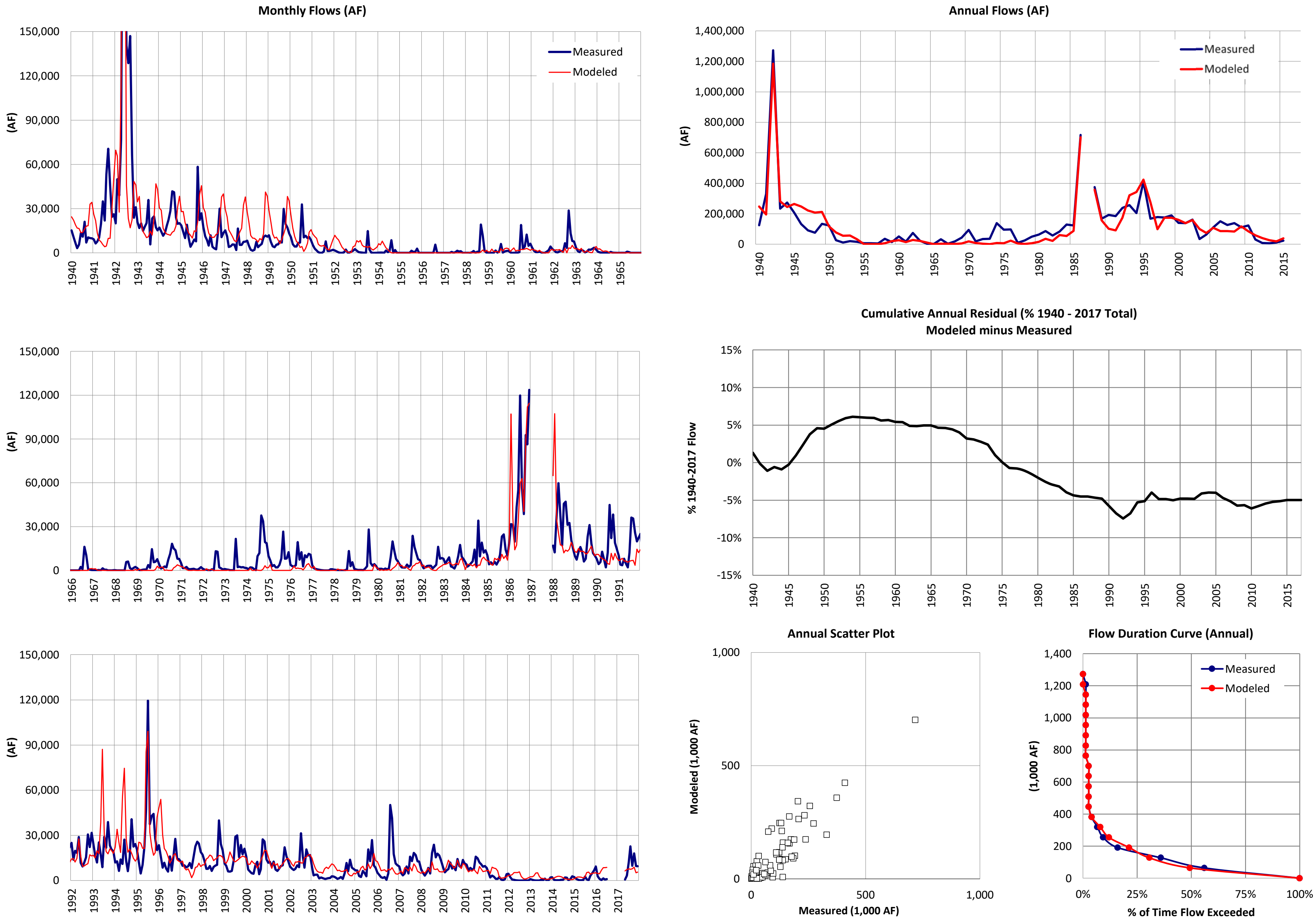


Figure 28-4

Integrated LRG Model Historical Calibration Results

Rincon Diversion

1940 - 2017

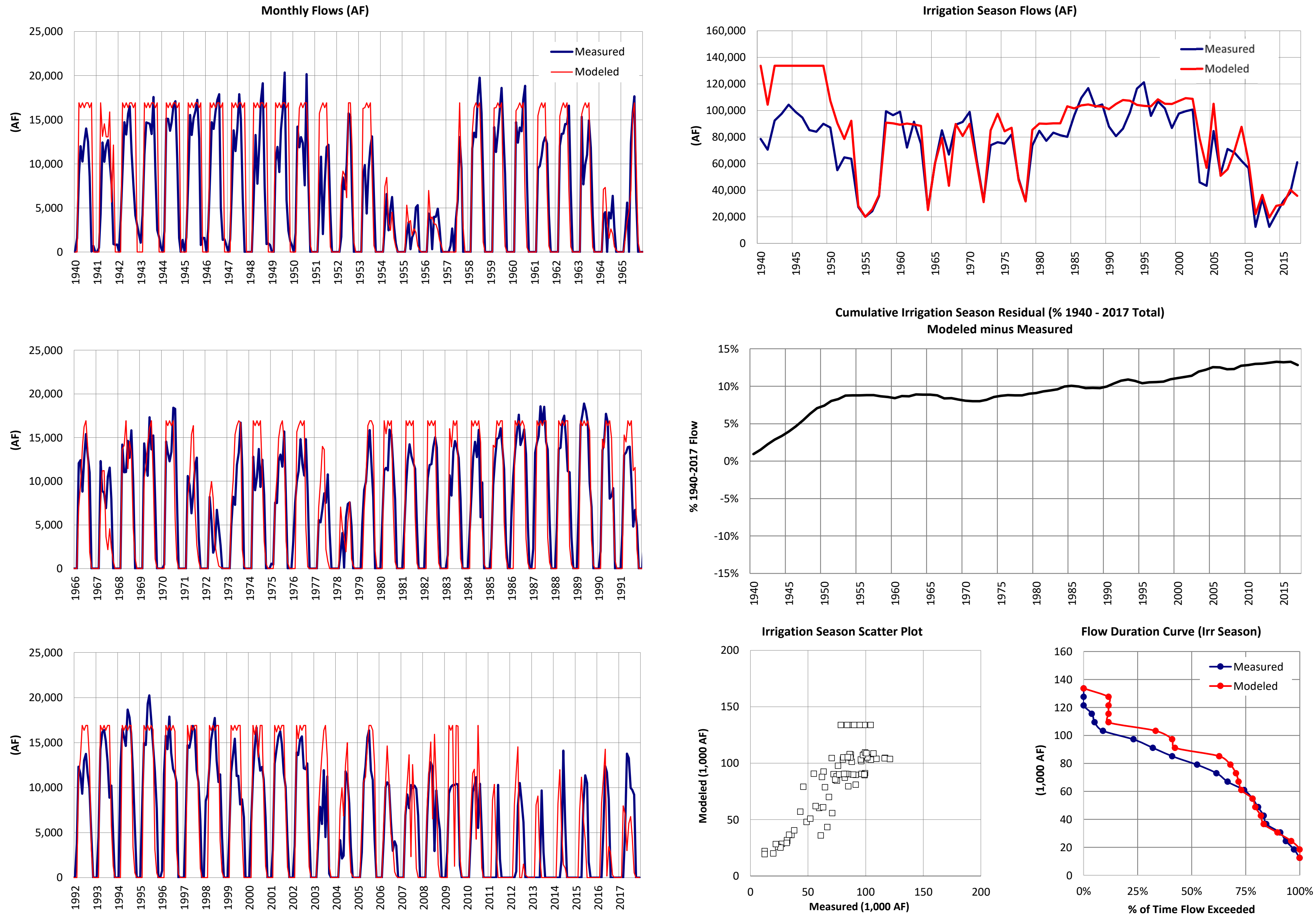


Figure 28-5

Integrated LRG Model Historical Calibration Results

Leasburg Diversion

1940 - 2017

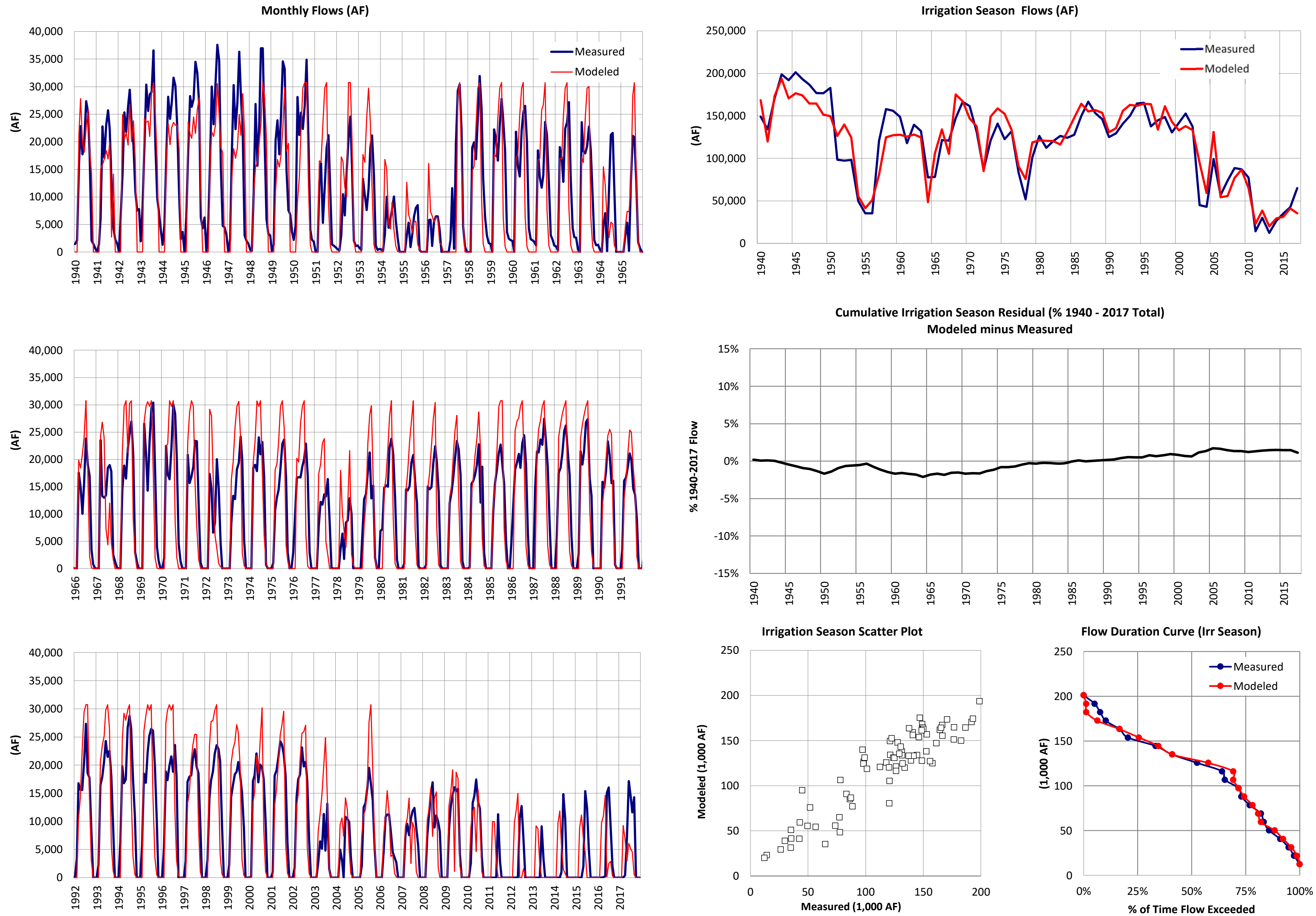


Figure 28-6

Integrated LRG Model Historical Calibration Results

Eastside Diversion

1940 - 2017

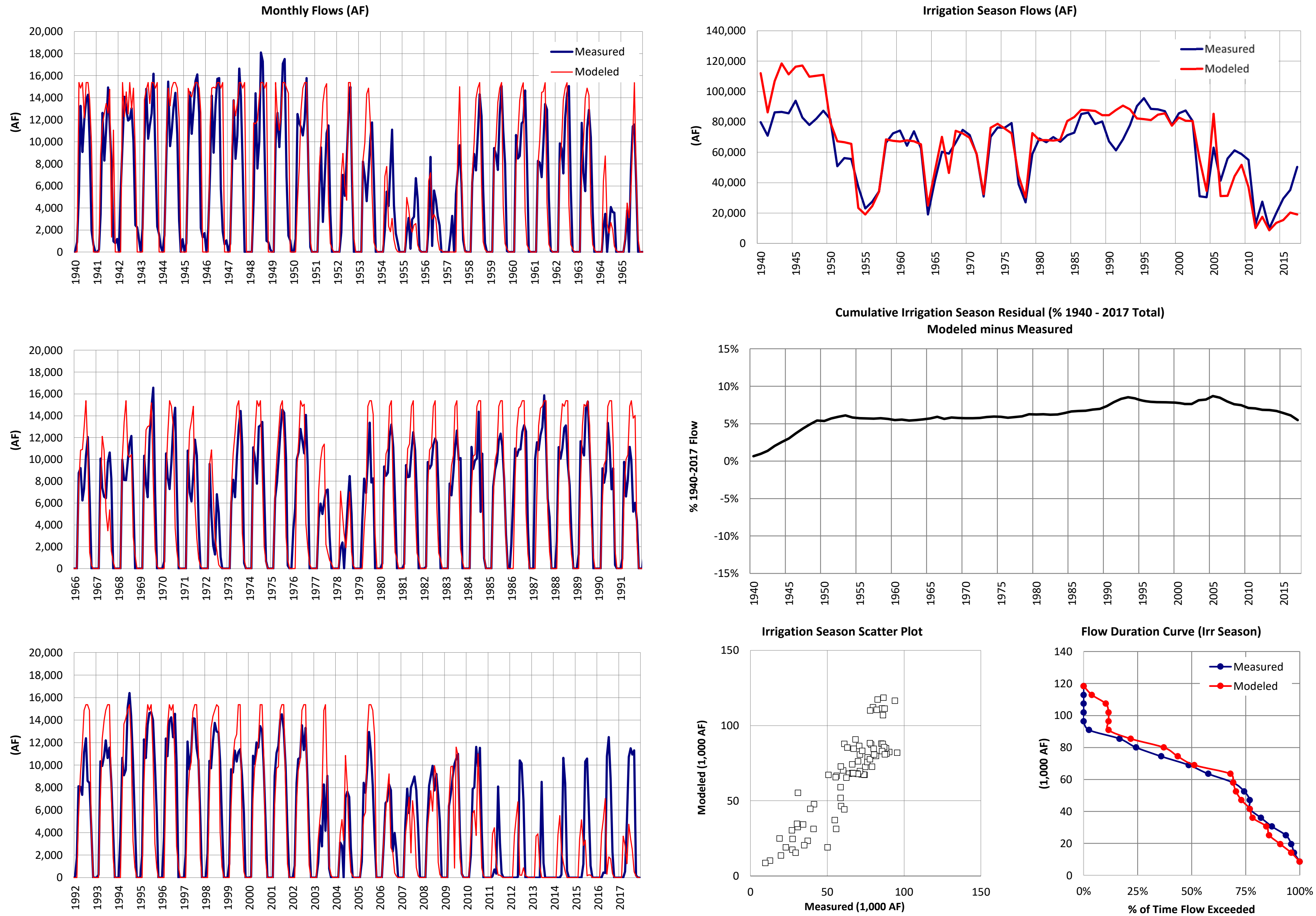


Figure 28-7

Integrated LRG Model Historical Calibration Results

Westside Diversion

1940 - 2017

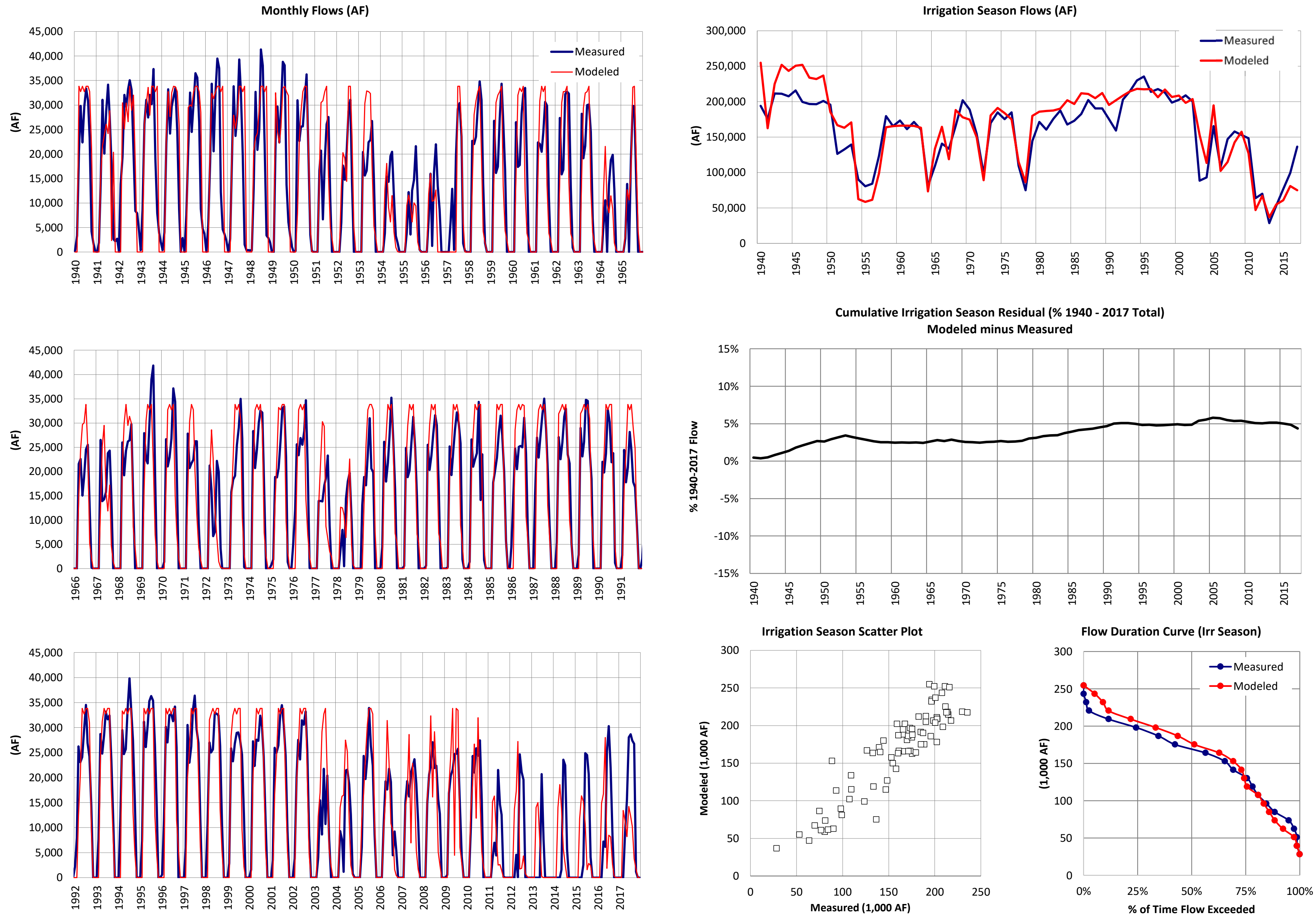
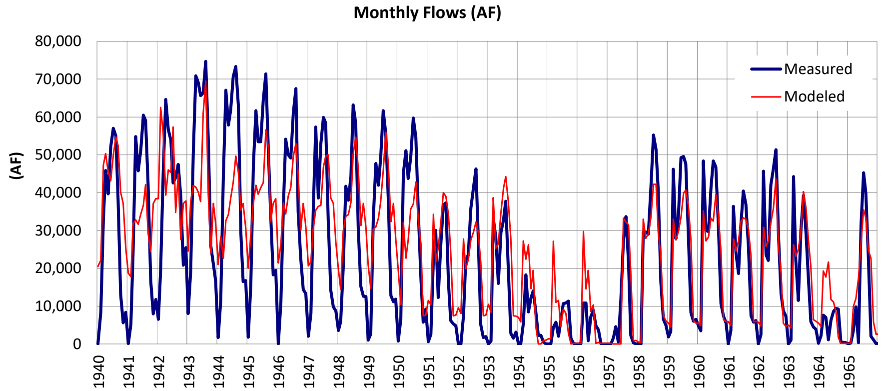
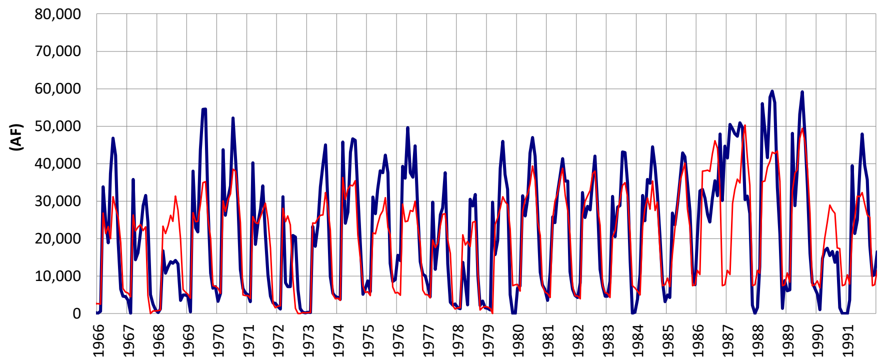
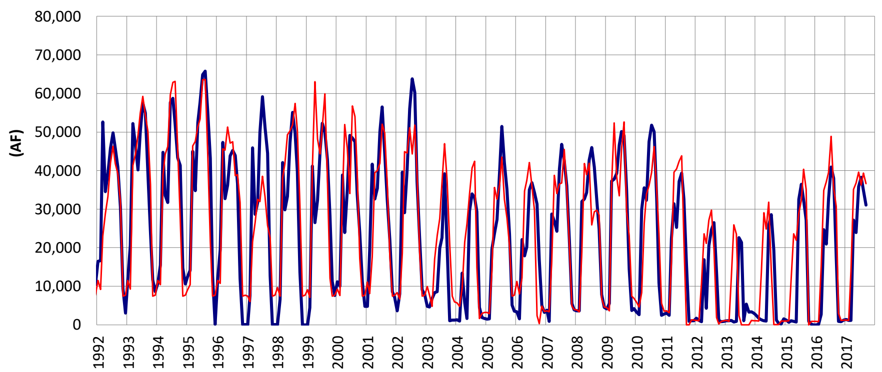


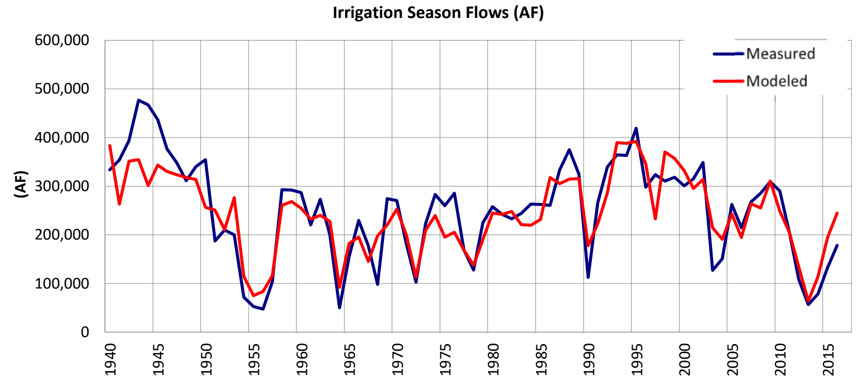
Figure 28-8

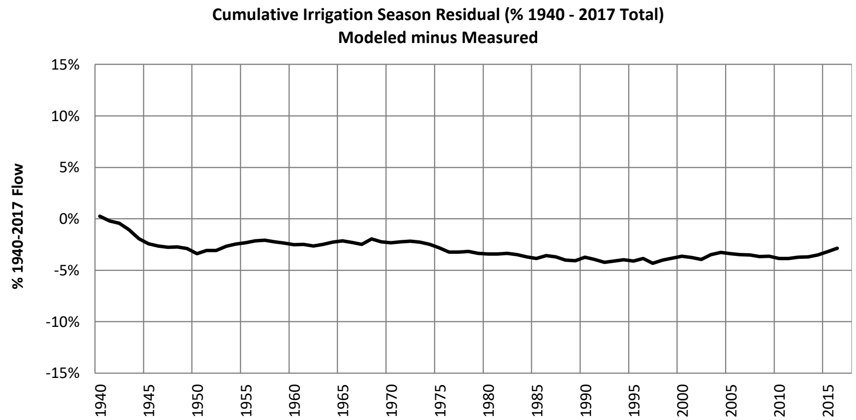
Integrated LRG Model Historical Calibration Results
American Diversion
1940 - 2017

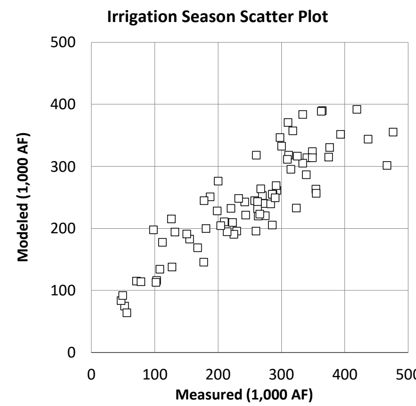












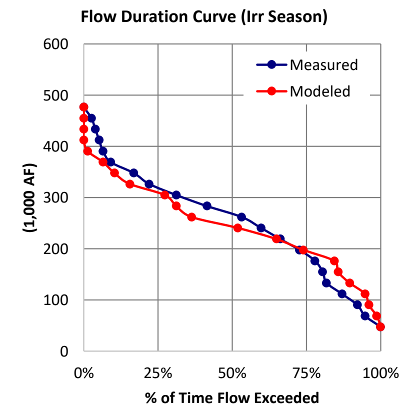


Figure 28-9

Integrated LRG Model Historical Calibration Results
Riverside Canal Gage
1940 - 2017

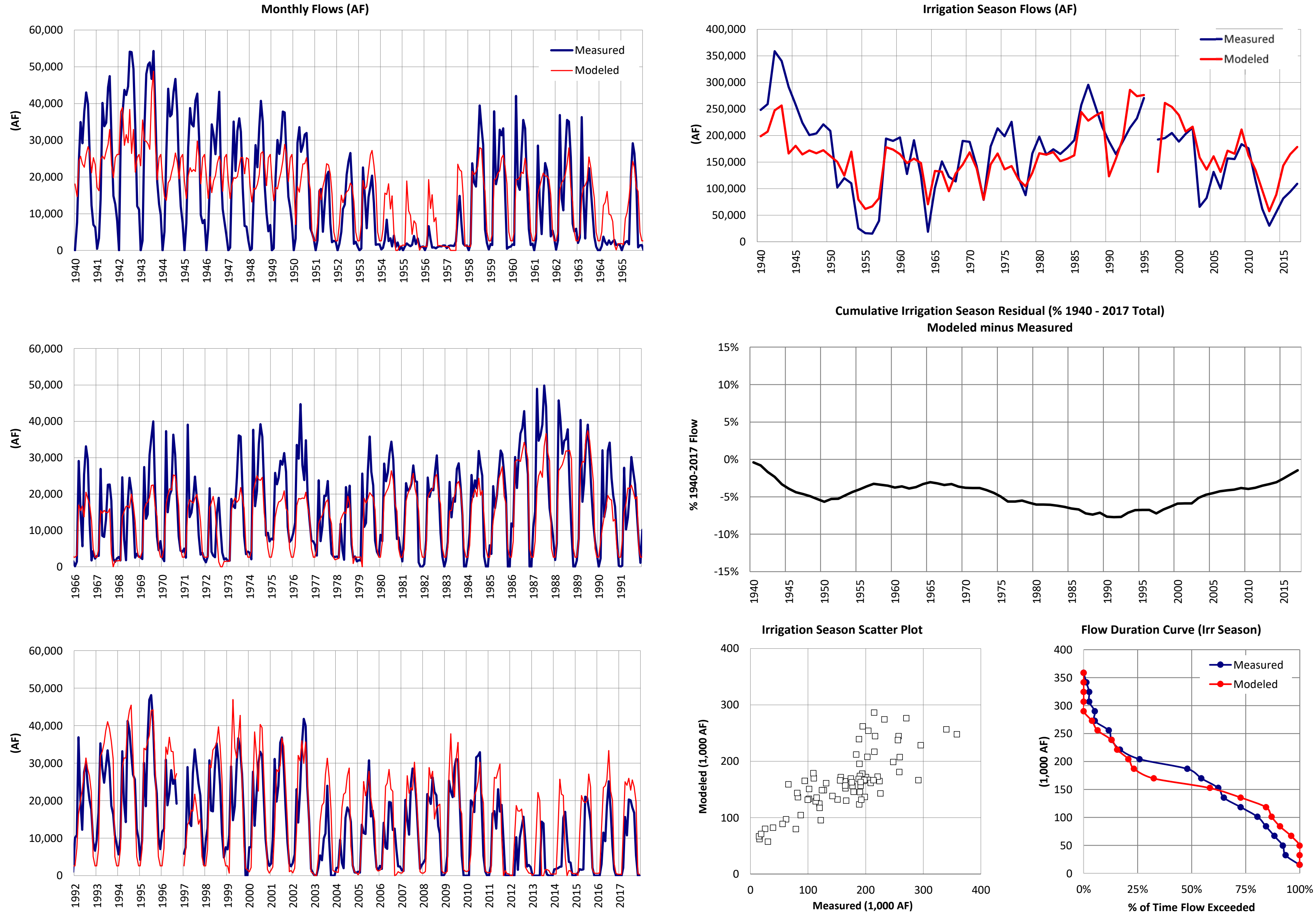
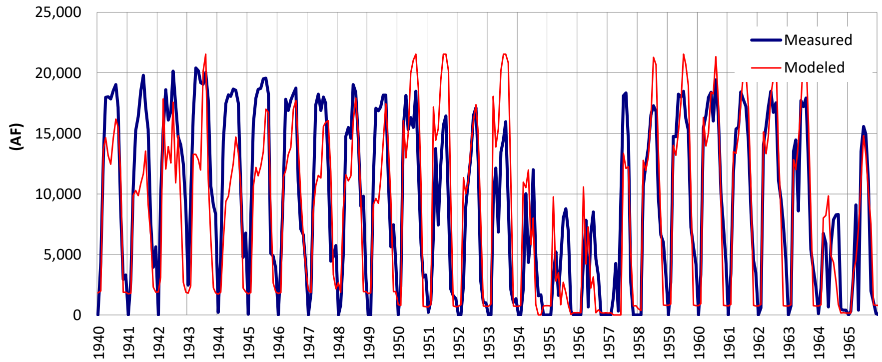


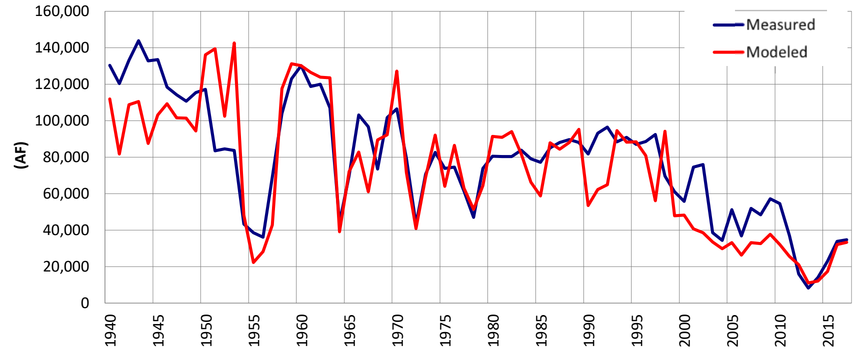
Figure 28-10

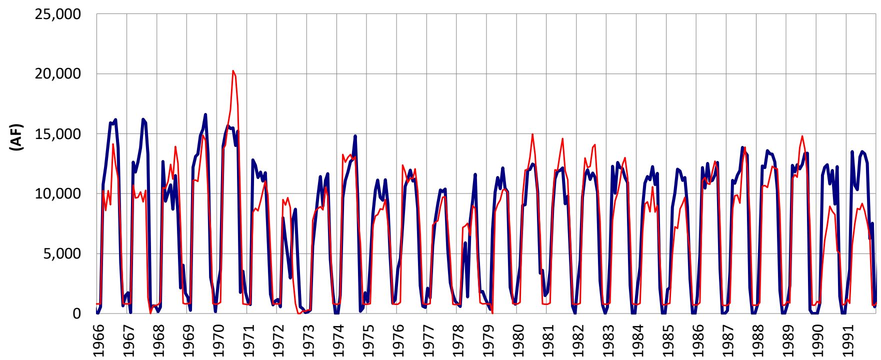
Integrated LRG Model Historical Calibration Results
Franklin Canal Gage
1940 - 2017

Monthly Flows (AF)

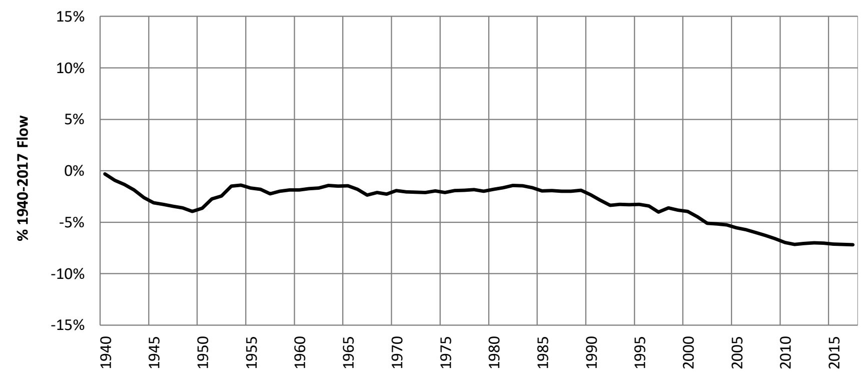


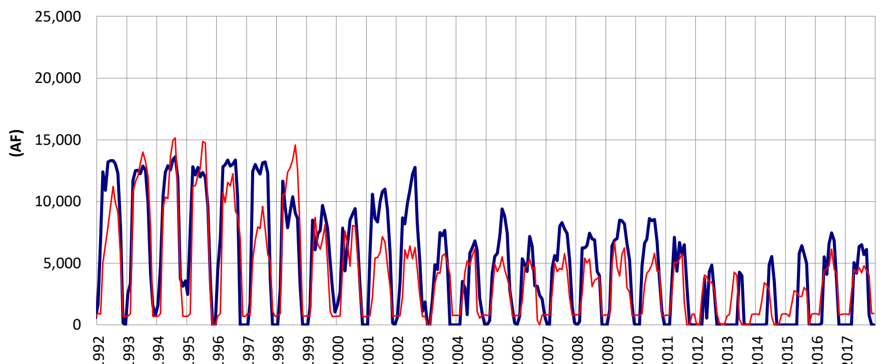
Irrigation Season Flows (AF)



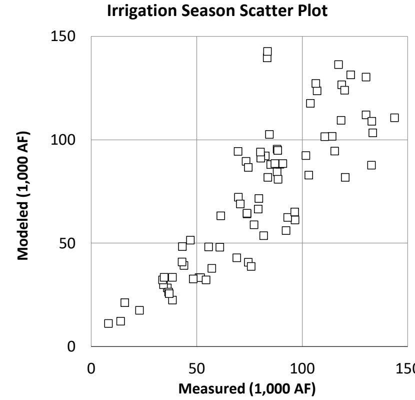


Cumulative Irrigation Season Residual (% 1940 - 2017 Total)
Modeled minus Measured





Irrigation Season Scatter Plot



Flow Duration Curve (Irr Season)

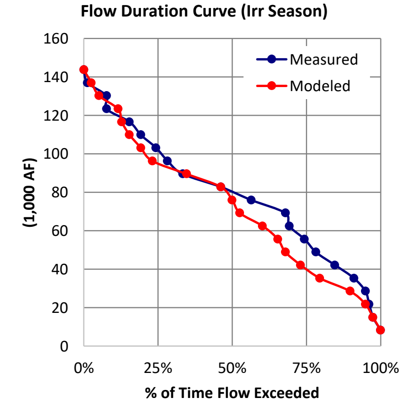


Figure 28-11

Integrated LRG Model Historical Calibration Results
Acequia Madre Diversion
1940 - 2017

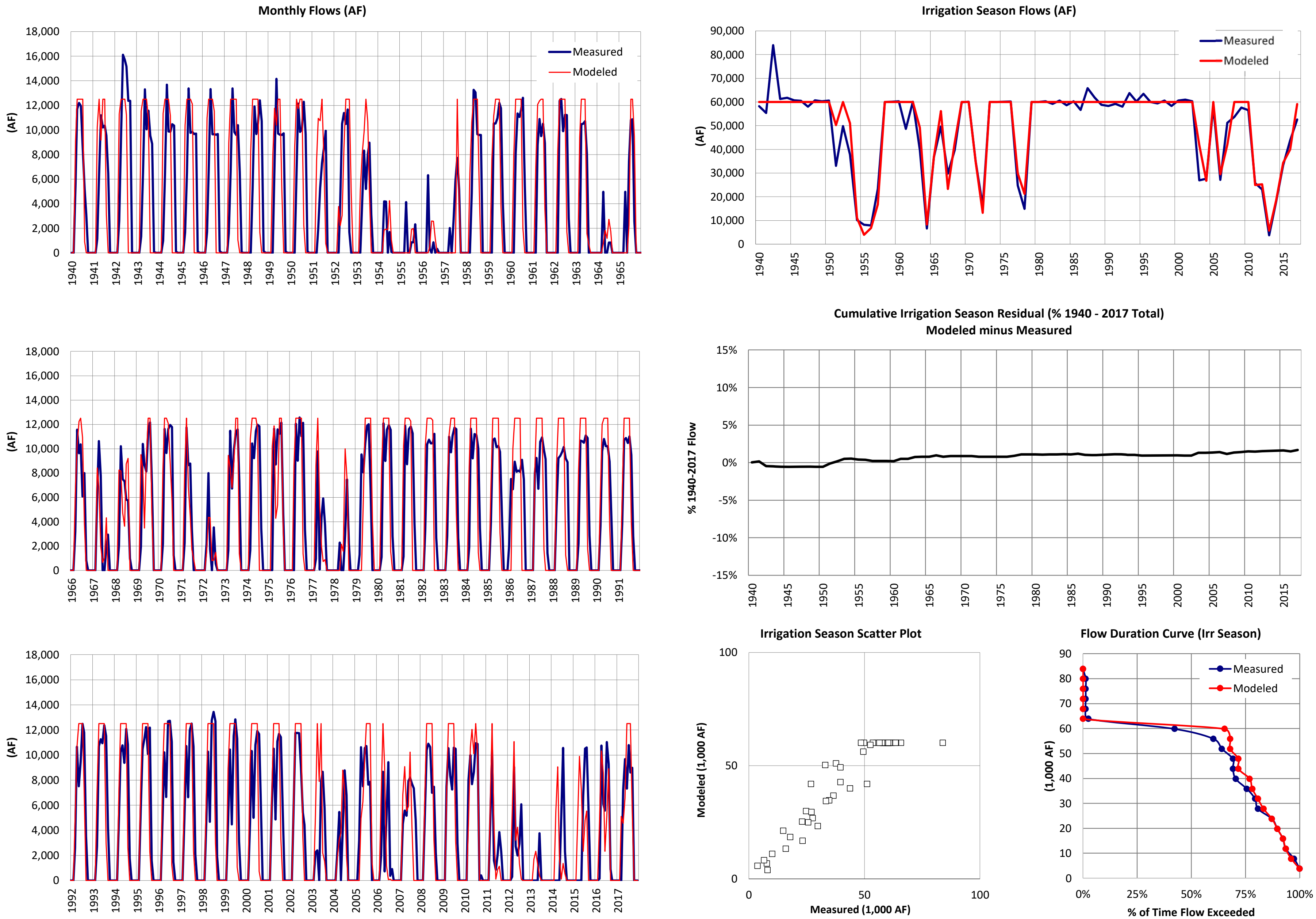


Figure 28-12

Integrated LRG Model Historical Calibration Results

Total HCCRD Supply

1940 - 2017

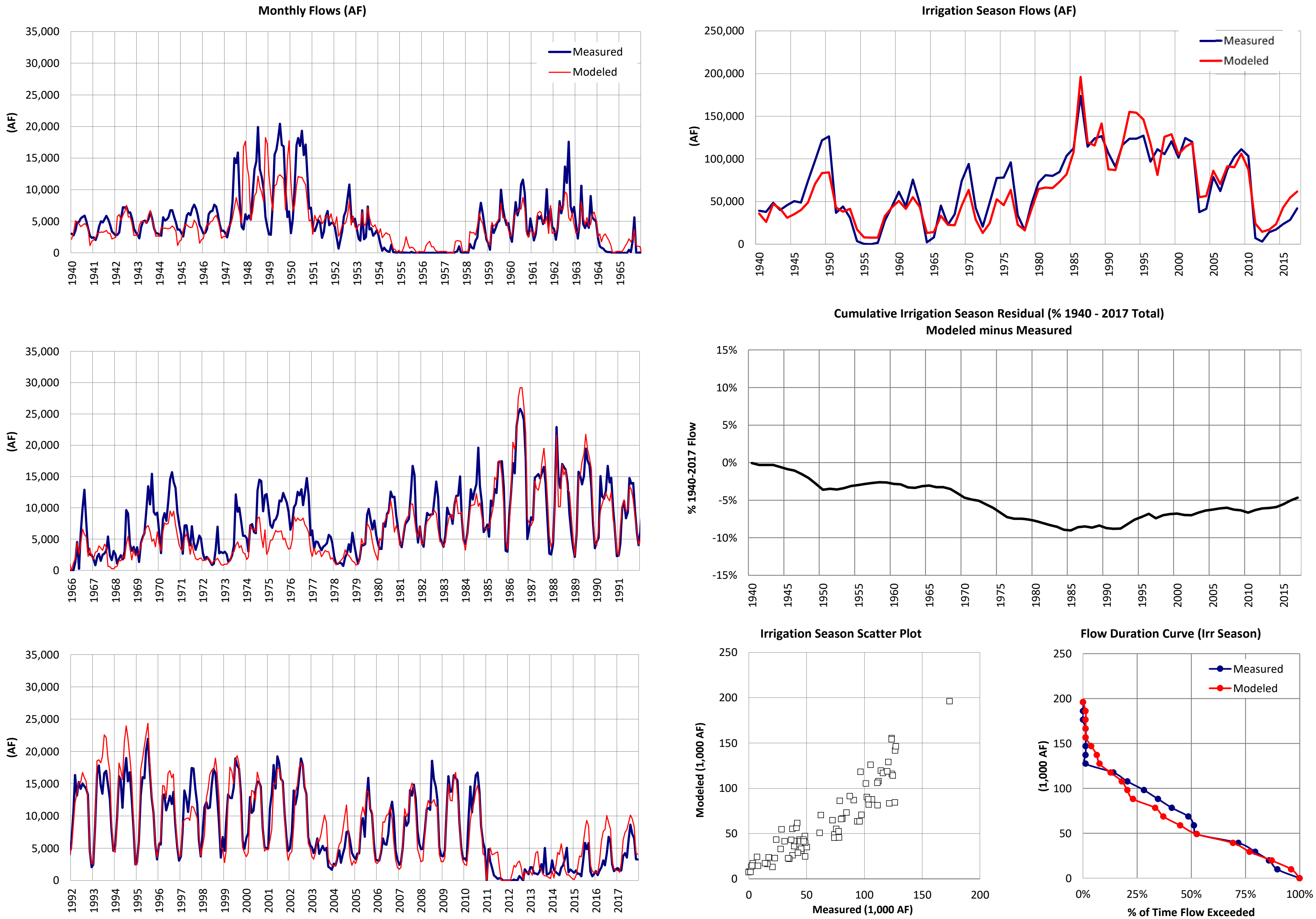


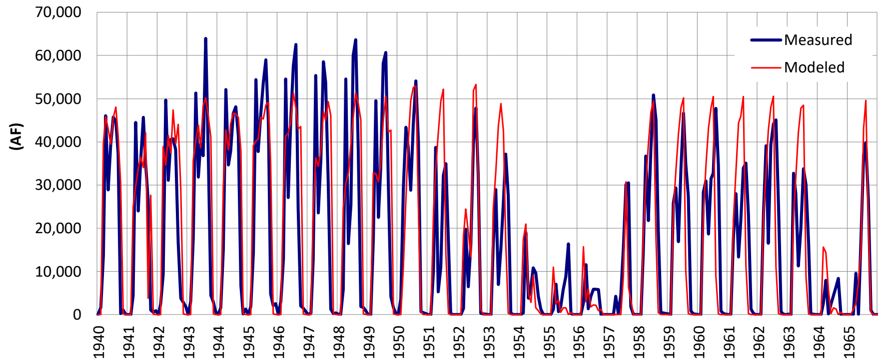
Figure 28-13

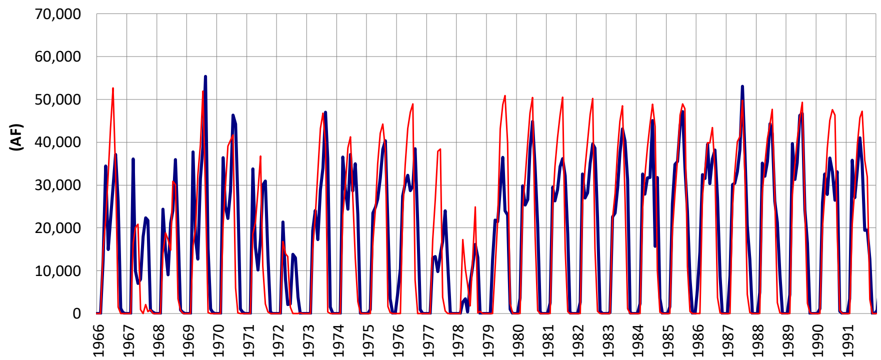
Integrated LRG Model Historical Calibration Results

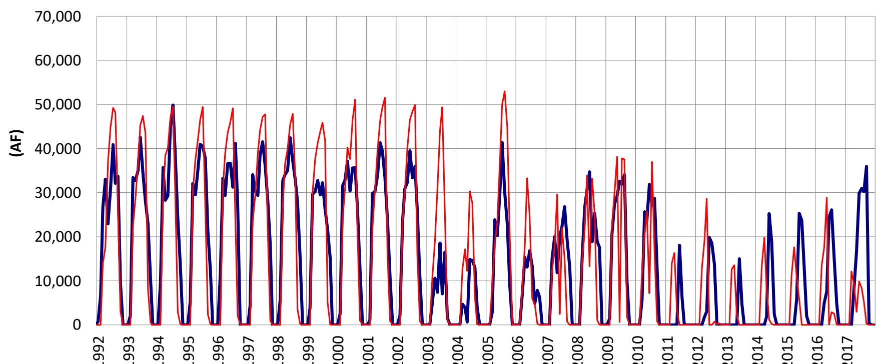
EBID FHG

1940 - 2017

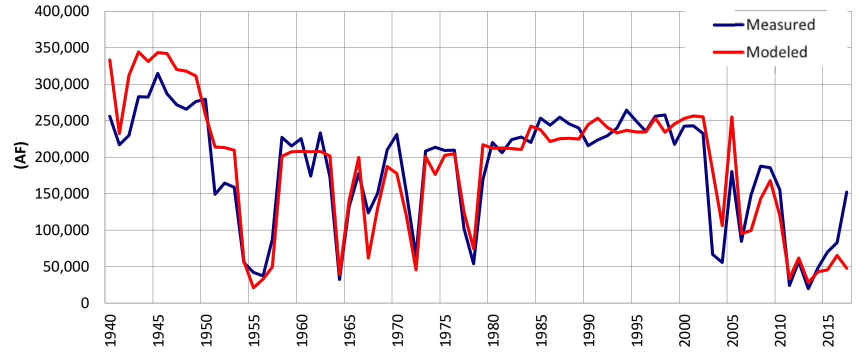
Monthly Flows (AF)



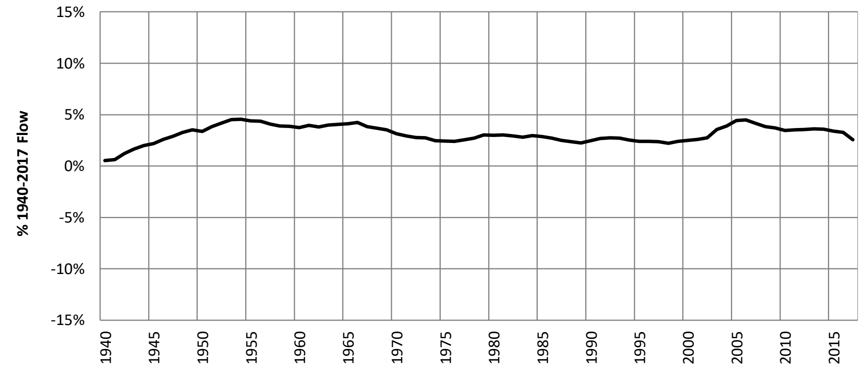




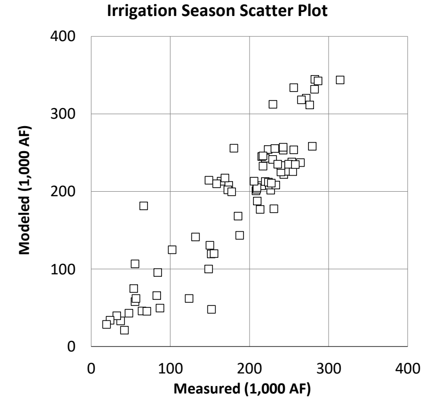
Irrigation Season Flows (AF)



Cumulative Irrigation Season Residual (% 1940 - 2017 Total)
Modeled minus Measured



Irrigation Season Scatter Plot



Flow Duration Curve (Irr Season)

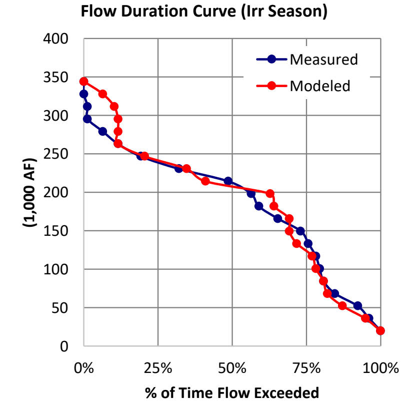


Figure 28-14

Integrated LRG Model Historical Calibration Results

EPCWID FHG

1940 - 2017

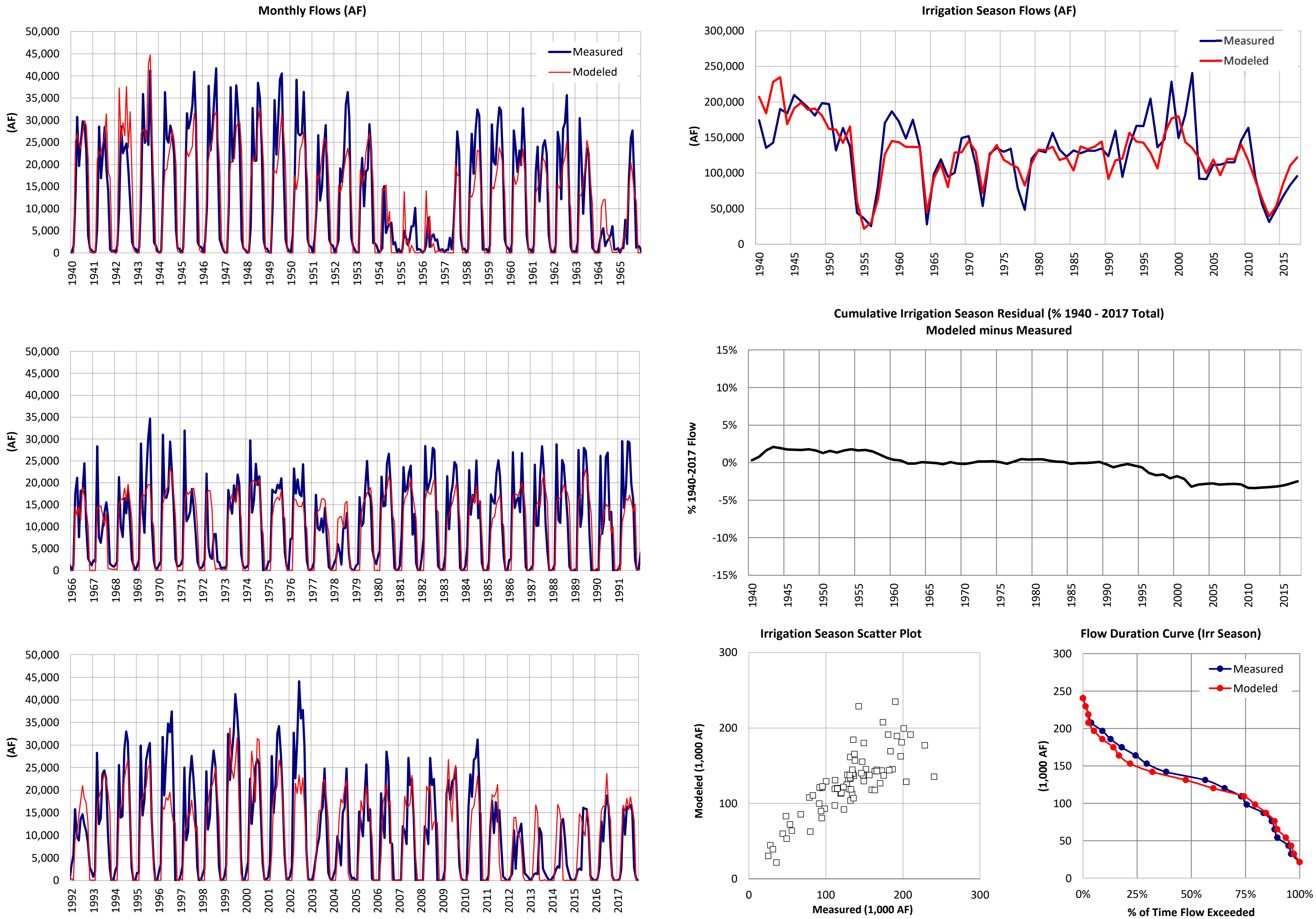


Figure 28-15

Integrated LRG Model Historical Calibration Results

HCCRD FHG

1940 - 2017

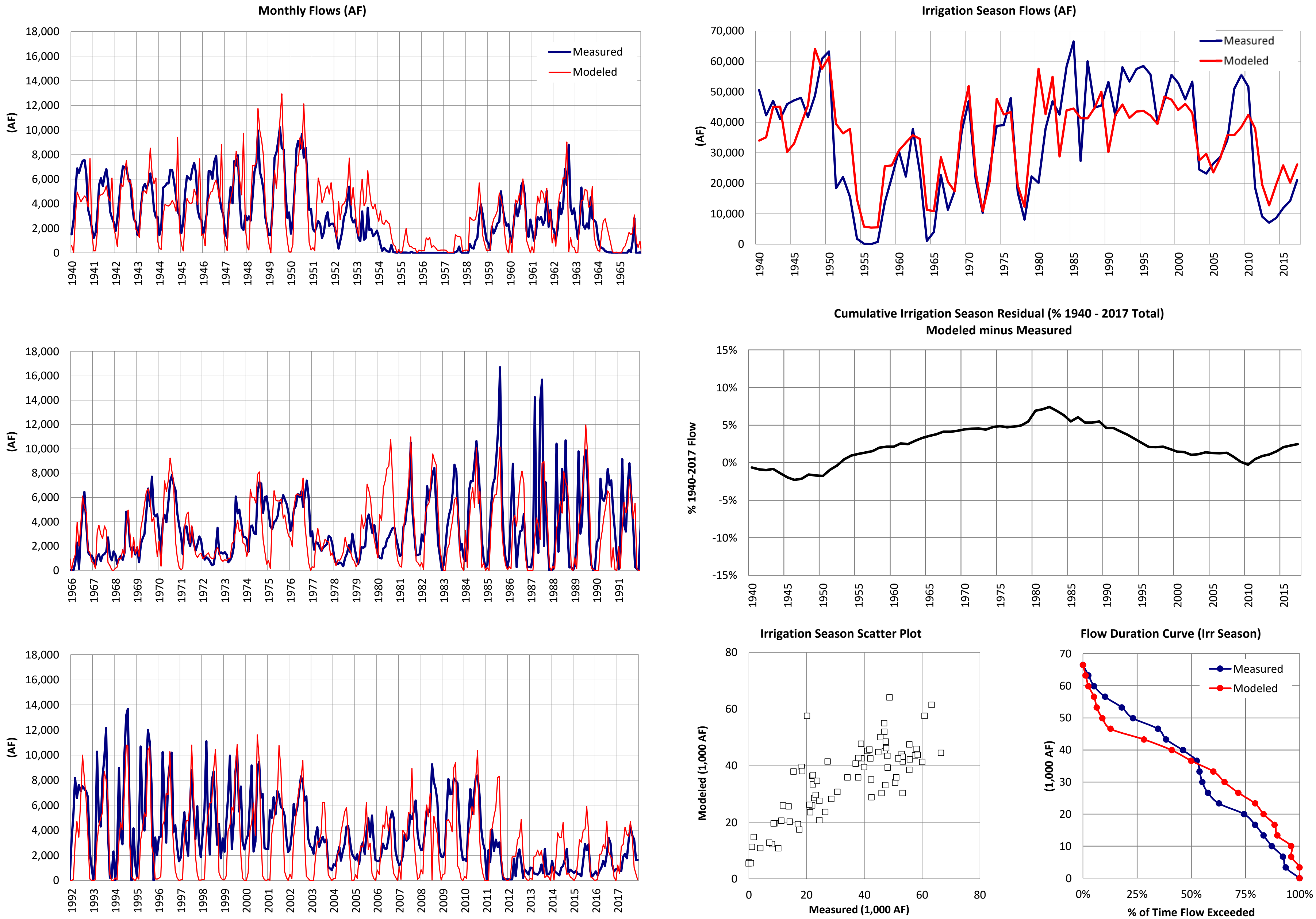


Figure 28-16

Integrated LRG Model Historical Calibration Results

EBID Supplemental Pumping

1940 - 2017

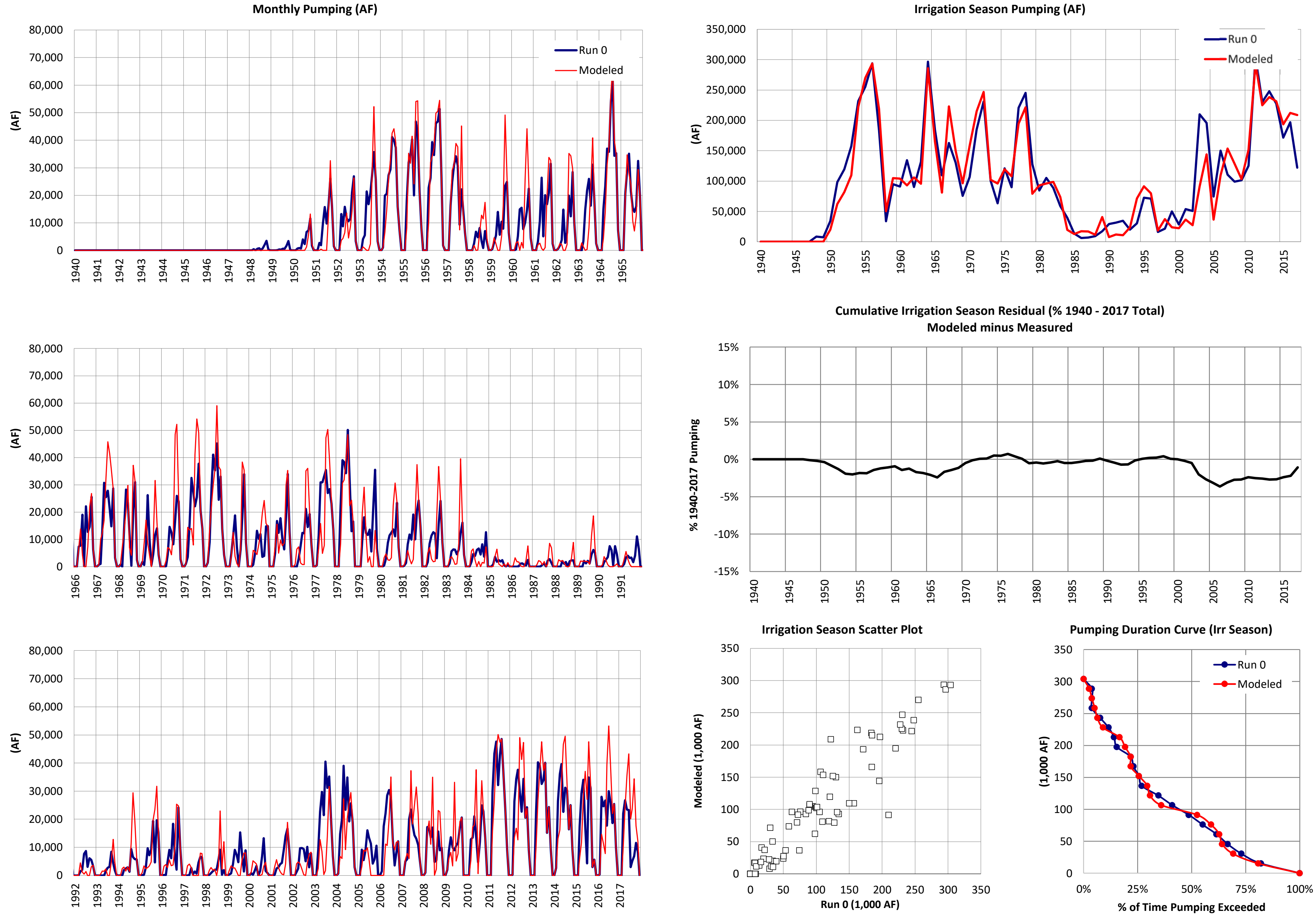


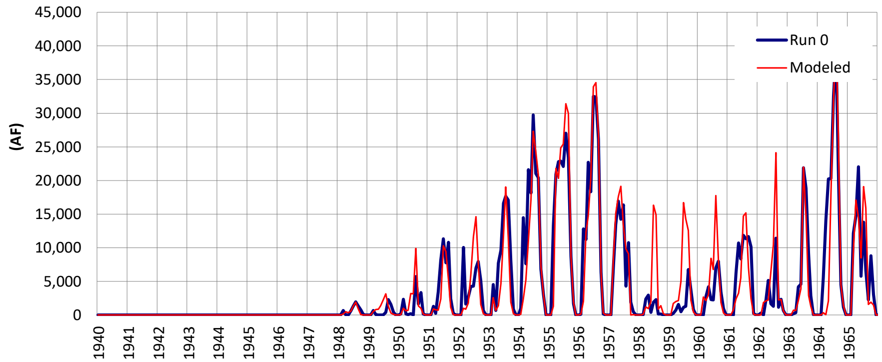
Figure 28-17

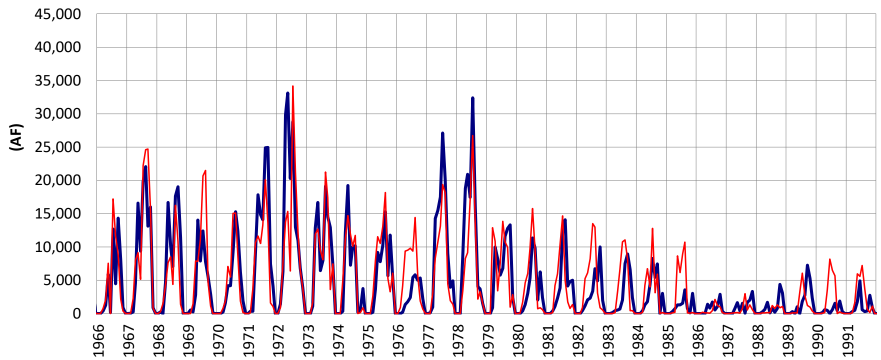
Integrated LRG Model Historical Calibration Results

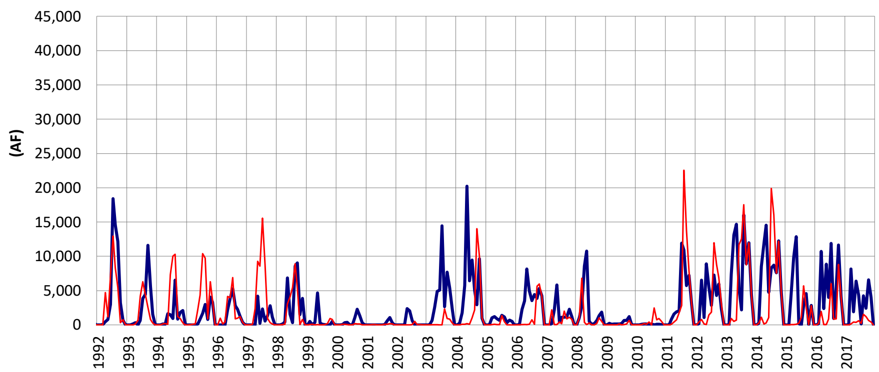
EPCWID Supplemental Pumping

1940 - 2017

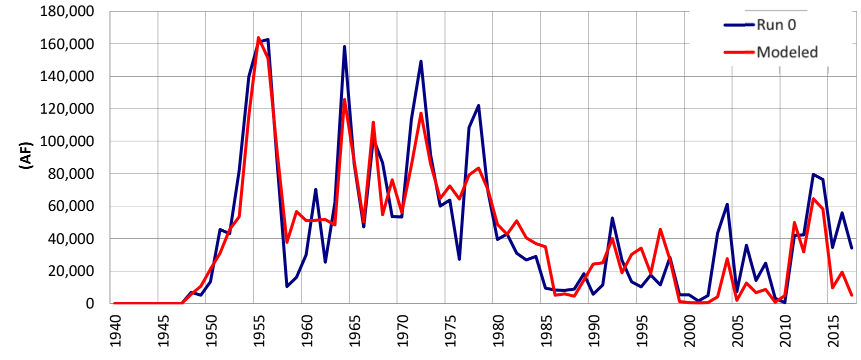
Monthly Pumping (AF)



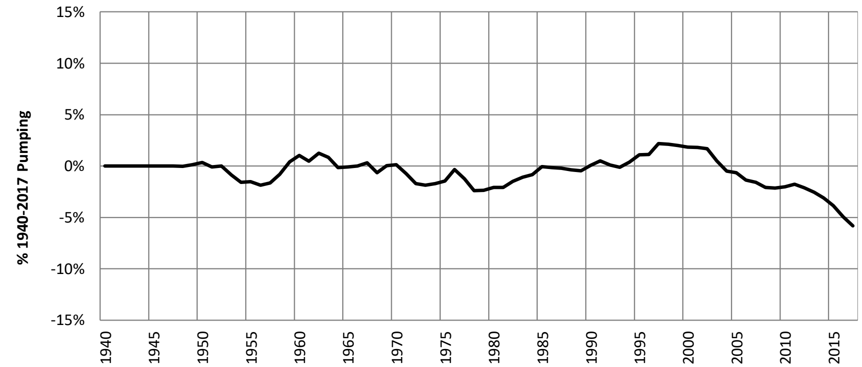




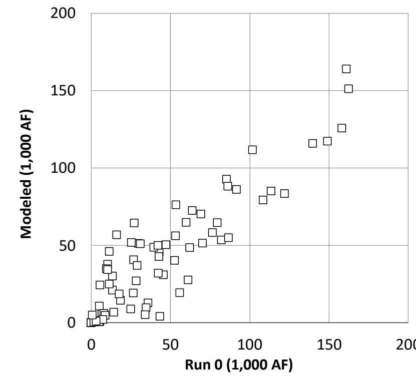
Irrigation Season Pumping (AF)



Cumulative Irrigation Season Residual (% 1940 - 2017 Total)
Modeled minus Measured



Irrigation Season Scatter Plot



Pumping Duration Curve (Irr Season)

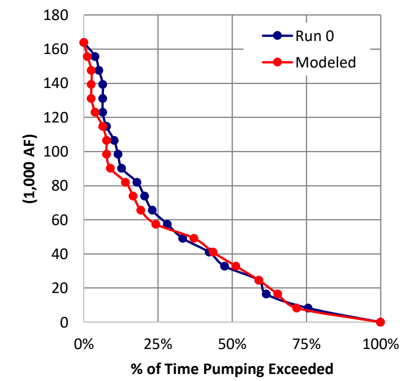


Figure 28-18

Integrated LRG Model Historical Calibration Results

HCCRD Supplemental Pumping

1940 - 2017

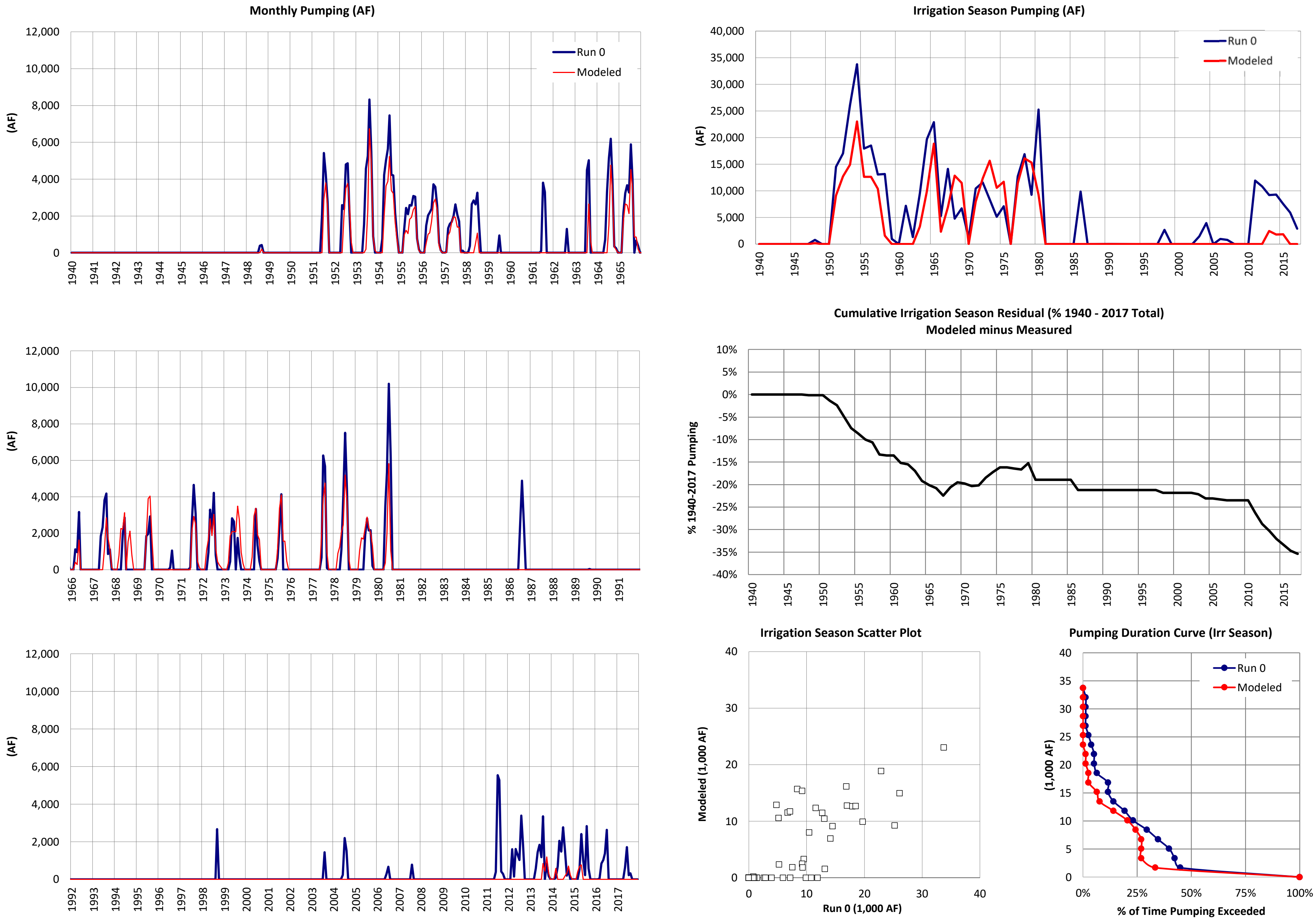
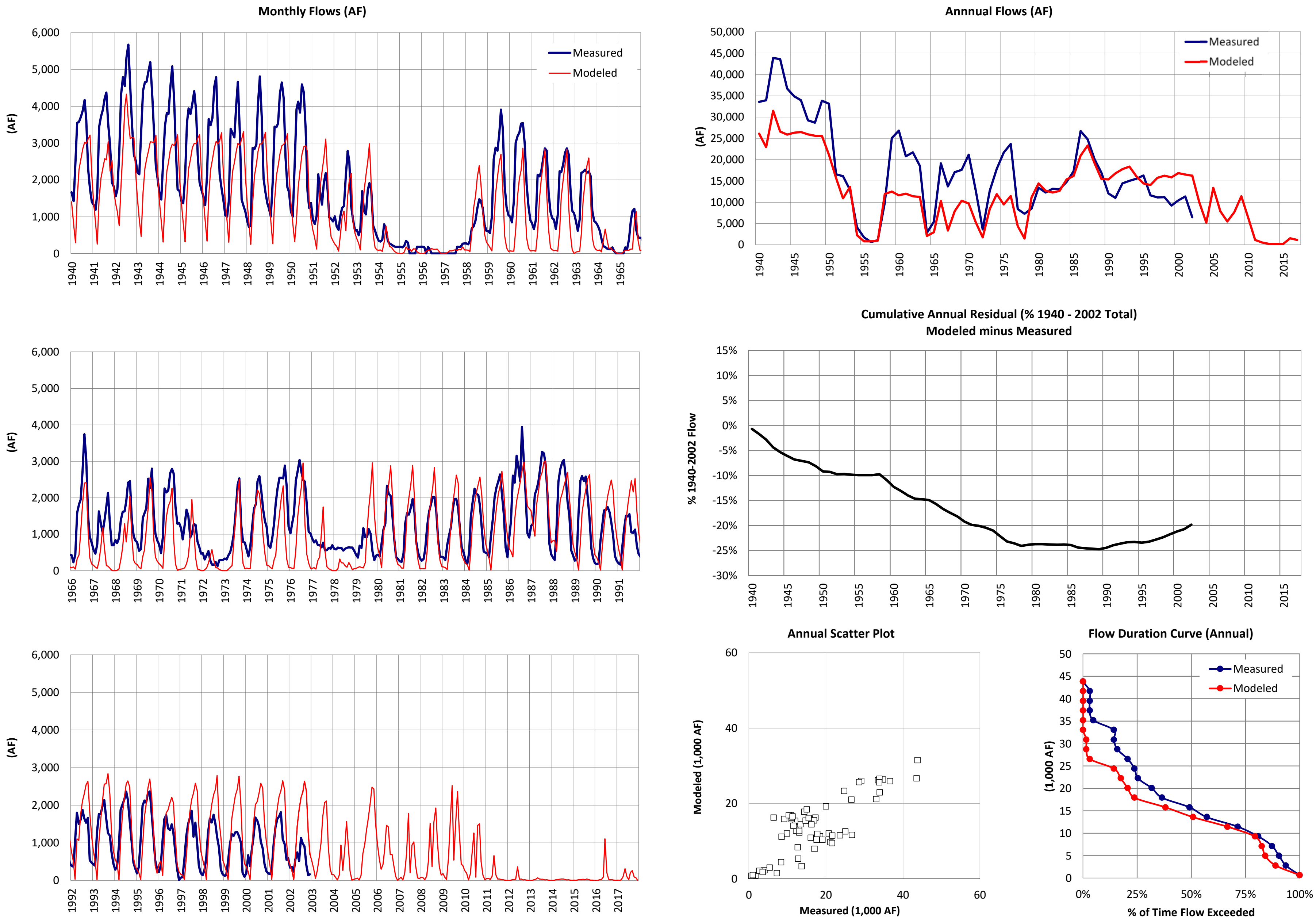


Figure 28-19

Integrated LRG Model Historical Calibration Results

Rincon Valley Drains

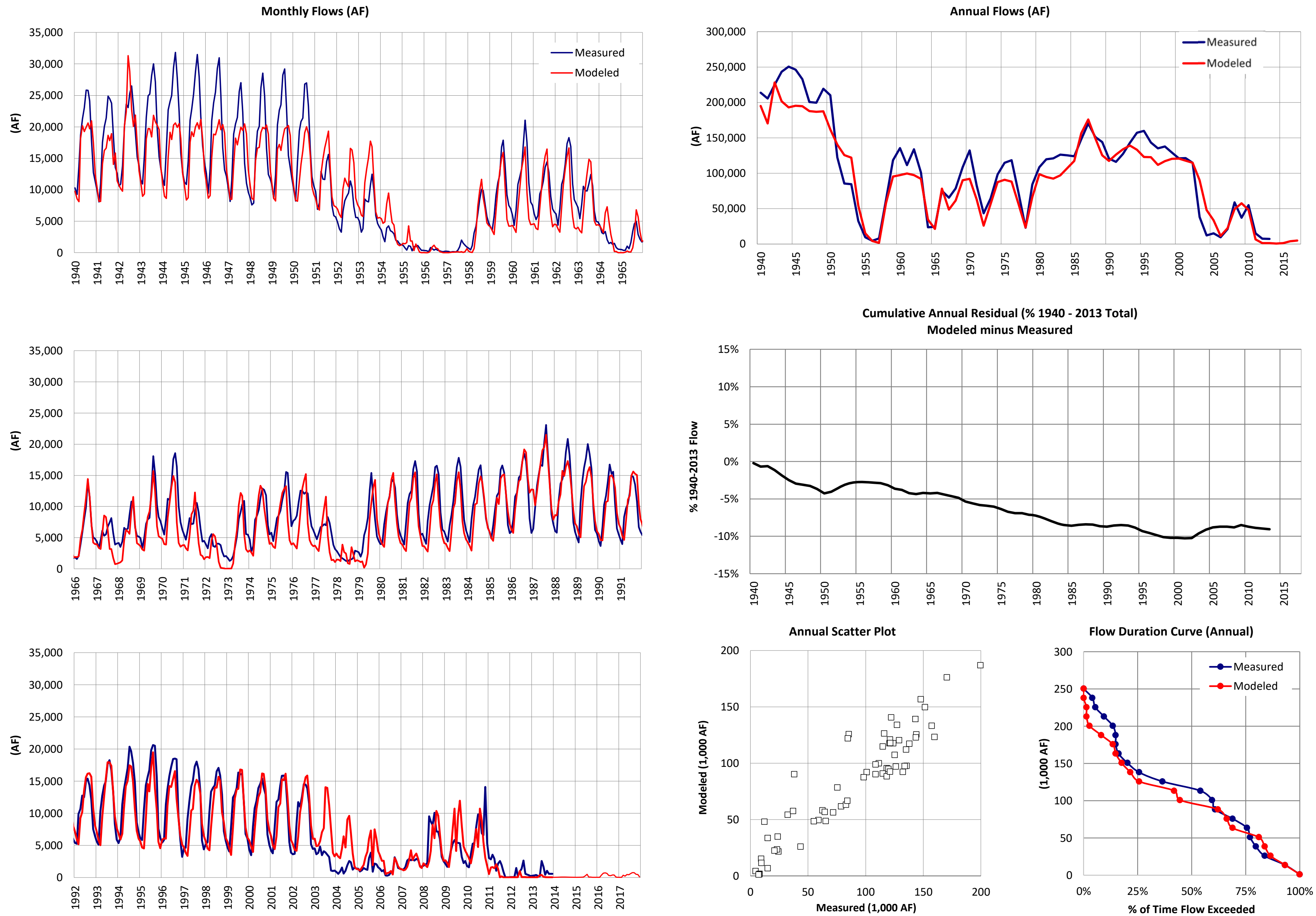
1940 - 2017



Note: Measured flows for Rincon Valley Drains shown for 1951-2002 due to limited data available after 2002. Modeled flows are shown in monthly and annual graphs after 2002 for reference.

Figure 28-20

Integrated LRG Model Historical Calibration Results
Mesilla Valley Drains
1940 - 2017

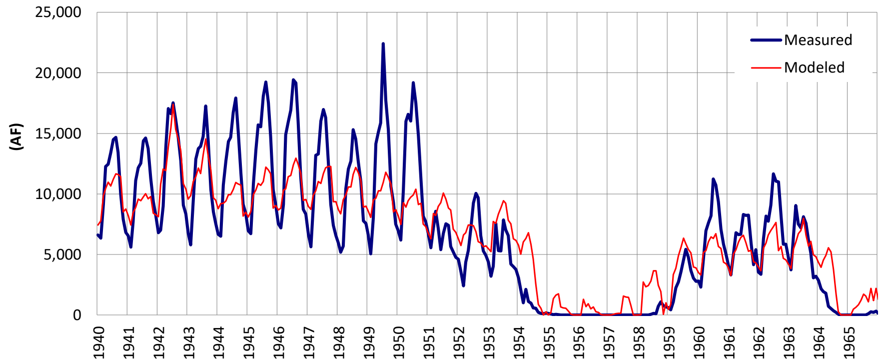


Note: Measured flows for Mesilla Valley Drains shown for 1951-2013 due to limited data available after 2013. Modeled flows are shown in monthly and annual graphs after 2013 for reference.

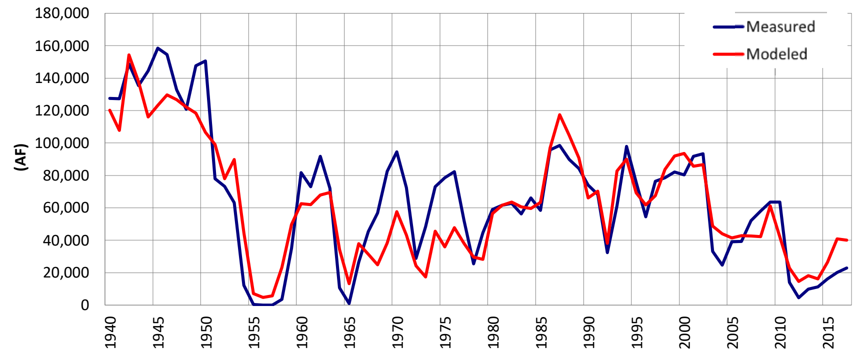
Figure 28-21

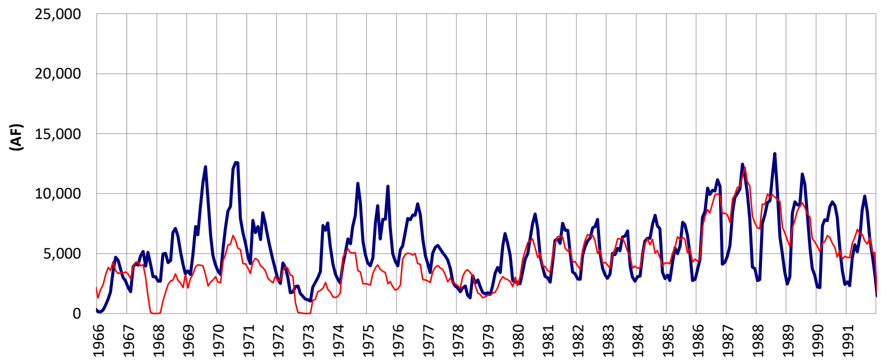
Integrated LRG Model Historical Calibration Results
El Paso Valley Drains
1940 - 2017

Monthly Flows (AF)

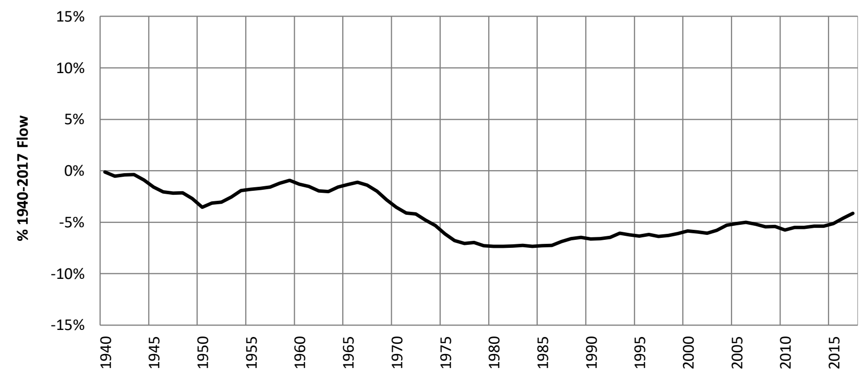


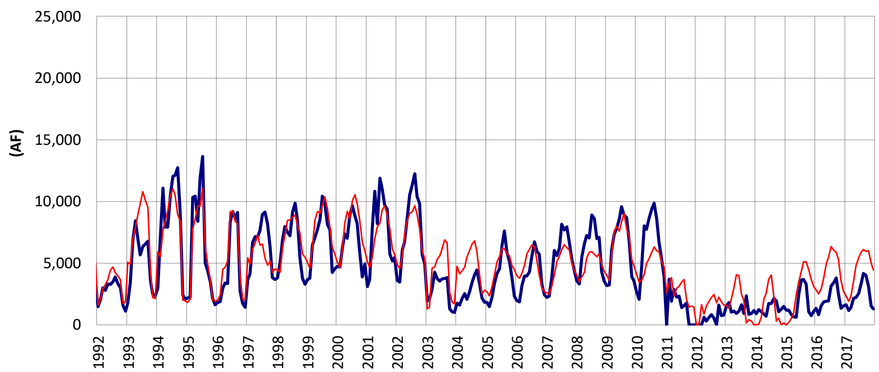
Annual Flows (AF)



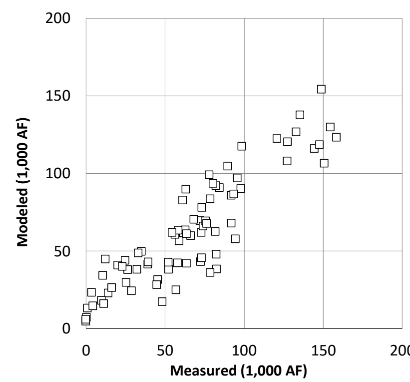


Cumulative Annual Residual (% 1940 - 2017 Total)
Modeled minus Measured





Annual Scatter Plot



Flow Duration Curve (Annual)

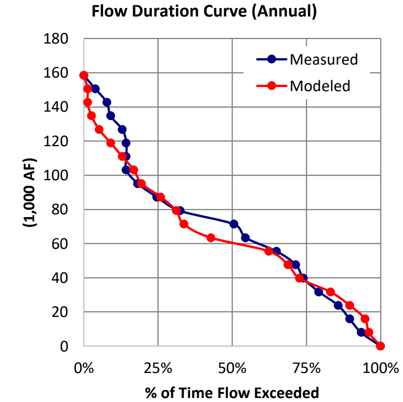
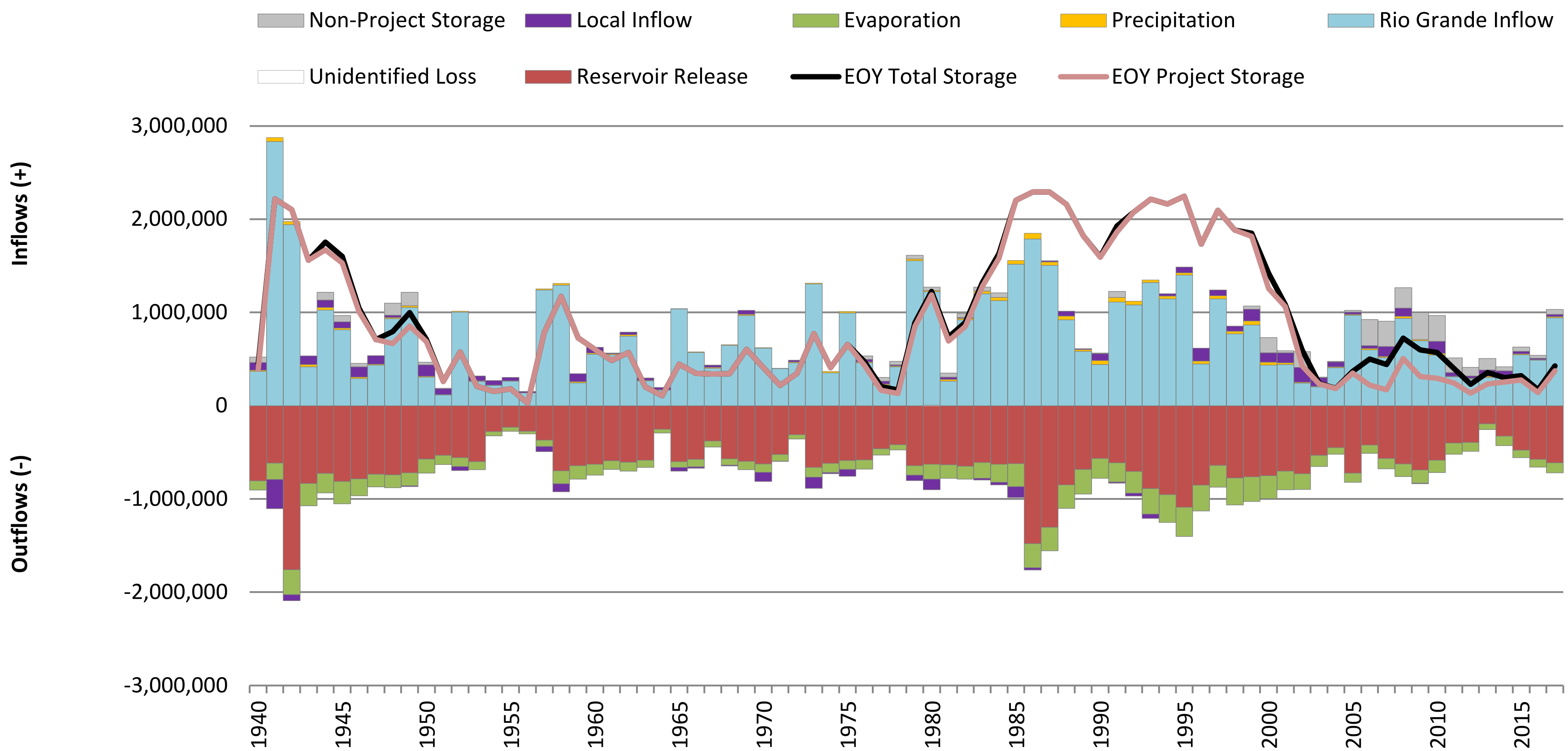


Figure 29-1

Annual Reservoir Water Budget Summary
Historical Base Run (Run 1)
Integrated LRG Model
1940 - 2017 (acre-feet)

Elephant Butte and Caballo Reservoirs (Project Total)



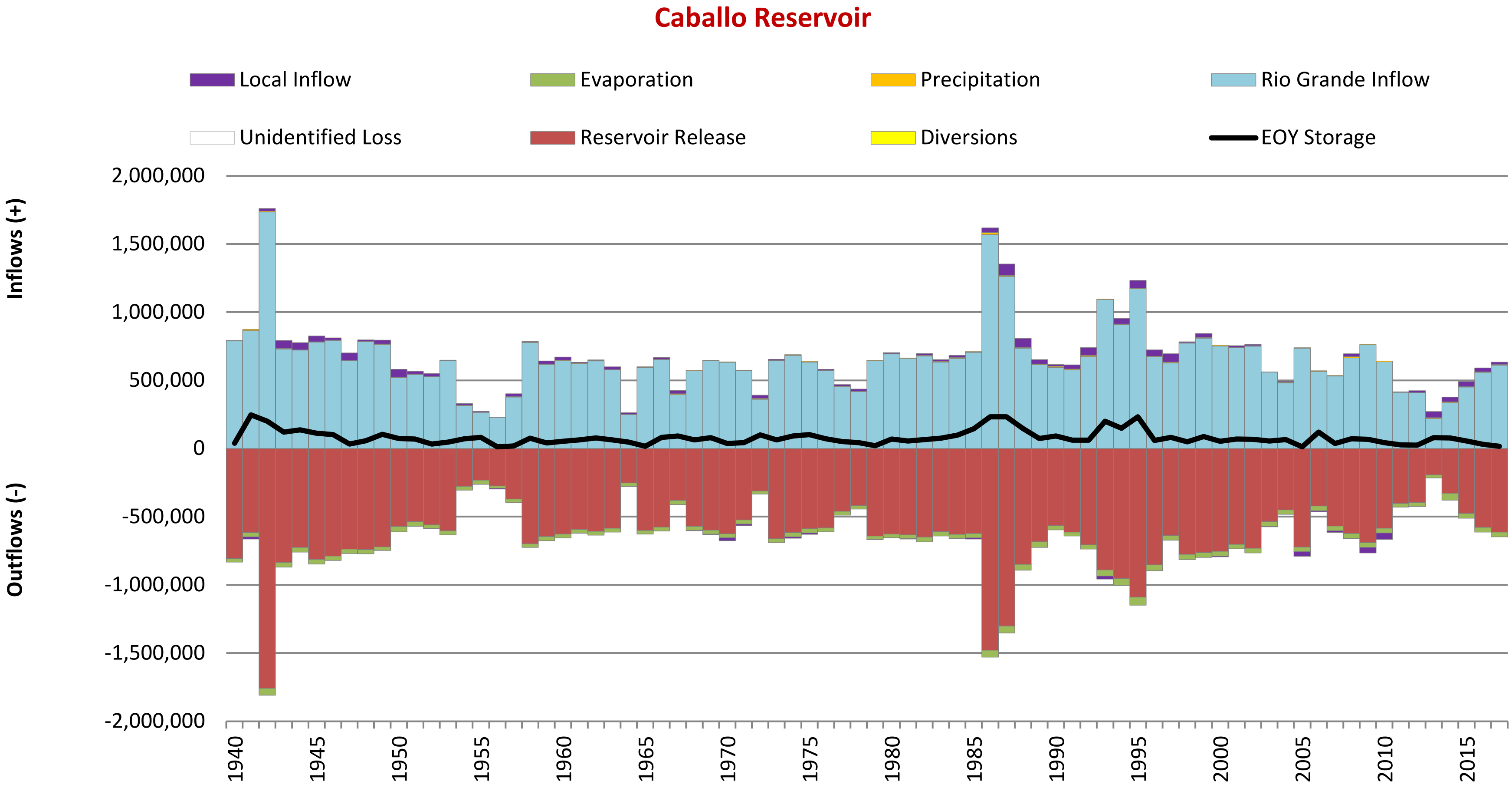
Notes:

Model Version: LRG Model v116 Operational Run 1 - Historical Base Run.

Total Storage in Elephant Butte Reservoir includes New Mexico and Colorado compact storage and San Juan Chama storage.

Figure 29-1

Annual Reservoir Water Budget Summary
Historical Base Run (Run 1)
Integrated LRG Model
1940 - 2017 (acre-feet)

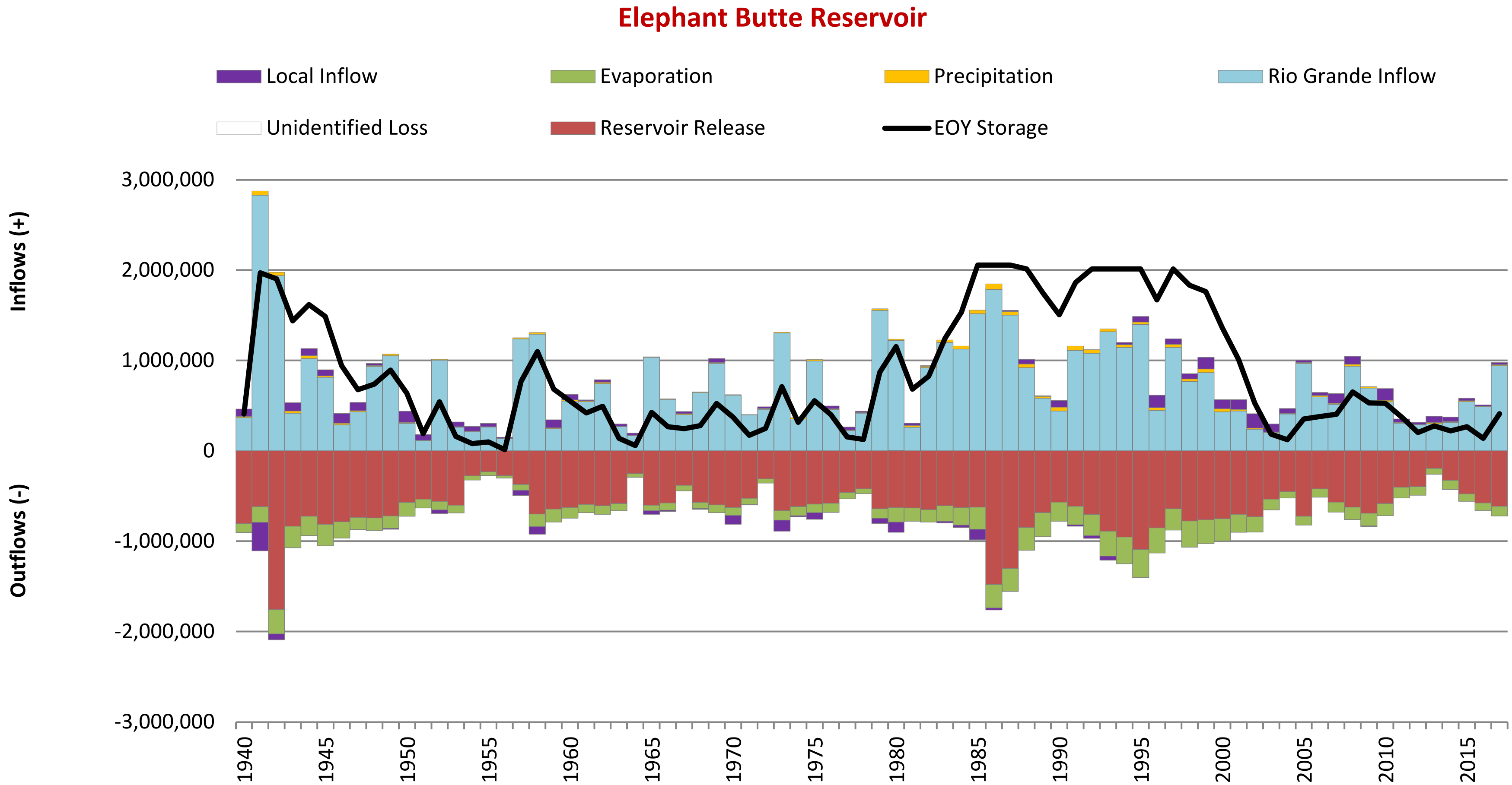


Notes:

Model Version: LRG Model v116 Operational Run 1 - Historical Base Run.

Figure 29-1

Annual Reservoir Water Budget Summary
Historical Base Run (Run 1)
Integrated LRG Model
1940 - 2017 (acre-feet)

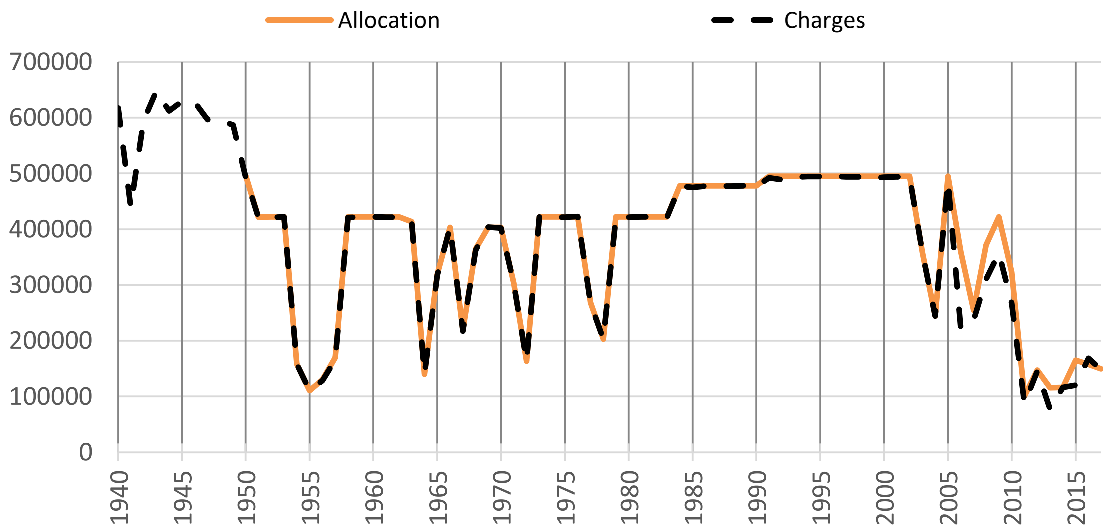


Notes:
Model Version: LRG Model v116 Operational Run 1 - Historical Base Run.
Total Storage in Elephant Butte Reservoir includes New Mexico and Colorado compact storage and San Juan Chama storage.

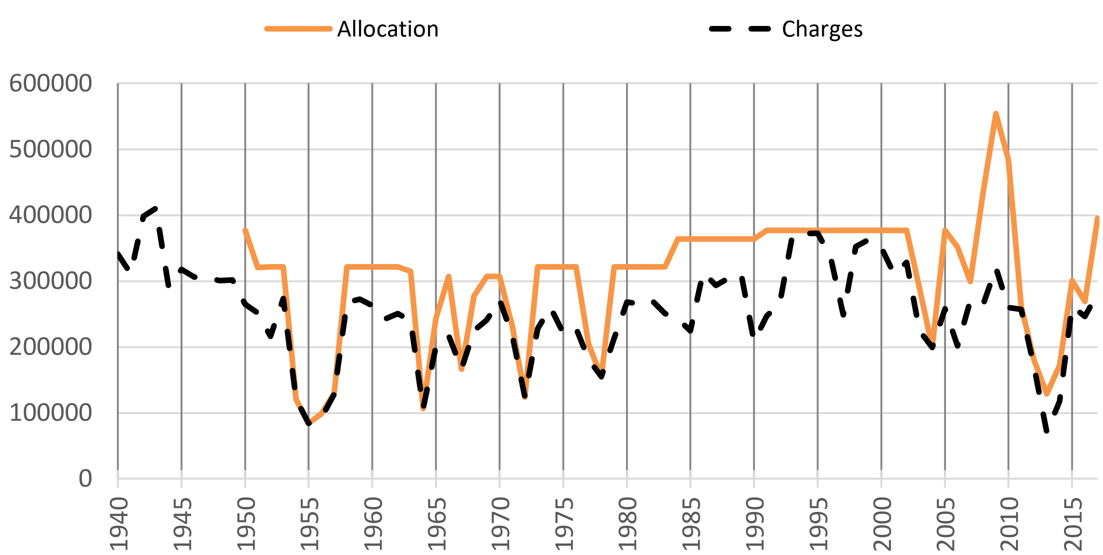
Figure 29-2

Annual Project Allocations and Charges
Historical Base Run (Run 1)
Integrated LRG Model
1940 - 2017 (acre-feet)

EBID



EPCWID



Notes:

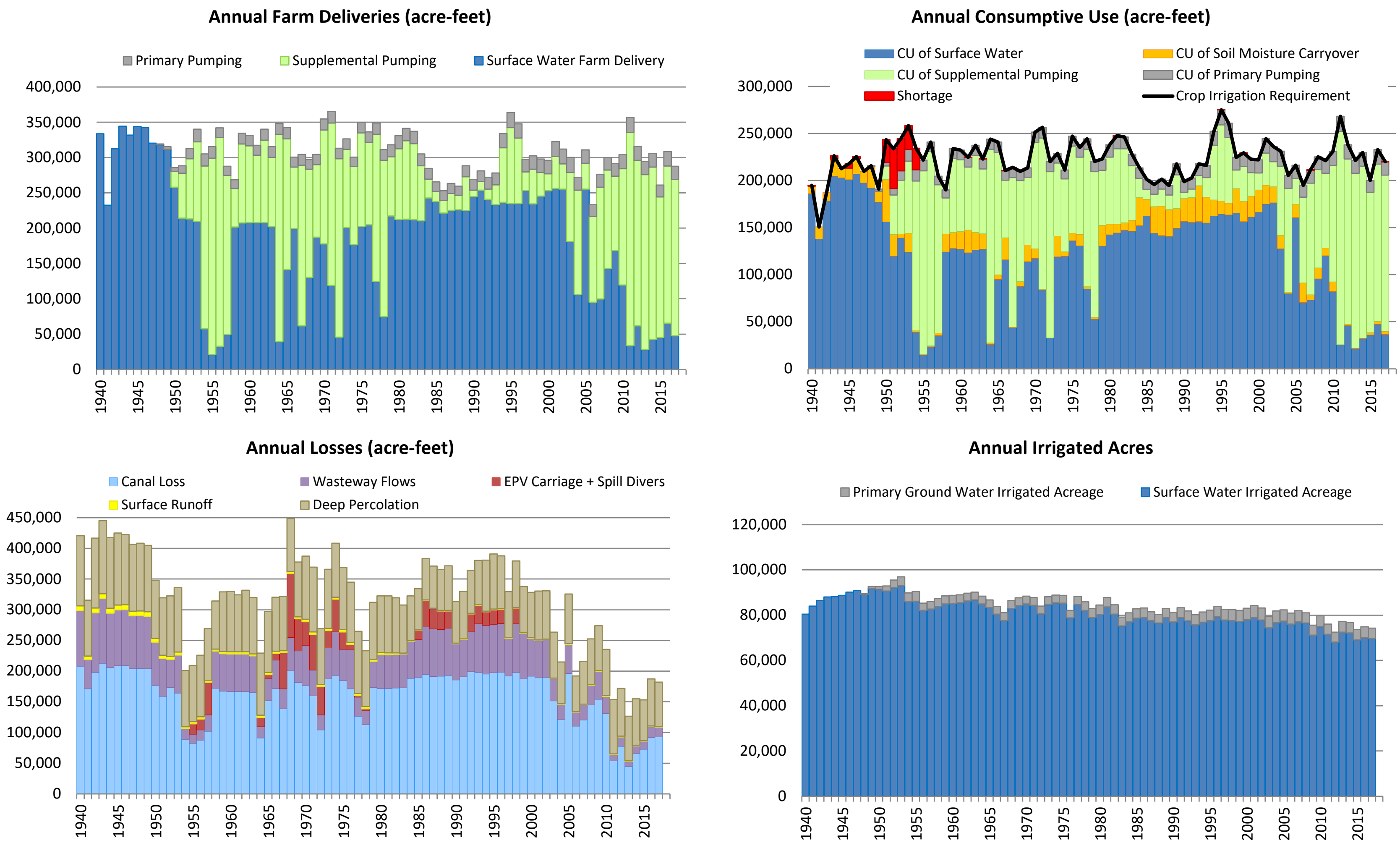
Model Version: LRG Model v116 Operational Run 1 - Historical Base Run.

Allocation calculated with carryover (2008 - 2017).

Allocation is calculated and used to limit diversions for EBID and EPCWID from 1950-2017.

Figure 29-3

Annual Canal and Farm Water Budget Summary
Historical Base Run (Run 1)
Integrated LRG Model
1940-2017
EBID Total



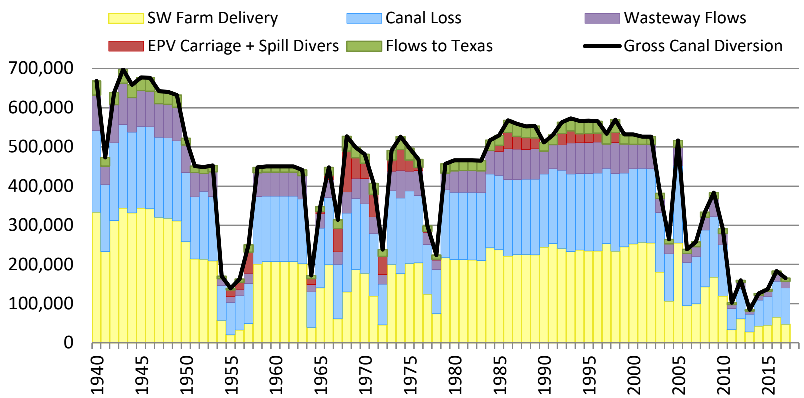
*Note: Different Scales

Model Version: LRG Model v116 Operational Run 1 - Historical Base Run.

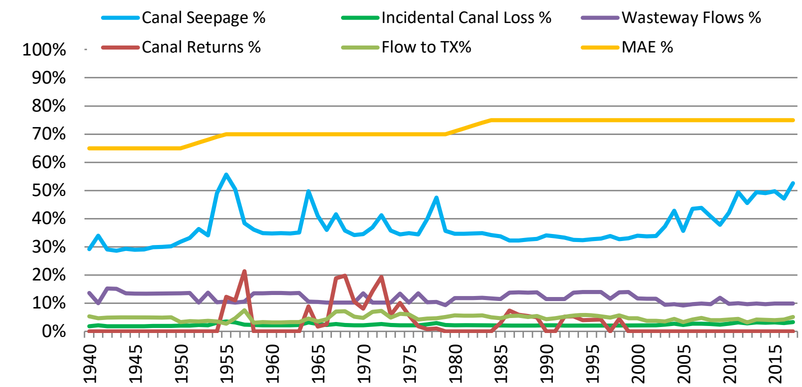
Figure 29-3

Annual Canal and Farm Water Budget Summary
Historical Base Run (Run 1)
Integrated LRG Model
1940-2017
EBID Total

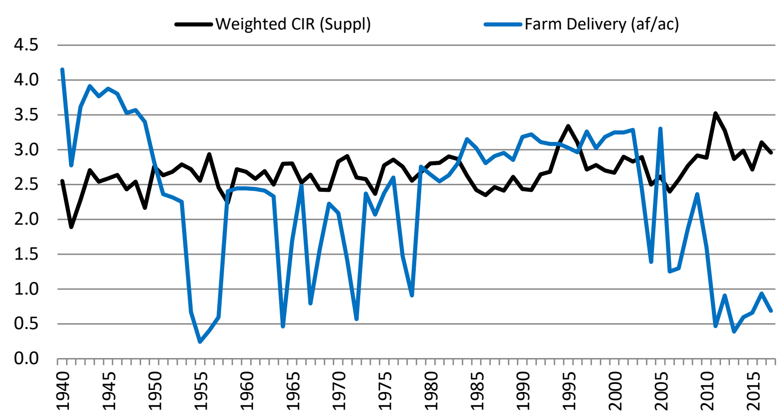
Annual Canal Diversions and Farm Deliveries (acre-feet)



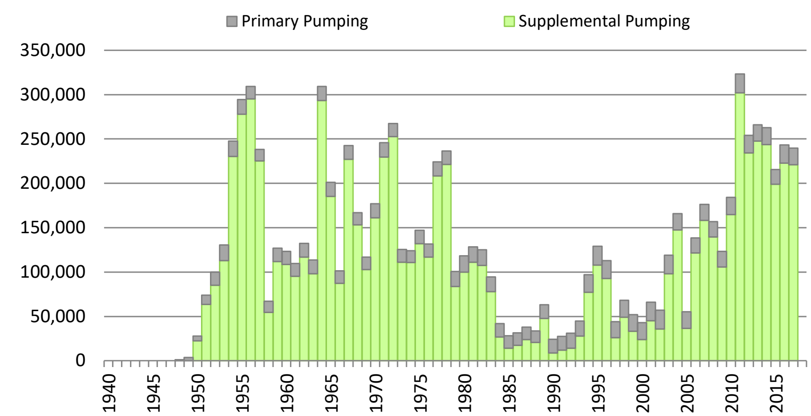
Maximum Application Efficiency and Loss Percentages



Annual Weighted Crop Irrigation Requirement (feet)



Annual Pumping (acre-feet)



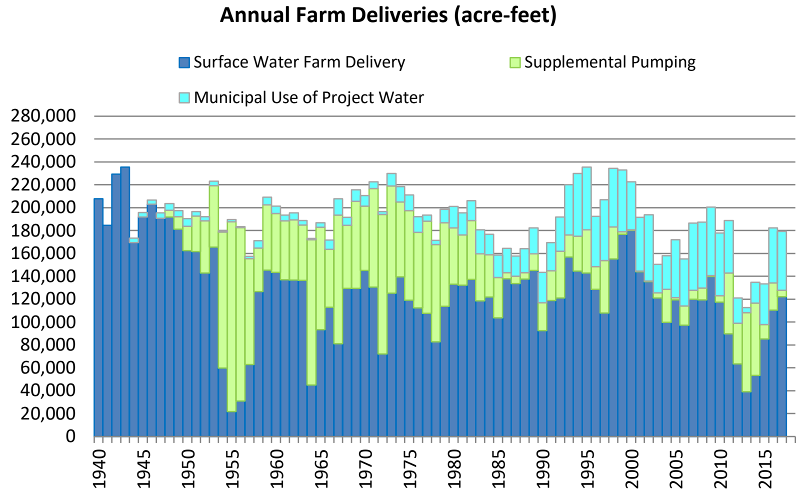
Model Version: LRG Model v116 Operational Run 1 - Historical Base Run.

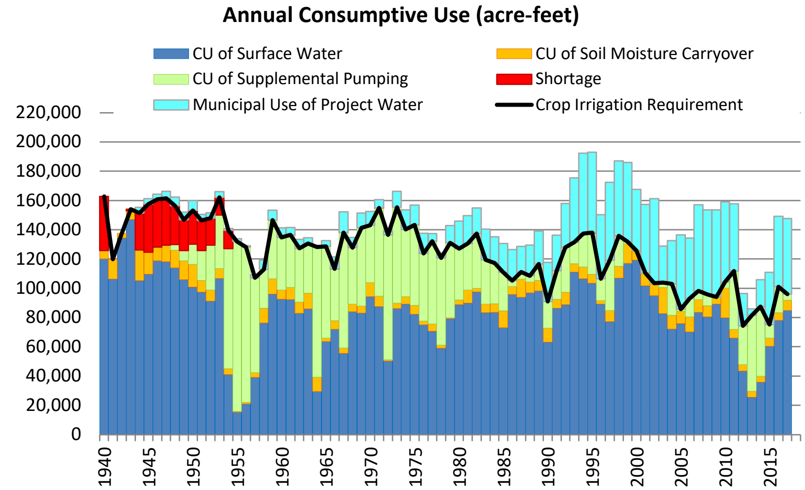
Notes:

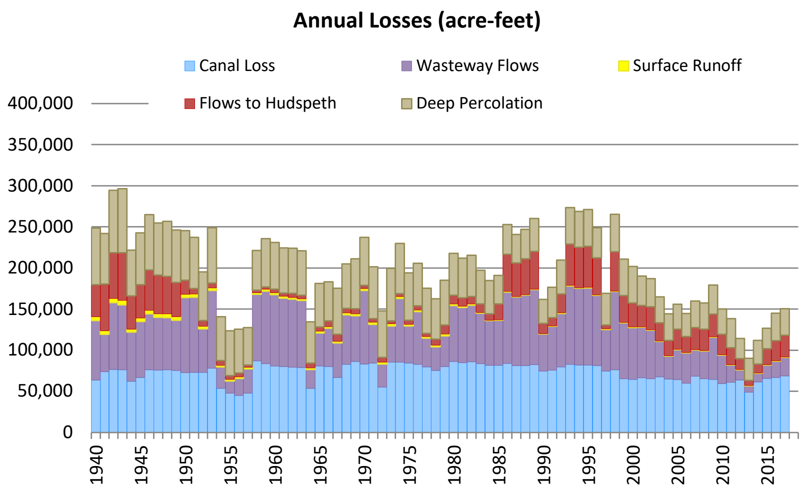
(1) Gross canal diversions are the sum of diversions at Percha Dam plus Leasburg Dam plus Mesilla Dam (East and West).
(2) Canal loss calculations occur at top of canal and are not in the surface water budget for Mesilla Texas. However a portion of the canal seepage accrues to the ground water objects for Mesilla TX.
(3) Canal returns to river are flows from the canal to the Rio Grande that are not through a wasteway. These can include EPV carriage water, spill water, and water diverted in excess of demands.
(4) Flows to Texas are flows to Texas from the Eastside and Westside Canal.
(5) Loss percentages are divided by canal diversion.
(6) Crop Irrigation Requirement ("CIR") is the total crop consumptive use (a.k.a. consumptive use of applied water) minus effective precipitation.

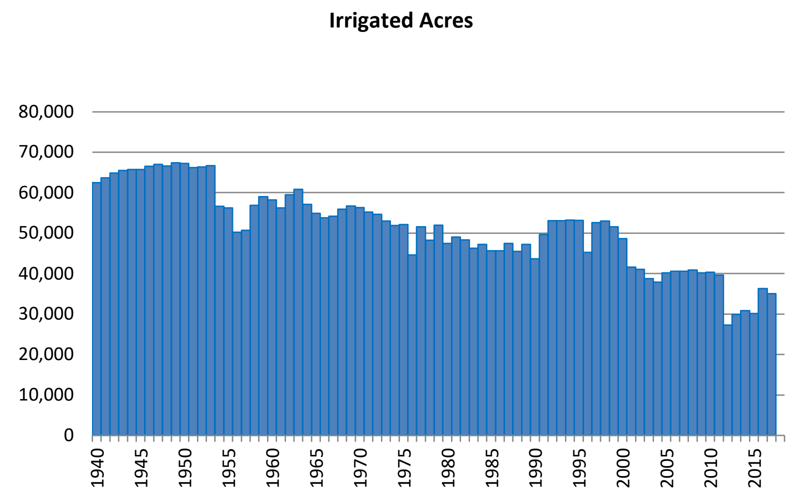
Figure 29-4

Annual Canal and Farm Water Budget Summary
Historical Base Run (Run 1)
Integrated LRG Model
1940-2017
EPCWID Total









*Note: Different Scales

Model Version: LRG Model v116 Operational Run 1 - Historical Base Run.

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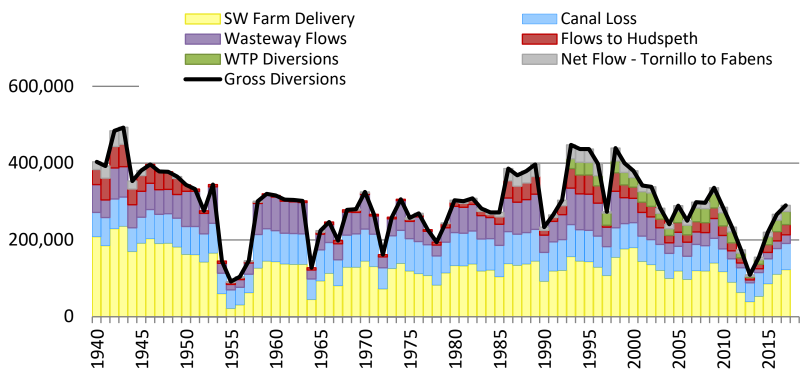
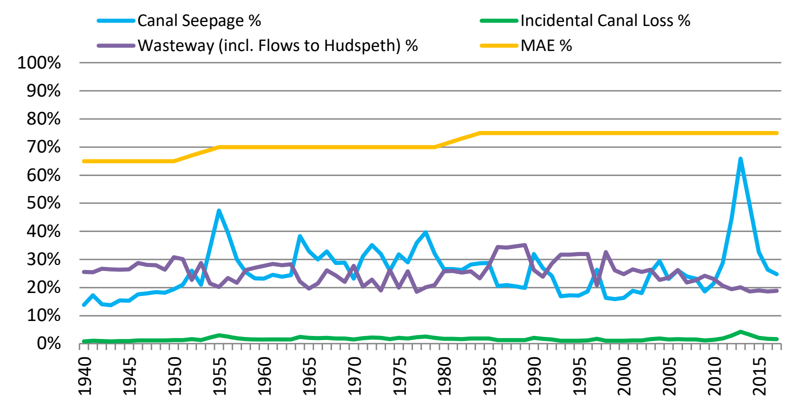
Figure 29-4

Annual Canal and Farm Water Budget Summary
Historical Base Run (Run 1)
Integrated LRG Model
1940-2017
EPCWID Total

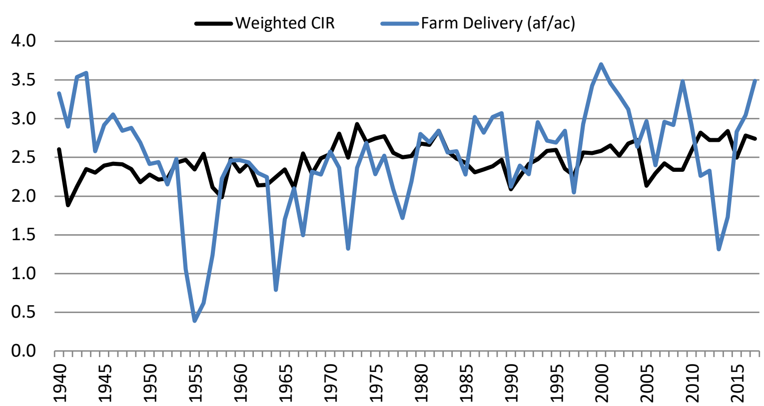
Annual Canal Diversions and Farm Deliveries (acre-feet)



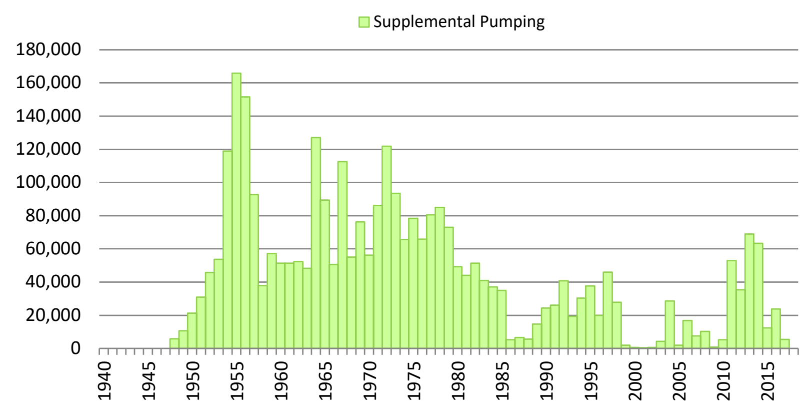
Maximum Application Efficiency and Loss Percentages



Annual Weighted Crop Irrigation Requirement (feet)



Annual Pumping (acre-feet)



Model Version: LRG Model v116 Operational Run 1 - Historical Base Run.

Notes:

(1) Gross Canal Diversions includes the sum of diversions from NM to TX Mesilla plus Franklin Canal diverisons plus Riverside Dam (or ACE post-1999) diversions plus net diversions to/from Tornillo Canal.
(2) Canal loss calculations occur at top of canal and are not in the surface water budget for Mesilla Texas. However a portion of the canal seepage accrues to the ground water objects for Mesilla TX.
(3) Net diversion includes canal diversions, drain returns to canals, and WWTP returns to canals.
(4) Loss percentages are divided by canal diversion.
(5) Crop Irrigation Requirement ("CIR") is the total crop consumptive use (a.k.a. consumptive use of applied water) minus effective precipitation.

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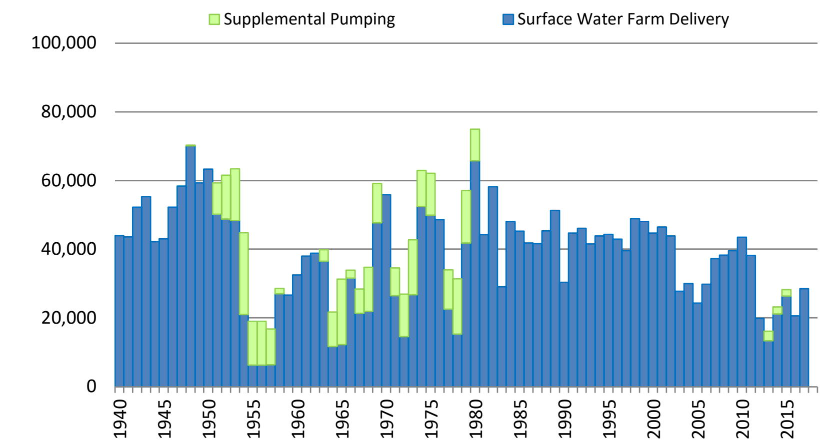
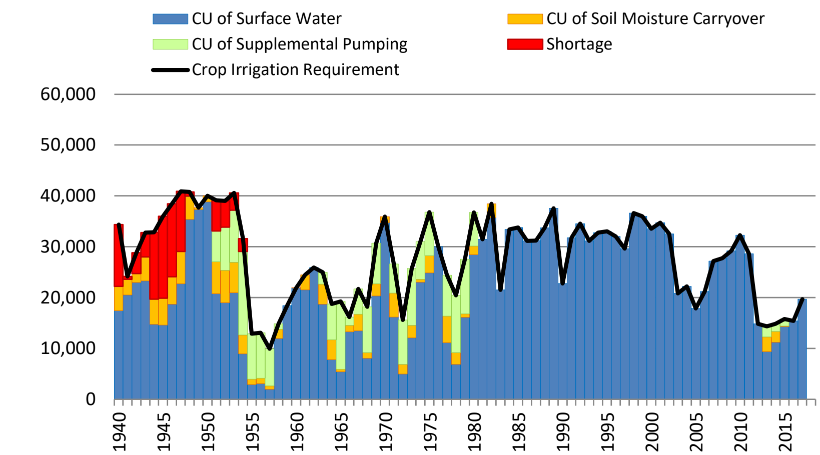
Figure 29-5

Annual Canal and Farm Water Budget Summary
Historical Base Run (Run 1)
Integrated LRG Model
1940-2017
HCCRD Total

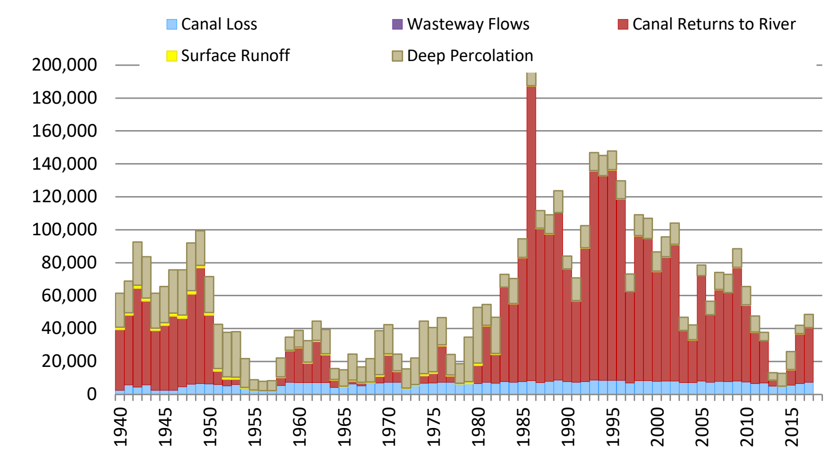
Annual Farm Deliveries (acre-feet)



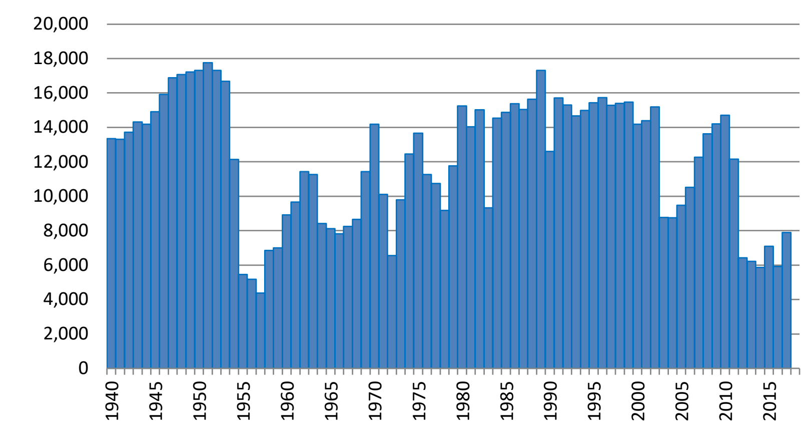
Annual Consumptive Use (acre-feet)



Annual Losses (acre-feet)



Irrigated Acres



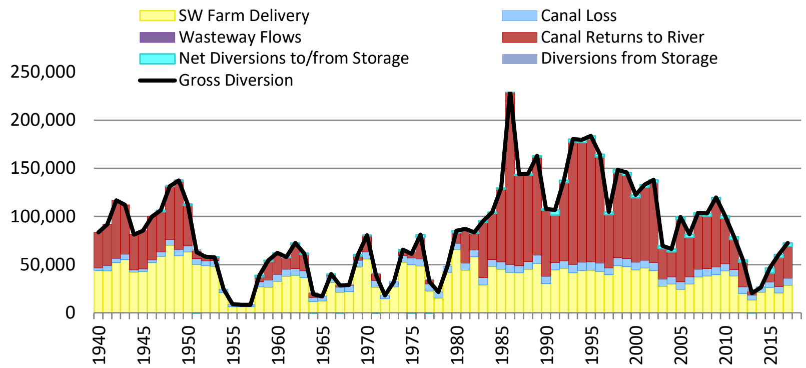
*Note: Different Scales

Model Version: LRG Model v116 Operational Run 1 - Historical Base Run.

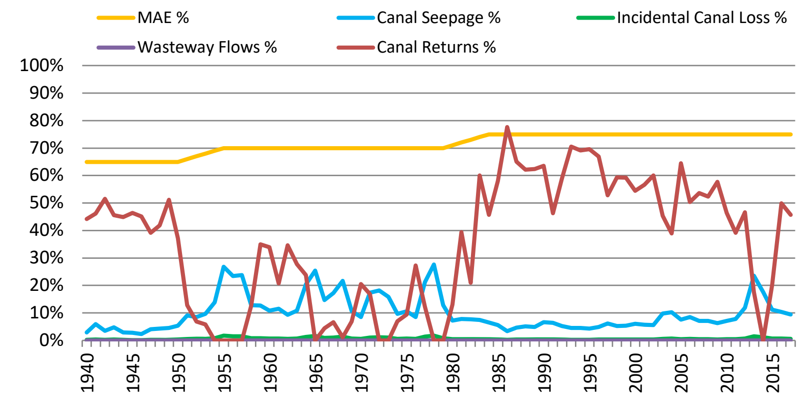
Figure 29-5

Annual Canal and Farm Water Budget Summary
Historical Base Run (Run 1)
Integrated LRG Model
1940-2017
HCCRD Total

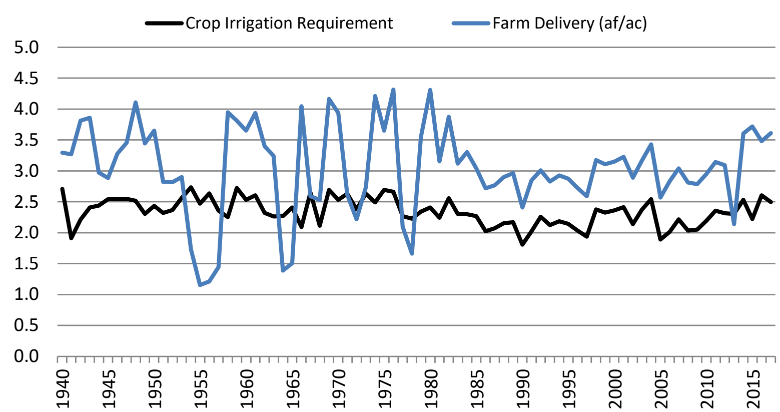
Annual Canal Diversions and Farm Deliveries (acre-feet)



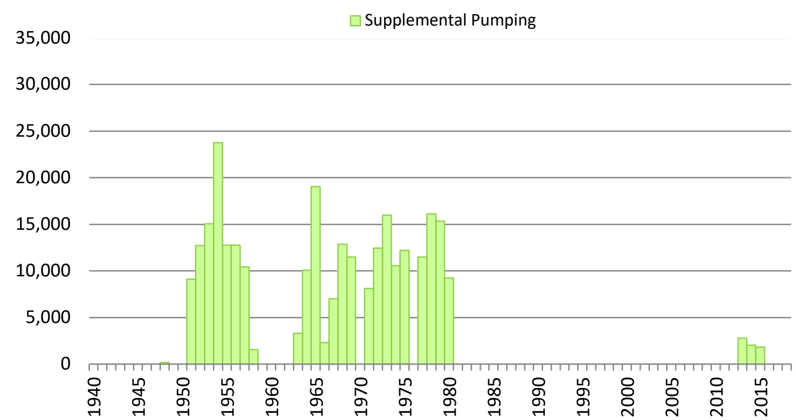
Maximum Application Efficiency and Loss Percentages



Annual Weighted Crop Irrigation Requirement (feet)



Annual Pumping (acre-feet)



Model Version: LRG Model v116 Operational Run 1 - Historical Base Run.

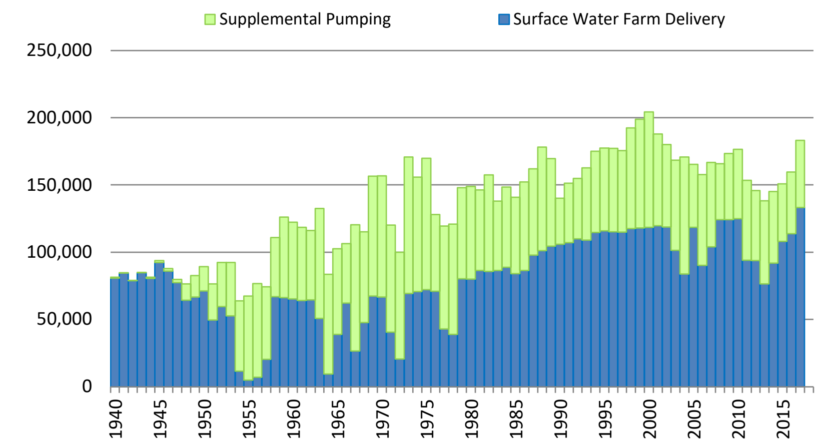
Notes:

(1) Gross Canal Diversions includes the sum of Hudspeth Feeder Canal flows plus Tornillo Canal at Alamo Alto flows plus Tornillo Drain flows plus diversions from drains plus net diversions to/from storage.
(2) Loss percentages divided by canal diversion. Canal seepage divided by canal diversion + water released from storage.
(3) Crop Irrigation Requirement ("CIR") is the total crop consumptive use (a.k.a. consumptive use of applied water) minus effective precipitation.

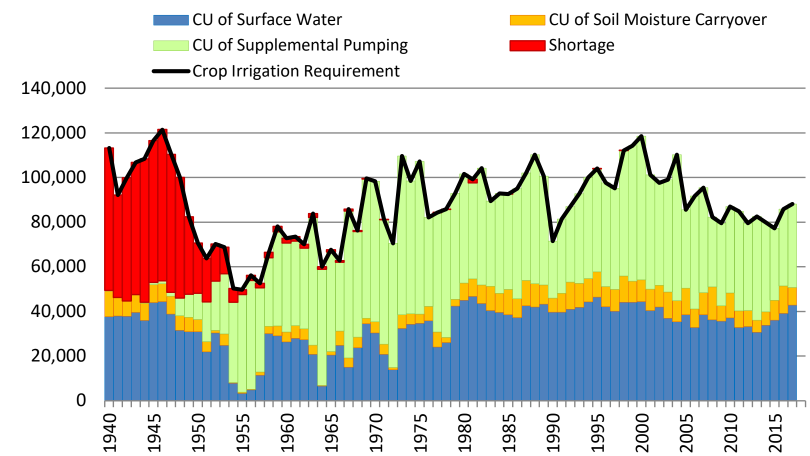
Figure 29-6

Annual Canal and Farm Water Budget Summary
Historical Base Run (Run 1)
Integrated LRG Model
1940-2017
JID Total

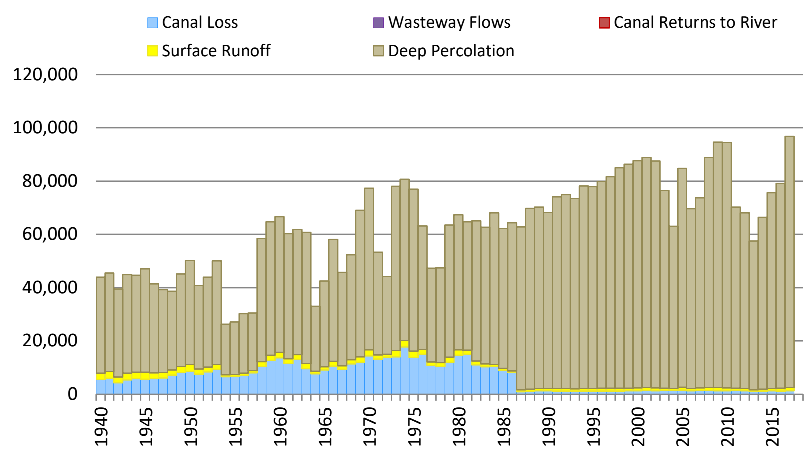
Annual Farm Deliveries (acre-feet)



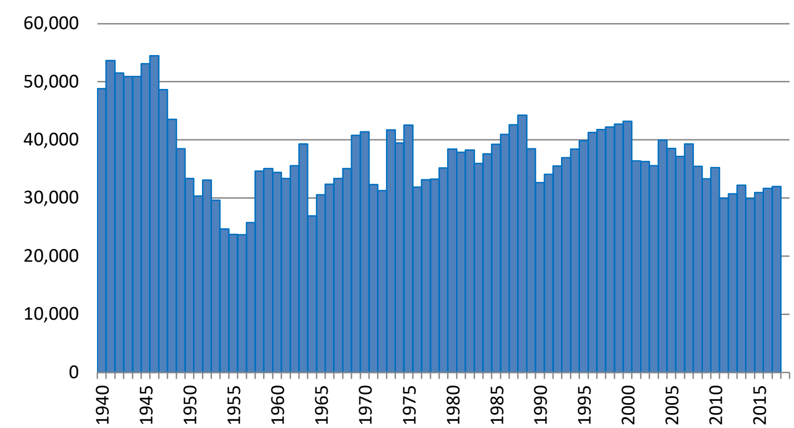
Annual Consumptive Use (acre-feet)



Annual Losses (acre-feet)



Irrigated Acres



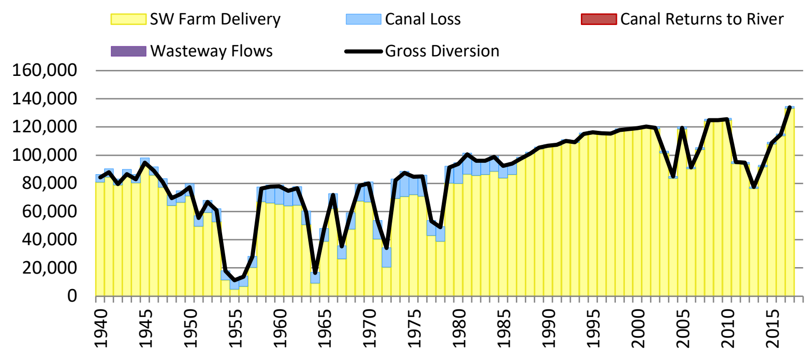
*Note: Different Scales

Model Version: LRG Model v116 Operational Run 1 - Historical Base Run.

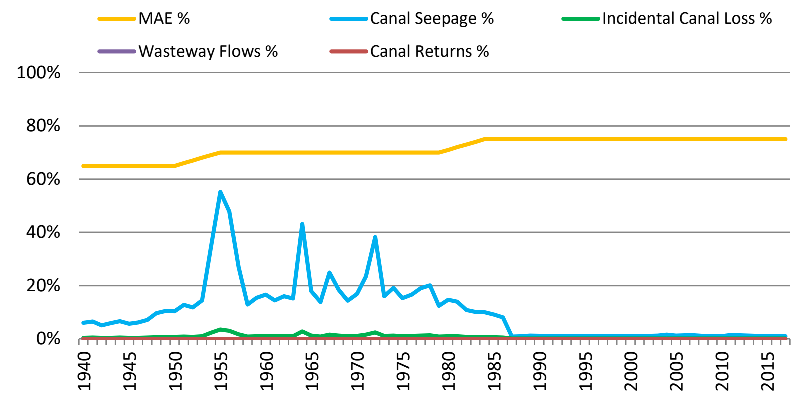
Figure 29-6

Annual Canal and Farm Water Budget Summary
Historical Base Run (Run 1)
Integrated LRG Model
1940-2017
JID Total

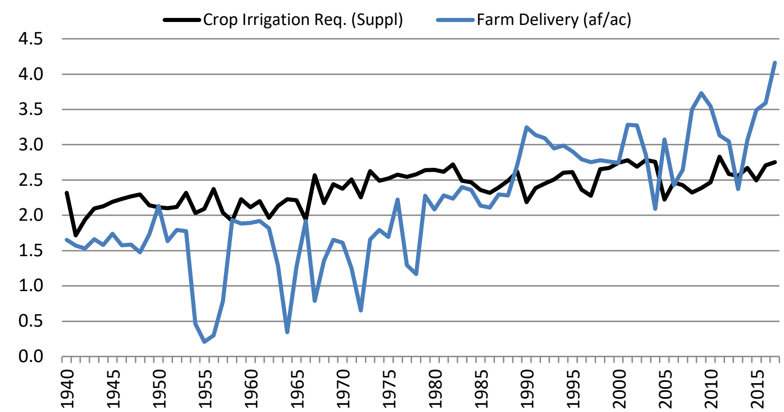
Annual Canal Diversions and Farm Deliveries (acre-feet)



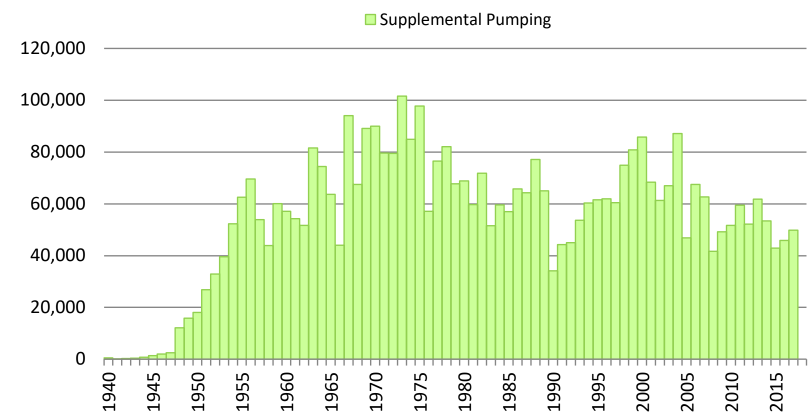
Maximum Application Efficiency and Loss Percentages



Annual Weighted Crop Irrigation Requirement (feet)



Annual Pumping (acre-feet)



Model Version: LRG Model v116 Operational Run 1 - Historical Base Run.

<u>**Notes:**</u>

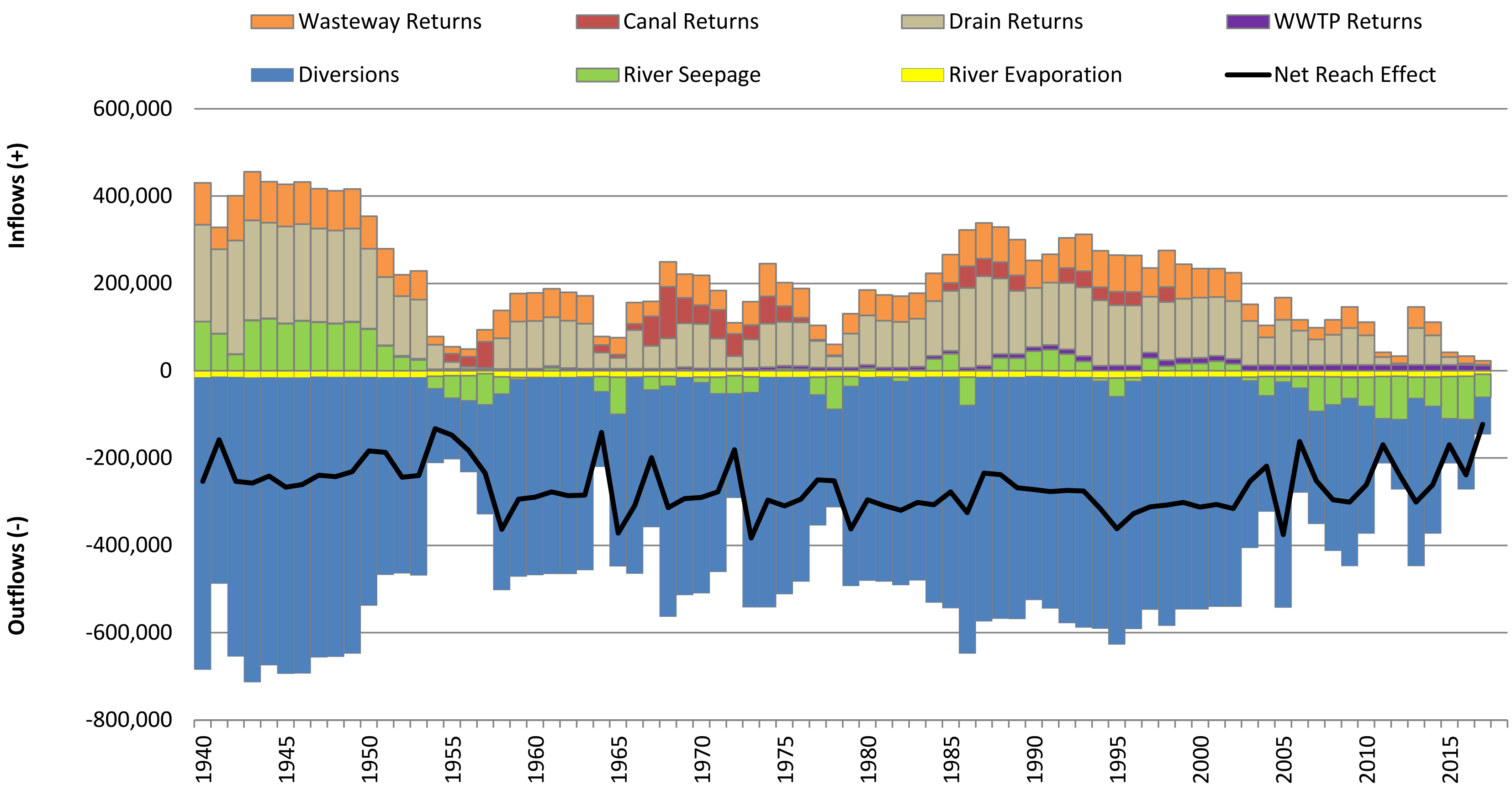
(1) Gross Canal Diversions includes the sum of Acequia Madre diversions, lower river diversions, and WWTP flows into canals.
(2) Loss percentages divided by diversions.
(3) Crop Irrigation Requirement ("CIR") is the total crop consumptive use (a.k.a. consumptive use of applied water) minus effective precipitation.

Figure 29-7

Annual River Budget Summary
Historical Base Run (Run 1)
Integrated LRG Model

1940 - 2017 (Acre-Feet)

Total Rincon-Mesilla (Below Caballo to El Paso)

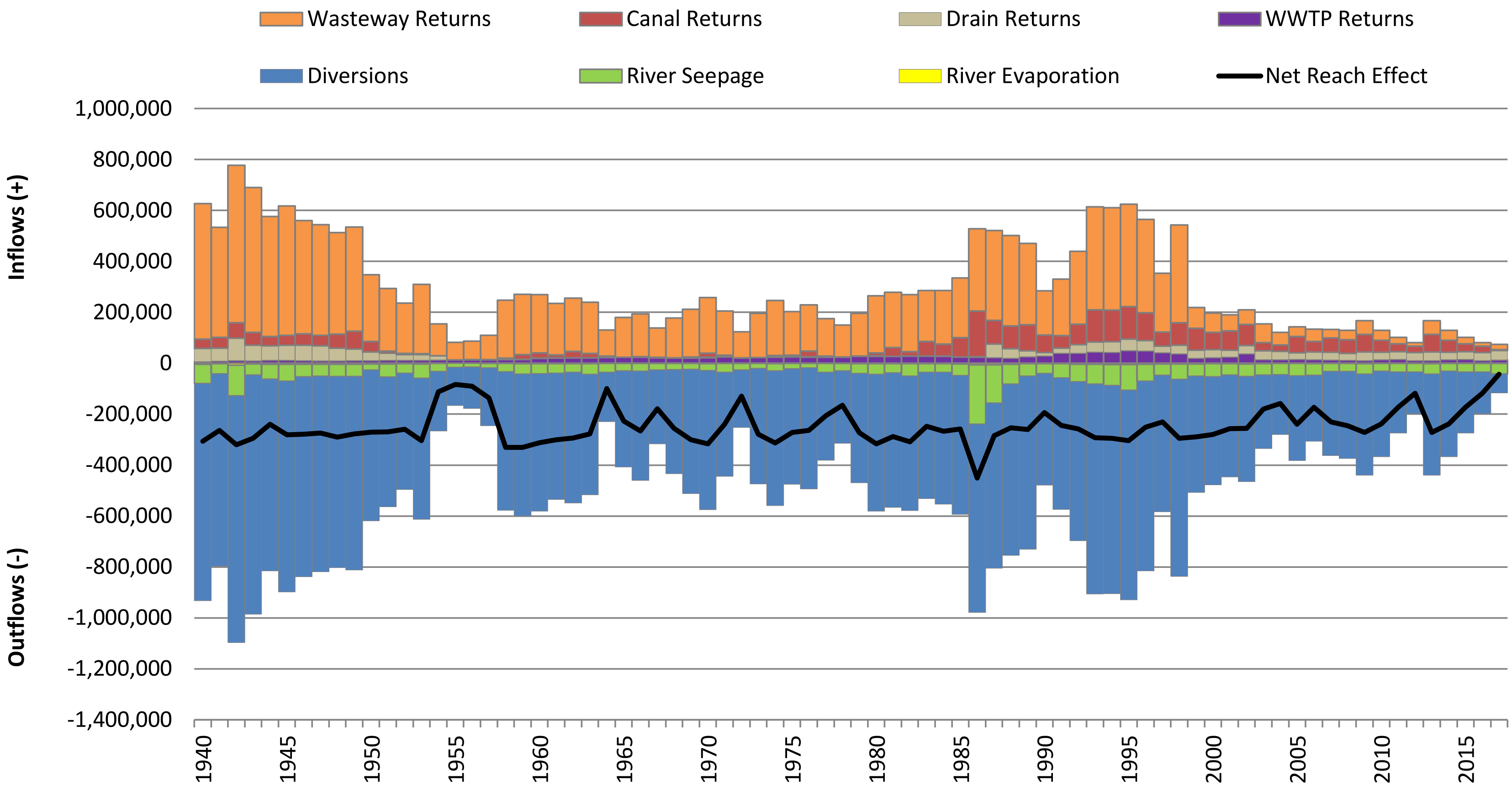


Note:
Net Reach Effect is the change in streamflow through the stream reach, equal to total inflows minus total outflows.
River inflows and outflows not shown on graph.
Model Version: LRG Model v116 Operational Run 1 - Historical Base Run.

Figure 29-8

Annual River Budget Summary
Historical Base Run (Run 1)
Integrated LRG Model
1940 - 2017 (Acre-Feet)

Total El Paso Valley (El Paso to Fort Quitman)



Notes:
Net Reach Effect is the change in streamflow through the stream reach, equal to total inflows minus total outflows.
River inflows and outflows not shown on graph.
Model Version: LRG Model v116 Operational Run 1 - Historical Base Run.

Figure 29-9

Annual Rio Grande Point Flows
Historical Base Run (Run 1)
Integrated LRG Model
1940-2017 (acre-feet)

*Note Different Scales
Model Version: LRG Model v116 Operational Run 1 - Historical Base Run.

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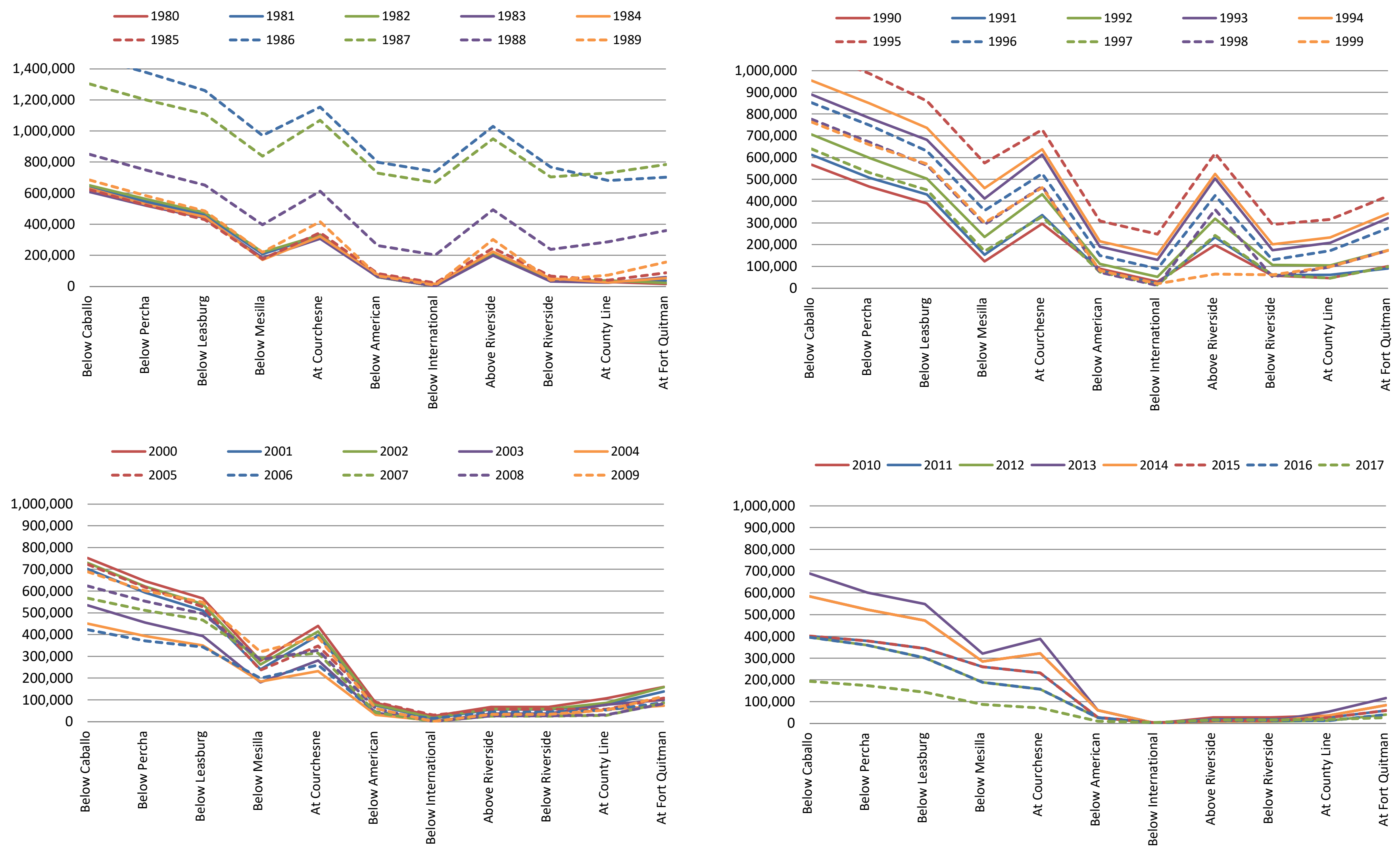
Figure 29-9

Annual Rio Grande Point Flows
Historical Base Run (Run 1)
Integrated LRG Model
1940-2017 (acre-feet)



*Note Different Scales
Model Version: LRG Model v116 Operational Run 1 - Historical Base Run.

Figure 29-10
Monthly Average Rio Grande Flows
Integrated LRG Model - Historical Base Run (Run 1)
1940 - 2017 (cfs)

Flow Legend (CFS)

	From	To
	0	10
	10	100
	100	200
	200	500
	500	Max

Year	Month	Below Caballo	Below Percha Dam	Below Leasburg Dam	Below Mesilla Dam	At Courchesne	Below American Dam	Below Intern'l Dam	Below Riverside Dam	At County Line	At Fort Quitman
1940	Jan	2	115	115	174	333	0	0	0	209	397
	Feb	221	271	271	278	386	0	0	91	242	385
	Mar	2264	1989	1641	771	917	148	0	196	294	307
	Apr	2017	1826	1358	568	1056	210	0	222	318	283
	May	1633	1486	1162	395	945	203	0	193	300	270
	Jun	1534	1405	1101	383	935	210	0	185	295	231
	Jul	1736	1609	1241	475	1015	203	0	209	331	227
	Aug	1592	1479	1061	322	906	15	0	234	374	265
	Sep	1436	1333	1026	304	881	0	0	234	388	304
	Oct	793	717	485	71	652	0	0	169	333	301
	Nov	57	241	241	310	692	67	67	229	480	554
	Dec	1	130	130	178	412	0	0	0	260	558
1941	Jan	2	92	92	128	304	0	0	0	212	426
	Feb	131	181	181	192	321	0	0	0	198	394
	Mar	1550	1280	1035	592	683	166	0	0	146	224
	Apr	1435	1289	1022	444	762	210	0	0	142	147
	May	1240	1110	835	257	664	149	0	0	132	122
	Jun	1433	1324	1014	362	788	210	0	0	139	93
	Jul	1265	1178	903	336	799	203	0	0	139	69
	Aug	1394	1264	941	265	735	50	0	0	151	75
	Sep	95	198	152	181	631	140	140	136	260	165
	Oct	795	720	489	11	398	0	0	0	173	162
	Nov	95	241	241	289	624	0	0	159	403	513
	Dec	704	766	766	742	863	239	239	401	610	838
1942	Jan	1152	1184	1184	1133	1198	573	573	732	910	1132
	Feb	1157	1186	1186	1141	1225	100	100	491	847	1183
	Mar	2296	2063	1657	881	1090	184	0	78	272	450
	Apr	3892	3680	3336	2637	2976	2315	2105	2124	2163	1922
	May	9526	9255	8903	7954	8076	7328	7124	7146	7040	6697
	Jun	6349	6206	5879	5201	5727	4965	4755	4846	4856	4909
	Jul	1327	1311	876	241	1115	182	0	134	414	743
	Aug	932	884	558	0	714	148	148	182	414	381
	Sep	1326	1243	843	139	755	0	0	48	291	285
	Oct	625	573	307	0	616	167	167	193	407	363
	Nov	243	408	408	462	816	191	191	348	629	815
	Dec	260	369	369	400	615	0	0	164	444	750
1943	Jan	79	169	169	206	399	0	0	0	270	563
	Feb	580	611	611	588	678	0	0	0	416	689
	Mar	2018	1774	1380	695	870	188	0	52	227	316
	Apr	1696	1529	1134	411	906	210	0	50	224	243
	May	1572	1436	1049	301	856	203	0	47	208	202
	Jun	1385	1271	918	284	844	210	0	44	217	174
	Jul	2036	1906	1436	677	1169	178	0	75	264	179
	Aug	1866	1758	1258	537	1130	0	0	107	341	240
	Sep	1182	1103	680	0	675	12	12	66	273	205
	Oct	1049	969	709	0	630	240	240	262	439	378
	Nov	202	376	376	446	867	242	242	402	648	787
	Dec	95	215	215	266	520	0	0	68	344	702
1944	Jan	5	101	101	144	341	0	0	0	234	495
	Feb	355	393	393	386	494	0	0	211	368	503
	Mar	1492	1244	968	370	553	185	0	77	200	272
	Apr	1707	1517	1125	322	757	210	0	120	232	236
	May	1328	1185	868	243	761	203	0	125	224	208
	Jun	1632	1491	1111	345	857	210	0	150	265	209
	Jul	1568	1444	1061	309	876	181	0	167	284	195
	Aug	1441	1329	955	218	808	0	0	202	326	228
	Sep	1389	1283	896	166	764	0	0	192	320	249
	Oct	912	828	524	0	606	30	30	171	323	296
	Nov	5	198	198	281	685	60	60	224	470	524
	Dec	132	243	243	280	499	0	0	48	312	624

Figure 29-10
Monthly Average Rio Grande Flows
Integrated LRG Model - Historical Base Run (Run 1)
1940 - 2017 (cfs)

Flow Legend (CFS)

	0	10
	10	100
	100	200
	200	500
	500	Max

Year	Month	Below Caballo	Below Percha Dam	Below Leasburg Dam	Below Mesilla Dam	At Courchesne	Below American Dam	Below Intern'l Dam	Below Riverside Dam	At County Line	At Fort Quitman
1945	Jan	11	103	103	142	326	0	0	0	219	456
	Feb	413	445	445	430	523	0	0	240	386	506
	Mar	2021	1755	1372	605	775	169	0	143	265	334
	Apr	1718	1536	1176	438	915	210	0	169	283	277
	May	1485	1340	1004	327	847	203	0	156	250	221
	Jun	1688	1549	1138	375	904	210	0	172	272	200
	Jul	1551	1430	1079	330	891	197	0	186	258	164
	Aug	1624	1507	1085	343	921	0	0	235	361	242
	Sep	1597	1486	1017	292	872	0	0	248	326	243
	Oct	837	761	577	0	631	104	104	226	383	342
	Nov	160	335	335	400	782	157	157	315	542	663
	Dec	310	415	415	439	646	21	21	192	444	741
1946	Jan	4	106	106	150	349	0	0	0	238	498
	Feb	328	369	369	363	474	0	0	194	335	498
	Mar	1746	1488	1228	645	786	179	0	147	251	305
	Apr	1710	1523	1157	360	787	210	0	161	198	227
	May	1540	1391	1049	326	840	203	0	166	199	181
	Jun	1664	1525	1138	372	905	210	0	177	229	176
	Jul	1833	1701	1204	460	997	187	0	215	257	173
	Aug	1500	1391	987	261	861	0	0	231	296	204
	Sep	1314	1214	895	168	759	0	0	189	299	223
	Oct	1110	1018	725	0	633	143	143	255	358	327
	Nov	126	309	309	385	799	174	174	265	473	637
	Dec	97	217	217	263	504	0	0	21	260	652
1947	Jan	10	105	105	145	336	0	0	0	199	480
	Feb	217	263	263	268	391	0	0	111	271	439
	Mar	1465	1215	999	503	639	146	0	97	199	253
	Apr	1667	1477	1162	443	804	210	0	120	217	224
	May	1329	1186	909	324	795	203	0	132	187	180
	Jun	1481	1346	1029	355	826	210	0	132	178	141
	Jul	1768	1634	1228	457	964	203	0	193	190	125
	Aug	1446	1336	991	249	824	17	0	200	248	169
	Sep	1595	1481	999	269	840	0	0	210	294	239
	Oct	1155	1064	712	0	639	11	11	152	294	272
	Nov	2	201	201	297	719	94	94	237	472	547
	Dec	2	131	131	188	436	0	0	0	241	617
1948	Jan	2	93	93	135	319	0	0	0	181	451
	Feb	2	70	70	101	252	0	0	0	119	366
	Mar	1493	1235	1060	480	622	136	0	95	162	193
	Apr	1470	1282	1023	417	778	210	0	133	146	170
	May	1329	1179	912	335	759	203	0	120	118	162
	Jun	1570	1427	1093	377	838	210	0	131	140	147
	Jul	1802	1667	1291	513	1020	203	0	189	170	118
	Aug	1716	1595	1095	359	915	27	0	226	221	159
	Sep	1476	1369	900	184	781	0	0	198	215	147
	Oct	1129	1038	709	0	632	122	122	225	269	212
	Nov	119	304	304	388	797	172	172	336	517	693
	Dec	85	207	207	258	499	0	0	44	289	624
1949	Jan	3	100	100	144	341	0	0	0	228	470
	Feb	2	74	74	107	266	0	0	0	172	381
	Mar	1724	1458	1276	431	619	124	0	96	138	209
	Apr	1354	1175	893	269	718	198	0	112	76	168
	May	1181	1037	785	266	711	169	0	108	101	173
	Jun	1475	1334	1040	416	842	210	0	127	103	147
	Jul	1736	1599	1234	459	948	203	0	171	138	101
	Aug	1816	1690	1203	456	993	84	0	223	216	149
	Sep	1336	1235	928	197	797	0	0	184	207	216
	Oct	1088	996	675	0	626	101	101	204	280	277
	Nov	101	283	283	360	768	143	143	309	537	643
	Dec	39	162	162	213	454	0	0	1	242	576

Figure 29-10
Monthly Average Rio Grande Flows
Integrated LRG Model - Historical Base Run (Run 1)
1940 - 2017 (cfs)

Flow Legend (CFS)

	0	10
	10	100
	100	200
	200	500
	500	Max

Year	Month	Below Caballo	Below Percha Dam	Below Leasburg Dam	Below Mesilla Dam	At Courchesne	Below American Dam	Below Intern'l Dam	Below Riverside Dam	At County Line	At Fort Quitman
1950	Jan	9	100	100	137	318	0	0	0	215	417
	Feb	0	69	69	97	246	58	58	113	177	304
	Mar	1157	988	838	591	661	138	0	87	121	181
	Apr	1293	1088	859	323	591	210	0	0	13	130
	May	1460	1289	929	260	637	191	0	0	13	112
	Jun	1776	1619	1119	349	810	210	0	28	25	63
	Jul	1628	1495	995	261	804	203	0	43	28	69
	Aug	1479	1361	861	150	732	37	0	102	58	16
	Sep	603	583	377	0	562	20	20	70	36	52
	Oct	14	166	144	128	469	37	37	69	96	107
	Nov	0	97	97	144	325	200	200	236	293	236
	Dec	0	70	70	106	253	128	128	206	224	257
1951	Jan	0	55	55	83	216	29	29	170	226	208
	Feb	0	46	46	67	189	2	2	56	108	201
	Mar	1587	1326	1057	615	680	123	0	120	161	161
	Apr	1368	1167	893	201	549	184	0	21	55	100
	May	1422	1253	877	168	587	175	0	13	84	79
	Jun	1689	1533	1033	266	747	210	0	48	121	78
	Jul	1637	1499	999	262	776	125	0	88	149	83
	Aug	487	534	390	150	647	12	0	81	124	59
	Sep	312	402	384	327	575	0	0	53	100	42
	Oct	293	333	333	290	397	0	0	27	94	32
	Nov	0	51	51	84	196	71	71	109	155	91
	Dec	0	40	40	63	170	45	45	126	151	148
1952	Jan	0	36	36	53	156	0	0	110	134	194
	Feb	0	33	33	44	140	0	0	8	81	175
	Mar	1302	1146	866	475	514	62	0	72	135	142
	Apr	1052	916	639	140	372	38	0	20	84	106
	May	839	746	553	144	411	49	0	14	73	62
	Jun	968	906	736	401	606	144	0	43	70	41
	Jul	2027	1767	1267	447	684	203	0	54	51	24
	Aug	1748	1549	1049	292	728	203	0	60	31	10
	Sep	1192	1096	753	290	706	210	0	53	7	6
	Oct	61	172	135	123	431	80	0	32	47	4
	Nov	0	70	70	114	247	122	122	156	163	71
	Dec	0	52	52	85	193	68	68	145	149	79
1953	Jan	0	44	44	68	171	0	0	123	136	134
	Feb	0	38	38	56	152	0	0	17	78	133
	Mar	1716	1439	1151	675	713	84	0	125	176	137
	Apr	1435	1228	954	260	561	135	0	17	57	89
	May	1544	1368	972	208	590	159	0	14	88	68
	Jun	1793	1631	1131	363	793	210	0	51	131	74
	Jul	1535	1398	1020	355	842	173	0	77	132	61
	Aug	907	914	722	404	799	79	0	105	153	72
	Sep	486	553	529	457	635	0	0	73	120	45
	Oct	487	494	494	430	453	0	0	36	105	31
	Nov	0	33	33	65	134	9	9	49	115	50
	Dec	0	26	26	46	120	0	0	77	112	62
1954	Jan	0	27	27	40	115	0	0	70	109	102
	Feb	0	27	27	35	106	0	0	0	75	99
	Mar	1225	1069	797	417	443	0	0	66	127	130
	Apr	1114	972	720	261	409	31	0	20	89	94
	May	626	598	513	317	458	31	0	17	101	55
	Jun	440	408	337	194	279	32	0	0	85	40
	Jul	902	797	651	369	386	69	0	0	60	16
	Aug	204	175	110	33	94	18	0	2	16	2
	Sep	44	31	12	0	33	33	33	48	26	1
	Oct	1	7	5	3	18	18	18	33	14	0
	Nov	0	6	6	5	16	0	0	0	0	0
	Dec	0	5	5	4	18	0	0	0	0	0

Figure 29-10
Monthly Average Rio Grande Flows
Integrated LRG Model - Historical Base Run (Run 1)
1940 - 2017 (cfs)

Flow Legend (CFS)

	From	To
	0	10
	10	100
	100	200
	200	500
	500	Max

Year	Month	Below Caballo	Below Percha Dam	Below Leasburg Dam	Below Mesilla Dam	At Courchesne	Below American Dam	Below Intern'l Dam	Below Riverside Dam	At County Line	At Fort Quitman
1955	Jan	0	5	5	7	23	0	0	0	0	0
	Feb	0	5	5	5	25	0	0	0	1	0
	Mar	1179	1034	828	508	442	0	0	22	31	0
	Apr	468	398	283	0	212	27	27	0	28	0
	May	577	487	396	159	188	0	0	0	23	0
	Jun	264	212	154	0	79	1	1	0	4	0
	Jul	567	480	392	132	181	31	0	0	6	0
	Aug	500	428	337	101	165	32	0	0	7	1
	Sep	200	163	139	65	49	0	0	0	2	1
	Oct	37	25	17	0	4	3	3	19	6	0
	Nov	0	2	2	3	3	0	0	0	1	0
	Dec	0	2	2	3	3	0	0	0	0	0
1956	Jan	0	2	2	3	3	0	0	0	1	0
	Feb	0	2	2	3	3	0	0	0	1	0
	Mar	1416	1233	972	581	485	0	0	48	45	2
	Apr	735	631	507	60	245	0	0	0	15	0
	May	884	770	663	378	325	8	0	0	18	0
	Jun	564	477	386	110	189	44	0	0	9	0
	Jul	622	529	426	122	210	42	0	0	10	1
	Aug	165	107	6	0	21	18	0	0	4	1
	Sep	60	29	0	0	7	0	0	0	2	1
	Oct	43	23	1	0	3	0	0	0	1	0
	Nov	0	1	1	2	3	0	0	0	1	0
	Dec	0	1	1	2	3	0	0	0	1	0
1957	Jan	0	2	2	3	3	0	0	0	1	0
	Feb	0	2	2	3	3	0	0	0	1	0
	Mar	0	3	3	3	4	4	4	20	7	0
	Apr	0	3	3	3	4	4	4	18	4	0
	May	0	2	2	3	4	4	4	19	7	0
	Jun	0	2	2	3	4	4	4	21	5	0
	Jul	1564	1340	882	341	541	0	0	20	25	1
	Aug	2278	1925	1425	688	728	203	0	33	30	0
	Sep	1461	1272	1000	475	601	73	0	38	33	0
	Oct	771	689	601	393	310	0	0	2	18	0
	Nov	0	24	24	29	15	0	0	0	0	0
	Dec	0	18	18	13	16	0	0	0	1	0
1958	Jan	0	19	19	13	8	0	0	0	1	0
	Feb	0	19	19	12	7	0	0	0	1	0
	Mar	1666	1415	1175	743	642	105	0	60	59	7
	Apr	1916	1659	1398	677	648	179	0	10	32	0
	May	1998	1784	1416	631	678	203	0	9	22	0
	Jun	2072	1885	1385	555	771	210	0	36	36	0
	Jul	2102	1936	1436	624	890	203	0	52	51	1
	Aug	1101	1071	912	524	774	88	0	50	20	1
	Sep	364	449	423	361	496	0	0	32	0	11
	Oct	291	353	353	321	381	0	0	19	0	31
	Nov	0	57	57	79	128	3	3	37	0	11
	Dec	0	41	41	52	99	0	0	52	9	29
1959	Jan	0	36	36	42	90	0	0	39	6	12
	Feb	0	32	32	35	81	0	0	0	1	12
	Mar	1750	1465	1177	685	660	123	0	83	63	41
	Apr	1742	1516	1225	495	650	187	0	12	31	14
	May	1761	1577	1182	425	687	203	0	15	42	15
	Jun	1857	1694	1194	415	773	210	0	41	51	16
	Jul	1852	1706	1206	451	852	203	0	57	60	4
	Aug	651	684	582	361	724	62	0	50	28	47
	Sep	487	550	532	470	617	0	0	46	44	21
	Oct	518	519	519	464	450	0	0	32	36	46
	Nov	0	30	30	63	105	0	0	15	28	54
	Dec	0	22	22	41	90	0	0	47	42	48

Figure 29-10
Monthly Average Rio Grande Flows
Integrated LRG Model - Historical Base Run (Run 1)
1940 - 2017 (cfs)

Flow Legend (CFS)

	0	10
	10	100
	100	200
	200	500
	500	Max

	Month	Below Caballo	Below Percha Dam	Below Leasburg Dam	Below Mesilla Dam	At Courchesne	Below American Dam	Below Intern'l Dam	Below Riverside Dam	At County Line	At Fort Quitman
1960	Jan	0	23	23	36	90	0	0	51	54	17
	Feb	0	24	24	31	84	0	0	0	25	37
	Mar	1768	1482	1206	732	703	130	0	101	93	56
	Apr	1800	1564	1265	501	669	210	0	12	23	23
	May	1755	1567	1162	379	663	203	0	12	25	30
	Jun	1838	1673	1173	398	769	210	0	42	29	25
	Jul	1713	1560	1060	316	733	203	0	43	25	39
	Aug	525	579	472	286	675	33	0	47	14	36
	Sep	482	527	511	461	569	0	0	40	29	42
	Oct	447	449	449	403	401	0	0	28	85	51
	Nov	0	29	29	62	109	0	0	26	86	42
	Dec	0	23	23	43	97	0	0	56	52	28
1961	Jan	0	24	24	38	96	0	0	56	57	42
	Feb	0	24	24	32	87	0	0	0	33	36
	Mar	1563	1291	1021	570	568	114	0	80	80	29
	Apr	1703	1465	1180	442	615	203	0	9	14	18
	May	1769	1577	1158	360	646	201	0	11	28	30
	Jun	1767	1602	1153	377	753	210	0	38	46	13
	Jul	1713	1567	1067	317	746	203	0	47	43	1
	Aug	489	529	405	194	595	57	0	46	39	1
	Sep	373	433	414	370	509	0	0	38	21	1
	Oct	376	395	395	353	379	0	0	30	44	2
	Nov	0	28	28	60	99	0	0	19	7	31
	Dec	0	25	25	45	98	0	0	60	69	38
1962	Jan	0	24	24	38	95	0	0	58	62	27
	Feb	0	25	25	33	87	0	0	0	32	39
	Mar	1670	1397	1120	654	637	135	0	93	94	32
	Apr	1718	1481	1198	471	644	210	0	8	14	37
	May	1710	1521	1123	356	645	203	0	9	28	22
	Jun	1821	1653	1153	375	747	210	0	40	38	7
	Jul	1763	1615	1115	365	787	203	0	44	25	50
	Aug	679	712	584	353	736	28	0	70	52	1
	Sep	327	372	352	319	431	0	0	32	36	57
	Oct	306	319	319	280	309	0	0	20	31	49
	Nov	0	23	23	54	93	0	0	13	25	86
	Dec	0	16	16	34	77	0	0	39	35	54
1963	Jan	0	19	19	31	82	0	0	41	52	45
	Feb	0	20	20	28	77	0	0	0	30	49
	Mar	1618	1340	1060	591	580	153	0	74	73	32
	Apr	1668	1428	1155	452	600	210	0	8	16	51
	May	1684	1492	1099	333	611	203	0	8	46	13
	Jun	1802	1633	1133	351	710	210	0	37	70	10
	Jul	1619	1473	985	259	681	26	0	72	98	25
	Aug	518	565	463	267	595	11	0	53	67	12
	Sep	343	397	380	336	453	0	0	35	46	3
	Oct	370	376	376	336	335	0	0	22	23	3
	Nov	0	31	31	63	109	0	0	31	42	48
	Dec	0	25	25	45	98	0	0	61	52	70
1964	Jan	0	25	25	38	90	0	0	55	74	43
	Feb	0	25	25	33	82	0	0	0	48	47
	Mar	1053	906	655	305	314	0	0	39	76	30
	Apr	912	793	588	58	311	13	0	8	71	18
	May	647	605	509	294	382	30	0	8	85	22
	Jun	337	317	273	102	218	20	0	0	78	19
	Jul	538	466	378	113	225	45	0	0	49	6
	Aug	478	408	325	111	165	28	0	0	19	1
	Sep	163	130	110	46	29	0	0	15	6	1
	Oct	24	17	10	0	4	1	1	31	13	0
	Nov	0	2	2	4	3	0	0	0	1	0
	Dec	0	2	2	3	3	0	0	0	1	0

Figure 29-10
Monthly Average Rio Grande Flows
Integrated LRG Model - Historical Base Run (Run 1)
1940 - 2017 (cfs)

Flow Legend (CFS)

	0	10
	10	100
	100	200
	200	500
	500	Max

Year	Month	Below Caballo	Below Percha Dam	Below Leasburg Dam	Below Mesilla Dam	At Courchesne	Below American Dam	Below Intern'l Dam	Below Riverside Dam	At County Line	At Fort Quitman
1965	Jan	0	2	2	4	3	0	0	0	1	0
	Feb	0	2	2	4	3	0	0	0	1	0
	Mar	495	429	356	223	161	0	0	0	5	0
	Apr	673	567	443	93	202	0	0	0	9	0
	May	897	765	647	350	282	0	0	0	16	0
	Jun	1418	1229	1027	572	487	37	0	13	20	1
	Jul	2447	2110	1648	835	781	203	0	40	43	1
	Aug	2401	2085	1585	727	746	203	0	33	34	1
	Sep	1197	1075	842	419	575	160	0	26	0	0
	Oct	335	380	349	290	369	0	0	25	46	2
	Nov	0	45	45	77	97	0	0	20	35	0
	Dec	0	22	22	39	41	0	0	10	20	0
1966	Jan	0	23	23	33	43	0	0	12	23	0
	Feb	0	23	23	28	44	0	0	0	22	0
	Mar	1427	1265	942	551	539	103	0	49	48	1
	Apr	1464	1291	982	374	533	174	0	3	6	0
	May	1646	1429	1086	411	577	199	0	5	38	0
	Jun	1652	1433	1031	313	546	210	0	20	4	0
	Jul	1866	1675	1175	397	685	178	0	36	3	1
	Aug	1041	951	662	151	520	62	0	32	0	1
	Sep	189	294	257	214	432	0	0	27	3	1
	Oct	205	255	254	243	307	0	0	20	27	0
	Nov	0	41	41	74	111	0	0	37	49	19
	Dec	0	30	30	53	93	0	0	60	57	20
1967	Jan	0	29	29	45	89	0	0	56	56	17
	Feb	0	27	27	38	79	0	0	0	31	21
	Mar	1451	1287	891	588	565	137	0	57	54	4
	Apr	1395	1220	768	256	486	116	0	4	22	1
	May	1136	986	596	72	407	32	0	0	33	0
	Jun	518	522	400	114	411	11	0	17	32	0
	Jul	549	526	454	206	376	17	0	0	19	1
	Aug	949	851	656	335	448	70	0	0	1	1
	Sep	183	147	69	0	82	0	0	0	0	1
	Oct	77	56	28	0	26	26	26	50	19	0
	Nov	0	5	5	9	11	0	0	0	0	0
	Dec	0	4	4	8	11	0	0	0	0	0
1968	Jan	0	6	6	8	12	0	0	0	0	0
	Feb	0	9	9	9	17	0	0	0	0	0
	Mar	1504	1293	951	423	514	134	0	51	30	0
	Apr	1498	1299	799	216	497	137	0	12	0	1
	May	1296	1105	605	0	498	117	40	50	34	1
	Jun	1219	1125	767	217	502	61	0	35	19	1
	Jul	1612	1422	930	369	543	142	0	26	0	0
	Aug	1512	1377	877	393	659	150	0	33	1	1
	Sep	372	426	276	224	464	0	0	32	11	1
	Oct	360	376	337	256	323	0	0	24	15	0
	Nov	0	38	38	70	107	0	0	25	24	0
	Dec	0	31	31	53	93	0	0	53	53	11
1969	Jan	0	29	29	44	83	0	0	44	15	0
	Feb	0	27	27	37	74	0	0	0	22	18
	Mar	1539	1357	919	561	592	155	0	65	44	1
	Apr	1489	1310	810	253	551	139	0	14	18	0
	May	1474	1265	767	118	458	57	0	11	7	0
	Jun	1752	1534	1034	378	644	154	0	32	0	1
	Jul	1934	1736	1236	497	772	203	0	36	0	1
	Aug	1181	1137	855	426	775	203	0	34	0	1
	Sep	218	318	286	217	499	77	0	22	0	1
	Oct	249	287	286	275	326	0	0	21	0	0
	Nov	0	45	45	82	140	15	15	56	51	12
	Dec	0	34	34	60	117	0	0	82	17	47

Figure 29-10
Monthly Average Rio Grande Flows
Integrated LRG Model - Historical Base Run (Run 1)
1940 - 2017 (cfs)

Flow Legend (CFS)

	0	10
	10	100
	100	200
	200	500
	500	Max

Year	Month	Below Caballo	Below Percha Dam	Below Leasburg Dam	Below Mesilla Dam	At Courchesne	Below American Dam	Below Intern'l Dam	Below Riverside Dam	At County Line	At Fort Quitman
1970	Jan	0	32	32	51	110	0	0	73	26	27
	Feb	0	29	29	43	96	0	0	0	25	42
	Mar	1642	1371	1007	585	624	134	0	82	61	36
	Apr	1702	1498	1114	395	668	210	0	9	7	1
	May	1765	1593	1093	351	695	203	0	9	30	4
	Jun	1698	1545	1045	343	740	203	0	35	25	1
	Jul	1654	1501	1001	337	773	146	0	41	17	1
	Aug	709	739	602	404	711	93	0	41	23	1
	Sep	636	637	603	464	548	0	0	37	4	29
	Oct	495	477	477	423	395	0	0	24	20	42
	Nov	0	17	17	51	84	0	0	5	22	65
	Dec	0	16	16	35	78	0	0	46	42	51
1971	Jan	0	19	19	31	78	0	0	47	46	44
	Feb	0	20	20	28	72	0	0	0	30	43
	Mar	1519	1337	958	551	553	132	0	79	59	23
	Apr	1640	1449	968	350	618	210	0	23	21	11
	May	1477	1247	747	138	502	112	0	15	27	1
	Jun	1570	1347	847	188	511	76	0	40	39	0
	Jul	676	660	398	143	475	28	0	46	21	1
	Aug	710	701	582	396	493	15	0	55	41	2
	Sep	628	598	570	450	422	0	0	53	38	1
	Oct	430	399	399	333	283	0	0	31	23	0
	Nov	0	10	10	29	45	0	0	0	22	0
	Dec	0	7	7	14	26	0	0	1	16	0
1972	Jan	0	9	9	13	32	0	0	1	16	0
	Feb	0	12	12	13	36	0	0	0	20	0
	Mar	1491	1304	830	438	480	23	0	91	89	19
	Apr	1359	1192	722	218	485	73	0	23	37	0
	May	1171	1038	765	343	494	71	0	28	61	7
	Jun	668	633	530	302	412	14	0	45	68	12
	Jul	304	282	224	96	164	14	0	0	30	1
	Aug	145	119	105	59	46	24	0	13	0	0
	Sep	3	5	0	2	10	10	10	37	0	0
	Oct	1	3	1	1	4	4	4	30	2	0
	Nov	0	2	2	5	4	0	0	0	0	0
	Dec	0	2	2	4	3	0	0	0	0	0
1973	Jan	0	2	2	5	5	0	0	0	0	0
	Feb	0	3	3	5	5	0	0	0	0	0
	Mar	1487	1304	1041	625	546	154	0	63	46	1
	Apr	1705	1479	1149	538	547	142	0	20	6	1
	May	1793	1525	1104	360	524	111	0	18	7	1
	Jun	1905	1678	1178	388	591	150	0	37	0	1
	Jul	1763	1576	1077	325	631	203	0	32	0	1
	Aug	1594	1443	1058	413	728	203	0	40	0	1
	Sep	261	368	318	167	501	23	0	44	0	1
	Oct	382	406	397	344	363	0	0	35	0	0
	Nov	0	30	30	65	84	0	0	10	4	0
	Dec	0	21	21	42	63	0	0	33	1	0
1974	Jan	0	23	23	37	67	0	0	36	13	0
	Feb	0	23	23	32	63	0	0	0	7	0
	Mar	1932	1639	1323	769	767	176	0	133	89	22
	Apr	1867	1639	1245	510	723	210	0	26	20	1
	May	1855	1666	1167	420	744	203	0	19	33	1
	Jun	1802	1639	1139	409	785	210	0	45	33	5
	Jul	1425	1326	826	223	745	190	0	38	0	2
	Aug	862	831	542	105	577	0	0	37	0	1
	Sep	293	338	239	167	353	0	0	18	0	1
	Oct	132	176	158	140	236	0	0	27	0	16
	Nov	0	48	48	80	144	19	19	65	18	54
	Dec	0	29	29	51	92	0	0	58	45	30

Figure 29-10
Monthly Average Rio Grande Flows
Integrated LRG Model - Historical Base Run (Run 1)
1940 - 2017 (cfs)

Flow Legend (CFS)

	0	10
	10	100
	100	200
	200	500
	500	Max

Year	Month	Below Caballo	Below Percha Dam	Below Leasburg Dam	Below Mesilla Dam	At Courchesne	Below American Dam	Below Intern'l Dam	Below Riverside Dam	At County Line	At Fort Quitman
1975	Jan	0	28	28	45	94	0	0	60	36	31
	Feb	0	27	27	38	86	0	0	0	8	71
	Mar	1363	1203	909	512	517	166	0	65	38	2
	Apr	1493	1313	989	405	558	200	0	21	3	1
	May	1496	1274	897	168	457	70	0	12	5	0
	Jun	1627	1408	908	154	532	91	0	32	0	0
	Jul	1682	1488	988	258	649	203	0	26	0	1
	Aug	1545	1409	992	339	706	203	0	28	0	1
	Sep	156	254	181	92	441	55	0	25	0	0
	Oct	305	337	314	272	343	0	0	32	0	0
	Nov	0	38	38	76	120	0	0	47	33	0
	Dec	0	24	24	50	89	0	0	60	23	0
1976	Jan	0	24	24	44	92	0	0	62	25	1
	Feb	0	24	24	37	84	0	0	0	0	20
	Mar	1693	1422	1094	599	615	141	0	99	40	50
	Apr	1799	1558	1230	447	623	210	0	17	0	21
	May	1735	1544	1112	313	605	203	0	5	0	25
	Jun	1723	1556	1056	294	672	210	0	19	0	23
	Jul	1605	1458	958	229	646	203	0	19	0	21
	Aug	340	426	325	114	510	22	0	19	0	5
	Sep	354	404	396	276	396	0	0	21	0	33
	Oct	330	341	341	301	305	0	0	21	0	64
	Nov	0	32	32	67	105	0	0	28	12	78
	Dec	0	23	23	44	82	0	0	49	35	40
1977	Jan	0	23	23	38	82	0	0	56	53	25
	Feb	0	24	24	32	76	0	0	0	26	49
	Mar	1310	1156	873	475	460	140	0	67	57	6
	Apr	1484	1307	987	419	505	210	0	19	25	0
	May	1470	1256	883	202	392	86	0	11	26	0
	Jun	1392	1220	820	152	428	33	0	36	41	1
	Jul	368	419	339	212	442	12	0	40	36	1
	Aug	649	629	587	447	448	15	0	44	33	1
	Sep	495	467	467	370	330	0	0	36	21	0
	Oct	434	401	401	322	261	0	0	25	28	0
	Nov	0	8	8	28	34	0	0	0	27	0
	Dec	0	6	6	13	20	0	0	0	27	0
1978	Jan	0	8	8	12	25	0	0	0	22	0
	Feb	0	9	9	11	27	0	0	0	26	0
	Mar	1227	1062	770	383	342	0	0	62	77	16
	Apr	854	761	594	266	308	0	0	19	53	3
	May	834	751	639	366	348	35	0	17	59	8
	Jun	655	598	532	360	327	26	0	0	55	6
	Jul	1382	1233	1039	643	559	163	0	1	21	1
	Aug	1647	1459	1107	571	523	123	0	35	4	1
	Sep	280	268	225	141	191	0	0	0	0	0
	Oct	6	22	8	22	49	34	34	50	35	0
	Nov	0	11	11	25	28	0	0	0	1	0
	Dec	0	15	15	23	30	0	0	5	3	0
1979	Jan	0	17	17	20	28	0	0	4	17	0
	Feb	0	19	19	19	25	0	0	0	21	0
	Mar	0	19	19	17	24	24	24	57	48	3
	Apr	1165	997	863	479	400	0	0	2	0	0
	May	1589	1369	1172	566	512	96	0	46	19	0
	Jun	2253	1951	1565	680	682	210	0	49	30	1
	Jul	2046	1810	1352	514	710	203	0	52	0	1
	Aug	1898	1698	1213	417	690	203	0	55	0	1
	Sep	1553	1394	1126	361	699	210	0	56	10	1
	Oct	103	240	215	113	434	67	0	46	23	0
	Nov	0	106	106	145	261	136	136	184	161	67
	Dec	0	69	69	96	158	33	33	127	108	34

Figure 29-10
Monthly Average Rio Grande Flows
Integrated LRG Model - Historical Base Run (Run 1)
1940 - 2017 (cfs)

Flow Legend (CFS)

	0	10
	10	100
	100	200
	200	500
	500	Max

	Month	Below Caballo	Below Percha Dam	Below Leasburg Dam	Below Mesilla Dam	At Courchesne	Below American Dam	Below Intern'l Dam	Below Riverside Dam	At County Line	At Fort Quitman
1980	Jan	0	55	55	73	126	0	0	98	84	25
	Feb	0	44	44	57	104	0	0	0	24	0
	Mar	1627	1327	1098	572	580	137	0	38	59	8
	Apr	1755	1534	1253	576	721	210	0	50	45	0
	May	1765	1566	1207	457	725	203	0	45	55	4
	Jun	1929	1745	1279	495	791	210	0	52	49	2
	Jul	1909	1738	1238	479	844	203	0	63	58	11
	Aug	782	811	664	205	605	26	0	54	7	1
	Sep	239	332	318	210	413	0	0	37	2	22
	Oct	329	365	365	267	339	0	0	32	45	37
	Nov	0	42	42	70	132	7	7	57	35	58
	Dec	0	30	30	47	94	0	0	64	16	89
1981	Jan	0	28	28	39	86	0	0	57	41	52
	Feb	0	26	26	33	77	0	0	0	26	63
	Mar	1688	1376	1142	582	580	166	0	35	48	32
	Apr	1871	1616	1319	584	715	210	0	50	41	42
	May	1794	1590	1213	453	725	203	0	44	54	32
	Jun	1951	1764	1312	517	812	210	0	54	54	12
	Jul	1883	1713	1213	452	831	200	0	61	31	1
	Aug	555	609	492	98	514	0	0	45	1	48
	Sep	326	412	401	285	463	0	0	43	30	58
	Oct	360	388	388	283	342	0	0	35	54	79
	Nov	0	38	38	66	127	2	2	57	74	81
	Dec	0	22	22	36	76	0	0	51	10	98
1982	Jan	0	23	23	32	76	0	0	50	44	46
	Feb	0	23	23	28	71	0	0	0	34	67
	Mar	1725	1409	1172	603	595	165	0	42	45	27
	Apr	1890	1630	1336	597	713	210	0	60	57	35
	May	1799	1591	1225	464	714	203	0	47	65	40
	Jun	1920	1731	1270	472	763	210	0	47	63	16
	Jul	1881	1707	1213	447	808	201	0	55	63	6
	Aug	727	765	647	234	619	0	0	57	51	1
	Sep	337	421	410	291	477	0	0	41	21	0
	Oct	419	443	443	334	384	0	0	41	51	24
	Nov	0	39	39	68	128	3	3	60	85	40
	Dec	0	26	26	43	90	0	0	66	59	52
1983	Jan	0	26	26	37	87	0	0	63	60	64
	Feb	0	25	25	31	77	0	0	0	39	75
	Mar	1433	1142	931	433	444	110	0	25	25	75
	Apr	1532	1319	1065	438	559	188	0	33	18	95
	May	1705	1488	1150	401	645	203	0	29	42	77
	Jun	1862	1668	1244	436	718	210	0	35	62	59
	Jul	1791	1616	1159	387	759	203	0	43	32	66
	Aug	1073	1052	842	220	643	74	0	50	10	80
	Sep	306	412	392	251	523	0	0	41	32	65
	Oct	309	349	349	260	340	0	0	34	1	116
	Nov	0	49	49	77	149	24	24	76	14	140
	Dec	0	37	37	54	111	0	0	81	59	71
1984	Jan	0	32	32	44	98	0	0	70	70	12
	Feb	0	30	30	36	85	0	0	0	23	76
	Mar	1591	1282	1054	508	515	139	0	38	6	64
	Apr	1773	1520	1245	553	680	210	0	56	3	65
	May	1745	1536	1199	445	704	203	0	51	19	49
	Jun	1767	1582	1181	374	678	210	0	45	2	74
	Jul	1818	1643	1177	405	778	203	0	57	1	28
	Aug	1193	1087	739	0	481	33	10	52	0	61
	Sep	452	516	423	133	499	0	0	48	1	60
	Oct	9	133	125	96	340	58	58	87	36	124
	Nov	0	91	91	126	264	139	139	191	151	153
	Dec	0	61	61	86	175	50	50	148	93	121

Figure 29-10
Monthly Average Rio Grande Flows
Integrated LRG Model - Historical Base Run (Run 1)
1940 - 2017 (cfs)

Flow Legend (CFS)

	0	10
	10	100
	100	200
	200	500
	500	Max

	Month	Below Caballo	Below Percha Dam	Below Leasburg Dam	Below Mesilla Dam	At Courchesne	Below American Dam	Below Intern'l Dam	Below Riverside Dam	At County Line	At Fort Quitman
	Jan	0	51	51	70	154	0	0	122	68	108
	Feb	0	42	42	56	130	0	0	17	43	111
	Mar	1172	928	741	314	369	112	0	23	2	69
	Apr	1514	1306	1054	447	594	210	0	33	8	59
	May	1719	1502	1153	451	752	283	80	131	62	136
1985	Jun	1990	1792	1292	526	804	210	0	75	32	123
	Jul	1829	1654	1154	425	819	203	0	77	3	135
	Aug	1599	1441	941	269	703	50	0	83	5	107
	Sep	356	438	317	0	503	34	34	87	1	185
	Oct	78	188	164	95	374	0	0	53	29	133
	Nov	0	99	99	138	301	176	176	222	224	169
	Dec	0	71	71	103	205	80	80	172	171	116
	Jan	443	459	459	436	459	271	271	418	336	283
	Feb	2928	2863	2863	2701	2510	2322	2322	2358	2119	1931
	Mar	2360	2098	1687	1109	1338	719	557	620	503	577
	Apr	1716	1532	1078	416	851	210	0	47	48	236
	May	1704	1532	1083	404	826	203	0	27	13	282
1986	Jun	2364	2202	1702	986	1385	748	538	556	362	566
	Jul	2962	2795	2295	1565	1973	1280	1076	1106	878	973
	Aug	2471	2364	2050	1324	1859	1109	1109	1152	953	1025
	Sep	1122	1213	1145	933	1384	643	643	693	565	679
	Oct	2037	2088	2077	1912	2073	1542	1542	1496	1407	1422
	Nov	2297	2330	2330	2265	2322	2197	2197	2213	2142	1881
	Dec	2168	2202	2202	2146	2214	2089	2089	2143	2055	1862
	Jan	1318	1373	1373	1360	1494	1310	1310	1438	1386	1356
	Feb	2785	2776	2776	2670	2643	2459	2459	2492	2421	2368
	Mar	2408	2177	1830	1292	1598	1122	988	1041	1015	1289
	Apr	2094	1925	1497	815	1284	732	521	564	620	779
	May	3521	3313	2871	2117	2458	1877	1674	1694	1699	1648
1987	Jun	2907	2763	2263	1560	2041	1457	1247	1290	1297	1439
	Jul	3876	3688	3188	2392	2777	2039	1836	1877	1864	1833
	Aug	1202	1140	882	294	990	175	146	225	328	599
	Sep	332	452	381	173	701	0	0	44	171	329
	Oct	233	339	327	243	555	0	0	0	199	265
	Nov	0	96	96	146	317	196	196	236	324	353
	Dec	952	955	955	906	906	785	785	857	865	805
	Jan	1137	1146	1146	1095	1108	924	924	1054	1028	1056
	Feb	2274	2250	2250	2139	2076	1892	1892	1926	1831	1866
	Mar	1525	1296	904	335	712	142	0	69	35	575
	Apr	2129	1918	1474	775	1138	547	337	364	474	437
	May	1665	1498	1036	362	835	203	0	44	222	284
1988	Jun	1812	1648	1148	442	891	210	0	38	119	289
	Jul	1802	1646	1146	448	901	203	0	39	160	195
	Aug	1018	932	709	166	713	21	0	37	147	227
	Sep	446	551	497	320	727	0	0	40	194	221
	Oct	296	390	382	310	570	0	0	0	161	236
	Nov	0	98	98	143	309	188	188	232	249	324
	Dec	0	61	61	91	197	76	76	163	195	271
	Jan	0	49	49	73	173	0	0	136	198	211
	Feb	0	41	41	59	148	0	0	31	109	223
	Mar	1809	1512	1124	475	663	134	0	18	52	246
	Apr	1914	1681	1237	518	838	210	0	28	88	218
	May	1791	1601	1144	433	824	203	0	27	73	214
1989	Jun	2029	1849	1349	602	993	210	0	37	103	215
	Jul	1999	1833	1333	590	1005	203	0	41	72	182
	Aug	1086	1013	830	204	775	29	0	38	88	193
	Sep	410	506	454	263	646	0	0	28	66	237
	Oct	231	312	305	230	433	0	0	0	38	270
	Nov	0	67	67	104	221	100	100	146	151	217
	Dec	0	45	45	71	153	32	32	123	160	165

Figure 29-10
Monthly Average Rio Grande Flows
Integrated LRG Model - Historical Base Run (Run 1)
1940 - 2017 (cfs)

Flow Legend (CFS)

Color	From	To
(white)	0	10
(light green)	10	100
(teal)	100	200
(medium blue)	200	500
(dark blue)	500	Max

Year	Month	Below Caballo	Below Percha Dam	Below Leasburg Dam	Below Mesilla Dam	At Courchesne	Below American Dam	Below Intern'l Dam	Below Riverside Dam	At County Line	At Fort Quitman
1990	Jan	0	40	40	61	139	0	0	106	136	180
	Feb	0	35	35	50	120	0	0	11	73	198
	Mar	1169	911	720	282	348	107	0	8	6	146
	Apr	1431	1223	976	383	537	202	0	16	5	136
	May	1585	1370	1046	311	596	203	0	23	7	120
	Jun	1793	1598	1189	387	694	210	0	39	4	115
	Jul	1576	1405	991	223	649	203	0	37	3	77
	Aug	1279	1158	758	19	496	63	0	33	2	69
	Sep	498	532	381	0	429	137	137	145	40	196
	Oct	15	141	126	88	380	101	101	134	88	117
	Nov	0	94	94	133	290	169	169	219	203	198
	Dec	0	68	68	99	202	81	81	174	191	139
1991	Jan	0	53	53	75	165	0	0	131	171	110
	Feb	0	43	43	59	138	0	0	26	78	129
	Mar	1302	1036	827	396	441	100	0	27	13	136
	Apr	1586	1372	1102	488	641	210	0	35	23	108
	May	1727	1515	1172	429	711	203	0	43	73	105
	Jun	1818	1628	1201	411	732	210	0	47	66	95
	Jul	1650	1480	1073	307	726	203	0	49	11	102
	Aug	1067	1012	711	77	536	63	0	44	5	109
	Sep	910	837	595	0	472	32	32	68	36	115
	Oct	41	166	132	44	415	0	0	56	59	57
	Nov	0	108	108	149	337	216	216	266	269	244
	Dec	0	76	76	108	227	106	106	203	210	197
1992	Jan	0	61	61	86	190	6	6	160	164	232
	Feb	0	49	49	67	156	0	0	47	63	254
	Mar	1112	915	746	408	449	78	0	16	6	200
	Apr	1494	1332	1093	584	800	318	140	186	156	249
	May	2191	1950	1579	843	1088	549	346	404	342	449
	Jun	1967	1774	1278	560	914	210	0	107	111	277
	Jul	1961	1781	1281	547	954	203	0	107	96	154
	Aug	1674	1513	1013	345	794	116	0	90	76	156
	Sep	1015	965	721	47	656	0	0	87	68	178
	Oct	207	311	261	102	517	0	0	67	72	181
	Nov	0	119	119	167	369	248	248	293	328	286
	Dec	0	83	83	116	235	113	113	204	245	265
1993	Jan	0	64	64	91	196	12	12	170	221	271
	Feb	0	51	51	72	164	0	0	51	71	271
	Mar	1804	1517	1185	665	784	115	0	25	47	319
	Apr	1909	1714	1320	621	951	210	0	45	83	301
	May	2548	2337	1929	1180	1495	699	495	537	560	628
	Jun	3767	3553	3053	2230	2520	1601	1391	1445	1431	1466
	Jul	1987	1847	1347	664	1164	204	0	92	174	494
	Aug	1640	1503	1072	416	930	48	0	57	130	314
	Sep	696	763	668	329	840	0	0	54	150	298
	Oct	320	421	402	296	588	0	0	0	113	341
	Nov	0	93	93	140	306	185	185	236	255	336
	Dec	0	63	63	96	209	88	88	182	228	293
1994	Jan	255	278	278	272	332	148	148	297	322	361
	Feb	707	706	706	659	656	472	472	532	489	611
	Mar	1843	1564	1168	517	749	120	0	39	69	408
	Apr	2090	1866	1375	652	952	210	0	44	121	313
	May	2901	2688	2234	1494	1792	1042	839	876	906	905
	Jun	3442	3243	2743	1934	2241	1240	1030	1102	1104	1253
	Jul	2114	1967	1467	749	1224	203	0	91	170	446
	Aug	1569	1454	1204	553	1067	43	0	70	178	304
	Sep	574	651	588	380	765	0	0	52	110	350
	Oct	284	341	333	266	445	0	0	0	70	295
	Nov	0	58	58	97	203	81	81	133	147	248
	Dec	0	41	41	69	150	29	29	123	200	209

Figure 29-10
Monthly Average Rio Grande Flows
Integrated LRG Model - Historical Base Run (Run 1)
1940 - 2017 (cfs)

Flow Legend (CFS)

	0	10
	10	100
	100	200
	200	500
	500	Max

Year	Month	Below Caballo	Below Percha Dam	Below Leasburg Dam	Below Mesilla Dam	At Courchesne	Below American Dam	Below Intern'l Dam	Below Riverside Dam	At County Line	At Fort Quitman
1995	Jan	0	37	37	58	135	0	0	119	183	234
	Feb	576	562	562	513	496	320	320	382	377	458
	Mar	2127	1825	1401	715	871	125	0	45	116	403
	Apr	2178	1945	1462	739	1000	210	0	51	116	360
	May	2038	1846	1346	633	1029	203	0	55	117	346
	Jun	3916	3691	3191	2345	2560	1672	1462	1503	1422	1437
	Jul	3884	3687	3187	2387	2704	1679	1476	1557	1507	1611
	Aug	1364	1288	1060	463	1063	38	0	98	167	523
	Sep	578	642	584	392	734	0	0	48	148	374
	Oct	123	191	183	141	342	0	0	0	91	272
	Nov	265	280	280	281	312	199	199	246	270	309
	Dec	955	924	924	861	786	674	674	752	723	685
1996	Jan	861	856	856	809	778	603	603	744	702	785
	Feb	1131	1122	1122	1055	1012	836	836	887	849	936
	Mar	2066	1786	1339	680	876	143	0	53	106	489
	Apr	2072	1853	1353	647	963	210	0	47	109	358
	May	2059	1870	1370	646	1029	203	0	52	170	316
	Jun	2027	1845	1345	602	994	210	0	53	159	268
	Jul	1964	1791	1291	558	967	203	0	53	135	186
	Aug	920	832	641	34	641	20	0	43	100	229
	Sep	549	606	554	361	646	0	0	37	106	281
	Oct	440	481	475	377	506	0	0	0	119	289
	Nov	0	49	49	89	177	64	64	114	161	228
	Dec	0	33	33	58	120	7	7	101	159	207
1997	Jan	0	30	30	49	109	0	0	95	139	196
	Feb	0	29	29	42	97	0	0	0	33	231
	Mar	1461	1158	944	438	465	125	0	39	20	135
	Apr	1637	1405	1151	515	647	210	0	61	42	116
	May	1758	1547	1209	463	724	203	0	75	66	125
	Jun	1831	1643	1247	442	739	210	0	79	58	91
	Jul	1808	1634	1220	441	821	203	0	92	42	30
	Aug	1412	1261	848	109	569	38	0	77	10	70
	Sep	609	619	460	0	440	15	15	72	2	147
	Oct	16	150	135	72	367	11	11	60	9	149
	Nov	0	99	99	134	260	147	147	196	168	193
	Dec	0	63	63	89	173	61	61	160	174	150
1998	Jan	0	51	51	71	145	0	0	126	117	168
	Feb	0	42	42	57	123	0	0	17	52	188
	Mar	1896	1597	1218	572	727	115	0	22	105	233
	Apr	2094	1859	1393	660	903	210	0	45	115	252
	May	2039	1845	1391	674	997	203	0	54	133	275
	Jun	2088	1912	1412	658	1047	210	0	59	133	270
	Jul	2054	1891	1391	669	1038	203	0	60	144	213
	Aug	1590	1451	1173	468	973	48	0	66	147	231
	Sep	678	761	694	455	839	0	0	61	136	250
	Oct	336	406	396	319	494	0	0	0	98	270
	Nov	0	89	89	132	278	165	165	208	267	275
	Dec	0	51	51	79	160	48	48	135	162	250
1999	Jan	0	43	43	63	135	0	0	110	161	197
	Feb	0	37	37	51	118	0	0	129	132	205
	Mar	2055	1746	1418	776	798	145	0	33	83	228
	Apr	2541	2288	1905	1125	1261	210	0	32	123	318
	May	1980	1790	1400	657	979	203	0	24	92	259
	Jun	1928	1756	1300	574	947	210	0	22	108	219
	Jul	2007	1843	1423	663	1030	203	0	42	100	202
	Aug	1744	1597	1277	525	982	17	0	49	143	216
	Sep	322	412	360	206	622	0	0	32	56	242
	Oct	0	126	121	134	361	175	175	183	186	251
	Nov	0	69	69	108	231	119	119	216	253	272
	Dec	0	45	45	73	158	46	46	153	196	258

Figure 29-10
Monthly Average Rio Grande Flows
Integrated LRG Model - Historical Base Run (Run 1)
1940 - 2017 (cfs)

Flow Legend (CFS)

Color	From	To
White	0	10
Light green	10	100
Teal	100	200
Medium blue	200	500
Dark blue	500	Max

Year	Month	Below Caballo	Below Percha Dam	Below Leasburg Dam	Below Mesilla Dam	At Courchesne	Below American Dam	Below Intern'l Dam	Below Riverside Dam	At County Line	At Fort Quitman
2000	Jan	0	40	40	61	140	0	0	148	183	239
	Feb	0	35	35	49	119	0	0	105	114	187
	Mar	1726	1416	1199	669	678	151	0	27	49	176
	Apr	2153	1900	1645	975	1072	210	0	26	90	218
	May	1992	1784	1432	673	935	203	0	22	94	188
	Jun	1606	1478	1169	421	767	210	0	17	76	183
	Jul	2181	1991	1595	788	1112	203	0	46	113	132
	Aug	1834	1672	1181	432	876	12	0	44	137	171
	Sep	874	864	716	210	651	0	0	46	116	224
	Oct	21	157	140	93	406	141	141	145	232	264
	Nov	0	103	103	140	292	181	181	276	325	337
	Dec	0	75	75	103	209	97	97	212	244	323
2001	Jan	0	57	57	79	166	0	0	162	179	258
	Feb	0	46	46	61	135	0	0	117	89	218
	Mar	1252	967	758	332	384	109	0	14	46	131
	Apr	1913	1667	1402	772	860	210	0	20	29	200
	May	1853	1649	1316	575	842	203	0	20	44	164
	Jun	2025	1836	1410	603	903	210	0	21	23	189
	Jul	2060	1883	1443	661	1038	203	0	42	82	125
	Aug	1823	1663	1182	438	850	54	0	40	105	150
	Sep	619	638	534	167	600	0	0	31	71	187
	Oct	19	151	139	97	370	89	89	98	122	207
	Nov	0	77	77	112	231	117	117	226	262	242
	Dec	0	51	51	75	150	34	34	142	206	237
2002	Jan	0	43	43	61	127	0	0	133	155	215
	Feb	0	37	37	50	110	0	0	108	108	196
	Mar	1330	1037	831	347	397	106	0	15	30	153
	Apr	2028	1782	1535	878	952	210	0	23	72	206
	May	1985	1772	1433	675	916	203	0	22	96	199
	Jun	2213	2016	1585	766	1056	210	0	26	91	217
	Jul	1906	1734	1312	538	912	203	0	36	72	189
	Aug	1833	1670	1229	475	890	56	0	42	115	189
	Sep	714	726	634	232	655	0	0	33	102	253
	Oct	20	152	139	108	386	81	81	90	107	253
	Nov	0	89	89	127	269	154	154	259	277	286
	Dec	0	57	57	86	174	60	60	177	201	278
2003	Jan	0	48	48	70	151	0	0	154	169	243
	Feb	0	40	40	56	127	0	0	120	128	200
	Mar	586	474	340	63	152	85	0	4	35	129
	Apr	1222	1043	854	429	487	210	0	9	37	101
	May	1433	1232	992	360	495	129	0	11	69	87
	Jun	1901	1665	1328	480	665	210	0	14	74	91
	Jul	1662	1467	1063	260	629	36	0	30	95	78
	Aug	1276	1162	929	485	781	25	0	38	137	125
	Sep	469	550	526	430	620	0	0	31	125	148
	Oct	255	298	298	259	334	0	0	17	106	129
	Nov	0	39	39	62	115	1	1	107	177	161
	Dec	0	29	29	41	86	0	0	87	143	178
2004	Jan	0	28	28	35	82	0	0	83	125	168
	Feb	0	26	26	30	75	0	0	82	100	147
	Mar	779	634	482	141	177	30	0	8	39	106
	Apr	1132	957	779	366	406	55	0	11	80	115
	May	977	898	778	410	482	62	0	13	83	98
	Jun	1871	1645	1407	679	712	148	0	17	93	100
	Jul	1598	1387	1190	596	771	117	0	33	96	106
	Aug	927	919	839	574	712	31	0	35	81	118
	Sep	138	188	178	135	240	0	0	12	57	75
	Oct	3	35	33	32	80	61	61	56	69	52
	Nov	0	16	16	20	41	0	0	43	46	52
	Dec	0	17	17	20	43	0	0	46	41	78

Figure 29-10
Monthly Average Rio Grande Flows
Integrated LRG Model - Historical Base Run (Run 1)
1940 - 2017 (cfs)

Flow Legend (CFS)

	0	10
	10	100
	100	200
	200	500
	500	Max

	Month	Below Caballo	Below Percha Dam	Below Leasburg Dam	Below Mesilla Dam	At Courchesne	Below American Dam	Below Intern'l Dam	Below Riverside Dam	At County Line	At Fort Quitman
2005	Jan	0	19	19	21	43	0	0	58	54	69
	Feb	0	21	21	21	42	0	0	41	33	104
	Mar	762	640	518	227	222	0	0	11	15	90
	Apr	1568	1361	1172	709	673	83	0	18	17	141
	May	1501	1339	1141	582	625	102	0	16	11	152
	Jun	1943	1727	1446	637	771	166	0	18	50	117
	Jul	2220	1989	1540	685	905	203	0	35	37	126
	Aug	1915	1713	1213	415	723	203	0	26	8	179
	Sep	1555	1388	1064	288	669	210	0	23	21	133
	Oct	454	414	317	0	406	80	57	68	53	163
	Nov	0	154	154	197	420	304	304	395	382	300
	Dec	0	102	102	131	242	126	126	229	255	215
2006	Jan	0	73	73	94	174	0	0	165	174	203
	Feb	0	55	55	70	136	0	0	116	128	175
	Mar	729	633	510	260	296	107	0	10	31	105
	Apr	1564	1384	1196	764	787	210	0	18	46	114
	May	1787	1574	1323	632	749	147	0	18	73	115
	Jun	1402	1285	1091	517	721	20	0	21	82	98
	Jul	691	675	614	381	580	1	0	29	75	124
	Aug	773	728	662	434	474	1	0	24	46	114
	Sep	11	67	55	46	155	125	125	118	46	142
	Oct	3	43	42	42	104	109	109	100	65	107
	Nov	0	27	27	30	72	0	0	69	64	74
	Dec	0	17	17	20	47	0	0	51	63	67
2007	Jan	0	20	20	21	50	0	0	54	67	78
	Feb	0	22	22	22	51	0	0	49	49	115
	Mar	1081	922	776	407	373	111	0	13	14	75
	Apr	1680	1478	1301	835	797	153	0	20	9	144
	May	1619	1421	1191	542	636	90	0	17	37	127
	Jun	792	826	784	591	707	99	0	18	45	107
	Jul	1715	1492	1333	761	757	166	0	30	16	143
	Aug	1421	1313	1173	723	802	71	0	37	31	103
	Sep	643	664	647	505	575	0	0	29	9	184
	Oct	374	382	382	323	329	0	0	17	27	151
	Nov	0	25	25	38	72	0	0	70	89	104
	Dec	0	20	20	25	55	0	0	58	76	87
2008	Jan	0	22	22	24	53	0	0	56	79	79
	Feb	0	22	22	23	48	0	0	47	48	101
	Mar	1204	1027	861	448	410	110	0	15	14	78
	Apr	1968	1728	1520	977	906	210	0	21	20	112
	May	2047	1804	1546	809	831	203	0	19	19	134
	Jun	1405	1346	1223	790	908	210	0	21	51	97
	Jul	1694	1444	1213	512	618	203	0	21	9	201
	Aug	1116	1023	775	278	522	53	0	24	8	124
	Sep	376	453	422	317	492	0	0	25	18	122
	Oct	452	491	490	413	454	0	0	23	19	125
	Nov	0	47	47	64	106	0	0	97	132	97
	Dec	0	30	30	36	66	0	0	68	107	92
2009	Jan	0	29	29	31	63	0	0	65	78	94
	Feb	0	26	26	28	57	0	0	53	54	119
	Mar	1779	1462	1256	751	693	111	0	30	45	152
	Apr	2298	2027	1773	1097	1084	210	0	26	63	227
	May	1917	1712	1400	641	820	203	0	19	70	183
	Jun	612	710	692	591	767	210	0	17	53	172
	Jul	2311	2030	1726	902	936	203	0	37	53	134
	Aug	1905	1698	1412	659	901	52	0	43	79	148
	Sep	231	330	295	207	486	0	0	25	52	227
	Oct	256	314	312	255	365	0	0	19	67	161
	Nov	0	48	48	67	127	10	10	114	124	131
	Dec	0	42	42	53	103	0	0	100	148	181

Figure 29-10
Monthly Average Rio Grande Flows
Integrated LRG Model - Historical Base Run (Run 1)
1940 - 2017 (cfs)

Flow Legend (CFS)

	0	10
	10	100
	100	200
	200	500
	500	Max

Year	Month	Below Caballo	Below Percha Dam	Below Leasburg Dam	Below Mesilla Dam	At Courchesne	Below American Dam	Below Intern'l Dam	Below Riverside Dam	At County Line	At Fort Quitman
2010	Jan	0	36	36	42	86	0	0	86	127	172
	Feb	0	32	32	35	75	0	0	67	70	141
	Mar	806	670	526	190	203	74	0	7	17	94
	Apr	1516	1309	1112	619	614	179	0	13	3	113
	May	1687	1503	1299	697	739	196	0	17	18	99
	Jun	1109	1075	997	684	770	170	0	18	19	124
	Jul	2154	1853	1599	808	837	203	0	32	20	95
	Aug	1382	1298	1126	726	911	166	0	38	36	72
	Sep	533	584	565	449	583	0	0	29	24	156
	Oct	414	428	428	362	375	0	0	19	48	125
	Nov	0	31	31	47	81	0	0	80	109	100
	Dec	0	18	18	23	45	0	0	52	96	101
2011	Jan	0	20	20	23	45	0	0	53	99	105
	Feb	0	21	21	23	42	0	0	45	52	119
	Mar	1103	926	763	377	349	96	0	13	49	75
	Apr	1768	1555	1387	937	860	210	0	20	28	149
	May	1112	1060	1010	770	715	72	0	20	34	132
	Jun	974	931	931	802	701	2	0	21	39	132
	Jul	1071	998	998	860	717	14	0	36	51	104
	Aug	589	536	536	456	362	18	0	18	36	35
	Sep	0	1	1	17	13	22	22	18	13	26
	Oct	0	1	1	10	10	20	20	16	4	28
	Nov	0	0	0	10	8	0	0	19	16	34
	Dec	0	0	0	9	7	0	0	18	17	40
2012	Jan	0	0	0	9	6	0	0	17	16	54
	Feb	0	0	0	9	6	0	0	15	4	60
	Mar	1002	813	653	303	251	86	0	9	3	62
	Apr	1629	1358	1156	674	575	186	0	12	7	88
	May	1597	1303	1060	416	387	52	0	10	11	84
	Jun	752	728	728	619	521	71	0	14	19	88
	Jul	797	741	741	627	498	22	0	24	29	94
	Aug	646	570	544	397	311	2	0	16	23	43
	Sep	95	70	64	39	23	0	0	2	6	22
	Oct	2	2	0	4	7	11	11	9	17	15
	Nov	0	1	1	10	7	0	0	13	27	22
	Dec	0	1	1	9	6	0	0	15	34	30
2013	Jan	0	1	1	9	6	0	0	28	31	39
	Feb	0	1	1	9	6	0	0	13	11	43
	Mar	941	758	609	256	214	27	0	10	27	50
	Apr	1321	1111	965	555	466	39	0	13	54	83
	May	827	742	707	488	394	21	0	12	66	83
	Jun	100	82	82	58	36	6	0	1	43	41
	Jul	0	2	2	10	9	20	20	16	18	22
	Aug	0	1	1	9	7	15	15	12	19	21
	Sep	0	0	0	9	7	16	16	13	0	16
	Oct	0	1	1	9	6	15	15	12	2	13
	Nov	0	0	0	8	6	0	0	16	24	16
	Dec	0	0	0	8	6	0	0	16	14	18
2014	Jan	0	0	0	8	6	0	0	15	0	22
	Feb	0	0	0	8	6	0	0	13	0	30
	Mar	1077	884	726	361	300	90	0	11	12	37
	Apr	1721	1444	1245	732	629	152	0	15	46	47
	May	1110	958	867	511	424	31	0	12	46	45
	Jun	982	892	867	651	525	2	0	16	64	42
	Jul	518	452	440	325	243	22	0	12	45	31
	Aug	0	2	2	10	8	18	10	8	8	18
	Sep	0	1	1	9	7	18	18	15	0	16
	Oct	0	1	1	9	7	18	18	14	1	11
	Nov	0	0	0	8	6	0	0	14	5	9
	Dec	0	0	0	8	6	0	0	15	3	10

Figure 29-10
Monthly Average Rio Grande Flows
Integrated LRG Model - Historical Base Run (Run 1)
1940 - 2017 (cfs)

Flow Legend (CFS)

(white)	0	10
(light green)	10	100
(teal)	100	200
(medium blue)	200	500
(dark blue)	500	Max

Year	Month	Below Caballo	Below Percha Dam	Below Leasburg Dam	Below Mesilla Dam	At Courchesne	Below American Dam	Below Intern'l Dam	Below Riverside Dam	At County Line	At Fort Quitman
2015	Jan	0	0	0	8	6	0	0	15	13	18
	Feb	0	1	1	8	5	0	0	24	13	32
	Mar	940	766	622	309	252	75	0	10	9	38
	Apr	1556	1300	1112	651	554	166	0	12	21	38
	May	1227	1060	947	557	467	118	0	11	40	36
	Jun	1167	1035	960	626	520	39	0	15	52	29
	Jul	922	859	859	734	597	78	0	26	52	39
	Aug	1132	1059	1059	899	739	90	0	33	73	84
	Sep	921	857	857	719	582	0	0	30	72	92
	Oct	0	4	4	11	9	16	16	13	68	68
	Nov	0	2	2	9	8	0	0	13	56	79
	Dec	0	2	2	9	7	0	0	14	43	79
2016	Jan	0	3	3	10	7	0	0	14	35	83
	Feb	0	5	5	11	6	0	0	11	32	79
	Mar	1099	911	753	372	316	77	0	12	42	72
	Apr	1782	1529	1346	863	752	174	0	18	70	114
	May	2014	1743	1505	815	736	139	0	18	76	137
	Jun	968	989	986	843	697	39	0	20	96	142
	Jul	1467	1360	1319	1027	870	83	0	40	115	142
	Aug	1271	1163	1117	848	713	145	0	29	84	141
	Sep	826	768	763	624	508	0	0	26	85	141
	Oct	76	68	67	52	37	0	0	3	76	69
	Nov	0	3	3	10	9	0	0	16	73	82
	Dec	0	3	3	10	7	0	0	18	56	86
2017	Jan	0	4	4	11	7	0	0	18	49	78
	Feb	0	6	6	12	6	0	0	16	30	77
	Mar	1037	858	707	356	299	83	0	11	33	66
	Apr	1410	1244	1129	783	659	77	0	18	61	88
	May	1231	1145	1096	833	697	107	0	18	74	103
	Jun	1717	1553	1451	1004	867	210	0	20	93	123
	Jul	1535	1362	1279	911	783	203	0	30	81	127
	Aug	1467	1354	1280	970	834	203	0	32	79	120
	Sep	1039	1000	991	832	698	90	0	31	80	131
	Oct	668	633	633	539	433	0	0	22	68	143
	Nov	0	17	17	27	24	0	0	30	52	87
	Dec	0	7	7	12	10	0	0	20	30	90

Model Version: LRG Model v116 Operational Run 1 - Historical Base Run.

Figure 29-11
Simulated Monthly Charged Diversions of Project Water by EBID and EPCWID
Integrated LRG Model - Historical Base Run (Run 1)
1940 - 2017

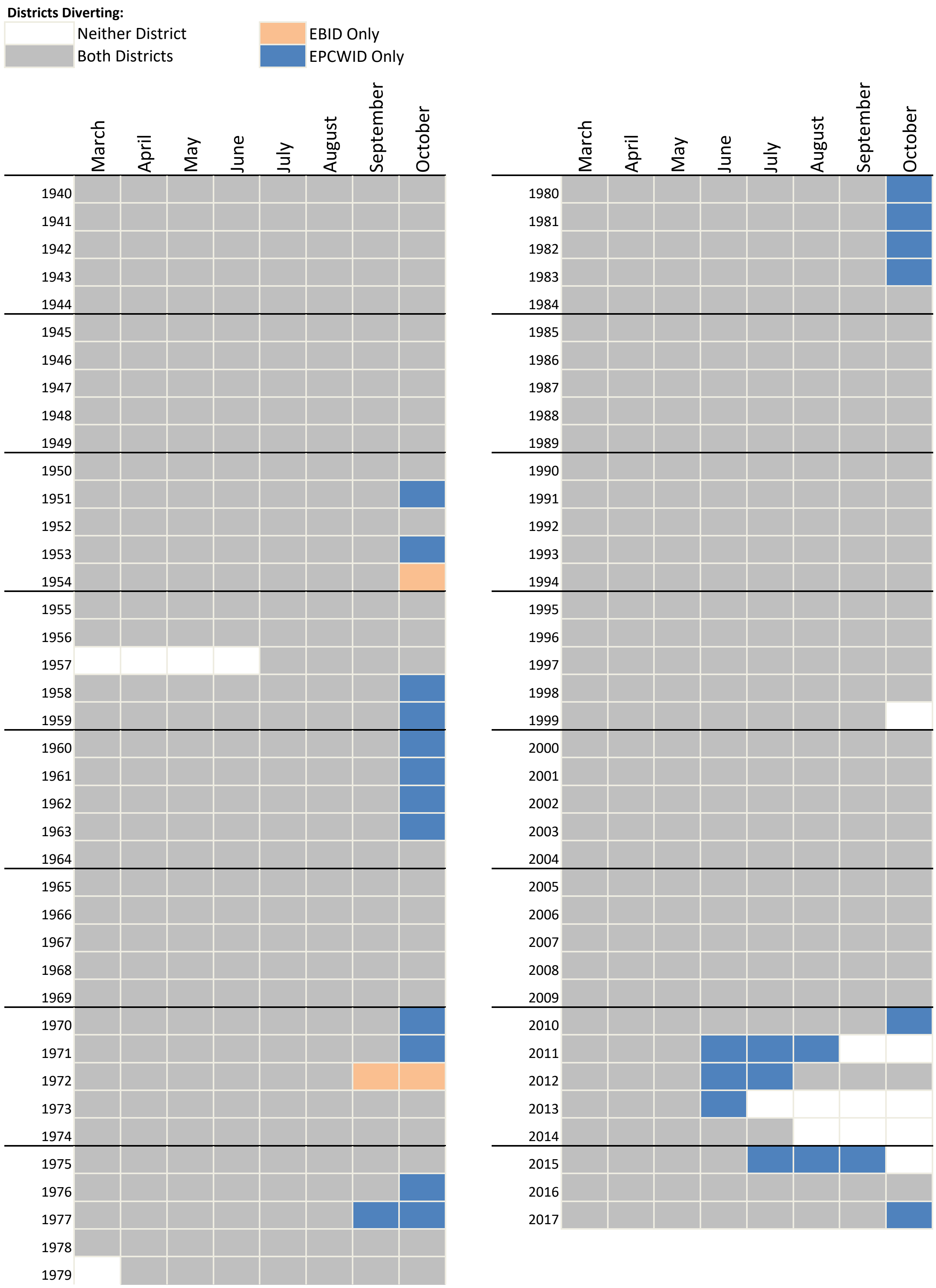
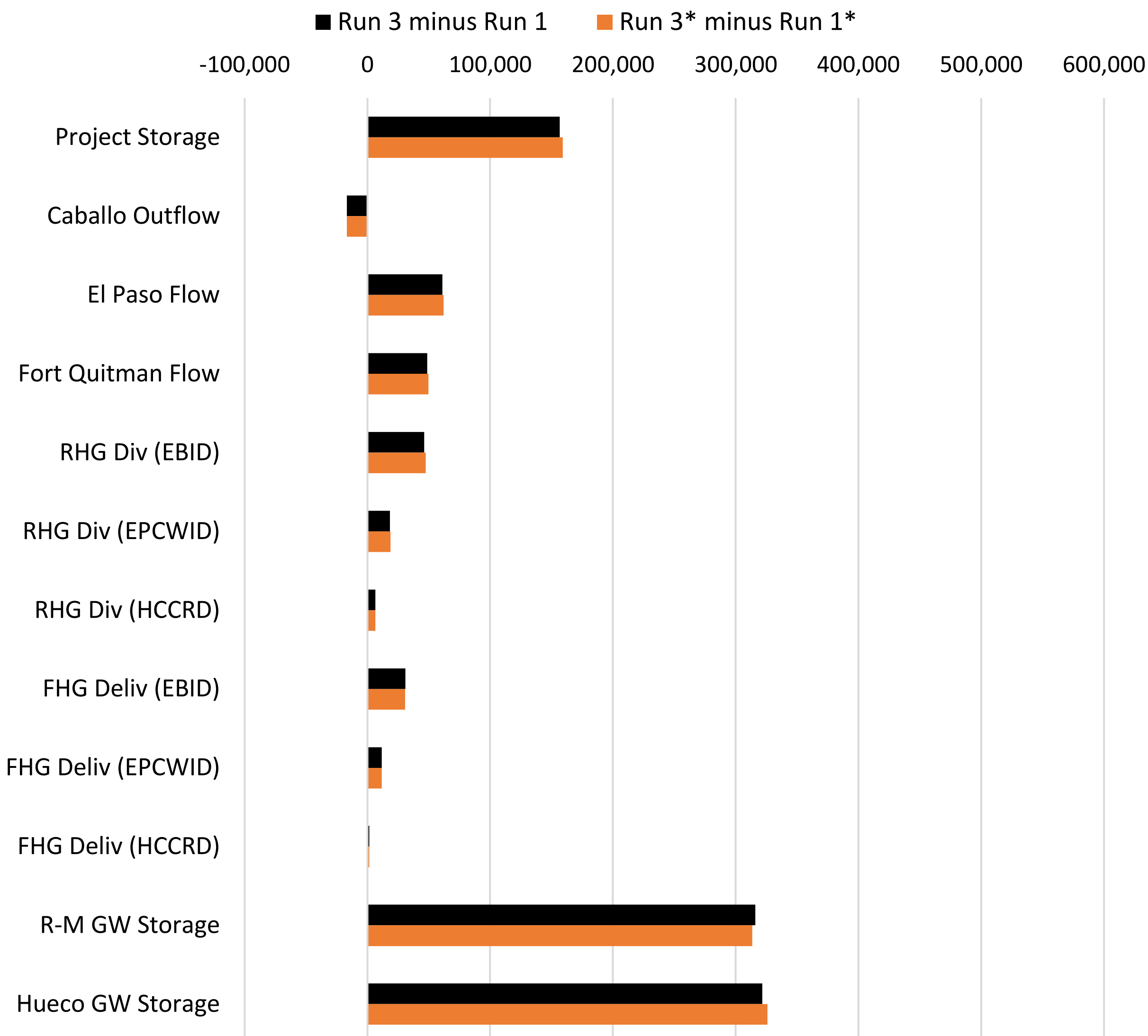


Figure 31-1

Summary of ILRG Model Sensitivity Analyses
Alluvial Aquifer Hydraulic Conductivity
Average Annual New Mexico Pumping Impacts (Run 3 minus Run 1)
1951 - 2017 (acre-feet)



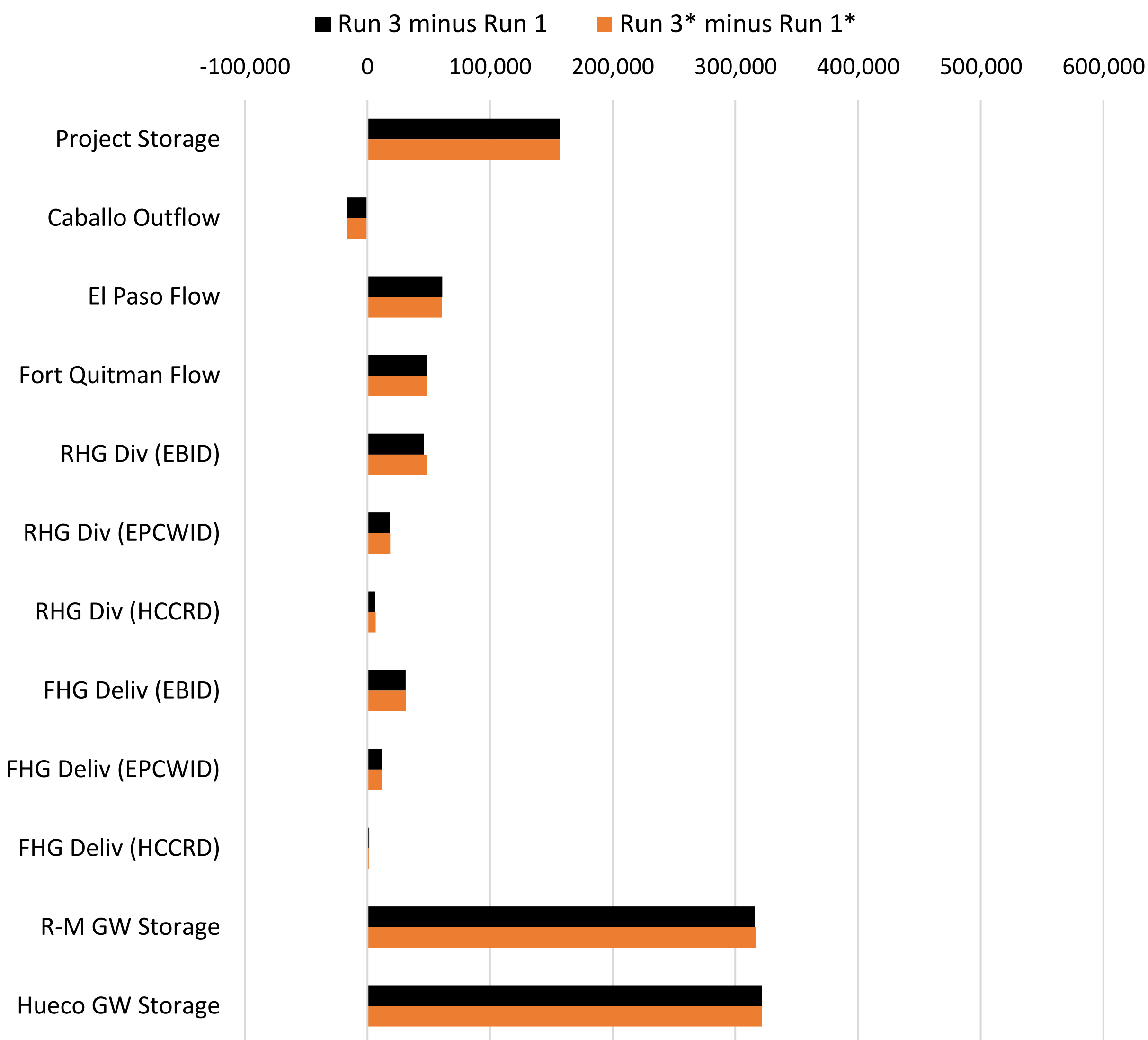
Notes:
Sensitivity Runs (10% Increase in Alluvial Aquifer Hydraulic Conductivity)
Run 1* (Historical Base Run)
Run 3* (NM Pumping Off)

Original Runs
Run 1 (Historical Base Run)
Run 3 (NM Pumping Off)

Changes in storage and flows are annual. Changes in RHG and FHG are irrigation season.

Figure 31-2

Summary of ILRG Model Sensitivity Analyses
River Bed Conductance
Average Annual New Mexico Pumping Impacts (Run 3 minus Run 1)
1951 - 2017 (acre-feet)



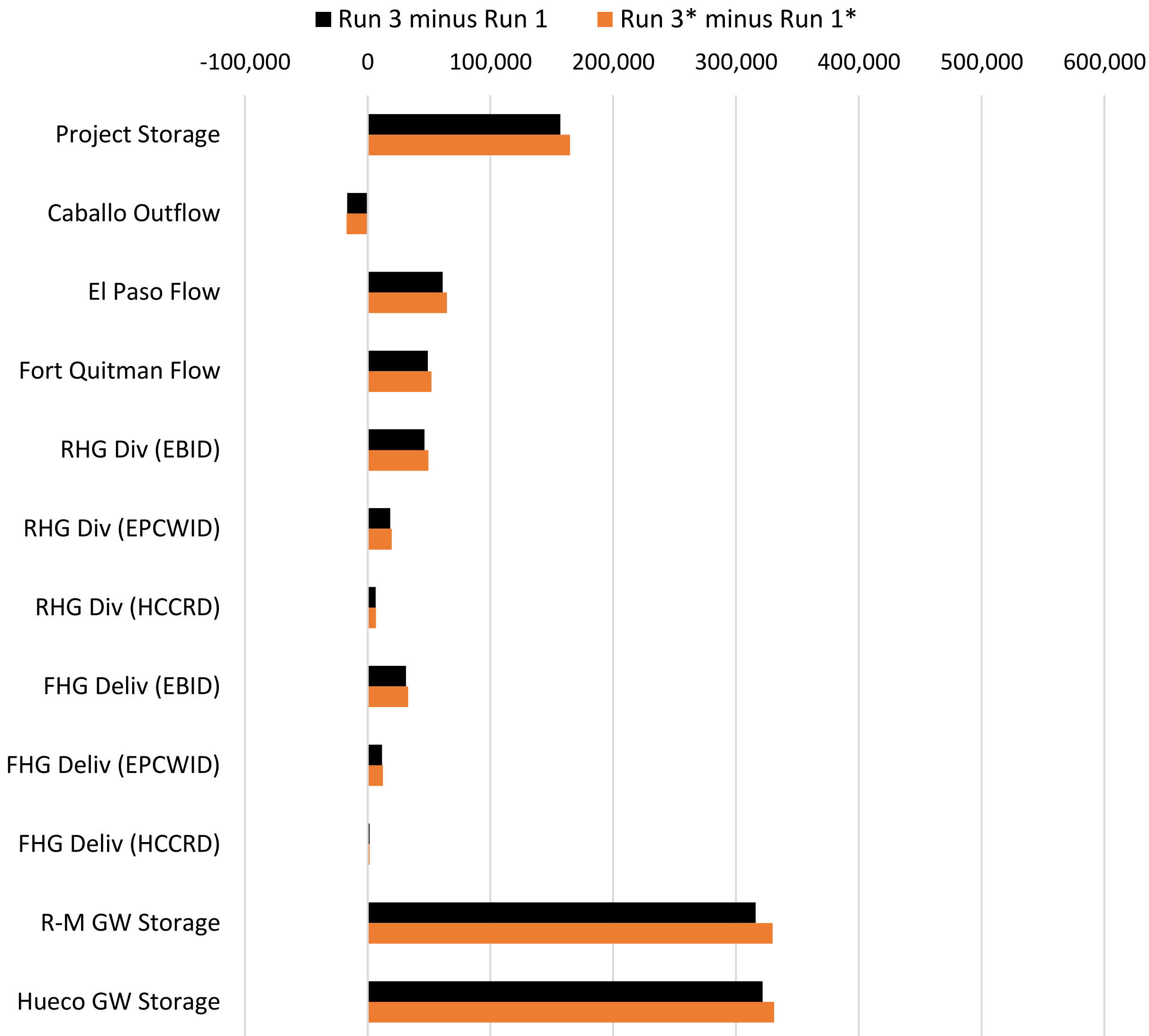
Notes:
Sensitivity Runs (10% Increase in River Bed Conductance)
Run 1* (Historical Base Run)
Run 3* (NM Pumping Off)

Original Runs
Run 1 (Historical Base Run)
Run 3 (NM Pumping Off)

Changes in storage and flows are annual. Changes in RHG and FHG are irrigation season.

Figure 31-3

Summary of ILRG Model Sensitivity Analyses
Canal Bed Conductance
Average Annual New Mexico Pumping Impacts (Run 3 minus Run 1)
1951 - 2017 (acre-feet)



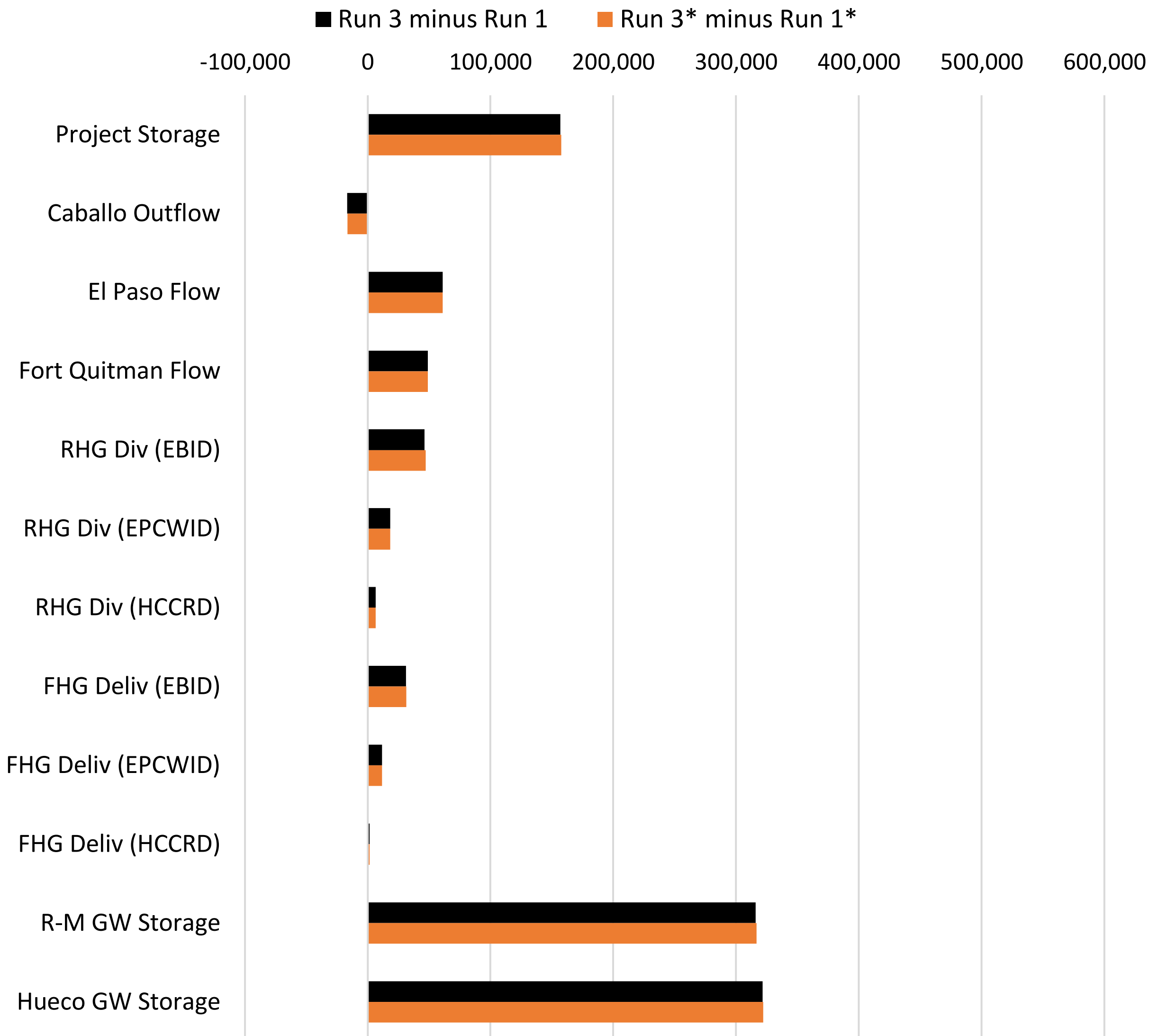
Notes:
Sensitivity Runs (10% Increase in Canal Bed Conductance)
Run 1* (Historical Base Run)
Run 3* (NM Pumping Off)

Original Runs
Run 1 (Historical Base Run)
Run 3 (NM Pumping Off)

Changes in storage and flows are annual. Changes in RHG and FHG are irrigation season.

Figure 31-4

Summary of ILRG Model Sensitivity Analyses
Drain Bed Conductance
Average Annual New Mexico Pumping Impacts (Run 3 minus Run 1)
1951 - 2017 (acre-feet)



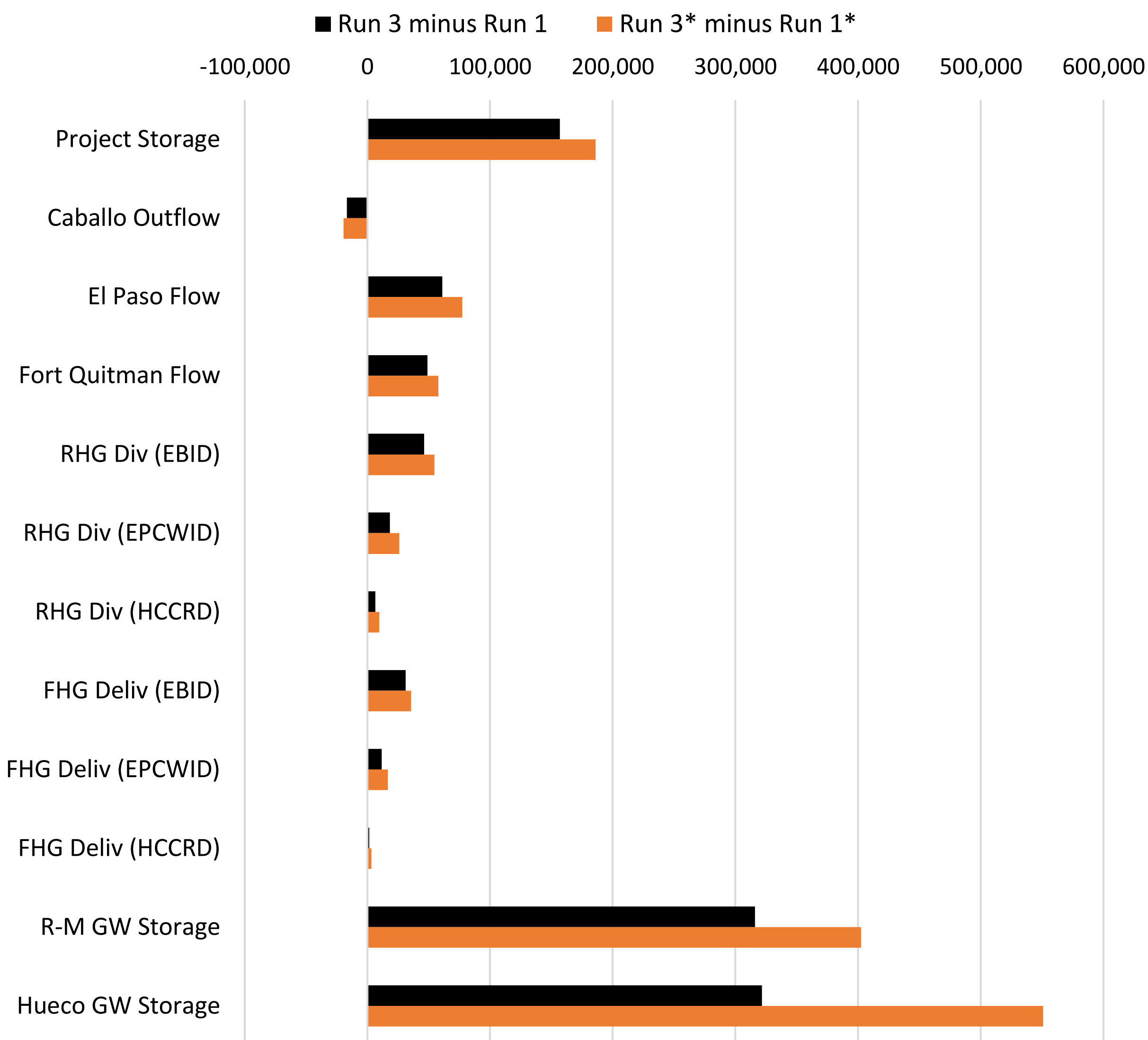
Notes:
Sensitivity Runs (10% Increase in Drain Bed Conductance)
Run 1* (Historical Base Run)
Run 3* (NM Pumping Off)

Original Runs
Run 1 (Historical Base Run)
Run 3 (NM Pumping Off)

Changes in storage and flows are annual. Changes in RHG and FHG are irrigation season.

Figure 31-5

Summary of ILRG Model Sensitivity Analyses
Crop Irrigation Requirement
Average Annual New Mexico Pumping Impacts (Run 3 minus Run 1)
1951 - 2017 (acre-feet)



Notes:

<u>Sensitivity Runs (10% Increase in Crop Irrigation Requirement)</u>
Run 1* (Historical Base Run)
Run 3* (NM Pumping Off)

<u>Original Runs</u>
Run 1 (Historical Base Run)
Run 3 (NM Pumping Off)

Changes in storage and flows are annual. Changes in RHG and FHG are irrigation season.

TABLES

Table 19-1
Water Supply to HCCRD (Irrigation Season)
1940 - 2017 (acre-feet)

Year	(1) EPCWID (El Paso Valley) Supply	(2) 10% EPCWID (El Paso Valley) Supply	(3) Tornillo Canal at Alamo Alto	(4) Hudspeth Feeder Canal	(5) Tornillo Drain	(6) Total Hudspeth Supply	(7) Undiverted Fabens Drains	(8) Fabens Drains in Hudspeth Feeder Canal	(9) Fabens WWTP	(10) Waste in Hudspeth Feeder Canal	(11) Total Waste to Hudspeth	(12) Total Waste to Hudspeth Exceeding 10 % EPCWID Supply	(13) Total Waste to Hudspeth (% EPCWID Supply)
1940	346,498								0				
1941	346,859								0				
1942	461,031								0				
1943	451,903								0				
1944	389,191								0				
1945	378,158						68,671		0				
1946	357,474						42,693		0				
1947	320,556	32,056	22,843	10,871	40,380	74,094	43,907	10,871	0	0	22,843	0	7%
1948	329,891	32,989	23,757	33,274	40,459	97,490	25,100	25,100	0	8,174	31,931	0	10%
1949	334,924	33,492	19,906	49,244	52,538	121,688	50,166	49,244	0	0	19,906	0	6%
1950	328,905	32,891	24,889	52,010	49,612	126,511	54,714	52,010	0	0	24,889	0	8%
1951	197,781	19,778	8,348	12,283	16,070	36,701	15,340	12,283	0	0	8,348	0	4%
1952	211,238	21,124	7,955	18,095	17,986	44,036	17,475	17,475	0	620	8,575	0	4%
1953	200,541	20,054	3,568	10,573	16,852	30,993	15,356	10,573	0	0	3,568	0	2%
1954	69,829	6,983	641	496	2,338	3,475	755	496	0	0	641	0	1%
1955	54,554	5,455	62	119	139	320	0	0	0	119	181	0	0%
1956	50,307	5,031	0	0	0	0	0	0	0	0	0	0	0%
1957	104,549	10,455	877	710	0	1,587	0	0	0	710	1,587	0	2%
1958	262,838	26,284	15,293	10,830	1,393	27,516	751	751	0	10,079	25,372	0	10%
1959	285,895	28,590	12,948	17,407	13,540	43,895	9,077	9,077	0	8,330	21,278	0	7%
1960	290,868	29,087	12,242	24,502	24,584	61,328	33,220	24,502	0	0	12,242	0	4%
1961	225,631	22,563	6,860	16,395	21,144	44,399	17,004	16,395	0	0	6,860	0	3%
1962	281,486	28,149	17,805	28,667	29,223	75,695	33,720	28,667	0	0	17,805	0	6%
1963	205,708	20,571	9,900	17,946	19,518	47,364	21,900	17,946	0	0	9,900	0	5%
1964	60,017	6,002	0	110	2,109	2,219	1,811	110	0	0	0	0	0%
1965	161,887	16,189	4,128	3,828	82	8,038	324	324	0	3,504	7,632	0	5%
1966	236,678	23,668	19,994	19,569	5,747	45,310	10,031	10,031	0	9,538	29,532	5,864	12%
1967	200,399	20,040	3,396	7,365	11,873	22,634	10,672	7,365	0	0	3,396	0	2%
1968	191,422	19,142	9,907	13,125	12,051	35,083	20,492	13,125	0	0	9,907	0	5%
1969	267,410	26,741	15,315	36,957	21,731	74,003	45,024	36,957	0	0	15,315	0	6%
1970	260,696	26,070	25,567	40,386	27,987	93,940	47,210	40,386	0	0	25,567	0	10%
1971	211,116	21,112	4,155	17,446	20,928	42,529	25,470	17,446	0	0	4,155	0	2%
1972	120,152	12,015	3,343	7,709	9,460	20,512	4,006	4,006	0	3,703	7,046	0	6%
1973	256,173	25,617	3,709	27,236	17,905	48,850	15,512	15,512	0	11,724	15,433	0	6%
1974	303,760	30,376	8,691	41,797	27,162	77,650	25,045	25,045	0	16,752	25,443	0	8%
1975	274,579	27,458	6,860	43,190	28,057	78,107	32,947	32,947	0	10,243	17,103	0	6%
1976	308,010	30,801	10,412	51,947	33,615	95,974	28,378	28,378	0	23,569	33,981	3,180	11%
1977	184,060	18,406	2,280	14,520	17,177	33,977	13,691	13,691	0	829	3,109	0	2%
1978	138,218	13,822	2,037	6,621	7,483	16,141	4,964	4,964	0	1,657	3,694	0	3%
1979	228,105	22,811	7,194	25,068	15,329	47,591	18,094	18,094	0	6,974	14,168	0	6%
1980	284,164	28,416	14,659	36,297	21,569	72,525	24,799	24,799	0	11,498	26,157	0	9%
1981	248,427	24,843	23,027	36,492	21,421	80,940	27,642	27,642	0	8,850	31,877	7,034	13%
1982	257,786	25,779	21,711	36,054	22,192	79,957	27,870	27,870	0	8,184	29,895	4,116	12%
1983	245,314	24,531	16,741	46,826	21,094	84,661	23,240	23,240	0	23,586	40,327	15,796	16%
1984	257,429	25,743	14,422	65,705	23,652	103,779	29,942	29,942	0	35,763	50,185	24,442	19%
1985	275,730	27,573	18,074	72,252	22,001	112,327	24,859	24,859	0	47,393	65,467	37,894	24%
1986	349,112	34,911	19,275	126,275	28,137	173,687	51,094	51,094	0	75,181	94,456	59,545	27%
1987	388,735	38,874	38,132	45,471	30,663	114,266	49,687	45,471	0	0	38,132	0	10%

Table 19-1
Water Supply to HCCRD (Irrigation Season)
1940 - 2017 (acre-feet)

Year	(1) EPCWID (El Paso Valley) Supply	(2) 10% EPCWID (El Paso Valley) Supply	(3) Tornillo Canal at Alamo Alto	(4) Hudspeth Feeder Canal	(5) Tornillo Drain	(6) Total Hudspeth Supply	(7) Undiverted Fabens Drains	(8) Fabens Drains in Hudspeth Feeder Canal	(9) Fabens WWTP	(10) Waste in Hudspeth Feeder Canal	(11) Total Waste to Hudspeth	(12) Total Waste to Hudspeth Exceeding 10 % EPCWID Supply	(13) Total Waste to Hudspeth (% EPCWID Supply)
1988	365,141	36,514	55,121	42,576	26,128	123,825	49,630	42,576	0	0	55,121	18,607	15%
1989	327,647	32,765	32,551	69,114	25,052	126,717	46,791	46,791	0	22,323	54,874	22,109	17%
1990	294,259	29,426	17,992	66,085	22,485	106,562	41,248	41,248	0	24,837	42,829	13,403	15%
1991	258,422	25,842	12,299	56,042	22,476	90,817	32,552	32,552	0	23,490	35,789	9,947	14%
1992	312,821	31,282	21,015	69,125	26,103	116,243	36,153	36,153	0	32,972	53,987	22,705	17%
1993	339,355	33,936	20,741	70,159	32,645	123,545	22,138	22,138	0	48,021	68,762	34,827	20%
1994	364,321	36,432	20,548	69,661	33,372	123,581	49,940	49,940	0	19,721	40,269	3,837	11%
1995	406,084	40,608	25,631	76,410	35,470	137,511	47,866	47,866	0	28,544	54,175	13,567	13%
1996	284,568	28,457	14,805	61,728	28,405	104,938	34,649	34,649	0	27,079	41,884	13,427	15%
1997	330,354	33,035	27,512	55,659	28,269	111,440	32,849	32,849	0	22,810	50,322	17,287	15%
1998	327,544	32,754	29,215	46,598	29,633	105,446	33,051	33,051	0	13,547	42,762	10,008	13%
1999	340,614	34,061	27,905	59,769	33,086	120,760	32,813	32,813	0	26,956	54,861	20,800	16%
2000	304,540	30,454	32,291	39,339	29,760	101,390	32,290	32,290	0	7,049	39,340	8,886	13%
2001	337,460	33,746	34,891	55,401	34,290	124,582	40,204	40,204	406	14,791	49,682	15,936	15%
2002	318,751	31,875	31,756	56,121	31,898	119,775	43,833	43,833	422	11,866	43,622	11,747	14%
2003	147,557	14,756	4,617	16,059	16,983	37,659	11,800	11,800	425	3,834	8,451	0	6%
2004	163,859	16,386	7,572	19,164	14,671	41,408	10,063	10,063	316	8,786	16,358	0	10%
2005	252,179	25,218	13,146	43,619	21,893	78,658	17,281	17,281	308	26,030	39,176	13,958	16%
2006	199,124	19,912	7,378	32,437	22,544	62,359	16,829	16,829	314	15,294	22,672	2,760	11%
2007	286,682	28,668	13,757	45,503	28,203	87,463	23,963	23,963	313	21,227	34,984	6,316	12%
2008	281,528	28,153	24,454	45,830	31,880	102,164	26,075	26,075	314	19,441	43,895	15,742	16%
2009	316,071	31,607	35,870	43,948	31,377	111,194	32,262	32,262	321	11,365	47,235	15,628	15%
2010	303,197	30,320	28,291	43,214	31,873	103,377	31,693	31,693	302	11,219	39,510	9,190	13%
2011	220,158	22,016	4,299	28,209	4,520	37,028	13,084	13,084	413	14,712	19,011	0	9%
2012	121,622	12,162	1,557	13,033	3,601	18,191	3,469	3,469	398	9,166	10,723	0	9%
2013	67,564	6,756	1,298	4,968	7,830	14,096	2,084	2,084	383	2,501	3,799	0	6%
2014	114,523	11,452	1,748	6,806	8,722	17,276	2,466	2,466	388	3,952	5,700	0	5%
2015	157,991	15,799	4,578	9,930	9,169	23,677	7,076	7,076	382	2,472	7,050	0	4%
2016	194,874	19,487	5,171	10,134	13,155	28,460	6,944	6,944	384	2,806	7,977	0	4%
2017	215,165	21,517	12,425	15,469	14,111	42,005	8,822	8,822	425	6,222	18,647	0	9%
Avg 47-17	245,336	24,534	14,808	33,772	21,054	69,633	23,820	22,275	88	11,409	26,216	6,459	11%
Avg 51-79	201,514	20,151	7,706	17,755	14,534	39,995	16,147	14,019	0	3,736	11,443	312	6%
Avg 80-02	313,851	31,385	24,796	59,094	27,383	111,273	36,310	35,820	36	23,237	48,034	16,779	15%

Notes:

All flow data from SWE SWDataSet.

(1) Sum of Franklin Canal gage, Riverside Canal gage, EPW diversions, WWTP returns, and drains diverted minus Ascarate Wasteway.
(2) 10 % x (1).
(3) Flow data from SWE SWDataset.
(4) Flow data from SWE SWDataset.
(5) Flow data from SWE SWDataset.
(6) Sum of (3) plus (4) plus (5).
(7) Undiverted Fabens Drains is the sum of the River Drain, Middle Drain, Mesa Drain, Cuadrilla Drain, and Fabens Intercepting Drain minus drain water diverted to Tornillo Canal from 1947-1983, and the Fabens Waste Drain from 1984-2017.
(8) Minimum of Hudspeth Feeder Canal flows (4) and Undiverted Fabens Drains (7).
(9) Fabens WWTP discharge into Fabens Waste Channel that can be diverted into Hudspeth Feeder Canal.
(10) Hudspeth Feeder Canal (4) minus Fabens Drains in Hudspeth Feeder Canal (8) minus Fabens WWTP discharge (9).
(11) Sum of Tornillo Canal at Alamo Alto (3) plus Waste in Hudspeth Feeder Canal (10).
(12) Total Waste to Hudspeth (11) in excess of 10 % of EPCWID (El Paso Valley) Supply (2).
(13) Total Waste to Hudspeth (11) / EPCWID (El Paso Valley) Supply (1).

Table 23-1

Spatial Scale of Selected LRG Data
Used in ILRG Model

LRG Data	Portion of Study Period 1940 - 1978	1979 - 2017
River Flows	Point (gage)	
River Headgate Diversions	Point (gage) (1)	
Farm Headgate Deliveries	Valley (2)	District (3)
Canal Loss	Valley (2)	District (3)
Total Waste	Valley (2)	District (3)
Irrigated Area	Valley (2, 4)	District (3, 4)
Cropping Pattern	Valley (2)	District (3)
ET/climate	Basin (5)	
Soils	Basin (5)	
Drain Flows	Point (gage/estimates) (1)	

Notes:

(1) Reported by Canal - Rincon, Leasburg, Eastside (NM and TX), Westside (NM and TX), American, Franklin, Riverside, and Acequia Madre.
(2) Reported by Valley - Rincon, Leasburg, Mesilla (Eastside plus Westside in NM and TX), and El Paso Valley.
(3) Reported by District - EBID, EPCWID, and HCCRD total There are several years after 1979 in which EBID data is separated into Rincon and Mesilla (including Leasburg) totals.
(4) Irrigated area determined by NDVI analysis of satellite imagery in selected years from 1975 - 2017 can be totaled by subarea.
(5) Computed for Rincon-Mesilla basin and Hueco basin.

Table 26-1
Summary of Estimated Data for Surface Water Dataset
Rio Grande Project, Hudspeth County, and Mexico
1903 - 2017

Structure	Start	Period of Record	Missing Data	Method for Estimating Missing Data
Canals - Hueco				
Acequia Madre	Pre-1903	1924 - 1925, 1930 - 1936, 6/1938 - 2006, 2008 - 2017	1903 - 1923, 1926 - 1929, 1937 - 5/1938, 2007	1903 -1923: Used 1924 - 1925 monthly regression with Courchesne gage capped at an estimated diversion capacity (300 cfs) and limited to season of use Mar 1 – Nov 30.
				1926 - 1929 and 1937: Used 1930 - 1936 monthly regression with Courchesne gage capped at an estimated diversion capacity (300 cfs) and limited to season of use Mar 1 – Nov 30.
				1/1938 – 5/1938: Used 1938 annual value less data for period of record in 1938 distributed from Mar - May using Franklin Canal flows.
				2007: Used reported 2007 annual diversion in Rio Grande Compact Commission Report distributed monthly using Franklin Canal diversions.
Franklin Canal	1889	1914 -1916, 1918 - 2017*	1903 – 1913, 1917	1903 -1913 and 1917: Used 1918 - 1938 monthly regression with Courchesne gage capped at an estimated diversion capacity (320 cfs) and limited to season of use Mar 1 – Nov 30. Do not have complete winter diversions in recent years - these winter diversions were not estimated.
Tornillo Canal at Alamo Alto	1947	1947 - 2017*	Various months 1995 – 1996 and 2004 – 2005	Various months 1995 - 1996 and 2004 - 2005: Used 1985 - 1994 monthly regression with Riverside Canal.
Hudspeth Feeder Canal	May-47	1947 - 2017*	2011 - 2012	2011 - 2012: Used 2005 - 2010 monthly regression with Franklin Canal.
Hudspeth Canal (Tornillo End)	1925	1935 - 1955 (ann)	1925 - 1934	1925 - 1934: Estimated flow using water balance (Tornillo Canal heading flow less seepage loss (15%*Tornillo Canal heading) less crop demand for Tornillo acres (CIR*acres/irrigation efficiency) less Tornillo Waste End flows).
				1935 - 1955: Annual data distributed monthly using Tornillo Canal heading flows.

Table 26-1
Summary of Estimated Data for Surface Water Dataset
Rio Grande Project, Hudspeth County, and Mexico
1903 - 2017

Structure	Start	Period of Record	Missing Data	Method for Estimating Missing Data
Canals - Hueco (cont.)				
Juarez River Diversions (below International Dam)	Pre-1903	Annual estimates 1930-1936, 1938-1947, and 1950-1984	1903 - 1929, 1937, 1948-1949, 1985 - 2017	1903 - 1929: Estimated flows based minimum of unmet demand (Farm Budget spreadsheet) limited by estimated flow below International Dam (Courchesne minus Franklin Canal minus Acequia Madre) minus Riverside Canal when applicable.
				1930-1936, 1938-1947, and 1950-1984: Distributed annual estimates monthly using Acequia Madre flows.
				1937: Set equal to 1936 annual estimate.
				1948 - 1949: Estimated flows based on gage differences from Island Station to Fort Quitman.
				1985 - 2017: Did not estimate because there are no gage records.
Wasteways - Hueco				
Franklin Settling Basin WW	1938?	No data		6/1938 – 2/1999: Data provided by Peggy Barroll, NMOSE. Computed using water balance approach (American Canal diversions less Franklin Canal diversions less City of El Paso municipal diversions). Split total computed waste 50/50 between Franklin Settling Basin and Leon St. wasteways. Estimates do not consider transit losses.
Leon St WW	1938?	No data		
Ascarate WW	1916?	1938 - 1954 (ann), 1955 - 2005*	1916 - 1937, 2011 - 2012	1916 - 1937: Used annual regression (1938 - 1949) with Franklin Canal and distributed annual data into monthly values proportional to Franklin Canal flows.
				1938 - 1955: Distributed annual data into monthly values proportional to Franklin Canal flows.
				2011 - 2012: Assumed no Ascarate Wasteway flows until more data become available due to little to zero flows reported since the completion of the American Canal Extension.

Table 26-1
Summary of Estimated Data for Surface Water Dataset
Rio Grande Project, Hudspeth County, and Mexico
1903 - 2017

Structure	Start	Period of Record	Missing Data	Method for Estimating Missing Data
Wasteways - Hueco (cont.)				
Riverside WW#1	1928?	1938 - 1955 (ann combined)**, 1981 - 1984, 1993 - 2017*	Pre-1938, 1956 - 1980,1985 - 1982	1928 – 1937: Used annual regression for combined Riverside WW#1 and WW#2 with Riverside Canal (1938 - 1949) and distributed annual data into monthly values using Riverside Canal diversions. Split between WW#1 and WW#2 using 1981 - 2013 average annual split. Assumed Riverside WW#2 flows do not start until 1930.
				1938 – 1955: Distributed annual data into monthly values proportional to Riverside Canal diversions. Split between WW#1 and WW#2 using 1981 – 2013 average annual split.
Riverside WW#2	1930?			1956 - 1980 and 1985 - 1992: Used annual regression for combined Riverside WW#1 and WW#2 with Riverside Canal (1993 - 2003) and distributed annual data into monthly values using Riverside Canal diversions. Split between WW#1 and WW#2 using 1981 - 2013 average annual split.
Municipal - Hueco				
Northwest WWTP Returns	1987	9/2002 - 2017*	1987 - 8/2002	1987 - 8/2002: Data provided by Nabil Shafike, NMISC - computed using regression with Mesilla EPWU ground water pumping.
Haskell WWTP Returns [(1)]	1923	1936 - 1939, 1940 - 1948**, 1949 - 1959, 1960 - 1975**, 1977 - 2017*	1923 - 1935, 1976, 1/1998 - 9/1998	1923 - 1935: Used annual 1936 - 1940 regression with EPWU pumping. Distributed annual data evenly in each month (divide by 12).
				1976: Used average 1975 and 1977 monthly flow data (i.e., Jan 1976 flow = average Jan 1975 and Jan 1977).
				1/1998 - 9/1998: Used average 1997 and 1999 monthly flow data.
Bustamante WWTP Returns	1991	9/1995 - 2017*	1991 – 8/1995	1991 - 1994: Annual volume derived from reported 1996 influent in gallons per day per capita scaled to Bustamante service area proportion of total City of El Paso population and subtracted Socorro WWTP flows (1991 - 1993). Annual volume divided by 12 to obtain monthly values.
				1/1995 - 8/1995: Annual reported value minus sum of remainder monthly flows (9/1995-12/1995) divided by 8.

Table 26-1
Summary of Estimated Data for Surface Water Dataset
Rio Grande Project, Hudspeth County, and Mexico
1903 - 2017

Structure	Start	Period of Record	Missing Data	Method for Estimating Missing Data
Municipal - Hueco (cont.)				
Socorro WWTP	1967	1967 - 2/1993	1985 - 1988	1967 - 1984: Distributed annual reported volumes evenly into each month (divided by 12). 1985 - 1988: Computed annual volume using linear regression between 1984 and 1989 annual data. Distributed annual estimates evenly into each month (divided by 12). 10/1991: Computed as average 9/1991 and 11/1991 flows.
Juarez Sewage to river	1926?	1940 - 1950 ann	1926 - 1939; 1951 - 2017	1926 - 1939: Data not estimated (not enough information available to estimate). 1940 - 1950: Distributed annual reported estimates evenly into each month (divided by 12). 1951 - 2017: Assume zero (discharge zero by late 1940s).
Juarez Sewage to canals	1926	1950 - 1984	1926 - 1949 and 1985 - 2017	1950 - 1984: Annual reported estimates divided by 12. 1926 - 1949 and 1985 - 2017: Used JMAS pumping provided by MMA multiplied by 49% (same methodology as IBWC 1989 report) minus Juarez Sewage to river (1940 - 1950).
Robertson-Umbenhauer WTP (aka Canal St. WTP)	Nov-43	11/1943 - 2017**	Records for total El Paso WTP prior to 2007	1943 - 1992: Robertson-Umbenhauer WTP equal to total City of El Paso until Jonathan Rogers comes online in 1993.
Jonathan Rogers WTP	1993	1993 - 2017**		1993 - 2006: Split total City of El Paso into each WTP using distribution from available data from 2007 - 2013.
Fabens WWTP	2001	2001 - 2017**	1/2001 - 5/2001, 7/2004, 10/2004	1/2001 - 5/2001 , 7/2004, and 10/2004: Computed using monthly averages from prior and subsequent year.
Municipal - Rincon-Mesilla				
Hatch WWTP	1940	2000 - 2017*	1940 - 1999	1940 - 1999: Computed using regression with population (no pumping data available).
			1/2000 - 9/2000, 11/2005, 10/2013	1/2000 - 9/2000, 11/2005, and 10/2013: Computed using monthly averages from prior and subsequent year.
Las Cruces WWTP	1940	1976 - 2017*	1940 - 3/1976, 5/1979 - 6/1979, 4/1985, 9/1985 - 10/1985	1940 - 3/1976, 5/1979 - 6/1979, 4/1985, and 9/1985 - 10/1985: Computed using regression with pumping.
Anthony NM WWTP	1989	2002 - 2017*	1989 - 1995	1989 - 1995: Computed using regression with pumping.

Table 26-1
Summary of Estimated Data for Surface Water Dataset
Rio Grande Project, Hudspeth County, and Mexico
1903 - 2017

Structure	Start	Period of Record	Missing Data	Method for Estimating Missing Data
Municipal - Rincon-Mesilla (cont.)				
Anthony TX WWTP	1953	2005 - 2017*	1953-2004, 1/2005-4/2005, 2/2006, 11/2006, 8/2007, 8/2016-12/2017	1953 - 2004: Computed using regression with pumping. 1/2005 - 4/2005, 2/2006, 11/2006, 8/2007, and 8/2016 - 12/2017: Computed using monthly averages from prior and subsequent year.
El Paso Electric WWTP	1950	2004 - 2017*	1950 - 2003, 2/2005, 10/2005 - 12/2005, 8/2006, 5/2009	1950 - 2003: Computed using regression with pumping. 2/2005, 10/2005 - 12/2005, 8/2006, and 5/2009: Computed using monthly averages from prior and subsequent year.
Gadsden School District WWTP	1991	1991 - 2017*	1/2016 - 4/2016, 11/2016, 1/2017, 6/2017, 12/2017	1/2016 - 4/2016, 11/2016, 1/2017, 6/2017, 12/2017: Computed using monthly averages from prior and subsequent year.
Total Sunland Park + Santa Teresa	1972	2004 - 2017	1972 - 2003	1972 - 2003: Computed using monthly averages from prior and subsequent year.

Notes:
All estimated data calculations in source folder: LRG.Doc.SW118.
*Missing months of data within period of record.
**Records combined with other flows, split total diversions out by structure.
(1) Records from 1940 - 1948 and 1960 - 1975 include Ascarate and Yselta EPCWID plant discharges.
(2) Annual estimates from Rio Grande Joint Investigations (1938), Carreno (1957), and IBWC (1989).

Table 28-1
Summary of Annual and Irrigation Season Calibration Statistics
ILRG Model
1951-2017

	Location	Ann/Irr (1)	Nash-Sutcliffe Efficiency (NSE)	Coeff. of Determin. (R^2)	Index of Agreement (d)	Mean Error (BIAS)	Percent Bias (PBIAS)	Mean Absolute Error (MAE)	Percent MAE (PMAE)	Root Mean Squared Error (RMSE)	RMSE - Obs Std Dev Ratio (RSR)	(2) Log NSE
	Caballo Outflow	A	0.93	0.93	0.98	617	0.1%	47,646	7.8%	58,055	0.26	0.93
	Rio Grande at El Paso	A	0.91	0.92	0.98	-376	-0.1%	41,484	12.3%	53,864	0.30	0.90
	Rio Grande at Fort Quitman	A	0.83	0.86	0.96	-13,875	-13.9%	35,666	35.8%	48,108	0.41	0.30
	Rincon Diversion	I	0.78	0.82	0.95	4,664	6.5%	9,889	13.8%	13,113	0.47	0.86
	Leasburg Diversion	I	0.82	0.84	0.95	3,878	3.6%	14,379	13.3%	18,241	0.42	0.86
	Eastside Diversion	I	0.75	0.81	0.94	77	0.1%	8,099	13.6%	10,836	0.50	0.74
	Westside Diversion	I	0.80	0.84	0.95	3,253	2.1%	16,704	11.0%	21,247	0.45	0.81
	American Diversion	I	0.79	0.79	0.93	1,585	0.7%	34,604	15.1%	41,637	0.46	0.81
	Riverside Canal Gage	I	0.62	0.64	0.88	8,135	5.4%	33,251	22.1%	40,208	0.62	0.59
	Franklin Canal Gage	I	0.55	0.73	0.91	-3,246	-4.6%	13,373	18.8%	18,231	0.67	0.73
	Acequia Madre Diversion	I	0.93	0.93	0.98	1,275	2.7%	2,956	6.4%	4,829	0.27	0.93
(3)	Total HCCRD Supply	I	0.86	0.87	0.97	-817	-1.2%	12,976	19.5%	15,752	0.37	0.69
	EBID FHG	I	0.79	0.81	0.95	-1,738	-1.0%	25,768	15.2%	33,881	0.46	0.79
	EPCWID FHG	I	0.65	0.67	0.87	-5,726	-4.7%	20,218	16.5%	27,008	0.59	0.79
	HCCRD FHG	I	0.62	0.64	0.86	1,661	5.3%	8,922	28.6%	11,373	0.61	0.57
	EBID Pumping	I	0.85	0.86	0.96	-850	-0.7%	23,365	19.9%	30,861	0.39	0.80
	EPCWID Pumping	I	0.79	0.79	0.94	-3,065	-6.2%	15,478	31.4%	19,564	0.46	0.51
	HCCRD Pumping	I	0.56	0.64	0.86	-2,276	-35.3%	3,381	52.5%	5,203	0.66	0.61
(4)	Rincon Valley Drains	A	0.11	0.32	0.74	-2,252	-16.3%	4,707	34.1%	6,140	0.94	0.50
(5)	Mesilla Valley Drains	A	0.82	0.83	0.95	-6,132	-6.9%	16,273	18.2%	20,406	0.43	0.72
(6)	El Paso Valley Drains	A	0.61	0.63	0.89	-462	-0.8%	14,026	25.1%	17,745	0.62	0.59

Performance Evaluation Criteria for Selected Statistics from Moriasi (2015)

Rating	NSE	R^2	d	PBIAS
Very Good	0.80 < NSE	0.85 < R^2	0.90 < d	PBIAS < +/- 5
Good	0.70 < NSE ≤ 0.80	0.75 < R^2 ≤ 0.85	0.85 < d ≤ 0.90	+/- 5 ≤ PBIAS < +/-10
Satisfactory	0.50 < NSE ≤ 0.70	0.60 < R^2 ≤ 0.75	0.75 < d ≤ 0.85	+/- 10 ≤ PBIAS < +/-15
Not Satisfactory	0.00 < NSE ≤ 0.50	0.18 < R^2 ≤ 0.60	0.60 < d ≤ 0.75	+/- 15 ≤ PBIAS < +/-30
Unacceptable	NSE ≤ 0.00	R^2 ≤ 0.18	d ≤ 0.60	+/- 30 ≤ PBIAS

Notes:

(1) Annual statistics denoted with (A), irrigation season statistics denoted with (I)
(2) Log NSE computed using modeled and observed flows adjusted by adding 1,000 AF to streamflows and 100 AF to diversions, farm headgate deliveries, pumping, and drains flows
(3) Total Hudspeth Supply includes Tornillo Drain, Tornillo Canal at Alamo Alto, and Hudspeth Feeder Canal
(4) Rincon Valley Drains statistics are computed for 1951-2002 due to limited data available after 2002
(5) Mesilla Valley Drains are computed for 1951-2013 due to limited data available after 2013
(6) El Paso Valley Drains include the Fabens Waste Drain and the Tornillo Drain

Table 30-1

List of Original Model Runs
ILRG Model

Run No.	Name	Compare To Run	Notes
0	Historical Calibration Run		
1	Historical Base Run (All Pumping On)	0	
2	All Pumping Off	1	(1)
3	NM Pumping Off	1	(1)
4	TX Pumping Off	1	(1,2)
5	MX Pumping Off	1	(1)
6	R-M Pumping Off	1	(1,3)
7	TX Mesilla Pumping Off	1	(1)
8	TX Non-Irrigation Pumping Off	1	(1)
9	NM Non-Irrigation Pumping Off	1	(1)
10	MX Non-Irrigation Pumping Off	1	(1)
11	D1/D2 Allocation (All Pumping On)	1	(4)
12	D3+Carryover Allocation (All Pumping On)	11	(4)
13	Reduced Waste	1	

Notes:
(1) Corresponding WWTP returns and urban deep percolation returns are also turned off (no UDP simulated in Mexico).
(2) Including Texas Mesilla (EPCWID Mesilla and EPW Canutillo Wellfield).
(3) Including Texas Mesilla and Mexico Conejos-Medanos.
(4) Project allocation procedure simulated for 1950-2017.

Table 30-2

List of Additional Model Runs
ILRG Model

Run No.	Name	Compare To Run	Notes
14	All Hueco Pumping Off	1	
14a	TX Hueco Pumping Off	1	
14b	MX Hueco Pumping Off	1	
14c	Texas WWTP Discharges Off	1	
14d	TX Hueco Pumping Off (Returns Left On)	1	
15	Early EPCWID Ops (WWTP & Fabens Drains)	1	(1)
15a	Early EPCWID Ops (WWTP)	1	(2)
15b	Early EPCWID Ops (Fabens Drains)	1	(3)
15c	Early EPCWID Ops (TX Hueco Pumping Off)	15	(1)
16	Conj Use 1: Hist All Acres D1/D2 (Hist M&I)	1	(1,4,9)
16a	Conj Use 1a: Hist All Acres D1/D2 (1978 M&I)	1	(1,5,9)
17	Conj Use 2: Hist Proj Acres (Hist M&I)	1	(1,6,9)
17a	Conj Use 2a: Hist Proj Acres (Pre-Comp M&I)	1	(1,7,9)
18	Conj Use 3: Auth Proj Acres (Pre-Comp M&I)	1	(1,8,9)

Notes:

(1) EPCWID increased use of Fabens drain flows; charge EPCWID for use of EPW WWTP returns and drain flows; No ACE or Haskell credits.
(2) Charge EPCWID for use of EPW WWTP returns; no ACE or Haskell credits.
(3) EPCWID increased use of Fabens drain flows and charge for drain flow use.
(4) Conjunctive use pumping on historical Project acres; pumping on NM GW only acres; D1/D2 allocation and accounting for 1951-2017; limit 10-year average irrigation pumping to 1951-1978 average; historical M&I pumping.
(5) Same as (4) except limit M&I pumping to 1951-1978 max.
(6) Conjunctive use pumping on historical Project acres; no pumping on NM GW only acres; D1/D2 allocation and accounting for 1951-2017; no limit on irrigation pumping; historical M&I pumping.
(7) Same as (6) except limit M&I pumping to pre-compact amounts.
(8) Conjunctive use pumping on authorized acres; irrigation of authorized Project acres every year 1940-2017 (EBID-88,000 ac, EPCWID-67,000 ac); irrigation of 17,750 acres (max) for HCCRD1 every year; irrigation of historical Juarez acres; no pumping on NM GW only acres; limit M&I pumping to pre-compact amounts, no EPW use of Project water.
(9) Turn off Las Cruces WWTP discharge and urban deep percolation that originates from pumping of Jornada wells.

Table 30-3

Average Annual Change in Simulated Flows
Rincon-Mesilla Pumping Off
1951-2016 (AF)

	Change in Model Output	(1) ILRG Model (Annual)	(2) ILRG Model (Irrigation Season)	(3) Texas Model (Hutchison)	(4) Texas Model (Moran)
	Reservoir Evaporation	17,600	14,800	n/a	n/a
(5)	Caballo Reservoir Releases	-38,200	-38,100	n/a	n/a
	Caballo Reservoir Spills	19,500	15,500	n/a	n/a
	Rincon-Mesilla Diversions	48,000	47,900	n/a	95,200
	Rincon-Mesilla FHG Deliveries	33,800	33,700	n/a	69,700
	Rio Grande at El Paso Flows	79,800	33,200 (5)	124,700	51,700
	EPCWID (EPV) Diversions	20,600	17,900	n/a	n/a
	EPCWID (EPV) FHG Deliveries	8,700	8,700	n/a	n/a
	Rio Grande at Ft. Quitman Flows	56,700	18,000 (5)	n/a	n/a

Notes:

(1) New Mexico ILRG Model (Run 6 minus Run 1) annual.
(2) New Mexico ILRG Model (Run 6 minus Run 1) irrigation season.
(3) Texas Model (no reoperation); 100% R-M Pumping Off (Hutchison, 2019).
(4) Texas Model (crude redistribution); 100% R-M Pumping Off (Moran, 2019).
(5) Not including spills.

Table 31-1

Summary of ILRG Model Sensitivity Analyses
New Mexico Pumping Impacts (Run 3 minus Run 1)
Average Change in Run Differences

Model Output	Run 3 - Run 1 (Original)	Alluvial Aquifer Hydraulic Conductivity (AF)	%	River Bed Conductance (AF)	%	Canal Bed Conductance (AF)	%	Drain Bed Conductance (AF)	%	Crop Irrigation Requirement (AF)	%
Project Storage	156,865	2,483	2%	-160	0%	7,997	5%	920	1%	29,195	19%
Caballo Outflow	-16,607	-19	0%	171	-1%	-543	3%	71	0%	-2,741	17%
El Paso Flow	61,104	1,023	2%	-187	0%	3,563	6%	52	0%	16,282	27%
Fort Quitman Flow	48,960	829	2%	-261	-1%	3,069	6%	56	0%	9,052	18%
RHG Div (EBID)	46,290	1,234	3%	2,183	5%	3,292	7%	905	2%	8,292	18%
RHG Div (EPCWID)	18,465	419	2%	272	1%	1,256	7%	-70	0%	7,476	40%
RHG Div (HCCRD)	6,547	112	2%	134	2%	261	4%	54	1%	3,290	50%
FHG Deliv (EBID)	31,204	-480	-2%	233	1%	1,801	6%	165	1%	4,589	15%
FHG Deliv (EPCWID)	11,745	66	1%	109	1%	755	6%	-115	-1%	5,033	43%
FHG Deliv (HCCRD)	1,642	-62	-4%	44	3%	-5	0%	41	2%	1,641	100%
R-M GW Storage	316,097	-2,557	-1%	1,236	0%	13,836	4%	531	0%	86,288	27%
Hueco GW Storage	321,784	4,080	1%	-100	0%	9,168	3%	364	0%	229,186	71%

Notes:

(1) Change in Run 3 minus Run 1 differences for a 10% increase in selected input parameters/data.
Run 3 (No NM Pumping) minus Run 1 (Historical Base Run)

(2) Percent change calculated using the following formula:

$$\frac{(Run\ 3^{*}\ minus\ Run\ 1^{*})\ minus\ (Run\ 3\ minus\ Run\ 1)}{(Run\ 3\ minus\ Run\ 1)}$$

(3) Changes in storage and flows are annual. Changes in RHG and FHG are irrigation season.

Appendix 17

Errata
Rebuttal Expert Report
Gregory K. Sullivan, P.E.
and
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Second Edition

Report Text

P. vi, Bullet 6, Line 1:	"River Conductance" should read "River Bed Conductance"
P. vi, Bullet 7, Line 1:	"Canal Conductance" should read "Canal Bed Conductance"
P. vi, Bullet 8, Line 1:	"Drain Conductance" should read "Drain Bed Conductance"
P. 1, Bullet 6, added:	Also on July 15, 2020, the New Mexico experts submitted revised or second editions of their opening expert reports.
P. 2, Paragraph 4, added:	A second edition of the SWE Rebuttal Report was prepared to describe corrections and improvements that have been made to the ILRG Model, to report the results of the model re-tuning, and to present the results of the updated Base Run (Run 1) and alternative scenario runs (Runs 2 – 18). This second edition report also corrects typographical errors in the original SWE Rebuttal Report. A new Appendix 17 is attached that contains an errata list for Sections 17-29 and 31, a redline depiction of the changes to Section 30, and a list of the figures, tables, and appendices revised for this second edition.
P. 7, Paragraph 6, Line 4:	"ILRG reflect" should read "ILRG Model reflect"
P. 8, Paragraph 5, Line 6:	"evaluated" should read "evaluation"
P. 9, Paragraph 5, Line 6:	"impacts being caused" should read "impacts caused"
P. 13, Paragraph 2, Line 1:	"(v111)" should read "(v116)"
P. 14, Paragraph 6, Line 8:	"Run 14c)" should read "(Run 14c)"
P. 25, Table for Run 14a, Line 2:	"-900" should read "-600", and "1,200" should read "-7,800"
P. 25, Table for Run 14a, Line 3:	"-400" should read "-300", and "1,600" should read "-4,000"
P. 25, Table for Run 14d, Line 2:	"3,400" should read "8,200", and "3,600" should read "3,400"
P. 25, Table for Run 14d, Line 3:	"1,900" should read "5,000", and "2,800" should read "2,000"
P. 26, Table for Run 14c, Line 2:	"-6,300" should read "-15,200", and "-21,300" should read "-25,000"
P. 26, Table for Run 14c, Line 3:	"-3,500" should read "-8,200", and "-10,600" should read "-11,700"
P. 32, Paragraph 8, Line 3:	"and discharges" should read "discharges"
P. 32, Paragraph 8, Line 4:	"discharges" should read "and discharges"
P. 33, Paragraph 2, Line 4:	"Figure 19-16" should read "Figure 19-13"
P. 49, Paragraph 1, Line 3:	"significance" should read "significant"
P. 54, Paragraph 3, Line 6:	"variable. Rio Grande inflows to Project storage are supply is managed" should read "variable Rio Grande inflows to Project storage are managed"
P. 55, Paragraph 1, Line 6:	"no" should read "not"
P. 60, Paragraph 1, Line 2:	"irrigation from" should read "irrigation season from"

P. 70, Paragraph 5, Line 6:	"15%" should read "16%"
P. 70, Paragraph 5, Line 6:	"(satisfactory to very good)" should read "(not satisfactory to very good)"
P. 71, Paragraph 2, Line 3:	"relative MAE" should read "PMAE"
P. 71, Paragraph 2, Line 4:	"34%" should read "36%"
P. 71, Paragraph 4, Line 4:	"three" should read "one"
P. 71, Paragraph 5:	"Of the three NSE values that are less than 0.50, two are for HCCRD – FHG deliveries and the related supplemental pumping to meet unmet demands. The simulated Total HCCRD Supply is simulated well with an NSE of 0.89. The less impressive simulation of HCCRD FHG deliveries is hampered by the general lack of information disclosed by Texas regarding how HCCRD operates. The third NSE value less than 0.50 is for the aggregated Rincon Valley drain flows which on average after 1950 flowed less than 15,000 AF/y." should read "The only NSE value less than 0.50 is for the aggregated Rincon Valley drain flows which on average after 1950 flowed less than 15,000 AF/y."
P. 72, Paragraph 7, Line 2:	"0.94" should read "0.93"
P. 73, Paragraph 3, Line 7:	"0.94" should read "0.93"
P. 75, Paragraph 2, Line 6:	"-1.6%" should read "-1.8%"
P. 82, Paragraph 5, Line 4:	"14,900" should read "17,800"
P. 82, Paragraph 5, Line 5:	"64,100" should read "54,600"
P. 86, Paragraph 5, Line 3:	"years, but not all, these impacts are particularly offset" should read "years some, but not all, of these impacts are offset"
P. 90, Paragraph 5, Line 1:	"reoperation" should read "redistribution"
P. 93, Table, Heading:	"Original (v 106) and Updated (v 111)" should read "Original (v106) and Updated (v116)"
P. 93, Table, Line 1:	"(v111)" should read "(v116)"
P. 93, Table, Line 3:	" -0.3" should read "-0.9"
P. 93, Table, Line 4:	"-1.4" should read "-0.7"
P. 93, Table, Line 7:	"-2.3" should read "-3.0"
P. 93, Table, Line 8:	"1.6" should read "2.3"
P. 93, Table, Line 9:	"-0.5" should read "-0.6"
P. 93, Paragraph 4, Line 2:	"44,700" should read "47,600"
P. 93, Paragraph 4, Line 2:	"54,700" should read "58,100"
P. 95, Paragraph 2, Line 4:	"average overprediction or underprediction" should read "average underprediction"

P. 95, Paragraph 2, Line 5:	“10%” should read “5%”
P. 95, Paragraph 2, Line 6:	“Good” should read “Very Good”
P. 102, Paragraph 2, Line 1:	“(v111)” should read “(v116)”
P. 104, Bullet 7, added:	River Headgate Demand - Rearrange the equation that computes the river headgate demands so that the tuning factor is only applied to the crop, soil moisture, and EPW demands, and not to the conveyance losses and EPCWID use of WWTP discharges and drain flows.
P. 104, Bullet 8, added:	EPCWID Allocation Limit - Adjust the rule that limits EPCWID diversions when the EPCWID has less remaining allocation than demand.
P. 104, Bullet 9, added:	EPCWID FHG Deliveries – Add river seepage as an independent term in the equation that computes the EPCWID farm headgate deliveries.
P. 104, Bullet 10, added:	ACE Credit – Revise the rule that computes the ACE Credit to use the equation that has historically been most frequently used in the Project accounting.
P. 105, Bullet 5, added:	Rincon and Mesilla Valley Canal Capacities – Reduce the simulated capacity of the Rincon, Leasburg, Eastside, and Westside canals to limit the simulated maximum monthly diversions consistent with historical diversion records.
P. 111, Bullet 4, Line 2:	“with a slight underprediction trend throughout the “should read “with some underprediction late in the”
P. 115 to 135, Section 30:	Section 30 changes are documented in the redline version of the text for this section that is included in this appendix as Attachment 17-A.
P. 137, Bullet 1, Line 3:	“(2% or less).” should read “(4% or less)
P. 137, Bullet 3, Line 4:	“(4% - 8%)” should read “(0% - 7%)”
P. 137, Bullet 3, Line 5:	“(3 - 4%)” should read “(3% - 5%)”
P. 137, Bullet 3, Line 6:	“(4% - 6%)” should read “(3% - 6%)”
P. 137, Bullet 5, Line 1	“had” should read “has”
P. 138, Paragraph 1, Line 2	“17% - 27%” should read “15% - 43%”

Figures, Tables, and Appendices Revised to Correct Typographical Errors

P. 148, Figure 19-3	Note "Missing Fabens Waste Drain flows in 1992, and in certain months in 1993-1996, 2003-2004, and 2012." should read "Missing Fabens Waste Drain flows in 1992, and in certain months in 1993-1996, 2003, and 2012."
P. 151, Figure 19-6	Note "(2) EPCWID Authorized Acres Demand computed as 3.024 AF/acre x EPCWID authorized acres (69,010)." should read "(4) EPCWID Authorized Acres Demand computed as 3.024 AF/acre x EPCWID authorized acres (69,010)."
P. 155, Figure 19-10	Note "(2) Sum of EPCWID and EBID irrigation pumping CU (incl. primary ground water lands) from SWE CFB Model plus Texas M&I pumping from NMR-M Model and Hueco Model minus return flows from NMR-M Model and Hueco Model inputs." should read "(2) Sum of EPCWID and HCCRD irrigation pumping CU from SWE CFB Model plus Texas M&I pumping from NMR-M Model and Hueco Model minus return flows from NMR-M Model and Hueco Model inputs."
P. 156, Figure 19-11	Note "(2) Sum of EPCWID and EBID irrigation pumping CU (incl. primary ground water lands) from SWE CFB Model plus Texas M&I pumping from NMR-M Model and Hueco Model minus return flows from NMR-M Model and Hueco Model inputs." should read "(2) Sum of EPCWID and HCCRD irrigation pumping CU from SWE CFB Model plus Texas M&I pumping from NMR-M Model and Hueco Model minus return flows from NMR-M Model and Hueco Model inputs."
P. 159, Figure 19-14	Note "(1) Socorro WWTP discharges estimated 1967 - 1988 from SWE SWDataSet." should read "(1) Monthly Socorro WWTP discharges estimated 1967 - 1988 from SWE SWDataSet (annual data only 1967 - 1984)."
P. 161, Figure 19-16	Note "(5) Fabens Waste Drain flows were estimated in 1992 and some months in 1993 - 1996 and 2003." should read "(5) Fabens Waste Drain flows were estimated in 1992 and some months in 1993 - 1996, 2003, and 2012."
P. 162, Figure 19-17	Note "(4) Usable Drain Supply at Fabens computed as the sum of the River Drain plus Middle Drain (1940 - 1983) and 70% of Fabens Waste Drain (1984 - 2017). Fabens Waste Drain flows were estimated in 1992 and some months in 1993 - 1996 and 2003." should read " (4) Usable Drain Supply at Fabens computed as the sum of the River Drain plus Middle Drain (1940 - 1983) and 70% of Fabens Waste Drain (1984 - 2017). Fabens Waste Drain flows were estimated in 1992 and some months in 1993 - 1996, 2003, and 2012."
P. 170, Figure 23-1	Note "Rincon drain data is unavailable from 2005-2017." should read "Rincon drain data is unavailable from 2006-2017."
P. 196, Figure 29-2	Footnote "Page 1 of 1" was removed.

P. 196, Figure 29-2	Note "Allocation is calculated and used to limit diversions for EBID and EPCWID from 1951-2017." should read "Allocation is calculated and used to limit diversions for EBID and EPCWID from 1950-2017."
P. 196, Figure 29-2	EBID Allocation: "1950 value" should be added
P. 196, Figure 29-2	EPCWID Allocation: "1950 value" should be added
P. 204, Figure 29-6	Footnote "(1) Gross Canal Diversions includes the sum of Acequia Madre diversions, lower river diversions, WWTP flows into canals, and drain returns to canals." should read "(1) Gross Canal Diversions includes the sum of Acequia Madre diversions, lower river diversions, and WWTP flows into canals."
P. 204, Figure 29-6	Footnote "(2) Diversions calculated as river headgate diversion + WWTP returns to canal." should be deleted
P. 234, Table 23-1	Footnote "Reported by Distriect - EBID, EPCWID, and HCCRD total There are several years after 1979 in which EBID data is separated into Rincon and Mesilla (including Leasburg) totals." should read "Reported by District - EBID, EPCWID, and HCCRD total There are several years after 1979 in which EBID data is separated into Rincon and Mesilla (including Leasburg) totals."
P. 241, Table 30-1	D1/D2 Allocation (All Pumping On) value in column Compare to Run "- -" should be "1"
P. 243, Table 30-3	Footnote "New Mexico ILRG Model (Runs minus Run 1) annual." should read "New Mexico ILRG Model (Run 6 minus Run 1) annual."
P. 243, Table 30-3	Footnote "New Mexico ILRG Model (Runs minus Run 1) irrigation season." should read "New Mexico ILRG Model (Run 6 minus Run 1) irrigation season."
P. 243, Table 30-3	Footnote "(4) Texas Model (crude reoperation); 100% R-M Pumping Off (Moran, 2019)." should read "(4) Texas Model (crude redistribution); 100% R-M Pumping Off (Moran, 2019)."

Figures, Tables, and Appendices Revised Due to Updated Base Run (Run 1) and Alternative Scenario Runs (Runs 2 - 18)

P. 147, Figure 19-2	Depletion to Rio Grande at El Paso Flow from Pumping in the Rincon and Mesilla Valleys, ILRG Model, 1950-2017
P. 172, Figure 28-1	Integrated LRG Model Historical Calibration Results, Caballo Release, 1940-2017
P. 173, Figure 28-2	Integrated LRG Model Historical Calibration Results, Rio Grande at El Paso, 1940-2017
P. 174, Figure 28-3	Integrated LRG Model Historical Calibration Results, Rio Grande at Fort Quitman, 1940-2017
P. 175, Figure 28-4	Integrated LRG Model Historical Calibration Results, Rincon Diversion, 1940-2017
P. 176, Figure 28-5	Integrated LRG Model Historical Calibration Results, Leasburg Diversion, 1940-2017
P. 177, Figure 28-6	Integrated LRG Model Historical Calibration Results, Eastside Diversion, 1940-2017
P. 178, Figure 28-7	Integrated LRG Model Historical Calibration Results, Westside Diversion, 1940-2017
P. 179, Figure 28-8	Integrated LRG Model Historical Calibration Results, American Diversion, 1940-2017
P. 180, Figure 28-9	Integrated LRG Model Historical Calibration Results, Riverside Canal Gage, 1940-2017
P. 181, Figure 28-10	Integrated LRG Model Historical Calibration Results, Franklin Canal Gage, 1940-2017
P. 182, Figure 28-11	Integrated LRG Model Historical Calibration Results, Acequia Madre Diversion, 1940-2017
P. 183, Figure 28-12	Integrated LRG Model Historical Calibration Results, Total HCCRD Supply, 1940-2017
P. 184, Figure 28-13	Integrated LRG Model Historical Calibration Results, EBID FHG, 1940-2017
P. 185, Figure 28-14	Integrated LRG Model Historical Calibration Results, EPCWID FHG, 1940-2017
P. 186, Figure 28-15	Integrated LRG Model Historical Calibration Results, HCCRD FHG, 1940-2017

P. 226, Figure 31-1	Summary of ILRG Model Sensitivity Analyses, Alluvial Aquifer Hydraulic Conductivity, Average Annual New Mexico Pumping Impacts (Run 3 minus Run 1), 1951-2017
P. 227, Figure 31-2	Summary of ILRG Model Sensitivity Analyses, River Bed Conductance, Average Annual New Mexico Pumping Impacts (Run 3 minus Run 1), 1951-2017
P. 228, Figure 31-3	Summary of ILRG Model Sensitivity Analyses, Canal Bed Conductance, Average Annual New Mexico Pumping Impacts (Run 3 minus Run 1), 1951-2017
P. 229, Figure 31-4	Summary of ILRG Model Sensitivity Analyses, Drain Bed Conductance, Average Annual New Mexico Pumping Impacts (Run 3 minus Run 1), 1951-2017
P. 230, Figure 31-5	Summary of ILRG Model Sensitivity Analyses, Crop Irrigation Requirement, Average Annual New Mexico Pumping Impacts (Run 3 minus Run 1), 1951-2017
P. 240, Table 28-1	Summary of Annual and Irrigation Season Calibration Statistics, ILRG Model, 1951-2017
P. 243, Table 30-3	Average Annual Change in Simulated Flows, Rincon-Mesilla Pumping Off, 1951-2016
P. 244, Table 31-1	Summary of ILRG Model Sensitivity Analyses, New Mexico Pumping Impacts (Run 3 minus Run 1), Average Change in Run Differences
P. 280-281, Appendix 18	Response to Revised Texas Analyses Submitted Without a Rebuttal Report (figures added)
P. 285-288, Appendix 18	Response to Revised Texas Analyses Submitted Without a Rebuttal Report (figures added)
P. 327-899, Appendix 30 B-AA	Comparison of ILRG Model Runs

Corrections to Run Summaries and Run Comparisons in Appendices 30B – 30AA

Column BB in the "ModelRun" tab in each run summary spreadsheet was corrected to reflect the total Rio Grande Project Storage (Elephant Butte Reservoir + Caballo Reservoir). This change affects the reservoir storage data presented in Figure 29-1. In addition, this change affects the reservoir storage data presented in the upper table on page 3, the upper graph on page 6, the upper left graph on page 11, and the graphs on page 19 for each run comparison included in Appendices 30B – 30AA.

Columns E, S, and AI on the "Diff Charts" tab in each run comparison spreadsheet were corrected to reflect annual Caballo Reservoir release data. This change affects the lower right inset graph for Caballo Reservoir Outflows on page 6 of each run comparison included in Appendices 30B – 30AA.

ATTACHMENT 17A

30.0 ALTERNATIVE RUNS OF ILRG MODEL

The updated ILRG Model (v1116) was used to re-run the no-pumping scenarios and operations scenarios that were presented in the SWE Report (Runs 2 – 13). A list of the original model runs is provided in **Table 30-1**.

In addition to re-running the original 13 scenarios, the updated ILRG Model was used to simulate additional no-pumping scenarios and operations scenarios. These included Run 14 and several variants that simulate the effects of pumping in the Hueco and Run 15 and several variants that simulate early EPCWID operations prior to changes in water use practices. In addition, five other scenarios were simulated (Runs 16, 16a, 17, 17a, and 18) to analyze conjunctive use of surface water and ground water. These conjunctive use scenarios are based on either a D1/D2 level of supplemental pumping or a supplemental pumping level up to the crop demands on the authorized Project acres, and were developed in consultation with representatives and legal counsel for New Mexico. A list of the additional model runs is provided in **Table 30-2**. Additional specifications for the model runs are provided in **Appendix 30-A** including details for Runs 15-18 and details for the WWTP discharges and urban deep percolation returns that are turned off or reduced in certain of the alternative scenarios.

The results from the re-running of the original scenarios and simulation of the new scenarios are presented in a consistent format in the tables and graphs in **Appendix 30**. These include tabular and graphical results similar to those presented in the SWE Report as well as several additional tables and graphs. Unless otherwise noted, all of the results presented in **Appendix 30** are comparisons between an alternative scenario and the Historical Base Run (Run 1). There are 22 pages of tables and graphs included in the run comparisons for each scenario. An overview of the format and content of each of these tables and graphs follows:

- Cover Page (p. 1) – Selected input specifications for the two runs being compared.

- Comparison of ILRG Model Runs (p. 2-3) – This two-page table provides a high-level overview of how the ILRG Model distributes the change in inputs (e.g., change in pumping stress or change in operating rules) into changes in model outputs. The first five rows of values are the average annual pumping stresses in each run, which consist of the irrigation pumping that is on in Run 1 and off in the alternative run, and the total non-irrigation pumping and non-irrigation pumping return flows (WWTP discharges and urban deep percolation). The Total Stress is computed as the sum of the irrigation and non-irrigation pumping less the non-irrigation returns flows. The third column of numbers shows the difference in stress between the two runs being compared. The remainder of the table reports the annual averages for selected ILRG Model outputs and the differences in outputs between the two runs. The fourth and fifth columns of numbers express the average annual output differences as percentages of the change in Total Stress and as percentages of the Base Run values. For the alternative runs that simulate differences in operating rules (i.e. Runs 11-13, 15-18), there are no rows in the table listing the stresses, nor is there a column listing the % Change Stress.

- Annual Differences in ILRG Model Outputs (p. 4-5) – This two-page table lists the differences in model outputs for selected model outputs. These include the differences in irrigation season and annual net RHG Diversions and FHG Deliveries, and differences in annual river flows at the Caballo outlet, El Paso, and Fort Quitman. Net RHG Diversions are defined as the simulated gross diversions less the historical El Paso carriage water that was delivered through the Rincon and Mesilla Valley canals and less the simulated flood control releases that were run through the canals in spill years. Reporting of differences in net RHG Diversions in the model results represents a change from the reporting of differences in gross RHG diversions that were presented in model results described in the SWE Report.

- Simulated Differences in ILRG Model Outputs (p. 6-9) – These four pages of graphs and tables show differences in model outputs expressed as either annual or irrigation season totals. There is a bar chart with the yearly differences in model output, an inset line chart showing the annual outputs that are differenced in the bar chart, and a table summarizing the yearly average differences (annual or irrigation season totals). The differences in net RHG diversions and FHG deliveries are shown in line graphs rather than bar charts.

- Annual Allocation and Charges (p. 10) – This chart summarizes for the two compared runs the simulated annual allocation and delivery charges for EBID and EPCWID, as well as the simulated annual Diversion Ratio computed as the sum of the annual diversion charges for EBID, EPCWID, and Mexico divided by the annual Caballo Reservoir releases.

- Annual Summary of Project Storage and Rio Grande Flows (p. 11) – This chart summarizes for the two compared runs the total year-end project storage in Elephant Butte and Caballo Reservoirs and the annual Rio Grande flow at the Caballo Reservoir outlet, at El Paso, and at Fort Quitman.

- Irrigation Season Summary of Irrigation Operations (p. 12-14) – These three pages of charts summarize for the two compared runs the net RHG diversions, FHG deliveries, irrigation pumping, and RHG diversions minus FHG deliveries (conveyance losses). There are separate pages for EBID, EPCWID, and HCCRD.

- Cumulative Change in Ground Water Storage (p. 15) – This chart summarizes for the two compared runs the cumulative year-end change in ground water storage in the alluvial and non-alluvial aquifers in the Rincon and Mesilla valleys and in the Hueco.

- Monthly Net RHG Diversions (p. 16-18) – These three pages of charts show for the two compared runs the simulated monthly net RHG diversions. There are charts showing the total EBID diversions, total EPCWID diversion, and the total flow to HCCRD.

- End of Month Reservoir Storage (Elephant Butte + Caballo) (p. 19) – This chart shows for the two compared runs the combined end-of-month Project storage in Elephant Butte and Caballo Reservoirs. This doesn't include storage of non-Project water.

- Monthly Rio Grande Flows (p. 20-22) – These three pages of charts show for the two compared runs the simulated monthly Rio Grande flows at the Caballo Reservoir outlet, at El Paso, and at Fort Quitman.

Narrative summaries of the ILRG Model simulations of alternative scenarios are provided below to highlight and explain some of the more significant results shown in the tabular and graphical summaries presented in **Appendix 30**. The tables in **Appendix 30** include annual and irrigation season differences in model outputs for all run comparisons. Averages are computed for the following noteworthy ranges of years:

1951-2017: Period with irrigation pumping development commencing with the beginning of the D1/D2 data period (57/43 allocation until 2006).

1951-1978: D1/D2 data period (57/43 allocation).

1979-2005: Post D1/D2 data period prior to the 2008 OA allocation and accounting that commenced in 2006 (57/43 allocation).

2006-2017: Period when the 2008 OA allocation and accounting was in effect (D3 allocation for 2006 and 2007, D3 allocation plus carryover for 2008-2017).

1985-2017: Period for which alleged damages were computed by Texas (1985-2016) plus the last year of the study period (2017).

1985-2005: Portion of the Texas damages period prior to commencement of the 2008 OA allocation and accounting.

Averages for other portions of the study periods can be computed from the data in the run comparison spreadsheets that are being disclosed with this report.

30.1 All Pumping Off (Run 2)

In Run 2, all irrigation and non-irrigation pumping in the study area is turned off, and all non-irrigation returns, including WWTP discharges and urban deep percolation returns, are also turned off. The changes in irrigation returns that result from turning off the irrigation pumping are simulated by the farm budget processes included in the model.

The ILRG Model re-operates the Project and all of the simulated irrigation systems in the absence of pumping. Turning off pumping increases drain flows and reduces river seepage in most years. During full allocation years, this results in water accumulating in storage as less water needs to be released to meet demands. Accumulating water in storage increases allocations and Caballo Reservoir releases in subsequent dry years (e.g., several years in the 1960s, 1970s, and 2000s). Spills are also larger due to the accumulated water in storage.

The increased allocations result in increased diversions and FHG deliveries to EBID in dry years between 1950 and 1978. During the full allocation years from 1979 – 2002, there is little change in EBID diversions, however FHG deliveries increase modestly due to reductions in the simulated canal conveyance losses in the no-pumping run that allowed more of the water that is diverted to be delivered to the farms. When dry conditions return, EBID diversions and FHG deliveries increase again in 2003 and 2004. EBID diversions increase substantially beginning in 2006 due to the effects that pumping has when the 2008 OA is in effect. As is discussed in Barroll (2019), EBID's allocation under the 2008 OA is sensitive to the diversion ratio. When pumping is turned off, the diversion ratio increases resulting in increased allocations and increased deliveries to EBID. On average from 2006 – 2017, EBID's diversions increase by 148,700~~145,400~~ AF and FHG deliveries increase by 92,700~~93,200~~ AF.

The increase in Project water allocations also results in increased diversions and FHG deliveries to EPCWID in many dry years in the 1950s – 1970s. There are also modest increases in EPCWID diversions during many full allocation years in the 1980s and 1990s because the reduction in EPW WWTP discharges to EPCWID canals results in EPCWID requiring more reservoir releases to meet its demands. Increases in deliveries also occur in several dry years in the 2000s – 2010s although the increases are not near as large under the 2008 OA after 2005 as they are for EBID.

Turning off pumping and the resulting effects on Project operations and deliveries results in increased Rio Grande at El Paso flow in most years averaging 79,000~~80,500~~ AF annually during 1951 – 2017. Of this amount, an average of only 33,100~~38,900~~ AF occurs during the irrigation season (Mar-Oct) and the remaining 45,900~~41,600~~ AF occurs during the non-irrigation season (Nov-Feb) or during reservoirs spill. During the 1985-2005 period, the increase in irrigation season flows, excluding spills, averages 15,700~~28,600~~ AF. A portion of the increase is attributable to turning off New Mexico pumping and a portion is due to turning off Texas pumping. Cessation of pumping also produces substantial increases in flow at Fort Quitman averaging 100,300~~102,900~~ AF annually during 1951-2017.

30.2 NM Pumping Off (Run 3)

In Run 3, all irrigation pumping and all non-irrigation pumping and returns in New Mexico is turned off. This includes all EBID supplemental irrigation pumping, all primary irrigation pumping in the Rincon Valley and Mesilla Valley, and all non-irrigation pumping and associated WWTP discharges and deep percolation returns in New Mexico.

Many of the simulated effects of turning off New Mexico pumping are similar to but smaller than the effects of turning off all pumping in Run 2. There is a similar pattern of accumulations in Project storage that are released in dry years when the simulated Project allocations increase~~d~~. The accumulated storage again leads to larger spills.

EBID diversions increase by an average of 46,300~~46,600~~ AF during 1951-2017, while FHG deliveries increase by an average of 31,200~~33,700~~ AF. When the 2008 OA is in effect during 2006-2017, turning off New Mexico pumping increases EBID diversions by an average of 137,500~~134,200~~ AF, and FHG deliveries increase by an average of 83,900~~84,100~~ AF.

The impacts of New Mexico pumping on EPCWID supply are less than the impacts on EBID. From 1951 – 2017, EPCWID irrigation season diversions increase by an average of 18,500~~19,200~~ AF and FHG deliveries increase by an average of 11,700~~11,600~~ AF. After 1984 when Texas is claiming damages, New Mexico pumping impacts EPCWID irrigation season diversions by an average of 17,200~~13,200~~ AF and irrigation season FHG deliveries by an average of 9,700~~7,400~~ AF (1985-2017). During 1985-2005, prior to implementation of the 2008 OA, EP~~W~~CWID irrigation season diversions increase by an average of 10,900~~7,200~~ AF and irrigation season FHG deliveries increase by an average of 5,100~~3,200~~ AF.

Simulated flows in the Rio Grande at El Paso increase when New Mexico pumping is turned off by an average of 61,100~~62,500~~ AF annually during 1951-2017, of which an average of 22,900~~24,800~~ AF occurs during the irrigation season and 38,200~~37,700~~ AF occurs during the non-irrigation season or during spills. Average annual flows at Fort Quitman during 1951-2017 increase by an average of 49,000~~49,900~~ AF due largely to return flows from increased surface water deliveries and reduced surface water depletions from pumping. This run shows that the Texas Model without reoperation greatly exaggerates the impacts of New Mexico pumping on El Paso flows.

30.3 TX Pumping Off (Run 4)

In Run 4, all supplemental irrigation pumping in EPCWID and HCCRD is turned off, as is all non-irrigation pumping and associated returns in the Texas portion of the Mesilla Valley and in the El Paso Valley. Deliveries of Project water to EPW and the associated return flows continue to be simulated in Run 4.

When Texas pumping is turned off, annual EBID diversions increase by an average of 5,400~~6,600~~ AF/y during 1951-1978, and by an average of 15,500~~20,400~~ AF during 2006-2017 when the 2008 OA is in effect. The impacts of Texas pumping are magnified by the sensitivity of changes in the diversion ratio on EBID allocations. The pattern of impacts on EBID FHG deliveries is similar with impacts to diversions that average 4,300~~4,900~~ AF during 1951-1978 and 9,600~~13,300~~ AF during 2006-2017.

Texas pumping also impacts Project water deliveries to EPCWID. The net effect on EPCWID supply depends on the relative positive effect of reducing depletions from pumping compared to the negative effect of turning off Texas WWTP discharges. During 1951-1978, EPCWID diversions increase by an average of 200~~3,100~~ AF, but FHG deliveries increase by an average of ~~only~~ 2,600~~800~~ AF. During the mostly full supply years of 1979-2005, EPCWID diversions increase by an average of 10,200~~11,900~~ AF to replace the significant reduction in WWTP discharges to the EPCWID canal system.

The reduction in the Texas WWTP discharges due to turning off the non-irrigation pumping and the concurrent increased deliveries of Project water to EPCWID, along with the reduction in stream depletions caused by Texas Mesilla irrigation pumping results in increased Rio Grande at El Paso flow in many years, particularly in the 1980s and 1990s. During 1985-2005, El Paso flows increase by an average of 27,800~~28,200~~ AF during the irrigation season, excluding spills.

30.4 MX Pumping Off (Run 5)

In Run 5, all supplemental pumping in JID and all municipal pumping and associated WWTP discharges in Ciudad Juarez is turned off. Turning off pumping in Mexico has much less effect on Project operations than turning off pumping in New Mexico or Texas.

Turning off Mexico pumping reduces the river and conveyance system losses in delivering Project water to EPCWID farmers. As a result, in full supply years, less water needs to be released from storage to meet EPCWID demands. This results in an accumulation of water in storage that increases allocations and deliveries in later non-full supply years. This is seen in the increased reservoir releases and deliveries in ~~1954,~~ 1955, 1964, 1967, ~~1971,~~ 1977, 1978 and several other years after 2000.

EBID FHG deliveries increase~~d~~ by an average of 2,400~~900~~ AF during 1951-1978, and 2,400~~1,900~~ AF during 2006-2017. EPCWID FHG deliveries increase~~d~~ by similar amounts averaging 1,500~~900~~ AF during 1951-1978 and 2,100~~1,800~~ AF during 2006-2017. The impact of Mexico pumping on the HCCRD supply is larger than on EBID or EPCWID, with the total irrigation season supply to HCCRD increasing by an average of 3,900~~4,800~~ AF during 1951-2007.

Mexico pumping also has a large impact on ground water storage in the Hueco. From 1951-2017, Hueco ground water storage is~~was~~ depleted by an average of 59,500~~59,700~~ AF/y. The effect of Juarez pumping from the new Conejos-Medanos wellfield is evident in the recent changes in Rincon-Mesilla ground water storage.

30.5 R-M Pumping Off (Run 6)

In Run 6, all irrigation pumping and non-irrigation pumping and associated returns in the Rincon and Mesilla basins is turned off. This includes turning off irrigation and non-irrigation pumping in the Texas portion of the Mesilla basin. The purpose of this run is to simulate a scenario that is~~was~~ directly comparable to the 100% reduced pumping run of the Texas Model described in the Hutchison Report.

As expected, the effect of turning off all Rincon-Mesilla pumping in Run 6 has a larger effect than turning off New Mexico pumping in Run 3, but with a similar pattern. Turning off R-M pumping increases the Project delivery efficiency by increasing drain flows, reducing river losses, and reducing canal seepage. In full allocation years, releases from storage can be reduced while still delivering full allocations to EBID and EPCWID. This accumulates water in storage leading to increased allocations and deliveries in dry years, and greater spills in very wet years.

As discussed in Section 18.0, the comparisons of simulated changes in El Paso flow between the ILRG Model and the Texas Model that were presented in the SWE Report were revised with results from the updated ILRG Model. The revised results are shown in revised **Figures 13-1** and **13-2** in **Appendix 18**.

Additional comparisons of the R-M Pumping Off results to comparable runs of the Texas Model presented in the Hutchison Report and the Second Supplemental Moran Report are presented in **Table 30-3**. These include comparisons of 1951-2016 averages for selected model outputs for the updated ILRG Model (Run 6), the Texas Model without reoperation (Hutchison; 100% R-M Pumping Off), and the Texas Model with crude redistribution~~reoperation~~ (Moran; 100% R-M Pumping Off). The updated ILRG Model results are summarized as annual averages and irrigation season averages. The Texas Model results are annual averages consistent with the annual stress periods in the Texas Model. The table entries for the Texas Model shown as “n/a” and shaded grey indicate outputs that are not simulated in the Texas Model.

Table 30-3 highlights many of the processes simulated in the ILRG Model that are not simulated in the Texas Model. It also contrasts long-term average differences between the models as to simulated changes in Rincon-Mesilla diversions and FHG deliveries, and El Paso flows. During 1951-2016, the average annual change in El Paso flow in the Texas Model is 124,700 AF without reoperation (Hutchison) and 51,700 AF with crude redistribution~~reoperation~~ (Moran). These results compare to the change in flow in the ILRG Model that averages 79,800~~79,500~~ AF year-around, and 33,200~~33,600~~ AF during the irrigation season, excluding spills. The change in flow goes down to ~~15,600~~12,900 AF during the irrigation season from 1985-2005.

30.6 TX Mesilla Pumping Off (Run 7)

In Run 7, all supplemental irrigation pumping and non-irrigation pumping in the Texas portion of the Mesilla basin is turned off. This includes turning off the EPW Canutillo wells and associated M&I return flows. The results of this run show that turning off Texas-Mesilla pumping has, on average over the whole study period, more impact on Project operations than does turning off all Texas pumping in Run 4. This is due to significant WWTP offsets that occur in Run 4.

Similar to many of the runs described above, turning off Texas-Mesilla pumping and returns increases the Project delivery efficiency due to increased drain flows, reduced river seepage, and reduced canal seepage. In turn, this reduces reservoir releases needed to deliver full supply allocations in wet years and the resulting storage accumulations increase allocations and deliveries in dry years.

Turning off Texas-Mesilla pumping causes EBID diversions to increase by an average of 7,200~~8,500~~ AF during 1951-1978 and 21,300~~21,300~~ AF during 2006-2017. EBID FHG deliveries increase in a similar pattern with average increases of 5,800~~6,800~~ AF in 1951-1978 and 12,500~~13,200~~ AF in 2006-2017. Impacts during recent years are magnified by the effect of the 2008 OA on EBID allocations.

EPCWID operations are also impacted by Texas-Mesilla pumping. Average irrigation season diversions by EPCWID increase by an average of 4,1005,800 AF during 1951-1978 and 2,6002,200 AF during 2006-2017. EPCWID FHG deliveries during 1951-1978 increase by an average of 2,0002,600 AF and during 2006-2017 by an average of 400300 AF.

30.7 TX Non-Irrigation Pumping Off (Run 8)

In Run 8, all Texas non-irrigation pumping and associated urban return flows are turned off. This includes pumping by EPW and other minor pumpers from the Hueco and pumping from EPW's Canutillo wellfield in the Mesilla Valley. Discharges from EPW's WWTPs are turned off except for amounts attributed to EPW's use of Project water which continue to be simulated. All urban deep percolation is also similarly eliminated or reduced.

Turning off the non-irrigation pumping and returns in Texas results in EPCWID ordering more Project water to replace the loss in WWTP discharge supply. This reduces the supply available for allocation in some dry years resulting in reduced diversions and/or deliveries to EBID and EPCWID. has a similar but smaller effect on Project operation compared to Run 4 in which all Texas pumping is turned off. Additional flow in the river from turning off the pumping allows the releases from storage to be reduced during full allocation years from 1958-1980. The accumulated additional stored water is allocated and released in dry years during this period. During the relatively wet period from 1980-2002, the loss of EPW WWTP discharges as an irrigation source causes increased releases from storage to meet EPCWID demands.

EBID diversions decreaseincrease by an average of 2,9001,600 AF during 1951-1978. with the increases occurring in years of less than full allocation when accumulated storage adds to the allocations. After the 2008 OA becomes effective, the increases in Project water diversions by EPCWID to replace the reduced WWTP discharge supply increases the computed diversion ratio resulting in and magnifies the effects of Texas pumping, EBID diversions increasinge by an average of 12,10016,300 AF during 2006-2017. EBID FHG deliveries changeincrease by corresponding amounts with an average decreasesincreases of 1,0001,900 AF from 1951-1978 and an average increases of 7,60011,100 AF from 2006-2017. The increase in EBID FHG deliveries is greater than the increase in EBID diversions during 1951-1978 because the reduction in Texas Mesilla pumping reduces EBID canal losses allowing more of the water that EBID diverts to be delivered to the farms.

Turning off Texas non-irrigation pumping causes EPCWID to order more Project water to replace the lost WWTP returnshas a significant effect on EPCWID supply. There is a modest increase in diversions during 1951-1978 averaging 2,5001,200 AF/y, which . This is followed by a much larger increase in diversions during 1979-2005 averaging 14,300~~13,500~~ AF/y.

30.8 NM Non-Irrigation Pumping Off (Run 9)

In this scenario, all non-irrigation pumping in New Mexico along with the associated WWTP discharges and urban deep percolation are turned off. The effects are similar in pattern, but much smaller than the effects of turning off all New Mexico pumping in Run 3.

The familiar pattern of accumulated water in Project storage in wet years followed by increases in allocation and releases in dry years is repeated in Run 9. EBID diversions increase by averages of 2,500~~2,500~~ AF during 1951-1978 and 23,400~~21,100~~ AF during 2006-2017 when the effects of pumping are elevated by interaction with the revised allocation procedure under the 2008 OA. EBID FHG deliveries increase proportionally by an average of 2,000~~2,000~~ AF/y during 1951-1978 and 14,100~~13,700~~ AF/y during 2006-2017.

EPCWID diversions and FHG deliveries increase by small amounts when the non-irrigation pumping in New Mexico is turned off. On average, irrigation season diversions for EPCWID increase by 900~~1,300~~ AF during 1951-1978 and 4,500~~2,500~~ AF during 1985-2017. Irrigation season FHG deliveries to EPCWID increase by 800~~1,000~~ AF from 1951-1978 and 2,000~~1,400~~ AF during 1985-2017.

The increases in Rio Grande at El Paso flow during the irrigation season are generally limited to times of increased deliveries to EPCWID, and these average 4,000~~2,800~~ AF during 1951-2017. ~~There are larger~~ The increases in El Paso flow during the non-irrigation season and during spills ~~that~~ average 2,100~~3,400~~ AF during 1951-2017.

~~This run shows that New Mexico M&I pumping has a relatively small effect on EPCWID diversions and deliveries to Texas water users. In sum, when New Mexico's non-irrigation pumping is turned off, EPCWID diversions only increase on the range of 9001,300 AF/yr (1951-1978) to 5,3002000 AF/yr (1985-2005) in the years prior to the implementation of the 2008 OA.~~

30.9 MX Non-Irrigation Pumping Off (Run 10)

In this scenario, all non-irrigation pumping for Ciudad Juarez in Mexico along with the associated sewage/WWTP returns are turned off. Mexico non-irrigation pumping has a relatively minor effect on Project operations and deliveries to EBID and EPCWID. For the analysis of all Mexico groundwater pumping off, refer to Run 5 in section 30.4 above.

Mexico irrigation pumping increases due to loss of Juarez WWTP discharges. This in turn increases EPCWID conveyance losses resulting in EPCWID having to increase diversions to deliver similar amounts to the farms. EPCWID irrigation season diversions increase by an average of 700700 AF/y during 1951-2017, andbut FHG deliveries decreaseincrease by an average of 200500 AF over the same period. The increase in EBID diversions and FHG over 1951-2017 is minimal averaging 300100 AF.

30.10 2008 Operating Agreement Scenarios (Runs 11 and 12)

Two runs of the ILRG Model were made to evaluate the effect of the D3+Carryover accounting in the 2008 OA on Project operations and LRG water supplies. In Run 11, the D1/D2 allocation procedure is simulated to allocate Project water during the entire period from 1950 - 2017 period, and in Run 12 the D3+Carryover accounting is simulated during this 68-year period[5]. Otherwise, both runs employ the same RiverWare simulation rules that are used in the Historical Base Run. Irrigation pumping is computed based on the unmet irrigation demand and the non-irrigation pumping and associated return flows are set at historical levels.

Comparison of the results of Run 11 to Run 1 show the effects of the 2008 OA on Project operations in Run 1 compared to what would have happened had the 2008 OA not been implemented and the D1/D2 allocation procedure been left in place.

When the D1/D2 allocation procedure is left in place during 2006-2017, the annual allocations to EBID increase substantially in most years during this period resulting in large increases in EBID diversions averaging 94,200103,200 AF and in EBID FHG deliveries averaging 54,60064,100 AF. These impacts on EBID from the 2008 OA are far greater than the impacts of New Mexico pumping on EPCWID irrigation season FHG deliveries that average 17,80014,900 AF during 2006-2017 as shown in the Run 3 results.

Conversely EPCWID diversions decline by an average of 23,00028,900 AF and FHG deliveries decline by an average of 17,20022,200 AF during 2006-2007. The reason for the decline in EPCWID supply is primarily due to the limited amount of Project water in storage. The increases in EBID's allocations and deliveries result in smaller amounts of Project water to allocate between the districts in subsequent years. Another factor is the absence of carryover for the individual districts and this results in more water allocated to EBID and less water available for EPCWID to use.

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[5] The RiverWare rules do not simulate annual allocations during the wet period from 1940 – 1949.

ATTACHMENT 17A

Comparison of the results of Run 12 to Run 11 allows differences between the D1/D2 and D3+Carryover allocation procedures to be evaluated over the entire 1950-2017 period. The differences between these runs are computed based on Run 12 (D3+CO) minus Run 11 (D1/D2) and therefore reflect the impacts of going from the D1/D2 allocation procedure to the D3+CO allocation procedure.

Comparison of Run 12 and Run 11 shows clearly the effect of the 2008 OA on EBID varies depending on the type of year. In wet years with a relatively high diversion ratio, the annual EBID allocation is greater under the D3+CO method than under D1/D2 method and this results in increased diversions and FHG deliveries during 26 of the 67 years between 1951-2017 period (1951-1952, 1959-1962, 1982-2001). EBID diversions and FHG deliveries were lower in the other 41 years which were generally years of average and below average water supply. On average during 1951-2017, EBID diversions declined by 34,40037,600 AF and FHG deliveries declined by 19,80022,100 AF.

Conversely, the 2008 OA has a positive effect on EPCWID allocations, diversions, and FHG deliveries in most years. During the irrigation season, diversions increased by an average of 13,10015,300 AF and FHG deliveries increased by an average of 8,20010,700 AF. The average increase in EPCWID supply is much less that the average decrease in EBID supply.

The following is a summary of the average annual effect on EBID and EPCWID FHG deliveries in dry, wet, and all years duringthree intervals of the 1951-2017 period.

ATTACHMENT 17A

Cumulative Volume Impact of 2008 Operating Agreement on March - October FHG Deliveries In Wet and Dry Periods 1951-2017

Condition	Years	EBID	EPCWID
Dry	1953-1958, 1963-1981, 2002-2017	-2.47-2.74 MAF	+0.37+0.47 MAF
Wet	1951-1952, 1959-1962, 1982-2001	+1.141.26 MAF	+0.17+0.25 MAF
All	1951-2017	-1.33-1.48 MAF	+0.55+0.71 MAF

The results in the above table show that the 2008 OA takes away critical surface water in the dry years when EBID has a greater need for water (2.472.74 MAF) than it gives back to EBID in wet years when the need is less (1.141.26 MAF) As a result, the 2008 OA forces EBID to pump more ground water in dry years to make up for the reduction in surface water supplies. The increased EBID pumping negatively affects the diversion ratio which contributes to the reduction in water allocated and delivered to EBID in dry years. This was termed a "vicious cycle" by Dr. Barroll (2019, 2020a).

30.11 Reduced Waste (Run 13)

As was described in Section 5.0 of the SWE Report, beginning with the 1950s drought and continuing through the 1970s, Reclamation was able to operate the Project with reported operational waste below 10% during most years. In a few years during the wet periods of the mid-1980s and mid-1990s, the EBID waste increased to approximately 20%. The situation in EPCWID was markedly different than in EBID from the 1980s through the 2000s (after EPCWID took over operations) with the operational waste consistently in the range of 20% to 30%.

A run of the ILRG Model was made to evaluate the benefit to the Project from reducing the operational waste. The RiverWare operational rules were modified so that the operational waste was limited to the lesser of the historical amounts or 10% of the simulated diversions.

Limiting operational waste in both Districts to no more than 10 percent reduces releases from Project storage in full allocation years resulting in increased allocations and deliveries in dry years with less than full allocations. As a result of the more efficient

Project operation, FHG deliveries to EBID and EPCWID increase~~occur~~ in many years during the 1950s – 1970s, and again after 2002. Increases in FHG deliveries to EBID average~~d~~ 35,300~~36,100~~ AF during 1951-1978 and 57,300~~48,900~~ AF during 2006-2017. Increases in FHG deliveries to EPCWID average~~s~~ 17,800~~30,700~~ AF during 1951-1978 and 18,500~~20,600~~ AF during 2006-2017.

30.12 Hueco Pumping Off (Runs 14, 14a, 14b, 14c, and 14d)

In response to questions from Texas legal counsel during depositions of the New Mexico experts, and in response to opinions from Texas and U.S. experts, several runs of the ILRG Model were made in which all or a portion of the pumping in the Hueco was turned off, as well as runs in which pumping was turned off without turning off WWTP discharges and vice-versa. The results from these runs are useful in assessing the effects of the Hueco pumping in isolation from pumping in other areas of the LRG basin and the effect of WWTP discharges in offsetting impacts from Hueco pumping.

The No Hueco Pumping Scenarios is~~were~~ simulated in the same manner as the other no pumping scenarios. The supplemental irrigation pumping from the Hueco in Texas and/or Mexico is~~was~~ turned off. In addition, the non-irrigation pumping in these areas and the corresponding WWTP and urban deep percolation return flows are~~were~~ also turned off. Specifications and summaries of the results of the No Hueco Pumping Scenarios are presented below. Runs 14a, 14b, 14c, and 14d were made to test various components of Run 14.

- All Hueco Pumping Off (Run 14) – In Run 14, all supplemental irrigation pumping and non-irrigation pumping in the Hueco in Texas and Mexico is~~was~~ turned off. In addition, the WWTP discharges by EPW and Ciudad Juarez from their Hueco pumping are~~were~~ turned off, as is~~was~~ the urban deep percolation from EPW[6].

  There are opposing effects within EPCWID from turning off Hueco pumping. Turning off Hueco pumping reduces canal and lateral losses in EPCWID and reduces river seepage between American Dam and Riverside Dam before the ACE was constructed in 1999. These changes can result in reduced Project water orders to deliver the same amount of water to EPCWID farm headgates. On the other hand, the reduction in WWTP discharges to the EPCWID canal system when M&I pumping is turned off reduces the irrigation supply available to deliver to EPCWID farm headgates and increases RHG demands for Project water. These

[6] No urban deep percolation is simulated for Mexico in the historical Base Run.

opposing effects can result in net increases or decreases in annual EPCWID FHG deliveries.

The effects within EPCWID from turning off Hueco pumping can propagate upstream and impact reservoir operations and deliveries to EBID depending on whether it is a full allocation year or non-full allocation year. In full allocation years, there is little effect on EBID FHG deliveries because EBID's allocation does not change. In non-full allocation years, accumulated changes in reservoir storage resulting from changes in EPCWID orders of Project water can result in changes in EBID allocations and deliveries.

When Hueco pumping is turned off in Run 14, there are some increases and decreases in EBID FHG deliveries that average to a 1,500~~300~~ AF increase during 1951-2017 with the increases occurring in dry years. ~~After the 2008 OA goes into effect, turning off Hueco pumping has a larger benefit to EBID, with FHG deliveries increasing by an average of 9002,300 AF during 2006-2017, with a few years of increases exceeding 10,000 AF~~. ~~The increases in recent years are elevated due to the effect of Hueco pumping on the diversion ratio and the sensitivity of the EBID allocation to changes in the diversion ratio.~~

Turning off Hueco pumping increases~~reduces~~ EPCWID FHG deliveries by an average of 800~~1,200~~ AF during 1951-2017. Turning off Hueco pumping results in a substantial increase in the total HCCRD supply (RHG diversions) averaging 7,500~~10,900~~ AF during 1951-2017.

- Texas Hueco Pumping Off (Run 14a) – In Run 14a, all supplemental irrigation pumping and non-irrigation pumping by Texas in the El Paso Valley is~~was~~ turned off, along with the WWTP discharges and urban deep percolation from the EPW Hueco pumping.

  Turning off Texas Hueco pumping reduces EBID FHG deliveries by an average of 1,000~~100~~ AF during 1951-2017. ~~However,~~ EBID FHG deliveries decrease~~increase~~ by an average of 4,000~~1,600~~ AF during 2006-2017 when the 2008 OA is in effect.

  During 1985-2017, Texas Hueco pumping reduces EPCWID FHG deliveries during the irrigation season by an average of 1,400~~1,700~~ AF and increases the total flow to HCCRD an average of 2,100~~2,300~~ AF.

  Contrary to the claims of the Texas and U.S. experts, the impacts of Texas Hueco pumping on Project operations and surface water supplies to EBID, EPCWID, and HCCRD are not negligible.

- Mexico Hueco Pumping Off (Run 14b) – In Run 14b, all supplemental irrigation pumping and non-irrigation pumping in the Mexico portion of the Hueco iswas turned off, along with the WWTP discharges from Ciudad Juarez pumping.

  Turning off Mexico pumping reduces canal seepage and river seepage in EPCWID causing reduced Project orders at EPCWID canal headings. This results in accumulation of water in Project storage that increases Project water deliveries to EBID in years with less than a full Project water allocation. Simulated increases in EBID FHG deliveries average 1,700800 AF during 1951-2017, and 3,2001,900 AF during 2006-2017, with increases exceeding 5,000 AF in several years and 10,000 AF in 20102013.

  Turning off Mexico Hueco pumping has similar effects on EPCWID with FHG deliveries increasing by an average of 1,500800 AF during 1951-2017. The increase in total HCCRD supply is greater averaging 4,8003,900 AF during 1951-2017.

- Texas WWTP Discharges Off (Run 14c) – In Run 14c, all discharges from Texas WWTPs arewere turned off. This includesd turning off discharges from the EPW's Northwest, Haskell, Socorro, and Bustamante WWTPs, as well as discharges from the Anthony TX WWTP and the Fabens WWTP. The purpose of this run iswas to quantify the benefit to the Project operations and LRG water users from the Texas WWTP discharges. Without these discharges, the impacts of Texas Hueco pumping would be much larger.

  When the Texas WWTP returns are turned off, EBID FHG deliveries decrease markedly in numerous years with less than full allocations. This shows the interconnected nature of the Project and how changes in supply at the bottom of the Project area can ripple through the Project and affect operations hundreds of miles upstream. On average during 1951-2017 the reduction in diversions averages 14,6009,500 AF and the reduction in FHG deliveries averages 6,6004,700 AF.

  Turning off Texas WWTP discharges results in increased Project releases and diversions to EPCWID to replace the reduction in irrigation supply to EPCWID farmers from the WWTP discharges. This results in large increases in El Paso flows to deliver additional Project water to EPCWID, particularly during the wet period in the 1980s and 1990s. The increase in El Paso flows during the irrigation season, excluding spills, average 38,30036,300 AF during 1985-2005.

Without the Texas WWTP discharges, the simulated impacts from Texas pumping would be much larger than the impacts shown in Runs 4, 7, 8, 14, and 14a. The results for Run 14c show the effect of Texas WWTP discharges have in offsetting the impacts of Texas pumping. Without these discharges (for example if EPW reused its WWTP discharges for non-potable uses), the effects of Texas pumping on Project operations, including deliveries to EBID would be much greater.

- Texas Hueco Pumping Off without WWTP Discharges Off (Run 14d) – In Run 14d, Texas Hueco pumping is~~was~~ turned off without turning off the associated Texas WWTP discharges and urban deep percolation. This test run simulates the effect of Texas Hueco pumping without the offsets from Texas M&I return flows.

  When the Texas Hueco pumping is turned off without turning off the M&I returns, the simulated impacts on Project operations increase. EBID FHG deliveries increase by an average of 5,000~~1,900~~ AF during 1951-1978 and 2,000~~2,800~~ AF during 2006-2017. FHG deliveries to EPCWID increase by 4,600~~6,200~~ AF during 1951-1978 and 2,000~~2,500~~ AF during 2006-2017. Total flows to HCCRD increase by 7,100~~9,700~~ AF during 1951-1978 and 3,700~~3,200~~ AF during 2006-2017.

30.13 Early EPCWID Ops (Runs 15, 15a, 15b, 15c)

Four scenarios were simulated using the ILRG Model to evaluate the effects on Project operations that would result from a return to EPCWID operations consistent with how the Project was operated in the past. These include simulating increased irrigation use of drain flows in the Fabens area and charging EPCWID for all water that it uses. Runs 15a, 15b, and 15c were made to test various components of Run 15. Descriptions of the four Early EPCWID Ops scenarios are provided below along with the scenario results.

- Early EPCWID Ops (WWTP & Fabens Drains) (Run 15) – In Run 15, simulation of EPCWID operations in the El Paso Valley are~~were~~ modified to simulate irrigation use of all available supplies consistent with how the Project was originally operated in the El Paso Valley. This includes simulation of irrigation use of the usable Fabens drain flows, which are~~were~~ estimated as 70% of the total Fabens drain flows limited to a monthly volume of 6,000 AF, based on available historical data (see response to Ferguson Opinion 9 for more information). In addition, EPCWID is charged for all use of drain flows and WWTP flows, and the ACE Credit and Haskell WWTP discharge credits are disabled. These changes reflect operations consistent with the original concept and implementation of the Project which was to use all available supplies ~~in the river~~ to minimize the amount of storage releases needed to meet Project water demands. Further, since EPCWID is charged for all of its water use including the water that arises within the EPCWID system, it has less unused allocation in many years and uses its entire allocation in more years than in the Historical Base Run (Run 1). The increased use of water arising within the EPCWID system reduces the releases from Project storage to meet EPCWID demands and the accumulated Project storage increases the supply available for allocation and use in subsequent years. When accounting under 2008 OA commences, EPCWID has less unused allocation to carryover to subsequent years. The following is a summary of the effects of the foregoing changes in EPCWID operations:

- EBID – FHG deliveries increase modestly by an average of 4,3004,500 AF during 1951-1978 and by a much larger amount, averaging 41,90037,800 AF, during 2006-2017. The large increases during the recent period result from significant increases in the diversion ratio that result from EPCWID being charged for all water that it uses, and the positive feedback of increases in the diversion ratio on EBID allocations under D3 accounting.

- EPCWID – FHG deliveries increase by an average of 1,4003,100 AF during 1951-2017. Simulated EPCWID RHG diversions decrease by an average of 15,10012,100 AF during 1951-2017 as diversions of Project water from the river are eschewed in favor of the supplies arising within EPCWID.

- HCCRD – The changes in EPCWID operations result in minor reductions in the water flowing to HCCRD. Annual total flow to HCCRD decreases by an average of 3,1002,100 AF during 1951-2017.

- Early EPCWID Ops (WWTP) (Run 15a) – In Run 15a, EPCWID is charged for irrigation use of WWTP flows, and the ACE Credit and Haskell WWTP discharge credits arewere disabled. However, the simulated use of drain flows is left at the historical levels simulated in Run 1, and EPCWID is not charged for the historical use of the drain flows. The results are similar in pattern to the Run 15 results but smaller in magnitude as follows:

  - EBID – FHG deliveries increase modestly by an average of only 200400 AF during 1951-1978, but by much larger amounts averaging 27,20023,600 AF during 2006-2017. Similar to Run 15, the large increases during the recent period result from the effect of an increase in the diversion ratio on EBID allocations under the 2008 OA.

  - EPCWID – FHG deliveries decrease by an average of 1,9001,800 AF during 1951-2017. Simulated EPCWID RHG diversions decrease by an average of

2,9002,800 AF during 1951-2017 with the increased use and charge for supplies arising within EPCWID.

- HCCRD – Charging EPCWID for use of WWTP flows and elimination of credits against charges reduces the total flow to HCCRD by an average of 500700 AF during 1979-2005 and 2,2002,500 AF during 2006-2017

- Early EPCWID Ops (Fabens Drains) (Run 15b) – In Run 15b, the model simulates and charges EPCWID for use of the usable Fabens drain flows as described above in Run 15. However, EPCWID is not charged for use of WWTP flows and is credited for Haskell WWTP discharges and the ACE Credit. The results are similar in pattern to the Run 15 results as follows:

  - EBID – FHG deliveries increase modestly by an average of 4,3004,200 AF during 1951-1978, and by an average of 21,80017,000 AF during 2006-2017. Similar to Run 15, the large increases during the recent period result from the effect of an increase in the diversion ratio on EBID allocations under the 2008 OA.

  - EPCWID – FHG deliveries increase by an average of 3,1005,300 AF during 1951-2017. Simulated EPCWID RHG diversions decrease by an average of 12,9009,100 AF during 1951-2017 with the simulated increased use and charge for drain flows arising within EPCWID.

  - HCCRD – The increased use of drain flows in EPCWID results in a reduction in the total flow to HCCRD averaging 2,6001,300 AF.

- Early EPCWID Ops (TX Hueco Pumping Off) (Run 15c) – In this scenario, the changes to EPCWID operations and accounting from Run 15 were simulated with the Texas Hueco pumping turned off. The effects of Texas Hueco pumping with the modified EPCWID operation were assessed by comparing the results of Run 15c and Run 15. The effects of the Texas Hueco pumping on EBID are mixed due to the opposing effects on EPCWID from pumping and WWTP discharges from pumping.

30.14 Conj Use 1: Hist All Acres D1/D2 (Runs 16 and 16a)

Two scenarios arewere simulated to evaluate conjunctive use of surface water and ground water within the Rio Grande Project under the D1/D2 allocation procedure with the historical irrigated area that evolved over time (including irrigation of the primary ground water only acres in New Mexico), and with the early EPCWID operations that arewere simulated in Run 15. In both scenarios, irrigation pumping in EBID and EPCWID is limited based on the irrigation pumping that existed during the 1951-1978 D1/D2 data period. This is implemented by not allowing the 10-year running average pumping after 1978 to exceed the 1951-1978 historical average annual pumping.

- Conj Use 1: Hist All Acres D1/D2 (Hist M&I) (Run 16) – Run 16 essentially combines the early EPCWID operations from Run 15 with the Run 11 continuation of D1/D2 allocation of Project water after 2005 along with a limit on irrigation pumping after 1978. In Run 16, the M&I pumping and returns are set at the historical amounts simulated in Run 1. The results for Run 16 are very similar to Run 15 until 2005. After that time, the differences from Run 1 represent the combination of the early EPCWID operations and continuation of D1/D2 accounting. The following are summaries of the differences between Run 16 and Run 1 after 2005:
    - EBID – FHG deliveries increase by an average 69,00078,300 AF during 2006 -2017 which is much greater than the increase of 41,90037,800 AF in Run 15.
    - EPCWID – FHG deliveries decrease by an average of 14,50020,100 AF during 2006 -2017 with the D1/D2 accounting compared to an average increasedecrease of only 700400 AF decrease in Run 15.
    - HCCRD – Total flows to HCCRD decline by an average of 9,50011,700 AF during 2006-2017, compared to an average decline of 3,8003,800 AF during this same period in Run 15.
- Conj Use 1: Hist All Acres D1/D2 (1978 M&I) (Run 16a) – The conditions simulated in Run 16a are the same as Run 16 except that M&I pumping in New Mexico and Texas after 1978 is limited to the levels that existed in 1978 at the end of the D1/D2 period. This limit has minimal effect on Texas M&I pumping because it exceeded the 1978 amount by only small amounts in a few years after 1978. When the M&I pumping is limited by the 1978 amount, the simulated M&I returns are scaled down proportionally. The results of Run 16a are very similar to Run 16 which reinforces that New Mexico M&I pumping has relatively little impact on Project operations.

- o EBID – FHG deliveries increase by an average of 72,40080,700 AF during 2006-2017 compared to an average increase of 69,00078,300 AF in Run 16.
- o EPCWID – FHG deliveries decrease by an average of 12,60018,500 AF during 2006-2017 compared to a decrease of 14,50020,100 AF in Run 16.
- o HCCRD – Total supply to HCCRD from 2006-2017 decreases by 9,20011,100 AF compared to an average decrease of 9,50011,700 AF in Run 16.

30.15 Conj Use 2: Hist Proj Acres (Runs 17 and 17a)

A second set of conjunctive use scenarios are simulated in Run 17 and Runs 17a under the D1/D2 allocation procedure with irrigation limited to the historical Project acres and no irrigation of the non-Project primary (ground water only) acres in New Mexico. The early EPCWID operations from Run 15 are also a part of these conjunctive use scenarios.

- Conj Use 2: Hist Proj Acres (Hist M&I) (Run 17) – In Run 17, the M&I pumping and returns are set at the historical amounts simulated in Run 1. The results from Run 17 are similar to the results from Run 16 and the differences largely reflect the effect of ground water pumping on primary acres in New Mexico.
  - o EBID – Annual FHG deliveries increase by an average of 7,5009,300 AF during 1951-1978, and by a much larger average of 75,60082,600 AF following the change to D1/D2 after 2005.
  - o EPCWID – Annual FHG deliveries increase by an average 5,1006,300 AF during 1951-1978, and decline by 10,70016,200 AF during 2006-2017 due to the change in allocation method from D3 to D1/D2 starting in 2006.
  - o HCCRD – Total flows to HCCRD decrease by an average of 8,6009,600 AF during 2006-2017.
- Conj Use 2: Hist Proj Acres (Pre-Comp M&I) (Run 17a) – The conditions simulated in Run 17a are the same as Run 17 except that M&I pumping in New Mexico and Texas is set at the pre-Compact amounts that existed in 1938 (736 AF/y in New Mexico and 13,744 AF/y in Texas). M&I returns are scaled down proportionally consistent with the pre-Compact pumping volumes. The differences between Run 17 and Run 17a reflect the effects of the post-compact increases in total M&I pumping throughout the study area on simulated surface water supplies.
  - o EBID – Annual FHG deliveries increase by an average of 9,50013,500 AF from 1951 – 1978 and 87,90093,400 AF from 2006-2017. These compare

to an increase of 7,5009,300 AF and an increase of 75,60082,600 AF in Run 17, respectively.

- o EPCWID – Annual FHG deliveries increase by an average 6,1001,700 AF during 1951-1978, and decrease by 4,3009,900 AF during 2006-2017 due to the change in allocation method to D1/D2. These compare to a 1951-1978 increase of 5,1006,300 AF and 2006-2017 decrease of 10,70016,200 AF in Run 17.
- o HCCRD – Total supply to HCCRD increases by an average of 1,1002,800 AF during 1951-2017 compared to an average decrease of 2,8002,300 AF in Run 17.

30.16 Conj Use 3: Auth Proj Acres (Pre-Comp M&I) (Run 18)

A third conjunctive use scenario is simulated in Run 18 under the D1/D2 allocation procedure with irrigation of the original authorized Project acres simulated in every year from 1940-2017 (88,000 acres in EBID and 67,000 acres in EPCWID). The irrigated area in HCCRD is set at the reported maximum historical amount of 17,750 acres that occurred in 1951, and the irrigated area in JID is set at historical levels. M&I pumping and returns arewere limited to the pre-Compact amounts as in Run 17a. The early EPCWID operations are also simulated as in the other conjunctive use scenarios. Finally, because the authorized EPCWID acres are simulated as irrigated in every year, there is no simulation of EPW use of Project water.

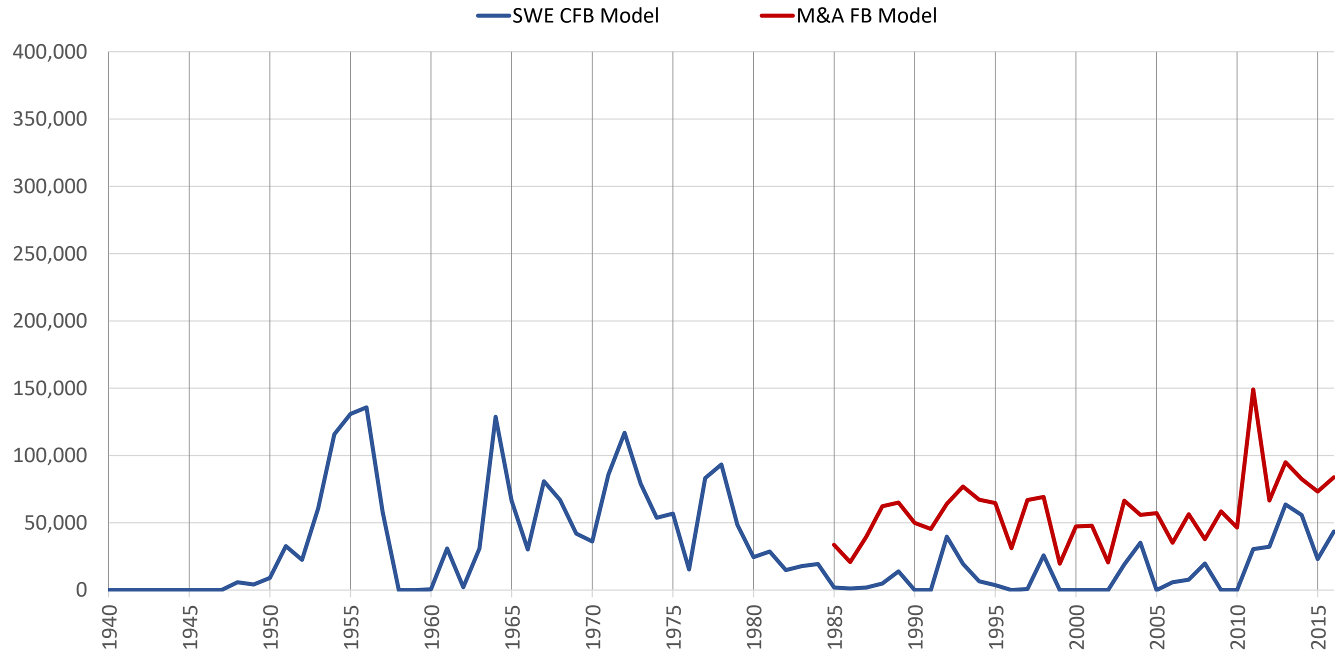
- EBID – Annual FHG deliveries decreaseincrease by an average of 1,8002,700 AF during 1951-1978, and increase by 51,50064,300 AF during 2006-2017 under D1/D2.
- EPCWID – Annual FHG deliveries increasedecrease by an average of 5,6004,000 AF during 1951-1978 and decrease by an average of 35,70038,650 AF during 2006-2017 when allocations revert back to the D1/D2 method.
- HCCRD – Total supply to HCCRD increases by 5001,200 AF during 1951-1978 and decreases by an average of 13,50013,700 AF during 2006-2017.

Appendix 18

Response to Revised Texas Analyses Submitted Without a Rebuttal Report

Figure 12-12

Comparison of Annual Quantities
SWE Farm Budget vs. M&A Farm Budget
1940-2016
El Paso Valley
Total Irrigation Pumping (AF/y) [1]



Averages	SWE	M&A	Difference	% Diff
1951-2016	34,340			
1985-2016	14,258	58,018	43,760	306.9%

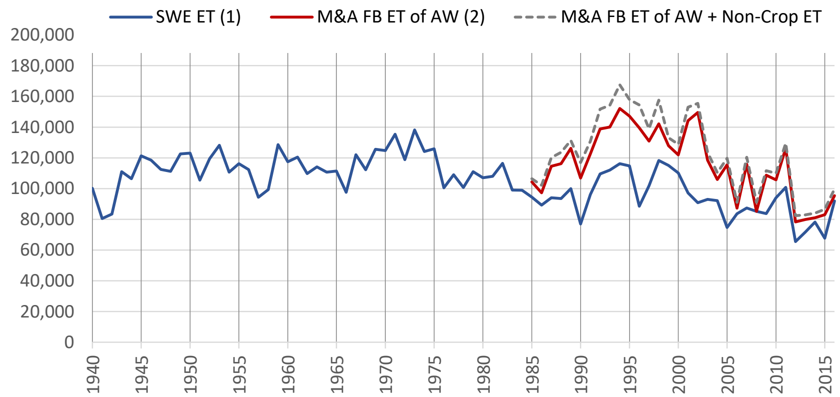
Note:

(1) Supplemental pumping for El Paso Valley.
(2) Updated M&A values for irrigation pumping were obtained from the February 4, 2020 State of Texas's Seventh Supplemental Disclosure of Expert Witness Information.

Figure 12-13

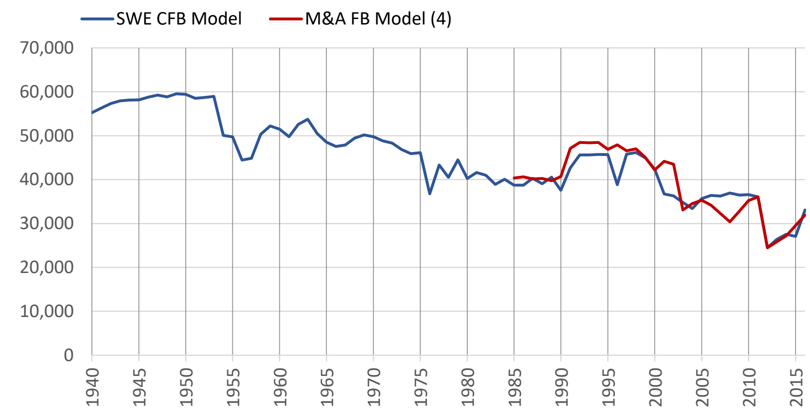
Comparison of Annual Quantities
SWE Farm Budget vs. M&A Farm Budget
1940-2016
El Paso Valley

Actual ET Volume (AF/y)



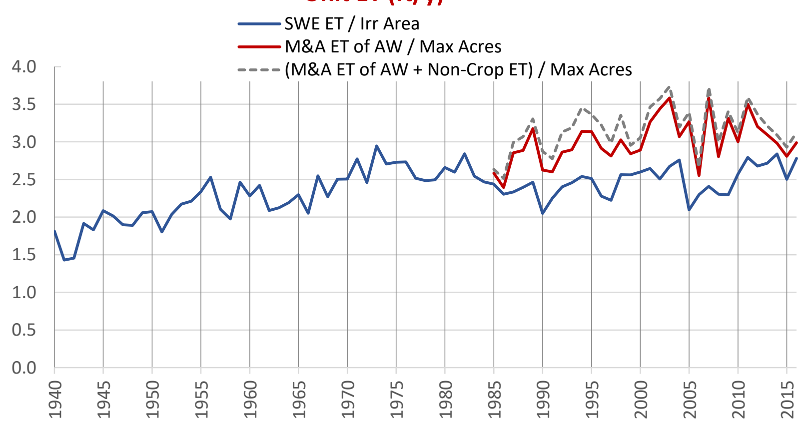
Averages	(1) SWE	(3) M&A	Difference	% Diff
1951-2016	103,997			
1985-2016	93,408	122,722	29,314	31.4%

Irrigated Area (acres)



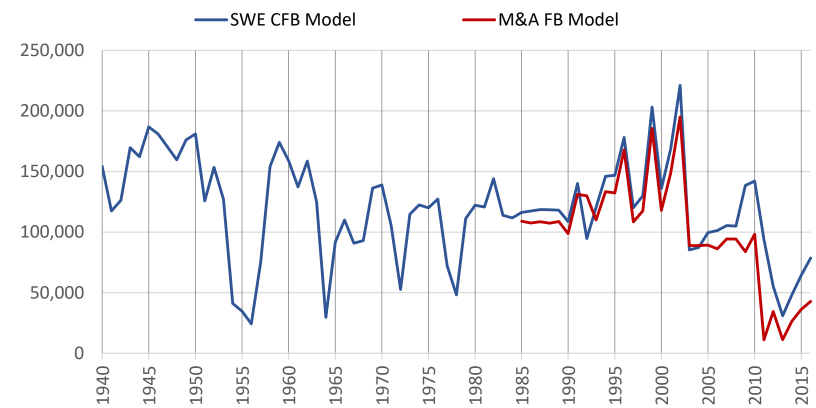
Averages	SWE	M&A	Difference	% Diff
1951-2016	42,952			
1985-2016	37,895	38,764	869	2.3%

Unit ET (ft/y)



Averages	(1) SWE	(3) M&A	Difference	% Diff
1951-2016	2.44			
1985-2016	2.48	3.17	0.69	28.0%

FHG Deliveries (AF/y)



Averages	SWE	M&A	Difference	% Diff
1951-2016	112,196			
1985-2016	116,818	100,099	-16,719	-14.3%

Notes:

(1) SWE ET calculated as sum of Consumptive Use (CU) of Surface Water and Groundwater.

(2) M&A ET is CU of applied water.

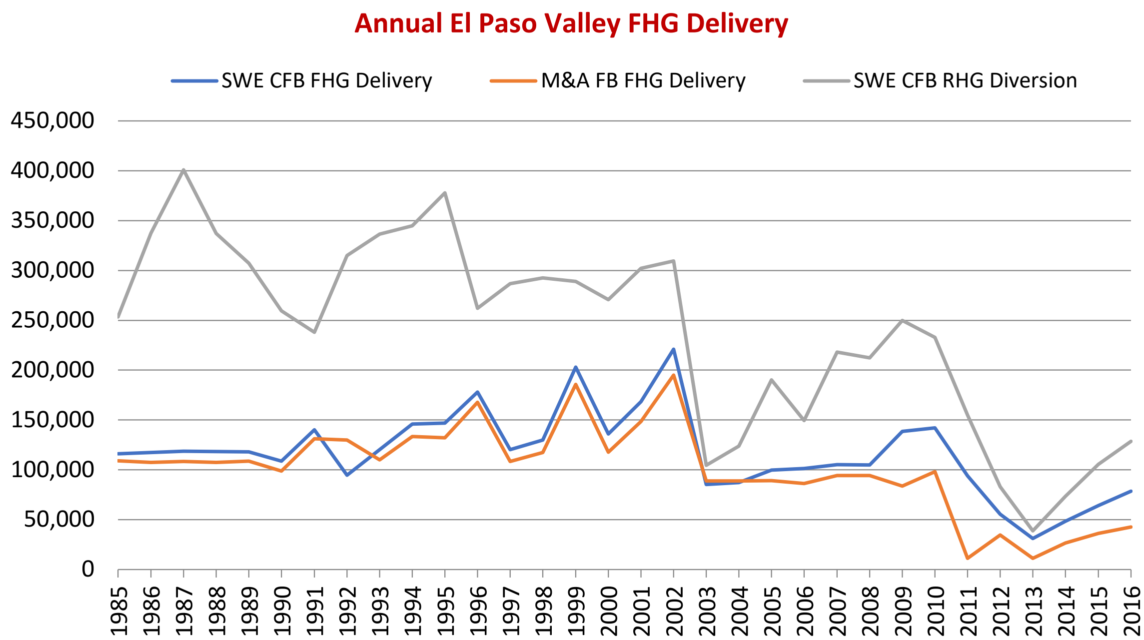
(3) Volume of bare ground ET within footprint of maximum monthly crop acres.

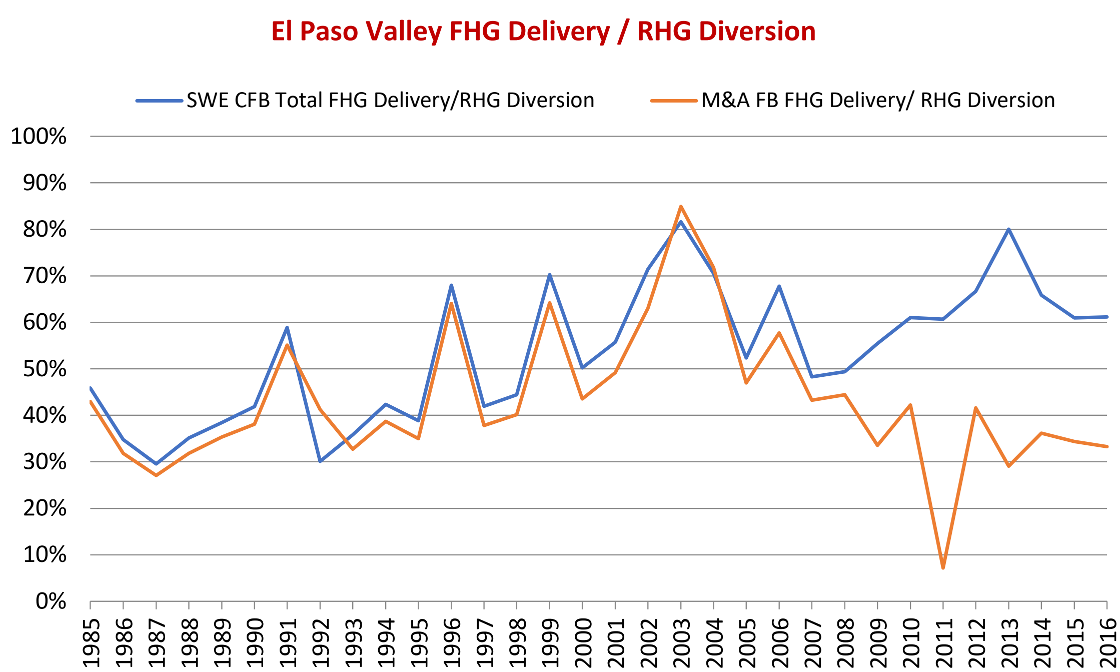
(4) M&A FB irrigated area is the maximum monthly crop acreage during each year.

(5) Updated M&A values for Actual ET Volume, Irrigated Area, and FHG Deliveries were obtained from the February 4, 2020 State of Texas's Seventh Supplemental Disclosure of Expert Witness Information.

Figure 12-14

Comparison of Annual FHG Deliveries
SWE Farm Budget vs. M&A Farm Budget
1985 - 2016





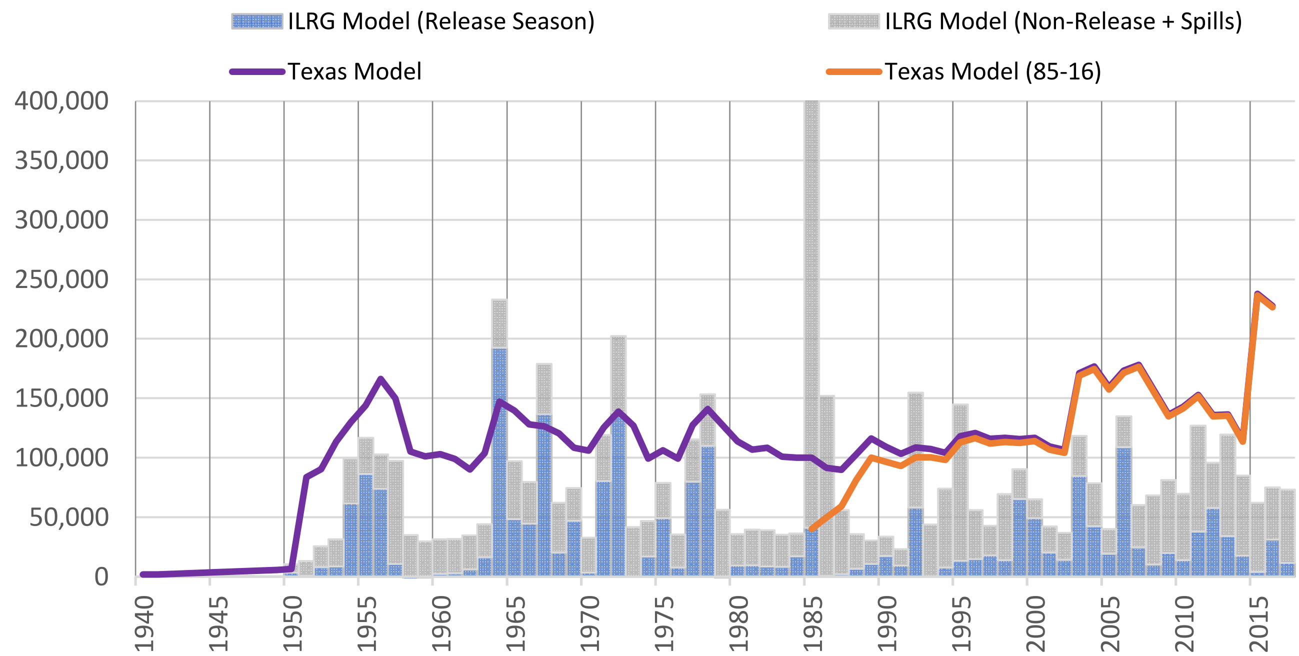
Notes:

El Paso RHG Diversion is equal to Franklin Canal diversions minus Ascarate Wasteway (Pre-1999) plus Riverside Canal diversions.

Updated M&A values for 2010 FHG Deliveries were obtained from the February 4, 2020 State of Texas's Seventh Supplemental Disclosure of Expert Witness Information.

Figure 13-1

Annual Impact of Pumping on Rio Grande at El Paso Flows
Integrated LRG Model (No R-M Pumping)
vs.
Texas Model (100% Reduction in R-M Pumping)
(acre-feet)

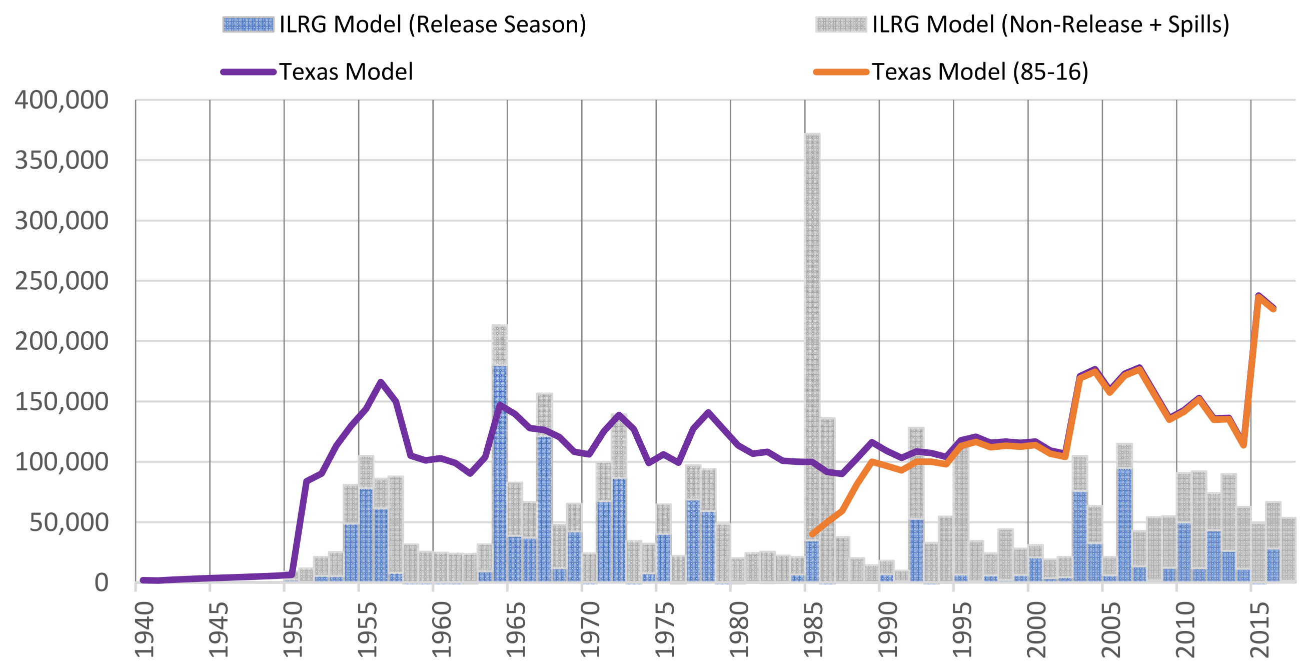


Averages	(1) ILRG Model (No R-M Pump)	(2) Texas Model (100% Reduction)	(3) Texas Model 85-16 (100% Reduction)
1985 - 2016 Annual (af):	87,479	132,866	124,658
1951 - 2016 Annual (af):	79,842	124,667	
1985 - 2016 Release Season (af):	27,152		
1951 - 2016 Release Season (af):	32,742		

Notes:
(1) ILRG Model change is computed as flows in Run 6 (no Rincon-Mesilla pumping) minus Run 1 (Historical Base Run).
(2) Texas Model (1938 - 2016 run) change is computed as the simulated flows with reduced pumping (100%) minus flows with no pumping reduction (historical simulation).
(3) Texas Model (1985 - 2016 run) change is computed as the simulated flows with reduced pumping (100%) minus flows with no pumping reduction (historical simulation).

Figure 13-2

Annual Impact of Pumping on Rio Grande at El Paso Flows
Integrated LRG Model (No NM Pumping)
vs.
Texas Model (100% Reduction in R-M Pumping)
(acre-feet)



Averages	(1) ILRG Model (No NM Pump)	(2) Texas Model (100% Reduction)	(3) Texas Model 85-16 (100% Reduction)
1985 - 2016 Annual (af):	65,965	132,866	124,658
1951 - 2016 Annual (af):	61,218	124,667	
1985 - 2016 Release Season (af):	16,890		
1951 - 2016 Release Season (af):	22,348		

Notes:

(1) ILRG Model change is computed as flows in Run 3 (no New Mexico pumping) minus Run 1 (Historical Base Run).

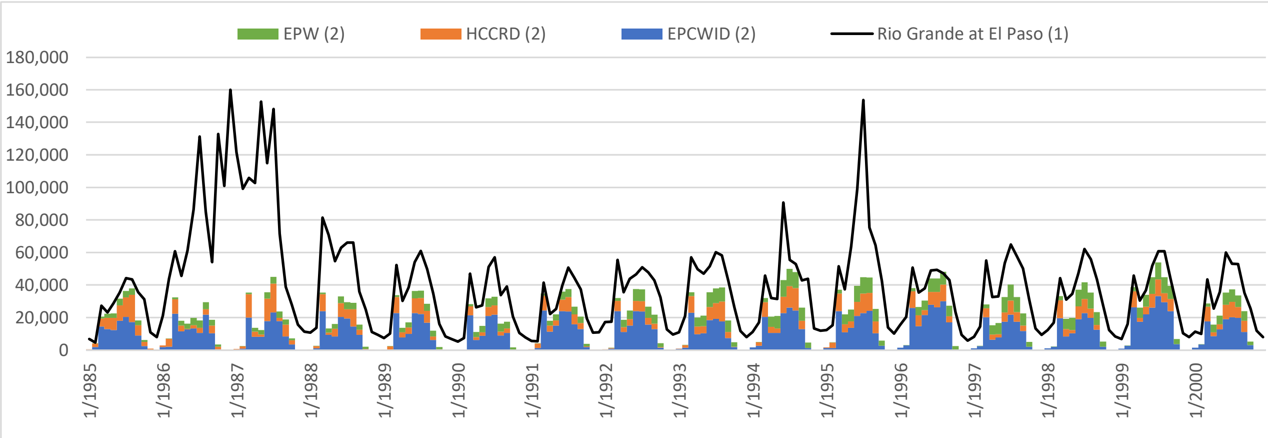
(2) Texas Model (1938 - 2016 run) change is computed as the simulated flows with reduced pumping (100%) minus flows with no pumping reduction (historical simulation).

(3) Texas Model (1985 - 2016 run) change is computed as the simulated flows with reduced pumping (100%) minus flows with no pumping reduction (historical simulation).

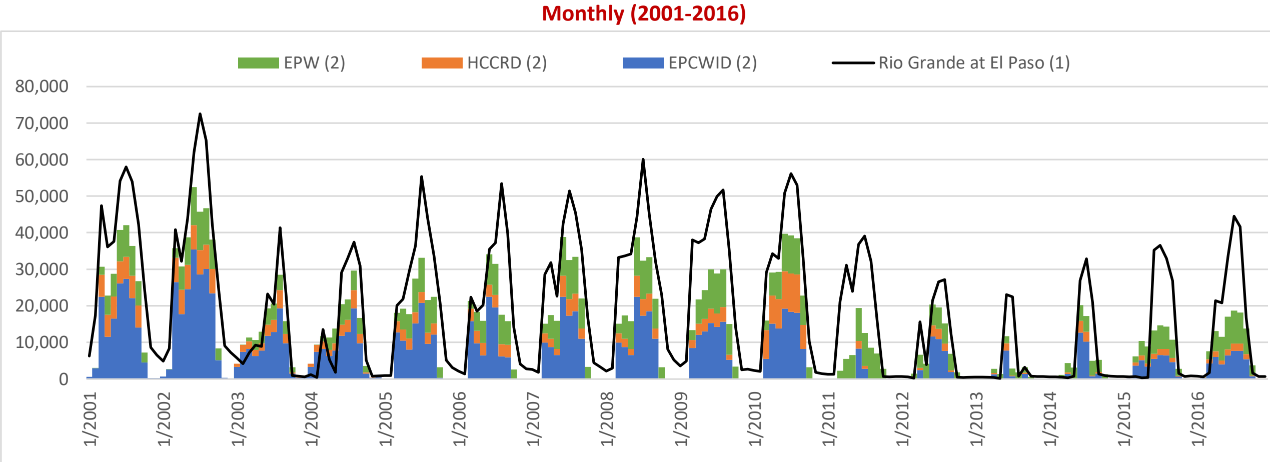
Figure 14-1

Historical Adjusted Rio Grande at El Paso Flows and Texas Deliveries
Dorrance Analysis
(acre-feet)

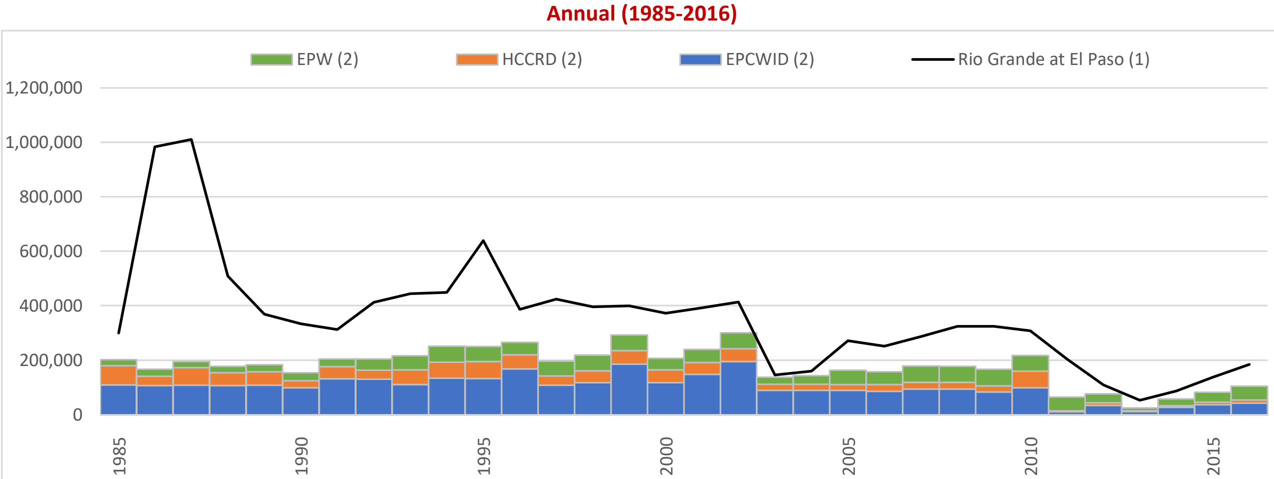
Monthly (1985-2000)



Monthly (2001-2016)



Annual (1985-2016)

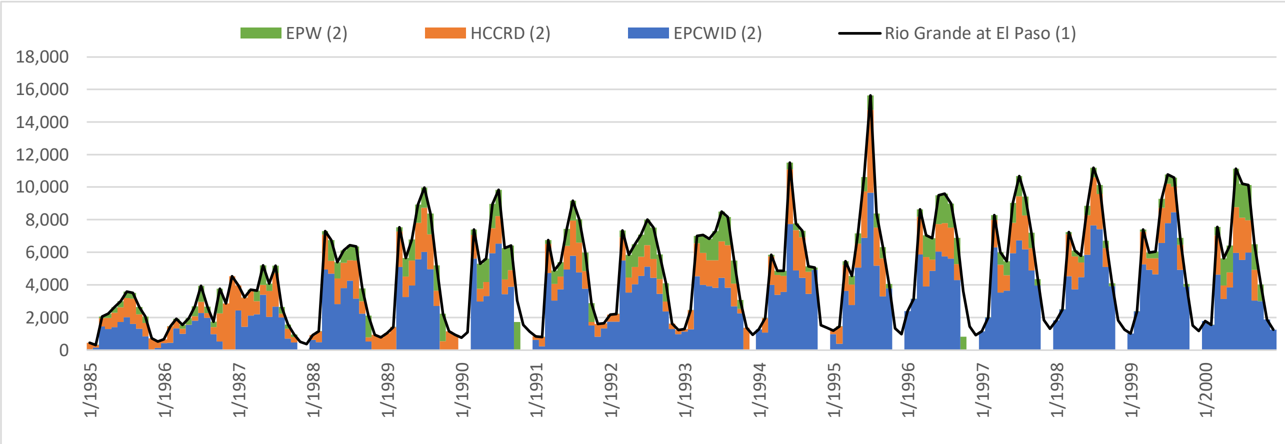


Notes:
(1) Rio Grande at El Paso is equal to historical Rio Grande at El Paso flow minus Acequia Madre diversions.
(2) Actual and estimated deliveries to Texas water users.
(3) Delivery data revised based on new data provided in the 12-30-2019 Sunding Reply and Rebuttal Expert Report.

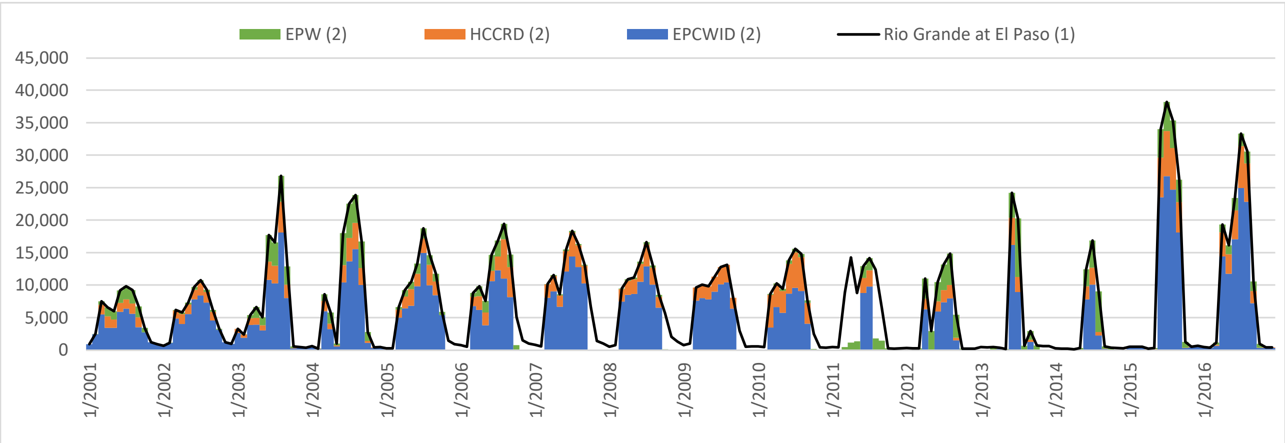
Figure 14-2

Increased Rio Grande at El Paso Flow and Amounts Made Available to Texas Water Users
Dorrance Analysis
(acre-feet)

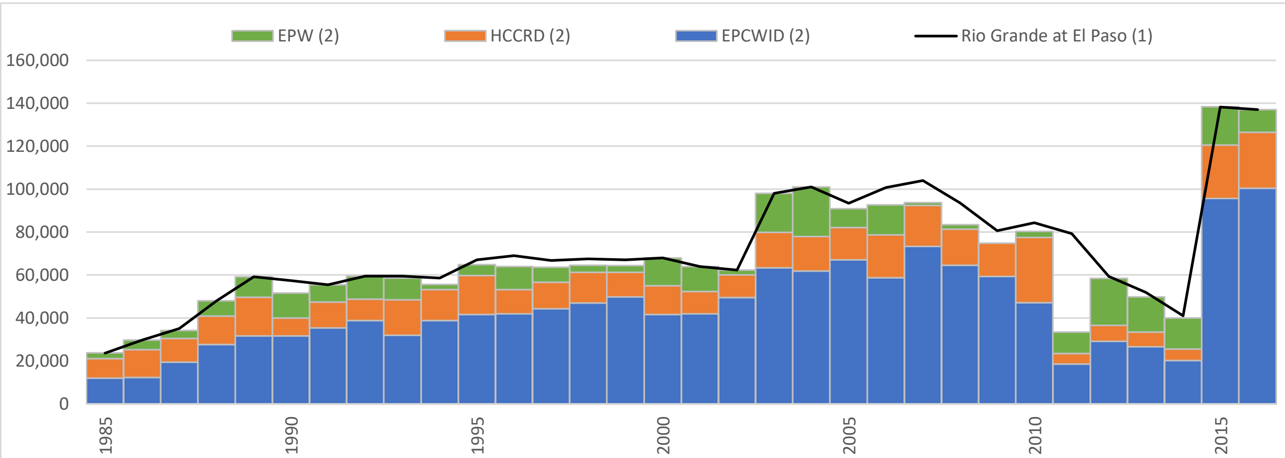
Monthly (1985-2000)



Monthly (2001-2016)



Annual (1985-2016)

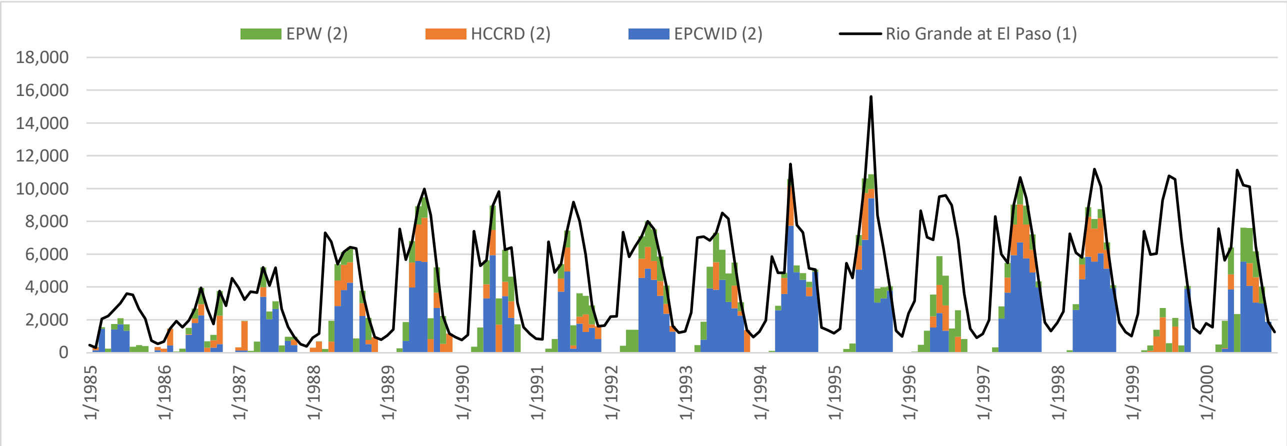


Notes:
(1) Increased Rio Grande at El Paso flow in 60% Rincon-Mesilla pumping reduction scenario simulated in Texas Model.
(2) Amounts of increased Rio Grande at El Paso flow made available for delivery to Texas water users.
(3) Delivery data revised based on new data provided in the 12-30-2019 Sunding Reply and Rebuttal Expert Report.

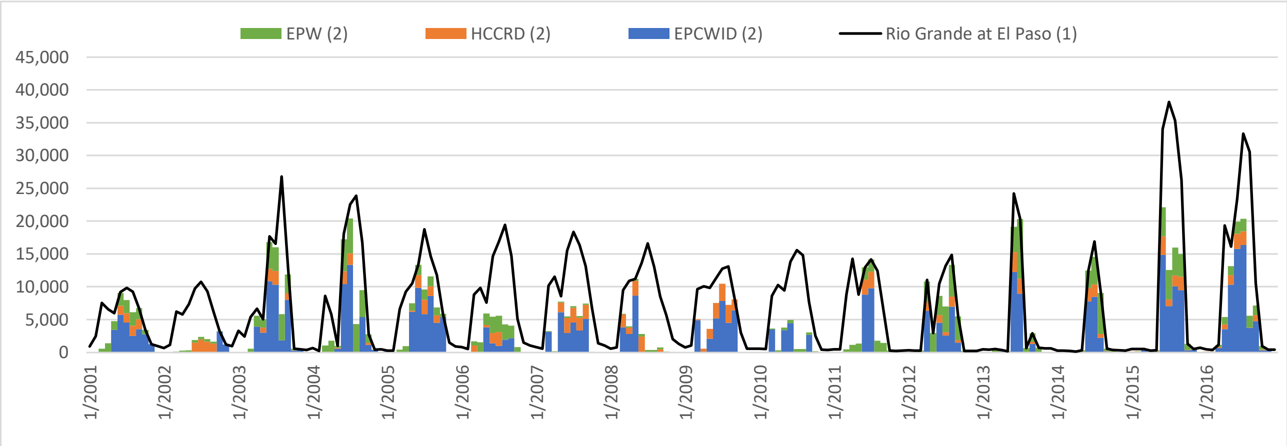
Figure 14-3

Increased Rio Grande at El Paso Flow and Increased Deliveries to Texas Water Users
Dorrance Analysis
(acre-feet)

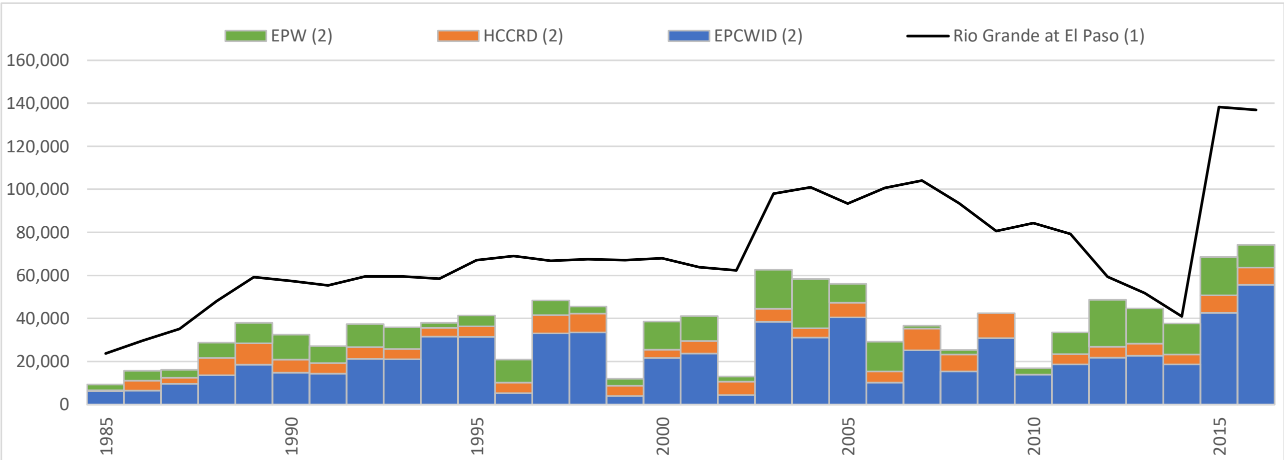
Monthly (1985-2000)



Monthly (2001-2016)



Annual (1985-2016)

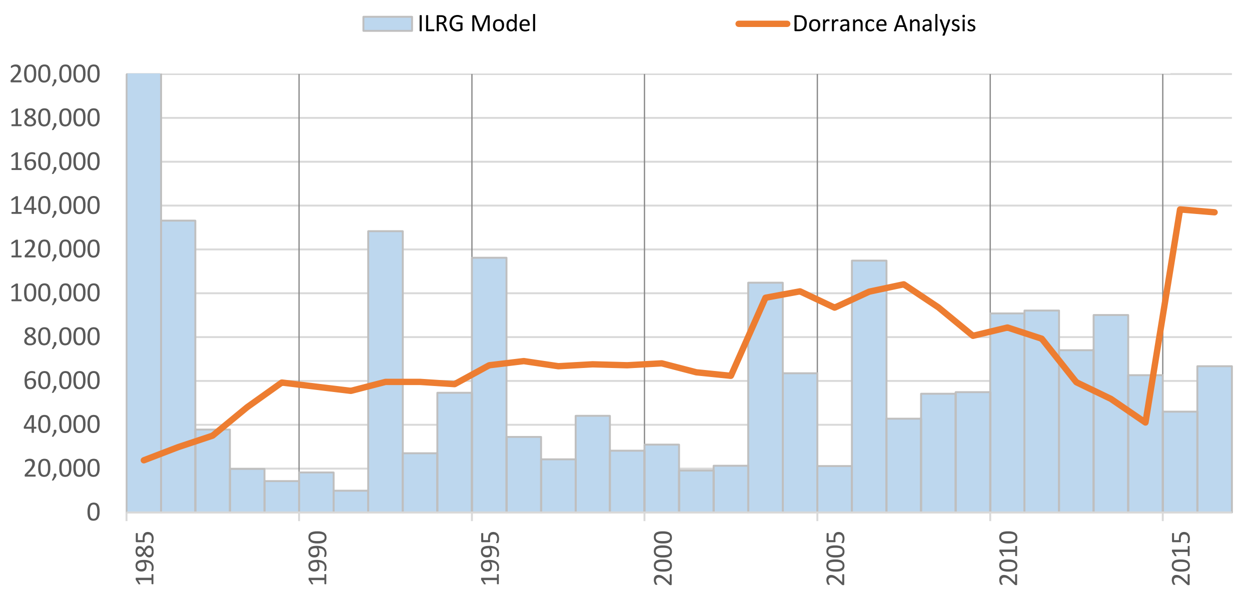


Notes:

(1) Increased Rio Grande at El Paso flow in 60% Rincon-Mesilla pumping reduction scenario simulated in Texas Model.
(2) Amounts of increased Rio Grande at El Paso flow assumed delivered to Texas water users to replace historical pumping.
(3) Delivery data revised based on new data provided in the 12-30-2019 Sunding Reply and Rebuttal Expert Report.

Figure 14-4

Annual Impact of Pumping on Rio Grande at El Paso Flows
Integrated LRG Model (No NM Pumping)
vs.
Dorrance (60% Reduction in R-M Pumping)
(acre-feet)



	(1) ILRG Model (No NM Pump)	(2) Dorrance (60% Reduction)
1985 - 2016 Average Annual (af):	65,965	71,232

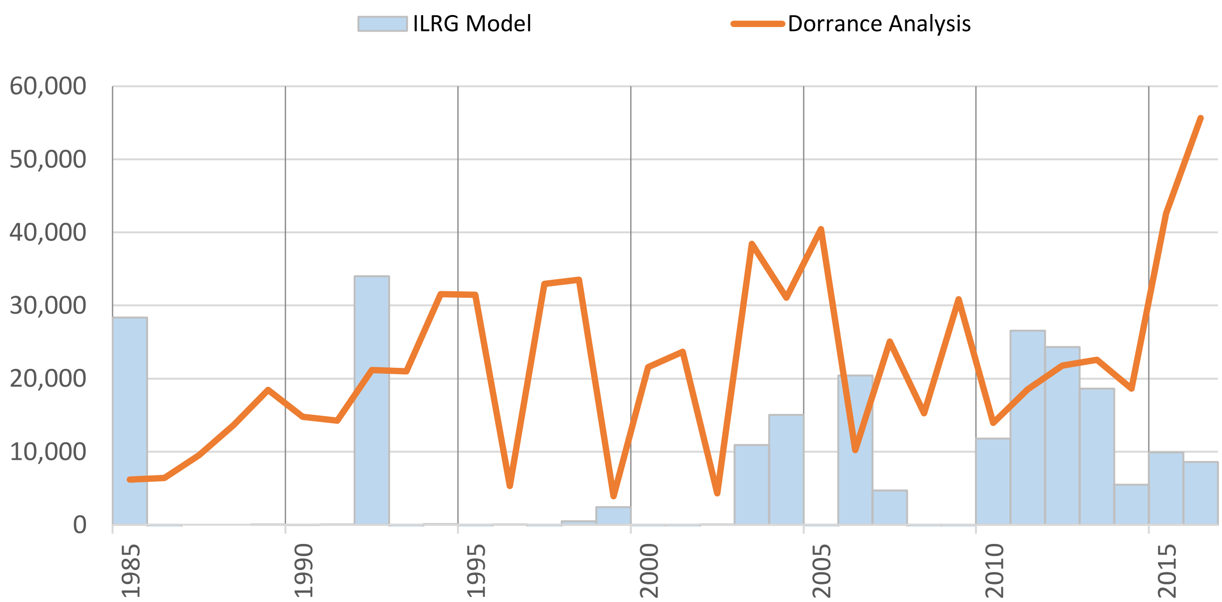
Notes:

(1) ILRG Model change computed as flows in Run 3 (no New Mexico pumping) minus Run 1 (all pumping on).

(2) Dorrance change computed as the increase in El Paso gage flows (Texas Model simulation of 60% reduction in R-M pumping minus historical El Paso gage flows) from 1985 - 2016 only.

Figure 14-5

Annual Impact of Pumping on EPCWID Irrigation Deliveries
Integrated LRG Model (No NM Pumping)
vs.
Dorrance (60% Reduction in R-M Pumping)
(acre-feet)



	(1) ILRG Model (No NM Pump)	(2) Dorrance (60% Reduction)
1985 - 2016 Average Annual (af):	6,416	21,837

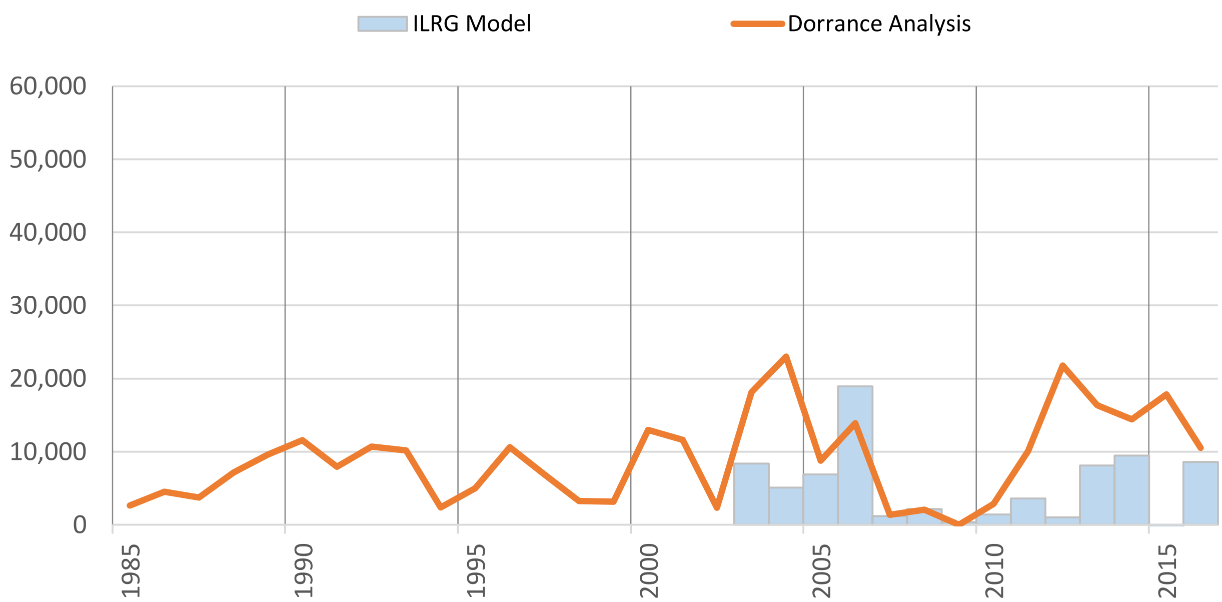
Notes:

(1) ILRG Model change computed as the El Paso Valley EPCWID farm deliveries in Run 3 (no New Mexico pumping) minus Run 1 (all pumping on).

(2) Dorrance change computed as the increase in El Paso gage flows (Texas Model simulation of 60% reduction in R-M pumping minus historical El Paso gage flows) distributed monthly using historical ratios of monthly to annual El Paso flows and ratios to historical EPCWID El Paso Valley deliveries.

Figure 14-6

Annual Impact of Pumping on EPW Deliveries
Integrated LRG Model (No NM Pumping)
vs.
Dorrance (60% Reduction in R-M Pumping)
(acre-feet)



	(1) ILRG Model (No NM Pump)	(2) Dorrance (60% Reduction)
1985 - 2016 Average Annual (af):	2,280	8,984

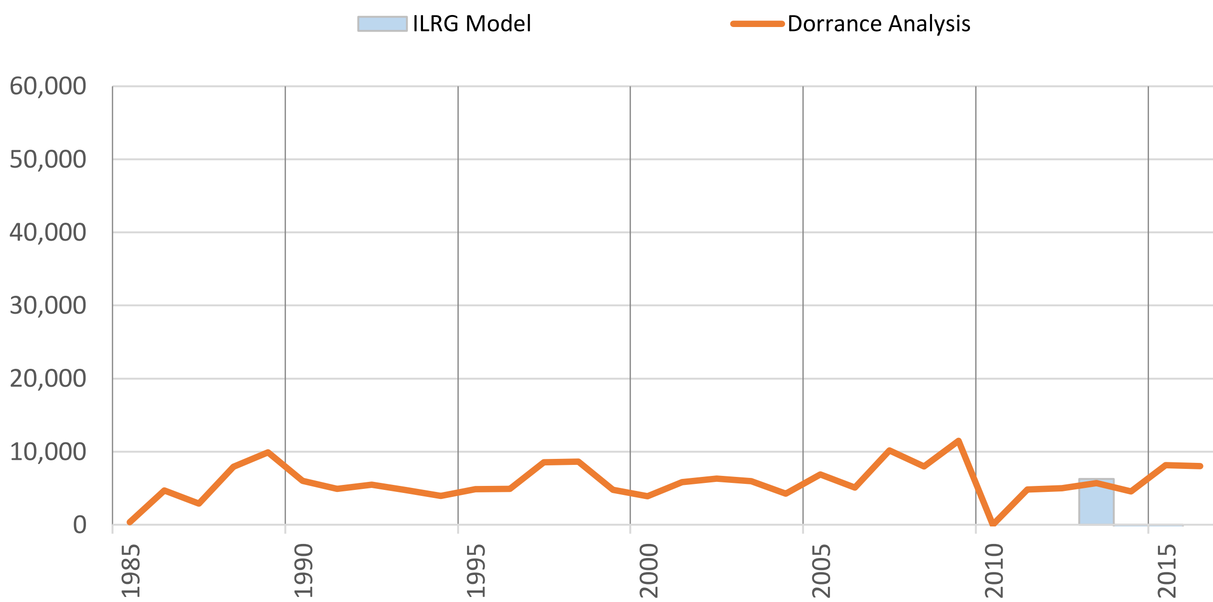
Notes:

(1) ILRG Model change computed as flows in Run 3 (no New Mexico pumping) minus Run 1 (all pumping on).

(2) Dorrance change computed as the increase in El Paso gage flows (Texas Model simulation of 60% reduction in R-M pumping minus historical El Paso gage flows) distributed monthly using historical ratios of monthly to annual El Paso flows and ratios to historical EPW deliveries. EPW deliveries limited maximum historical monthly deliveries.

Figure 14-7

Annual Impact of Pumping on HCCRD Deliveries
Integrated LRG Model (No NM Pumping)
vs.
Dorrance (60% Reduction in R-M Pumping)
(acre-feet)



	(1) ILRG Model (No NM Pump)	(2) Dorrance (60% Reduction)
1985 - 2016 Average Annual (af):	68	5,844

Notes:
(1) ILRG Model change computed as the HCCRD farm deliveries in Run 3 (no New Mexico pumping) minus Run 1 (all pumping on).
(2) Dorrance change computed as the increase in El Paso gage flows (Texas Model simulation of 60% reduction in R-M pumping minus historical El Paso gage flows) distributed monthly using historical ratios of monthly to annual El Paso flows and ratios to historical HCCRD deliveries.

Appendix 27
Inputs for Hueco Annual CFB Models
1903 – 1937

1. Introduction

The CFB Models contain canal and farm budget calculations on an annual time-step for units overlying the Hueco ground water basin, including EPCWID (El Paso Valley), HCCRD, and JID Units 1 – 3. The annual Hueco CFB Models are from 1903 – 1937. This appendix describes the inputs used in the annual Hueco CFB Models.

2. Annual Hueco CFB Model Inputs

2.1 Surface Water Supplies

Surface water supplies were input into the CFB Models using flow data from the surface water dataset ("SWDataSet") and accounting dataset prepared by SWE. The following table summarizes the annual surface water supplies used in the annual Hueco CFB Models for the 1903 – 1937 period.

Irrigation Unit	Surface Water Supplies (1903 – 1937)
EPCWID (El Paso Valley)	1903-1919, 1922, 1924-1926, 1928-1930, 1932, and 1935: Franklin Canal (1903 – 1937) - Ascarate Wasteway (1916 – 1937) + Riverside Canal (1928 – 1937) 1920-1921, 1923, 1927, 1931, 1933-1934, 1936-1937: Reported annual total diversion from WDR reports.
HCCRD	1915 – 1923: Calculated (irrigated acres x 4 feet) 1924 – 1937: Tornillo Canal Waste End + Tornillo Drain
JID Unit 1 JID Unit 2 JID Unit 3	Acequia Madre (1903 – 1937) + Cuidad Juarez Sewage (1926 – 1937) + River Diversions (1907 – 1937); split proportionally between units using irrigated acreage

Available surface water flows from 1903 – 1937 have been compiled, but there are significant data gaps during this period. SWE coordinated with MMA to estimate the missing 1903 – 1937 annual data. The start dates for different canals, wasteways, and drains were provided by MMA. These estimates are described in detail below.

EPCWID (El Paso Valley) 1903 – 1937

Annual data for the Franklin Canal date back to 1914 (missing data in 1917). Prior to the construction of the American Dam in 1938, the Franklin Canal diverted at the International Dam. Franklin Canal diversion data from 1903 – 1913 and 1917 were estimated using an annual 1918 – 1938 regression with streamflows for the Rio Grande at El Paso gage. The Franklin Canal diversions were estimated as the minimum of the computed canal flow using the regression and the estimated capacity of the canal (320 cubic feet per second ["cfs"]). The Franklin Canal diversions were also limited to an irrigation season of March to November.

The Ascarate Wasteway was constructed around 1916, but annual flow records are only available after 1938. Annual Ascarate Wasteway flows from 1916 – 1937 were estimated using a 1938 – 1949 annual regression with the Franklin Canal.

The Riverside Canal was constructed around 1928 and the annual records for the Riverside Canal from 1928 – 1937 are complete.

HCCRD 1903 – 1937

Irrigation in HCCRD commenced around 1915 with the construction of ditches that diverted water from the Rio Grande and HCCRD was organized in 1924 (Reclamation, 2013). HCCRD flows were measured starting in the 1920s. Measurement of the Tornillo Drain flows began in 1923 and measurement of the Hudspeth Canal (Tornillo End) began in 1925. The total flow to HCCRD was assumed to be the sum of the Tornillo Drain and the Hudspeth Canal (Tornillo End). According to the HCCRD water supply schematic (see SWE Report Figure 6-4; Sullivan and Welsh 2019), the Hudspeth Canal (Tornillo End) began in 1925. There are no Hudspeth Canal (Tornillo End) flow records from 1925 – 1934 and only annual data are available 1935 – 1937. The Hudspeth Canal (Tornillo End) flows are estimated from 1925 – 1934 using a water balance approach, calculated as the Tornillo Canal heading flow minus an assumed seepage loss minus farm headgate demands for the Tornillo acres minus Tornillo Waste. Annual Hudspeth Canal (Tornillo End) flows are distributed monthly using the same distribution as the Tornillo Canal heading monthly flows.

Various regression equations to estimate diversions for the Tornillo Drain and Hudspeth Canal (Tornillo End) from 1915 – 1923 were tested and did not yield good fits. Therefore, the diversions from 1915 – 1923 were estimated as the total irrigated acres multiplied by four feet.

JID Units 1 – 3 1903 – 1937

Diversion records for Acequia Madre are available from 1924 – 1925 and 1930 – 1936. Missing data for 1903 – 1923, 1926 – 1929, and 1937 were estimated using an annual 1930 – 1936 regression with the Rio Grande at El Paso gaged flows. The Acequia Madre diversions were estimated as the minimum of the computed canal flow using the regression and the estimated capacity of the canal (300 cfs). The Acequia Madre diversions were also limited to an irrigation season of March to November. A water balance calculation was conducted to check that the estimated combined diversions at Franklin Canal and Acequia Madre did not exceed the total Rio Grande flow at El Paso gage.

The Sewage Flow from 1926 – 1937 was estimated to be 49 percent of the Cuidad Juarez (“JMAS”) pumping using methodology described in the report**.** There are no data for JMAS pumping prior to 1926, although the annual JMAS pumping was less than 500 acre-feet in the late 1920s. Because of the lack of data and the small magnitude of the JMAS pumping, no Sewage Flows were computed to include in the surface water supply to Juarez prior to 1926. Sewage Flow available to the farms from 1926 – 1937 was limited to the irrigation season of March to October.

Annual estimates of River Diversions from 1930 – 1936 from the 1938 Rio Grande Joint Investigation (“RGJI”) were used in the CFB Models (USNRC, 1938). Due to similar hydrological conditions, annual data for 1937 was assumed to be equal to 1936. The River Diversions prior to 1930 were computed as the estimated available river flow limited to the JID irrigation demand.

The total JID water supplies from 1903 – 1937 were distributed to the JID units based on the irrigated area in each unit. This distribution of water is consistent with the water distribution used during this period in Carreno (1957), except in the drought years 1903 – 1906 in which water was assumed to only be available to JID Unit 1.

2.2 Irrigated Area

Available irrigated area data from 1903 – 1937 were compiled for use in the annual Hueco CFB Models. There are no data on primary acres in Texas and Mexico and all irrigated lands for these areas are assumed to be supplemental acres.

Available irrigated area in Texas, EPCWID (El Paso Valley) and HCCRD, from 1903 – 1937 are from the 1938 RGJI. The 1938 RGJI records are not complete from 1903 – 1937, and missing irrigated area data were estimated using interpolation/extrapolation of the years with data. The reported and estimated irrigated acreage data used in the CFB Models are shown in the table below.

The irrigated area data for JID was obtained from various reports (USNRC, 1938 and IBWC, 1989). Similar to EPCWID (El Paso Valley) and HCCRD, the irrigated acreage for years of no data were interpolated between the available reported acreage. The total acreage was distributed into the three JID units primarily using the reported distribution from Carreno (1957), except from 1903 – 1906, it was assumed that during low flows all diversions would go to JID Unit 1. In 1904, it was assumed that there were zero irrigated acres since there were no flows at the Rio Grande at El Paso gage that year from March – July.

The irrigated area used in the annual Hueco CFB Models is summarized in the table below.

District	Supplemental Acres 1903 – 1937
EPCWID (El Paso Valley)	1903 – 1906: Set equal to 1907 acreage from RGJI (USNRC, 1938) 1907, 1914, and 1920 – 1935: Acreage from RGJI (USNRC, 1938) 1908 – 1913: Linear interpolation between 1907 and 1914 acreage from RGJI (USNRC, 1938) 1915 – 1917: Set equal to 1914 acreage from RGJI (USNRC, 1938) 1918 – 1919 and 1936 – 1937: Reclamation Water Distribution Reports (Accounting DataSet)
HCCRD	1903 – 1914: Assumed zero irrigated acres (MMA) 1915 – 1919: Linear interpolation between zero acres in 1914 to 1920 acreage from RGJI (USNRC, 1938) 1920 – 1936: Acreage from RGJI (USNRC, 1938) 1937: Davids Engineering (2018)
JID Units 1 – 3	1903, 1905, 1908 – 1914, 1916 – 1922, 1927 – 1929, and 1931 – 1937: Acreage interpolated from IBWC (1989) and RGJI (USNRC, 1938), data provided by MMA 1904, 1906, 1915, and 1930: Acreage from IBWC (1989), data provided by MMA 1907 and 1923 – 1926: Acreage from RGJII (USNRC, 1938), data provided by MMA

2.3 Crop Irrigation Requirement and Excess Effective Precipitation

For the 1903 – 1935 annual Hueco CFB Models, the CIR is the average annual 1936 – 1937 CIR from DE reduced by 5 percent. For 1936 – 1937, the annual CIR from DE was reduced by 5 percent. There is no assumed excess effective precipitation simulated in the 1903 – 1937 annual CFB Models.

2.4 Conveyance and Other Losses

For the HCCRD and JID CFB Models, the total canal loss and wasteway flows loss is a user-specified percent of the total diversions for each annual CFB Model. These percentages do not vary from year-to-year. The total canal loss is set to 40% for the HCCRD and JID CFB Models from 1903 – 1937. The wasteway flow percentage is set to 0%.

For the EPCWID (El Paso Valley), the canal loss and waste are user-specified percentage (40% and 10%) for years with no WDR records (1903-1919, 1922, 1924-1926, 1928-1930, 1932, and 1935).

For years with WDR records (1920-1921, 1923, 1927, 1931, 1933-1934, 1936-1937), the total canal loss is the minimum of 40% and the river headgate ("RHG") diversion minus the farm headgate ("FHG") delivery divided by the RHG diversion. However, in all years, the canal loss is equal to the minimum 40%. For years with WDR records, the waste is computed as a residual (RHG diversion minus the canal loss). The waste residual volume is used to compute a waste percent (waste residual divided by RHG diversion) that is used in the EPCWID (El Paso Valley) annual CFB Model.

2.4.1 Incidental Canal Loss and Canal Seepage

The incidental canal loss is computed based on a user specified a percentage of the total canal loss and is set at 6%.

2.5 Maximum On-Farm Irrigation Efficiency ("MFE")

The MFE is a user-specified percent for each annual CFB Model. The MFE does not vary from year-to year. The MFE is currently set at 68% for all irrigation units.

2.6 On-Farm Loss Split

The surface runoff percentage is a user-specified percent for each annual CFB Model that does not vary from year-to year. The surface runoff percentage is currently set at the 6% for all irrigation units. The deep percolation percent is computed as one minus the surface runoff percent (94%).

2.7 Soil Moisture Reservoir

The soil moisture reservoir (inches) for the annual Hueco CFB Models are set equal to the values used in the monthly CFB Models.

2.8 Ground Water Pumping

There is no ground water pumping for irrigation supply on the Hueco lands from 1903 – 1937. However, the structure to simulate the supplemental and primary pumping has been added to the annual Hueco CFB Models.

Appendix 28

Hydrologic and Water Quality Models: Performance Measures and Evaluation Criteria

Moriasi et al. (2015)

HYDROLOGIC AND WATER QUALITY MODELS: PERFORMANCE MEASURES AND EVALUATION CRITERIA

D. N. Moriasi, M. W. Gitau, N. Pai, P. Daggupati

ABSTRACT. *Performance measures (PMs) and corresponding performance evaluation criteria (PEC) are important aspects of calibrating and validating hydrologic and water quality models and should be updated with advances in modeling science. We synthesized PMs and PEC from a previous special collection, performed a meta-analysis of performance data reported in recent peer-reviewed literature for three widely published watershed-scale models (SWAT, HSPF, WARMF), and one field-scale model (ADAPT), and provided guidelines for model performance evaluation. Based on the synthesis, meta-analysis, and personal modeling experiences, we recommend coefficient of determination (R^2; in conjunction with gradient and intercept of the corresponding regression line), Nash Sutcliffe efficiency (NSE), index of agreement (d), root mean square error (RMSE; alongside the ratio of RMSE and standard deviation of measured data, RSR), percent bias (PBIAS), and several graphical PMs to evaluate model performance. We recommend that model performance can be judged "satisfactory" for flow simulations if monthly $R^2 > 0.70$ and $d > 0.75$ for field-scale models, and daily, monthly, or annual $R^2 > 0.60$, $NSE > 0.50$, and $PBIAS \le \pm 15\%$ for watershed-scale models. Model performance at the watershed scale can be evaluated as "satisfactory" if monthly $R^2 > 0.40$ and $NSE > 0.45$ and daily, monthly, or annual $PBIAS \le \pm 20\%$ for sediment; monthly $R^2 > 0.40$ and $NSE > 0.35$ and daily, monthly, or annual $PBIAS \le \pm 30\%$ for phosphorus (P); and monthly $R^2 > 0.30$ and $NSE > 0.35$ and daily, monthly, or annual $PBIAS \le \pm 30\%$ for nitrogen (N). For RSR, we recommend that previously published PEC be used as detailed in this article. We also recommend that these PEC be used primarily for the four models for which there were adequate data, and used only with caution for other models. These PEC can be adjusted within acceptable bounds based on additional considerations, such as quality and quantity of available measured data, spatial and temporal scales, and project scope and magnitude, and updated based on the framework presented herein. This initial meta-analysis sets the stage for more comprehensive meta-analysis to revise PEC as new PMs and more data become available.*

Keywords. *Guidelines, Model calibration and validation, Performance measures and evaluation criteria.*

Hydrologic and water quality (H/WQ) models are increasingly being used to determine the impacts of land management, land use, climate, and conservation practices on water resources, ecology, and water-related ecosystem services. Hydrologic cycle components and fate and transport of sediments and chemicals are examples of complex systems comprised of many processes that can be simulated using H/WQ models. A majority of H/WQ models require some degree of calibration to reduce the uncertainty of predictions (Engel et al., 2007; USEPA, 2009). Calibration is the process of adjusting input parameter values and initial or boundary conditions within reasonable ranges until the simulated results closely match the observed variables (Zeckoski et al., 2015). Calibration requires the examination of accuracy of outputs and process simulation (Sorooshian, 1983) to ensure adequate watershed and scenario representation. This requires use of model performance measures (PMs) and the corresponding performance evaluation criteria (PEC). Throughout this article, the term "PMs" refers to the statistical and graphical methods used during model calibration and validation, "performance data" refers to the reported values of each of the statistical PMs (e.g., 0.5 for NSE), and "PEC" refers to model performance qualitative ratings (e.g., very good, good, satisfactory, or unsatisfactory) with the corresponding quantitative thresholds for the statistical PMs of interest (e.g., NSE, PBIAS, or R^2). Validation is the process by which a calibrated model is shown to be capable of reproducing a set of field observations or predicting future conditions without further adjustment to the calibrated parameters (Zheng et al., 2012).

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Modelers have used different PMs, including statistical, graphical, or a combination of both. For example, Herr and Chen (2012) preferred the use of absolute and relative error, while Huth et al. (2012) recommended and used a variety of measures, including Nash-Sutcliffe efficiency (NSE; Nash and Sutcliffe, 1970) and the ratio of root mean square error (RMSE) and standard deviation of measured data (RSR; Moriasi et al., 2007). Commonly used graphical PMs include time series plots (e.g., van der Keur et al., 2001; Mutiti and Levy, 2010; Palosuo et al., 2011; Arnold et al., 2012; Herr and Chen, 2012; Huth et al., 2012), scatter plots (e.g., Palosuo et al., 2011; Herr and Chen, 2012), cumulative charts (e.g., Herr and Chen, 2012), and contour maps (e.g., Zheng et al., 2012).

Nevertheless, the use of both graphical and statistical PMs is essential for robust model performance evaluation (Biondi et al., 2012; Bennett et al., 2013; Harmel et al., 2014; Daggupati et al., 2015a). For instance, measures such as the NSE are insensitive to systematic errors and yield good model performance even if low values are poorly fitted (Krause et al., 2005; Ritter and Muñoz-Carpena, 2013; Pfannerstill et al., 2014). In such cases, graphical PMs provide supplementary evidence as to where (e.g., in the time series, magnitude of event, depth, etc.) the model is not performing adequately. In addition, pre-inspection of graphical output likely minimizes equifinality (or parameter non-uniqueness), a situation in which a variety of parameter sets can yield acceptable model performance (Beven and Freer, 2001; Doherty and Johnston, 2003). This is achieved by allowing identification of parameter sets that provide better process simulation, thereby reducing the number of possible parameter sets that yield acceptable model performance. Recent works indicate that the intended use of the model could serve as an important factor in the selection of PMs and PEC (Finsterle et al., 2012; Harmel et al., 2014).

Past literature on model PMs includes Willmott (1984), Loague and Green (1991), ASCE (1993), Refsgaard (1997), Gupta et al. (1998), Legates and McCabe (1999), Santhi et al. (2001), Krause (2005), McCuen et al. (2006), Engel et al. (2007), and Moriasi et al. (2007). With respect to PEC, several studies have provided a summary of ranges of values for use in assessing model performance (Popov, 1979; Ramanarayanan et al., 1997; Gassman et al., 2007; Moriasi et al., 2007; Douglas-Mankin et al., 2010; Tuppad et al., 2011; Ritter and Muñoz-Carpena, 2013). The use of PEC provides objective indications of the adequacy of model performance, hence affording greater credibility to the modeling work (Duda et al., 2012). General PEC help model users and decision makers estimate model calibration and validation accuracy, usability for their specific application, and uncertainty or reliability of model predictions (Duda et al., 2012). It is also important to set PEC before beginning model evaluation (ASCE, 1993; USEPA, 2002; Engel, 2007; Moriasi et al., 2007).

Selection and use of PEC also varies by study and by model (Santhi et al., 2001; Van Liew et al., 2007; Parajuli et al., 2009; Benett et al., 2013, Daggupati et al., 2014; Harmel et al., 2014). This could result in inconsistent model evaluation, making it difficult to provide a benchmark for further model improvements. Moriasi et al. (2007) provided guidance to facilitate a more consistent and structured approach for model performance evaluation. However, the scope of the guidelines provided by Moriasi et al. (2007) was limited to NSE, percent bias (PBIAS; Gupta et al., 1999), and RSR for stream flow, sediment, and nutrient (N and P) simulations at a monthly temporal scale and watershed spatial scale. Different PMs can have differing ranges of conditions for which they are best suited (Krause et al., 2005; Gupta et al., 2009; Westerberg et al., 2011; Pushpalatha et al., 2012). Just as there are differences in PMs, there are also differences in the PEC for each measure. In addition, models perform differently for different simulated response outputs and, perhaps, at different temporal and spatial scales (Westerberg et al., 2011; Biondi et al., 2012), which may require different PEC. For example, regions with a shallow water table (e.g., south Florida) experience rapid water table rise within 12 hours of rainfall or irrigation input (Jaber et al., 2006; Hendricks et al., 2013). Hendricks et al. (2013) evaluated a daily temporal scale model for simulating water table responses in a shallow water table region of Florida and concluded that a daily temporal scale was a fundamental limitation because the hydrologic response time was less than 12 hours. Therefore, there is need to explore how different models perform under different conditions using different PMs to help determine appropriate PEC. Further, Moriasi et al. (2007) stated that "as new and improved methods and information are developed, the recommended guidelines should be updated to reflect these developments."

Recently, Biondi et al. (2012), Ritter and Muñoz-Carpena (2013), Moriasi et al. (2012), Pushpalatha et al. (2012), Bennett et al. (2013), Black et al. (2014), and Harmel et al. (2014) focused on various aspects of performance of H/WQ models. Biondi et al. (2012) performed a literature review and provided general model validation guidelines that cover several topics discussed in this special collection. Black et al. (2014) provided general guidance on the implementation and application of water resource management models focused on scenario analysis. Bennett et al. (2013) reviewed and provided methods available across different fields for describing the performance of environmental models focusing on model PMs. Pushpalatha et al. (2012) analyzed several forms of NSE to determine the form that was suitable for flows. Ritter and Muñoz-Carpena (2013) presented a unified framework for determining model PEC in a statistically rigorous way and for the evaluation of bias, outliers, and repeated data focused on RMSE and NSE. Harmel et al. (2014) reviewed literature and recommended a broad methodology that takes into account intended use to establish model performance expectations. The methodology provides a brief summary of several topics, including model valuation, interpretation, and communication of model results.

Moriasi et al. (2012) summarized the results of 25 H/WQ models in a special collection of 22 articles, each focusing on individual model calibration and validation strategies. The special collection provided a good source of model-specific calibration and validation examples, performance evaluation examples, and references. However, there is need for consistent model calibration and validation guidelines (Moriasi et al., 2012), including PMs and PEC.

Recognizing the good work done by others, in this article we: (1) synthesize the special collection articles (Moriasi et al., 2012) with respect to PMs and PEC; (2) perform a meta-analysis of performance data as reported in peer-reviewed literature by considering the effects of calibration and validation periods, simulated components, and spatial and temporal scales; and (3) establish guidelines for model performance evaluation based on information from the synthesis (objective 1) and meta-analysis (objective 2). Further, we present an example case study illustrating the application of our recommendations in model calibration and validation.

In summary, this article is one of nine topic-specific articles in a special collection whose main goal is to provide recommendations, which together with information from other literature will be used to develop model calibration and validation engineering practices for H/WQ models. These articles extensively cover critical issues related to the calibration and validation of H/WQ models. This article focuses on model PMs and the corresponding PEC related to models in the Moriasi et al. (2012) special collection and provides a more rigorous framework than Moriasi et al. (2007, 2012) for determining PEC, involving a meta-analysis of the performance data collected in this study and using the results to guide PEC development.

METHODS

SYNTHESIS OF PERFORMANCE MEASURES AND EVALUATION CRITERIA

As a starting point, the articles in the Moriasi et al. (2012) special collection were reviewed to determine the statistical and graphical PMs used for each of the models. The models in the special collection were grouped into three spatial categories (point to plot, field, and watershed; table 1). PMs and PEC reported outside of the special collection were helpful in broadening the outlook on PEC and providing additional materials useful for establishing guidelines. Commonly used PMs and PEC within and outside the special collection (Moriasi et al., 2012) for each model were recorded for in-depth analyses.

Although there are several ways in which statistical PMs can be categorized (Moriasi et al., 2007; Bennett et al., 2013), in this article statistical PMs are discussed and divided into three broad categories: (1) standard regression, (2) dimensionless, and (3) error index based on Moriasi et al. (2007). Standard regression measures determine the strength of the linear relationship between simulated and measured data. Dimensionless measures provide a relative model evaluation assessment, and error index measures quantify the deviation in the units of the data of interest (Legates and McCabe, 1999). Graphical PMs are divided into two categories (direct and derived comparison), and information about the strengths and weaknesses of each of the measures was obtained from the literature. In this article, we define direct comparison graphical PMs as graphical PMs in which original measured and simulated data are compared with each other, for instance, with time series graphs. Derived graphical PMs are those in which meas-

Table 1. Models in the Moriasi et al. (2012) special collection grouped by spatial scale.

Model	Simulated Processes (Components)	Reference
Point to plot scale		
COUPMODEL	Hydrology, N, carbon, plant growth, heat, tracer, chloride	Jansson (2012)
HYDRUS	Water flow, solute transport, heat transfer, carbon dioxide	Šimůnek et al. (2012)
MACRO	Macropore flow, pesticides	Jarvis and Larsbo (2012)
MT3DMS	Multispecies solute transport, groundwater	Zheng et al. (2012)
SHAW	Hydrology, heat transfer	Flerchinger et al. (2012)
STANMOD	Solute transport in soils and groundwater	van Genuchten et al. (2012)
SWIM3	Water and solute movement	Huth et al. (2012)
TOUGH2	Multiphase, multicomponent fluids in porous and fractured geologic media	Finsterle et al. (2012)
VS2DI	Water, solute, heat transport	Healy and Essaid (2012)
Field scale		
ADAPT	Hydrology, erosion, nutrients, pesticides, subsurface tile drainage	Gowda et al. (2012)
CREAMS/GLEAMS	Hydrology, erosion, pesticides, sediments, nutrients, plant growth	Knisel and Douglas-Mankin (2012)
DAISY	Water, snowmelt, carbon cycle, energy balance, N cycle, crop production, pesticides	Hansen et al. (2012)
DRAINMOD	Hydrology (water table depth, tile flow, surface runoff, depth of irrigation water applied, wetland hydrology), plant growth (crop yield)	Skaggs et al. (2012
EPIC/APEX	Hydrology (surface runoff, stream flow, tile flow), plant growth, erosion, sediments, nutrients, pesticides	Wang et al. (2012)
RZWQM2	Hydrology, plant growth, nutrients, pesticides	Ma et al. (2012)
WEPP Hillslope	Hydrology, soil erosion	Flanagan et al. (2012)
Watershed scale		
BASINS/HSPF	Hydrology, snowmelt, pollutant loadings, erosion, fate and transport	Duda et al. (2012)
KINEROS2/AGWA	Runoff, erosion, sediments	Goodrich et al. (2012)
MIKE-SHE	Surface and subsurface water dynamics, interception, evapotranspiration, overland flow, channel flow, unsaturated flow, saturated zone flow, water levels, surface and groundwater quality	Jaber and Shukla (2012)
SWAT	Hydrology, plant growth, sediments, nutrients, pesticides	Arnold et al. (2012)
WAM	Hydrology, sediments, nutrients	Bottcher et al. (2012)
WARMF	Hydrology, sediments, nutrients, acid mine, carbon, bacteria	Herr and Chen (2012)
WEPP Watershed	Hydrology, soil erosion	Flanagan et al. (2012)

ured or simulated data are first transformed into another form before they are displayed in a comparative graph, for example, frequency duration curves.

A comparative analysis of the reported PMs was performed to evaluate (1) how they compare across the models, (2) their advantages and disadvantages, and (3) their usability (ease of and suitability for use) from a user or non-developer perspective. Additional considerations for PMs included their suitability for event-based vs. continuous models and their use with missing and/or discrete observed data. Based on this analysis, recommendations are made for suitable PMs.

META-ANALYSIS OF PERFORMANCE DATA

A statistical meta-analysis was performed on the model performance data to guide the development of the PEC. Simply stated, a meta-analysis (Glass, 1976; Hunter et al., 1982; Hunt, 1997; Lyons, 1998; among others) is the accumulation and analysis of data from separate but similar studies for the purpose of obtaining insights from the pooled data that are not discernible from the individual studies. The methodology provides an avenue for bringing together information from various related studies in search of common patterns and conclusions. It can also be used to reconcile data from disparate studies. Since its inception in the 1970s, meta-analysis has been applied successfully in various fields, including medical research and social studies (Egger and Smith, 1997; Lyons, 1998; Bland, 2000). The methodology has also been used successfully in natural resources and environmental systems for the development of a Best Management Practice (BMP) tool (Gitau et al., 2005).

The accumulation of data from existing studies is the most involved part of a meta-analysis, as it requires considerable attention to some key considerations, as described in ensuing subsections.

Kinds of Articles to Include

It is necessary that articles be relevant to the study at hand (Light and Smith, 1971; Hunt, 1997) and that the articles contain the information needed to achieve study goals. As materials may be subject to re-interpretation, it is preferable that the articles contain original material and include a detailed account of the study. Further, given a common tendency toward selecting articles that favor an author's viewpoint and/or that align with prevailing opinion (Egger and Smith, 1997), it is important that article selection follows an objective procedure. For example, in this article, the articles included are primary sources that provided performance data for the various PMs. Additional criteria included the presence of details such as models used, evaluation time step, components evaluated, and whether data reported were for calibration or validation.

Whether or Not to Use Only Published Material

Generally, published material is deemed to have more reliable data and is afforded more credibility than unpublished material. However, published material is often preferential in nature, favoring research works based on reported significance (Lipsey and Wilson, 2001). For example, in regard to model performance, articles reporting higher values of NSE may be preferentially published, whereas those with lower values (albeit with better parameter representations) may take a while longer or may not be published at all. Including only published material may result in a publication bias (Light and Smith, 1971; Hunter et al., 1982; Light and Pillemer, 1984; Bland, 2000); thus, we recommend that both published and unpublished material be included. The challenge lies in being able to find unpublished information, as this is not generally available. Thus, the dataset developed for this article only contains data from published material (peer-reviewed journal articles after 1990).

Rejection of Articles on the Basis of Perceived Inadequacies in the Methodology

Another important consideration is the determination of article suitability for inclusion based on methodologies used. This is especially so for unpublished information, as a work may be unpublished due to unsuitable methodologies. However, it is important to note that flaws can be identified in almost any article (Hunter et al., 1982; Lipsey and Wilson, 2001) given that opinions tend to differ among researchers. The use of methodology as a basis for article inclusion would thus introduce elements of subjectivity into the analysis (Light and Smith, 1971) and would result in a reduced dataset (Glass, 1976; Hunter et al., 1982), which would then impact the analysis. In this study, no judgements were made as to the adequacy or inadequacy of the methodologies used once an article was deemed suitable for inclusion based on study goals.

Amount of Data Necessary for Analyses

The ideal case would be to have all existing data; in this case, the details and results of all studies in which model calibration and validation have been conducted and performance values have been reported. However, this is generally not practical, due to limited access to unpublished material, if nothing else, and thus the need for a representative sample arises. In addition, it is necessary to consider the study goals. For example, in this article, the goal was to capture recent advances in modeling (in the 1990s and later) for commonly used H/WQ models published in a recent special collection (Moriasi et al., 2012) when establishing performance criteria. For this work, the target was to review a minimum of 20 articles (outside the Moriasi et al. (2012) special collection) per model for the most commonly simulated output responses (flow, sediment, and nutrients) to be reviewed. To enable meta-analysis, each reported entry of performance data was extracted and tabulated along with size of the study area (supplemental material tables S1-1 through S1-22, available at http://bit.ly/NRES_SW10715). Exceptions were permitted for models for which the available peer-reviewed articles numbered less than 20, in which case all available articles were reviewed. Data on stream flow, surface runoff, base flow, and tile flow model performance values were combined as appropriate and referred to as flow for the watershed-scale and ADAPT models to ensure that there were sufficient data for analyses. Where stream flow was the only component used in the analysis and/or discussion, the term "stream flow" was used to distinguish it from the combined flow component. Data were commonly reported in the literature at annual, monthly, and daily temporal scales for watershed-scale models and at a monthly temporal scale for field-scale models. In addition, there was a substantial amount of seasonal data associated with PBIAS.

Handling of Extreme Values

Values showing up as extreme values, once all data are assembled, may reflect extreme site or study characteristics; thus, their exclusion would mask the existence of extremes. Therefore, extreme values such as values of other PMs for studies in which there were negative NSE values were not excluded from the primary analysis. However, negative NSE values were not included in criteria development, as such values represent unacceptable model performance. Further description is provided under the "Meta-Analysis of Performance Data" subheading within the "Results and Discussion" section.

Data Analyses

Once all data are assembled, the most basic analysis involves determining an average for each data component (Hunter et al., 1982; Light and Pillimer, 1984; Hunt, 1997), for example, an average of all NSE values. More detailed approaches involve the computation of standardized metrics to account for differences in the amounts of data among studies (Light and Pillimer, 1984; Lipsey and Wilson, 2001). In either case, this would mask the variability in the data, so more in-depth analysis allowing the examination of factors that could affect results (Hunter et al., 1982; Light and Pillimer, 1984; Hunt, 1997) and extraction of other pertinent information are necessary.

In this study, descriptive statistics such as mean, median, minimum, and maximum were computed for the performance data, and the associated distributions were plotted in order to make a determination on subsequent analysis. Following these preliminary diagnostics, significant differences in reported values were determined based on (1) calibration or validation; (2) scale (specifically watershed-scale studies based on Hydrologic Unit Code (HUC; https://pubs.er.usgs.gov/publication/ofr84708; direct comparisons were not made between watershed and field scales due to the large difference in available data); and (3) model components (e.g., flow, sediment, and nutrients). The analysis was conducted using the median test, a non-parametric (typically distribution-free) test based on median rank scores (SAS, 2007; Sheskin, 2003; Brown and Mood, 1951). The test considers all observations and ranks them as 0 or 1 based on their location around (above or below) the median. Resulting rank scores are then used for the comparisons based on the chi-square statistic and associated probabilities. In addition, the performance data were plotted on a common axis to provide a visual comparison. All analyses were carried out using JMP statistical software (SAS, 2008).

Development of Guidelines for Model Performance Evaluation

The median test on reported performance data was used to determine whether separate PEC were needed for calibration and validation periods, spatial and temporal scales, and for different simulated response outputs. Following the median test, thresholds for model PEC ratings were established by computing percentiles or quartiles of model PM data collected from peer-reviewed articles outside the Moriasi et al. (2012) special collection. The thresholds obtained for the defined ratings formed the initial PEC, which along with the results of the synthesis of the PEC and the modeling experience of the authors were used to develop final PEC guidelines for identified separate categories. A similar approach was used by USEPA (2010) as part of an evaluation of the potential benefits of numeric nutrient criteria for Florida's flowing waters. The guidelines are in the form of recommended PMs and PEC. Brief descriptions are provided for (1) the importance of following proper calibration and validation procedures (Zeckoski et al., 2015; Arnold et al., 2015; Baffaut et al., 2015; Malone et al., 2015; Daggupati et al., 2015b; Guzman et al., 2015; and Yuan et al., 2015) prior to using these general guidelines; (2) additional considerations for adjusting the general recommendations because of the variety of modeling applications; and (3) a framework for determining recommended model PMs and their corresponding PEC.

Results and Discussion

Synthesis of Performance Measures and Evaluation Criteria

The most commonly used graphical PMs in the special collection articles were time series charts (table 2; e.g., WARMF, DAISY, VS2DI, SWIM3, and SWAT). Other graphical PMs included scatter plots (e.g., APEX/EPIC, CREAMS/GLEAMS, DAISY, WARMF, and SWAT), cumulative frequency curves (e.g., WARMF, SWAT), contour maps (e.g., MT3DMS), depth profile plots (e.g., SWIM3), thermographs in which heat is used as a surrogate for water movement (e.g., VS2DI), and bar charts (e.g., EPIC/APEX). Thermographs are quite common in soil/water-solute transport applications.

The most commonly used statistical PMs were NSE, RMSE (also called root mean square deviation, RMSD), and R^2 (table 2). Other reported statistical PMs included *d* (Willmott, 1981), PBIAS (Gupta et al., 1999), mean absolute error, R, absolute error, relative error, standard error of estimate, non-parametric tests, RSR (Moriasi et al., 2007), 95% confidence intervals (to account for uncertainty, mean, and standard deviation), autocorrelation, and cross-correlation (table 2). Brief descriptions as well as discussions of the strengths, weaknesses, and usage of the commonly used measures are presented in ensuing subsections. The abbreviations of the models in the Moriasi et al. (2012) special collection are provided in the Appendix, while the statistical PMs and associated equations are provided in table 5. Detailed accounts of these and other measures can be obtained from model-specific articles and in the literature (e.g., Wilmott, 1984; Legates and McCabe, 1999; Krause et al., 2005; Moriasi et al., 2007; Ritter and Muñoz-Carpena, 2013; Bennett et al., 2013; Harmel et al., 2014).

Of the models within the Moriasi et al. (2012) special collection, only a few provided PEC (table 3), including

Table 2. Summary of performance measures and evaluation criteria for H/WQ models in the Moriasi et al. (2012) special collection.

Model	Suggested Performance Measures and Evaluation Criteria							
	Statistical Performance Measures[a]						Performance Evaluation Criteria[b]	Graphical Performance Measures[c]
	NSE	R^2	RMSE	*d*	PBIAS	Other		
Point to plot scale								
COUPMODEL	X	X	-	-	-	-	n.p.	Time series
HYDRUS	-	X	-	-	-	X	n.p.	Time series
MACRO	X	-	X	-	-	-	n.p.	-
MT3DMS	-	-	-	-	-	X	n.p.	Contour maps, time series
SHAW	-	-	X	-	-	-	n.p.	Time series
STANMOD	-	-	-	-	-	X	n.p.	Time series
SWIM3	X	-	-	-	-	X	Moriasi et al. (2007)	Time series
TOUGH2	-	-	-	-	-	X	n.p.	-
VS2DI	-	-	-	-	-	X	n.p.	Time series
Field scale								
ADAPT	X	-	X	X	-	X	n.p.	Time series, scatter plots
CREAMS/GLEAMS	X	X	-	X	-	X	n.p.	Time series
DAISY	-	-	X	X	-	-	n.p.	Scatter plots
DRAINMOD	X	X	-	-	-	X	Table 3	Time series
EPIC/APEX	X	X	X	-	X	X	Table 3	Time series, scatter plots, bar charts
RZWQM2	-	-	X	-	-	-	Table 3	Time series
WEPP Hillslope	X	-	X	-	X	X	Moriasi et al. (2007)	-
Watershed scale								
BASINS/HSPF	-	X	-	-	-	X	Table 3	Time series, scatter plots, CFC
KINEROS2/AGWA	X	-	-	-	-	X	Table 3	Time series
MIKE-SHE	-	-	X	X	-	-	n.p.	Time series
SWAT	X	X	X	-	X	X	Moriasi et al. (2007)	Time series, scatter plots, CFC
WAM	X	-	X	-	-	-	n.p.	Time series
WARMF	-	-	-	-	-	X	Table 3	Time series, scatter plots, CFC
WEPP Watershed	X	-	X	-	X	X	Moriasi et al. (2007)	-

[a] NSE = Nash Sutcliffe efficiency/coefficient, R^2 = coefficient of determination, RMSE = root mean square error/deviation, *d* = index of agreement, PBIAS = percent bias/deviation. "Other" includes root mean square error to standard deviation ratio, linear or weighted correlation coefficient, mean error, mean absolute error, standard error of estimate, 95% confidence interval, comparison between observed and predicted means and standard deviations, mean and variance of weighted residuals, autocorrelation, cross-correlation, nonparametric tests, t-tests, and objective functions.
[b] n.p. = not provided and user-defined.
[c] CFC = cumulative frequency curves.

BASINS/HSPF (Duda et al., 2012), DRAINMOD (Skaggs et al., 2012), EPIC/APEX (Wang et al., 2012), KINEROS/AGWA (Goodrich et al., 2012), RZWQM2 (Ma et al., 2012), and WARMF (Herr and Chen, 2012). PEC from Moriasi et al. (2007) were cited for SWAT (Arnold et al., 2012), SWIM3 (Huth et al., 2012), and WEPP (Flanagan et al., 2012). With the exception of SWIM3 (Huth et al., 2012), all point and plot scale models (table 3) employed user-defined objective function thresholds with autocalibration algorithms (Moriasi et al., 2012). The MIKE-SHE (Jaber and Shukla, 2012) and WAM (Bottcher et al., 2012) articles do not provide any PEC.

Graphical Performance Measures

Graphical PMs provide an important complementary tool for modelers to support the calibration and validation of H/WQ models (Daggupati et al., 2015a). Graphical PMs allow visual comparison of simulated and measured output response data, help identify model bias, identify differences in timing and magnitude of peaks (e.g., peak flows) and shape of recession curves, incorporate measurement (Harmel and Smith, 2007) and model (Shirmohammadi et al., 2006) uncertainty, and illustrate how well the model reproduces the frequency of measured daily values (Pfannerstill et al., 2014). The disadvantage of graphical PMs is that model performance can be obtained only qualitatively through them. In addition, graphical PMs can easily be manipulated to look good by scaling.

Table 4 lists a variety of graphical PMs used commonly to support and present results of H/WQ model calibration and validation. The graphical PMs are grouped into two broad categories (direct and derived) to enable users to determine appropriate graphical PMs for their study.

The spatial and temporal scale of simulation could be used to determine graphical performance measures that will be effective in communicating model performance to end users. The most effective graphical measures are ones that highlight specific predictive capabilities of the model. For shorter-term modeling (<1 year), a time series plot can be an effective tool. The performance of models for longer-duration datasets (≥10 years of daily data) is better understood by using either a scatter plot or a duration curve. For instance, when Duda et al. (2012) presented the daily-scale five-year calibration results for an HSPF model application, they provided both a time series graph and a duration curve. The time series graph, which contained approximately 1825 data points, gave the impression that the model sometimes overestimated or underestimated peak flows, depending on the peak. This presented a confusing picture of model performance. The authors then presented the same data in the form of a flow duration curve. The flow duration curve not only indicated that, in general, the model-simulated values were close to the observed values (similar to what was understood from the time series plot), but it also showed that the model overestimated higher flows and underestimated medium and lower flows during the validation period. Thus, the duration curve was a more effective tool for understanding and communicating daily model

Table 3. Reported performance evaluation criteria for models in the Moriasi et al. (2012) special collection.

Model (and Reference)	Response Output	Performance Evaluation Criteria				
BASINS/HSPF (Duda et al., 2012)		Difference between Simulated and Recorded Values (%)				
		Very Good	Good	Fair		
	Hydrology/flow	<10	10 to 15	15 to 25		
	Sediment	<20	20 to 30	30 to 45		
	Water temperature	<7	8 to 12	13 to 18		
	Water quality/nutrients	<15	15 to 25	25 to 35		
	Pesticides/toxics	<20	20 to 30	30 to 40		
		Statistical Evaluation Criteria				
	Hydrology/flow	Statistic	Very Good	Good	Fair	Poor
	Daily	R	≥0.89[a]	≥0.84	≥0.77	<0.77
	Monthly	R	≥0.92	≥0.87	≥0.81	<0.81
	Daily	R^2	≥0.80	≥0.70	≥0.60	<0.60
	Monthly	R^2	≥0.85	≥0.75	≥0.65	<0.65
DRAINMOD (Skaggs et al., 2012)		Statistical Evaluation Criteria				
		Statistic	Excellent	Good	Acceptable	
	Water table depth (daily)	MAE (cm)	<10	<15	<20	
		NSE	>0.75	>0.60	>0.40	
	Drainage volume ($cm^3\ cm^{-2}$)					
	Daily	NSE	>0.75	>0.60	>0.40	
	Monthly	NSE	>0.80	>0.70	>0.50	
	Annual	NSE	>0.85	>0.75	>0.60	
		NPE	<5%	<15%	<25%	
EPIC/APEX (Wang et al., 2012)		Satisfactory Calibration Criteria				
		R^2	NSE	PBIAS	Mean and SD	Graphical
	Runoff or water yield	≥0.60	≥0.55	Within 20%	-	Simulated time-series flow captures the trend or pattern of measured data.
	Crop yield	≥0.60	-	Within 25%	-	Simulated time-series crop yield captures the trend or pattern of measured data.
	Sediment yield	≥0.60	≥0.50	Within 35%	Simulated mean and SD compare closely with measured values	Simulated time-series sediment yield captures the trend or pattern of measured data.
	Nutrient loss	≥0.60	≥0.50	Within 50%	-	Simulated time-series nutrient loss captures the trend or pattern of measured data.
KINEROS/AGWA (Goodrich et al., 2012)		Acceptable Model Performance				
	Runoff, erosion, sediments	Simulated values within 30% of observed (Al-Qurashi et al., 2008)				
RZWQM2 (Ma et al., 2012)		Acceptable Model Simulation				
		R^2	NSE	*d*	PBIAS	
	Hydrology, plant growth, nutrients, pesticides	≥0.80	≥0.70	≥0.70	Within 15%	
WARMF (Herr and Chen, 2012)		Good Model Performance				
	Hydrology/flow	<20% absolute error				
	Nutrients	<30% absolute error				
	Phytoplankton and suspended sediment	<50% absolute error				

[a] Values estimated from figure 4 (Duda et al., 2012).

performance for their case study. The effectiveness of using a duration curve is also demonstrated in a case study presented later in this article.

As discussed in table 4, certain derived graphical PMs, such as cumulative plots and maps, can provide a misleading picture of model performance. For instance, a combination of cumulative and daily time series plot was used by Bottcher et al. (2012) to present results of the WAM model (fig. 1). The presentation of these two plots was essential because the cumulative plot gives the impression that the model overpredicts initially and underpredicts in the latter part of simulation but has reasonable overall performance. On the other hand, the time series plot shows that certain important flow peaks were completed missed. The time series plot allows the modeler to find temporal mismatches that could go unnoticed by using only a cumulative plot.

Maps are also effective tools for presenting key results and meeting the objectives of watershed models. For example, to build confidence in an uncalibrated SWAT model, Srinivasan et al. (2010) used maps to show that SWAT-simulated annual corn and soybean yields for each subbasin were consistent with USDA-NASS estimates. Pai et al. (2011) and Daggupati et al. (2011) used maps of sediment, total P, and nitrate-N outputs to prioritize subwatersheds and fields in SWAT model applications in Arkansas and Kansas. Such maps could be used to assess spatial model performance.

STATISTICAL PERFORMANCE MEASURES

Statistical PMs are widely used to quantify the performance of H/WQ models in describing the "closeness" of the simulated behavior to observations. Table 5 summarizes commonly used statistical PMs based on the Moriasi et al. (2012) special collection, along with their demonstrated advantages/disadvantages, ranges, optimal values, and the equations used to compute them. Harmel et al. (2014), Bennett et al. (2013), Krause et al. (2005), and Coffey (2004) also provide a comprehensive list of statistical PMs. Although there are different ways to categorize PMs (Moriasi et al., 2007; Bennett et al., 2013), the PMs in this article

Table 4. Summary of graphical performance measures for H/WQ model calibration and validation.

	Purpose	Advantages/Disadvantages
Direct comparison		
Scatter plots	Compare observed and simulated data with no dependent variable. A least square regression line can be fitted to observe deviation from the 1:1 line.	**Advantages:** Divergence from the 1:1 line provides a visual understanding of the underlying behavior of the model, including any bias or systematic variance. **Disadvantages:** Data points clumped in the low intensity, high frequency range and few in the high intensity, low frequency range can artificially make a model's performance look good.
Time-series plots	Compare observed and simulated data with time as a dependent variable.	**Advantages:** Helps inspect and support troubleshooting event-specific prediction issues, including mismatches in magnitude of peaks and shape of recession curve, and outliers. Time series plots can also guide selection of parameters to be used for calibration. **Disadvantages:** Time series plots become cluttered with too many data points.
Derived comparison		
Cumulative plots	Compare cumulative observed and simulated values with time as dependent variable.	**Advantages:** Allows identification of any systematic temporal divergence between observed and simulated values. **Disadvantages:** Cumulative plots may still converge, with major temporal mismatches. They should be used as a preliminary model performance-screening tool.
Flow and load duration curves	Compare observed and simulated values with probability as a dependent variable.	**Advantages:** Provides insight into model performance over different flow/load regimes (i.e., low, medium, high; Pfannerstill et al., 2014). **Disadvantages:** Needs a larger number of data points to derive meaningful conclusions. Duration curves are most useful for long-term monthly, daily, or subdaily calibrations.
Maps	Map showing the output of interest at the desired spatial scale. Examples include showing annual sediment loss for each subwatershed.	**Advantages:** Useful for presenting field-scale to watershed-scale model results for understanding the spatial performance of the model. Pollutant hotspots within a watershed can be quickly identified using color-codes. **Disadvantages:** Choices of color-coding and grouping within a map can sometimes be misleading. For example, red colored areas may or may not represent critical areas depending on actual values plotted.

are grouped as standard regression, dimensionless, and error index, as discussed below.

Standard Regression

Pearson's correlation coefficient (r) and coefficient of determination (R^2) describe the degree of collinearity between simulated and measured data. The correlation coefficient is an index that is used to investigate the degree of linear relationship between observed and simulated data. R^2 is the squared value of r, although it can also be expressed as the squared ratio between the covariance and the multiplied standard deviations of the observed and predicted values (Krause et al., 2005).

Dimensionless

The Nash-Sutcliffe efficiency (NSE) is a normalized statistic that determines the relative magnitude of the residual variance ("noise") compared to the measured data variance ("information"; Nash and Sutcliffe, 1970). NSE indicates how well the plot of observed versus simulated data fits the 1:1 line. Many studies (e.g., Santhi et al., 2001; Vazquez-Amabile and Engel, 2005; Reungsang et al., 2010; Pai et al., 2011; Douglas-Mankin et al., 2013) have used NSE to evaluate model performances for various output responses (e.g., flow, sediment, N, P, crop yields, etc.) using different models (MIKE-SHE, ADAPT, SWAT, WARMF, HSPF, etc.).

The index of agreement (*d*) was developed by Willmott (1981) as a standardized measure of the degree of model prediction error. The index of agreement represents the ratio between the mean square error and the "potential error" (Willmott, 1984). The potential error (denominator in index of agreement equation in table 5) represents the largest value that the squared difference of each pair can attain. The index of agreement can detect additive and proportional differences in the observed and simulated means and variances.

Error Index

The root mean square error (RMSE) is the square root of mean square error (MSE). The MSE is also known as standard error of the estimate in regression analysis. The RMSE is measured in the same units as the model output response of interest and is representative of the size of a typical error.

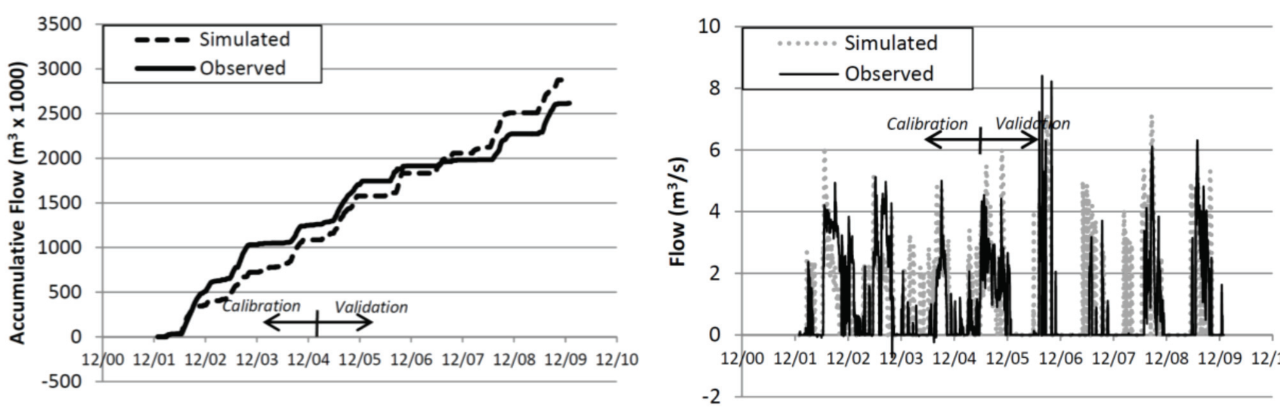


Figure 1. Calibrated daily flow using the WAM model (reproduced from Bottcher et al., 2012).

Table 5. Equations, ranges, optimal values, and advantages and disadvantages for statistical performance measures in the Moriasi et al. (2012) special collection (*O* and *P* are observed and predicted values, respectively).

Statistic	Equation	Range	Optimal Value	Advantages/Disadvantages
r	$\frac{\sum_{i=1}^{n}\left(O_i-\bar{O}\right)(P_i-\bar{P})}{\sqrt{\sum_{i=1}^{n}\left(O_i-\bar{O}\right)^2}\sqrt{\sum_{i=1}^{n}\left(P_i-\bar{P}\right)^2}}$	-1.0 to 1.0	-1.0 (negative slope) or 1.0 (positive slope)	**Advantages:** R^2 and r are widely used in hydrological modeling studies, thus serving as a benchmark for performance evaluation. **Disadvantages:** R^2 and r are oversensitive to high extreme values (Krause et al., 2005) and insensitive to additive and proportional differences between model predictions and measured data (Legates and McCabe, 1999). **Notes:** We recommend that the regression line gradient and intercept be reported when R^2 is used as a performance measure. For a good agreement, the intercept should be close to zero and the gradient should be close to one (Krause et al., 2005).
R^2	$\left[\frac{\sum_{i=1}^{n}\left(O_i-\bar{O}\right)(P_i-\bar{P})}{\sqrt{\sum_{i=1}^{n}\left(O_i-\bar{O}\right)^2}\sqrt{\sum_{i=1}^{n}\left(P_i-\bar{P}\right)^2}}\right]^2$	0.0 to 1.0	1.0	
NSE	$1-\frac{\sum_{i=1}^{n}\left(O_i-P_i\right)^2}{\sum_{i=1}^{n}\left(O_i-\bar{O}\right)^2}$	-∞ to 1.0	1.0	**Advantages:** NSE is: (1) a quantitative measure conducive to development of PEC; (2) good for use with continuous long-term simulations and can be used to determine how well the model simulates trends for the output response of concern; (3) robust and can be used to evaluate model performance for several output responses (e.g., stream flow, sediments, nutrients, pesticides) and temporal scales; and (4) commonly used, which means that there is extensive information on reported values, which can be used for comparison purposes. Further, it can incorporate measurement uncertainty (Harmel and Smith, 2007; Harmel et al., 2010). **Disadvantages:** NSE cannot help identify model bias and cannot be used to identify differences in timing and magnitude of peak flows and shape of recession curves; in other words, it cannot be used for single-event simulations. **Notes:** NSE is sensitive to extreme values due to the squared differences (Krause et al., 2005). To overcome extreme-value cases and increase sensitivity to lower measured and simulated values, Krause et al. (2005) recommended the use of logarithmic and relative derivatives forms of NSE and *d*. In cases where the measured data are bi-modal with high and low distributions in the same study area, such as the measured flows in Cho and Olivera (2009), it is recommended that the two data categories be separated to avoid the bias toward simulation of lower values.
d	$1-\frac{\sum_{i=1}^{n}\left(O_i-P_i\right)^2}{\sum_{i=1}^{n}\left(\left\|P_i-\bar{O}\right\|+\left\|O_i-\bar{O}\right\|\right)^2}$	0.0 to 1.0	1.0	**Advantages:** The index of agreement (1) detects additive and proportional differences in the observed and simulated means and variances and (2) is widely used, and thus there is comprehensive information on reported values in the literature. **Disadvantages:** Overly sensitive to extreme values due to the squared differences (Legates and McCabe, 1999). High values of *d* were reported even for poor model fits (Krause et al., 2005). **Notes:** *d* should be evaluated based on the phenomenon studied, measurement accuracy, and the model employed. It can also be used as a substitute for R^2 to identify the degree to which model predictions are error-free (Legates and McCabe, 1999). Further, it can incorporate measurement uncertainty (Harmel and Smith, 2007; Harmel et al., 2010).
RMSE or RMSD	$\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(O_i-P_i\right)^2}$	0.0 to ∞	0.0	**Advantages:** RMSE and MAE are: (1) computed and reported in the same units as the model output of concern and are hence easy for readers to interpret; (2) work well for continuous long-term simulations; and (3) commonly used in model performance evaluation. **Disadvantages:** Error indices are measured in the same unit as the model output being investigated, so they cannot be used by themselves to gauge model performance for values other than zero. **Notes:** RMSE and MAE can be used to determine confidence intervals in model predictions, and it is possible to incorporate measurement uncertainty (Harmel and Smith, 2007; Harmel et al., 2010).
MAE	$\frac{1}{n}\sum_{i=1}^{n}\left\|O_i-P_i\right\|$	0.0 to ∞	0.0	
RSR	$\frac{\sqrt{\sum_{i=1}^{n}\left(O_i-P_i\right)^2}}{\sqrt{\sum_{i=1}^{n}\left(O_i-\bar{P}\right)^2}}$	0.0 to ∞	0.0	**Advantages:** RSR incorporates the benefits of error index statistics and includes a scaling/normalization factor, so the resulting statistics and reported values can apply to various output responses. **Disadvantages:** RSR gives more weight to high values when compared with low values because errors in high values are usually greater in absolute value than errors in low values due to the squared difference values in the denominator. **Notes:** RSR has not been widely used in the H/WQ modeling literature since it is a relatively new statistical performance measure.

Table 5 (continued). Equations, ranges, optimal values, and advantages and disadvantages for statistical performance measures in the Moriasi et al. (2012) special collection (O and P are observed and predicted values, respectively).

Statistic	Equation	Range	Optimal Value	Advantages/Disadvantages
RE or PE	$\left\lvert\frac{O_i - P_i}{O_i}\right\rvert \times 100$	0.0 ∞ to ∞	0.0	**Advantages:** (1) RE facilitates comparison of model performance between different output responses, and (2) differences between observed and predicted values are quantified as relative deviations. This significantly reduces the influence of absolute differences during high flows. **Disadvantages:** The absolute lower differences during low flow periods are enhanced because they are significant if looked at in a relative sense. As a result, there might be a systematic over- or underprediction during low flow periods. **Notes:** RE can be used along with other statistics to quantify low flow simulations
PBIAS	$\frac{\sum_{i=1}^{n} O_i - P_i}{\sum_{i=1}^{n} O_i} \times 100$	-∞ to ∞	0.0	**Advantages:** PBIAS: (1) can be used to determine how well the model simulates the average magnitudes for the output response of interest; (2) is useful for continuous long-term simulations; (3) is robust and commonly used, which means that there is extensive information on reported values; (4) can help identify average model simulation bias (overprediction vs. underprediction); and (5) can incorporate measurement uncertainty (Harmel et al., 2010). **Disadvantages:** PBIAS cannot be used (1) for single-event simulations to identify differences in timing and magnitude of peak flows and the shape of recession curves nor (2) to determine how well the model simulates residual variations and/or trends for the output response of interest. **Notes:** PBIAS can give a deceiving rating of model performance if the model overpredicts as much as it underpredicts, in which case PBIAS will be close to zero even though the model simulation is poor. It is therefore recommended that PBIAS be used with other statistical and graphical PMs to determine model performance.

The mean absolute error (MAE) is also measured in the same units as the model output response of interest. It is usually similar in magnitude but slightly smaller than the RMSE. The RMSE also tends to give more weight to high values than low values because errors in high values are usually greater in absolute value than errors in low values (Gan et al., 1997; Gan and Biftu, 1996; Eckhardt and Arnold, 2001; van Griensven and Bauwens, 2003; Huisman et al., 2003; Cho and Olivera, 2009). To get around this limitation, Moriasi et al. (2007) recommended that RMSE be normalized using the observations standard deviation, giving a measure referred to as the RMSE-observations standard deviation ratio (RSR).

Although it is commonly accepted that the lower the RMSE, the better the model performance, only Singh et al. (2004) published a guideline to qualify what is considered a low RMSE based on the observations standard deviation (SD). Singh et al. (2004) stated that RMSE values of less than half of the SD of the observations may be considered low. Based on the recommendation by Singh et al. (2004), Moriasi et al. (2007) developed the RSR.

Relative error (RE), absolute relative error, or absolute relative deviation is the ratio of absolute error of the simulated data to the observed data. It indicates the mismatch that occurs between the observed and modeled values, expressed in terms of ratios and percentages. Krause et al. (2005) recommended relative efficiency criteria for NSE and *d* in which relative deviations are derived for NSE and *d*. These can be used to quantify low flow simulations. Relative bias (RB), relative volume error (RVE), and many other bias-based statistics are derived based on RE to report statistical PMs in evaluating hydrological model performances.

Percent bias (PBIAS) measures the average tendency of the simulated data to be larger or smaller than observed counterparts (Gupta et al., 1999). It also measures over- and underestimation of bias and expresses it as a percentage. Percent stream flow volume error (PVE; Singh et al., 2004), prediction error (PE; Fernandez et al., 2005), and percent deviation of stream flow volume (D_v; ASCE, 1993; Moriasi et al., 2007) are calculated in a similar manner as PBIAS.

Meta-Analysis of Performance Data

Reported Value Ranges for Performance Measures

For each model included in the Moriasi et al. (2012) special collection, approximately 20 available peer-reviewed articles were collected. Performance data for case studies in the Moriasi et al. (2012) special collection and for articles reviewed by Moriasi et al. (2007) were not considered in this study. While this effort was by no means exhaustive, it yielded a sizeable dataset including 312 data points for R^2 and 435 data points for NSE that were used in the meta-analysis. Due to the volume of material involved, reported performance data for each simulated component during calibration and validation were recorded (supplemental material tables S1-1 through S1-22, available at http://bit.ly/NRES_SW10715). These data were collected from articles published from 1992 to 2013; 93% were published in 2000 or later, and 53% were published after 2007. Most of the reported parameters are for field-scale (tables S1-2 to S1-10) and watershed-scale (tables S1-11 to S1-22) models that utilize both manual and autocalibration methods. Of the reviewed articles, most reported model calibration and validation on flow-related components (tables S1-2 to S1-5 and S1-11 to S1-15), and most are based on the

SWAT model. The least reported model calibration and validation PM values were those associated with point to plot scale models (table S1-1). Most of the models in this category utilize autocalibration algorithms that select all possible combinations of solutions that meet the set threshold for the selected objective function.

Of the models examined (table 1), only SWAT, HSPF, WARMF (watershed-scale), and ADAPT (field-scale) had sufficient model performance data for meaningful analyses. The total numbers of reviewed articles from which data were obtained for analyses of SWAT, HSPF, WARMF, and ADAPT models were 33, 17, 2, and 16, respectively. For each of the aforementioned models, values for R^2, NSE, and PBIAS were reported most frequently, but there was also an appreciable amount of data on the index of agreement (*d*) at field scale. Based on reviewed literature, point to plot (and to some extent field-scale) models used different simulated response outputs to evaluate model performance. For instance, Essaid et al. (2008) and Healy and Essaid (2012) used streambed water flux and temperature to evaluate VS2DI performance, while Huth et al. (2012) used soil water content to evaluate SWIM3. Krobel et al. (2010) and Diekkruger et al. (1995) also used soil water content to evaluate the performance of the DAISY model. The use of different simulated response outputs and the limited amount of reported peer-reviewed model performance data made it difficult to conduct statistical comparisons for these smaller spatial scale models, so they were excluded from the analysis and PEC development.

Table 6. Summary of the performance data used for detailed statistical analyses.

Performance Measure		Temporal Scale[a] Annual	Monthly	Daily	Seasonal
Watershed scale					
R^2	Entries	89	196	27	-
	Mean	0.67	0.63	0.63	-
	Median	0.67	0.72	0.70	-
	Minimum	0.32	0.18	0.02	-
	Maximum	1.00	0.99	0.97	-
NSE	Entries	87	233	115	-
	Mean	0.58	0.44	0.13	-
	Median	0.60	0.59	0.53	-
	Minimum	-0.91	-7.89	-10.3	-
	Maximum	0.99	0.96	0.96	-
PBIAS	Entries	26	57	-	29
	Mean	-14.92	7.51	-	20.4
	Median	0	6.4	-	8
	Minimum	-81.1	-38.4	-	-46.4
	Maximum	35.3	53.1	-	167
Field scale					
R^2	Entries	-	29	-	-
	Mean	-	0.74	-	-
	Median	-	0.75	-	-
	Minimum	-	0.18	-	-
	Maximum	-	0.91	-	-
d	Entries	-	33	-	-
	Mean	-	0.88	-	-
	Median	-	0.91	-	-
	Minimum	-	0.60	-	-
	Maximum	-	0.99	-	-

[a] Blank entries mean that either there were no data or that available data were insufficient for meaningful statistical analyses. All available raw data are presented in the supplemental material tables (available at http://bit.ly/NRES_SW10715).

Preliminary Diagnostics of Data Used for Meta-Analysis

Table 6 summarizes the data used for the meta-analysis. Based on a preliminary analysis, reported performance data values for watershed-scale models, irrespective of output response and temporal scale, varied from 0.02 to 1.00 for R^2, from -10.30 to 0.99 for NSE, and from -81.1% to 167% for PBIAS (table 4). Reported R^2 values for field-scale models for flow at a monthly temporal scale varied from 0.18 to 0.91, while *d* values varied from 0.60 to 0.99 (table 6).

Further analysis of the distributions of the combined datasets (regardless of whether they pertained to calibration or validation, watershed size, and/or the components) showed that most tended to be skewed toward the higher values of the specific PMs (table 6 and fig. 2). This was expected because calibration and validation efforts are usually geared toward finding the best suitable values, which are the highest values for measures such as R^2, NSE, and *d*. Exceptions to this trend were values of PBIAS, which were more centrally located. Again, this is not surprising, as

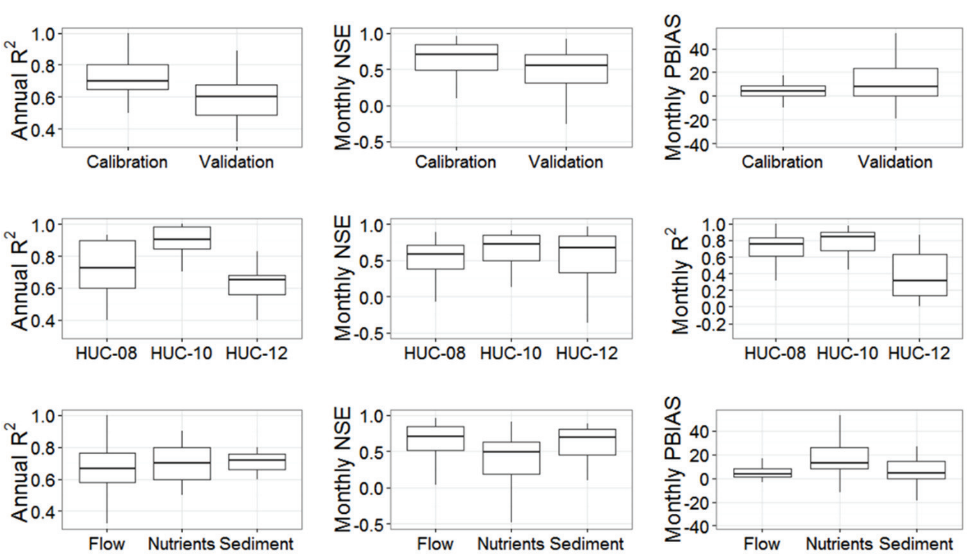


Figure 2. Box and whisker plots showing comparisons of performance data considering: (top row) calibration and validation, (middle row) watershed size (HUC-08 includes data for watersheds at HUC 8 and larger), and (bottom row) simulated component.

PBIAS can vary between small and large values, both negative and positive, and by definition PBIAS values close to zero indicate better model performance and are thus more desirable. The other exception was R^2 values, for which the data were approximately normally distributed. At this point, it is unclear why this was the case. Based on the approximate distributions of the performance data, the non-parametric median test was used to test whether there were significant differences among reported performance values data (table 7) among the various categories to warrant development of separate PEC.

For most of the watershed-scale analyses performance data, values for calibration were significantly different (table 7) from those reported for validation, with those for calibration being better (fig. 2). This was not the case for the field-scale data, for which the performance data values were not significantly different between the calibration and validation periods. Ideally, performance values obtained for validation need to be close to those obtained during calibration; a discrepancy between these values is evidence of model divergence (Sorooshian and Gupta, 1995; Duda et al., 2012; Zheng et al., 2012), suggesting calibrated model inaccuracies in process representation (Sorooshian, 1983). Since calibration efforts rely on comparisons between observed and measured data, it is possible to make parameter adjustments simply to suit this kind of comparison while ignoring the accuracy of the process simulation. Thus, in recommending guidelines, we do not make a distinction between calibration and validation periods.

Significant differences were also observed in reported performance data values at the watershed scale, with the exception of monthly NSE values (table 7 and fig. 2). Although no clear patterns were discernible, the models seemed to perform better for HUC-10 watersheds than for HUC-08+ and HUC-12 watersheds. Similarly, at each temporal scale, there were significant differences among PMs based on the response output being simulated and the available data for reported model PM values (table 7). For example, data analysis indicated better simulation of flow than all other response outputs. This was expected, given that hydrologic processes are the primary drivers within a watershed; thus, associated simulated response outputs are calibrated first and more extensively. In addition, more observed data are available to calibrate models for flow than for sediments or nutrients.

Further analyses based on both simulated response output and temporal scale (e.g., annual flow, monthly flow, etc.) also showed significant differences for R^2 and NSE ($p = 0.0002$ and 0.0001, respectively), although no significant differences were observed among the temporal scales when all data were grouped together and analyzed solely by temporal scale ($p = 0.0661$, 0.1957, and 0.0811 for R^2, NSE, and PBIAS, respectively). Due to the difficulties in duplicating the timing of flow, and given the uncertainties in the timing of model inputs (mainly precipitation; Duda et al., 2012), model calibration is considered to be simpler at the annual temporal scale and is progressively more difficult as the temporal scale resolutions becomes finer (Engel et al., 2007; Moriasi et al., 2007; Duda et al., 2012). Thus, this latter finding was somewhat surprising. However, the art of model calibration has greatly improved in recent years due to model autocalibration tools and techniques. These are designed to find optimal parameters based on PMs, hence increasing the likelihood that resulting model PM values will be comparable regardless of the temporal scale.

Based on the meta-analysis results, we determined that there was a need for separate PEC for each of the commonly simulated response outputs, watershed- and field-scale models, temporal scales, and for the recommended PMs.

Table 7. Summary of results of the statistical analyses on the performance data.

	Temporal Scale and Performance Measure						
	Annual			Monthly			Daily
Comparisons	R^2	NSE	PBIAS	R^2	NSE	PBIAS	NSE
Watershed scale							
Calibration vs. validation							
Calibration entries	57	53	8	106	127	27	66
Validation entries	32	34	18	90	106	30	49
p-value[a]	0.0047*	0.0112*	0.0401*	0.5674	0.0131*	0.0249*	<0.0001*
Comparison by HUC							
HUC-08+ entries	26	4	10	138	118	56	5
HUC-10 entries	7	6	16	14	54	1	62
HUC-12 entries	56	76	0	44	61	0	40
p-value	0.0002*	-	0.0123*	<0.0001*	0.2330	-	0.0158*
Comparison by component							
Flow entries[b]	84	72	26	88	119	32	88
Sediment entries	3	4	0	46	31	15	3
N entries	2	0	0	31	49	10	18
P entries	0	11	0	31	34		6
p-value	-	0.0453*	-	<0.0004*	<0.0001*	0.1281	<0.0001*
Field scale				R^2	*d*		
Calibration entries				17	18		
Validation entries				12	15		
p-value				0.5799	0.3499		

[a] Probability that observed differences in reported performance data values are attributable to error or chance given an α level of significance ($\alpha = 0.05$ in this case). Values <α indicate that the reported performance data values (e.g., for calibration vs. validation) are significantly different at that level of significance, with smaller values indicating higher significance (i.e., probability that observed differences were due to error or chance is very small). Asterisks (*) indicate significant differences in performance data values for calibration vs. validation, HUC, and modeled component.

[b] Combines data for stream flow, surface runoff, and base flow as reported.

However, there was also the need for general PEC that could be used across temporal scales. The final recommended PEC for the identified separate categories are based primarily on the results of computed percentiles of reported performance data to determine thresholds for the different qualitative ratings used in this article, existing PEC (Al-Qurashi et al., 2008; Moriasi et al., 2007; Duda et al., 2012; Herr and Chen, 2012; Ma et al., 2012; Skaggs et al., 2012; Wang et al., 2012), and our modeling experience.

Development of Criteria for Selected Statistical Performance Measures

The final step of the meta-analysis was to compute percentiles of available performance data to develop separate PEC for R^2, NSE, PBIAS, and *d* for the spatial and temporal scales and simulated response outputs identified by the median test in the previous subsection. There were 57 negative NSE values reported for watershed-scale models (supplemental material tables S1-11 to S1-20). However, by definition, NSE < 0.0 indicates that the mean observed value is a better predictor than the simulated value, which indicates unacceptable performance. Therefore, all negative values for NSE were excluded. While we agree that NSE is more stringent than R^2 or *d*, we did not exclude any reported performance data for R^2 and *d* corresponding to the studies that reported negative NSE. This is because different PMs have varied strengths that aid in determining the performance of a given model during the calibration and validation periods. Therefore, the reported performance data for each PM were analyzed independently.

To be consistent with model PEC previously recommended by Moriasi et al. (2007), "very good," "good," "satisfactory," and "not satisfactory" ratings were defined. Initial PEC were then developed for each of the ratings based on different data distributions at spatial and temporal scales and simulated response outputs for the recommended criteria. Even though percentile is used to measure spread, we also found it appropriate to use as an initial step in determining the thresholds for the defined ratings due to the fact that the calibration process seeks to optimize PMs for response outputs of interest. Considering the ranges of model PM data obtained (table 6) and expected reasonable PM data values, model performance values at and below the 25th percentile were considered "not satisfactory," model performance values between the 25th to 50th percentiles were considered "satisfactory," model performance values within and including the 50th to 75th percentiles were considered "good," and those above the 75th percentile were considered "very good." Values obtained based on percentiles were adjusted accordingly (e.g., rounded off) to produce meaningful intervals for these initial PEC. Figure 3 shows an example of the PEC development process. To facilitate PEC development for PBIAS, all related entries were converted into absolute values (fig. 3b). Because of the nature of this statistic, the rating and corresponding percentile ranges were reversed.

Analysis of the initial PEC based on data distributions resulted in several noteworthy differences (table 8). For example, with NSE, the resulting PEC for flow were different from those for N and P, with the former PEC being stricter. This was expected due to the large amount of observed flow calibration data, which is not the case for sediment and nutrient data. It is also critical that flow simulation be accurate, as flow is the primary driver of watershed processes. Sediment seemed to exhibit a similar response to flow, possibly for the same reasons. This explains why PEC were stricter for flow than for N and P.

(a) NSE - General **(b) Monthly Flow PBIAS (absolute)**

(a)

100.0%	maximum	0.99
99.5%		0.99
97.5%		0.94525
90.0%		0.88
75.0%	quartile	0.8
50.0%	median	0.64
25.0%	quartile	0.4875
10.0%		0.269
2.5%		0.09475
0.5%		0.03895
0.0%	minimum	0.03

(b)

100.0%	maximum	38.39
99.5%		38.39
97.5%		38.39
90.0%		25.087
75.0%	quartile	13.5825
50.0%	median	7.325
25.0%	quartile	2.8175
10.0%		1.773
2.5%		0.19
0.5%		0.19
0.0%	minimum	0.19

Resulting Initial criteria

	V. Good	Good	Satisfactory	Not Satisfactory
NSE	>0.80	0.60≤NSE≤0.80	0.50<NSE<0.60	≤0.50
PBIAS	≤3.0	3.0<PBIAS<10	10≤PBIAS≤15	>15

Figure 3. Example of initial performance evaluation criteria development for flow: (a) annual NSE and (b) monthly PBIAS.

Table 8. Initial performance evaluation criteria for recommended statistical performance measures for watershed- and field-scale models based on the distribution of existing data.

Measure	Component	Temporal Scale	n	Very Good	Good	Satisfactory	Not Satisfactory
Watershed scale							
R^2	Flow	Annual	84	>0.75	$0.70 \le R^2 \le 0.75$	$0.60 < R^2 < 0.70$	≤0.60
		Monthly	87	>0.85	$0.80 \le R^2 \le 0.85$	$0.70 < R^2 < 0.80$	≤0.70
		Daily	27	>0.85	$0.70 \le R^2 \le 0.85$	$0.50 < R^2 < 0.70$	≤0.50
	Sediment	Annual	3	-	-	-	-
		Monthly	46	>0.80	$0.65 \le R^2 \le 0.80$	$0.40 < R^2 < 0.65$	≤0.40
		Daily	0	-	-	-	-
	N	Annual	2	-	-	-	-
		Monthly	31	>0.70	$0.60 \le R^2 \le 0.70$	$0.30 < R^2 < 0.60$	≤0.30
		Daily	0	-	-	-	-
	P	Annual	0	-	-	-	-
		Monthly	31	>0.80	$0.65 \le R^2 \le 0.80$	$0.40 < R^2 < 0.65$	≤0.40
		Daily	0	-	-	-	-
	General		311	>0.80	$0.70 \le R^2 \le 0.80$	$0.50 < R^2 < 0.70$	≤0.50
NSE	Flow	Annual	71	>0.75	0.60 ≤ NSE ≤ 0.75	0.50 < NSE < 0.60	≤0.50
		Monthly	109	>0.85	0.70 ≤ NSE ≤ 0.85	0.55 < NSE < 0.70	≤0.55
		Daily	79	>0.80	0.70 ≤ NSE ≤ 0.80	0.50 < NSE < 0.70	≤0.50
	Sediment	Annual	4	-	-	-	-
		Monthly	31	>0.80	0.70 ≤ NSE ≤ 0.80	0.45 < NSE < 0.70	≤0.45
		Daily	3	-	-	-	-
	N	Annual	0	-	-	-	-
		Monthly	31	>0.70	0.60 ≤ NSE ≤ 0.70	0.35 < NSE < 0.60	≤0.35
		Daily	6	>0.55	0.40 ≤ NSE ≤ 0.55	0.25 < NSE < 0.40	≤0.25
	P	Annual	10	>0.65	0.60 ≤ NSE ≤ 0.65	0.50 < NSE < 0.60	≤0.50
		Monthly	33	>0.65	0.50 ≤ NSE ≤ 0.65	0.40 < NSE < 0.50	≤0.40
		Daily	1	-	-	-	-
	General		378	>0.80	0.60 ≤ NSE ≤ 0.80	0.50 < NSE < 0.60	≤0.50
PBIAS (%)[a]	Flow	Annual	26	≤±2.5	±2.5 < PBIAS < ±15	±15 ≤ PBIAS ≤ ±35	>±35
		Monthly	32	≤±3.0	±3.0 < PBIAS < ±10	±10 ≤ PBIAS ≤ ±15	>±15
		Seasonal	29	≤±10	±10 < PBIAS < ±15	±15 ≤ PBIAS ≤ ±45	>±45
	Sediment	Annual	0	-	-	-	-
		Monthly	15	≤±1	±1 < PBIAS < ±10	±10 ≤ PBIAS ≤ ±20	>±20
		Seasonal	0	-	-	-	-
	Nutrients	Annual	0	-	-	-	-
		Monthly	10	≤±10	±10 < PBIAS < ±15	±15 ≤ PBIAS ≤ ±30	>±30
		Seasonal	0	-	-	-	-
	General		112	≤±5	±5 < PBIAS < ±10	±10 ≤ PBIAS ≤ ±25	>±25
Field scale							
R^2		Monthly	29	>0.85	$0.75 \le R^2 \le 0.85$	$0.70 < R^2 < 0.75$	≤0.70
d		Monthly	33	>0.90	$0.85 \le d \le 0.90$	$0.75 < d < 0.85$	≤0.75

[a] Values are absolute.

With regard to temporal scale, however, the distinctions were not as clear. While data were not always sufficient to allow comparisons for each component, in some instances the resulting PEC were contradictory, e.g., initial PEC were stricter for monthly flow than for annual flow. This was in contrast to Moriasi et al. (2007), who suggested more relaxed PEC for a daily temporal scale and progressively higher thresholds for subsequent coarser temporal scales. As previously discussed, our data did not show significant differences on the basis of temporal scale alone, which could possibly explain these discrepancies. For each of the PMs, general initial PEC (table 8) were also derived independent of either component or temporal scale and seemed to offer more unifying values that could be used as alternates where contradictions were encountered.

As a final step, the initial PEC were reviewed and revised based on previous PEC as reported in the literature (Al-Qurashi et al., 2008; Moriasi et al., 2007; Duda et al., 2012; Herr and Chen, 2012; Ma et al., 2012; Skaggs et al., 2012; Wang et al., 2012) and on our modeling experience. The final PEC developed are reported under the "Guidelines for Model Performance Evaluation: Recommended Measures and Criteria" subheading.

Guidelines for Model Performance Evaluation: Recommended Measures and Criteria

Prior to providing any general recommendations for model PMs and their corresponding PEC, we note that it is critical that model users follow proper calibration and validation procedures to obtain the correct model performance for the right reasons (Kirchner, 2006; Arnold et al., 2015). In this regard, we recommend that model users should consider recommendations for all other key calibration and validation topics covered in this special collection. These include (1) ensuring that terminology is clearly defined (Zeckoski et al., 2015), (2) selecting an appropriate model based on the study goals and ensuring that the model and fluxes are well represented (Arnold et al., 2015), (3) considering appropriate spatial and temporal scales (Baffaut et al., 2015), (4) parameterizing the model appropriately

(Malone et al., 2015), and (5) employing appropriate calibration and validation strategies (Daggupati et al., 2015b), including sensitivity (Yuan et al., 2015) and uncertainty (Guzman et al., 2015) analyses. Having taken all these important modeling aspects into consideration, model users should then use appropriate PMs along with the corresponding general PEC recommended in this article. Finally, we recommend that all these aspects of modeling be properly documented and reported (Saraswat et al., 2015) with sufficient detail to ensure repeatability.

The first step in evaluating model performance is to use recommended graphical PMs because they provide a visual indication of model performance. The next step is to compute values for the recommended statistical PMs. The computed values are then compared with recommended PEC to assess model performance with respect to statistical PMs.

Recommended Performance Measures

Due to varied strengths of the different PMs described in this article, we recommend the use of multiple graphical and statistical PMs. Both direct and derived graphical PMs are recommended in determining model calibration and validation performance. For shorter periods and coarse temporal resolutions (e.g., monthly calibration for one to three years), time series and scatter plots are most effective for data visualization and demonstration of model performance. With increasing data points, an inconsistent understanding of model performance may result from direct graphical PMs. Under such circumstances, derived measures such as cumulative distributions or duration curves should be employed. For field- and watershed-scale models, where calibration and validation are done at the outlet, we recommend using maps to ensure that non-calibrated locations provide reasonable values for outputs of interest such as soil erosion or nutrient loss. This will ensure a more comprehensive evaluation of model performance and confidence in model outputs.

The most commonly used statistical PMs with varied complementary strengths are recommended. These include R^2 (in conjunction with the gradient b and the intercept a of the corresponding regression line), NSE, d, RMSE alongside RSR, and PBIAS. These statistics can be used for daily, monthly, and yearly temporal scales and for all major output responses. During low flow simulations, logarithmic or relative derivatives of NSE or d need to be used, as recommended by Krause et al. (2005). We also recommend that RSR be reported alongside RMSE, with RMSE providing model performance in the units of the output response of interest and RSR providing a normalized value for comparison of model performance for various studies.

Recommended Performance Criteria

The recommended PEC for the statistical PMs NSE, R^2, d, and PBIAS for different output responses at different spatial and temporal scales are presented in table 9. The PEC in table 9 result from a combination of previous PEC as reported in the literature (Al-Qurashi et al., 2008; Moriasi et al., 2007; Duda et al., 2012; Herr and Chen, 2012; Ma et al., 2012; Skaggs et al., 2012; Wang et al., 2012), meta-analysis conducted in this study, and our modeling experience. For a given study, the same PBIAS PEC are recommended for the three temporal scales because PBIAS is computed based on observed daily, monthly, and annual values derived from data collected or measured at a finer temporal scale, such as hourly or sub-hourly. These PEC apply to both model calibration and validation periods. For example, based on table 9, model performance can be judged as “satisfactory” for flow simulations if monthly $R^2 > 0.70$ and $d > 0.75$ for field-scale models and daily, monthly, or annual $R^2 > 0.60$, NSE > 0.50, and PBIAS ≤ ±15% for watershed-scale models. Although we recommend RMSE (with RSR) and the logarithmic or relative derivative of d or NSE statistical PMs, no PEC were developed for them because the available data were not sufficient for meta-analysis and thus for PEC development. However, for RSR, we recommend that the PEC proposed by Moriasi et al. (2007) be used until new PEC can be developed. The intent of this study was to develop generalizable PEC for all models. However, sufficient data for meta-analysis were available only for SWAT, HSPF, WARMF, and ADAPT, as mentioned earlier. Therefore, we also recommend that the PEC developed in this study be used primarily for these models and used only with caution for other models. For example, in the absence of spatial-specific model criteria, the stated watershed PMs and corresponding criteria can be adopted and/or modified for oth-

Table 9. Final performance evaluation criteria for recommended statistical performance measures for watershed- and field-scale models.

Measure	Output Response	Temporal Scale[a]	Performance Evaluation Criteria: Very Good	Good	Satisfactory	Not Satisfactory
Watershed scale						
R^2	Flow[b]	D-M-A	$R^2 > 0.85$	$0.75 < R^2 \le 0.85$	$0.60 < R^2 \le 0.75$	$R^2 \le 0.60$
	Sediment/P[c]	M	$R^2 > 0.80$	$0.65 < R^2 \le 0.80$	$0.40 < R^2 \le 0.65$	$R^2 \le 0.40$
	N	M	$R^2 > 0.70$	$0.60 < R^2 \le 0.70$	$0.30 < R^2 \le 0.60$	$R^2 \le 0.30$
NSE	Flow	D-M-A	NSE > 0.80	0.70 < NSE ≤ 0.80	0.50 < NSE ≤ 0.70	NSE ≤ 0.50
	Sediment	M	NSE > 0.80	0.70 < NSE ≤ 0.80	0.45< NSE ≤ 0.70	NSE ≤ 0.45
	N/P[c]	M	NSE > 0.65	0.50 < NSE ≤ 0.65	0.35< NSE ≤ 0.50	NSE ≤ 0.35
PBIAS (%)	Flow	D-M-A	PBIAS < ±5	±5 ≤ PBIAS < ±10	±10 ≤ PBIAS < ±15	PBIAS ≥ ±15
	Sediment	D-M-A	PBIAS < ±10	±10 ≤ PBIAS < ±15	±15 ≤ PBIAS < ±20	PBIAS ≥ ±20
	N/P[c]	D-M-A	PBIAS < ±15	±15 ≤ PBIAS < ±20	±20 ≤ PBIAS < ±30	PBIAS ≥ ±30
Field scale						
R^2	Flow	M	$R^2 > 0.85$	$0.75 < R^2 \le 0.85$	$0.70 < R^2 < 0.75$	$R^2 \le 0.70$
d	Flow	M	$d > 0.90$	$0.85 < d \le 0.90$	$0.75 < d < 0.85$	$d \le 0.75$

[a] D, M, and A denote daily, monthly, and annual temporal scales, respectively.
[b] Includes stream flow, surface runoff, base flow, and tile flow, as appropriate, for watershed- and field-scale models.
[c] Where there were no differences, PEC were grouped for the output responses.

er spatial scale models.

The PEC recommended in this study are general and can be adjusted as appropriate. However, we consider some values of the recommended PMs to be unacceptable beyond certain reasonable ranges. For example, as explained earlier, we consider negative values of NSE to indicate unacceptable model performance. Unacceptable values of PBIAS can be derived from Harmel et al. (2006), with maximum measurement uncertainties under typical measurement scenarios considered to be ±19% for stream flow, ±69% for nitrate-N (NO_3-N), ±100% for ammonium-N (NH_4-N), ±70% for total N, ±104% for dissolved P, ±110% for total P, and ±53% for total suspended sediments (TSS). Al-Qurashi et al. (2008) defined acceptable performance for flow simulations as being within 30% of observed values for KINEROS/AGWA (Goodrich et al., 2012). For performance measure *d*, Krause et al. (2005) stated that high values of *d* (over 0.65) were reported even for poor model fits. In this article, the minimum *d* value obtained as reported in literature was 0.60, and the overall minimum R^2 value reported in literature and used in the meta-analysis in this article was 0.18. Such low values do not provide much information about model performance and, similar to NSE < 0.0, can indicate that the mean observed value is a better predictor than the simulated value.

Thus, in this article, $R^2 < 0.18$, NSE < 0.0, PBIAS ≥ ±30% for flow, PBIAS ≥ ±55% for sediments, PBIAS ≥ ±70% for nutrients, and $d < 0.60$ represent unacceptable model performance.

ADDITIONAL CONSIDERATIONS

The recommendations for model PMs and their corresponding PEC presented in the previous section apply to the typical case of continuous, long-term simulation for the given output responses at specified spatial and temporal scales (table 9). However, because of the diversity of modeling applications, these recommendations may be adjusted based on the quality and quantity of available measured data, spatial and temporal scales, and project scope and magnitude. It is also important to note that the recommended PMs are based only on the measures reported primarily in the Moriasi et al. (2012) special collection. Therefore, we have provided some additional considerations in this subsection to assist users in their calibration and validation efforts.

The PEC results presented herein are based on a meta-analysis of a selection of published data. As mentioned earlier, this body of data is not all-inclusive; this work can be extended by including data from a more extensive body of literature. However, in order to maintain the integrity of the database, article selection and data collection must be subject to the same considerations and follow the same procedures as outlined in this work. It is also important to note that substantial advances have been made in model calibration and validation such that it is now possible to obtain far better model performance and parameter representation than was possible at its nascence. Thus, we do not recommend the inclusion of historical and early development and application works, as resulting criteria may not be representative of the current state-of-the-art. We suggest using works only from the last 20 years.

A major limitation of the meta-analysis is the exclusion of unpublished data. In further extending the analysis, we recommend, inasmuch as is possible, identification and inclusion of unpublished material that fit all other criteria as outlined under key considerations in the "Meta-analysis of Performance Data" subsection. The use of only published material in this work has its strengths and weaknesses; while the results are based on data that has undergone a thorough quality assurance and quality review via the peer-review process, a weakness is that typically only good results (with the best performance data values) are published, likely contributing to the lack of distinction among temporal scales. This effect might not be discernible at other levels of analysis since the datasets at those levels are much smaller.

Finally, we recommend presenting summary statistics such as the mean, median, percentiles, and standard deviation of the observed and simulated response outputs. This information is useful and can provide benchmarks for follow up studies.

Residual Analysis

The residual (or error) is the difference between individual observed and simulated values; these values represent the uncertainty of the simulation. Ideally, the residuals should be close to zero and normally distributed. Any skew indicates a systematic bias, which could be potentially resolved by further calibration. Bennett et al. (2013) observed that residual analysis was an important part of model evaluation. They recommended using residual or QQ plots to examine any systematic divergence from zero. Residual plots are graphs of the residuals against time or space, which are useful in identifying any systematic bias. In a QQ plot, quantiles of the residuals are plotted against Gaussian quantiles. This is helpful in determining if the distribution of residuals is normal. Jain and Sudheer (2008) demonstrated that residual analysis, such as checking for homoscedasticity (unsystematic variance), could result in additional insight and improved model evaluations. In addition to graphical analysis, Bennett et al. (2013) recommended calculating the MSE or RMSE of the residuals for a quantitative evaluation.

Despite its documented advantages, residual analysis continues to be a rarely used and/or sparsely reported practice in the modeling literature. Guidelines are needed for simplifying and integrating residual analysis into H/WQ model performance evaluation.

Quality and Quantity of Measured Data

The quality of measured data should be considered in evaluating model calibration and validation performance whenever such information is available (Harmel et al., 2006). According to Harmel et al. (2006), measured data are obtained under best-case, typical, and worst-case data quality scenarios. The best-case scenario represents procedures used with a concentrated effort in quality assurance/quality control (QA/QC), unconstrained by financial and personnel resource limitations, and in ideal hydrologic conditions. The typical scenario represents procedures conducted with a moderate effort at QA/QC and under typical hydrologic conditions. The worst-case scenario represents data measurements conducted with minimal attention to QA/QC, with limited financial and personnel resources, and in difficult hydrologic conditions. Harmel and Smith (2007) provide modified NSE, *d*, RMSE, and MAE statistics that account for measurement uncertainty. The recommended model PEC presented herein are for data of typical scenario quality. PEC should be stricter when data of best-case scenario quality are available and more relaxed where uncertainty is high (Moriasi et al., 2007). In such cases, however, users should not over-calibrate their models to obtain values of statistical performance measures better than the uncertainty of the available measured data. Harmel et al. (2010) provide adjustments that can be made to statistical PMs based on uncertainty in measured and simulated data. Alternative measures, such as comparison of means and other graphical PMs such as percentiles and frequency distributions, may be more appropriate for measured datasets derived from either incomplete or low-frequency sampling (Moriasi et al., 2007).

Spatial and Temporal Scale of Study

The recommended PEC are intended for field- to watershed-scale modeling studies and mainly for one or more temporal scales (daily, monthly, and annual) depending on the statistical PMs used and the model output response. More strict PEC are recommended for point to plot scale studies in which there is less complexity of the processes involved and less uncertainty in model inputs (Guzman et al., 2015) due to the small spatial scale (Baffaut et al., 2015. For example, Ma et al. (2012) defined NSE > 0.70 and $R^2 > 0.80$ as acceptable model performance values for RZWQM2. It is also necessary to adjust the PEC as the temporal scale changes, utilizing stricter PEC as the evaluation temporal scale decreases from hourly to daily to annual (Moriasi et al., 2007).

Project Scope, Magnitude, and Intended Purpose

Moriasi et al. (2007) discussed the effects of scope and magnitude of the modeling project on model PEC, which should be taken into account when assessing model performance. More stringent PEC are recommended for projects that involve potentially large consequences, while the PEC may be relaxed for proof-of-concept studies. Similarly, Harmel et al. (2014) provided criteria for interpreting model results considering general intended use categories, which include exploratory, planning, and regulatory/legal.

Calibration vs. Validation Performance Criteria

Although prior studies have recommended different PEC for calibration and validation periods (e.g., Moriasi et al., 2007), and our analyses showed significant differences in reported values, this should not be the case. Based on discussions in Sorooshian and Gupta (1995) and Sorooshian (1983), this occurrence in some cases points to inaccuracies in process representation. In other cases, differences in performance during the calibration and validation periods may indicate substantially different climate (Van Liew and Garbrecht, 2003) and land use data (Pai and Saraswat, 2011) and/or the need for further calibration. Thus, the recommended model PEC in this article apply for both the calibration and validation periods. It is also essential to use observed calibration and validation data at spatial and temporal scales that are consistent with the model computations; otherwise, a justification should be provided (Baffaut et al., 2015; Daggupati et al., 2015b).

Framework for Updating Recommended Model Performance Measures and Evaluation Criteria

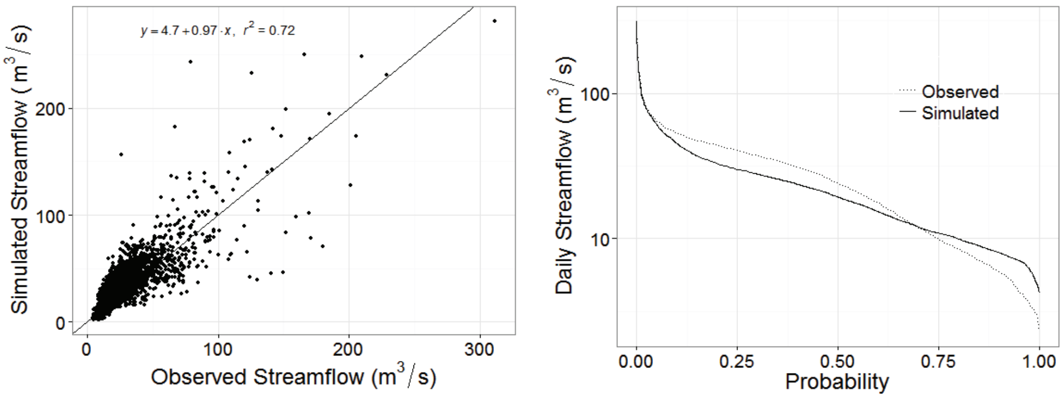
This initial meta-analysis sets the stage for a more comprehensive meta-analysis including a broader range of articles (including unpublished material) and covering a larger suite of models. To assist with this future endeavor, we present a framework for determining recommended model PMs and their corresponding PEC. The framework consists of (1) reviewing current modeling literature to determine the PMs used and collect study-specific calibration and validation data as reported and (2) developing PEC for the recommended PMs based on a meta-analysis of a comprehensive dataset collected from published and unpublished sources while taking into account all key considerations described herein. The scope and limitations of the recommended PEC in this article have been clearly defined in prior sections but can be updated as more information becomes available. For future work, we recommend using performance data values reported for other models, for different output responses, and at various spatial and temporal scales both from published and unpublished literature. In addition, reported study-specific graphical PMs need to be recorded and discussed in depth.

We have established a database with an inventory of reported model performance values and respective study details (e.g., spatial scales, outputs, objective functions) to enable modelers to query and develop custom model PEC better suited to their study goals. This database can be extended frequently as H/WQ model PMs and related PEC continue to evolve and when new understandings of modeling science arise. We intend to make this database available in an open and user-friendly format to provide opportunities for updates through crowd-sourcing. The analysis framework and the developed database will enable modifications of the recommended PMs and PEC as more information is obtained.

Demonstration of Recommended Model Performance Measures and Criteria

An example case study was conducted with a hypothetical watershed-scale H/WQ model. The model was calibrated at the outlet for stream flow on a daily temporal scale for ten years (2001 to 2010). The model name and the study location are not mentioned here to emphasize the generic nature of the guidelines. Figure 4 and table 10 show the graphical and statistical performance of the model based on the recommended PMs.

Since this is a daily temporal scale, ten-year evaluation, the recommended graphical PMs are the scatter plot and flow duration curves (fig. 4). Note that a time series graph was not recommended in this case because of the large dataset. The slope and intercept values are provided on the



(a) **(b)**

Figure 4. Graphical performance measures of a hypothetical model: (a) scatter plot and (b) flow duration curve.

Table 10. Statistical performance evaluation criteria of a hypothetical model.

Average		Standard Deviation		Statistics				
Measured	Simulated	Measured	Simulated	R^2	PBIAS (%)	NSE	RSR	RMSE
24.4	28.3	21.0	23.9	0.72 (slope 0.97, intercept 4.7) (Satisfactory)	-16 (Not satisfactory)	0.60 (Satisfactory)	0.63 (Satisfactory; Moriasi et al., 2007)	13.26

scatter plot based on the least square regression line. The slope of the line is close to a value of one, while the intercept is close to a value of zero, indicating good model performance. The flow duration curve shows that model predictions were close to the observed data for all flow regimes, although the model tended to underestimate the observed data during low flows (>80% probability), slightly overestimate during medium flows (>20% and <50% probability), and had a good agreement during high flows (>10%). By using this figure, a modeler and end user can easily visualize model performance and further identify parameters that can be tweaked to improve performance. For instance, in this case, parameters related to base flow can be adjusted, allowing the model to simulate slightly higher low flows.

Based on the statistical PMs, we can say that the model adequately captured the mean and standard deviation of the daily flow rates. Using the performance values in table 9, we can say that model performance was "satisfactory" based on R^2 and NSE, "not satisfactory" based on the PBIAS of -16%, and satisfactory based on the RSR of 0.63 (Moriasi et al., 2007). Adjustments can be made to model parameters to obtain better agreement among the PMs.

Although H/WQ models provide outputs in various file formats, performance evaluation is typically performed using a spreadsheet. However, setting up a spreadsheet to calculate the numerous graphical and statistical PMs can be a tedious task and prone to errors. Therefore, to support the task of model performance evaluation, a Microsoft Excel spreadsheet was developed (available at http://bit.ly/NRES_SW10715). The objectives of the spreadsheet are to (1) demonstrate the various statistical and graphical PMs discussed in the case study and (2) provide a starting point for H/WQ model users to conduct model performance evaluation.

In situations with conflicting performance ratings, we recommend that those differences be clearly described. For example, if simulation for one output variable in one watershed produces unbalanced performance ratings of "satisfactory" for R^2 and "unsatisfactory" for *d* for field-scale flow simulation, then the overall performance should be described conservatively as "unsatisfactory" for that one study area and that one model response output. However, we recommend that users describe model performance with respect to the degree of collinearity between simulated and measured data (R^2) as "satisfactory" and with respect to prediction error (*d*) as "unsatisfactory." Similarly, if performance ratings differ for various field- and watershed-scale studies and/or response outputs, then those differences need to be clearly described.

Summary and Conclusions

This is one of nine topic-specific articles in a special collection whose main goal is to provide recommendations that, together with recommendations by Harmel et al. (2014), will contribute toward the development of ASABE engineering practices for calibration and validation of H/WQ models. In this research, articles in the Moriasi et al. (2012) special collection were synthesized with respect to performance measures (PMs) and performance evaluation criteria (PEC). In addition, a detailed literature review centered on graphical and statistical PMs used by models described in the special collection was carried out to determine PMs to recommend for use. Further, an initial meta-analysis of performance data reported in literature (outside of the special collection) was performed to establish PEC for various PMs. Data were collected from articles published from 1992 to 2013; 93% were published in and after 2000, and 53% were published after 2007. Finally, specific guidelines for model performance evaluation were established based on the synthesis and results of the meta-analysis. Additional considerations were also presented to allow users to adjust recommended PMs and/or associated PEC to their specific needs. A framework for determining recommended model PMs and their corresponding PEC, based on a more comprehensive meta-analysis, was presented.

Based on the synthesis, we recommend that a combination of multiple graphical and statistical PMs be used for evaluating model performance. Recommended graphical PMs include time series, scatter plots, cumulative distribution, flow and load duration, and maps, while the recommended statistical PMs include R^2 (in conjunction with slope and intercept of the pertinent regression line), NSE, *d*, RMSE (together with RSR), and PBIAS.

In this study, we do not go further into specifying PEC based on watershed size, although further work would be needed in this regard. However, the results strongly suggest the need to provide PEC at different scales; therefore, we provide separate PEC for the watershed scale and the field scale. We do not provide (or even recommend) separate PEC for calibration and validation periods. Based on the meta-analysis results, previous PEC reported in the literature, and our modeling experience, recommended PEC are presented in table 9. In general, model performance can be judged "satisfactory" for flow simulations if monthly $R^2 > 0.70$ and $d > 0.75$ for field-scale models and daily, monthly, or annual $R^2 > 0.60$, NSE > 0.50, and PBIAS ≤ ±15% for watershed-scale models. Additionally, model performance can be judged "satisfactory" if monthly $R^2 > 0.40$ and NSE > 0.45 and daily, monthly, or annual PBIAS ≤ ±20% for sediment; monthly $R^2 > 0.40$ and NSE > 0.35 and daily, monthly, or annual PBIAS ≤ ±30% for P; and monthly $R^2 > 0.30$ and NSE > 0.35 and daily, monthly, or annual PBIAS ≤ ±30% for N. For RSR, we recommend that the PEC proposed by Moriasi et al. (2007) be used until new PEC are developed. These PEC, which apply to calibration and validation periods, may be adjusted to be more or less strict based on considerations of the quality and quantity of available measured data, spatial and temporal scales, and project scope, magnitude, and intended purpose. As more data become available and as new PMs are developed and used more frequently, the recommended PMs and their corresponding general PEC can be adjusted based on the framework developed in this study.

However, we consider some values of the recommended statistical PMs to be unacceptable beyond certain reasonable ranges. Thus, in this article, $R^2 < 0.18$, NSE < 0.0, PBIAS ≥ ±30% for flow, PBIAS ≥ ±55% for sediment, PBIAS ≥ ±70% for nutrients, and $d < 0.60$ represent unacceptable model performance. An example case study and an Excel spreadsheet are provided to illustrate the application of the recommended PMs and the corresponding developed PEC guidelines.

The guidelines developed in this study go beyond the scope of those provided by Moriasi et al. (2007), which were limited to NSE, PBIAS (Gupta et al., 1999), and RSR for stream flow, sediment, and nutrient (N and P) simulations at a monthly temporal scale and watershed spatial scale. In this study, PEC for R^2 were added and PEC for NSE were disaggregated by output parameter (flow, sediment, N/P), and limits were adjusted based on current data. Limits were also adjusted for PBIAS for each output parameter, and some PEC were explicitly extended to daily and annual scales. In addition, PEC for R^2 and *d* were added for ADAPT. These current results provide updated guidance on performance measures and corresponding performance evaluation criteria for calibrating and validating hydrologic and water quality models.

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APPENDIX

ABBREVIATIONS FOR MODEL NAMES

ADAPT	Agricultural Drainage and Pesticide Transport
AGWA	ArcGIS-based Automated Geospatial Watershed Assessment
APEX	Agricultural Policy/Environmental eX-tender
BASINS	Better Assessment Science Integrating Point and Nonpoint Sources
COUPMODEL	Coupled Heat and Mass Transfer model
CREAMS	Chemicals, Runoff, and Erosion from Agricultural Management Systems
DAISY	Danish Simulation Model
EPIC	Erosion Productivity Impact Calculator
GLEAMS	Groundwater Loading Effects of Agricul-tural Management Systems
HSPF	Hydrological Simulation Program - Fortran
H/WQ	Hydrologic and water quality (models)
HYDRUS	-
KINEROS	KINematic runoff and EROSion
MIKE SHE	MIKE System Hydrologique European (SHE)
MT3DMS	Modular 3-Dimensional Multispecies Transport Model
RZWQM	Root Zone Water Quality Model
SHAW	Simultaneous Heat and Water
STANMOD	STudio of ANalytical MODels
SWAT	Soil and Water Assessment Tool
SWIM	Soil Water Infiltration and Movement
TOUGH	Transport of Unsaturated Groundwater and Heat
VS2DI	-
WAM	Watershed Assessment Model
WARMF	Watershed Analysis Risk Management Framework
WEPP	Water Erosion Prediction Project

STATISTICAL TERMS AND PERFORMANCE MEASURES

d	Index of agreement
D_v	Deviation volume
HUC	Hydrologic unit code
MAE	Mean absolute error
ME	Mean error
MSE	Mean square error
NSE	Nash-Sutcliffe efficiency
PBIAS	Percent bias
PE	Prediction error
PPS	Point to plot scale
PVE	Percent volume error
r	Pearson's correlation coefficient
R^2	Coefficient of determination
RB	Relative bias
RE	Relative error
RMSD	Root mean square deviation
RMSE	Root mean square error
RSR	RMSE-observations standard deviation ratio
RVE	Relative volume error
SD	Standard deviation

Appendix 30A

Specifications for Runs 15 – 18

and

Specifications for Simulated WWTP Discharges and Urban Deep Percolation

ILRG Model

Early EPCWID Ops (WWTP & Fabens Drains) (Run 15)
Early EPCWID Ops (WWTP) (Run 15a)
Early EPCWID Ops (Fabens Drains) (Run 15b)
Early EPCWID Ops (TX Hueco Pumping Off) (Run 15c)

Irrigation Pumping

- Supplemental pumping to meet unmet demand after use of surface water.
  - **Run 15c**: Texas Hueco pumping off.
- Pumping on NM primary ground water acres to meet crop demand.

Non-Irrigation Pumping and Returns

- Historical non-irrigation pumping and returns.
  - **Run 15c**: Texas Hueco pumping off.

Irrigated Area

- Project Acres: Historical
- HCCRD and MX Acres: Historical
- NM Primary GW Acres: Historical

Crop Evapotranspiration

- Historical.

Irrigation Infrastructure and Irrigation Practices

- EBID: Historical
- HCCRD: Historical
- Mexico: Historical
- EPCWID
  - **Run 15 & 15c**:
    - Charge EPCWID for use of EPW WWTP returns.
    - No ACE or Haskell credits for EPCWID.
    - Simulate EPCWID (EPV) increased use of Fabens drain flows*.
    - Charge EPCWID for use of Fabens drain flows.
  - **Run 15a**:
    - Charge EPCWID for use of EPW WWTP returns.
    - No ACE or Haskell credits for EPCWID.
  - **Run 15b**:
    - Simulate EPCWID (EPV) increased use of Fabens drain flows*.
    - Charge EPCWID for use of Fabens drain flows.

* Starting in July 1945, use 70% of simulated Fabens drain flow up to 6,000 af/month for irrigation in EPCWID.

Project Allocation Rules

- 1951-2005: D1/D2 Project allocation rules.
- 2006-2007: D3 Project allocation rules without carryover accounting.
- 2008-2017: D3 Project allocation rules with carryover accounting.

Conj Use 1: Hist All Acres D1/D2 (Hist M&I) (Run 16)

Conj Use 1a: Hist All Acres D1/D2 (1978 M&I) (Run 16a)

Irrigation Pumping

- Supplemental pumping to meet unmet demand after use of surface water.
- Pumping on NM primary ground water acres to meet crop demand.
- Limit 10-year average irrigation pumping to 1951-1978 averages:
  - NM: 166,866 AF (includes primary GW pumping)
  - TX: 81,971 AF (limit EPCWID+HCCRD)
    - EPCWID: 70,783 AF
    - HCCRD : 11,188 AF
  - MX: No limit

Non-Irrigation Pumping and Returns

- **Run 16 (Hist M&I):**
  - Historical non-irrigation pumping and returns.
  - Set Las Cruces returns from use of Jornada wells to zero (results in a simulated offset from return flows attributed to this imported water source).
- **Run 16a (1978 M&I):**
  - Limit annual M&I pumping to 1951-1978 maximums:
    - NM: 20,993 AF
    - TX (Hueco): 89,979 AF
    - TX (Mesilla): 30,264 AF
    - MX: No limit
  - Reduce M&I returns by same percentage as M&I pumping reduced:
    - For Las Cruces, this reduction applies to their use of Mesilla wells (not to their Jornada wells).
    - Don't reduce EPW returns from use of Project water.
  - Set Las Cruces returns from use of Jornada wells to zero (results in a simulated offset from return flows attributed to this imported water source).

Irrigated Area

- Project Acres: Historical
- HCCRD and MX Acres: Historical
- NM Primary GW Acres: Historical

Crop Evapotranspiration

- Historical.

Irrigation Infrastructure and Irrigation Practices

- EBID: Historical
- HCCRD: Historical
- Mexico: Historical
- EPCWID (Run 15 Conditions):
    - Charge EPCWID for use of EPW WWTP returns.
    - No ACE or Haskell credits for EPCWID.
    - Simulate EPCWID (EPV) increased use of Fabens drain flows*.
    - Charge EPCWID for use of Fabens drain flows.

* Starting in July 1945, use 70% of simulated Fabens drain flow up to 6,000 af/month for irrigation in EPCWID.

Project Allocation Rules

- D1/D2 Project allocation rules from 1951-2017.

Conj Use 2: Hist Proj Acres (Hist M&I) (Run 17)
Conj Use 2a: Hist Proj Acres (Pre-Comp M&I) (Run 17a)

Irrigation Pumping

- Supplemental pumping to meet unmet demand after use of surface water (same as Historical Base Run).
- No pumping on NM primary ground water acres.

Non-Irrigation Pumping and Returns

- **Run 17 (Hist M&I)**:
  - Historical non-irrigation pumping and returns.
  - Set Las Cruces returns from use of Jornada wells to zero (results in a simulated offset from return flows attributed to this imported water source).
- **Run 17a (Pre-Comp M&I)**:
  - Limit M&I pumping to pre-Compact levels:
    - NM: 736 AF
    - TX: 13,744 AF
  - Reduce M&I returns by same percentage as M&I pumping reduced
    - For Las Cruces, this reduction applies to their use of Mesilla wells (not to their Jornada wells).
    - Don't reduce EPW returns from use of Project water.
  - Set Las Cruces returns from use of Jornada wells to zero (results in a simulated offset from return flows attributed to this imported water source).

Irrigated Area

- Project Acres: Historical
- HCCRD and Mexico Acres: Historical
- NM Primary GW Acres: None

Crop Evapotranspiration

- Historical

Irrigation Infrastructure and Irrigation Practices

- EBID: Historical
- HCCRD: Historical
- Mexico: Historical
- EPCWID (Run 15 Conditions):
  - Charge EPCWID for use of EPW WWTP returns.
  - No ACE or Haskell credits for EPCWID.
  - Simulate EPCWID (EPV) increased use of Fabens drain flows*.
  - Charge EPCWID for use of Fabens drain flows*.

* Starting in July 1945, use 70% of simulated Fabens drain flow up to 6,000 af/month for irrigation in EPCWID.

Project Allocation Rules

- D1/D2 Project allocation rules from 1951-2017.

Conj Use 3: Auth Proj Acres (Pre-Comp M&I) (Run 18)

Irrigation Pumping

- Supplemental pumping to meet unmet demand after use of surface water (same as Historical Base Run).
- No pumping on primary ground water acres in EBID.

Non-Irrigation Pumping and Returns

- Limit M&I pumping to pre-Compact levels:
  - NM: 736 AF
  - TX: 13,744 AF
- Reduce M&I returns by same percentage as M&I pumping reduced
  - For Las Cruces, this reduction applies to their use of Mesilla wells (not to their Jornada wells).
- Set Las Cruces returns from use of Jornada wells to zero (results in a simulated offset from return flows attributed to this imported water source).
- No EPW use of Project water and no returns from EPW use of Project water.

Irrigated Area

- Project Acres: Set irrigated area to the original authorized Project acres in every year of the study period from 1940 – 2017:
  - EBID: 88,000 acres
  - EPCWID: 67,000 acres
- Other Acres: Set the irrigated area for HCCRD to the maximum historical acres which occurred in 1951, and use the actual historical acres that vary through time for Mexico:
  - HCCRD: 17,750 acres
  - MX: Historical acres (same as Base Run)
- NM Primary GW Acres: None

Crop Evapotranspiration

- Simulate the historical crop-weighted average unit crop irrigation requirement (CIR) for each irrigation district (EBID, EPCWID, HCCRD, Mexico); this reflects the historical changes in cropping pattern through time (same as Base Run).

Irrigation Infrastructure and Irrigation Practices

- Simulate the historical infrastructure as it evolved through time (same as Base Run).
- For all areas, simulate the historical water distribution losses, irrigation efficiency, deep percolation/surface runoff split, etc. as these changed through time (same as Base Run).
- EPCWID (Run 15 Conditions):
  - Charge EPCWID for use of EPW WWTP returns.
  - No ACE or Haskell credits for EPCWID.
  - Simulate EPCWID (EPV) increased use of Fabens drain flows*.
  - Charge EPCWID for use of Fabens drain flows*.

* Starting in July 1945, use 70% of simulated Fabens drain flow up to 6,000 af/month for irrigation in EPCWID.

Project Allocation Rules

- D1/D2 Project allocation rules from 1951-2017.

Simulated WWTP Discharges and Urban Deep Percolation for ILRG Model Runs

Run No.	Run Name	Description (1)	WWTP Discharge (2)	Urban Deep Percolation (3)
	Base Run Volume 1940 - 2017 Avg (AF/y)		75,649	11,436
			Volume Turned Off 1940 - 2017 Avg (AF/y)	
0	Historical Calibration Run	Base	0	0
1	Historical Base Run (All Pumping On)	Base	0	0
2	All Pumping Off	All Off	65,814	9,083
3	NM Pumping Off	NM Off	7,327	2,648
4	TX Pumping Off	TX Off	27,641	6,435
5	MX Pumping Off	MX Off	30,847	0
6	R-M Pumping Off	R-M Off	16,229	4,493
7	TX Mesilla Pumping Off	TX Mesilla Off	7,505	1,846
8	TX Non-Irrigation Pumping Off	TX Off	27,641	6,435
9	NM Non-Irrigation Pumping Off	NM Off	7,327	2,648
10	MX Non-Irrigation Pumping Off	MX Off	30,847	0
11	D1/D2 Allocation (All Pumping On)	Base	0	0
12	D3+Carryover Allocation (All Pumping On)	Base	0	0
13	Reduced Waste	Base	0	0
14	All Hueco Pumping Off	All Hueco Off	49,591	4,666
14a	TX Hueco Pumping Off	TX Hueco Off	20,142	4,666
14b	MX Hueco Pumping Off	MX Hueco Off	29,449	0
14c	TX WWTP Discharges Off	TX WWTP Off	27,641	0
14d	TX Hueco Pumping Off (Returns Left On)	Base	0	0
15	Early EPCWID Ops (WWTP & Fabens Drains)	Base	0	0
15a	Early EPCWID Ops (WWTP)	Base	0	0
15b	Early EPCWID Ops (Fabens Drains)	Base	0	0
15c	Early EPCWID Ops (TX Hueco Pumping Off)	TX Hueco Off	20,142	4,666
16	Conj Use 1: Hist All Acres D1/D2 (Hist M&I)	Base-Jornada	479	186
16a	Conj Use 1a: Hist All Acres D1/D2 (1978 M&I)	1978 Max	2,779	961
17	Conj Use 2: Hist Proj Acres (Hist M&I)	Base-Jornada	479	186
17a	Conj Use 2a: Hist Proj Acres (Pre-Comp M&I)	PreComp GW	29,907	8,282
18	Conj Use 3: Auth Proj Acres (Pre-Comp M&I)	PreComp	39,742	10,634

Notes:

(1) See detail for description on Page 2.
(2) "2020-06-17 WWTP Returns for Model Runs Rev.xlsx"
(3) "UrbanDeepPerc_Summary_ProposedUpdate_20200625 with Monthly Updates.xlsx"

Key to Simulated WWTP Discharges and Urban Deep Percolation for ILRG Model Runs

Description	WWTP Discharges ("WWTP")	Urban Deep Percolation ("UDP")
Base	All WWTP on.	All UDP on.
All Off	Turn off WWTP from NM Off, TX Off, and MX Off. Leave on WWTP from Haskell and Bustamante from EPW surface water diversions.	Turn off UDP from NM Off and TX Off.
NM Off	Turn off WWTP from Las Cruces, Salem, Hatch, Anthony NM, Gadsden School District, South Central Regional, Sunland Park and Santa Teresa, and El Paso Electric.	Turn off UDP from pumping from Las Cruces, Santa Teresa, Anthony NM, Mesquite, Berino, Garfield, and Radium Springs.
TX Off	Turn off WWTP from Anthony TX, Northwest, Socorro, and Fabens. Turn off WWTP from Haskell and Bustamante from EPW Mesilla and Hueco pumping. Leave on WWTP from Haskell and Bustamante from EPW surface water diversions.	Turn off UDP from Mesilla and Hueco pumping. Leave on UDP from EPW surface water diversions.
MX Off	Turn off WWTP from Juarez.	No MX UDP simulated in runs.
R-M Off	Turn off WWTP from NM Off and TX Mesilla Off. Turn off WWTP from Juarez Mesilla (Conjeos Medanos) pumping.	Turn off UDP from NM Off and TX Mesilla Off.
TX Mesilla Off	Turn off WWTP from Anthony TX and Northwest and WWTP from Haskell from EPW Mesilla pumping.	Turn off UDP from EPW Mesilla pumping. Computed as total EPW UDP multiplied by EPW Mesilla pumping divided by total EPW use.
All Hueco Off	Turn off WWTP from TX Hueco Off and MX Hueco Off.	Turn off UDP from TX Hueco Off.
TX Hueco Off	Turn off WWTP from include Socorro and Fabens. Turn off WWTP from of Haskell and Bustamante from EPW Hueco pumping. Leave on Haskell and Bustamante WWTP from EPW surface water diversions. Leave on Haskell WWTP from EPW Mesilla pumping.	Turn off UDP from EPW Hueco pumping. Computed as total EPW UDP multiplied by EPW Hueco pumping divided by total EPW use.
MX Hueco Off	Turn off WWTP from Juarez Hueco pumping. Leave on WWTP from Juarez Mesilla (Conejos Medanos) pumping.	All UDP on.
TX WWTP Off	Turn off WWTP from Anthony TX, Northwest, Haskell, Bustamante, Socorro, and Fabens.	All UDP on.
Base-Jornada	Turn off WWTP from Las Cruces from Jornada pumping. Computed as total Las Cruces WWTP multiplied by Jornada pumping divided by total Las Cruces pumping.	Turn off UDP from Las Cruces Jornada pumping. Computed as total Las Cruces UDP multiplied by Jornada pumping divided by total Las Cruces pumping .
1978 Max	For NM and TX, turn off WWTP from pumping that exceeds the maximum annual 1951-1978 pumping. Computed as WWTP multiplied by pumping reduction percentages.	For NM and TX, turn off UDP from pumping that exceeds the maximum annual 1951-1978 pumping. Computed as UDP multiplied by pumping reduction percentages.
PreComp GW	For NM and TX, set WWTP to pre-compact amounts. NM pre-compact WWTP is equal to the 1940 Hatch and Las Cruces amounts. TX pre-compact WWTP is equal to the 1938 Haskell amount. Leave on Haskell and Bustamante WWTP from EPW surface water diversions.	For NM and TX, set UDP to pre-compact amounts. NM pre-compact UDP is equal to the 1940 UDP from Hatch and Las Cruces pumping. TX pre-compact UDP is equal to the 1938 UDP from Haskell pumping. Leave on UDP from EPW surface water diversions.
PreComp	For NM and TX, set WWTP to pre-compact amounts. NM pre-compact WWTP is equal to the 1940 Hatch and Las Cruces amounts. TX pre-compact WWTP is equal to the 1938 Haskell amount.	For NM and TX, set UDP to pre-compact amounts. NM pre-compact UDP is equal to the 1940 UDP from Hatch and Las Cruces pumping. TX pre-compact UDP is equal to the 1938 UDP from Haskell pumping.

Appendix 30B - 30AA

Comparison of ILRG Model Runs

Appendix 30B

Comparison of ILRG Model Runs
Run 2 v. Run 1

Model Run Specifications

Model Version: LRG_v116

Name: **Run 2 - All Pumping Off**

Run ID: LRG_v116_Operational_Run2
Date: 8/24/2020

Name: **Run 1 - Historical Base Run**

Run ID: LRG_v116_Operational_Run1
Date: 8/23/2020

Selected Model Inputs

Pumping and Returns	**Run 2**	**Run 1**
Irrigation Pumping	All Off	On
Irrigated Area	Hist	Hist
Non-Irrigation Pumping	All Off	On
Non-Irrigation Pumping Returns	All Off	On
Las Cruces Jornada Pumping Returns	Off	On

Project Allocation Rules		
1950-2005	D1/D2	D1/D2
2006-2007	D3	D3
2008-2017	D3 + CO	D3 + CO

EPCWID Operations		
Charge EPCWID for Use of WWTP Returns	Off	Off
ACE and Haskell Credits for EPCWID	On	On
Increased EPCWID Use of Fabens Drain Flows	Off	Off
Charge EPCWID for Fabens Drain Flow Use	Off	Off

Run 2 - All Pumping Off
Comparison of ILRG Model Runs
Run 2 v. Run 1
1951 - 2017 Annual Average
(1,000 acre-feet)

Run No.	1	2	2 - 1		
Simulated Input or Output	**Run 1**	**Run 2**	**Run 2 minus Run 1**		
Pumping Stress					
Irrigation Pumping	254.9	0.0	-254.9		
Non-Irrigation Pumping	181.0	0.0	-181.0		
WWTP Flows	58.0	11.1	-46.9		
Urban Deep Percolation	13.1	2.7	-10.4		
Total Stress	364.8	-13.8	-378.6		
	Stress is Pumping minus WWTP and Urban Deep Perc				
Effects of Pumping Stress				***% Chg***	
FHG Deliveries (Mar - Oct)				***Stress***	***% Diff.***
EBID	167.6	202.2	34.6	*-9%*	*21%*
EPCWID (incl. EPW)	139.9	152.1	12.3	*-3%*	*9%*
HCCRD	32.8	35.5	2.6	*-1%*	*8%*
Total	340.3	389.8	49.5	*-13%*	*15%*
FHG Deliveries (Nov - Feb)					
EBID	0.0	0.1	0.1	*0%*	*991%*
EPCWID (incl. EPW)	0.2	0.2	0.0	*0%*	*-11%*
HCCRD	2.4	2.2	-0.2	*0%*	*-8%*
Total	2.6	2.4	-0.2	*0%*	*-6%*
Irrigation Pumping					
EBID	140.4	0.0			
EPCWID (Mesilla Valley)	7.4	0.0			
EPCWID (El Paso Valley)	40.1	0.0			
HCCRD	4.2	0.0			
	Pumping turned off.	*Other values are simulated responses and are totaled.*			
Other Inflows/Outflows					
Net Reservoir Evaporation	125.3	143.7	18.4	*-5%*	*15%*
Riparian ET	70.9	83.9	13.0	*-3%*	*18%*
River Evaporation + Incidental Canal Loss	30.3	31.5	1.2	*0%*	*4%*
Total	226.6	259.2	32.6	*-9%*	*14%*
Rio Grande at Fort Quitman					
Reservoir Spills	33.3	50.7	17.4	*-5%*	*52%*
Nov-Feb Flows	21.4	60.3	38.9	*-10%*	*182%*
Mar - Oct Flows	41.1	85.1	44.0	*-12%*	*107%*
Underflow (GW Model)	0.2	0.3	0.1	*0%*	*32%*
Total	96.0	196.3	100.4	*-27%*	*105%*

Run 2 - All Pumping Off

Comparison of ILRG Model Runs

Run 2 v. Run 1

1951 - 2017 Annual Average

(1,000 acre-feet)

Run No.	1	2	2 - 1		
Simulated Input or Output	**Run 1**	**Run 2**	**Run 2 minus Run 1**		
Effects of Pumping Stress (continued)				***% Chg***	
Change in Storage				***Stress***	***% Diff.***
Reservoir Storage	-4.7	-3.6	1.1	*0%*	*-23%*
Alluvial GW Storage (RW Model)	-23.6	-0.4	23.2	*-6%*	*-98%*
Non-alluvial GW Storage (GW Models)	-96.4	-0.3	96.1	*-25%*	*-100%*
Soil Moisture Storage	0.6	0.7	0.1	*0%*	*17%*
Total	-124.0	-3.6	120.4	*-32%*	*-97%*
Summary of Effects					
FHG Deliveries (Mar-Oct)	340.3	389.8	49.5	*-13%*	*15%*
FHG Deliveries (Nov-Feb)	2.6	2.4	-0.2	*0%*	*-6%*
Irrigation Pumping	0.0	0.0	0.0	*0%*	*0%*
Riparian ET + Evaporation	226.6	259.2	32.6	*-9%*	*14%*
Fort Quitman Flow	96.0	196.3	100.4	*-27%*	*105%*
Change in Storage	-124.0	-3.6	120.4	*-32%*	*-97%*
Total	541.5	844.2	302.8	*-80%*	*56%*
Other Effects of Pumping Stress				***% Chg***	
Rio Grande at El Paso				***Stress***	***% Diff.***
Reservoir Spills	49.4	66.8	17.4	*-5%*	*35%*
Nov-Feb Flows	22.8	51.3	28.5	*-8%*	*125%*
Mar - Oct Flows	263.8	296.8	33.1	*-9%*	*13%*
Total	336.0	414.9	79.0	*-21%*	*24%*
Rio Grande below Caballo					
Reservoir Spills	65.9	83.9	18.0	*-5%*	*27%*
Nov-Feb Flows	0.5	0.5	0.0	*0%*	*5%*
Mar - Oct Flows	541.3	504.3	-37.0	*10%*	*-7%*
Total	607.6	588.7	-19.0	*5%*	*-3%*
Surface Water Diversions (Mar - Oct)					
EBID	366.5	416.8	50.3	*-13%*	*14%*
EPCWID (incl. EPW)	236.8	258.1	21.3	*-6%*	*9%*
HCCRD	67.5	80.5	13.0	*-3%*	*19%*
Total	670.8	755.4	84.5	*-22%*	*13%*
Surface Water Diversions (Nov - Feb)					
EBID	0.0	0.0	0.0	*0%*	*0%*
EPCWID (incl. EPW)	14.3	15.7	1.3	*0%*	*9%*
HCCRD	14.2	17.8	3.6	*-1%*	*25%*
Total	28.5	33.5	4.9	*-1%*	*17%*

Run 2 - All Pumping Off
Annual Differences in ILRG Model Outputs
Run 2 minus Run 1
1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1940	-70	-70	-825	537	-406	703	-8	24	848	898	-320	-320	-7,706	-7,295	7,168
1941	-273	-273	-769	-1,275	-2	85	-41	-3	-39	-105	12	-23	6,848	5,472	8,000
1942	-232	-232	-304	-2,114	-90	-108	26	65	282	-178	-114	-123	936	2,541	3,756
1943	-250	-250	-344	-1,474	-96	-115	43	83	325	135	-89	-310	2,294	2,670	2,949
1944	-282	-282	-732	-2,062	-15	-235	-2	39	-81	-293	-38	-202	-452	-67	2,246
1945	-284	-284	-485	-2,095	53	-481	27	65	-91	-383	47	109	479	977	2,679
1946	-220	-220	-361	-2,293	141	-542	52	94	68	-406	97	29	339	940	2,836
1947	-263	-263	-125	-1,484	-24	-321	23	67	638	181	-51	-33	-1,017	-296	3,190
1948	-1,035	-1,035	-1,436	-2,563	373	220	472	520	513	359	380	157	-4,281	-3,101	8,191
1949	-2,145	-2,145	-2,855	-4,130	1,432	1,710	155	209	-109	-136	-138	-281	-6,174	-3,209	13,441
1950	-265	-265	-4,038	-4,768	1,631	2,075	2,268	2,322	-104	-80	-27	-48	-5,582	6,827	17,603
1951	439	439	-4,566	-5,138	1,704	2,497	3,387	3,443	85	115	1,786	1,313	-30,442	9,452	37,549
1952	-177	-177	-6,838	-7,399	2,004	3,004	7,775	7,831	-471	-424	1,848	1,114	-48,835	18,961	45,519
1953	-652	-652	-8,384	-8,970	3,528	5,115	7,329	7,383	-560	-508	3,606	4,094	-55,975	22,853	64,328
1954	48,884	48,884	36,956	43,264	5,129	9,314	31,475	31,513	33,479	33,550	6,177	9,147	16,237	105,775	72,212
1955	51,927	51,927	40,655	53,567	16,005	22,896	32,174	32,200	31,941	31,797	13,241	18,435	-4,453	115,421	78,887
1956	25,255	25,255	26,205	40,191	12,388	18,390	23,556	23,579	24,793	24,071	10,760	13,776	-46,688	103,442	63,607
1957	68,024	68,024	27,490	39,122	14,263	21,385	25,034	25,072	11,377	11,036	10,045	12,060	-48,359	91,894	60,524
1958	-1,222	-1,222	-28,014	-20,277	9,184	17,320	11,228	11,270	-2,195	-2,206	-1,396	1,082	-176,116	11,292	102,747
1959	-1,327	-1,327	-16,145	-14,012	6,454	11,495	7,294	7,342	-783	-706	403	682	-102,822	12,862	89,989
1960	-1,394	-1,394	-13,565	-11,820	5,478	9,077	7,469	7,518	-1,415	-1,333	0	0	-96,553	18,727	84,004
1961	-1,305	-1,305	-12,947	-11,473	5,694	9,097	7,106	7,155	169	248	1,543	-351	-84,485	20,007	82,956
1962	-1,322	-1,322	-12,003	-10,630	5,281	8,498	7,011	7,060	-611	-530	822	1,280	-86,794	25,639	82,205
1963	7,457	7,457	-12,507	-10,602	5,421	8,905	13,003	13,052	-1,206	-1,121	2,506	1,991	-78,348	32,635	82,913
1964	268,545	268,545	139,372	146,153	18,356	24,923	147,941	147,989	95,054	94,800	13,409	15,769	252,583	230,861	114,047
1965	84,909	84,909	10,109	16,861	12,030	20,091	67,032	67,081	26,168	25,856	12,629	15,184	-109,023	85,445	107,640
1966	-86	-86	20,567	23,861	17,130	22,964	-2,219	-2,172	16,126	16,221	-2,697	-4,654	-80,608	68,626	111,070
1967	186,249	186,249	100,548	106,797	20,226	29,634	106,970	107,018	71,490	71,080	10,339	12,266	122,722	167,392	106,571
1968	38,137	38,137	24,995	30,862	22,887	32,934	25,765	25,819	18,479	18,185	12,093	9,482	-74,236	97,208	123,196
1969	729	729	26,295	28,330	24,401	30,943	-2,565	-2,513	19,087	19,162	3,056	-1,594	-78,806	61,865	114,201
1970	-1,480	-1,480	-10,573	-9,807	8,942	13,479	8,470	8,521	-1,134	-1,066	-1,274	-2,725	-110,118	22,344	96,250
1971	117,695	117,695	36,716	40,045	20,158	26,567	67,799	67,852	20,409	20,513	13,777	14,722	815	111,601	114,869
1972	201,568	201,568	122,379	132,400	26,645	35,584	98,954	99,002	74,881	74,734	12,888	11,452	151,754	208,136	135,030
1973	-418	-418	25,660	32,614	34,384	43,619	350	401	15,956	15,813	18,401	15,966	-133,161	77,120	121,431
1974	-1,803	-1,803	-5,006	-2,705	20,666	29,092	13,151	13,207	1,409	1,491	-3,923	-6,152	-91,360	41,630	123,924
1975	-77	-77	35,374	36,390	28,064	35,560	-1,596	-1,548	18,628	18,703	8,101	3,486	-66,046	74,422	111,651
1976	-2,200	-2,200	2,664	3,835	17,671	25,472	9,158	9,189	438	485	-1,658	-5,752	-88,026	36,272	90,297
1977	153,118	153,118	43,238	48,034	21,636	29,039	90,338	90,389	18,795	18,895	16,781	15,626	45,124	118,358	107,462
1978	222,302	222,302	62,020	69,188	19,285	28,464	135,551	135,604	36,845	36,968	16,117	14,160	78,581	157,338	122,364

Run 2 - All Pumping Off
Annual Differences in ILRG Model Outputs
Run 2 minus Run 1
1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1979	1,249	1,249	26,261	30,157	15,032	22,930	11,025	11,080	17,638	17,740	2,378	-604	-107,349	59,625	107,575
1980	-1,428	-1,428	4,552	4,497	10,320	14,227	9,365	9,424	921	999	-4,644	-9,127	-71,658	37,280	116,711
1981	-1,289	-1,289	8,038	9,716	8,948	11,684	9,005	9,051	825	907	-56	-412	-69,531	45,743	95,599
1982	-1,384	-1,384	7,165	8,908	8,453	10,979	8,614	8,669	852	936	-2,057	-4,030	-76,875	45,692	108,357
1983	-983	-983	10,423	11,757	11,716	14,224	7,828	7,883	726	804	0	0	-62,373	43,307	84,378
1984	-1,232	-1,232	12,253	13,225	18,360	20,184	7,875	7,921	715	781	0	0	-36,011	43,290	82,420
1985	1,570	1,570	82,844	82,225	44,447	45,705	-5,291	-5,233	28,626	28,581	0	0	357,218	410,939	410,830
1986	-654	-654	13,088	12,546	12,174	12,561	7,248	7,322	-4,044	-3,987	0	0	87,233	151,523	319,143
1987	-1,560	-1,560	22,282	21,721	9,938	8,932	4,511	4,579	546	595	0	0	45	56,591	120,743
1988	-1,163	-1,163	23,489	22,926	9,867	8,325	5,557	5,622	413	458	0	0	-16,512	42,066	80,214
1989	-952	-952	25,371	24,547	10,892	9,556	6,947	7,002	883	551	0	0	-16,847	51,784	72,871
1990	-701	-701	23,899	23,014	14,149	13,059	6,794	6,854	637	174	0	0	-15,214	45,839	62,361
1991	-2,704	-2,704	11,299	10,301	6,379	5,812	3,112	3,179	357	-379	0	0	-24,404	28,113	61,145
1992	1,422	1,422	88,132	87,313	41,134	41,711	-5,917	-5,855	34,442	34,145	0	0	55,449	116,855	126,465
1993	-558	-558	-6,039	-6,640	2,220	1,962	7,055	7,125	-2,428	-2,382	0	0	-20,360	39,184	79,937
1994	-979	-979	289	-333	3,890	3,754	9,204	9,290	3,149	3,209	0	0	-15,559	74,034	111,168
1995	-959	-959	-276	-954	3,580	3,222	11,344	11,424	3,581	3,609	0	0	38,068	147,652	178,364
1996	-1,506	-1,506	-1,730	-2,352	2,789	2,552	11,766	11,851	786	869	0	0	-80,076	47,656	83,942
1997	-881	-881	-6,571	-7,795	5,072	4,514	8,400	8,461	-1,146	-2,095	0	0	-45,934	38,457	76,532
1998	-1,112	-1,112	314	-414	4,309	3,428	8,974	9,056	1,070	1,131	0	0	-14,547	72,684	113,140
1999	-1,958	-1,958	-13,233	-15,859	30,845	31,505	-2,465	-2,405	-16,558	-16,518	0	0	8,718	95,774	137,493
2000	-887	-887	21,833	18,772	5,930	6,775	-1,246	-1,195	-2,043	-2,013	0	0	-20,510	68,670	86,516
2001	-399	-399	17,537	13,546	6,797	8,042	7,663	7,708	8,080	8,131	0	0	-23,365	51,715	59,673
2002	-767	-767	-257	-2,335	2,653	4,197	8,562	8,605	498	555	0	0	-50,325	33,784	53,692
2003	112,776	112,776	65,045	62,586	19,471	20,877	68,685	68,747	20,334	20,409	0	0	95,568	134,394	96,715
2004	29,520	29,520	16,712	15,138	5,954	8,291	26,603	26,654	5,972	6,045	0	0	-45,119	78,246	74,919
2005	1,140	1,140	9,543	6,603	6,246	8,557	13,955	14,017	7,008	7,086	0	0	-78,994	39,229	62,967
2006	113,465	113,465	77,838	74,778	21,144	23,813	69,488	69,538	37,585	37,646	0	0	93,952	134,426	102,339
2007	116,138	116,138	8,314	6,131	5,104	7,409	82,171	82,220	9,827	9,911	0	0	-35,966	54,073	65,691
2008	184,221	184,221	1,667	-498	4,367	5,933	127,155	127,271	3,225	3,422	0	0	19,896	64,318	89,612
2009	169,956	169,956	1,140	-968	3,022	4,940	116,446	116,603	516	718	0	0	26,377	80,304	109,576
2010	186,430	186,430	4,267	2,307	4,209	6,038	127,637	127,745	2,490	2,662	0	0	6,683	65,750	90,960
2011	111,519	111,519	63,776	63,134	28,695	37,880	55,719	55,763	43,893	44,005	0	0	13,047	127,832	100,518
2012	103,391	103,391	46,169	44,525	27,677	34,751	55,402	55,434	23,637	23,741	0	0	-33,111	106,308	84,433
2013	63,297	63,297	34,132	33,249	13,693	17,203	37,131	37,162	11,688	11,775	5,985	7,791	20,923	114,891	75,575
2014	75,601	75,601	26,931	24,985	15,010	20,636	36,426	36,447	14,946	15,030	902	2,237	-30,070	87,072	71,172
2015	172,196	172,196	22,987	21,518	9,788	13,538	96,285	96,316	12,082	12,186	-4,382	-3,770	-37,547	66,916	74,512
2016	171,041	171,041	17,834	16,499	5,641	8,561	105,374	105,404	13,939	14,054	0	0	-60,762	72,316	64,623
2017	317,337	317,337	6,667	6,157	4,714	7,163	202,857	202,953	8,423	8,594	0	0	19,442	68,703	84,679
Averages															
1951-2017	50,298	50,298	21,264	22,587	12,980	16,579	34,570	34,626	12,259	12,238	2,649	2,447	-18,953	78,964	100,373
1951-1978	52,206	52,206	23,239	27,810	14,465	20,549	33,891	33,938	18,830	18,780	6,406	6,138	-36,551	76,699	94,551
1979-2005	4,579	4,579	17,121	16,401	11,910	12,873	9,451	9,512	4,142	4,087	-162	-525	-9,232	77,782	113,477
2006-2017	148,716	148,716	25,977	24,318	11,922	15,655	92,674	92,738	15,188	15,312	209	521	239	86,909	84,474
1985-2017	57,978	57,978	21,373	19,890	11,873	13,370	39,805	39,869	8,255	8,240	76	190	5,376	86,912	105,531
1985-2005	6,128	6,128	18,741	17,360	11,845	12,064	9,593	9,657	4,293	4,199	0	0	8,311	86,914	117,563

Notes:

EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

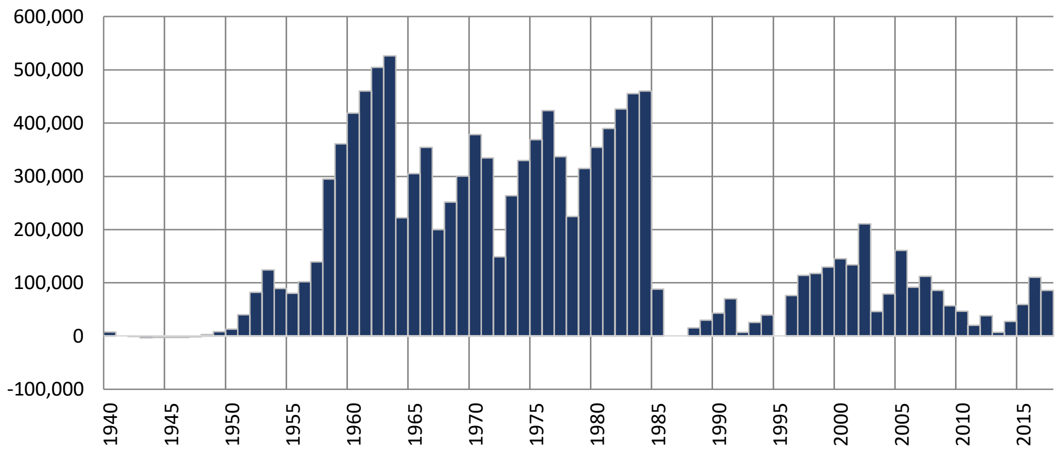
Run 2 - All Pumping Off

Simulated Differences in ILRG Model Outputs

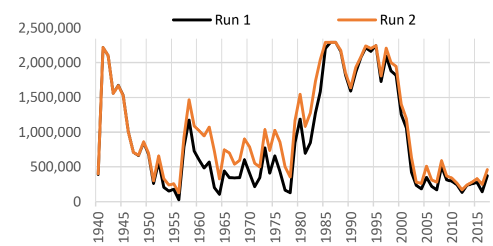
Run 2 minus Run 1

1940 - 2017 (acre-feet)

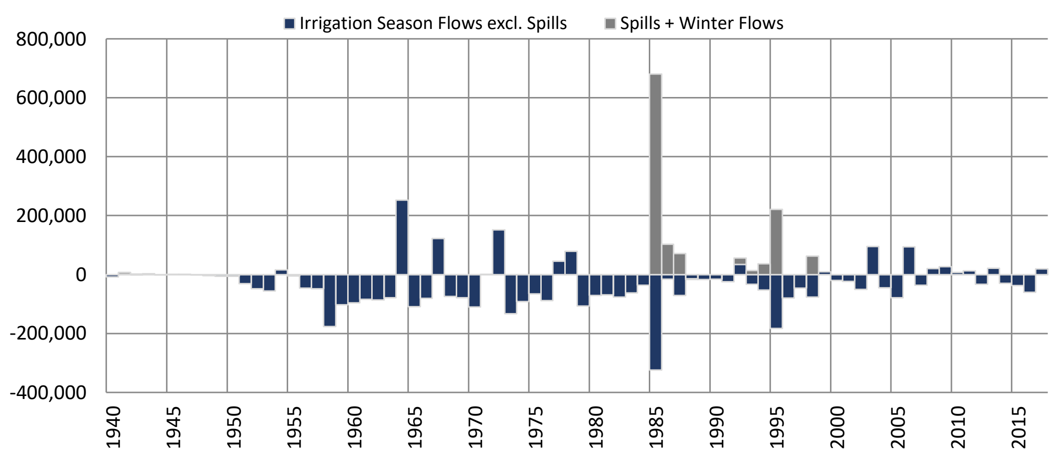
Total Project Storage (Year End)



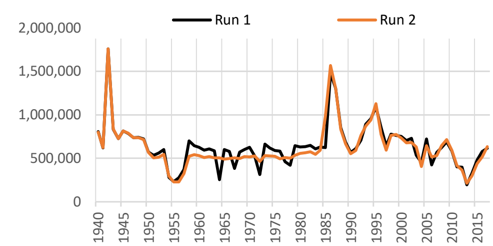
Period	Average Difference
1951-2017	1,087
1951-1978	7,562
1979-2005	-2,360
2006-2017	-6,267
1985-2017	-11,345
1985-2005	-14,246



Caballo Reservoir Outflows (Annual)



	Average Difference		
Period	Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	-36,983	18,030	-18,953
1951-1978	-36,551	0	-36,551
1979-2005	-53,973	44,741	-9,232
2006-2017	239	0	239
1985-2017	-31,231	36,607	5,376
1985-2005	-49,214	57,525	8,311



Notes:

Reservoir storage does not include storage attributed to SJC, CO, or NM credit waters.

Average differences calculated as (Final Storage - Initial Storage)/(no. years).

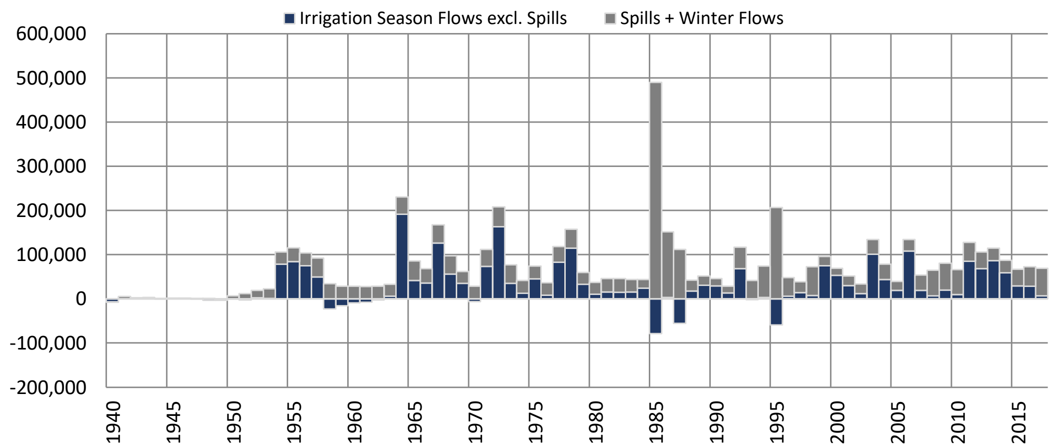
Run 2 - All Pumping Off

Simulated Differences in ILRG Model Outputs

Run 2 minus Run 1

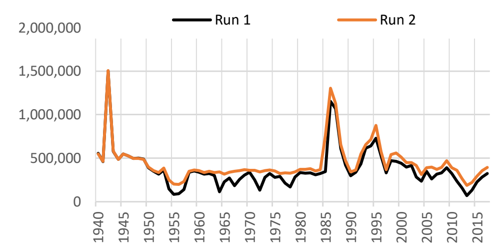
1940 - 2017 (acre-feet)

Rio Grande at El Paso (Annual)

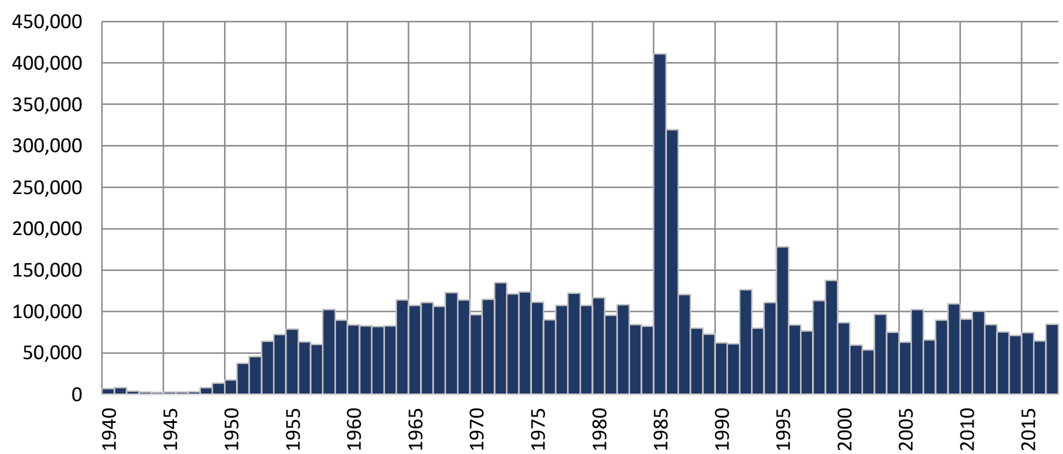


Average Difference

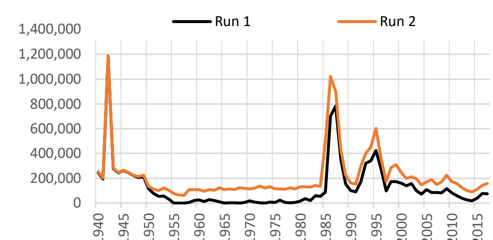
Period	Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	33,065	45,900	78,964
1951-1978	44,593	32,106	76,699
1979-2005	16,339	61,443	77,782
2006-2017	43,798	43,111	86,909
1985-2017	25,891	61,021	86,912
1985-2005	15,659	71,255	86,914



Rio Grande at Fort Quitman (Annual)



Period	Average Difference
1951-2017	100,304
1951-1978	94,449
1979-2005	113,419
2006-2017	84,456
1985-2017	105,499
1985-2005	117,524



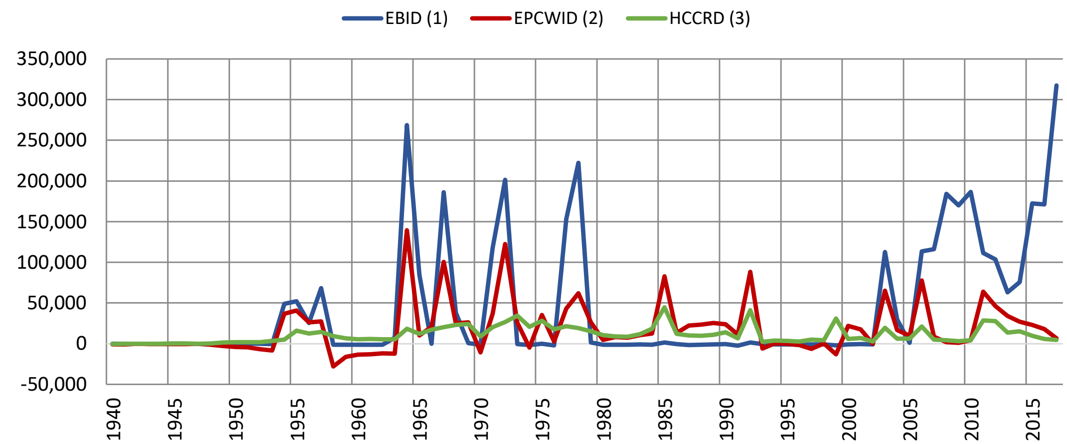
Run 2 - All Pumping Off

Simulated Differences in ILRG Model Outputs

Run 2 minus Run 1

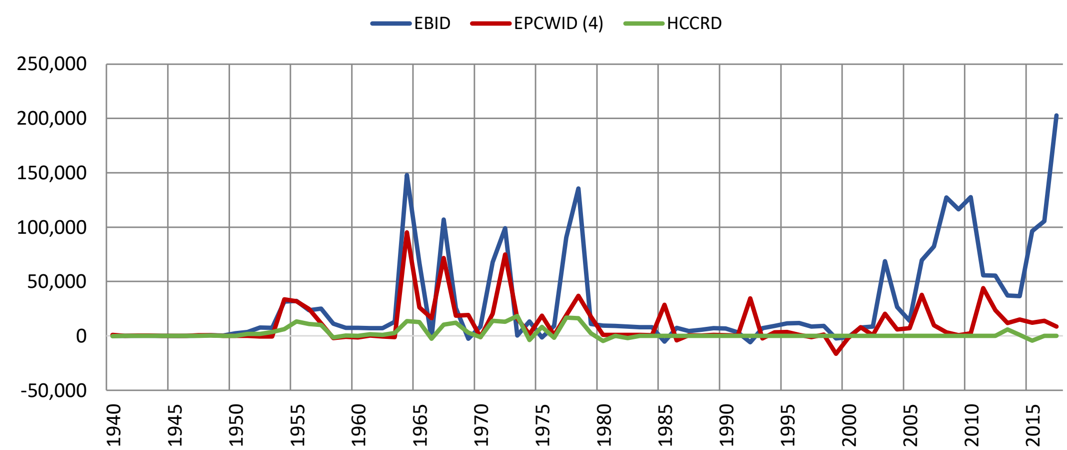
1940 - 2017 (acre-feet)

River Headgate (RHG) Diversions (Irrigation Season)



	Average Difference		
Period	EBID	EPCWID	HCCRD
1951-2017	50,298	21,264	12,980
1951-1978	52,206	23,239	14,465
1979-2005	4,579	17,121	11,910
2006-2017	148,716	25,977	11,922
1985-2017	57,978	21,373	11,873
1985-2005	6,128	18,741	11,845

Farm Headgate (FHG) Deliveries (Irrigation Season)



	Average Difference		
Period	EBID	EPCWID	HCCRD
1951-2017	34,570	12,259	2,649
1951-1978	33,891	18,830	6,406
1979-2005	9,451	4,142	-162
2006-2017	92,674	15,188	209
1985-2017	39,805	8,255	76
1985-2005	9,593	4,293	0

Notes:

(1) EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

(2) EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

(3) HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

(4) EPCWID FHG values include deliveries to Rogers WTP and R/U WTP.

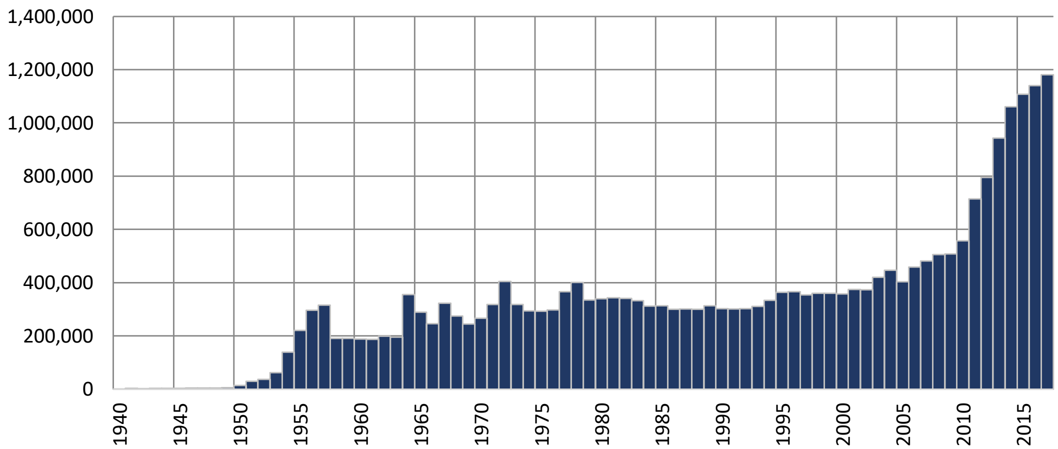
Run 2 - All Pumping Off

Simulated Differences in ILRG Model Outputs

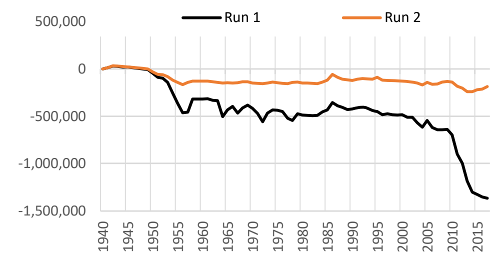
Run 2 minus Run 1

1940 - 2017 (acre-feet)

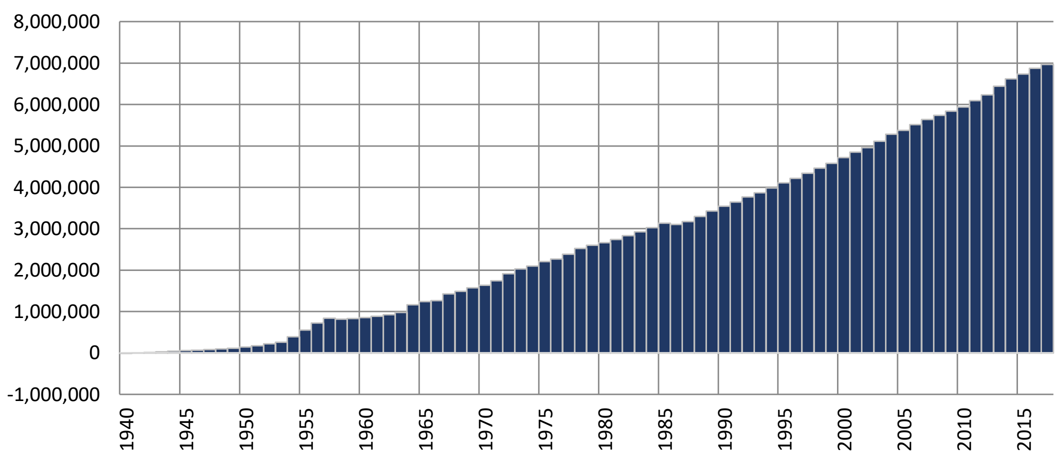
Cumulative Annual Rincon-Mesilla Groundwater Storage



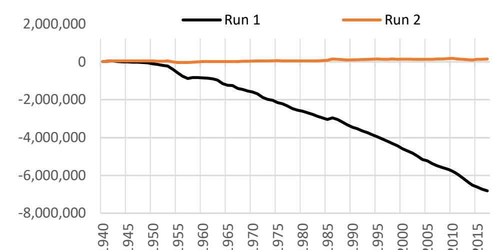
Period	Average Difference
1951-2017	17,417
1951-1978	13,807
1979-2005	96
2006-2017	64,812
1985-2017	26,339
1985-2005	4,354



Cumulative Annual Hueco Groundwater Storage



Period	Average Difference
1951-2017	101,839
1951-1978	84,954
1979-2005	105,574
2006-2017	132,836
1985-2017	119,492
1985-2005	111,867



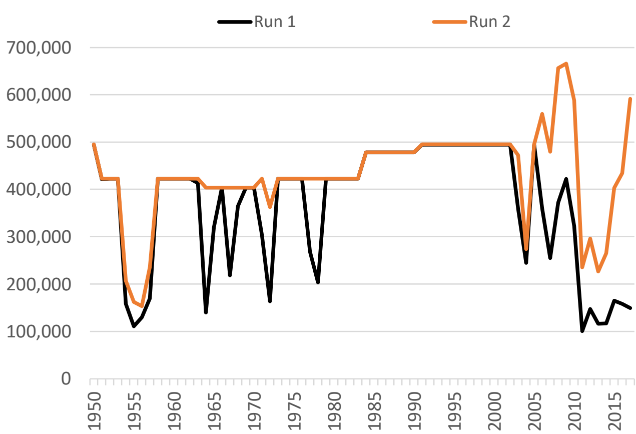
Notes:

Cumulative storage change in alluvial and non-alluvial aquifers.

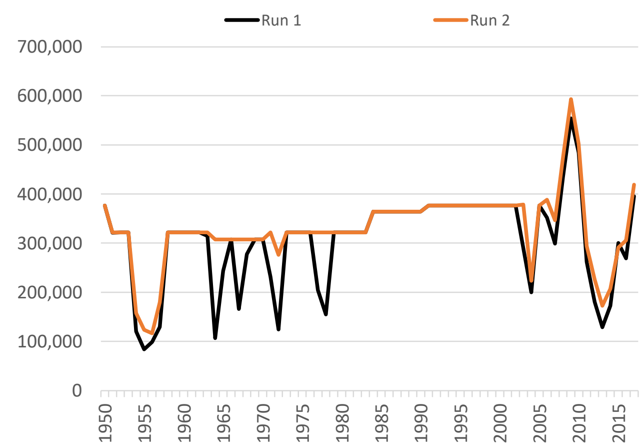
Average differences calculated as (Final Storage - Initial Storage)/(no. years).

Run 2 - All Pumping Off
Annual Allocation and Charges
Run 2 v. Run 1
ILRG Model
1950 - 2017 (acre-feet)

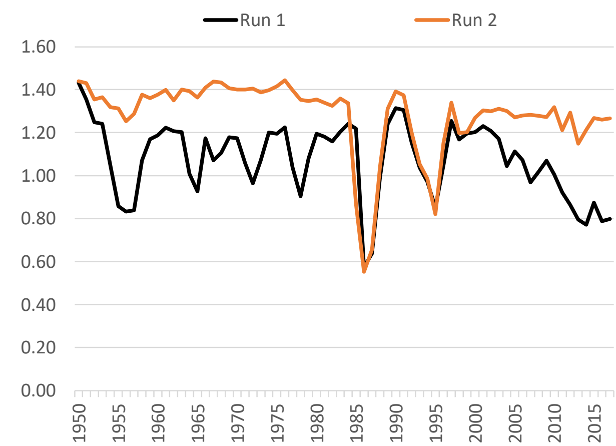
Total Allocation - EBID



Total Allocation - EPCWID

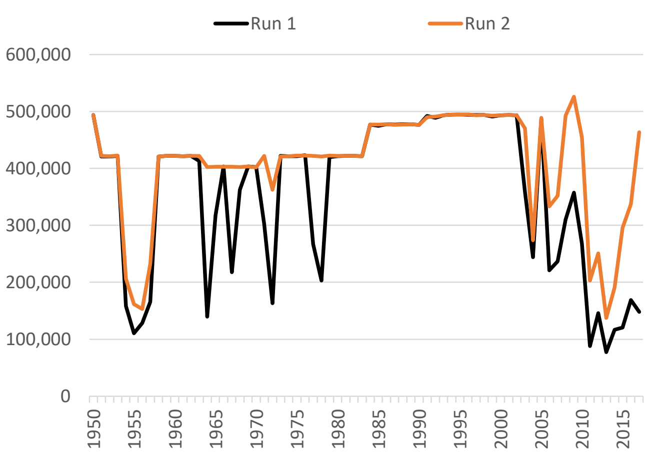


Diversion Ratio

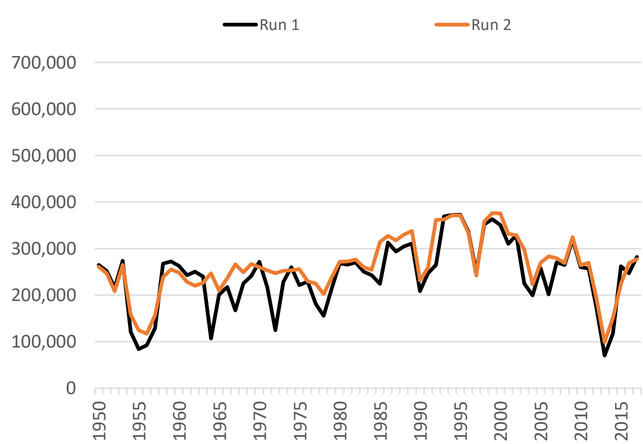


Note:
Computed as Total Charges/Caballo Release.

Annual Delivery Charges - EBID



Annual Delivery Charges - EPCWID



Run 2 - All Pumping Off

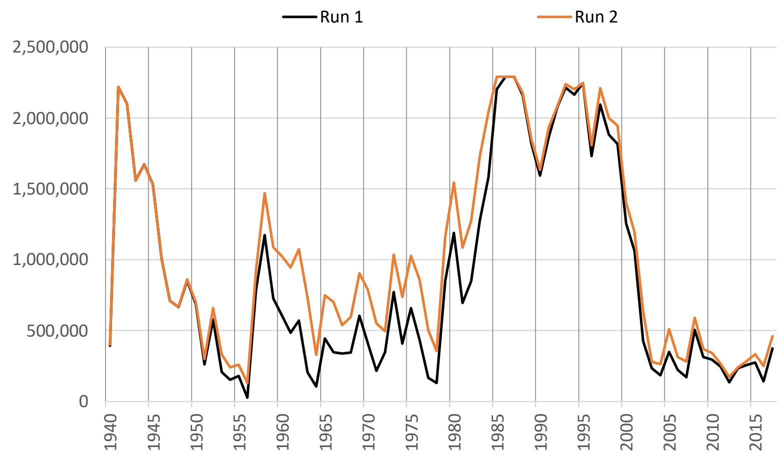
Annual Summary of Project Storage and Rio Grande Flows

Run 2 v. Run 1

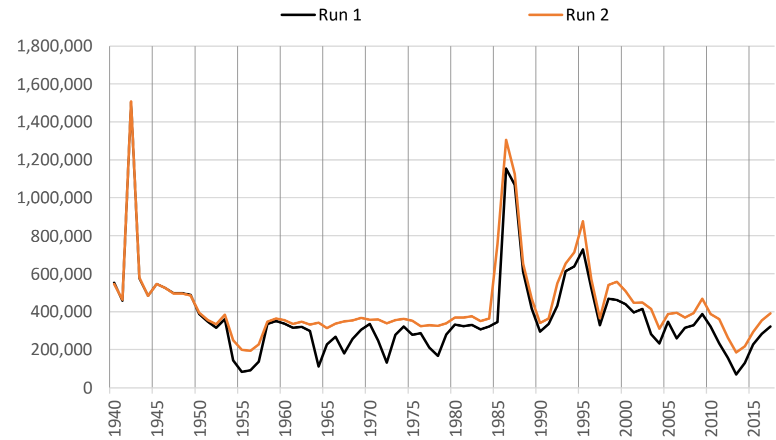
ILRG Model

1940 - 2017 (acre-feet)

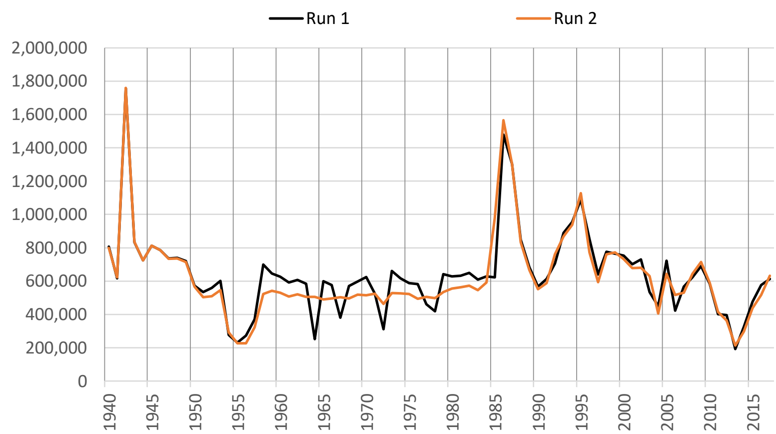
Total Year-End Project Reservoir Storage



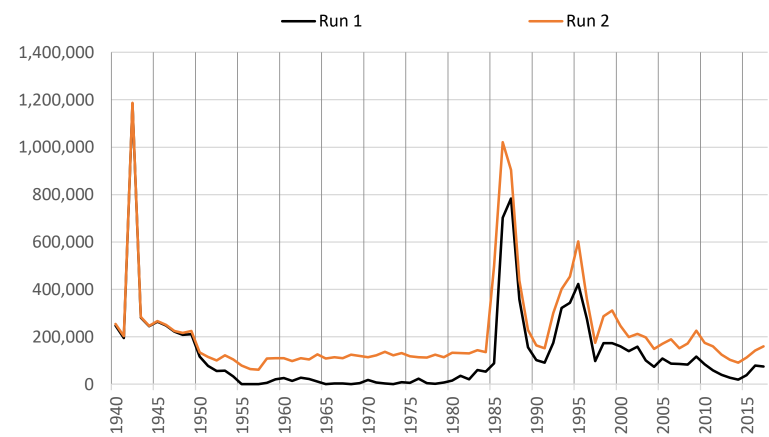
Rio Grande at El Paso



Rio Grande Below Caballo



Rio Grande at Fort Quitman

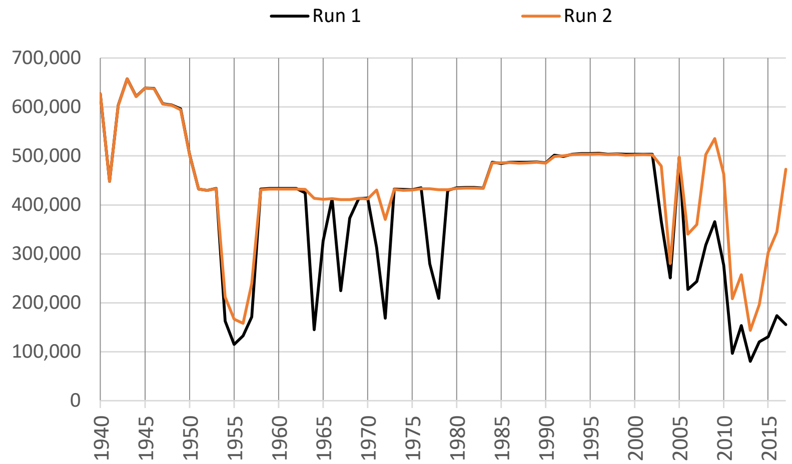


***Note different scales.**

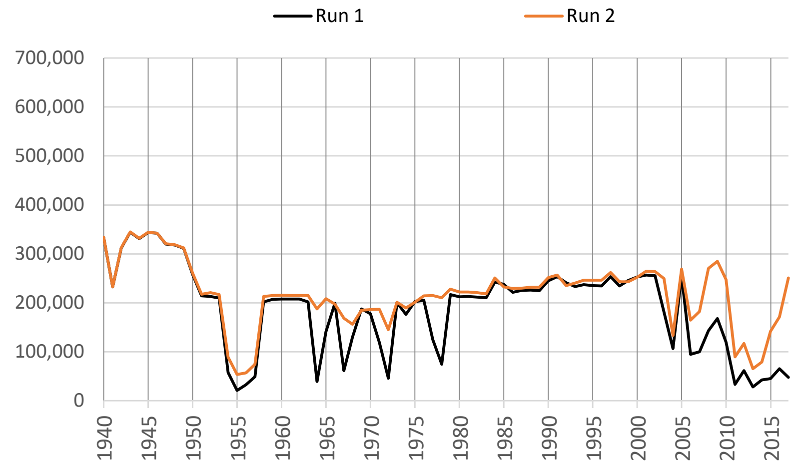
Run 2 - All Pumping Off
Irrigation Season Summary of Irrigation Operations
Run 2 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

EBID Total

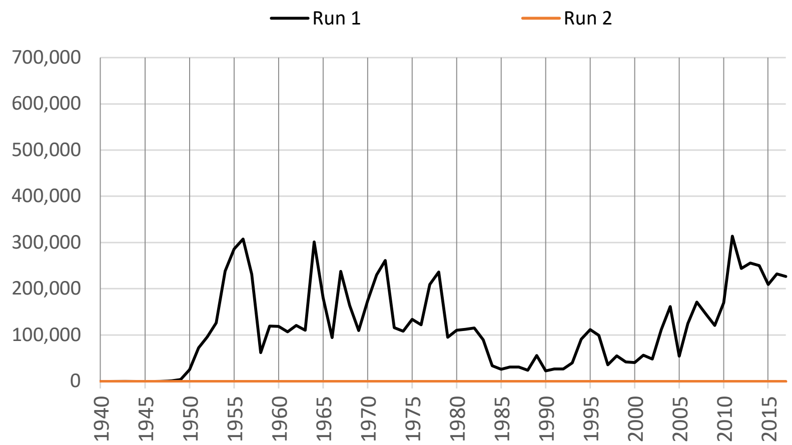
Net River Headgate Diversions



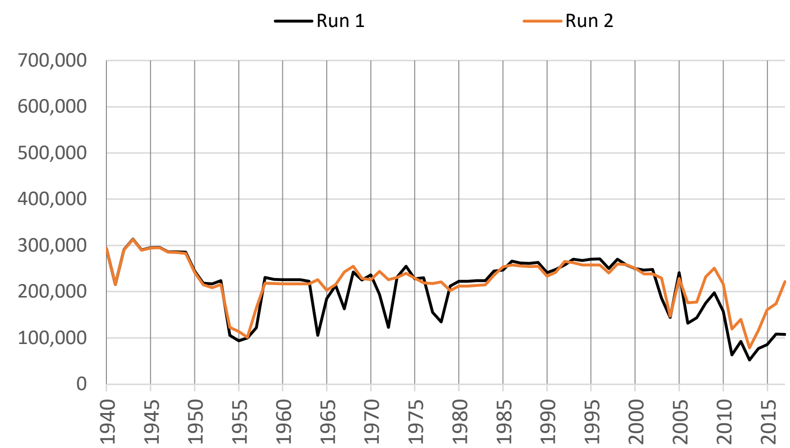
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries

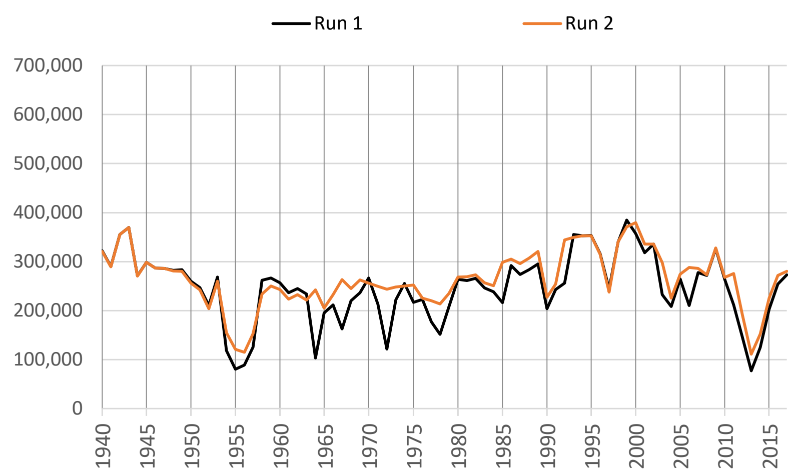


Notes: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).
Pumping includes Supplemental and Primary groundwater pumping.

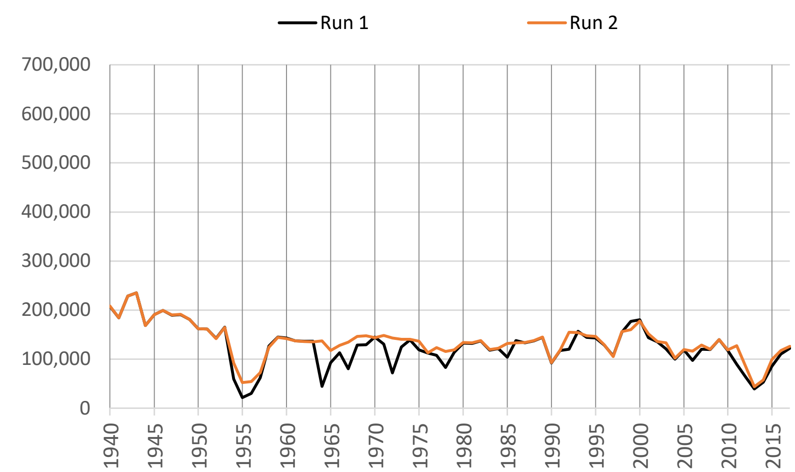
Run 2 - All Pumping Off
Irrigation Season Summary of Irrigation Operations
Run 2 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

EPCWID Total

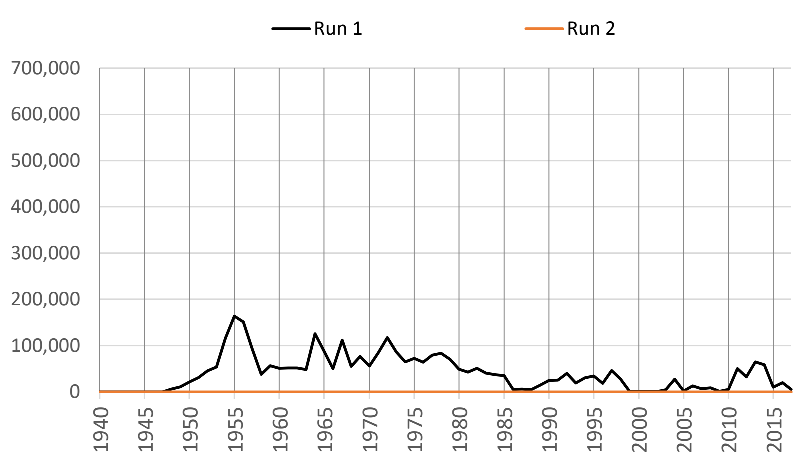
Net River Headgate Diversions



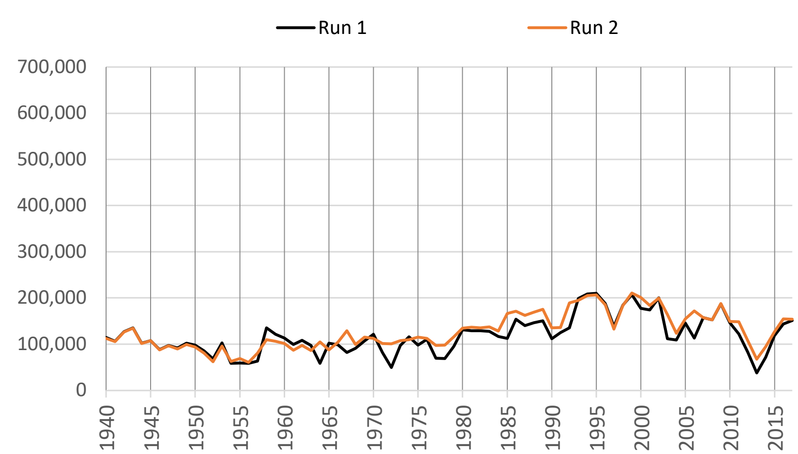
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries

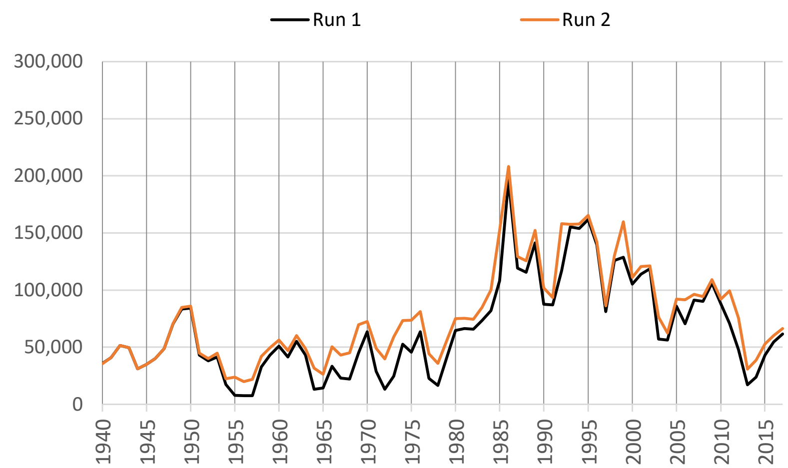


Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

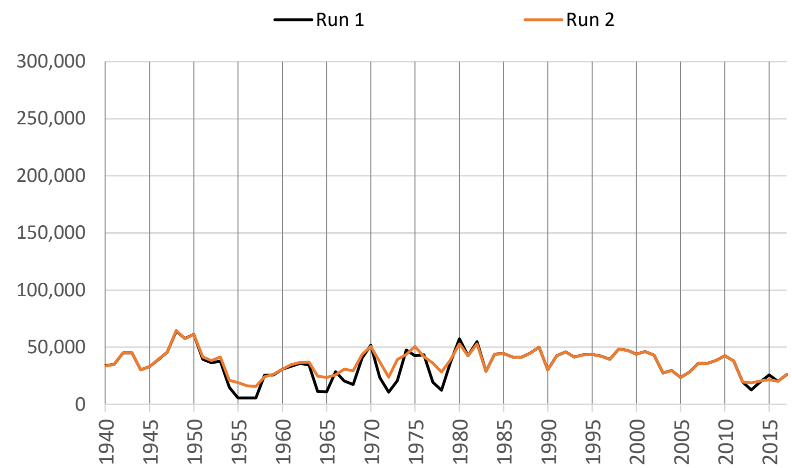
Run 2 - All Pumping Off
Irrigation Season Summary of Irrigation Operations
Run 2 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

HCCRD Total

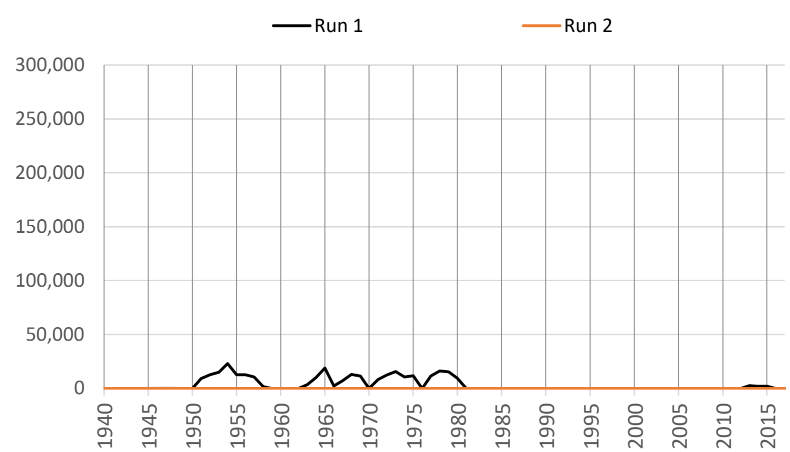
Net River Headgate Diversions



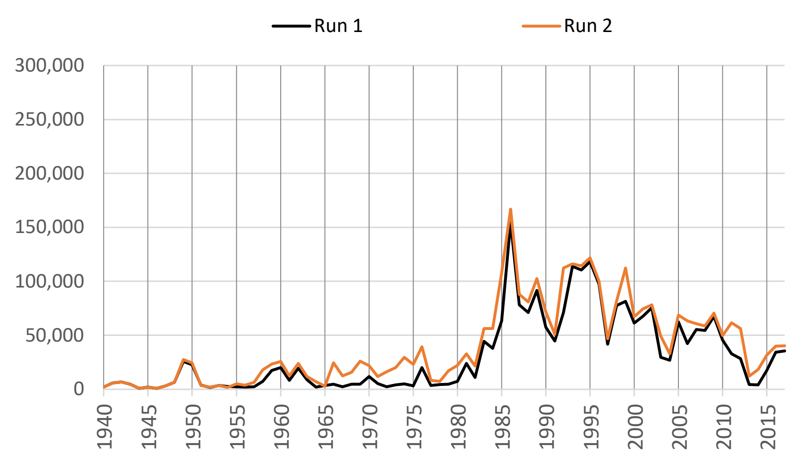
Farm Headgate Deliveries



Pumping



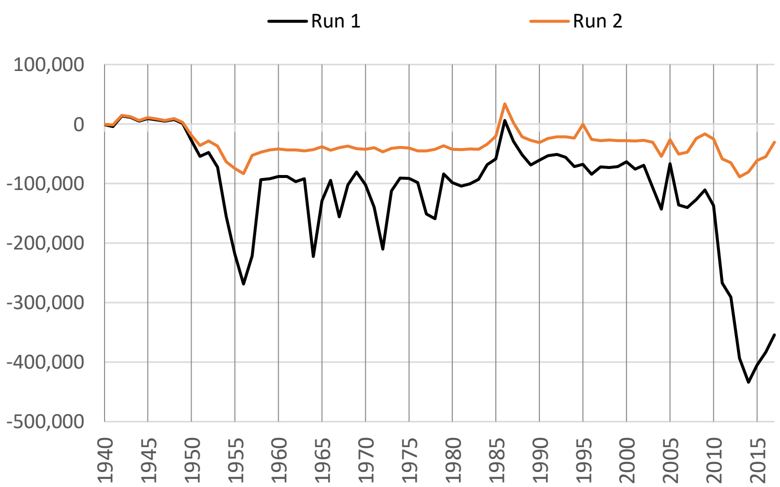
RHG Diversions - FHG Deliveries



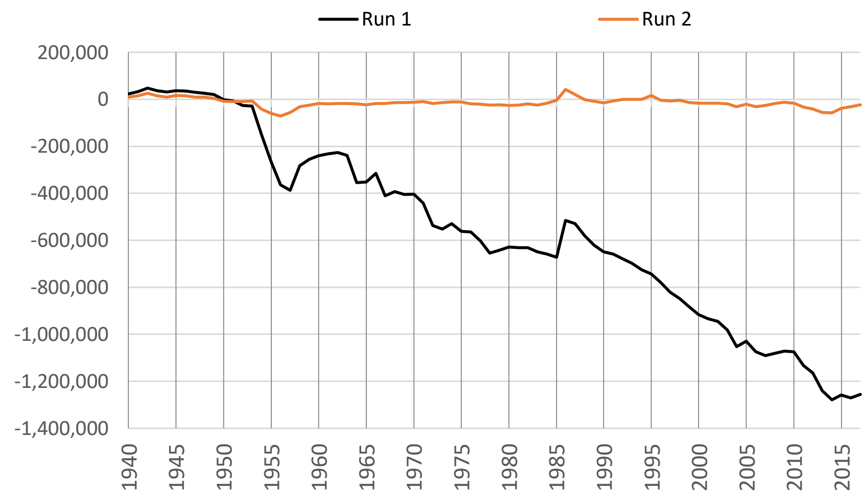
Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

Run 2 - All Pumping Off
Cumulative Change in Ground Water Storage
Run 2 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

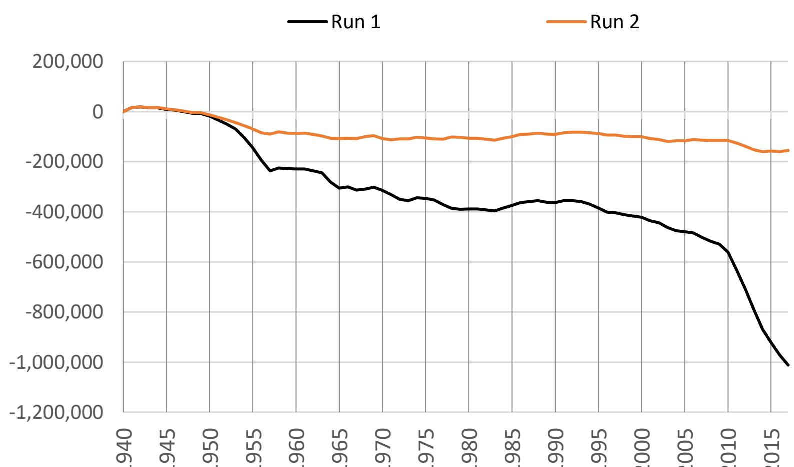
Rincon-Mesilla Alluvial Aquifer



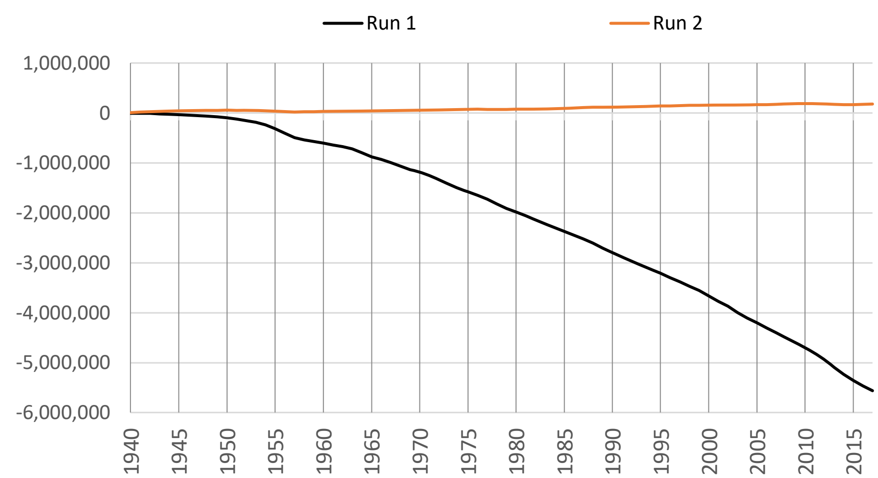
Hueco Alluvial Aquifer



Rincon-Mesilla Non-Alluvial Aquifer

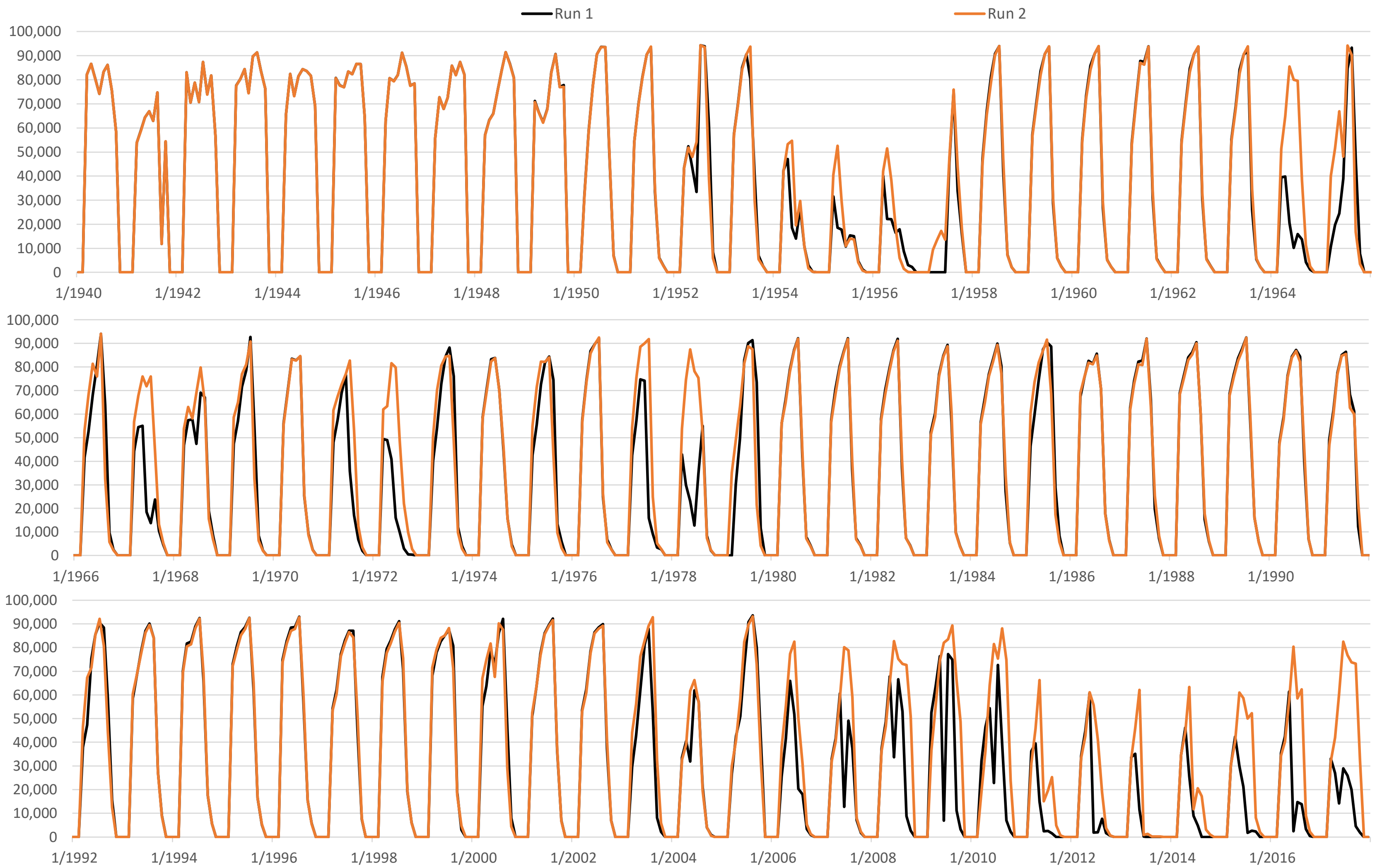


Hueco Non-Alluvial Aquifer



***Note different scales.**

Run 2 - All Pumping Off
Monthly Net RHG Diversions
Run 2 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
EBID Total

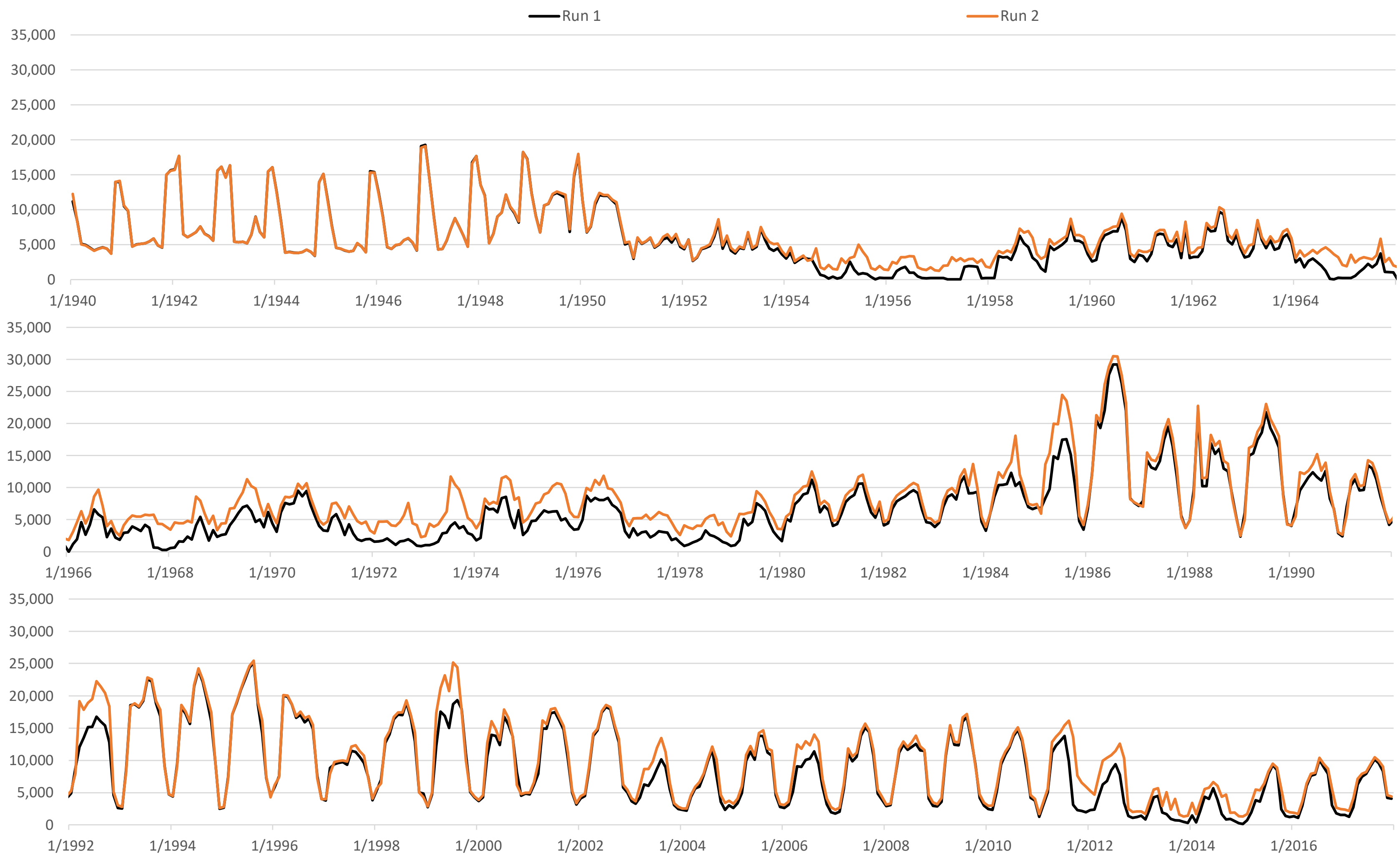


Note: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

Run 2 - All Pumping Off
Monthly Net RHG Diversions
Run 2 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
EPCWID Total

Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

Run 2 - All Pumping Off
Monthly Net RHG Diversions
Run 2 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
HCCRD Total



Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

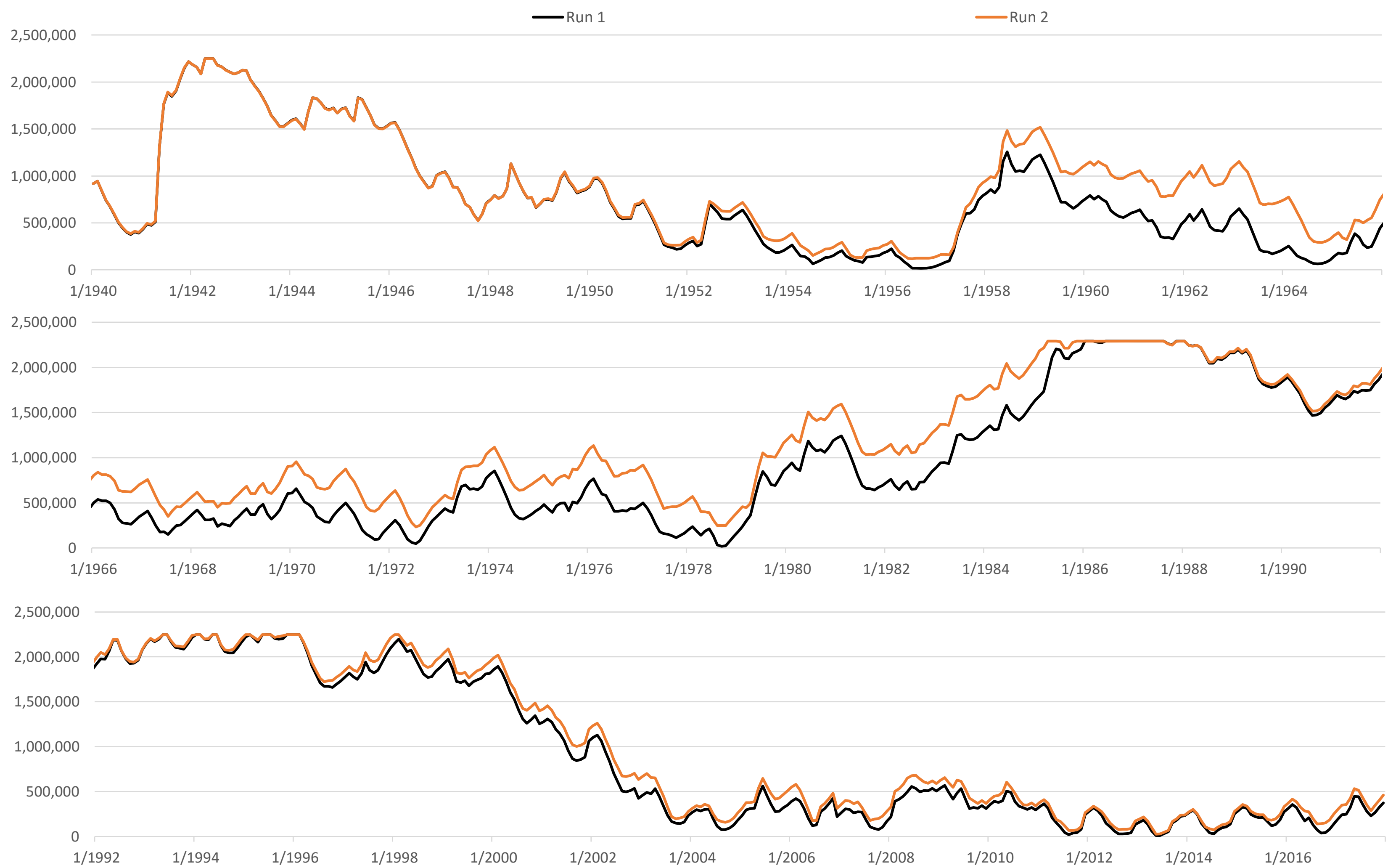
Run 2 - All Pumping Off

End of Month Reservoir Storage (Elephant Butte + Caballo)

Run 2 v. Run 1

ILRG Model

1940 - 2017 (acre-feet)



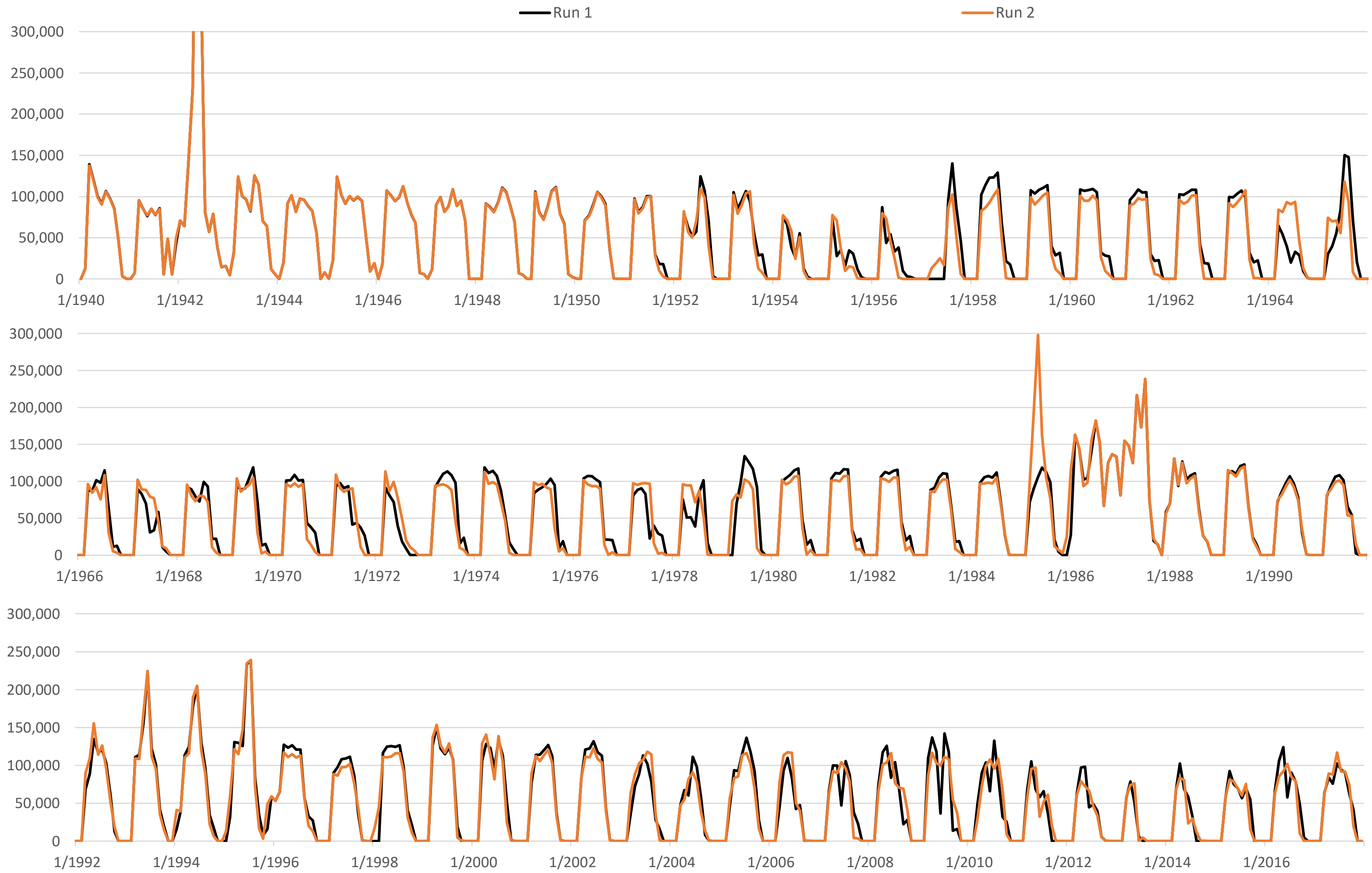
Run 2 - All Pumping Off

Monthly Caballo Releases

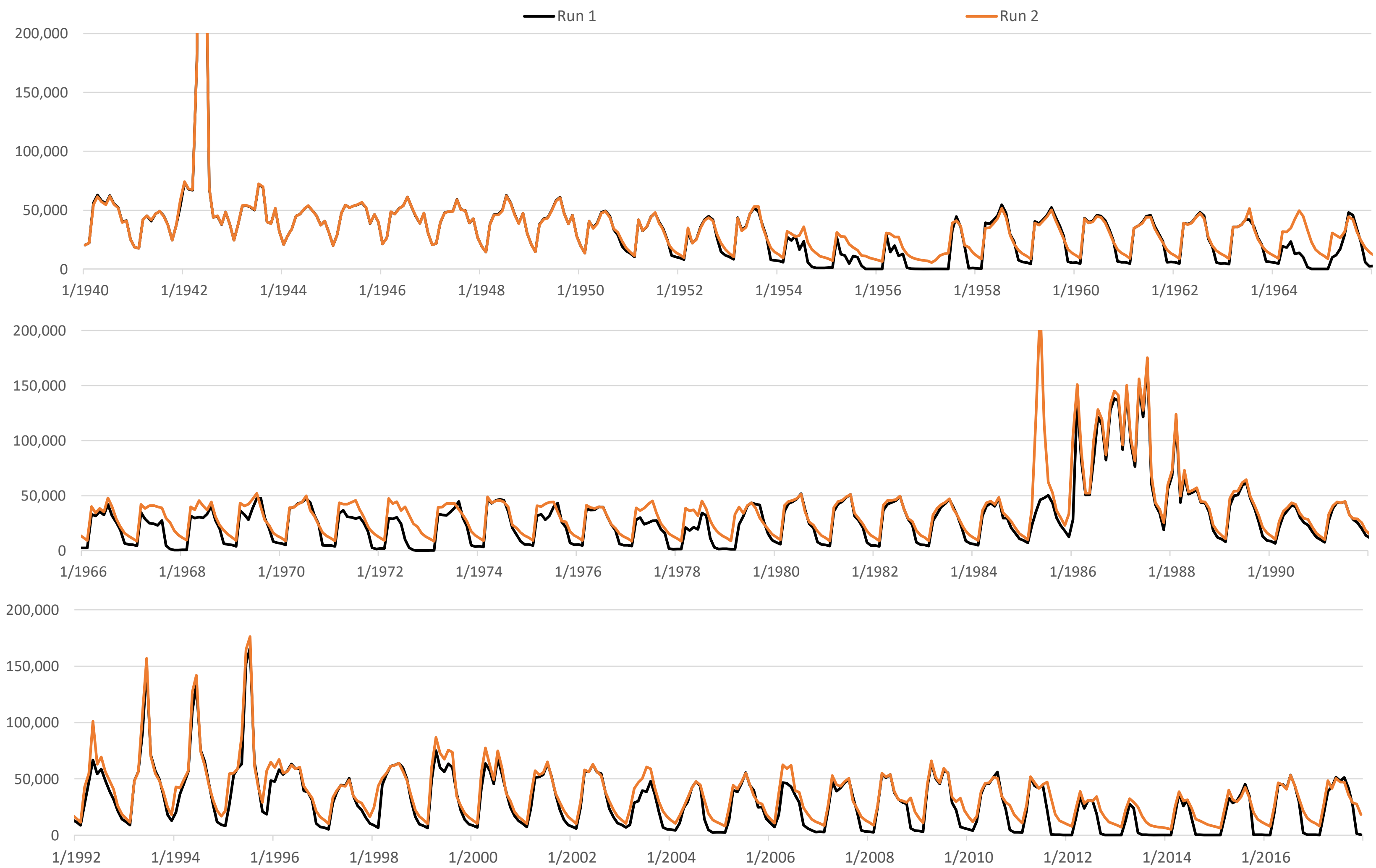
Run 2 v. Run 1

ILRG Model

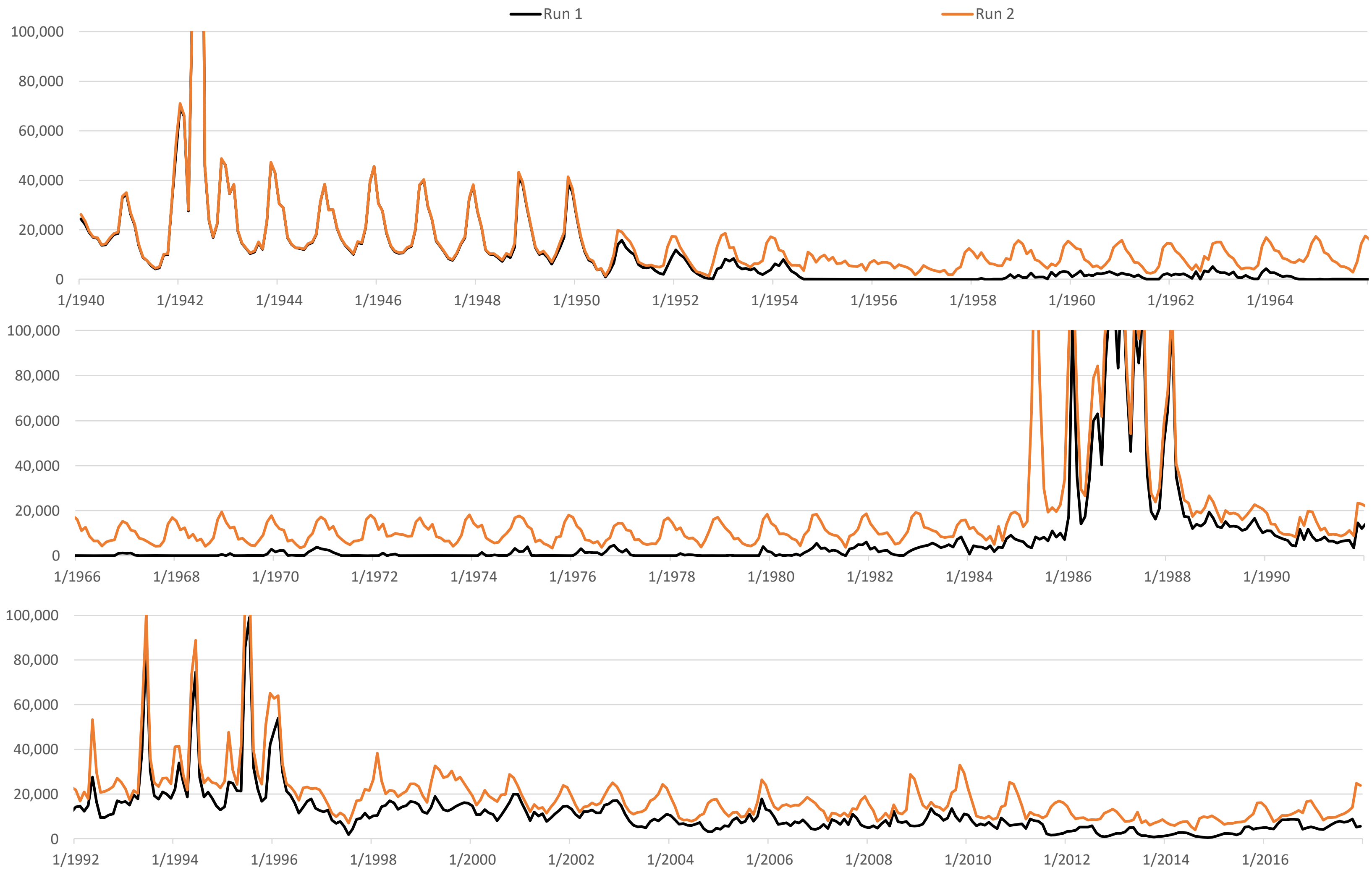
1940 - 2017 (acre-feet)



Run 2 - All Pumping Off
Monthly Rio Grande at El Paso Flow
Run 2 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)



Run 2 - All Pumping Off
Monthly Rio Grande at Fort Quitman Flow
Run 2 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)



Appendix 30C

Comparison of ILRG Model Runs
Run 3 v. Run 1

Model Run Specifications

Model Version: LRG_v116

Name: **Run 3 - NM Pumping Off**

Run ID: LRG_v116_Operational_Run3
Date: 8/24/2020

Name: **Run 1 - Historical Base Run**

Run ID: LRG_v116_Operational_Run1
Date: 8/23/2020

Selected Model Inputs

Pumping and Returns	Run 3	Run 1
Irrigation Pumping	NM Off	On
Irrigated Area	Hist	Hist
Non-Irrigation Pumping	NM Off	On
Non-Irrigation Pumping Returns	NM Off	On
Las Cruces Jornada Pumping Returns	Off	On

Project Allocation Rules		
1950-2005	D1/D2	D1/D2
2006-2007	D3	D3
2008-2017	D3 + CO	D3 + CO

EPCWID Operations		
Charge EPCWID for Use of WWTP Returns	Off	Off
ACE and Haskell Credits for EPCWID	On	On
Increased EPCWID Use of Fabens Drain Flows	Off	Off
Charge EPCWID for Fabens Drain Flow Use	Off	Off

Run 3 - NM Pumping Off
Comparison of ILRG Model Runs
Run 3 v. Run 1
1951 - 2017 Annual Average
(1,000 acre-feet)

Run No.	1	3	3 - 1		
Simulated Input or Output	**Run 1**	**Run 3**	**Run 3 minus Run 1**		
Pumping Stress					
Irrigation Pumping	140.4	0.0	-140.4		
Non-Irrigation Pumping	181.0	153.9	-27.1		
WWTP Flows	58.0	52.3	-5.7		
Urban Deep Percolation	13.1	10.0	-3.0		
Total Stress	250.3	91.5	-158.8		
	Stress is Pumping minus WWTP and Urban Deep Perc				
Effects of Pumping Stress				***% Chg***	
FHG Deliveries (Mar - Oct)				***Stress***	***% Diff.***
EBID	167.6	198.8	31.2	*-20%*	*19%*
EPCWID (incl. EPW)	139.9	151.6	11.7	*-7%*	*8%*
HCCRD	32.8	34.5	1.6	*-1%*	*5%*
Total	340.3	384.9	44.6	*-28%*	*13%*
FHG Deliveries (Nov - Feb)					
EBID	0.0	0.1	0.1	*0%*	*950%*
EPCWID (incl. EPW)	0.2	0.2	0.0	*0%*	*-1%*
HCCRD	2.4	2.3	-0.1	*0%*	*-5%*
Total	2.6	2.5	-0.1	*0%*	*-3%*
Irrigation Pumping					
EBID	140.4	0.0			
EPCWID (Mesilla Valley)	7.4	5.8	-1.5	*1%*	*-21%*
EPCWID (El Paso Valley)	40.1	31.9	-8.2	*5%*	*-20%*
HCCRD	4.2	2.1	-2.1	*1%*	*-51%*
	51.7	39.8	-11.9	*7%*	*-23%*
	Pumping turned off.	*Other values are simulated responses and are totaled.*			
Other Inflows/Outflows					
Net Reservoir Evaporation	125.3	141.2	15.9	*-10%*	*13%*
Riparian ET	70.9	76.8	5.9	*-4%*	*8%*
River Evaporation + Incidental Canal Loss	30.3	32.1	1.8	*-1%*	*6%*
Total	226.6	250.2	23.6	*-15%*	*10%*
Rio Grande at Fort Quitman					
Reservoir Spills	33.3	47.0	13.7	*-9%*	*41%*
Nov-Feb Flows	21.4	41.3	19.9	*-13%*	*93%*
Mar - Oct Flows	41.1	56.4	15.4	*-10%*	*37%*
Underflow (GW Model)	0.2	0.3	0.1	*0%*	*24%*
Total	96.0	145.0	49.0	*-31%*	*51%*

Run 3 - NM Pumping Off
Comparison of ILRG Model Runs
Run 3 v. Run 1
1951 - 2017 Annual Average
(1,000 acre-feet)

Run No.	1	3	3 - 1		
Simulated Input or Output	Run 1	Run 3	Run 3 minus Run 1		
Effects of Pumping Stress (continued)				*% Chg*	
Change in Storage				*Stress*	*% Diff.*
Reservoir Storage	-4.7	-3.5	1.2	*-1%*	*-25%*
Alluvial GW Storage (RW Model)	-23.6	-17.4	6.2	*-4%*	*-26%*
Non-alluvial GW Storage (GW Models)	-96.4	-82.8	13.5	*-9%*	*-14%*
Soil Moisture Storage	0.6	0.7	0.1	*0%*	*24%*
Total	-124.0	-103.0	21.0	*-13%*	*-17%*
Summary of Effects					
FHG Deliveries (Mar-Oct)	340.3	384.9	44.6	*-28%*	*13%*
FHG Deliveries (Nov-Feb)	2.6	2.5	-0.1	*0%*	*-3%*
Irrigation Pumping	51.7	39.8	-11.9	*7%*	*-23%*
Riparian ET + Evaporation	226.6	250.2	23.6	*-15%*	*10%*
Fort Quitman Flow	96.0	145.0	49.0	*-31%*	*51%*
Change in Storage	-124.0	-103.0	21.0	*-13%*	*-17%*
Total	593.1	719.4	126.3	*-80%*	*21%*
Other Effects of Pumping Stress				*% Chg*	
Rio Grande at El Paso				*Stress*	*% Diff.*
Reservoir Spills	49.4	64.6	15.2	*-10%*	*31%*
Nov-Feb Flows	22.8	45.7	23.0	*-14%*	*101%*
Mar - Oct Flows	263.8	286.7	22.9	*-14%*	*9%*
Total	336.0	397.1	61.1	*-38%*	*18%*
Rio Grande below Caballo					
Reservoir Spills	65.9	82.7	16.9	*-11%*	*26%*
Nov-Feb Flows	0.5	0.2	-0.3	*0%*	*-57%*
Mar - Oct Flows	541.3	508.1	-33.2	*21%*	*-6%*
Total	607.6	591.0	-16.6	*10%*	*-3%*
Surface Water Diversions (Mar - Oct)					
EBID	366.5	412.8	46.3	*-29%*	*13%*
EPCWID (incl. EPW)	236.8	255.3	18.5	*-12%*	*8%*
HCCRD	67.5	74.1	6.5	*-4%*	*10%*
Total	670.8	742.1	71.3	*-45%*	*11%*
Surface Water Diversions (Nov - Feb)					
EBID	0.0	0.0	0.0	*0%*	*0%*
EPCWID (incl. EPW)	14.3	17.4	3.0	*-2%*	*21%*
HCCRD	14.2	16.8	2.6	*-2%*	*18%*
Total	28.5	34.2	5.6	*-4%*	*20%*

Run 3 - NM Pumping Off
Annual Differences in ILRG Model Outputs
Run 3 minus Run 1
1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1940	-96	-96	5	3	1	1	17	49	3	2	1	1	-127	-29	-53
1941	-306	-306	-2	-4	-1	-2	-47	-10	-1	0	-1	-4	105	276	169
1942	-193	-193	-1	-5	1	4	14	52	2	8	1	0	-268	153	129
1943	-235	-235	0	-5	3	5	25	65	-8	-9	2	-1	-270	120	36
1944	-272	-272	-153	-138	-107	-85	5	46	9	-10	-97	-98	-418	-73	17
1945	-269	-269	-3	39	-104	-32	23	60	-5	-32	-102	30	-367	89	41
1946	-212	-212	20	53	12	40	41	82	17	18	-5	-66	-316	169	183
1947	-252	-252	-8	61	-34	19	24	68	-5	-15	-38	-38	-386	143	171
1948	-1,032	-1,032	80	103	2	19	484	532	85	77	3	3	-891	17	31
1949	-2,151	-2,151	-89	-86	-19	-8	164	217	-48	-52	0	0	-2,873	-107	-91
1950	63	63	146	212	5	89	2,057	2,112	94	111	0	-1	-1,052	8,896	6,073
1951	984	984	218	245	93	192	3,071	3,127	180	203	69	115	-23,154	11,765	10,030
1952	464	464	500	539	165	264	6,543	6,600	375	411	170	255	-38,896	21,167	15,711
1953	230	230	-315	-276	278	380	6,725	6,780	-222	-181	83	-135	-41,209	25,263	19,770
1954	27,222	27,222	20,902	27,845	1,754	3,303	22,016	22,053	16,881	16,933	2,042	3,333	-9,023	80,958	23,834
1955	50,004	50,004	38,972	51,943	7,071	9,585	31,143	31,168	28,094	27,930	6,474	8,628	805	104,717	17,517
1956	20,506	20,506	21,680	36,034	5,143	5,636	20,194	20,216	18,706	17,961	5,400	5,305	-49,829	85,890	9,140
1957	65,790	65,790	37,242	49,284	4,239	6,640	22,227	22,264	8,752	8,392	2,481	3,693	-35,030	87,893	8,097
1958	-540	-540	-14,306	-5,889	6,079	11,895	10,303	10,346	-1,296	-1,322	-1,397	859	-153,702	17,395	30,809
1959	-239	-239	-3,317	-502	2,905	6,066	6,117	6,166	261	318	403	682	-74,571	20,578	32,468
1960	-207	-207	-1,677	768	1,466	3,085	6,151	6,201	219	277	0	0	-72,303	21,215	30,000
1961	-211	-211	-1,175	978	1,797	3,418	5,600	5,649	1,722	1,777	1,098	-817	-62,295	20,960	33,969
1962	-163	-163	-419	1,627	1,383	2,651	5,621	5,670	518	572	213	81	-67,197	21,798	31,310
1963	8,731	8,731	-797	1,768	1,179	2,792	10,909	10,958	276	331	461	478	-52,618	31,524	29,514
1964	244,624	244,624	147,016	154,459	14,276	18,915	130,791	130,838	94,769	94,480	12,381	14,864	244,864	213,207	58,632
1965	84,431	84,431	22,016	29,434	8,880	15,292	61,208	61,267	26,208	25,872	9,304	13,121	-79,686	82,850	62,843
1966	830	830	30,383	34,337	14,218	18,424	-3,212	-3,163	16,726	16,796	-3,642	-5,539	-62,202	66,650	66,393
1967	156,007	156,007	106,422	113,405	15,880	23,907	85,106	85,152	69,471	69,043	10,090	11,522	117,433	156,512	52,632
1968	37,794	37,794	-6,061	559	10,249	18,542	39,685	39,742	1,376	1,057	9,160	7,979	-89,278	47,784	48,304
1969	1,383	1,383	36,190	38,918	18,861	23,219	-3,554	-3,501	20,308	20,364	3,024	-1,398	-55,149	65,290	57,437
1970	-459	-459	-3,230	-1,795	3,269	5,594	7,066	7,118	-666	-618	-1,274	-2,725	-89,289	19,994	34,270
1971	119,074	119,074	42,198	46,146	11,645	15,288	65,995	66,049	21,958	22,032	8,859	10,869	17,297	99,727	38,480
1972	126,680	126,680	81,097	91,811	8,090	14,773	69,289	69,331	55,286	55,205	7,506	7,072	76,423	139,434	40,277
1973	-1,366	-1,366	-6,402	1,194	12,696	18,411	11,357	11,407	1,364	1,194	14,006	14,423	-137,569	27,897	30,985
1974	-762	-762	-506	2,417	7,524	12,499	11,821	11,876	1,616	1,678	-754	-1,878	-79,620	32,131	39,185
1975	947	947	34,627	36,263	18,953	23,752	-3,882	-3,835	18,523	18,578	8,209	3,692	-53,214	64,767	43,868
1976	-245	-245	-627	1,195	5,246	10,623	6,726	6,757	461	494	-1,658	-5,752	-74,903	20,948	33,379
1977	154,691	154,691	40,116	45,490	13,096	18,707	87,670	87,721	19,996	20,065	11,515	11,912	56,467	97,052	30,458
1978	187,071	187,071	25,593	33,315	3,934	11,483	123,344	123,393	22,464	22,554	5,317	6,255	40,744	93,976	36,844

Run 3 - NM Pumping Off
Annual Differences in ILRG Model Outputs
Run 3 minus Run 1
1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1979	2,325	2,325	22,848	27,297	8,484	14,190	9,253	9,305	17,922	17,986	2,729	311	-99,403	38,741	42,062
1980	-518	-518	-124	448	3,524	6,039	7,108	7,166	768	844	-3,189	-6,812	-65,715	19,381	47,745
1981	-447	-447	-82	2,176	2,029	3,952	7,440	7,485	645	704	-56	-242	-68,802	24,057	36,777
1982	-431	-431	-24	2,446	1,634	3,289	6,943	6,998	613	795	-375	-1,153	-75,243	24,800	44,604
1983	-337	-337	26	2,124	1,721	3,179	6,384	6,439	465	608	0	0	-64,570	21,884	35,745
1984	-531	-531	170	1,759	4,988	6,209	6,071	6,116	503	615	0	0	-37,267	21,321	28,654
1985	2,185	2,185	64,010	64,067	34,844	36,264	-6,670	-6,613	28,516	28,602	0	0	335,686	371,925	333,193
1986	-35	-35	-7,601	-7,600	1,089	2,593	5,995	6,068	-4,139	-4,102	0	0	87,161	133,112	262,461
1987	-762	-762	-15	-7	981	1,587	3,573	3,640	446	471	0	0	-11	37,803	62,024
1988	-405	-405	-30	-19	834	1,329	4,215	4,281	312	336	0	0	-20,029	19,834	27,113
1989	-154	-154	185	209	714	1,049	5,156	5,210	377	408	0	0	-34,986	14,188	17,830
1990	-212	-212	221	318	2,187	2,436	5,221	5,279	241	299	0	0	-24,168	18,131	19,583
1991	-1,613	-1,613	6	50	673	919	2,849	2,914	210	336	0	0	-25,721	9,902	21,469
1992	1,917	1,917	75,564	75,272	35,308	36,697	-6,929	-6,868	34,244	33,917	0	0	84,039	128,281	116,616
1993	157	157	-5,497	-5,533	-431	436	5,975	6,045	-2,678	-2,656	0	0	-15,695	26,977	40,058
1994	-223	-223	263	261	720	1,200	7,373	7,457	650	688	0	0	-14,434	54,486	55,234
1995	-328	-328	2,440	2,426	2,609	3,246	9,431	9,508	253	253	0	0	30,526	116,123	111,567
1996	-383	-383	443	479	728	1,320	9,866	9,951	624	682	0	0	-65,529	34,405	37,924
1997	-248	-248	-220	-383	818	1,264	6,573	6,634	103	-323	0	0	-35,739	24,246	23,788
1998	-353	-353	987	973	1,269	1,180	7,316	7,394	949	987	0	0	-18,411	44,048	47,460
1999	-122	-122	860	1,376	354	721	6,099	6,159	2,559	2,622	0	0	-27,342	28,082	28,222
2000	1,113	1,113	17,527	18,359	1,484	1,874	-2,866	-2,815	-2,095	-2,073	0	0	-33,557	30,945	34,218
2001	84	84	-665	-141	271	677	5,876	5,921	-182	-151	0	0	-33,968	19,011	19,539
2002	-248	-248	-232	818	490	1,075	6,757	6,798	243	279	0	0	-39,528	21,310	23,237
2003	121,481	121,481	47,140	48,153	13,026	14,159	71,509	71,574	21,247	21,309	0	0	92,835	104,794	62,568
2004	44,059	44,059	30,381	33,203	5,633	8,609	34,492	34,545	21,073	21,141	0	0	-27,876	63,431	40,608
2005	1,813	1,813	2,978	4,653	2,752	4,523	12,929	12,989	4,748	4,797	0	0	-77,608	21,106	32,475
2006	101,910	101,910	79,855	81,341	18,711	20,944	61,314	61,362	41,386	41,435	0	0	88,286	114,933	60,006
2007	106,680	106,680	6,212	8,450	2,463	4,583	74,196	74,244	7,263	7,335	0	0	-29,243	42,726	34,803
2008	186,956	186,956	2,838	4,983	2,222	3,749	127,019	127,135	3,726	3,872	0	0	34,982	54,062	53,783
2009	137,148	137,148	-1,548	917	857	2,603	94,648	94,743	-240	-130	0	0	1,113	54,879	58,304
2010	195,927	195,927	41,983	44,567	14,497	16,304	123,268	123,341	15,088	15,188	0	0	58,169	90,781	74,853
2011	86,109	86,109	49,649	53,427	17,696	25,020	44,335	44,373	34,204	34,292	0	0	-8,438	92,132	68,637
2012	88,948	88,948	40,370	43,986	18,139	25,464	45,362	45,392	29,152	29,236	0	0	-47,630	73,998	64,543
2013	63,296	63,296	46,089	49,210	13,038	16,253	33,291	33,321	28,292	28,363	5,864	6,279	22,632	90,050	53,761
2014	72,740	72,740	24,091	26,936	9,808	13,525	35,159	35,179	16,860	16,927	-189	-374	-31,236	62,525	45,328
2015	161,950	161,950	17,881	20,999	5,148	7,920	88,536	88,566	11,676	11,765	-4,340	-3,741	-38,008	45,959	50,621
2016	148,083	148,083	27,399	31,046	5,074	7,692	88,530	88,559	20,827	20,932	0	0	-55,273	66,691	47,677
2017	300,626	300,626	4,420	8,119	1,919	4,002	191,038	191,109	5,731	5,864	0	0	14,038	53,531	52,465
Averages															
1951-2017	46,290	46,290	18,465	21,473	6,547	9,155	31,204	31,257	11,745	11,744	1,642	1,510	-16,607	61,104	49,011
1951-1978	45,831	45,831	23,084	28,268	7,156	10,905	30,215	30,262	15,869	15,800	3,912	3,818	-30,239	63,548	34,506
1979-2005	6,214	6,214	9,317	10,118	4,768	5,926	8,812	8,873	4,764	4,792	-33	-292	-10,198	54,531	61,214
2006-2017	137,531	137,531	28,270	31,165	9,131	12,338	83,891	83,944	17,830	17,923	111	180	783	70,189	55,398
1985-2017	55,094	55,094	17,212	18,513	6,543	8,219	36,407	36,466	9,747	9,785	40	66	4,395	65,588	63,090
1985-2005	7,987	7,987	10,893	11,283	5,064	5,865	9,273	9,337	5,129	5,134	0	0	6,459	62,959	67,485

Notes:

EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

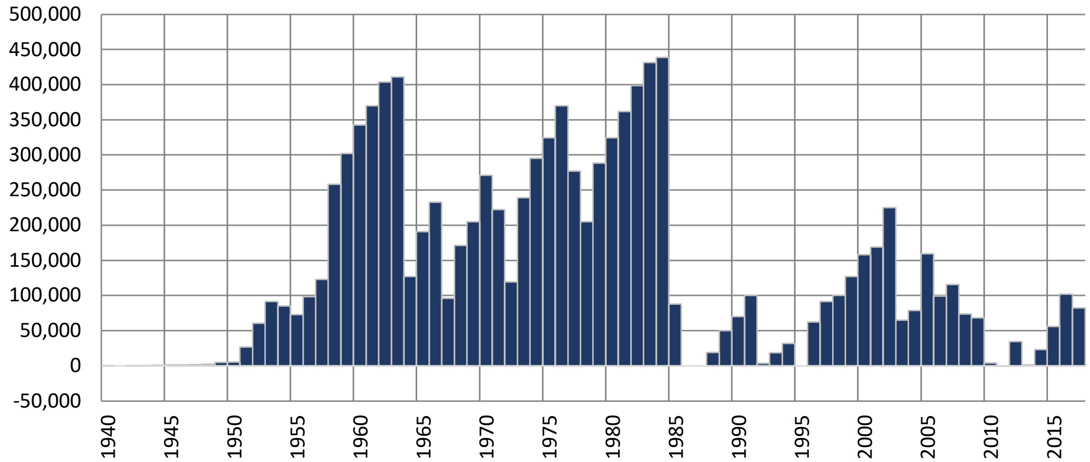
Run 3 - NM Pumping Off

Simulated Differences in ILRG Model Outputs

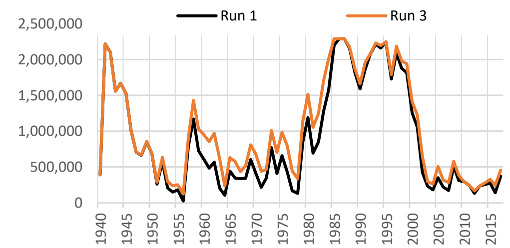
Run 3 minus Run 1

1940 - 2017 (acre-feet)

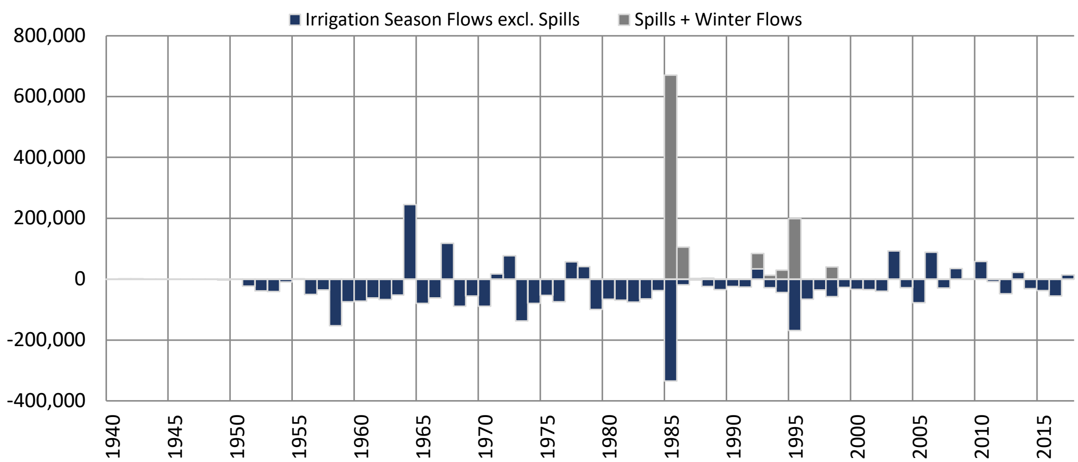
Total Project Storage (Year End)



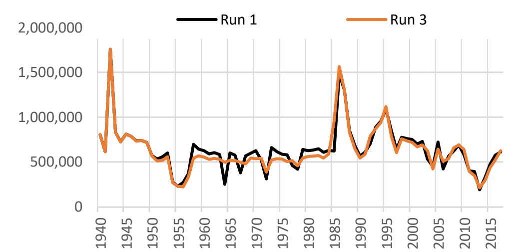
Period	Average Difference
1951-2017	1,151
1951-1978	7,128
1979-2005	-1,695
2006-2017	-6,390
1985-2017	-10,790
1985-2005	-13,305



Caballo Reservoir Outflows (Annual)



Period	Average Difference Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	-33,225	16,618	-16,607
1951-1978	-30,239	0	-30,239
1979-2005	-51,435	41,237	-10,198
2006-2017	783	0	783
1985-2017	-29,344	33,740	4,395
1985-2005	-46,560	53,019	6,459



Notes:

Reservoir storage does not include storage attributed to SJC, CO, or NM credit waters.

Average differences calculated as (Final Storage - Initial Storage)/(no. years).

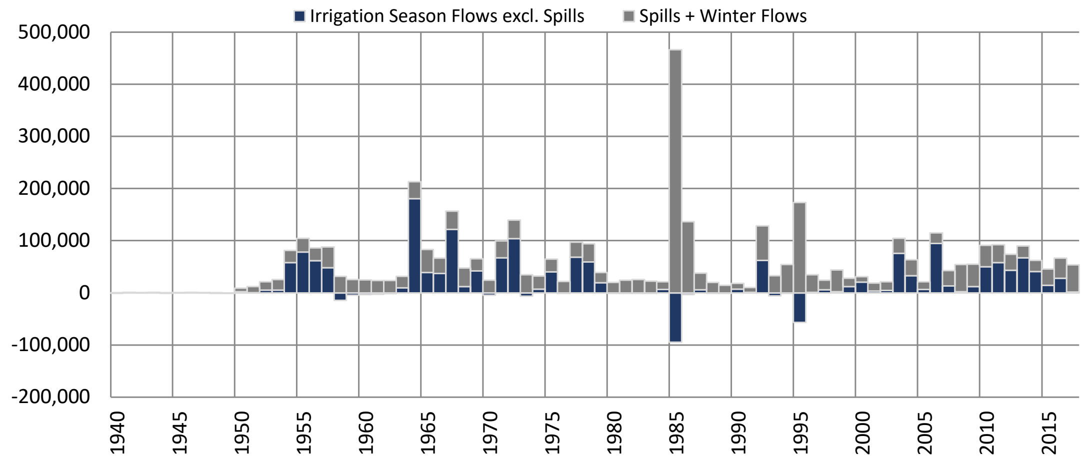
Run 3 - NM Pumping Off

Simulated Differences in ILRG Model Outputs

Run 3 minus Run 1

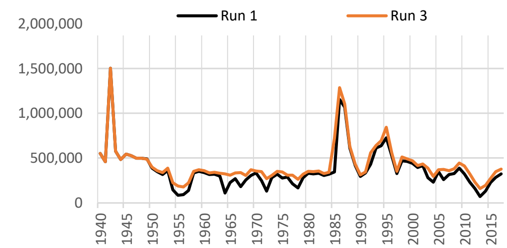
1940 - 2017 (acre-feet)

Rio Grande at El Paso (Annual)

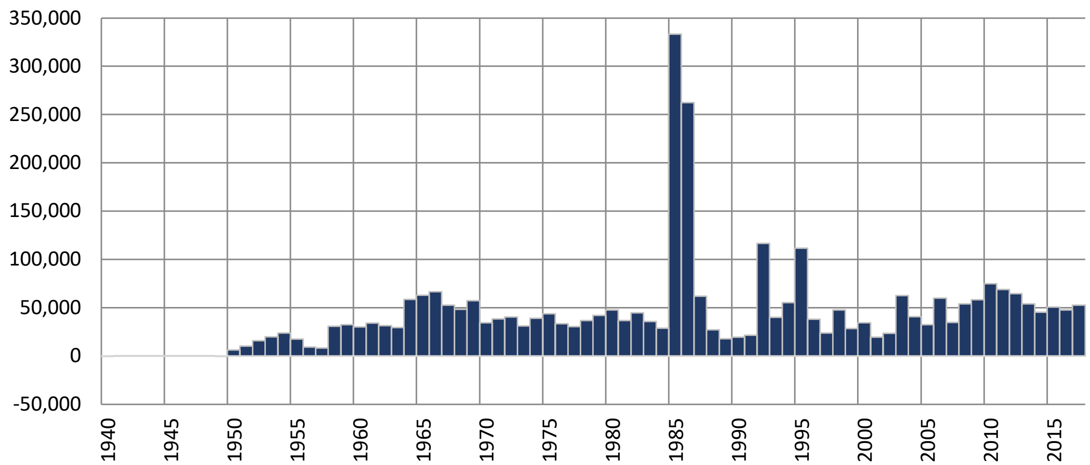


Average Difference

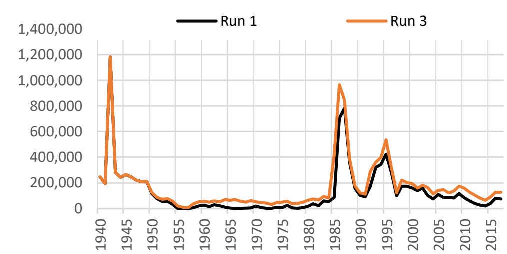
Period	Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	22,907	38,197	61,104
1951-1978	35,942	27,606	63,548
1979-2005	3,827	50,704	54,531
2006-2017	35,419	34,770	70,189
1985-2017	15,288	50,300	65,588
1985-2005	3,785	59,174	62,959



Rio Grande at Fort Quitman (Annual)



Period	Average Difference
1951-2017	48,960
1951-1978	34,432
1979-2005	61,170
2006-2017	55,385
1985-2017	63,066
1985-2005	67,456



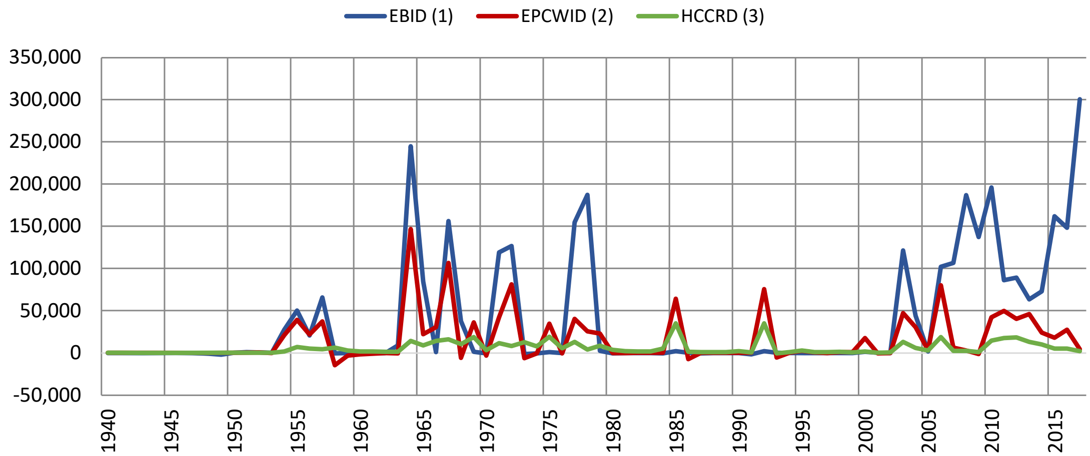
Run 3 - NM Pumping Off

Simulated Differences in ILRG Model Outputs

Run 3 minus Run 1

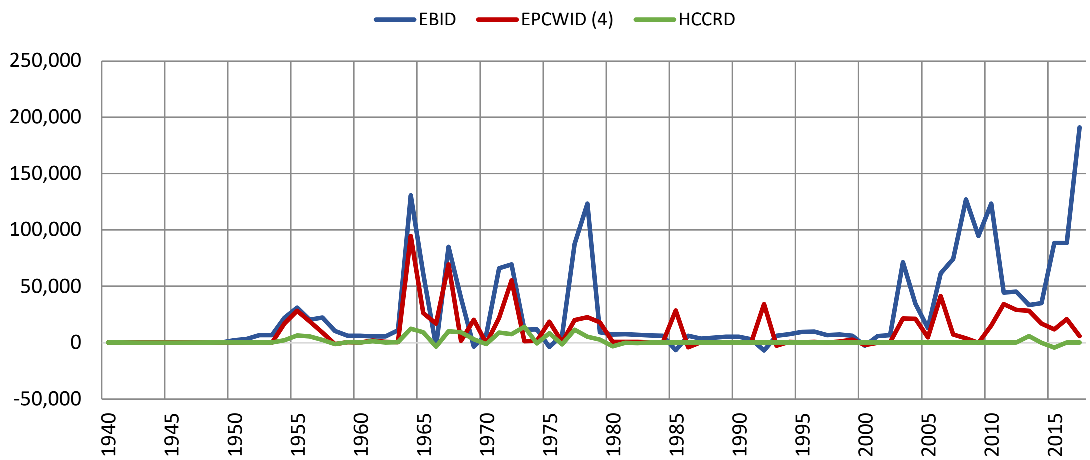
1940 - 2017 (acre-feet)

River Headgate (RHG) Diversions (Irrigation Season)



Period	Average Difference EBID	EPCWID	HCCRD
1951-2017	46,290	18,465	6,547
1951-1978	45,831	23,084	7,156
1979-2005	6,214	9,317	4,768
2006-2017	137,531	28,270	9,131
1985-2017	55,094	17,212	6,543
1985-2005	7,987	10,893	5,064

Farm Headgate (FHG) Deliveries (Irrigation Season)



Period	Average Difference EBID	EPCWID	HCCRD
1951-2017	31,204	11,745	1,642
1951-1978	30,215	15,869	3,912
1979-2005	8,812	4,764	-33
2006-2017	83,891	17,830	111
1985-2017	36,407	9,747	40
1985-2005	9,273	5,129	0

Notes:

(1) EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

(2) EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

(3) HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

(4) EPCWID FHG values include deliveries to Rogers WTP and R/U WTP.

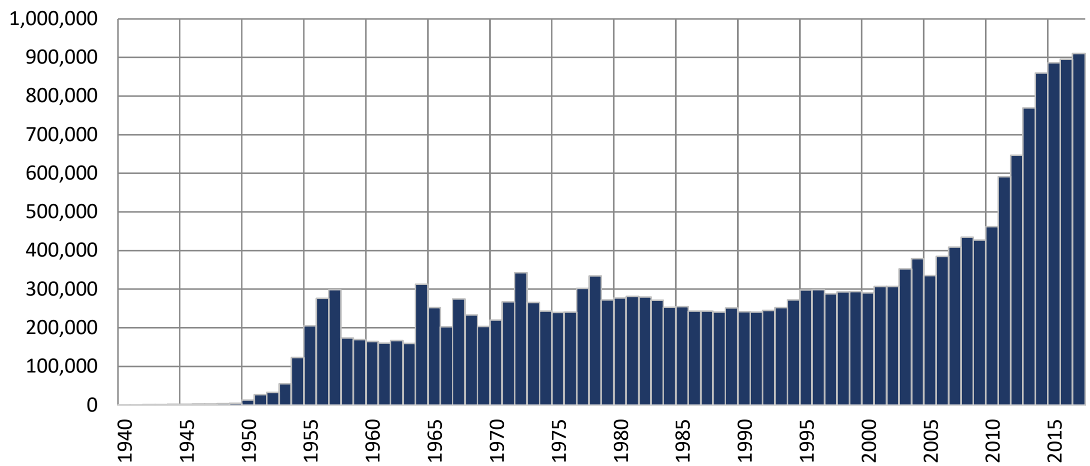
Run 3 - NM Pumping Off

Simulated Differences in ILRG Model Outputs

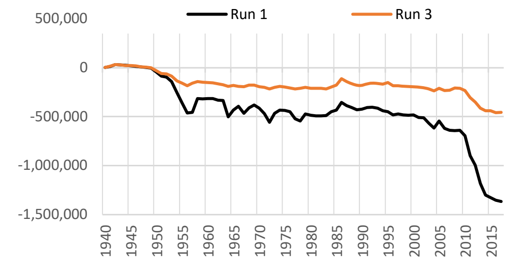
Run 3 minus Run 1

1940 - 2017 (acre-feet)

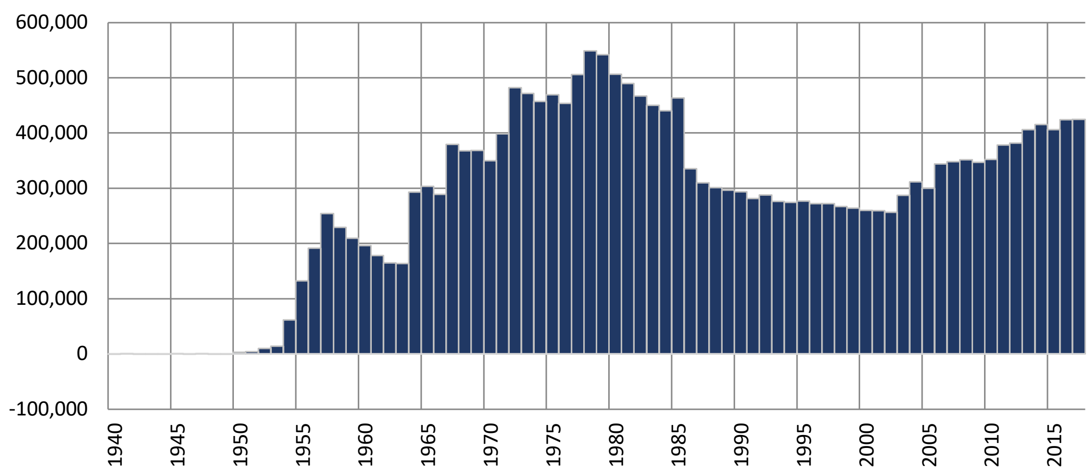
Cumulative Annual Rincon-Mesilla Groundwater Storage



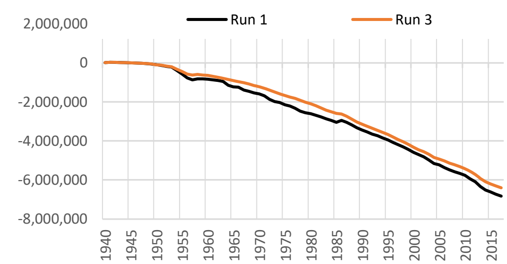
Period	Average Difference
1951-2017	13,394
1951-1978	11,472
1979-2005	36
2006-2017	47,933
1985-2017	19,917
1985-2005	3,908



Cumulative Annual Hueco Groundwater Storage



Period	Average Difference
1951-2017	6,296
1951-1978	19,498
1979-2005	-9,221
2006-2017	10,401
1985-2017	-473
1985-2005	-6,687



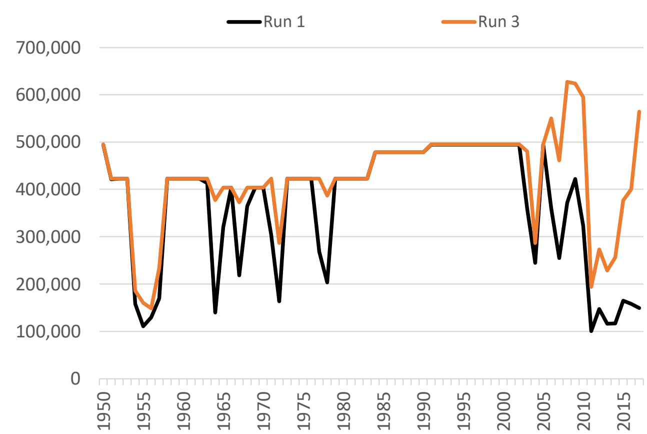
Notes:

Cumulative storage change in alluvial and non-alluvial aquifers.

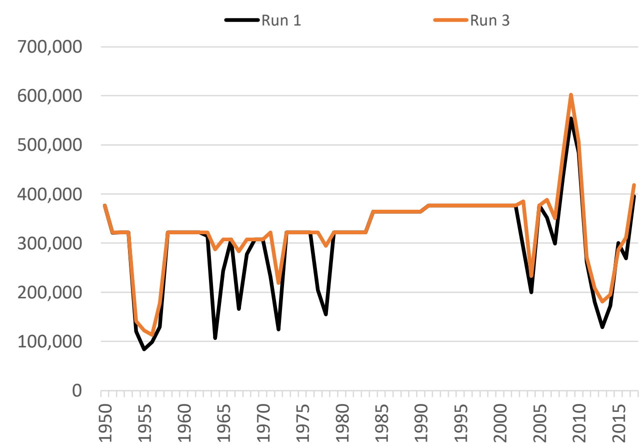
Average differences calculated as (Final Storage - Initial Storage)/(no. years).

Run 3 - NM Pumping Off
Annual Allocation and Charges
Run 3 v. Run 1
ILRG Model
1950 - 2017 (acre-feet)

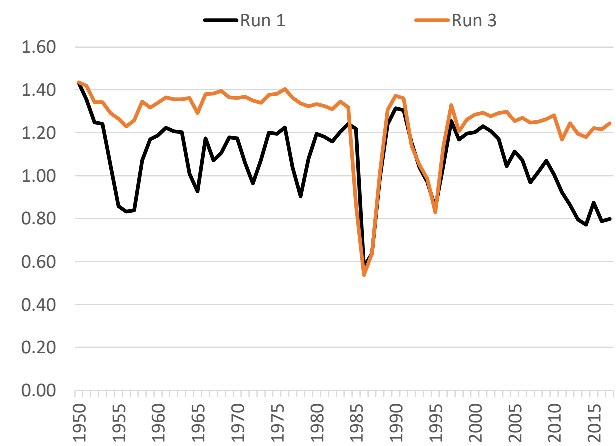
Total Allocation - EBID



Total Allocation - EPCWID

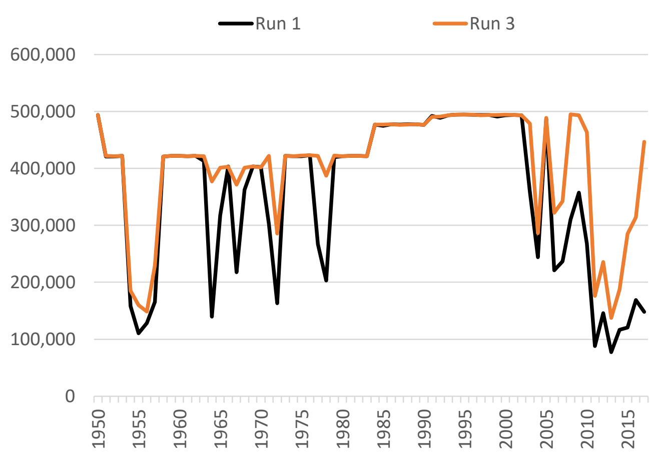


Diversion Ratio

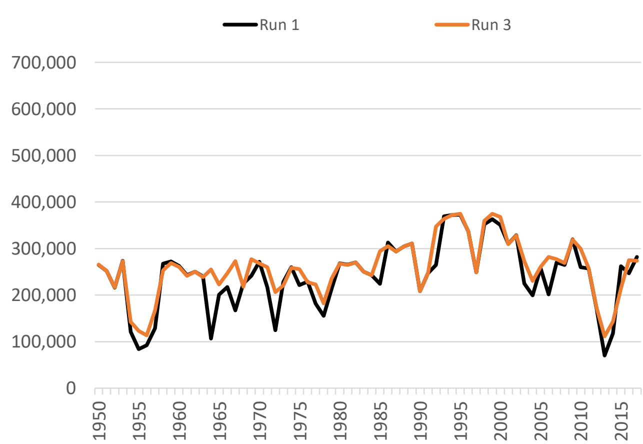


Note:
Computed as Total Charges/Caballo Release.

Annual Delivery Charges - EBID

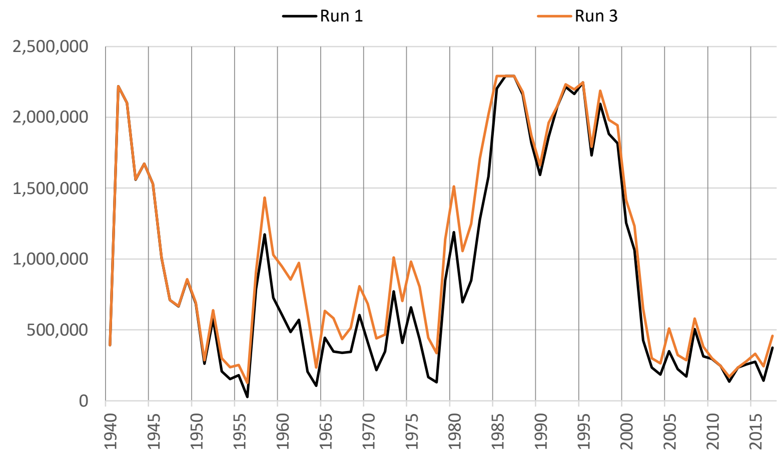


Annual Delivery Charges - EPCWID

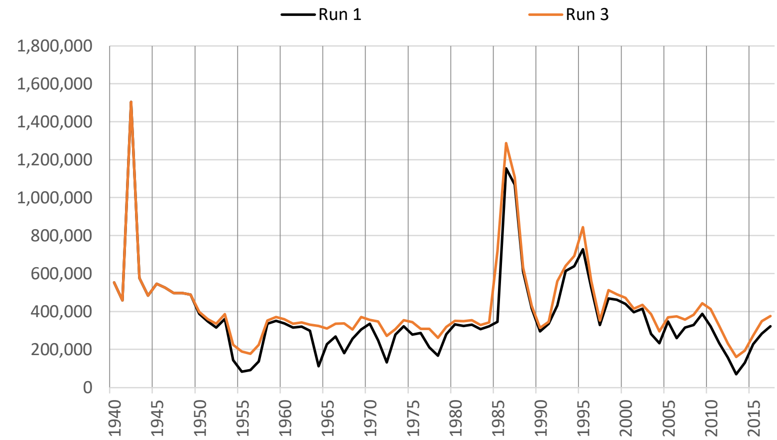


Run 3 - NM Pumping Off
Annual Summary of Project Storage and Rio Grande Flows
Run 3 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

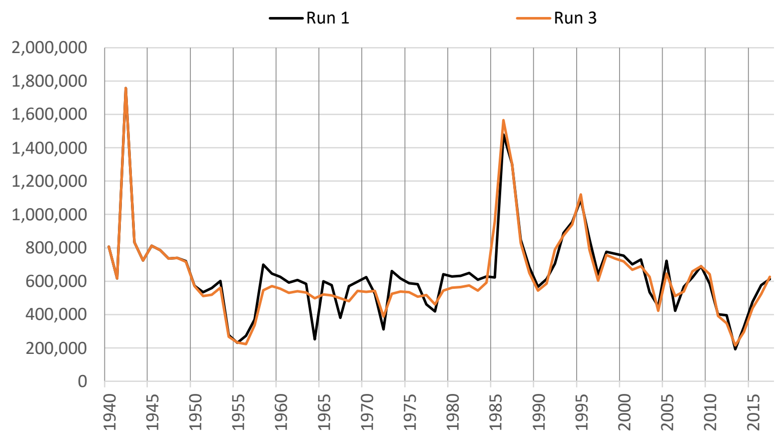
Total Year-End Project Reservoir Storage



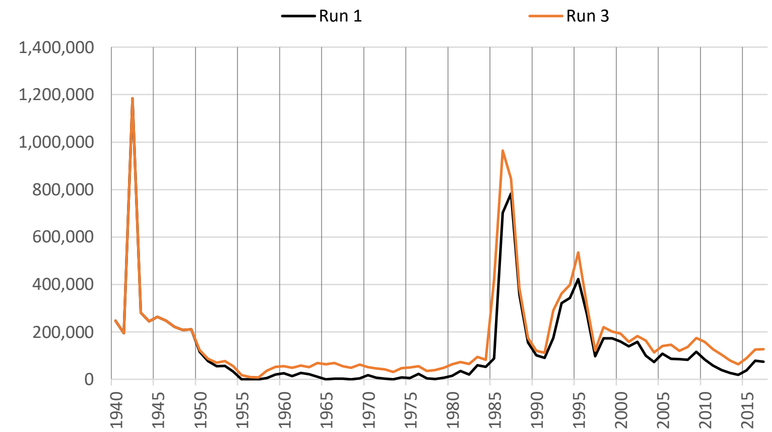
Rio Grande at El Paso



Rio Grande Below Caballo



Rio Grande at Fort Quitman

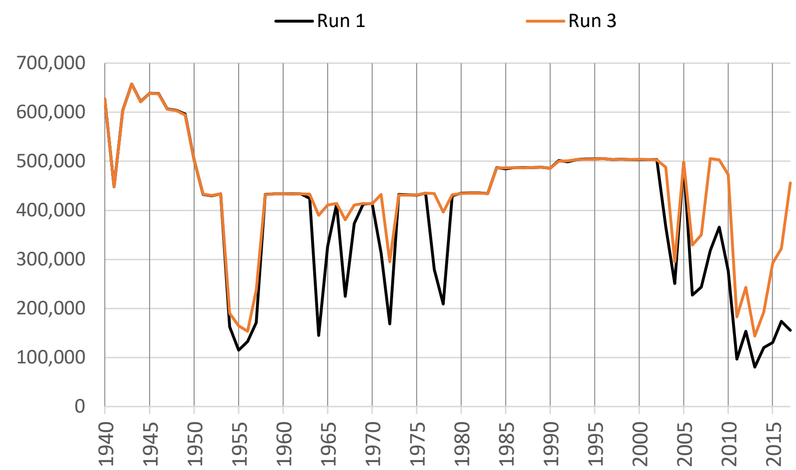


***Note different scales.**

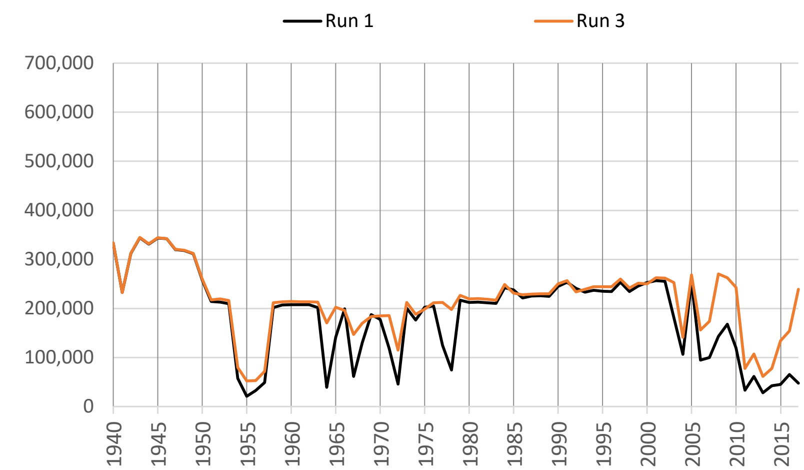
Run 3 - NM Pumping Off
Irrigation Season Summary of Irrigation Operations
Run 3 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

EBID Total

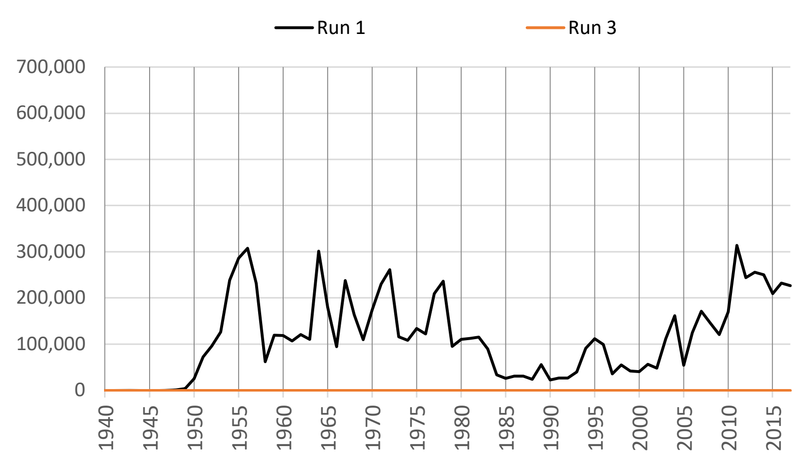
Net River Headgate Diversions



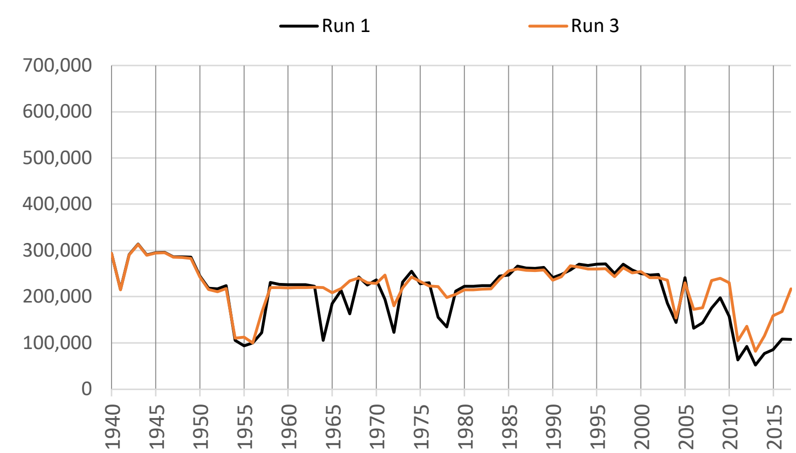
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries

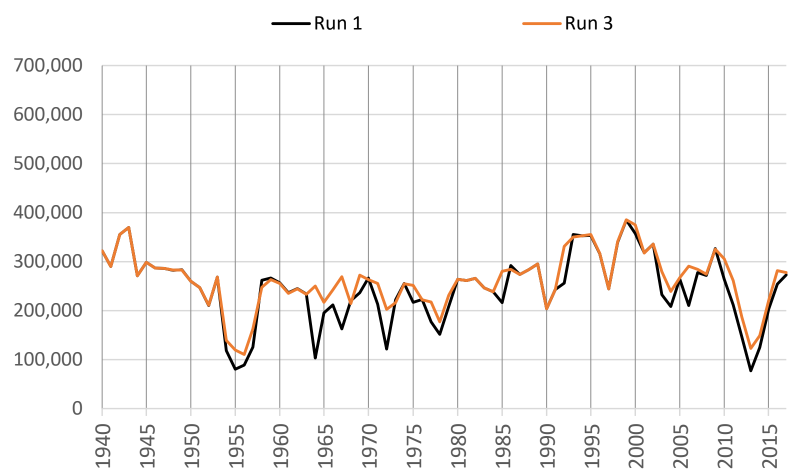


Notes: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).
Pumping includes Supplemental and Primary groundwater pumping.

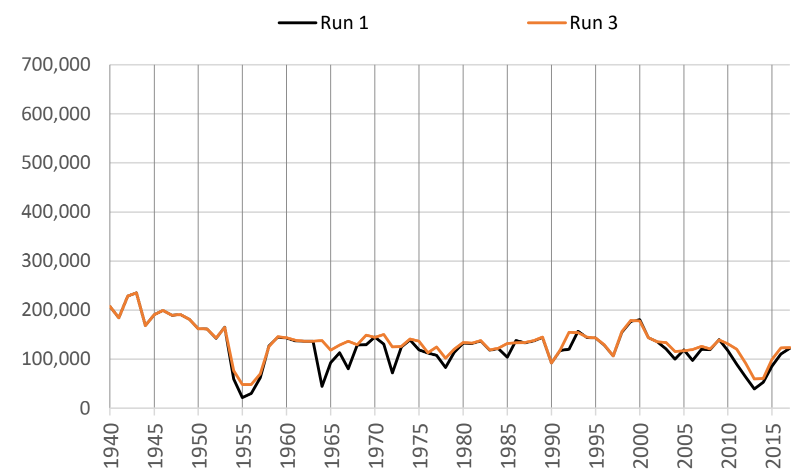
Run 3 - NM Pumping Off
Irrigation Season Summary of Irrigation Operations
Run 3 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

EPCWID Total

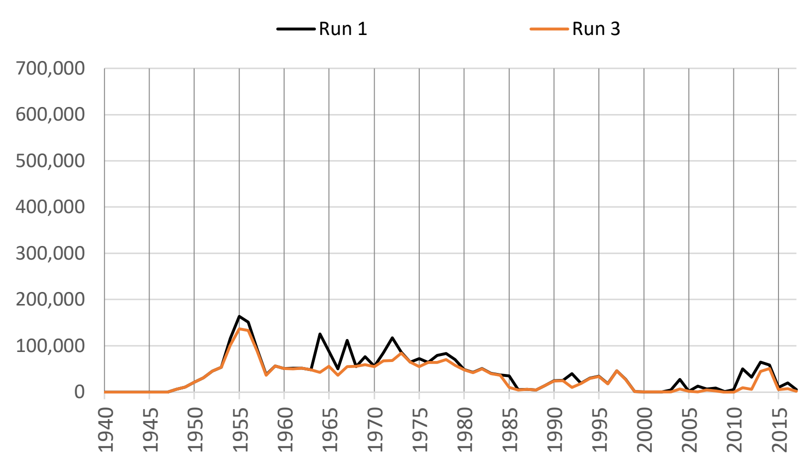
Net River Headgate Diversions



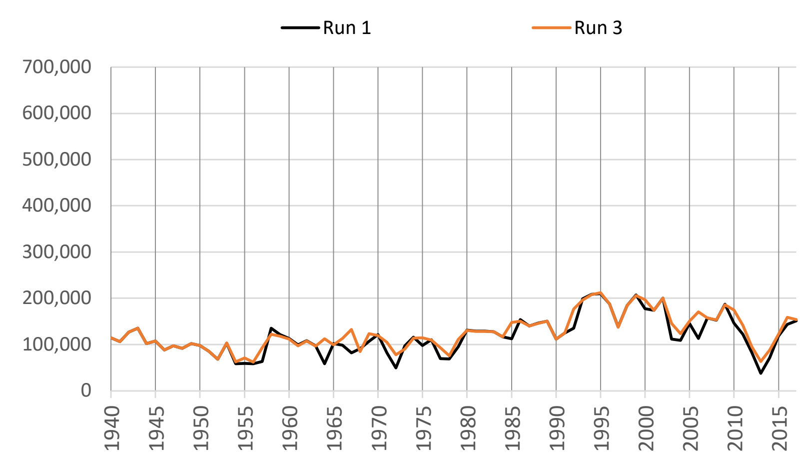
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries

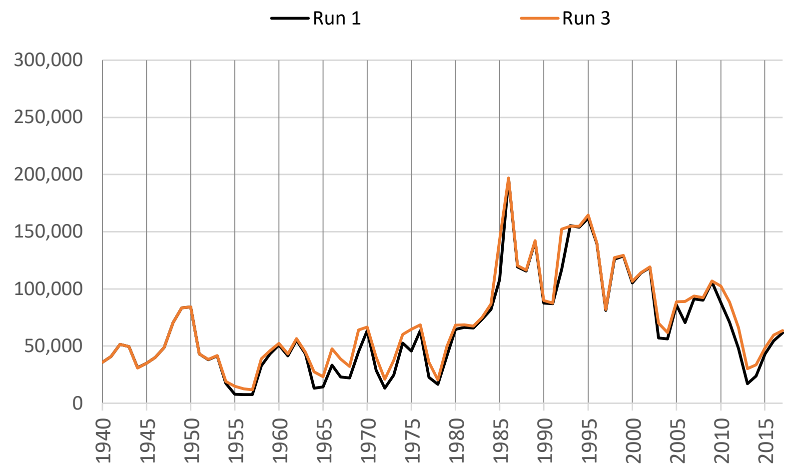


Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

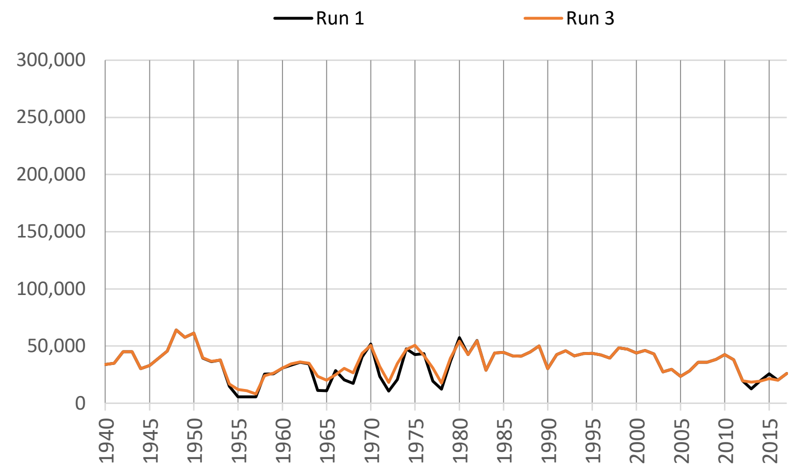
Run 3 - NM Pumping Off
Irrigation Season Summary of Irrigation Operations
Run 3 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

HCCRD Total

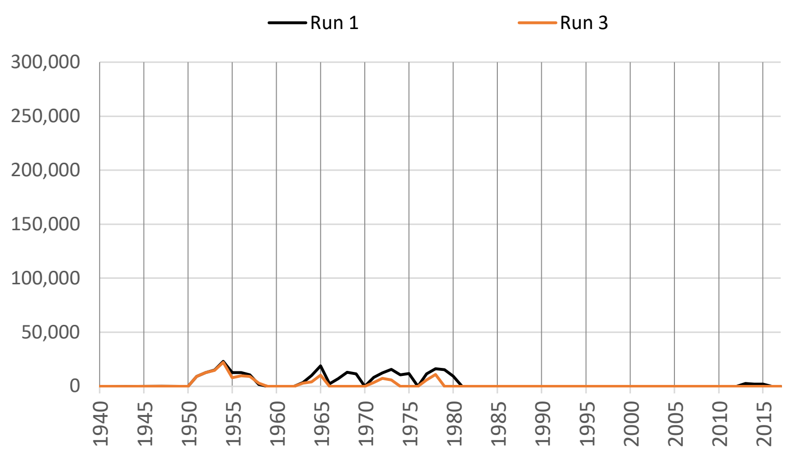
Net River Headgate Diversions



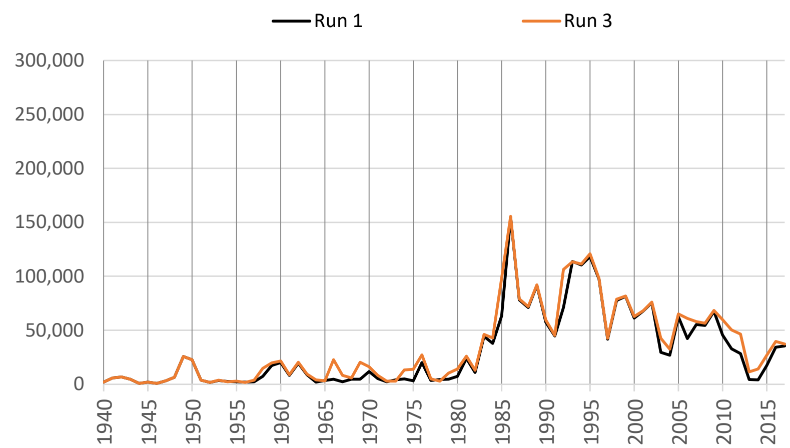
Farm Headgate Deliveries



Pumping



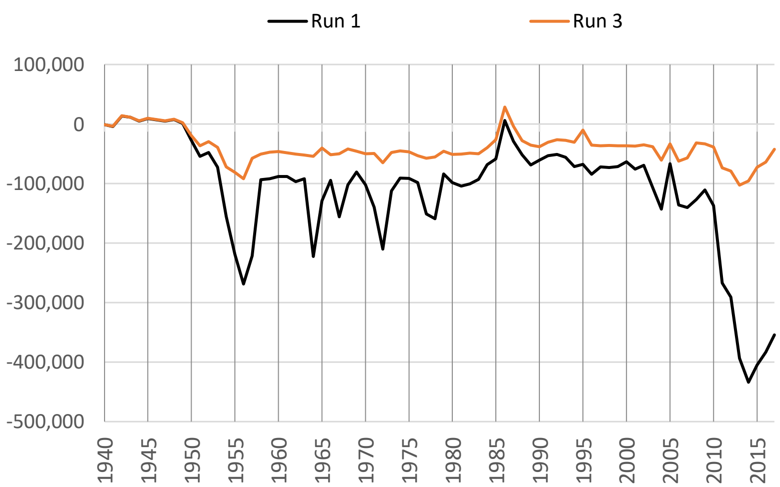
RHG Diversions - FHG Deliveries



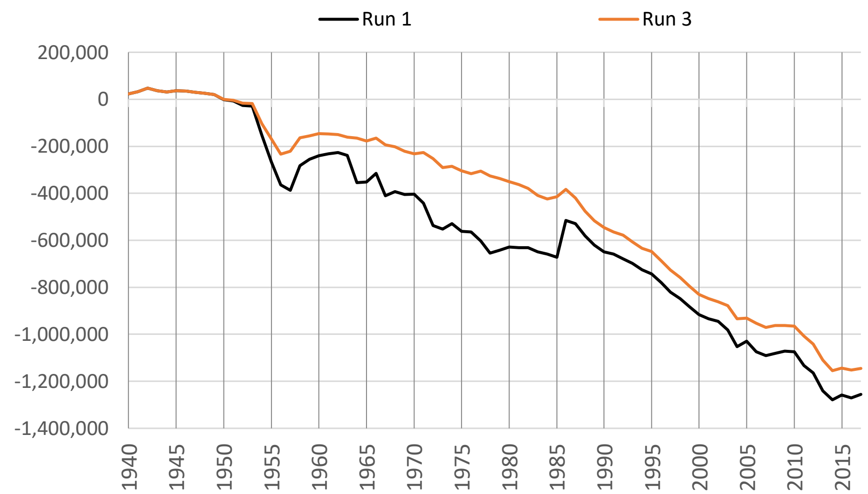
Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

Run 3 - NM Pumping Off
Cumulative Change in Ground Water Storage
Run 3 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

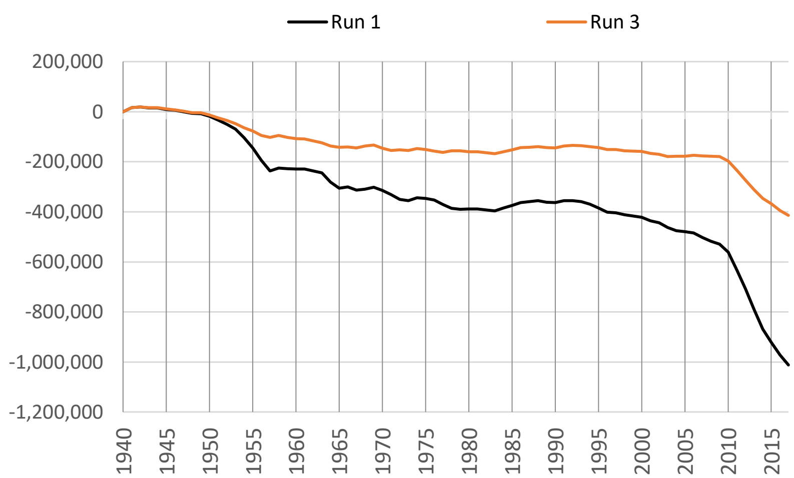
Rincon-Mesilla Alluvial Aquifer



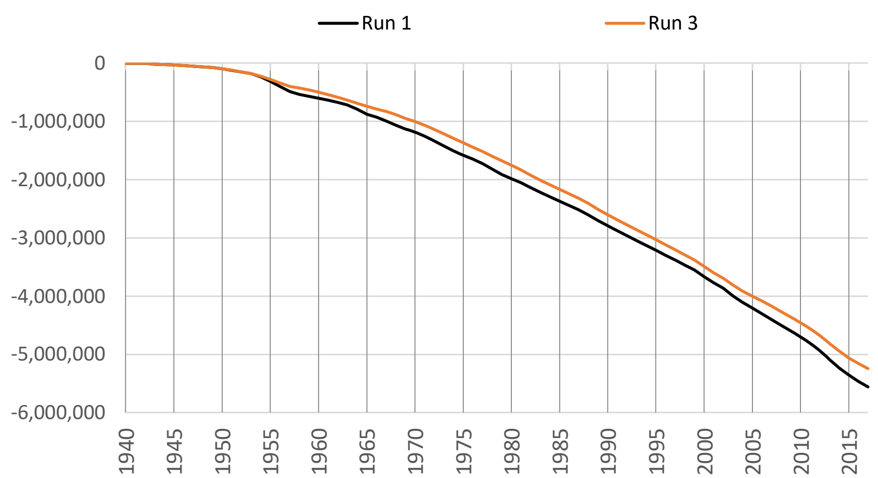
Hueco Alluvial Aquifer



Rincon-Mesilla Non-Alluvial Aquifer

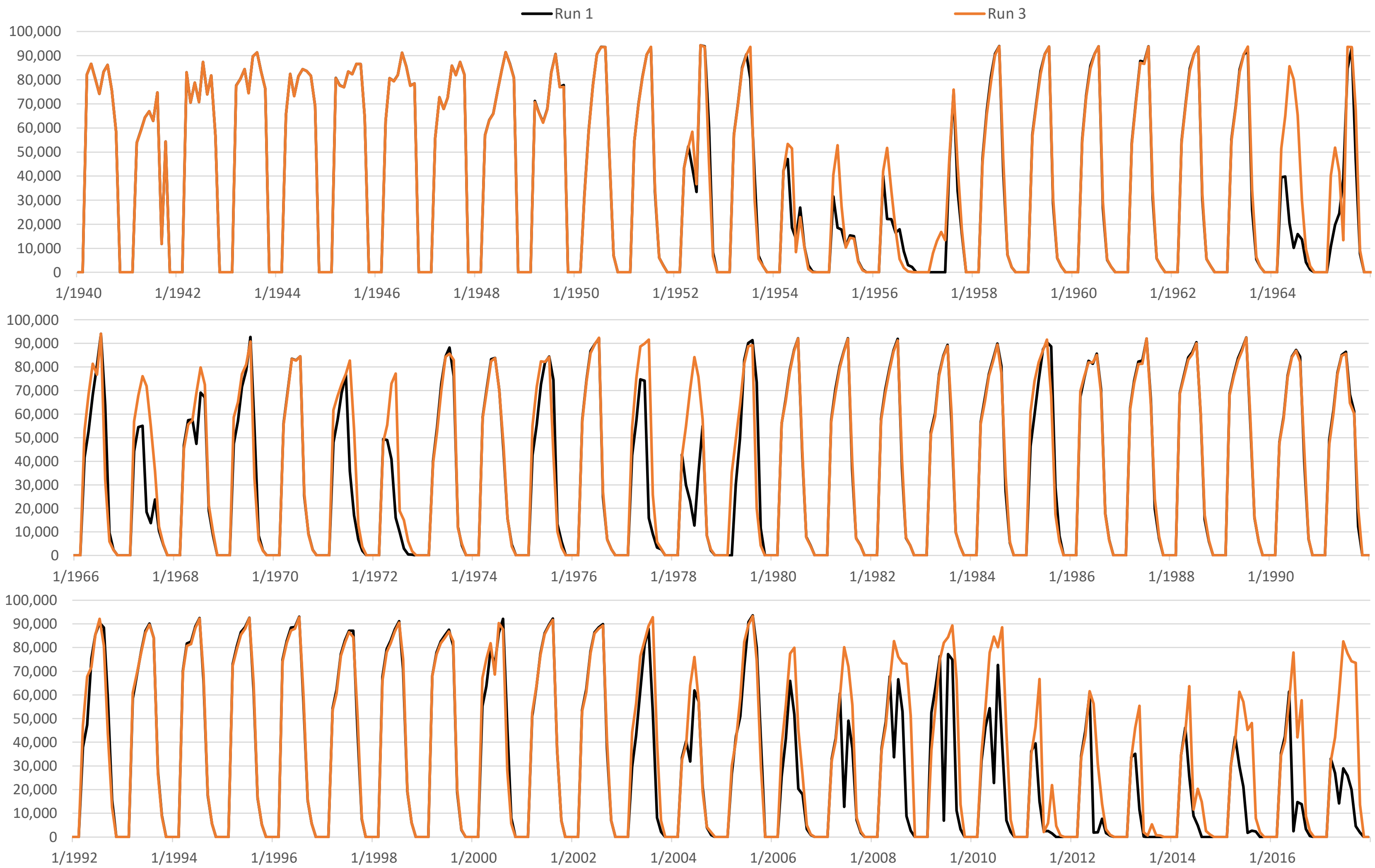


Hueco Non-Alluvial Aquifer



***Note different scales.**

Run 3 - NM Pumping Off
Monthly Net RHG Diversions
Run 3 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
EBID Total

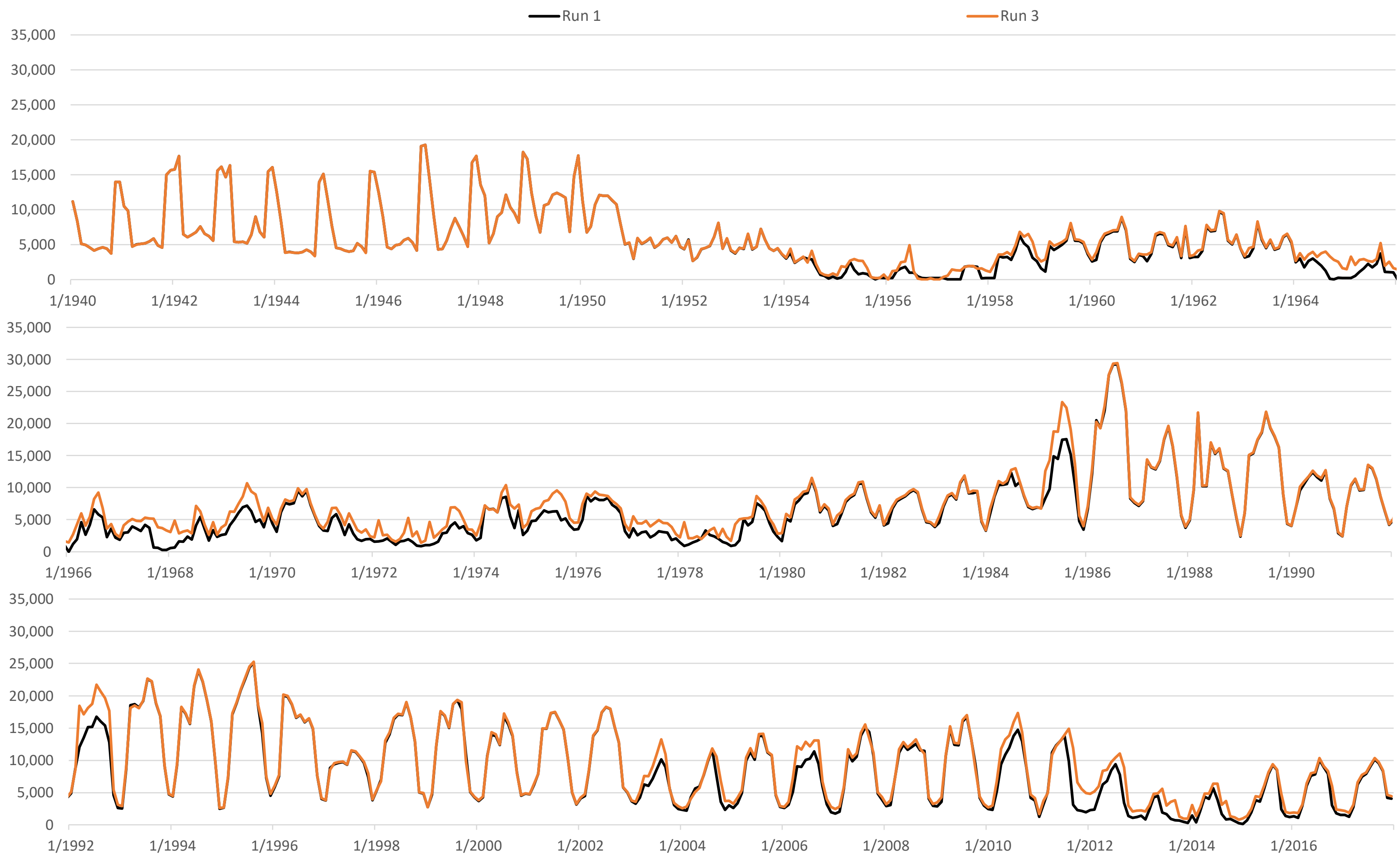


Note: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

Run 3 - NM Pumping Off
Monthly Net RHG Diversions
Run 3 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
EPCWID Total

Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

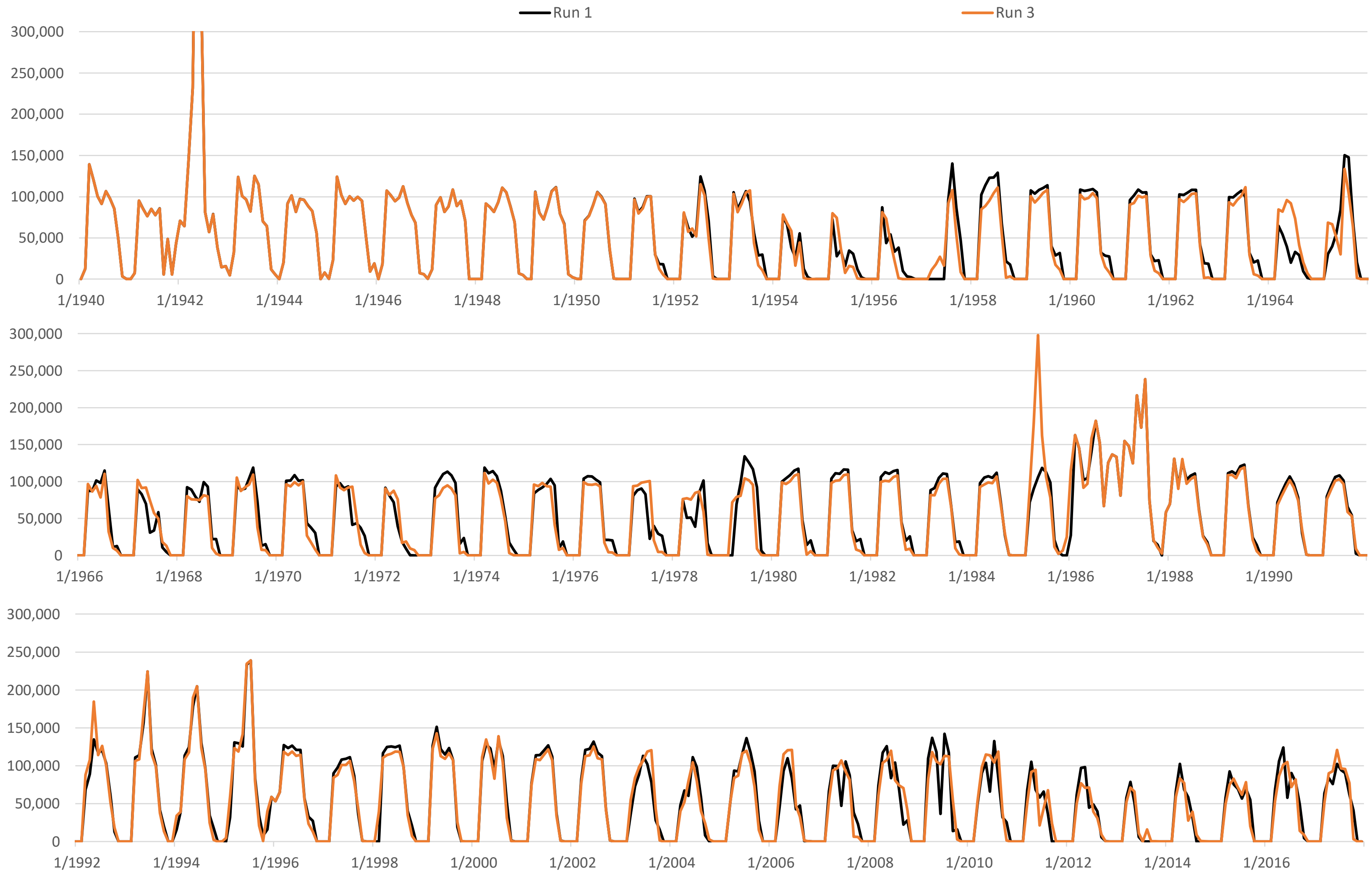
Run 3 - NM Pumping Off
Monthly Net RHG Diversions
Run 3 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
HCCRD Total



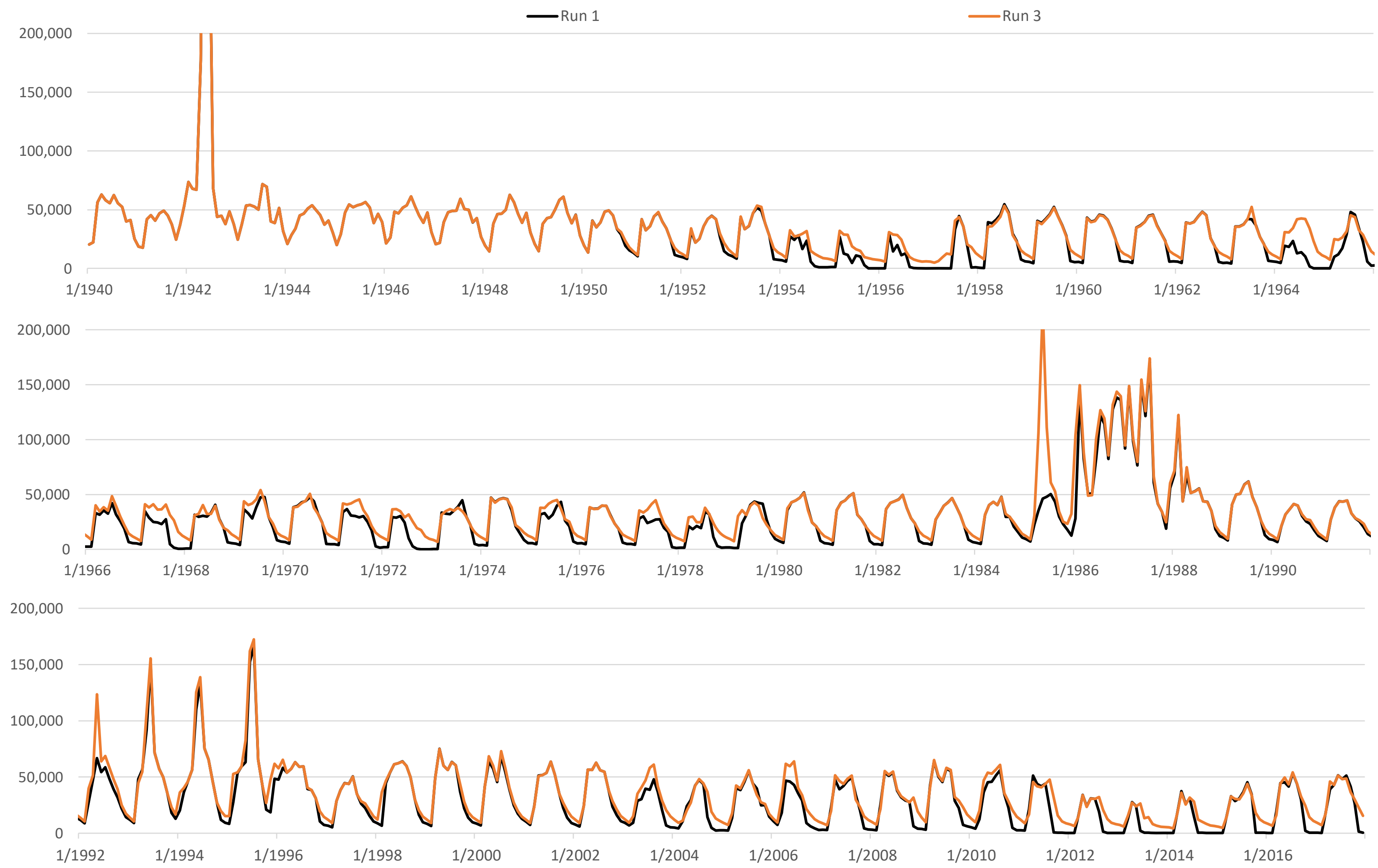
Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

Run 3 - NM Pumping Off
End of Month Reservoir Storage (Elephant Butte + Caballo)
Run 3 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

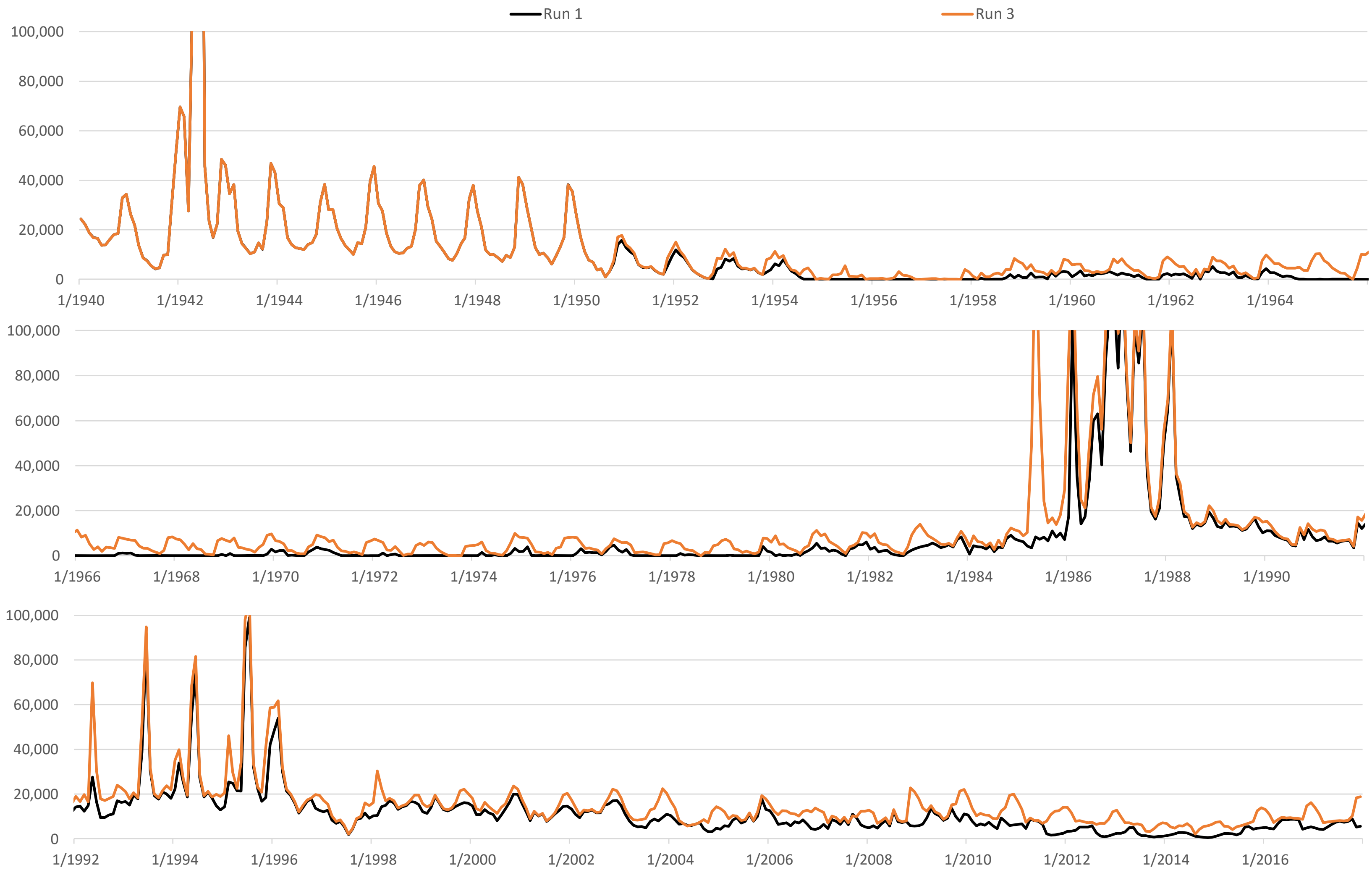
Run 3 - NM Pumping Off
Monthly Caballo Releases
Run 3 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)



Run 3 - NM Pumping Off
Monthly Rio Grande at El Paso Flow
Run 3 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)



Run 3 - NM Pumping Off
Monthly Rio Grande at Fort Quitman Flow
Run 3 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)



Appendix 30D

Comparison of ILRG Model Runs
Run 4 v. Run 1

Model Run Specifications

Model Version: LRG_v116

Name: **Run 4 - TX Pumping Off**

Run ID: LRG_v116_Operational_Run4
Date: 8/28/2020

Name: **Run 1 - Historical Base Run**

Run ID: LRG_v116_Operational_Run1
Date: 8/23/2020

Selected Model Inputs

Pumping and Returns	Run 4	Run 1
Irrigation Pumping	TX Off	On
Irrigated Area	Hist	Hist
Non-Irrigation Pumping	TX Off	On
Non-Irrigation Pumping Returns	TX Off	On
Las Cruces Jornada Pumping Returns	On	On

Project Allocation Rules		
1950-2005	D1/D2	D1/D2
2006-2007	D3	D3
2008-2017	D3 + CO	D3 + CO

EPCWID Operations		
Charge EPCWID for Use of WWTP Returns	Off	Off
ACE and Haskell Credits for EPCWID	On	On
Increased EPCWID Use of Fabens Drain Flows	Off	Off
Charge EPCWID for Fabens Drain Flow Use	Off	Off

Run 4 - TX Pumping Off
Comparison of ILRG Model Runs
Run 4 v. Run 1
1951 - 2017 Annual Average
(1,000 acre-feet)

Run No.	1	4	4 - 1		
Simulated Input or Output	**Run 1**	**Run 4**	**Run 4 minus Run 1**		
Pumping Stress					
Irrigation Pumping	51.7	0.0	-51.7		
Non-Irrigation Pumping	181.0	96.9	-84.1		
WWTP Flows	58.0	40.6	-17.4		
Urban Deep Percolation	13.1	5.7	-7.3		
Total Stress	161.5	50.6	-111.0		
	Stress is Pumping minus WWTP and Urban Deep Perc				
Effects of Pumping Stress				***% Chg***	
FHG Deliveries (Mar - Oct)				***Stress***	***% Diff.***
EBID	167.6	171.7	4.1	*-4%*	*2%*
EPCWID (incl. EPW)	139.9	140.3	0.4	*0%*	*0%*
HCCRD	32.8	34.8	1.9	*-2%*	*6%*
Total	340.3	346.8	6.4	*-6%*	*2%*
FHG Deliveries (Nov - Feb)					
EBID	0.0	0.0	0.0	*0%*	*1%*
EPCWID (incl. EPW)	0.2	0.1	-0.1	*0%*	*-46%*
HCCRD	2.4	2.3	-0.1	*0%*	*-3%*
Total	2.6	2.4	-0.2	*0%*	*-6%*
Irrigation Pumping					
EBID	140.4	136.5	-4.0	*4%*	*-3%*
EPCWID (Mesilla Valley)	7.4	0.0			
EPCWID (El Paso Valley)	40.1	0.0			
HCCRD	4.2	0.0			
	140.4	136.5	-4.0	*4%*	*-3%*
	Pumping turned off.	*Other values are simulated responses and are totaled.*			
Other Inflows/Outflows					
Net Reservoir Evaporation	125.3	126.6	1.3	*-1%*	*1%*
Riparian ET	70.9	76.4	5.5	*-5%*	*8%*
River Evaporation + Incidental Canal Loss	30.3	29.9	-0.4	*0%*	*-1%*
Total	226.6	232.9	6.4	*-6%*	*3%*
Rio Grande at Fort Quitman					
Reservoir Spills	33.3	32.8	-0.5	*0%*	*-1%*
Nov-Feb Flows	21.4	27.7	6.3	*-6%*	*29%*
Mar - Oct Flows	41.1	54.9	13.8	*-12%*	*34%*
Underflow (GW Model)	0.2	0.3	0.1	*0%*	*24%*
Total	96.0	115.6	19.7	*-18%*	*20%*

Run 4 - TX Pumping Off
Comparison of ILRG Model Runs
Run 4 v. Run 1
1951 - 2017 Annual Average
(1,000 acre-feet)

Run No.	1	4	4 - 1		
Simulated Input or Output	**Run 1**	**Run 4**	**Run 4 minus Run 1**		
Effects of Pumping Stress (continued)				*% Chg*	
Change in Storage				***Stress***	***% Diff.***
Reservoir Storage	-4.7	-4.7	0.0	*0%*	*0%*
Alluvial GW Storage (RW Model)	-23.6	-15.6	8.0	*-7%*	*-34%*
Non-alluvial GW Storage (GW Models)	-96.4	-49.4	46.9	*-42%*	*-49%*
Soil Moisture Storage	0.6	0.6	0.0	*0%*	*4%*
Total	-124.0	-69.1	54.9	*-49%*	*-44%*
Summary of Effects					
FHG Deliveries (Mar-Oct)	340.3	346.8	6.4	*-6%*	*2%*
FHG Deliveries (Nov-Feb)	2.6	2.4	-0.2	*0%*	*-6%*
Irrigation Pumping	140.4	136.5	-4.0	*4%*	*-3%*
Riparian ET + Evaporation	226.6	232.9	6.4	*-6%*	*3%*
Fort Quitman Flow	96.0	115.6	19.7	*-18%*	*20%*
Change in Storage	-124.0	-69.1	54.9	*-49%*	*-44%*
Total	681.9	765.1	83.2	*-75%*	*12%*
Other Effects of Pumping Stress				*% Chg*	
Rio Grande at El Paso				***Stress***	***% Diff.***
Reservoir Spills	49.4	45.9	-3.5	*3%*	*-7%*
Nov-Feb Flows	22.8	28.2	5.4	*-5%*	*24%*
Mar - Oct Flows	263.8	282.1	18.4	*-17%*	*7%*
Total	336.0	356.2	20.2	*-18%*	*6%*
Rio Grande below Caballo					
Reservoir Spills	65.9	58.8	-7.0	*6%*	*-11%*
Nov-Feb Flows	0.5	0.5	0.0	*0%*	*2%*
Mar - Oct Flows	541.3	547.1	5.8	*-5%*	*1%*
Total	607.6	606.4	-1.2	*1%*	*0%*
Surface Water Diversions (Mar - Oct)					
EBID	366.5	371.1	4.6	*-4%*	*1%*
EPCWID (incl. EPW)	236.8	241.3	4.5	*-4%*	*2%*
HCCRD	67.5	73.0	5.5	*-5%*	*8%*
Total	670.8	685.4	14.6	*-13%*	*2%*
Surface Water Diversions (Nov - Feb)					
EBID	0.0	0.0	0.0	*0%*	*0%*
EPCWID (incl. EPW)	14.3	12.7	-1.6	*1%*	*-11%*
HCCRD	14.2	14.9	0.7	*-1%*	*5%*
Total	28.5	27.6	-0.9	*1%*	*-3%*

Run 4 - TX Pumping Off
Annual Differences in ILRG Model Outputs
Run 4 minus Run 1
1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1940	5	5	-620	68	-149	555	-12	-12	377	377	-94	-94	-3,500	-3,375	6,842
1941	0	0	-111	-1,249	219	51	3	4	-2	-199	200	110	3,200	2,930	3,444
1942	-32	-32	-49	-2,055	-175	-176	10	10	464	-154	-197	-220	1,886	1,888	-298
1943	-38	-38	-158	-1,659	-156	-294	23	23	433	189	-100	-403	4,298	4,215	2,293
1944	-41	-41	-488	-1,869	133	-167	0	0	-236	-448	82	-150	1,807	1,796	2,067
1945	-47	-47	-260	-2,172	217	-415	12	12	-299	-699	192	215	2,967	2,923	2,497
1946	-24	-24	51	-2,523	319	-529	25	26	-48	-860	257	180	2,979	3,078	2,615
1947	-43	-43	471	-1,544	175	-463	9	9	643	57	121	152	1,912	2,067	2,796
1948	-32	-32	-978	-2,388	568	295	-6	-6	306	-1	438	215	-756	-518	4,478
1949	-30	-30	-2,384	-4,199	1,613	1,573	0	0	-380	-403	-148	-299	-714	-553	6,967
1950	-325	-325	-3,690	-4,605	1,768	1,934	234	234	-423	-417	-35	-61	-2,267	223	6,980
1951	-4,090	-4,090	-4,432	-4,889	1,640	2,246	-1,756	-1,757	-430	-427	1,724	1,251	-6,894	-410	17,111
1952	-807	-807	-6,369	-6,938	1,729	2,505	842	841	-900	-893	1,560	844	-8,779	-590	17,084
1953	-752	-752	-7,667	-8,139	3,214	4,563	1,378	1,378	-853	-844	3,565	3,977	-12,289	81	29,454
1954	4,590	4,590	4,075	3,312	3,698	5,281	6,680	6,680	9,489	9,505	3,854	5,591	6,285	21,083	22,856
1955	7,789	7,789	5,955	5,122	8,498	11,356	3,945	3,945	6,710	6,504	7,888	10,495	10,809	17,526	15,618
1956	1,543	1,543	267	-1,457	7,526	9,895	-1,614	-1,614	3,456	2,674	6,980	8,587	250	10,632	8,182
1957	-392	-392	-8,108	-9,099	829	4,021	325	325	1,696	1,275	1,683	3,284	-11,115	2,548	5,452
1958	-869	-869	-21,576	-21,990	6,285	11,335	1,040	1,040	-2,326	-2,404	-1,655	-200	-39,572	-9,921	35,328
1959	-1,066	-1,066	-13,330	-13,813	5,121	7,976	1,150	1,150	-1,545	-1,525	403	682	-28,431	-2,377	38,073
1960	-1,144	-1,144	-11,147	-12,122	3,953	5,254	1,268	1,268	-2,298	-2,275	0	0	-19,091	3,953	31,983
1961	-1,045	-1,045	-10,119	-11,080	4,285	5,471	1,306	1,305	-818	-795	1,521	-425	-16,279	6,602	35,762
1962	-1,118	-1,118	-9,069	-10,106	3,868	4,964	1,324	1,324	-1,659	-1,633	793	1,223	-16,383	8,130	32,699
1963	7,662	7,662	-8,365	-9,214	4,015	5,016	6,388	6,389	-2,062	-2,031	2,444	2,238	-2,615	20,429	35,088
1964	27,627	27,627	19,031	17,291	5,588	7,290	26,689	26,689	15,569	15,229	5,763	7,278	25,870	45,367	26,012
1965	35,496	35,496	9,122	7,491	8,303	11,681	19,828	19,828	17,155	16,758	8,966	11,404	25,721	39,212	30,426
1966	255	255	23,623	23,836	14,933	18,306	-8,857	-8,857	14,803	14,834	-2,501	-4,764	-1,113	51,198	54,526
1967	15,109	15,109	13,348	13,023	7,333	11,936	9,555	9,555	15,226	14,736	6,074	9,637	17,069	29,689	24,895
1968	2,692	2,692	-7,010	-7,150	10,550	15,450	4,399	4,399	628	255	8,921	8,287	-14,076	13,762	24,132
1969	-646	-646	-6,827	-7,375	12,375	15,636	1,539	1,539	-280	-259	2,988	-1,539	-20,528	8,113	36,311
1970	-950	-950	-3,905	-4,765	5,640	7,152	1,348	1,348	-902	-883	-1,274	-2,725	-11,960	12,993	31,944
1971	27,296	27,296	-2,732	-3,091	6,647	9,173	18,260	18,260	-470	-443	5,995	8,477	9,362	22,538	25,269
1972	-3,103	-3,103	-1,510	-2,222	10,332	12,324	-4,188	-4,188	-7,715	-7,955	8,611	8,427	-9,499	16,257	22,052
1973	-1,493	-1,493	-1,679	-3,197	18,019	21,175	2,783	2,783	727	504	17,067	15,068	-20,233	15,751	15,521
1974	-1,282	-1,282	139	-471	16,045	20,248	2,106	2,106	255	277	-2,914	-4,687	-13,815	17,920	44,700
1975	-1,043	-1,043	2,765	1,473	15,344	19,054	2,460	2,460	98	117	10,065	6,626	-6,111	19,587	23,750
1976	-1,362	-1,362	6,620	5,320	12,502	16,449	2,676	2,676	-299	-285	-1,658	-5,716	-5,753	23,848	33,136
1977	42,138	42,138	42,434	43,227	17,454	20,915	18,377	18,377	14,387	14,414	15,176	14,379	55,885	76,182	36,947
1978	1,121	1,121	1,152	1,397	9,115	12,465	1,316	1,316	-4,990	-4,959	9,714	9,431	-5,769	24,721	23,254

Run 4 - TX Pumping Off
Annual Differences in ILRG Model Outputs
Run 4 minus Run 1
1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1979	-882	-882	5,055	4,272	6,925	10,375	2,477	2,478	6	43	6,924	9,302	-10,854	30,973	28,965
1980	-936	-936	8,314	7,791	6,594	8,142	1,714	1,715	173	198	-1,599	-3,741	-1,382	30,294	57,931
1981	-892	-892	11,875	10,820	5,212	4,583	1,711	1,711	162	182	-56	-258	5,500	30,900	35,456
1982	-963	-963	11,051	9,639	4,847	4,086	1,576	1,576	152	170	-1,240	-2,706	7,385	32,246	46,225
1983	-677	-677	13,730	12,173	8,105	7,370	1,425	1,426	171	188	0	0	10,907	32,964	33,716
1984	-704	-704	15,090	13,835	10,879	9,754	1,541	1,541	154	173	0	0	8,811	31,725	26,430
1985	-560	-560	17,172	16,700	6,376	5,311	3,367	3,368	92	20	0	0	10,046	29,009	25,332
1986	-628	-628	22,680	22,502	8,134	5,975	1,157	1,155	98	109	0	0	-22,614	-970	91,807
1987	-855	-855	25,591	25,423	7,825	5,287	968	968	143	158	0	0	142	20,188	17,286
1988	-676	-676	27,109	26,941	8,279	5,389	1,715	1,716	84	98	0	0	18,649	36,823	12,579
1989	-813	-813	28,978	28,525	9,348	6,729	1,814	1,816	502	134	0	0	34,170	53,915	23,578
1990	-491	-491	25,495	24,744	10,187	7,735	1,545	1,545	345	-155	0	0	15,906	36,172	13,315
1991	-958	-958	12,416	11,754	4,158	2,529	-245	-244	-87	-860	0	0	11,581	28,593	19,556
1992	-803	-803	8,613	8,197	2,283	1,415	2,868	2,871	-131	-454	0	0	-21,871	-4,828	-3,876
1993	-795	-795	247	63	1,313	-238	1,098	1,099	-479	-469	0	0	-35,331	-16,200	-22,942
1994	-901	-901	618	431	1,987	599	1,616	1,615	1,127	1,133	0	0	-8,045	14,919	7,044
1995	-865	-865	164	-61	1,383	-381	1,710	1,710	1,854	1,807	0	0	3,411	29,014	16,042
1996	-1,159	-1,159	921	767	1,520	-7	1,907	1,907	174	191	0	0	-2,954	25,346	7,551
1997	-455	-455	-4,028	-6,595	3,776	1,402	1,327	1,327	-2,445	-3,452	0	0	-1,116	22,852	15,549
1998	-772	-772	4,359	3,994	2,676	746	1,644	1,644	772	782	0	0	3,025	29,636	21,710
1999	-823	-823	-2,358	-5,396	438	-458	1,602	1,602	-2,750	-2,743	0	0	-1,797	23,538	10,385
2000	-577	-577	15,645	11,727	3,444	3,077	1,807	1,808	2,178	2,188	0	0	10,235	33,937	1,056
2001	-560	-560	9,223	4,653	2,144	1,833	1,493	1,493	-188	-181	0	0	790	24,195	-2,037
2002	-533	-533	3,642	538	18	-369	1,685	1,685	251	260	0	0	-7,850	16,976	-6,028
2003	-106	-106	20,102	16,702	3,490	2,488	1,478	1,478	-275	-268	0	0	19,717	39,746	4,694
2004	-10,593	-10,593	-14,153	-18,299	-1,854	-2,652	-4,574	-4,574	-13,462	-13,452	0	0	-20,511	9,738	1,798
2005	72	72	7,244	2,737	824	398	1,773	1,770	284	302	0	0	-4,455	19,209	-203
2006	8,900	8,900	-272	-4,597	-482	-650	5,552	5,552	-4,611	-4,600	0	0	316	16,666	1,487
2007	13,874	13,874	3,568	-684	242	-42	8,208	8,208	771	788	0	0	-6,210	13,297	877
2008	27,738	27,738	3,398	-691	807	99	18,851	18,851	68	86	0	0	-793	16,772	1,760
2009	41,648	41,648	5,941	1,437	520	-198	23,919	23,919	-167	-147	0	0	4,289	21,118	5,566
2010	45,408	45,408	6,290	2,006	1,537	1,487	29,096	29,096	730	750	0	0	6,340	22,189	6,048
2011	23,513	23,513	4,790	858	6,035	7,970	12,925	12,925	2,622	2,640	0	0	11,062	20,408	11,284
2012	-8,158	-8,158	2,710	-1,589	5,540	5,610	-1,379	-1,379	-6,636	-6,624	0	0	-13,033	19,300	10,033
2013	5,073	5,073	-7,990	-11,179	2,246	2,420	2,791	2,791	-12,518	-12,507	2,838	3,112	2,398	13,871	2,666
2014	4,450	4,450	-3,970	-7,753	4,306	4,947	2,625	2,625	-6,063	-6,054	2,711	3,038	694	10,898	7,618
2015	2,749	2,749	1,588	-1,991	2,421	2,593	1,731	1,731	-4,883	-4,873	-1,935	-1,678	4,567	16,005	13,366
2016	1,682	1,682	-2,060	-6,058	-841	-1,202	630	630	-4,361	-4,351	0	0	-9,418	10,030	-4,540
2017	19,232	19,232	5,435	2,117	1,206	1,117	10,011	10,011	823	833	0	0	14,561	18,541	137
Averages															
1951-2017	4,617	4,617	4,461	2,848	5,503	6,185	4,085	4,086	408	321	1,931	1,854	-1,236	20,221	19,654
1951-1978	5,434	5,434	167	-558	8,030	10,684	4,306	4,306	2,595	2,481	4,348	4,183	-4,252	17,672	27,770
1979-2005	-1,071	-1,071	10,178	8,688	4,456	3,375	1,415	1,415	-411	-515	149	96	796	24,478	17,886
2006-2017	15,509	15,509	1,619	-2,344	1,961	2,012	9,580	9,580	-2,852	-2,838	301	373	1,231	16,591	4,692
1985-2017	4,917	4,917	6,943	4,483	3,069	2,150	4,325	4,325	-1,398	-1,482	109	136	482	20,330	9,409
1985-2005	-1,136	-1,136	9,985	8,383	3,702	2,229	1,322	1,322	-567	-707	0	0	54	22,467	12,105

Notes:

EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

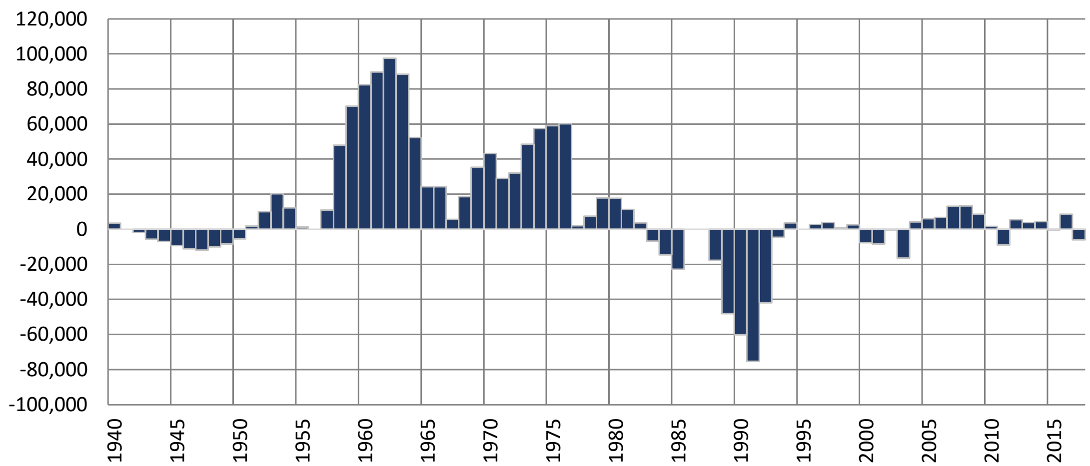
Run 4 - TX Pumping Off

Simulated Differences in ILRG Model Outputs

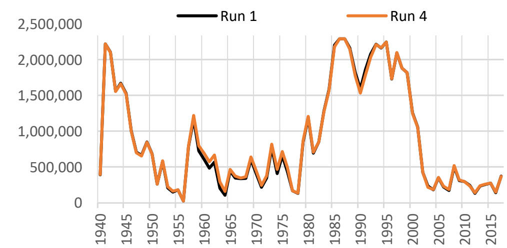
Run 4 minus Run 1

1940 - 2017 (acre-feet)

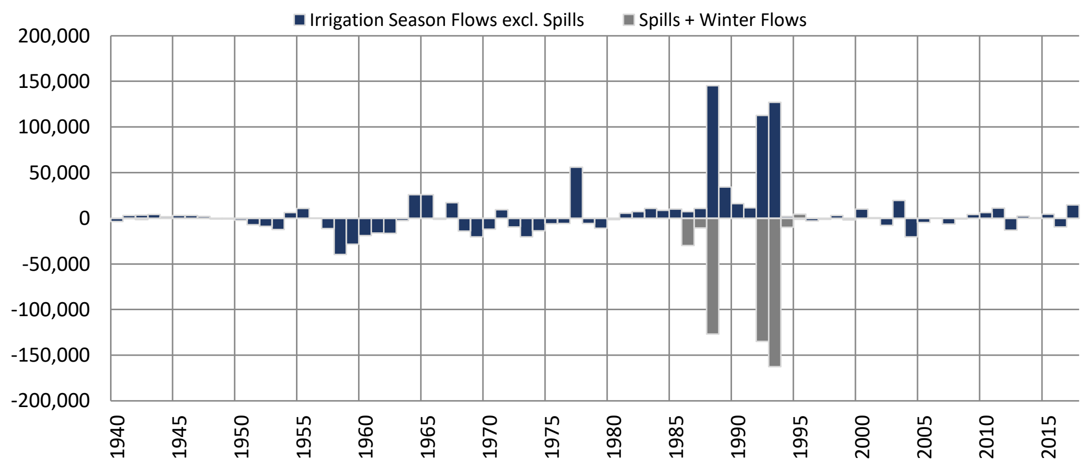
Total Project Storage (Year End)



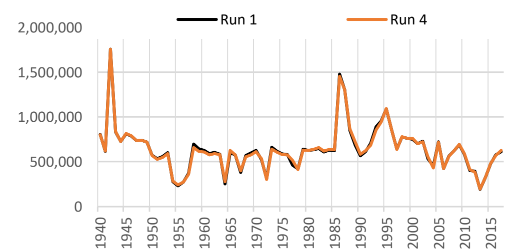
Period	Average Difference
1951-2017	-10
1951-1978	457
1979-2005	-50
2006-2017	-1,006
1985-2017	261
1985-2005	985



Caballo Reservoir Outflows (Annual)



Period	Average Difference Irr Season (excl. Spills)	Average Difference Nov-Feb and Spills	Average Difference Annual
1951-2017	5,778	-7,013	-1,236
1951-1978	-4,252	0	-4,252
1979-2005	18,200	-17,404	796
2006-2017	1,231	0	1,231
1985-2017	14,721	-14,239	482
1985-2005	22,430	-22,376	54



Notes:

Reservoir storage does not include storage attributed to SJC, CO, or NM credit waters.

Average differences calculated as (Final Storage - Initial Storage)/(no. years).

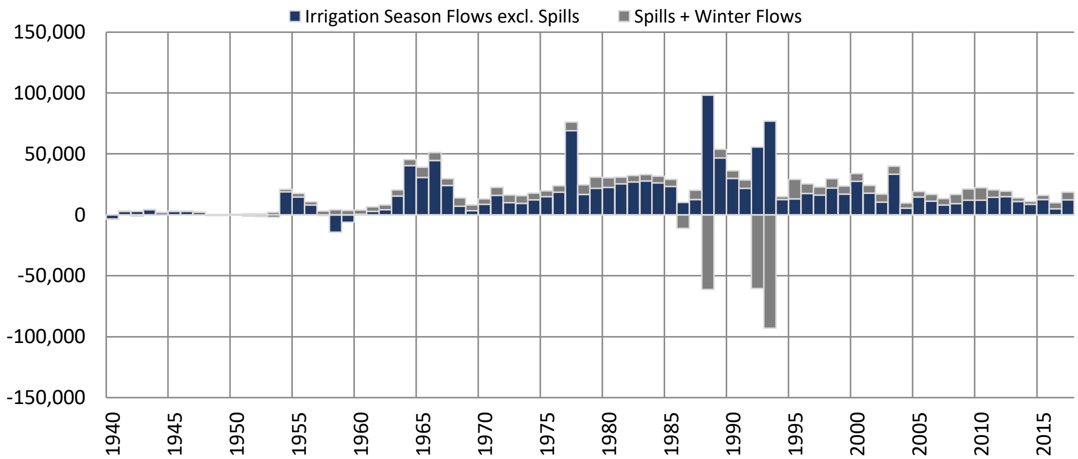
Run 4 - TX Pumping Off

Simulated Differences in ILRG Model Outputs

Run 4 minus Run 1

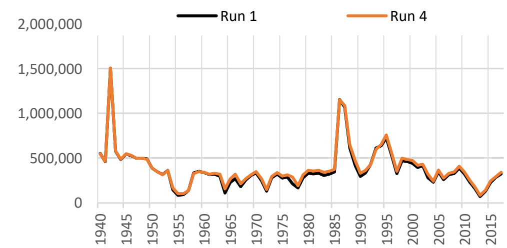
1940 - 2017 (acre-feet)

Rio Grande at El Paso (Annual)

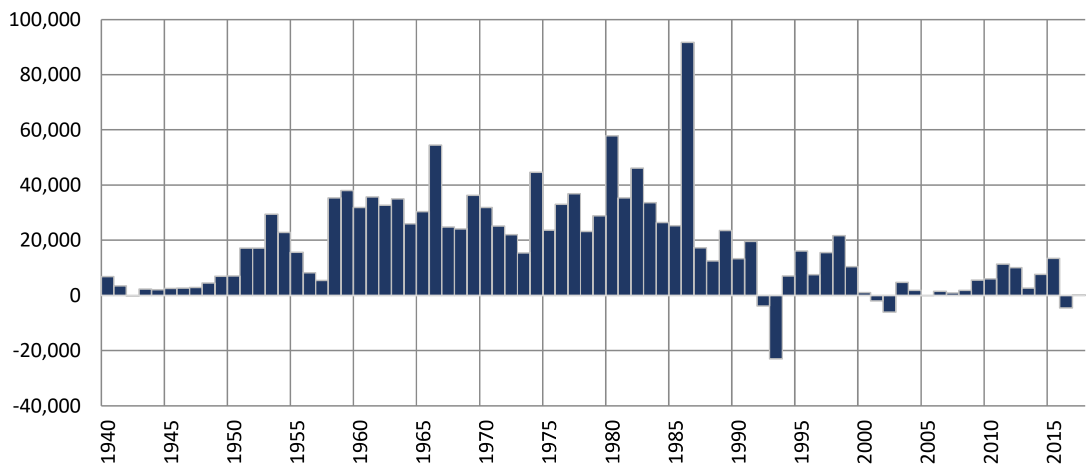


Average Difference

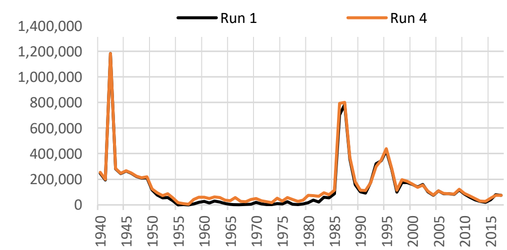
Period	Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	18,357	1,864	20,221
1951-1978	13,037	4,635	17,672
1979-2005	27,171	-2,693	24,478
2006-2017	10,942	5,649	16,591
1985-2017	21,648	-1,317	20,330
1985-2005	27,765	-5,298	22,467



Rio Grande at Fort Quitman (Annual)

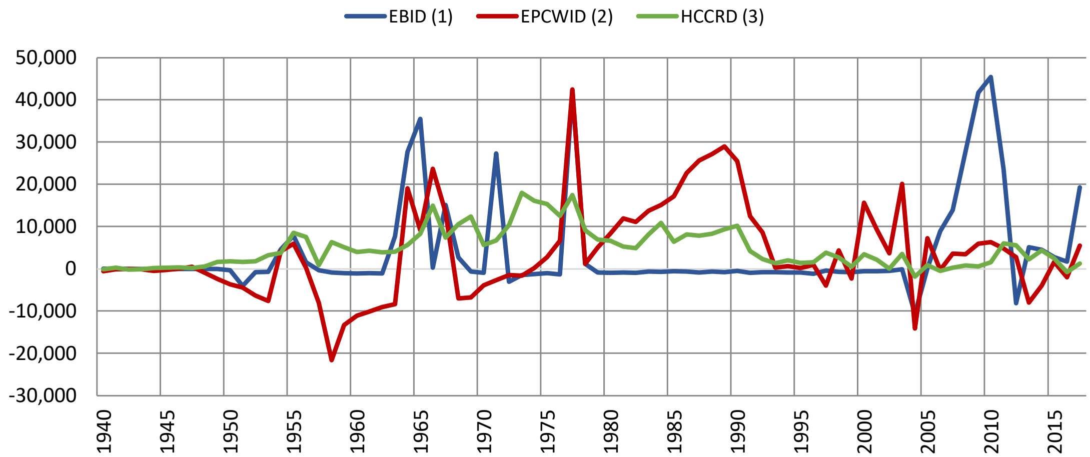


Period	Average Difference
1951-2017	19,602
1951-1978	27,695
1979-2005	17,839
2006-2017	4,682
1985-2017	9,386
1985-2005	12,074



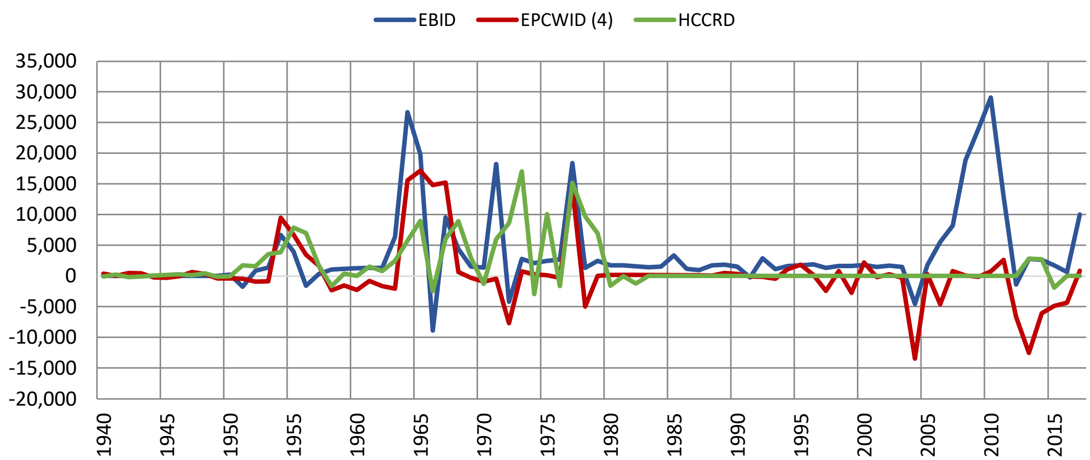
Run 4 - TX Pumping Off
Simulated Differences in ILRG Model Outputs
Run 4 minus Run 1
1940 - 2017 (acre-feet)

River Headgate (RHG) Diversions (Irrigation Season)



	Average Difference		
Period	EBID	EPCWID	HCCRD
1951-2017	4,617	4,461	5,503
1951-1978	5,434	167	8,030
1979-2005	-1,071	10,178	4,456
2006-2017	15,509	1,619	1,961
1985-2017	4,917	6,943	3,069
1985-2005	-1,136	9,985	3,702

Farm Headgate (FHG) Deliveries (Irrigation Season)



	Average Difference		
Period	EBID	EPCWID	HCCRD
1951-2017	4,085	408	1,931
1951-1978	4,306	2,595	4,348
1979-2005	1,415	-411	149
2006-2017	9,580	-2,852	301
1985-2017	4,325	-1,398	109
1985-2005	1,322	-567	0

Notes:

(1) EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

(2) EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

(3) HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

(4) EPCWID FHG values include deliveries to Rogers WTP and R/U WTP.

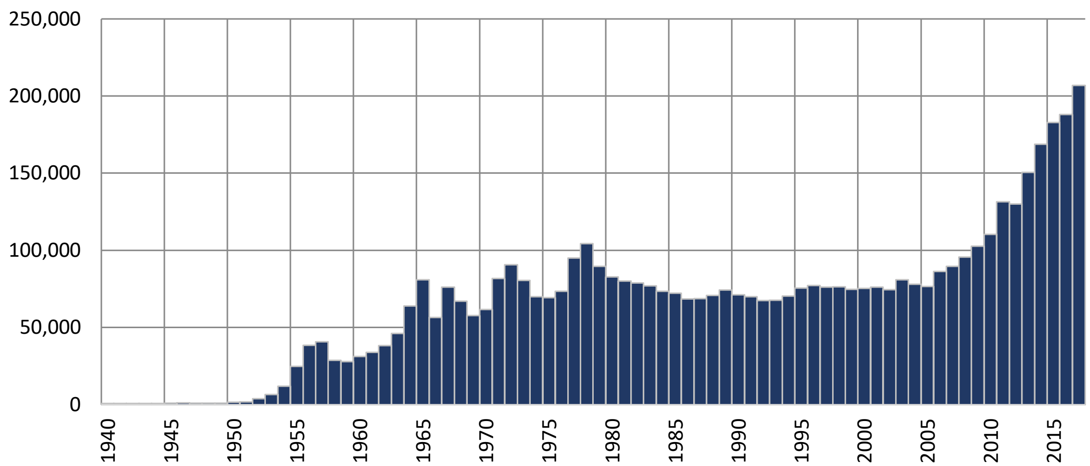
Run 4 - TX Pumping Off

Simulated Differences in ILRG Model Outputs

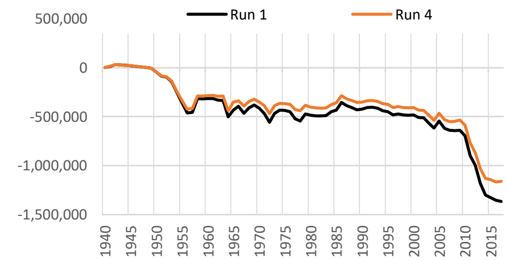
Run 4 minus Run 1

1940 - 2017 (acre-feet)

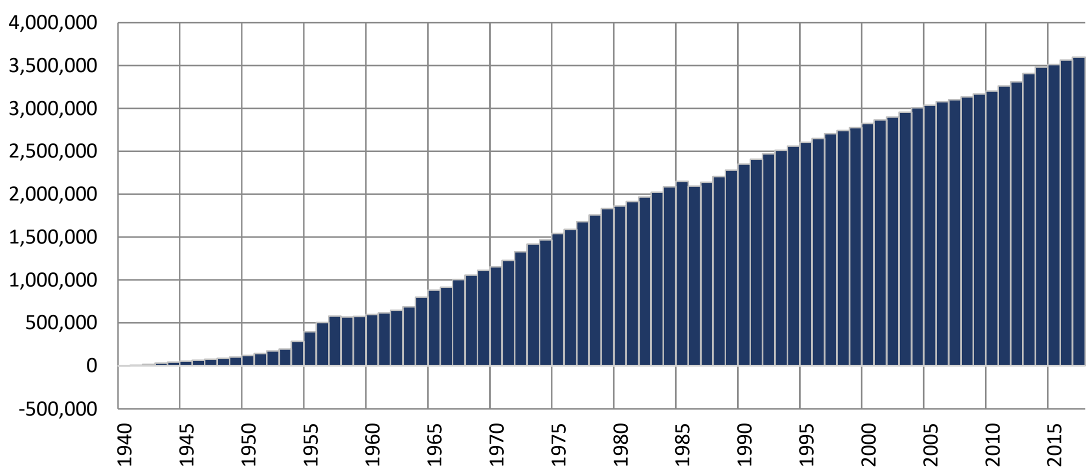
Cumulative Annual Rincon-Mesilla Groundwater Storage



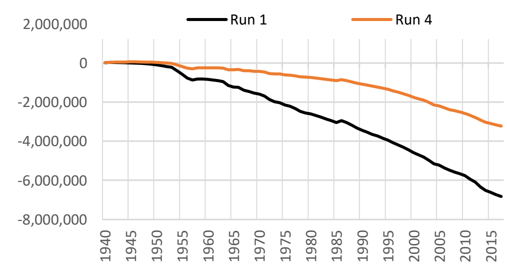
Period	Average Difference
1951-2017	3,063
1951-1978	3,666
1979-2005	-1,024
2006-2017	10,853
1985-2017	4,044
1985-2005	153



Cumulative Annual Hueco Groundwater Storage



Period	Average Difference
1951-2017	51,833
1951-1978	58,494
1979-2005	47,347
2006-2017	46,385
1985-2017	45,711
1985-2005	45,326



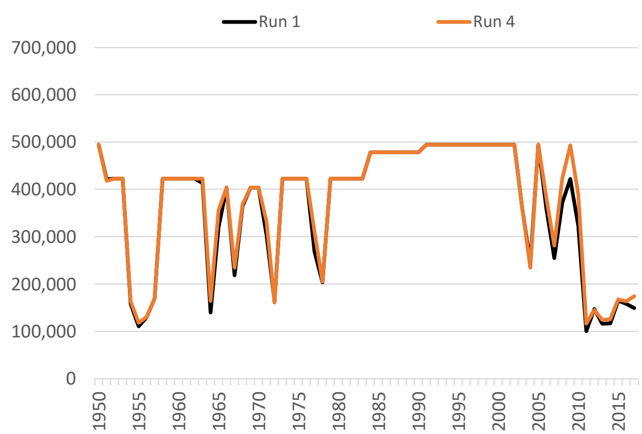
Notes:

Cumulative storage change in alluvial and non-alluvial aquifers.

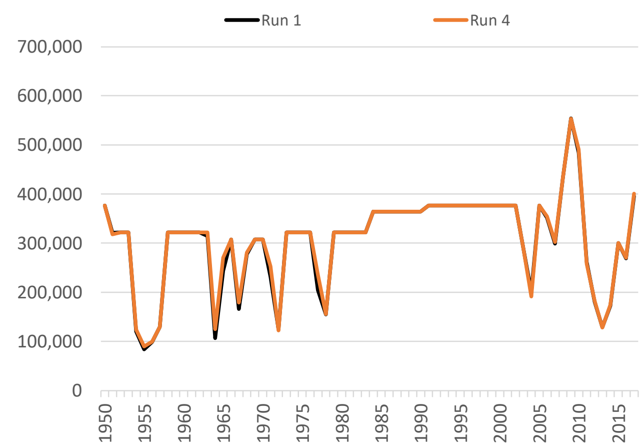
Average differences calculated as (Final Storage - Initial Storage)/(no. years).

Run 4 - TX Pumping Off
Annual Allocation and Charges
Run 4 v. Run 1
ILRG Model
1950 - 2017 (acre-feet)

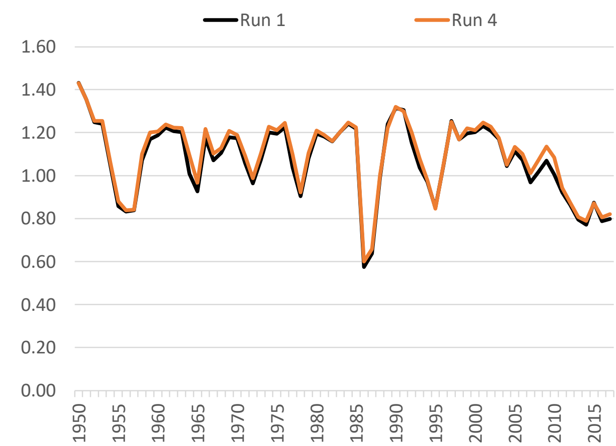
Total Allocation - EBID



Total Allocation - EPCWID

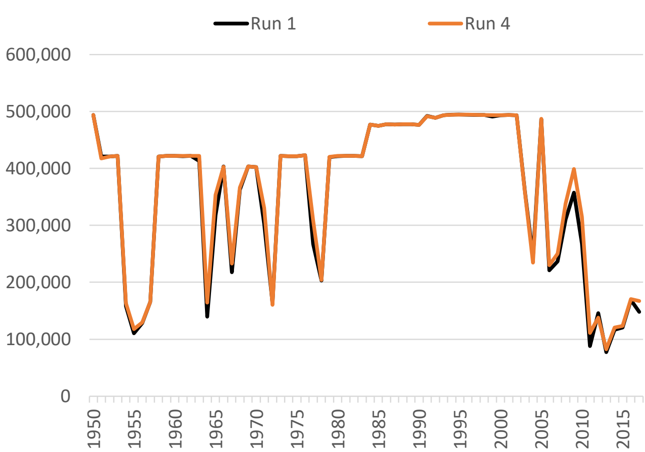


Diversion Ratio

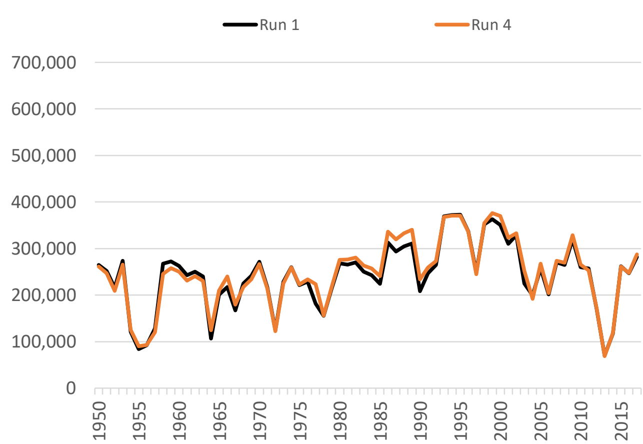


Note:
Computed as Total Charges/Caballo Release.

Annual Delivery Charges - EBID

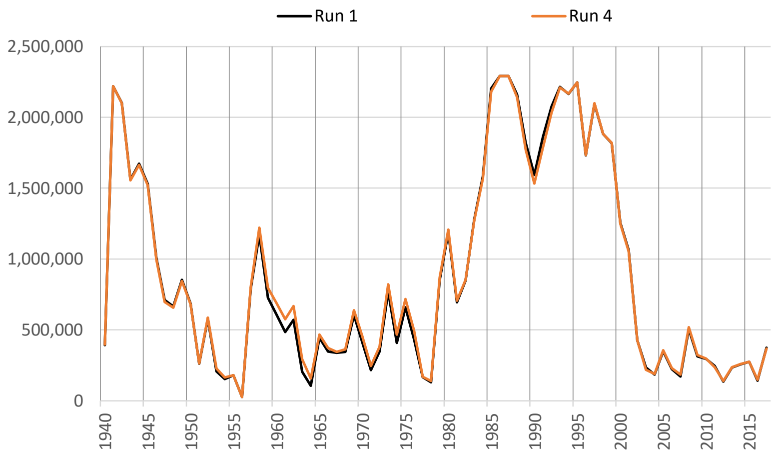


Annual Delivery Charges - EPCWID

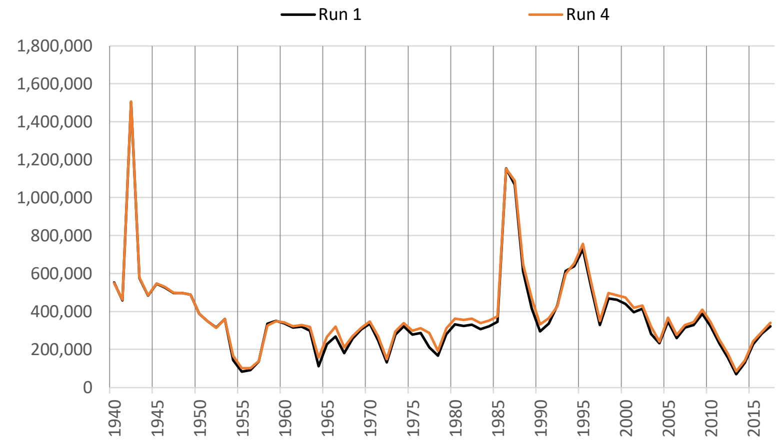


Run 4 - TX Pumping Off
Annual Summary of Project Storage and Rio Grande Flows
Run 4 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

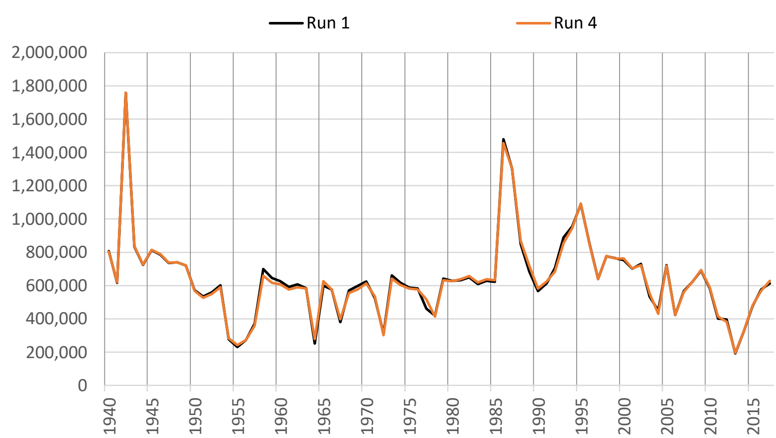
Total Year-End Project Reservoir Storage



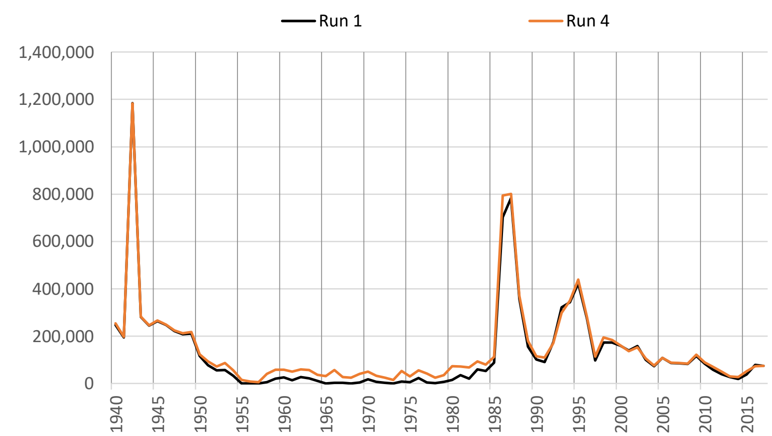
Rio Grande at El Paso



Rio Grande Below Caballo



Rio Grande at Fort Quitman

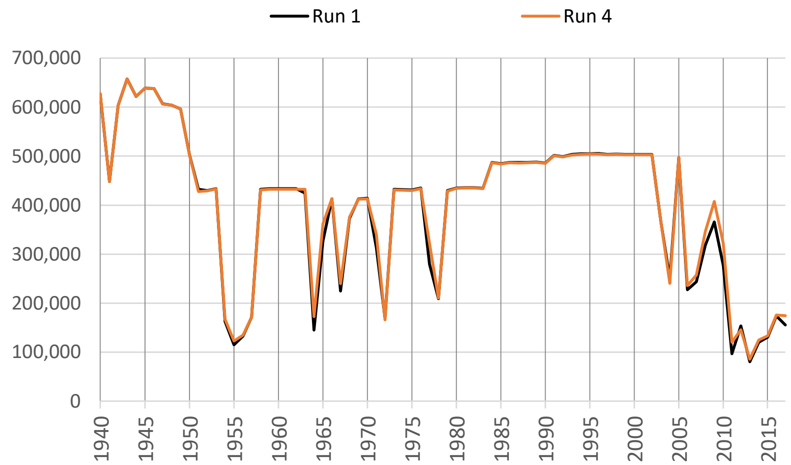


***Note different scales.**

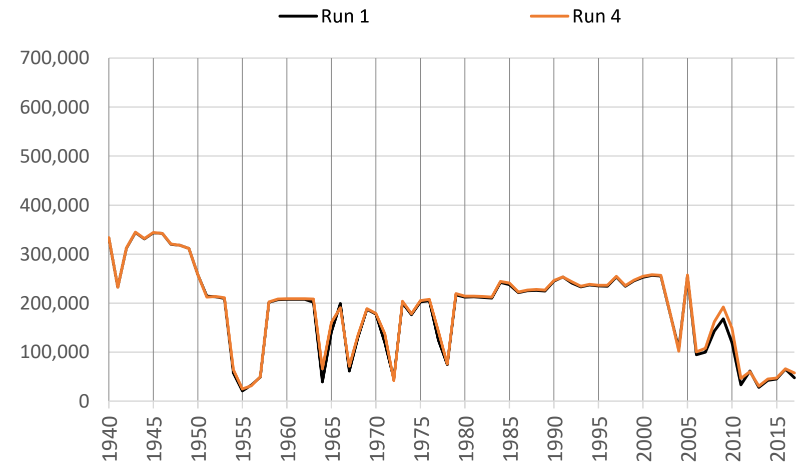
Run 4 - TX Pumping Off
Irrigation Season Summary of Irrigation Operations
Run 4 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

EBID Total

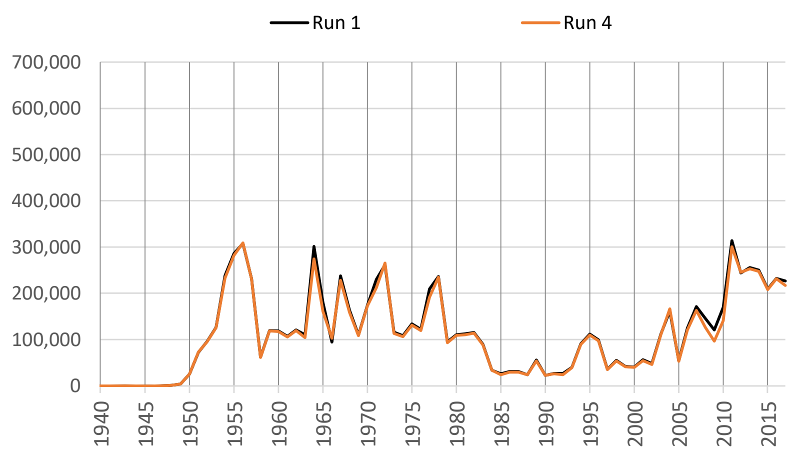
Net River Headgate Diversions



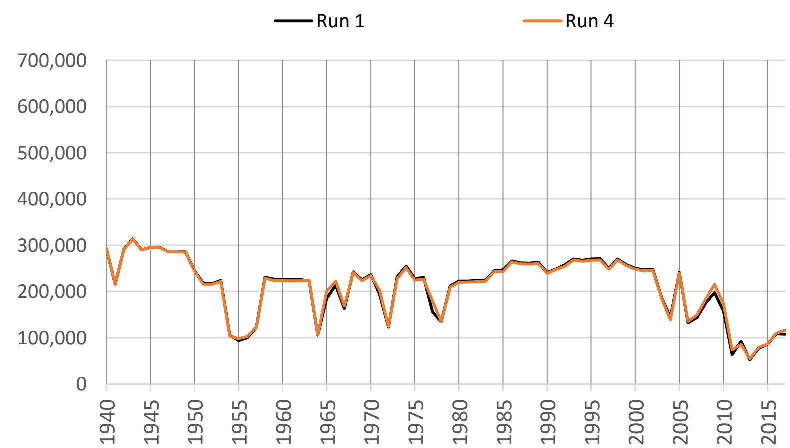
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries

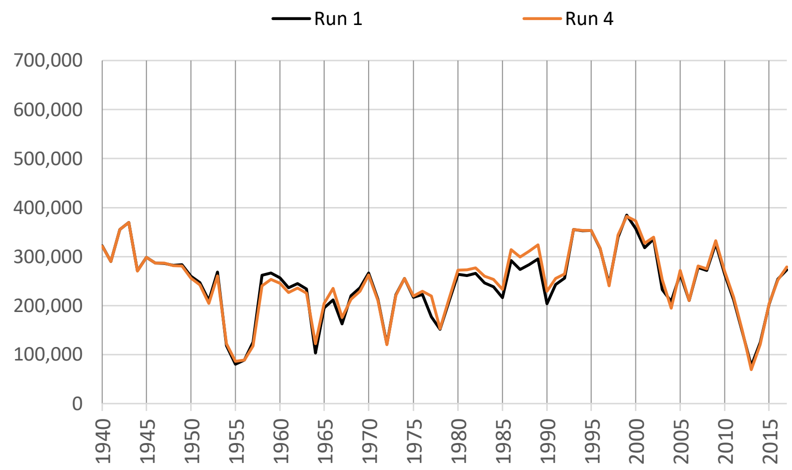


Notes: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).
Pumping includes Supplemental and Primary groundwater pumping.

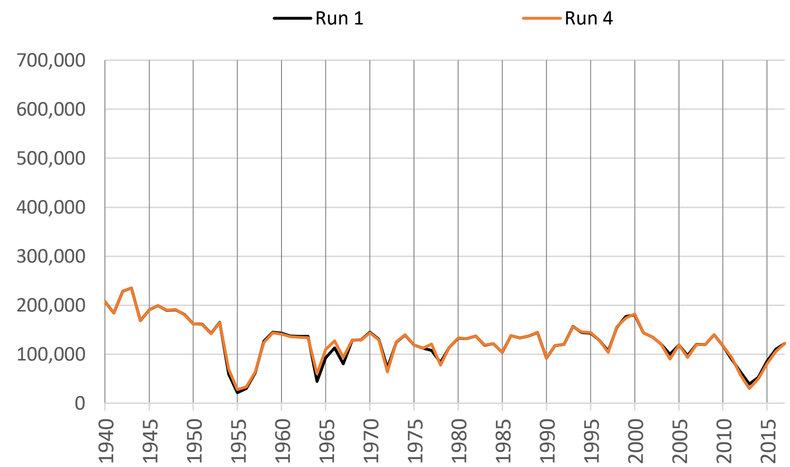
Run 4 - TX Pumping Off
Irrigation Season Summary of Irrigation Operations
Run 4 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

EPCWID Total

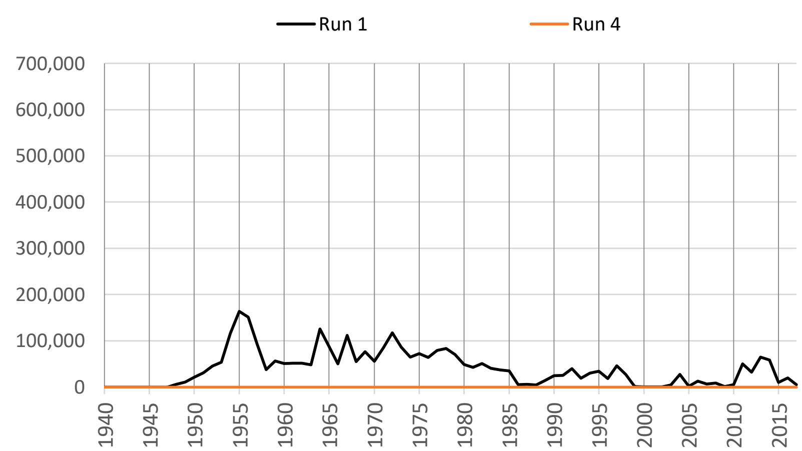
Net River Headgate Diversions



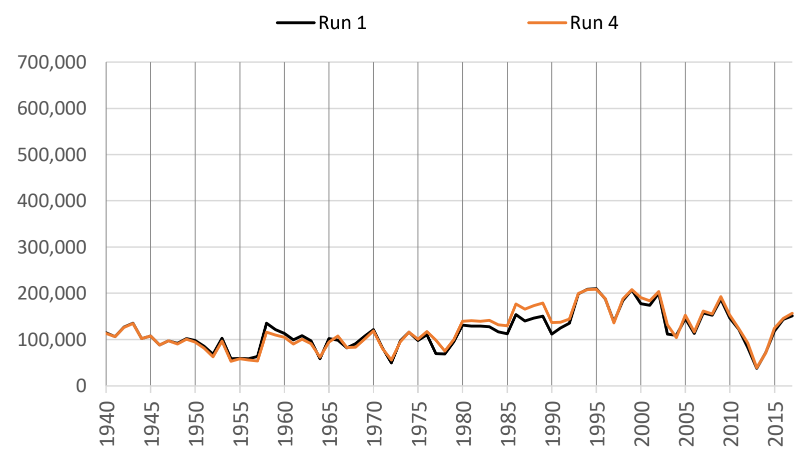
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries

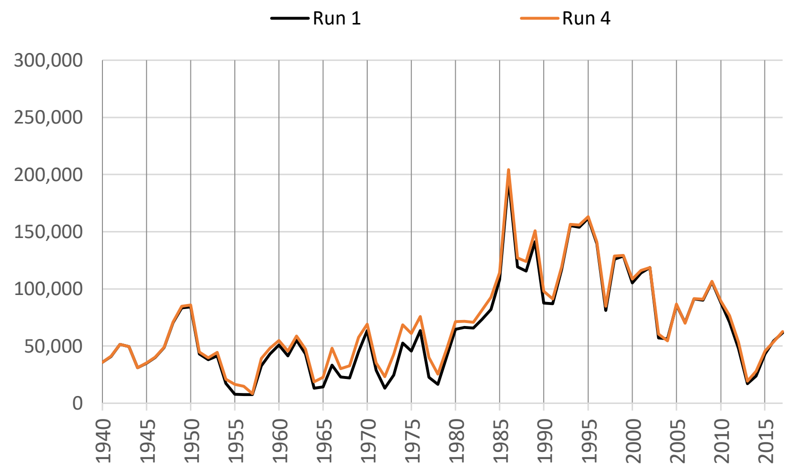


Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

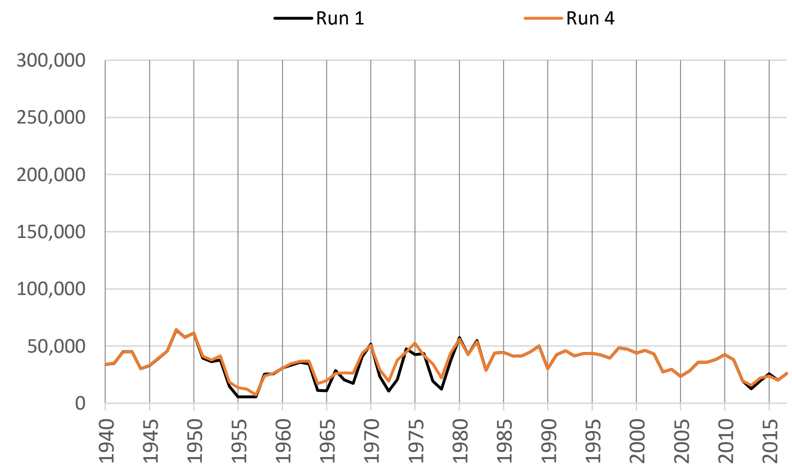
Run 4 - TX Pumping Off
Irrigation Season Summary of Irrigation Operations
Run 4 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

HCCRD Total

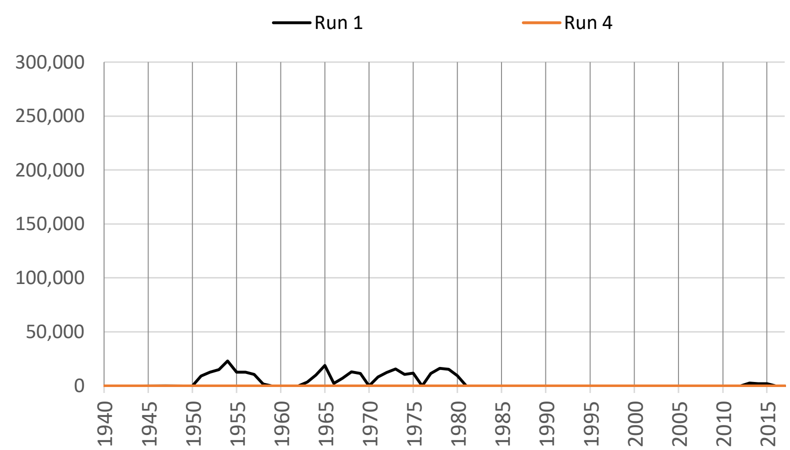
Net River Headgate Diversions



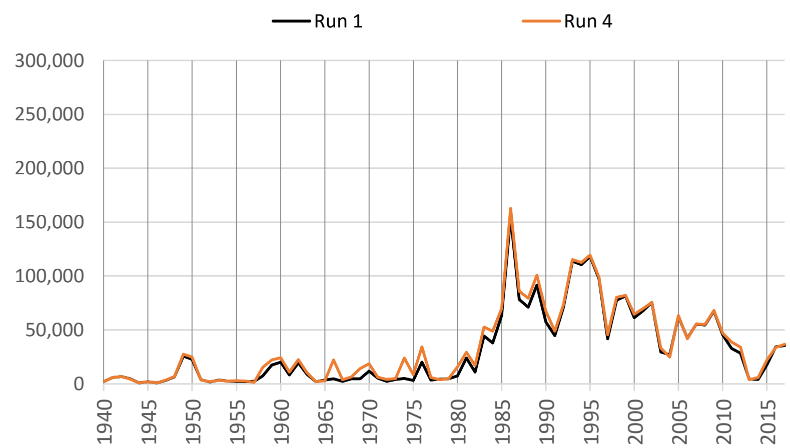
Farm Headgate Deliveries



Pumping



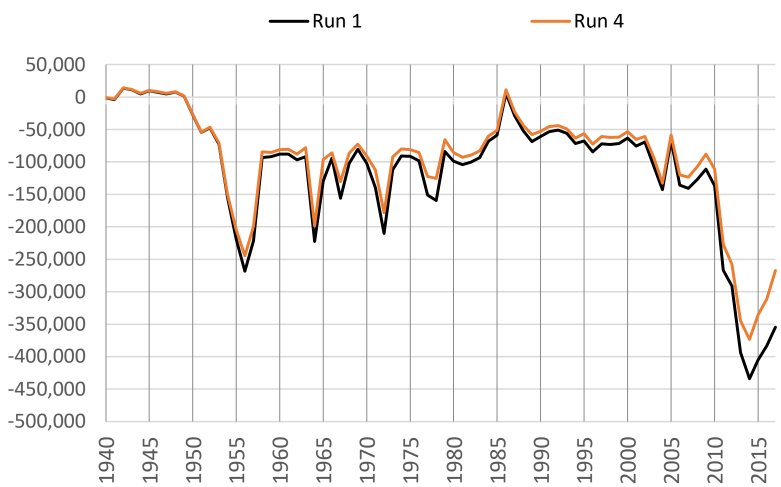
RHG Diversions - FHG Deliveries



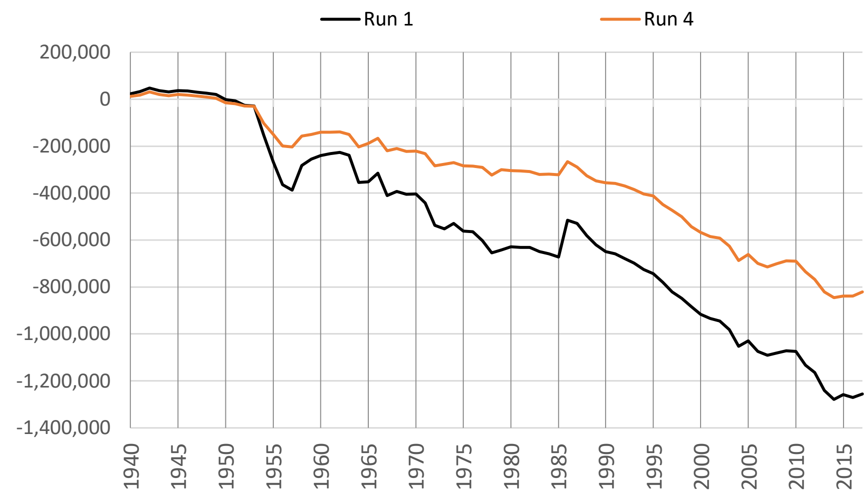
Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

Run 4 - TX Pumping Off
Cumulative Change in Ground Water Storage
Run 4 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

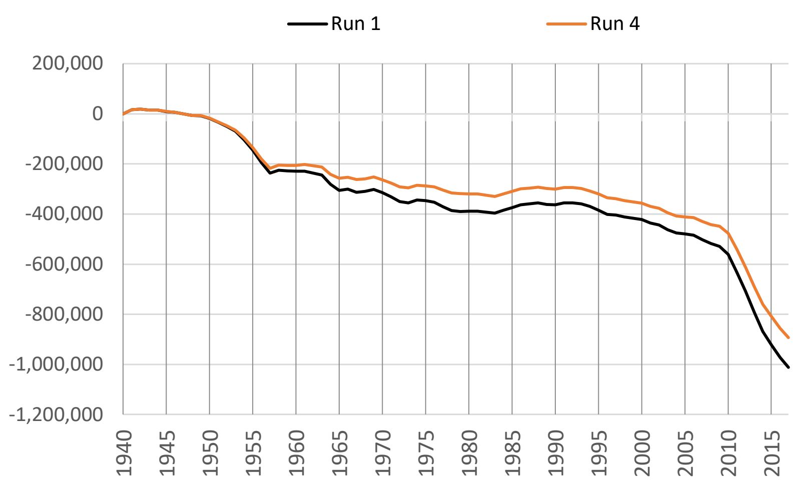
Rincon-Mesilla Alluvial Aquifer



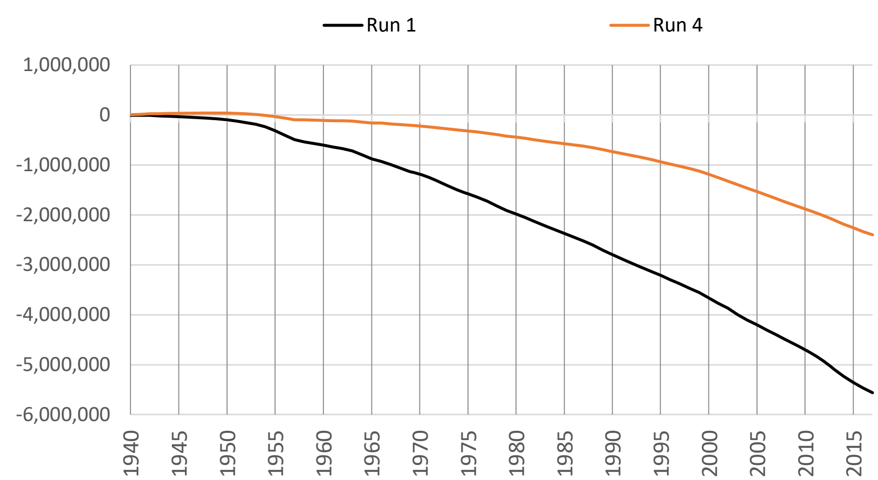
Hueco Alluvial Aquifer



Rincon-Mesilla Non-Alluvial Aquifer

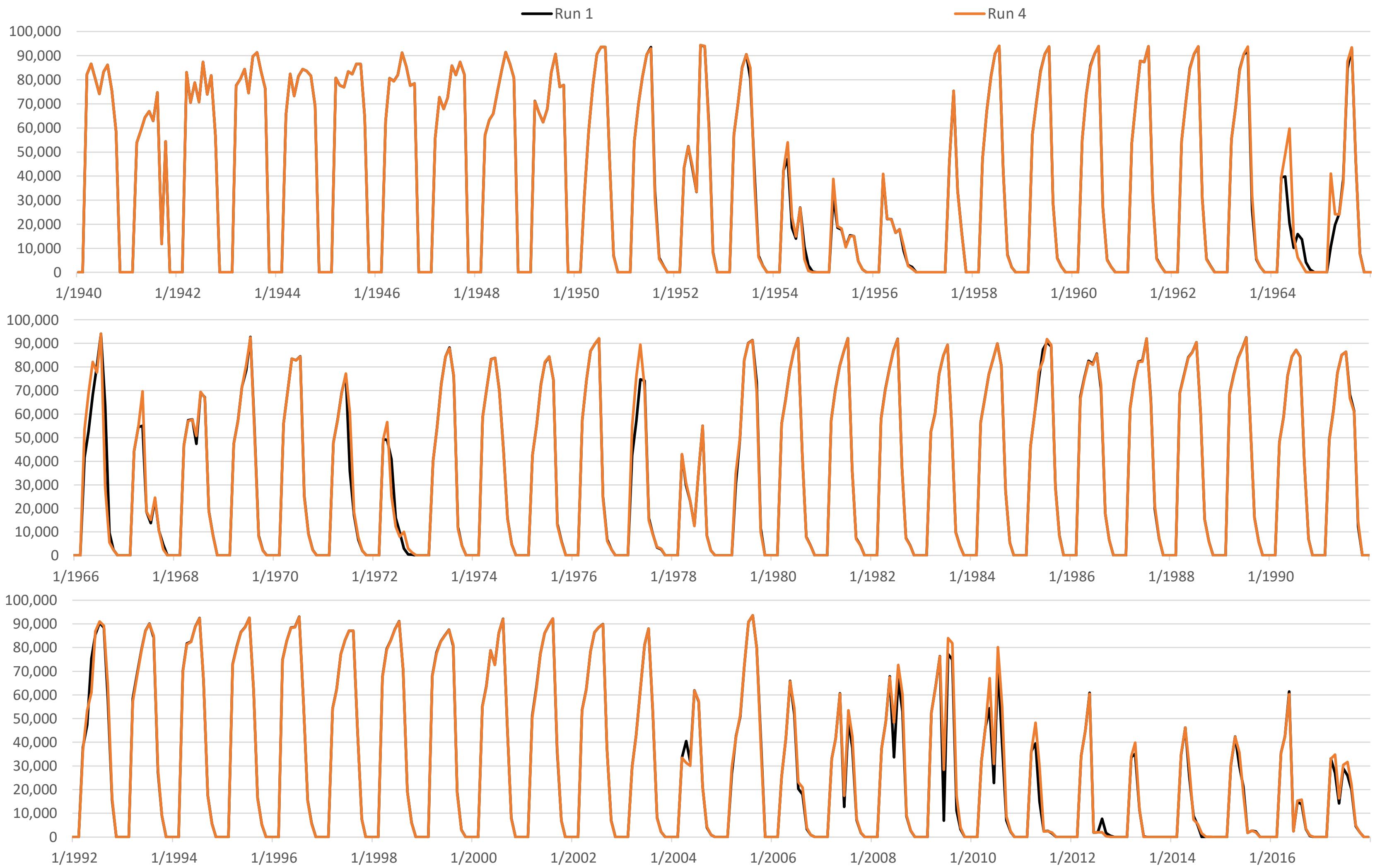


Hueco Non-Alluvial Aquifer



***Note different scales.**

Run 4 - TX Pumping Off
Monthly Net RHG Diversions
Run 4 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
EBID Total



Note: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

Run 4 - TX Pumping Off

Monthly Net RHG Diversions

Run 4 v. Run 1

ILRG Model

1940 - 2017 (acre-feet)

EPCWID Total

Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

Run 4 - TX Pumping Off

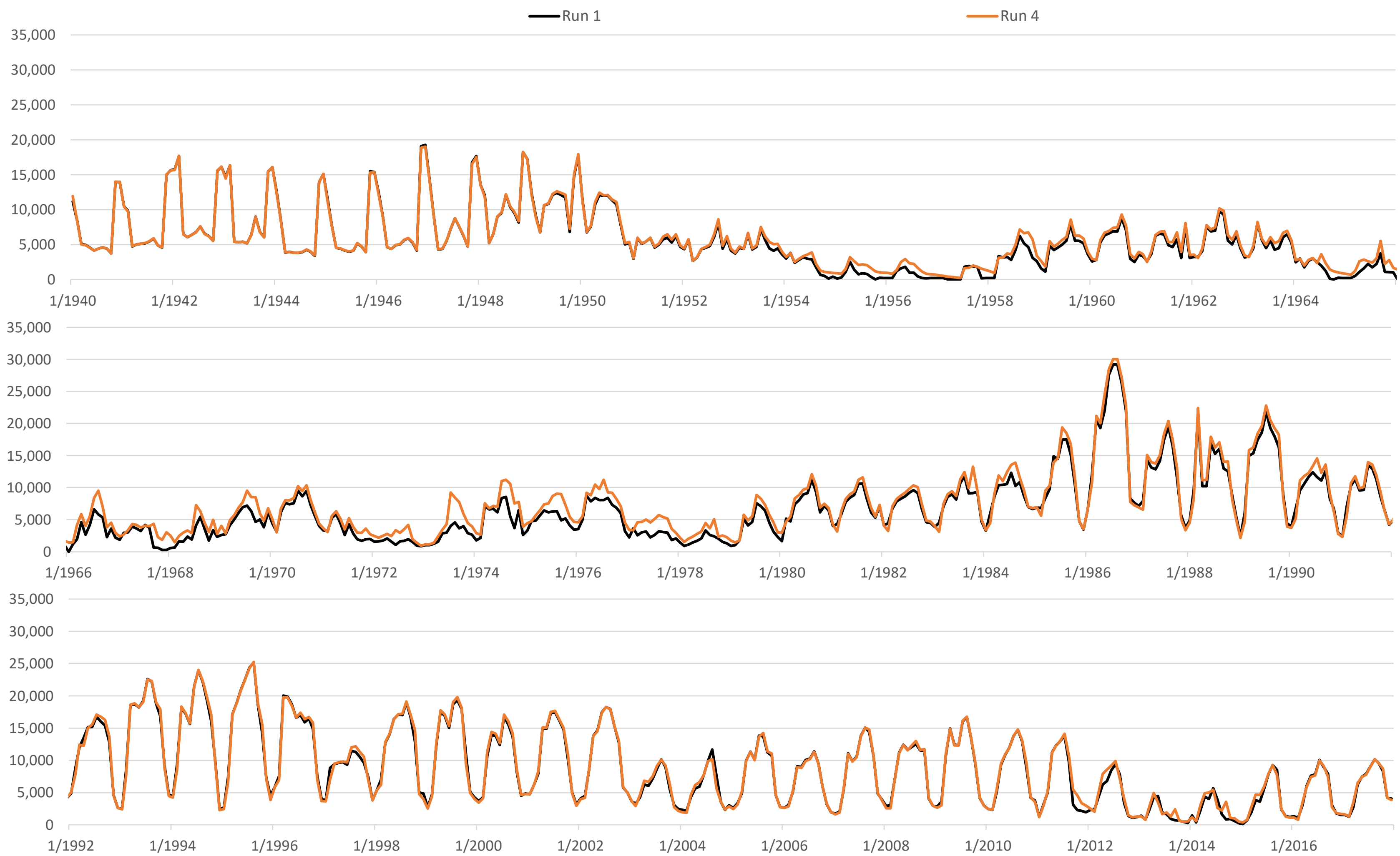
Monthly Net RHG Diversions

Run 4 v. Run 1

ILRG Model

1940 - 2017 (acre-feet)

HCCRD Total



Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

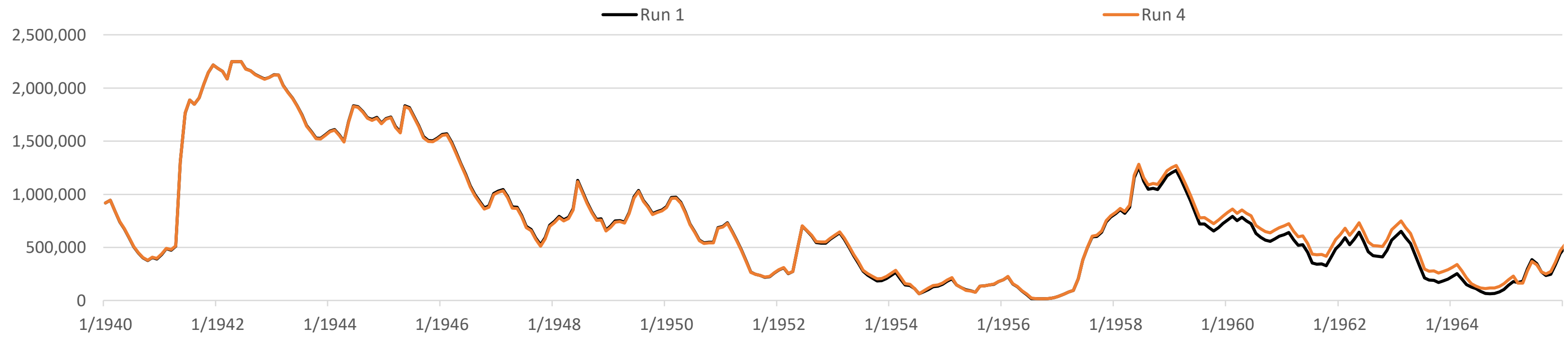
Run 4 - TX Pumping Off

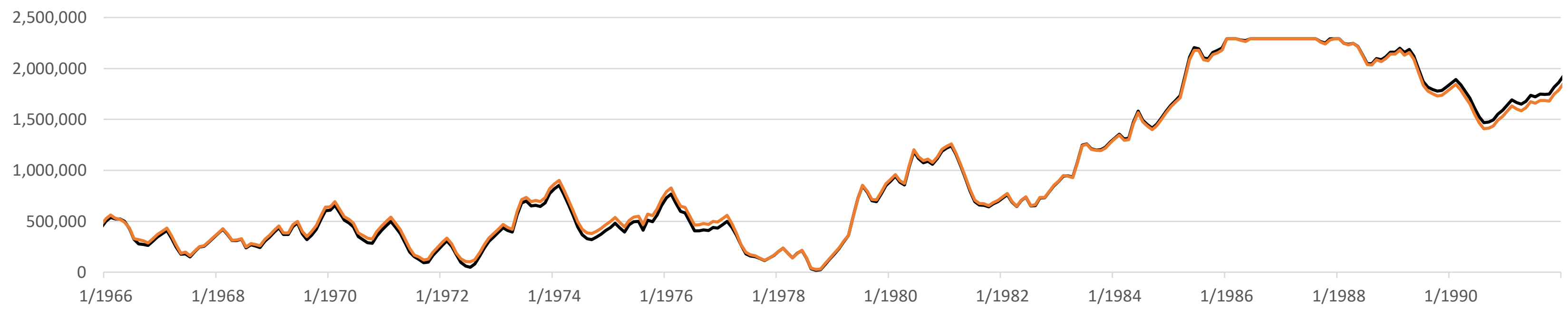
End of Month Reservoir Storage (Elephant Butte + Caballo)

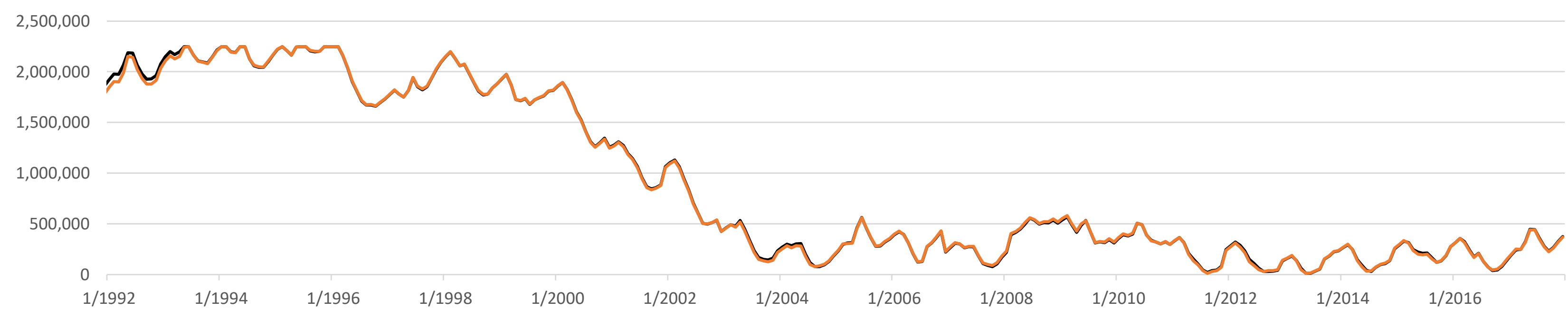
Run 4 v. Run 1

ILRG Model

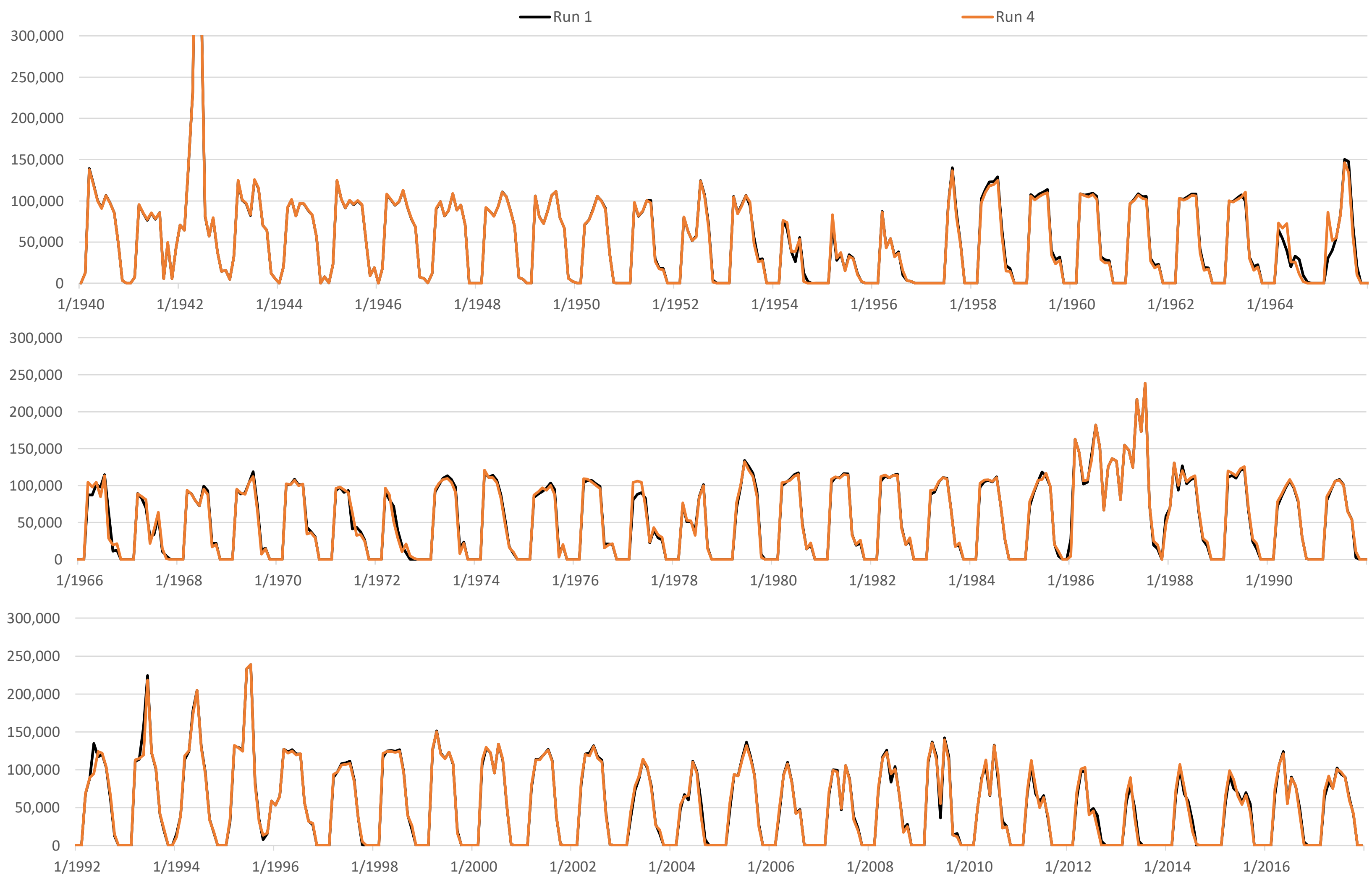
1940 - 2017 (acre-feet)







Run 4 - TX Pumping Off
Monthly Caballo Releases
Run 4 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)



Run 4 - TX Pumping Off
Monthly Rio Grande at El Paso Flow
Run 4 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

Run 4 - TX Pumping Off
Monthly Rio Grande at Fort Quitman Flow
Run 4 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

Appendix 30E

Comparison of ILRG Model Runs
Run 5 v. Run 1

Model Run Specifications

Model Version: LRG_v116

Name: **Run 5 - MX Pumping Off**

Run ID: LRG_v116_Operational_Run5
Date: 8/25/2020

Name: **Run 1 - Historical Base Run**

Run ID: LRG_v116_Operational_Run1
Date: 8/23/2020

Selected Model Inputs

Pumping and Returns	**Run 5**	**Run 1**
Irrigation Pumping	MX Off	On
Irrigated Area	Hist	Hist
Non-Irrigation Pumping	MX Off	On
Non-Irrigation Pumping Returns	MX Off	On
Las Cruces Jornada Pumping Returns	On	On
Project Allocation Rules		
1950-2005	D1/D2	D1/D2
2006-2007	D3	D3
2008-2017	D3 + CO	D3 + CO
EPCWID Operations		
Charge EPCWID for Use of WWTP Returns	Off	Off
ACE and Haskell Credits for EPCWID	On	On
Increased EPCWID Use of Fabens Drain Flows	Off	Off
Charge EPCWID for Fabens Drain Flow Use	Off	Off

Run 5 - MX Pumping Off

Comparison of ILRG Model Runs

Run 5 v. Run 1

1951 - 2017 Annual Average

(1,000 acre-feet)

Run No.	1	5	5 - 1		
Simulated Input or Output	**Run 1**	**Run 5**	**Run 5 minus Run 1**		
Pumping Stress					
Irrigation Pumping	62.8	0.0	-62.8		
Non-Irrigation Pumping	181.0	109.2	-71.7		
WWTP Flows	58.0	34.3	-23.8		
Urban Deep Percolation	13.1	13.1	0.0		
Total Stress	172.7	61.9	-110.7		
	Stress is Pumping minus WWTP and Urban Deep Perc				
Effects of Pumping Stress				***% Chg***	
FHG Deliveries (Mar - Oct)				***Stress***	***% Diff.***
EBID	167.6	169.1	1.5	*-1%*	*1%*
EPCWID (incl. EPW)	139.9	141.4	1.5	*-1%*	*1%*
HCCRD	32.8	33.6	0.7	*-1%*	*2%*
Total	340.3	344.0	3.7	*-3%*	*1%*
FHG Deliveries (Nov - Feb)					
EBID	0.0	0.0	0.0	*0%*	*-2%*
EPCWID (incl. EPW)	0.2	0.2	0.0	*0%*	*-8%*
HCCRD	2.4	2.4	0.0	*0%*	*-1%*
Total	2.6	2.6	0.0	*0%*	*-1%*
Irrigation Pumping					
EBID	140.4	139.0	-1.5	*1%*	*-1%*
EPCWID (Mesilla Valley)	7.4	7.3	-0.1	*0%*	*-1%*
EPCWID (El Paso Valley)	40.1	38.9	-1.3	*1%*	*-3%*
HCCRD	4.2	2.9	-1.3	*1%*	*-31%*
	192.1	188.0	-4.1	*4%*	*-2%*
	Pumping turned off.	*Other values are simulated responses and are totaled.*			
Other Inflows/Outflows					
Net Reservoir Evaporation	125.3	126.4	1.1	*-1%*	*1%*
Riparian ET	70.9	77.0	6.1	*-5%*	*9%*
River Evaporation + Incidental Canal Loss	30.3	30.1	-0.2	*0%*	*-1%*
Total	226.6	233.5	7.0	*-6%*	*3%*
Rio Grande at Fort Quitman					
Reservoir Spills	33.3	36.3	3.0	*-3%*	*9%*
Nov-Feb Flows	21.4	30.4	9.0	*-8%*	*42%*
Mar - Oct Flows	41.1	54.2	13.1	*-12%*	*32%*
Underflow (GW Model)	0.2	0.2	0.0	*0%*	*16%*
Total	96.0	121.2	25.2	*-23%*	*26%*

Run 5 - MX Pumping Off
Comparison of ILRG Model Runs
Run 5 v. Run 1
1951 - 2017 Annual Average
(1,000 acre-feet)

Run No.	1	5	5 - 1		
Simulated Input or Output	**Run 1**	**Run 5**	**Run 5 minus Run 1**		
Effects of Pumping Stress (continued)				***% Chg***	
Change in Storage				***Stress***	***% Diff.***
Reservoir Storage	-4.7	-4.8	-0.1	*0%*	*3%*
Alluvial GW Storage (RW Model)	-23.6	-6.2	17.4	*-16%*	*-74%*
Non-alluvial GW Storage (GW Models)	-96.4	-51.2	45.1	*-41%*	*-47%*
Soil Moisture Storage	0.6	0.4	-0.2	*0%*	*-26%*
Total	-124.0	-61.8	62.2	*-56%*	*-50%*
Summary of Effects					
FHG Deliveries (Mar-Oct)	340.3	344.0	3.7	*-3%*	*1%*
FHG Deliveries (Nov-Feb)	2.6	2.6	0.0	*0%*	*-1%*
Irrigation Pumping	192.1	188.0	-4.1	*4%*	*-2%*
Riparian ET + Evaporation	226.6	233.5	7.0	*-6%*	*3%*
Fort Quitman Flow	96.0	121.2	25.2	*-23%*	*26%*
Change in Storage	-124.0	-61.8	62.2	*-56%*	*-50%*
Total	733.6	827.5	94.0	*-85%*	*13%*
Other Effects of Pumping Stress				***% Chg***	
Rio Grande at El Paso				***Stress***	***% Diff.***
Reservoir Spills	49.4	48.3	-1.1	*1%*	*-2%*
Nov-Feb Flows	22.8	23.0	0.2	*0%*	*1%*
Mar - Oct Flows	263.8	263.5	-0.2	*0%*	*0%*
Total	336.0	334.8	-1.2	*1%*	*0%*
Rio Grande below Caballo					
Reservoir Spills	65.9	63.5	-2.4	*2%*	*-4%*
Nov-Feb Flows	0.5	0.6	0.1	*0%*	*23%*
Mar - Oct Flows	541.3	542.6	1.3	*-1%*	*0%*
Total	607.6	606.7	-0.9	*1%*	*0%*
Surface Water Diversions (Mar - Oct)					
EBID	366.5	368.9	2.4	*-2%*	*1%*
EPCWID (incl. EPW)	236.8	236.5	-0.3	*0%*	*0%*
HCCRD	67.5	71.5	3.9	*-4%*	*6%*
Total	670.8	676.9	6.0	*-5%*	*1%*
Surface Water Diversions (Nov - Feb)					
EBID	0.0	0.0	0.0	*0%*	*0%*
EPCWID (incl. EPW)	14.3	14.4	0.1	*0%*	*0%*
HCCRD	14.2	16.3	2.1	*-2%*	*15%*
Total	28.5	30.7	2.1	*-2%*	*8%*

Run 5 - MX Pumping Off
Annual Differences in ILRG Model Outputs
Run 5 minus Run 1
1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1940	3	3	-152	475	-246	83	-13	-13	464	517	-223	-223	-4,018	-3,818	157
1941	-113	-113	-693	71	-262	35	0	1	-37	99	-229	-161	3,487	2,229	4,518
1942	-4	-4	-312	485	111	101	3	4	-280	118	71	88	-690	494	4,058
1943	7	7	-330	266	44	161	-11	-11	-263	-158	78	242	-1,961	-1,899	277
1944	15	15	-310	81	-195	-100	-7	-7	156	247	-157	-45	-2,132	-2,065	110
1945	12	12	-249	248	-160	13	-8	-9	155	294	-141	-118	-2,154	-2,114	163
1946	6	6	-370	338	-180	18	-12	-12	96	443	-160	-144	-2,306	-2,263	132
1947	10	10	-674	-40	-210	-192	-11	-11	-131	300	-174	-187	-2,669	-2,619	6
1948	16	16	-597	63	-202	-7	-9	-9	36	346	-78	-50	-2,768	-2,717	3,623
1949	17	17	-424	270	-188	123	-7	-7	246	406	12	25	-2,719	-2,679	6,432
1950	1	1	-532	-333	-71	151	-8	-8	86	86	8	15	-2,414	-2,372	4,261
1951	1,018	1,018	-409	-441	17	149	553	553	236	236	39	110	-1,541	-1,815	8,870
1952	198	198	-689	-711	148	292	380	379	221	219	156	95	-6,625	-4,884	7,154
1953	180	180	-739	-753	104	317	1,159	1,158	207	205	135	99	-1,663	-2,733	12,700
1954	3,318	3,318	2,641	2,634	925	1,056	5,732	5,732	5,569	5,568	902	1,116	2,389	6,160	9,552
1955	8,708	8,708	6,244	6,133	-488	-757	4,497	4,497	4,387	4,202	-368	-532	18,975	9,243	352
1956	-3,077	-3,077	-1,740	-1,740	-559	-677	-2,347	-2,347	-1,786	-2,282	-824	-1,171	-5,292	-2,175	-87
1957	0	0	-9	-20	-12	35	-12	-12	11	-238	-149	-295	75	8	-82
1958	-3	-3	-3,096	-3,132	1,082	3,006	0	0	12	-87	-414	-765	-4,808	-3,260	3,296
1959	0	0	-1,801	-1,837	3,043	4,886	-1	-1	219	219	6	23	-4,509	-3,930	7,073
1960	1	1	-1,715	-1,615	2,365	3,678	-13	-13	247	247	0	0	-6,844	-6,385	7,011
1961	3	3	-2,674	-2,448	2,766	4,367	-21	-21	1,664	1,664	1,294	-874	-8,959	-8,411	15,046
1962	6	6	-2,681	-2,450	2,528	4,036	-15	-15	349	349	414	478	-8,874	-8,469	19,027
1963	8,877	8,877	-3,427	-3,199	2,228	3,698	4,798	4,798	423	424	948	976	-2,521	-5,887	19,745
1964	15,982	15,982	11,569	11,920	3,846	4,966	8,501	8,501	8,026	7,697	3,329	3,574	20,306	11,770	17,271
1965	2,819	2,819	-916	-952	2,580	4,816	1,357	1,357	914	596	2,464	4,819	-3,747	-200	1,003
1966	-20	-20	-2,612	-2,300	5,992	8,632	127	127	-22	-20	-3,351	-4,245	-7,744	-4,043	14,078
1967	9,251	9,251	7,253	8,001	4,985	7,348	5,760	5,760	6,583	6,089	4,090	4,926	11,094	6,899	12,048
1968	927	927	-4,611	-3,890	5,656	8,920	835	835	201	-200	6,001	7,379	-5,862	-2,877	5,253
1969	4	4	-4,606	-4,542	6,957	10,374	205	205	-100	-99	5,099	3,034	-7,695	-5,972	20,191
1970	1	1	-4,534	-4,525	5,297	8,058	5	5	33	33	-1,268	-2,376	-8,832	-7,917	26,348
1971	13,048	13,048	-2,715	-2,244	4,966	8,186	7,930	7,930	373	374	4,009	5,968	2,106	-3,397	13,122
1972	-1,070	-1,070	-1,178	-986	4,869	7,096	4,972	4,972	230	148	4,561	5,053	-6,112	64	10,548
1973	-72	-72	-3,871	-3,900	2,284	4,369	-102	-102	357	288	2,252	2,809	-2,861	-4,536	3,696
1974	-4	-4	-3,788	-3,822	5,214	10,399	-31	-31	460	460	1,165	1,064	-6,665	-5,957	18,325
1975	-219	-219	-3,459	-3,445	8,282	13,821	1,042	1,042	169	169	7,514	8,997	-8,014	-6,170	19,566
1976	-11	-11	-2,544	-2,554	7,513	13,869	356	356	58	58	-924	-3,065	-5,284	-5,371	31,149
1977	21,799	21,799	-2,322	-1,312	7,542	12,859	13,402	13,402	315	316	7,018	8,191	8,164	-497	14,261
1978	14,393	14,393	10,212	11,647	5,674	11,389	7,817	7,817	12,429	12,431	5,812	6,823	24,247	16,497	16,267

Run 5 - MX Pumping Off

Annual Differences in ILRG Model Outputs

Run 5 minus Run 1

1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1979	-401	-401	-5,546	-5,178	7,839	12,970	130	130	-1,174	-1,169	3,114	737	-9,367	-3,303	27,004
1980	-56	-56	-3,423	-3,233	6,437	10,771	122	122	35	38	-3,919	-7,987	-7,496	-4,238	51,823
1981	-17	-17	-2,966	-2,987	4,772	7,511	183	183	13	13	-56	-339	-4,827	-3,718	39,921
1982	-6	-6	-3,009	-3,021	4,191	6,766	44	44	5	44	-1,041	-2,368	-4,306	-3,572	48,827
1983	-7	-7	-2,366	-2,414	4,372	6,825	37	37	-24	-23	0	0	-3,230	-2,674	36,176
1984	-10	-10	-2,032	-2,013	6,285	8,565	27	27	2	87	0	0	-980	-889	30,826
1985	-16	-16	-1,881	-1,830	4,757	6,960	13	13	-162	-3	0	0	-2,527	-2,054	33,767
1986	-12	-12	-1,950	-1,982	4,125	6,350	77	80	6	9	0	0	20,324	19,934	170,337
1987	-9	-9	-1,909	-1,960	2,719	4,728	10	11	1	2	0	0	-28	-119	70,007
1988	-3	-3	-1,812	-1,868	2,243	4,068	22	22	1	1	0	0	-3,899	-3,041	44,478
1989	-3	-3	-1,891	-1,845	2,230	3,898	10	10	-172	18	0	0	-2,670	-2,397	34,208
1990	-38	-38	-609	-486	4,535	5,946	149	149	-120	159	0	0	425	697	23,745
1991	-19	-19	-406	-416	2,439	3,700	80	80	-92	-4	0	0	-1,020	-737	34,355
1992	1,230	1,230	72,354	72,271	28,846	31,052	-8,171	-8,178	32,201	32,215	0	0	44,882	47,625	65,521
1993	497	497	-6,270	-6,374	260	1,917	632	628	-2,957	-2,963	0	0	-39,052	-39,186	4,230
1994	86	86	-98	-199	1,665	2,845	-175	-175	873	872	0	0	602	-1,043	31,205
1995	113	113	-287	-260	1,692	2,860	-13	-13	557	772	0	0	2,549	1,760	38,696
1996	-41	-41	-1,246	-1,347	1,537	2,772	321	321	31	31	0	0	-5,220	-3,667	36,759
1997	-4	-4	-1,934	-1,822	1,769	2,617	-42	-42	-100	243	0	0	-2,465	-2,483	27,331
1998	-3	-3	-2,281	-2,384	1,489	2,542	-9	-9	-156	-27	0	0	-5,396	-5,011	36,522
1999	124	124	-233	-296	2,415	3,716	4	4	1,823	1,903	0	0	0	-559	38,156
2000	-6	-6	-6,388	-6,457	1,778	3,235	-17	-17	-1,832	-1,832	0	0	-6,453	-6,064	36,192
2001	-8	-8	-2,717	-2,799	2,771	4,336	-10	-10	-4	-4	0	0	-2,423	-2,406	35,203
2002	-5	-5	-2,792	-2,874	2,754	4,291	-8	-8	3	3	0	0	-2,456	-2,417	34,585
2003	14,759	14,759	-1,642	-1,685	2,514	4,168	9,308	9,308	1,041	1,045	0	0	6,823	1,225	26,641
2004	2,563	2,563	1,861	1,897	3,503	5,266	1,714	1,714	2,888	2,891	0	0	2,428	3,395	27,833
2005	-3	-3	-3,900	-3,959	3,860	5,734	77	78	74	76	0	0	-5,346	-3,123	30,791
2006	4,758	4,758	6,444	6,400	4,333	6,234	2,923	2,923	5,585	5,587	0	0	5,397	3,659	33,521
2007	3,320	3,320	1,952	1,987	4,289	6,344	1,564	1,564	5,001	5,004	0	0	5,297	3,636	26,328
2008	6,575	6,575	-6,169	-6,205	3,758	5,673	4,250	4,250	-1,087	-1,085	0	0	-6,565	-5,716	33,811
2009	6,439	6,439	-4,284	-4,380	2,369	3,859	2,832	2,832	47	49	0	0	-3,400	-3,908	36,634
2010	17,893	17,893	-3,524	-3,583	2,230	3,689	11,206	11,206	243	248	0	0	882	-3,074	33,013
2011	12,006	12,006	1,386	1,312	8,303	9,739	6,518	6,518	3,497	3,499	0	0	8,690	2,477	22,728
2012	-573	-573	125	10	9,594	11,838	737	737	2,633	2,634	0	0	-1,749	48	10,732
2013	-3,329	-3,329	-1,169	-1,281	3,168	4,728	-1,715	-1,715	730	730	1,599	2,124	-4,349	-1,156	3,273
2014	42	42	-996	-1,109	4,626	7,331	-67	-67	1,369	1,370	54	2,827	-800	-1,136	-2,335
2015	-1,545	-1,545	-6,731	-6,852	3,945	6,104	-883	-883	12	12	-2,633	-1,437	-10,191	-6,830	9,156
2016	-1,065	-1,065	4,657	4,535	3,966	6,176	-777	-777	8,077	8,079	0	0	11,825	6,391	13,605
2017	4,321	4,321	-9,493	-9,601	2,474	4,378	2,099	2,099	-534	-533	0	0	-10,053	-9,726	20,271
Averages															
1951-2017	2,442	2,442	-319	-250	3,920	5,995	1,494	1,494	1,494	1,478	702	683	-944	-1,159	25,204
1951-1978	3,431	3,431	-651	-446	3,422	5,685	2,389	2,389	1,492	1,395	1,782	1,865	-968	-1,580	11,885
1979-2005	693	693	542	536	4,215	6,163	167	167	1,213	1,274	-70	-369	-1,153	-669	41,301
2006-2017	4,070	4,070	-1,483	-1,564	4,421	6,341	2,390	2,390	2,131	2,133	-82	293	-418	-1,278	20,061
1985-2017	2,062	2,062	490	441	4,029	5,730	990	989	1,802	1,848	-30	106	-180	-455	33,979
1985-2005	914	914	1,618	1,587	3,805	5,381	189	189	1,615	1,686	0	0	-44	16	41,932

Notes:

EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

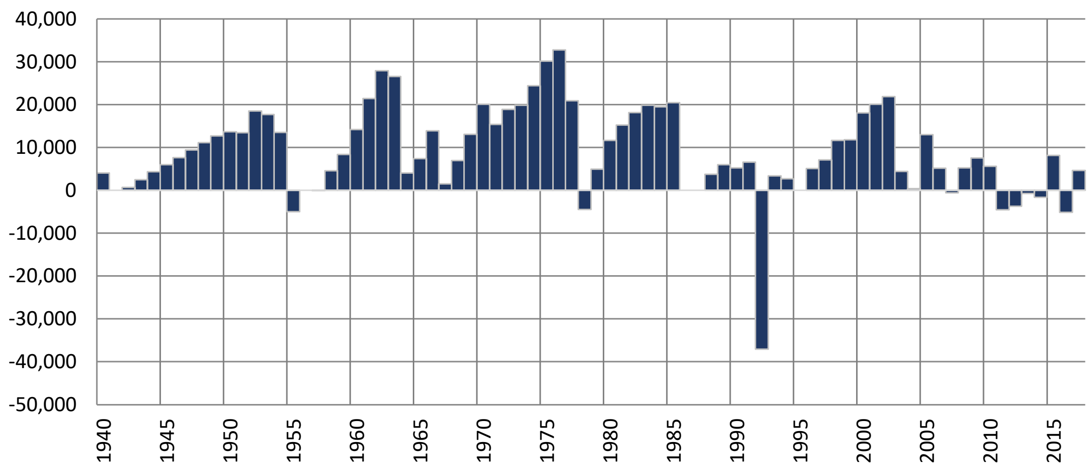
Run 5 - MX Pumping Off

Simulated Differences in ILRG Model Outputs

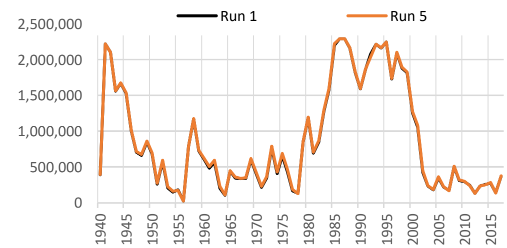
Run 5 minus Run 1

1940 - 2017 (acre-feet)

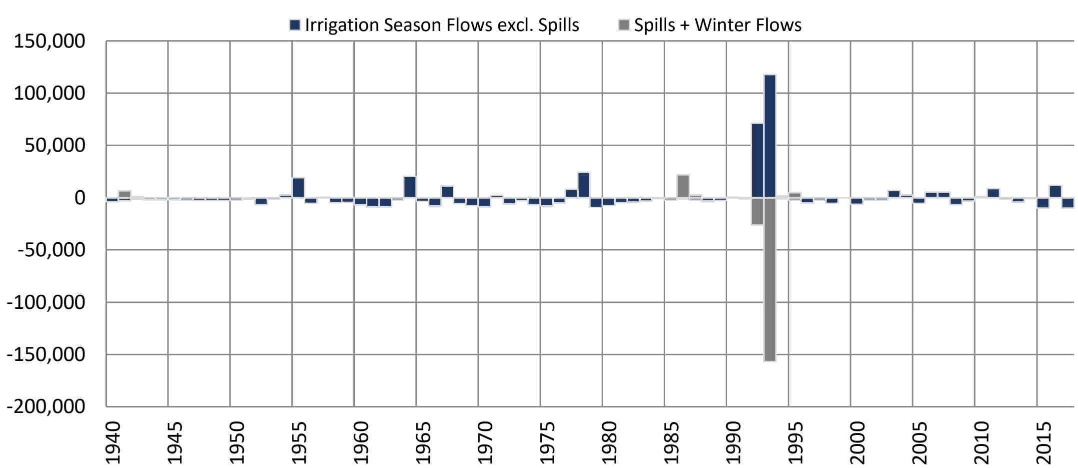
Total Project Storage (Year End)



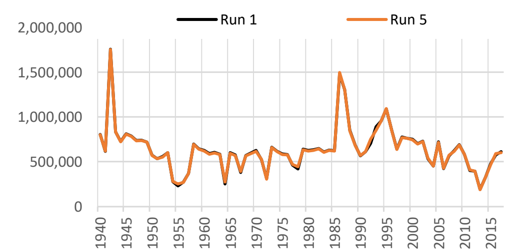
Period	Average Difference
1951-2017	-135
1951-1978	-648
1979-2005	646
2006-2017	-696
1985-2017	-451
1985-2005	-311



Caballo Reservoir Outflows (Annual)



	Average Difference		
Period	Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	1,339	-2,283	-944
1951-1978	-968	0	-968
1979-2005	4,511	-5,664	-1,153
2006-2017	-418	0	-418
1985-2017	4,454	-4,634	-180
1985-2005	7,239	-7,282	-44



Notes:

Reservoir storage does not include storage attributed to SJC, CO, or NM credit waters.

Average differences calculated as (Final Storage - Initial Storage)/(no. years).

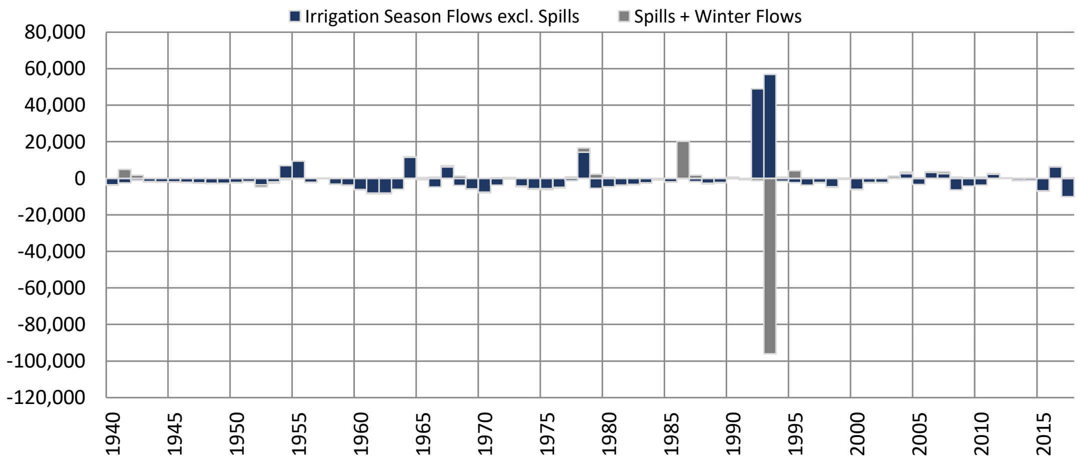
Run 5 - MX Pumping Off

Simulated Differences in ILRG Model Outputs

Run 5 minus Run 1

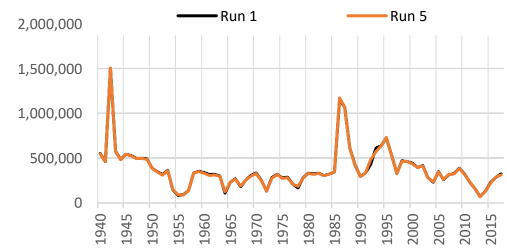
1940 - 2017 (acre-feet)

Rio Grande at El Paso (Annual)

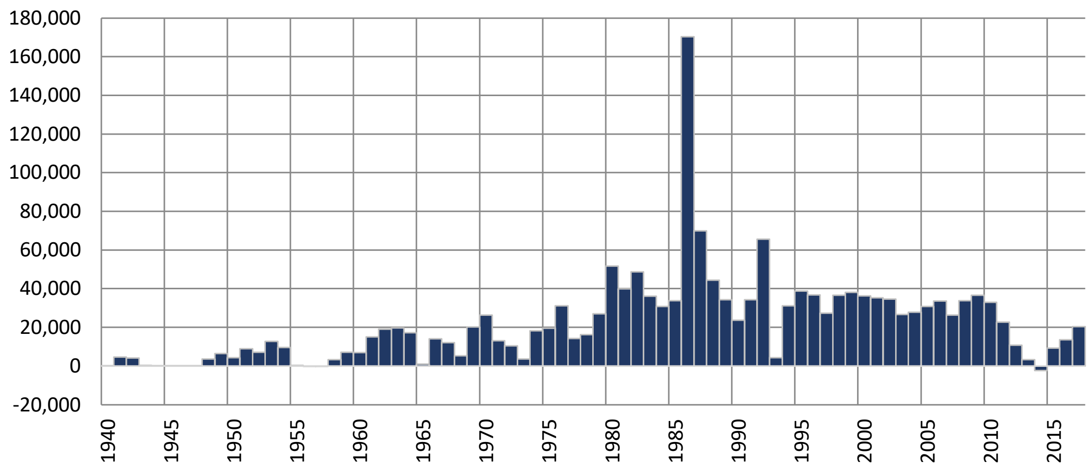


Average Difference

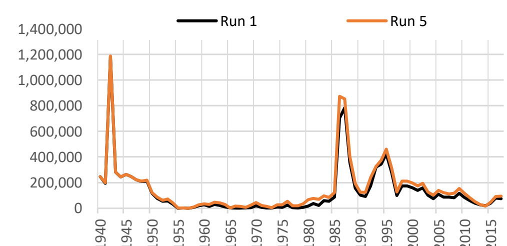
Period	Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	-224	-935	-1,159
1951-1978	-1,617	37	-1,580
1979-2005	1,825	-2,494	-669
2006-2017	-1,582	304	-1,278
1985-2017	1,544	-1,999	-455
1985-2005	3,331	-3,315	16



Rio Grande at Fort Quitman (Annual)



Period	Average Difference
1951-2017	25,169
1951-1978	11,841
1979-2005	41,265
2006-2017	20,053
1985-2017	33,960
1985-2005	41,907



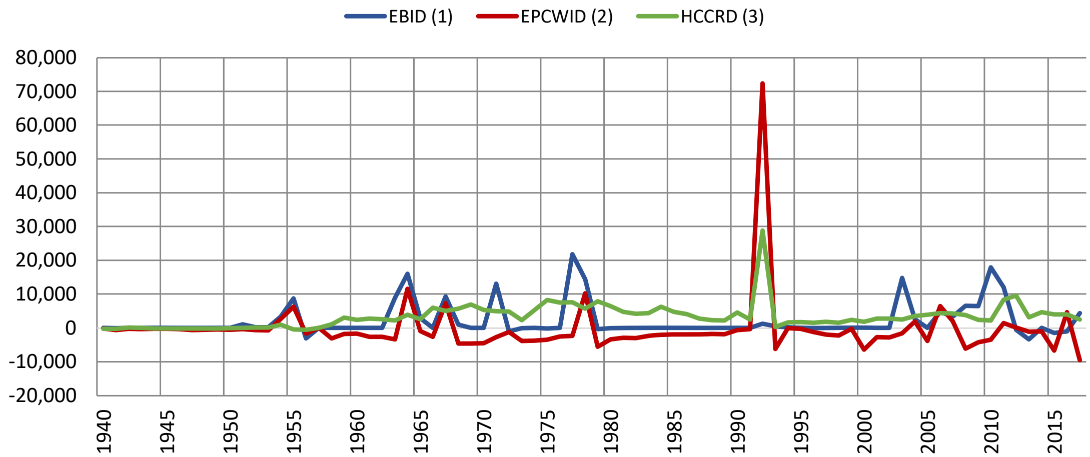
Run 5 - MX Pumping Off

Simulated Differences in ILRG Model Outputs

Run 5 minus Run 1

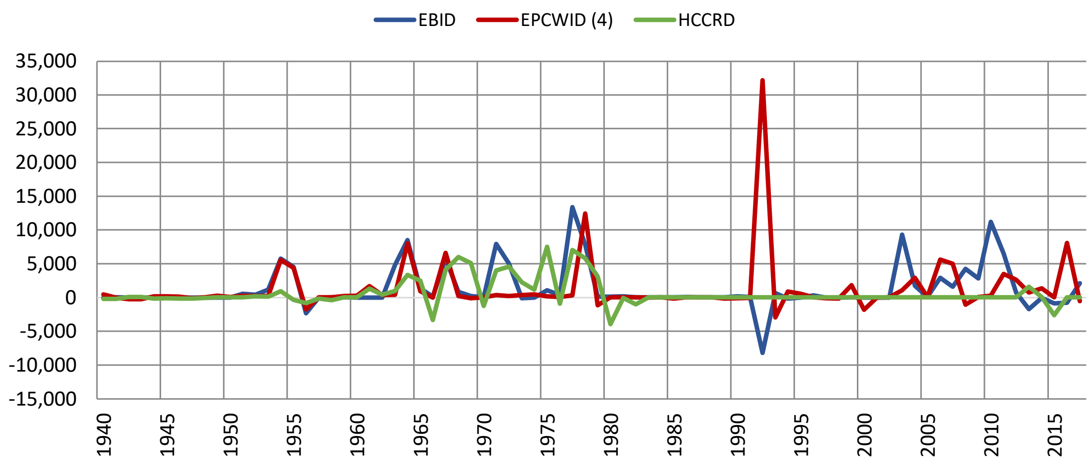
1940 - 2017 (acre-feet)

River Headgate (RHG) Diversions (Irrigation Season)



	Average Difference		
Period	EBID	EPCWID	HCCRD
1951-2017	2,442	-319	3,920
1951-1978	3,431	-651	3,422
1979-2005	693	542	4,215
2006-2017	4,070	-1,483	4,421
1985-2017	2,062	490	4,029
1985-2005	914	1,618	3,805

Farm Headgate (FHG) Deliveries (Irrigation Season)



	Average Difference		
Period	EBID	EPCWID	HCCRD
1951-2017	1,494	1,494	702
1951-1978	2,389	1,492	1,782
1979-2005	167	1,213	-70
2006-2017	2,390	2,131	-82
1985-2017	990	1,802	-30
1985-2005	189	1,615	0

Notes:

(1) EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

(2) EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

(3) HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

(4) EPCWID FHG values include deliveries to Rogers WTP and R/U WTP.

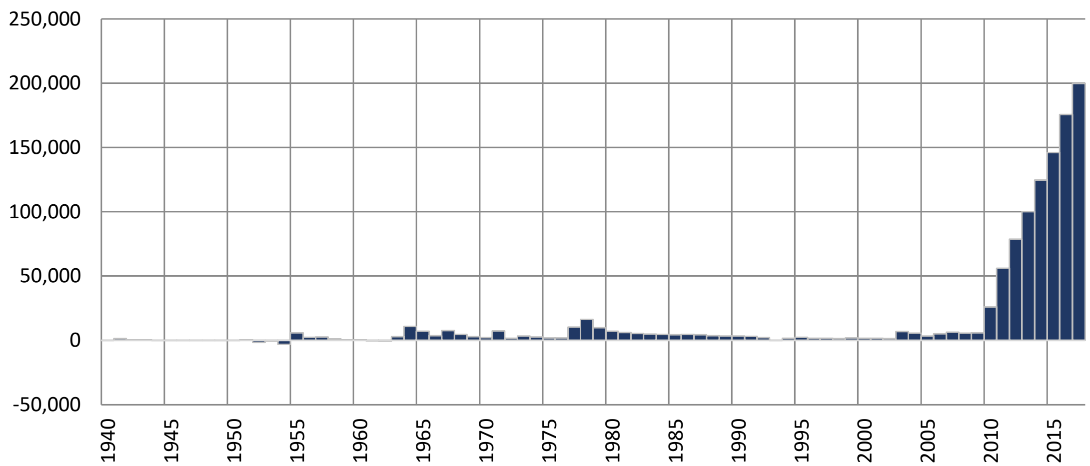
Run 5 - MX Pumping Off

Simulated Differences in ILRG Model Outputs

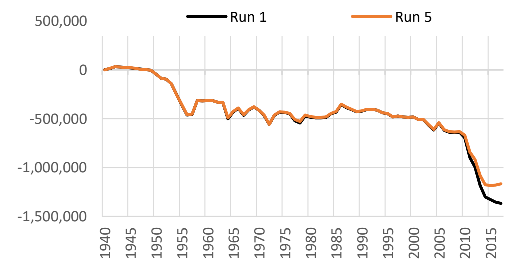
Run 5 minus Run 1

1940 - 2017 (acre-feet)

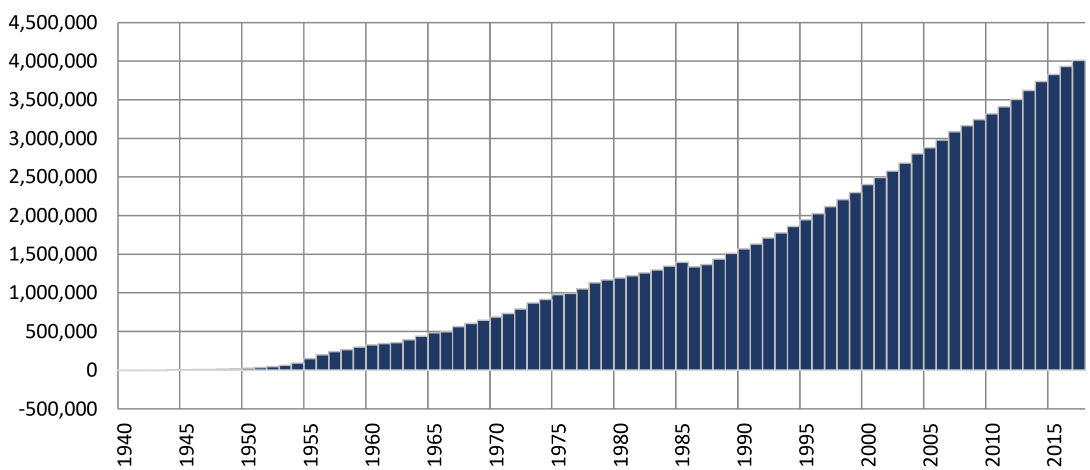
Cumulative Annual Rincon-Mesilla Groundwater Storage



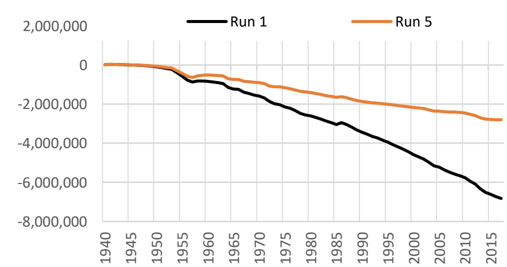
Period	Average Difference
1951-2017	2,980
1951-1978	584
1979-2005	-477
2006-2017	16,348
1985-2017	5,907
1985-2005	-60



Cumulative Annual Hueco Groundwater Storage



Period	Average Difference
1951-2017	59,524
1951-1978	39,524
1979-2005	64,726
2006-2017	94,489
1985-2017	80,745
1985-2005	72,892



Notes:

Cumulative storage change in alluvial and non-alluvial aquifers.

Average differences calculated as (Final Storage - Initial Storage)/(no. years).

Run 5 - MX Pumping Off

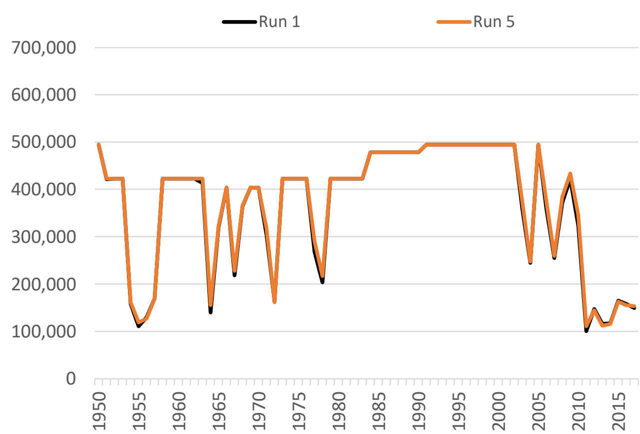
Annual Allocation and Charges

Run 5 v. Run 1

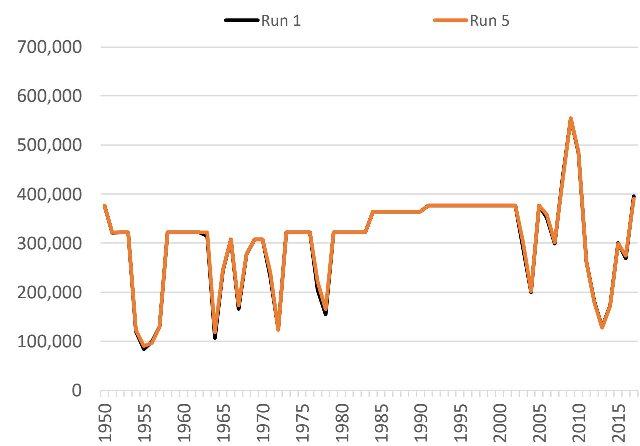
ILRG Model

1950 - 2017 (acre-feet)

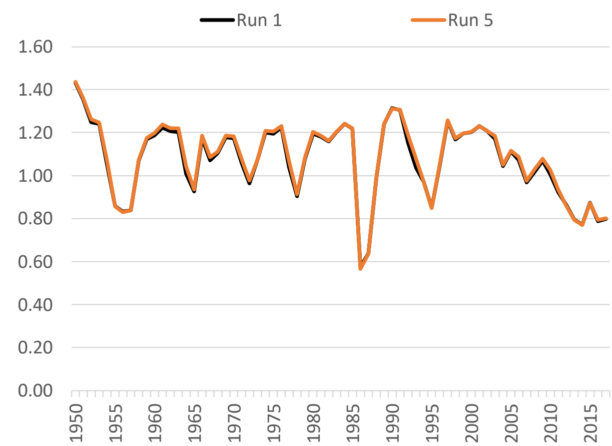
Total Allocation - EBID



Total Allocation - EPCWID



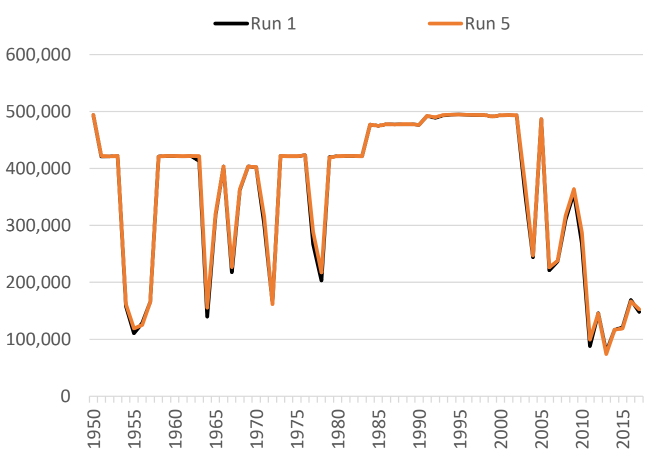
Diversion Ratio



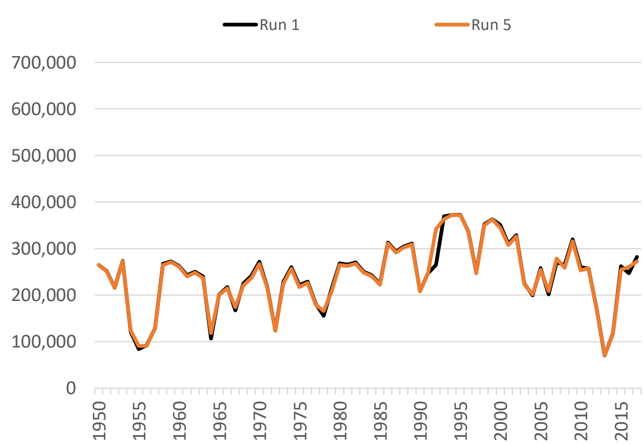
Note:

Computed as Total Charges/Caballo Release.

Annual Delivery Charges - EBID



Annual Delivery Charges - EPCWID



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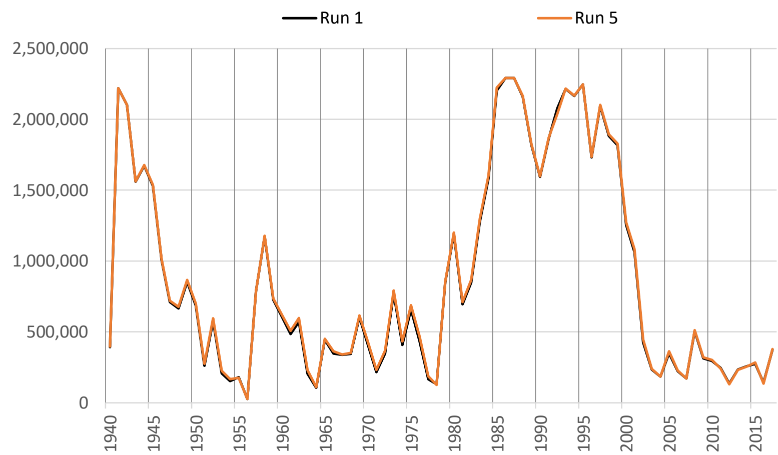
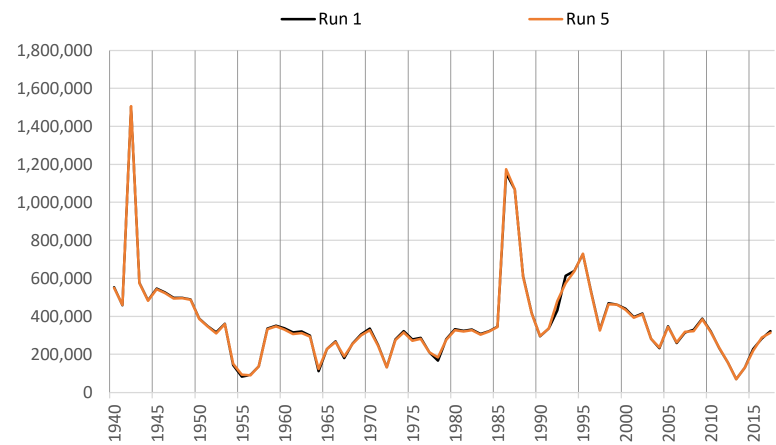
Run 5 - MX Pumping Off
Annual Summary of Project Storage and Rio Grande Flows
Run 5 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

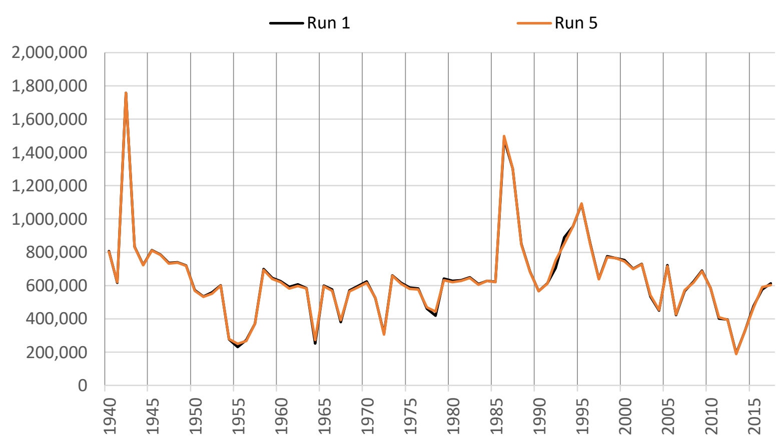
Total Year-End Project Reservoir Storage



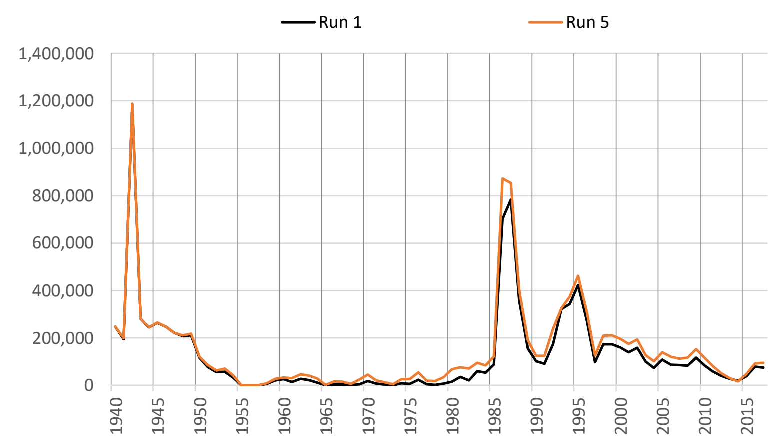
Rio Grande at El Paso



Rio Grande Below Caballo



Rio Grande at Fort Quitman

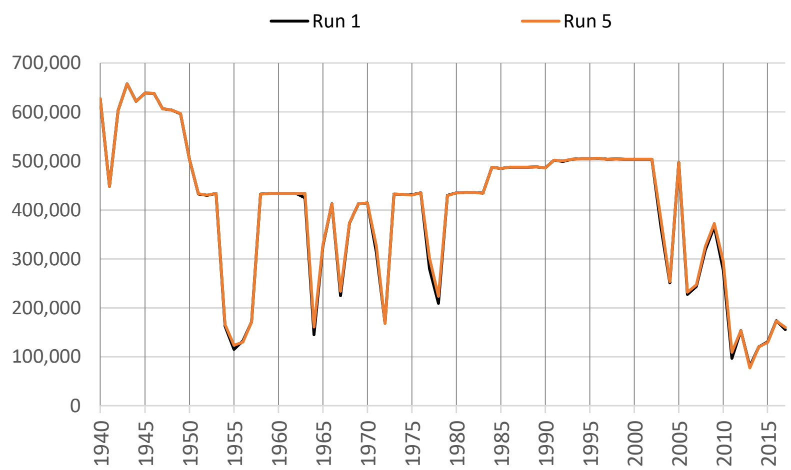


***Note different scales.**

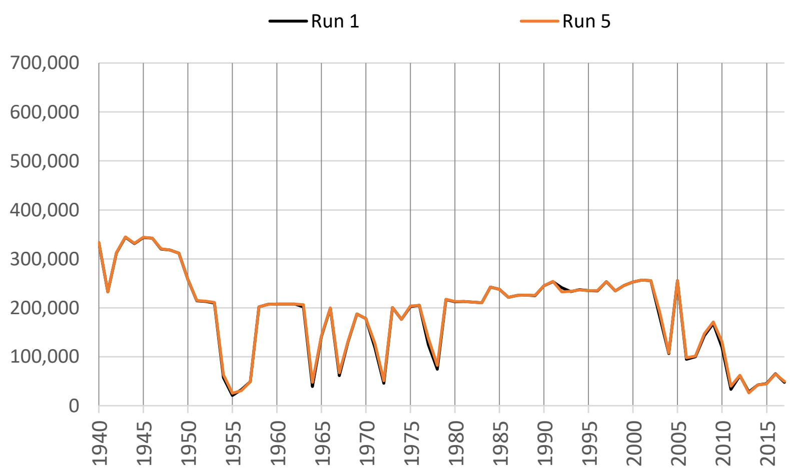
Run 5 - MX Pumping Off
Irrigation Season Summary of Irrigation Operations
Run 5 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

EBID Total

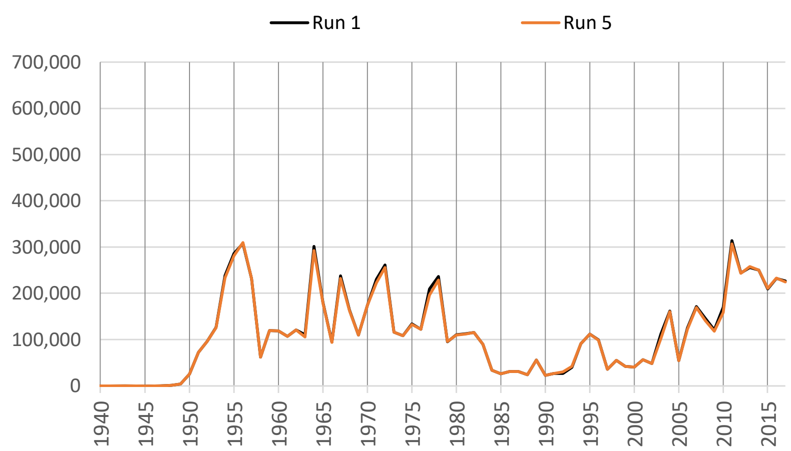
Net River Headgate Diversions



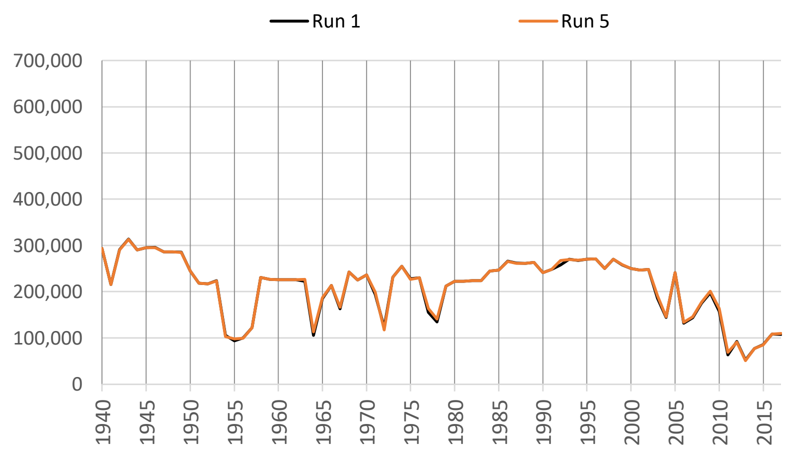
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries

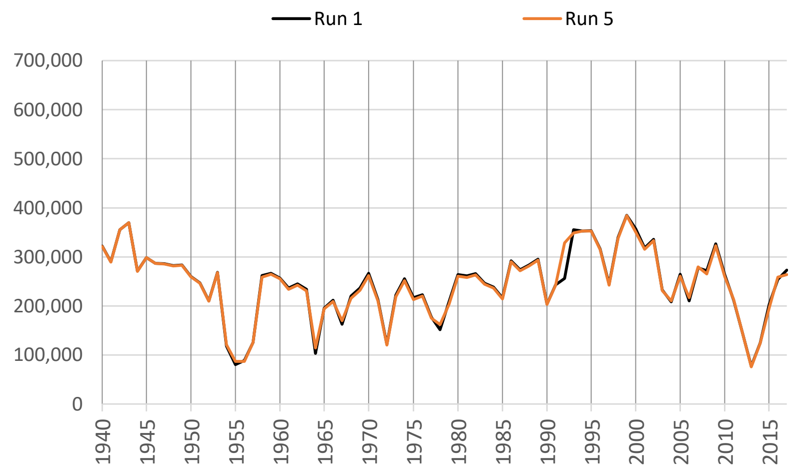


Notes: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).
Pumping includes Supplemental and Primary groundwater pumping.

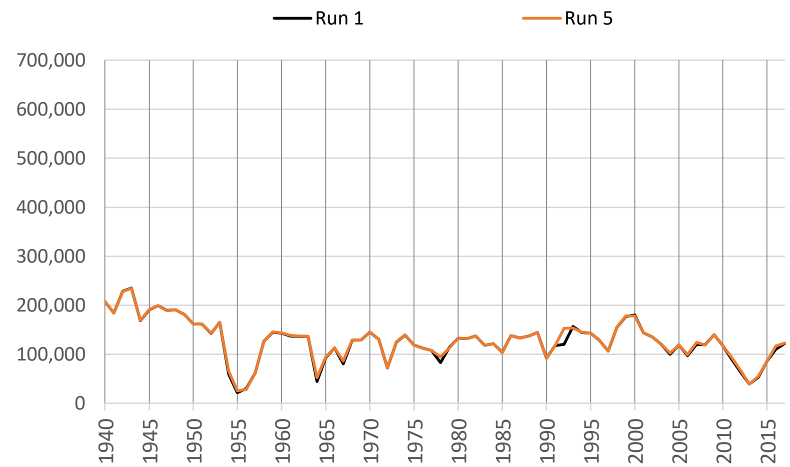
Run 5 - MX Pumping Off
Irrigation Season Summary of Irrigation Operations
Run 5 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

EPCWID Total

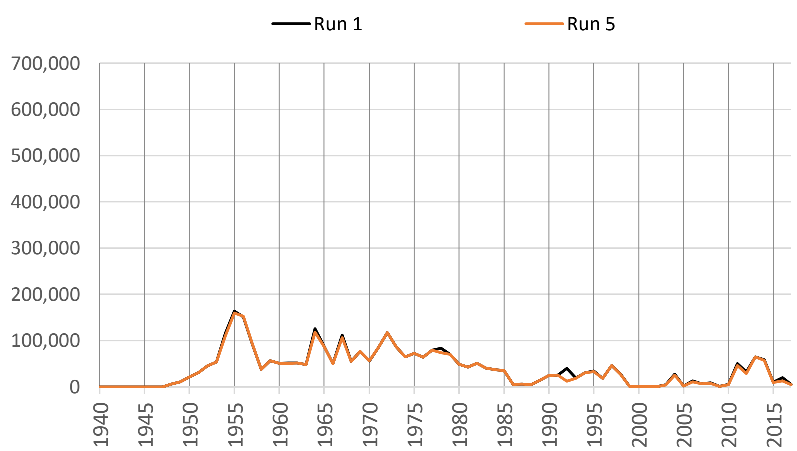
Net River Headgate Diversions



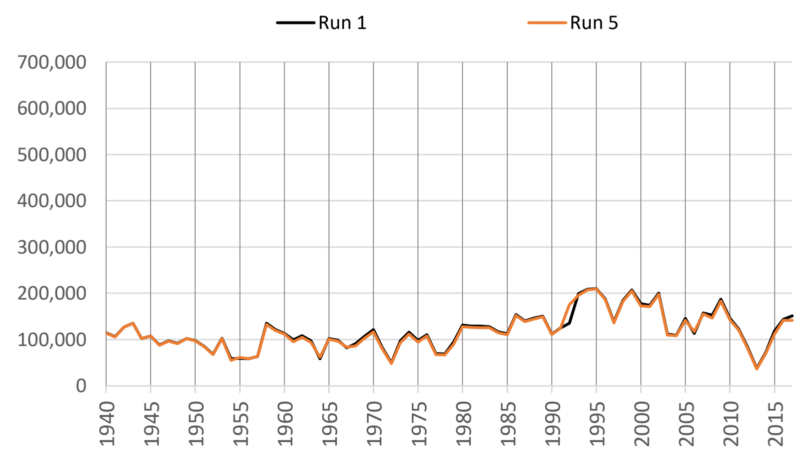
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries

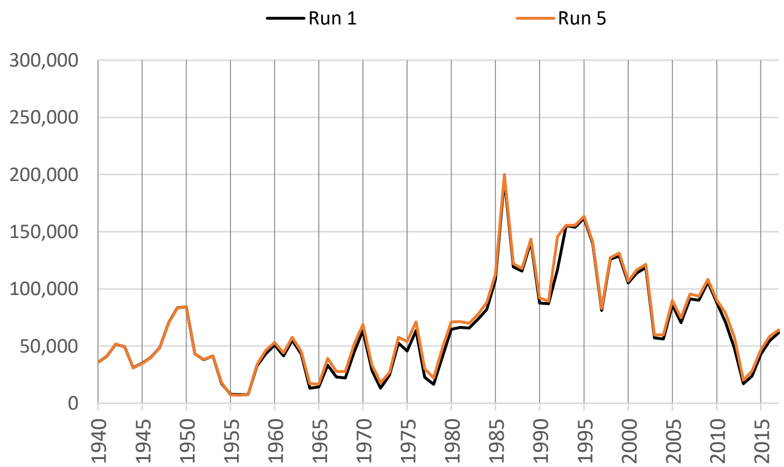


Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

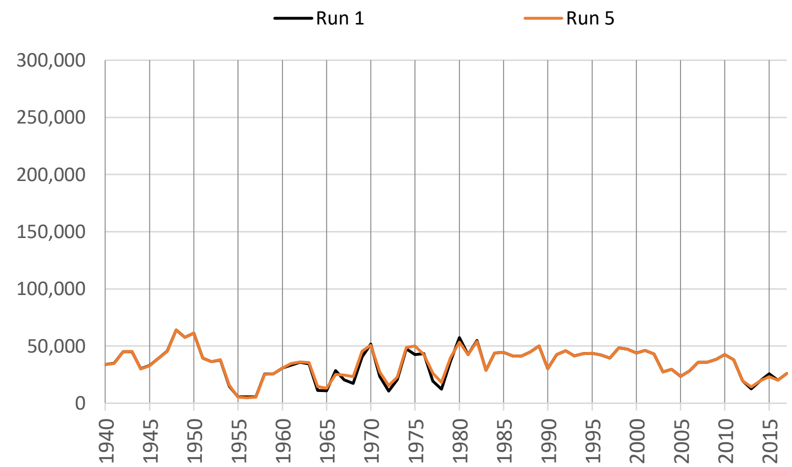
Run 5 - MX Pumping Off
Irrigation Season Summary of Irrigation Operations
Run 5 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

HCCRD Total

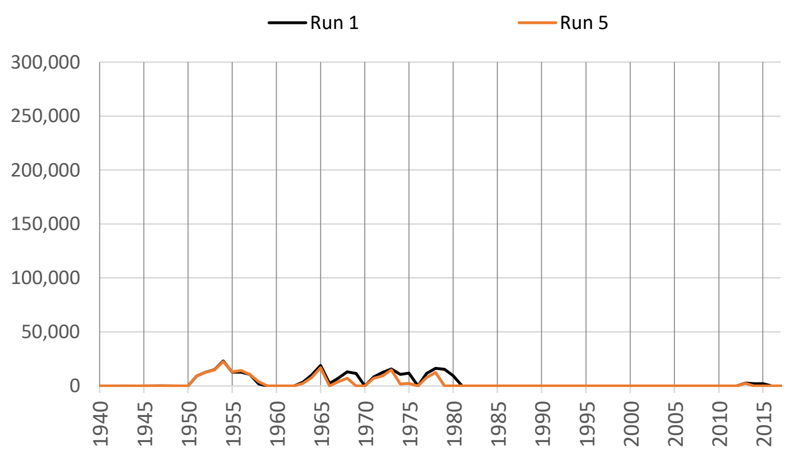
Net River Headgate Diversions



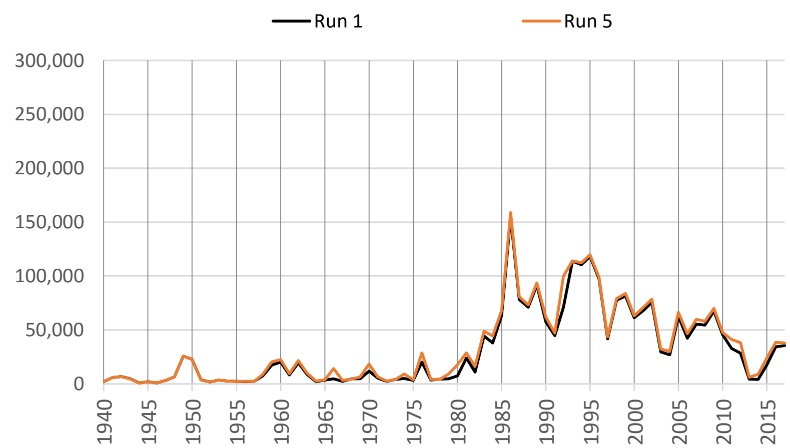
Farm Headgate Deliveries



Pumping



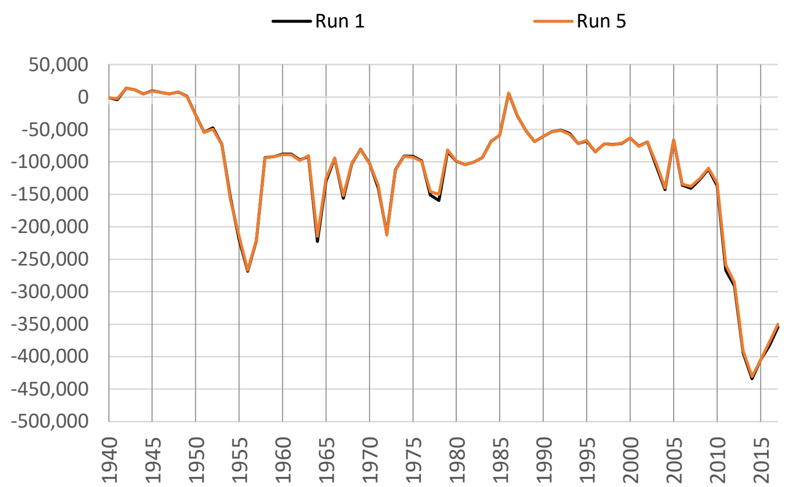
RHG Diversions - FHG Deliveries



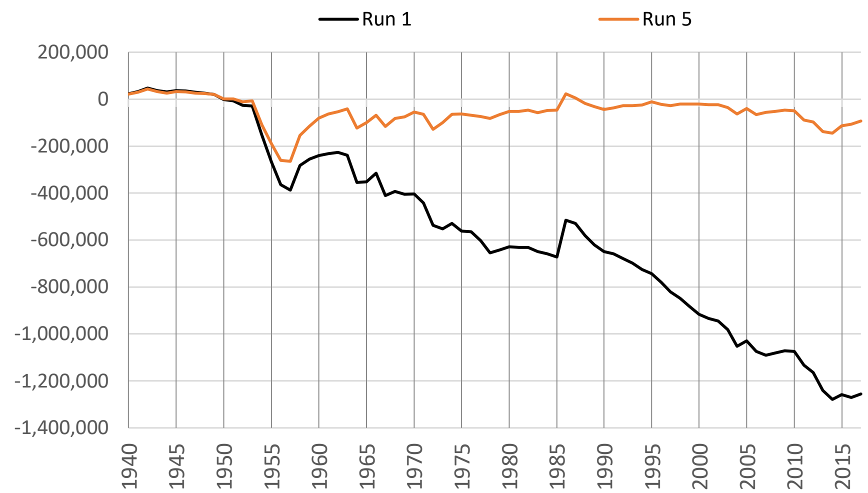
Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

Run 5 - MX Pumping Off
Cumulative Change in Ground Water Storage
Run 5 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

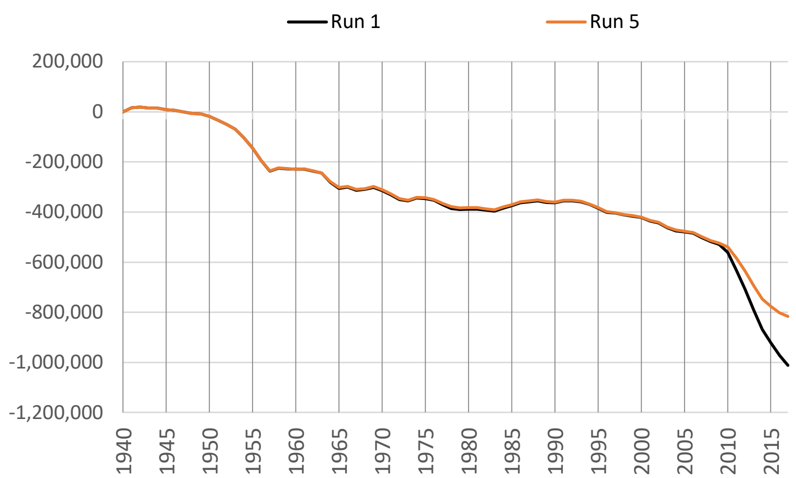
Rincon-Mesilla Alluvial Aquifer



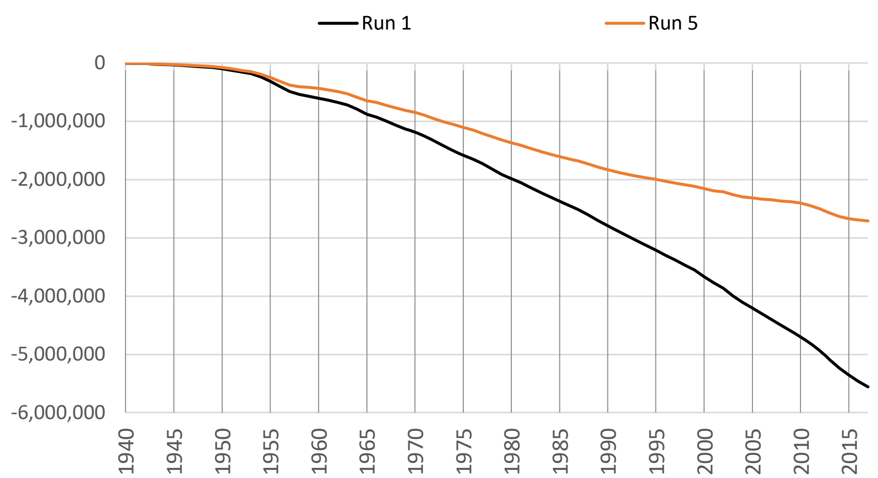
Hueco Alluvial Aquifer



Rincon-Mesilla Non-Alluvial Aquifer

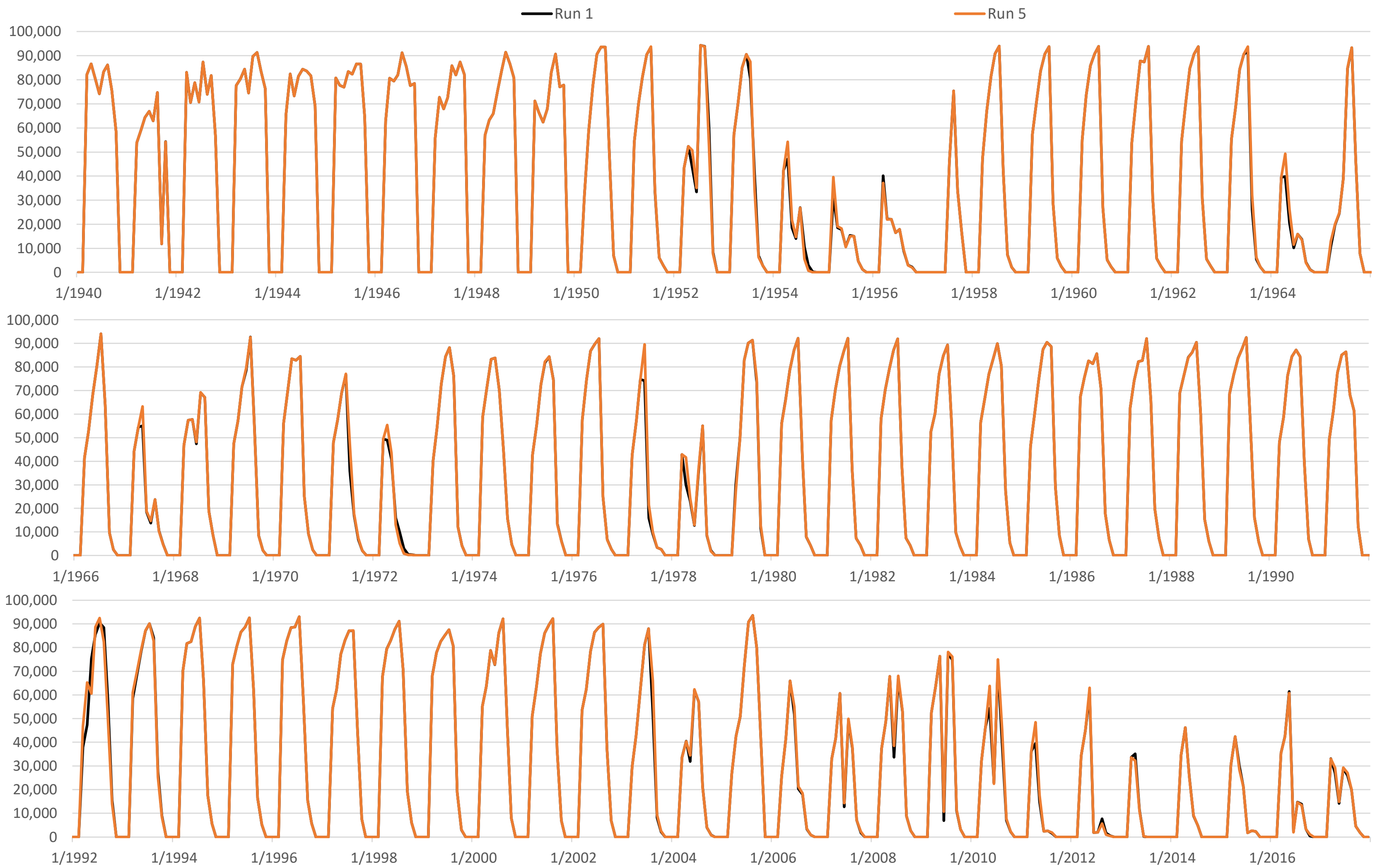


Hueco Non-Alluvial Aquifer



***Note different scales.**

Run 5 - MX Pumping Off
Monthly Net RHG Diversions
Run 5 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
EBID Total



Note: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

Run 5 - MX Pumping Off

Monthly Net RHG Diversions

Run 5 v. Run 1

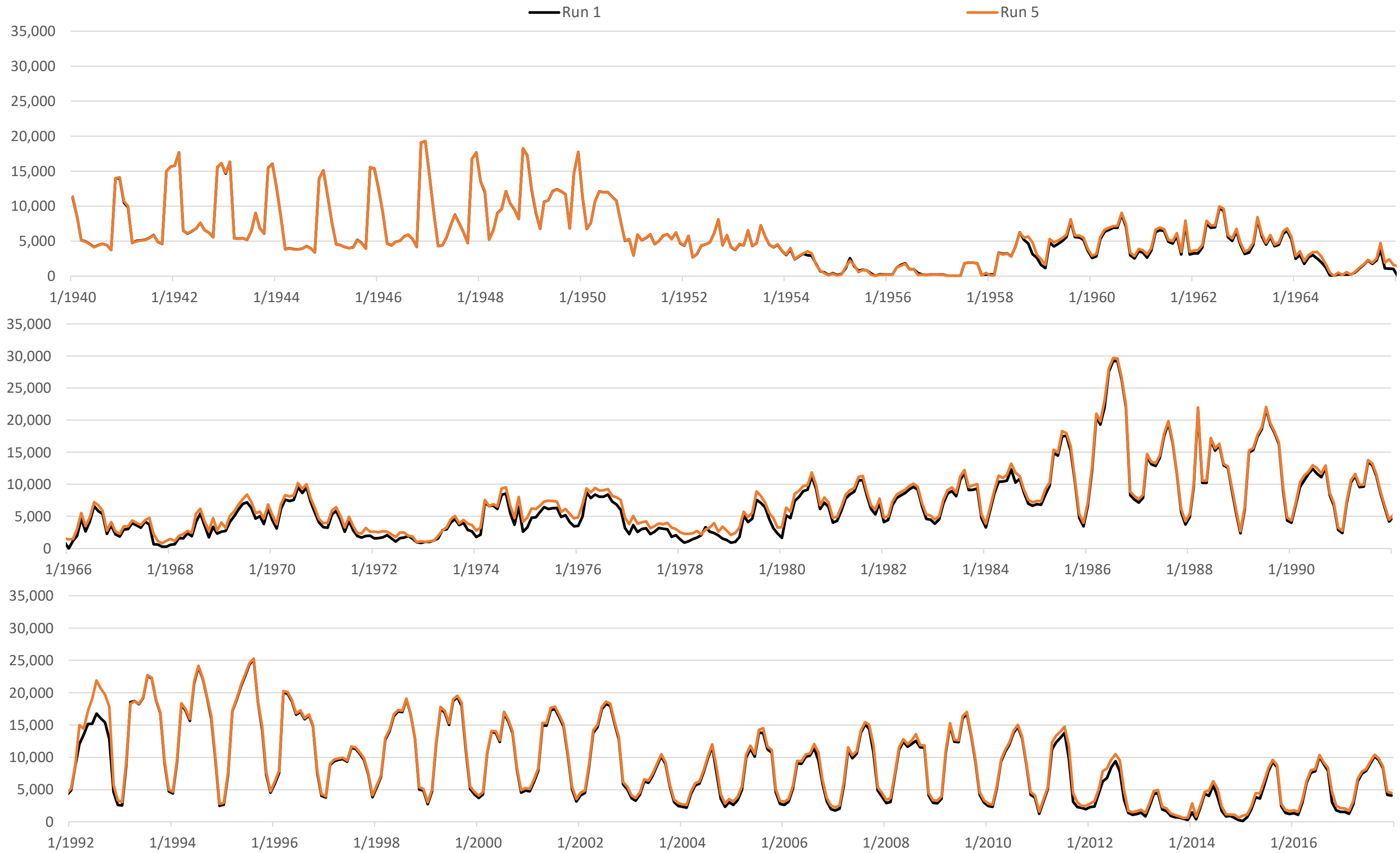
ILRG Model

1940 - 2017 (acre-feet)

EPCWID Total

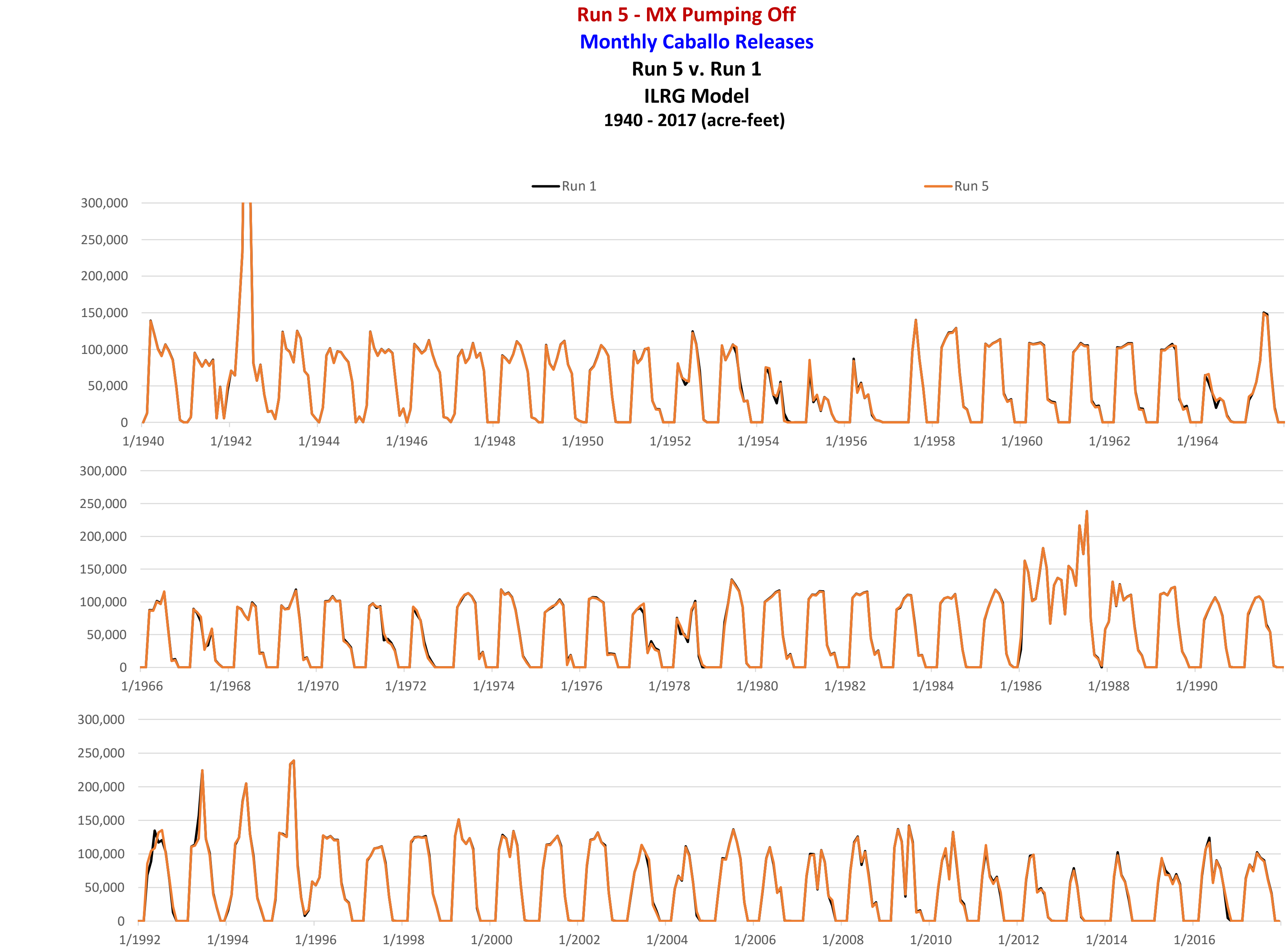
Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

Run 5 - MX Pumping Off
Monthly Net RHG Diversions
Run 5 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
HCCRD Total



Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

Run 5 - MX Pumping Off
End of Month Reservoir Storage (Elephant Butte + Caballo)
Run 5 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)


Run 5 - MX Pumping Off
Monthly Caballo Releases
Run 5 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
Run 1
Run 5
300,000
250,000
200,000
150,000
100,000
50,000
0
1/1940
1/1942
1/1944
1/1946
1/1948
1/1950
1/1952
1/1954
1/1956
1/1958
1/1960
1/1962
1/1964
1/1966
1/1968
1/1970
1/1972
1/1974
1/1976
1/1978
1/1980
1/1982
1/1984
1/1986
1/1988
1/1990
1/1992
1/1994
1/1996
1/1998
1/2000
1/2002
1/2004
1/2006
1/2008
1/2010
1/2012
1/2014
1/2016

Run 5 - MX Pumping Off

Monthly Rio Grande at El Paso Flow

Run 5 v. Run 1

ILRG Model

1940 - 2017 (acre-feet)

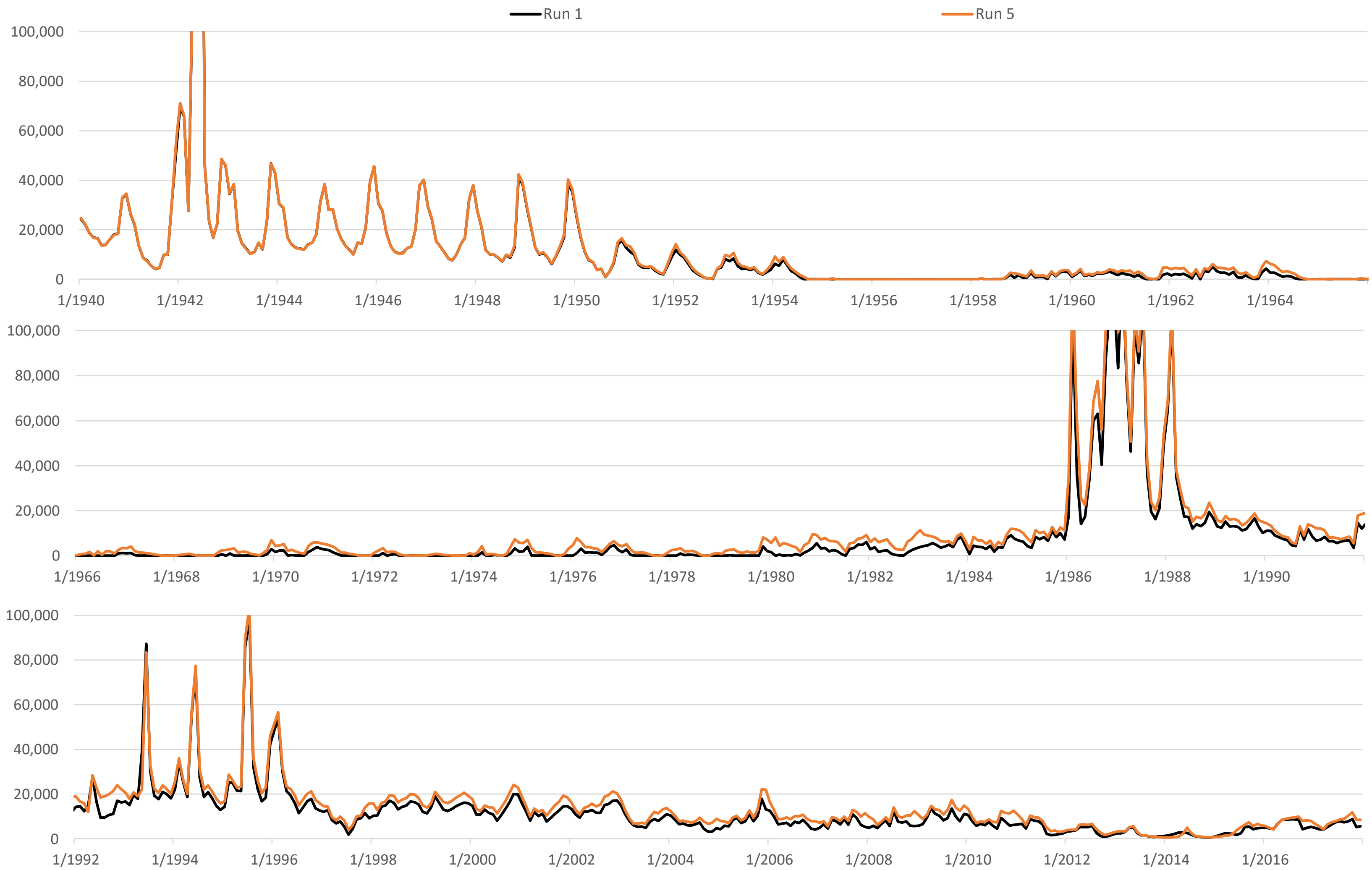
Run 5 - MX Pumping Off

Monthly Rio Grande at Fort Quitman Flow

Run 5 v. Run 1

ILRG Model

1940 - 2017 (acre-feet)



Appendix 30F

Comparison of ILRG Model Runs
Run 6 v. Run 1

Model Run Specifications

Model Version: LRG_v116

Name: **Run 6 - RM Pumping Off**

Run ID: LRG_v116_Operational_Run6
Date: 8/25/2020

Name: **Run 1 - Historical Base Run**

Run ID: LRG_v116_Operational_Run1
Date: 8/23/2020

Selected Model Inputs

Pumping and Returns	Run 6	Run 1
Irrigation Pumping	RM Off	On
Irrigated Area	Hist	Hist
Non-Irrigation Pumping	RM Off	On
Non-Irrigation Pumping Returns	RM Off	On
Las Cruces Jornada Pumping Returns	Off	On

Project Allocation Rules		
1950-2005	D1/D2	D1/D2
2006-2007	D3	D3
2008-2017	D3 + CO	D3 + CO

EPCWID Operations		
Charge EPCWID for Use of WWTP Returns	Off	Off
ACE and Haskell Credits for EPCWID	On	On
Increased EPCWID Use of Fabens Drain Flows	Off	Off
Charge EPCWID for Fabens Drain Flow Use	Off	Off

Run 6 - RM Pumping Off

Comparison of ILRG Model Runs

Run 6 v. Run 1

1951 - 2017 Annual Average

(1,000 acre-feet)

Run No.	1	6	6 - 1		
Simulated Input or Output	**Run 1**	**Run 6**	**Run 6 minus Run 1**		
Pumping Stress					
Irrigation Pumping	147.8	0.0	-147.8		
Non-Irrigation Pumping	181.0	129.4	-51.5		
WWTP Flows	58.0	45.2	-12.9		
Urban Deep Percolation	13.1	7.9	-5.2		
Total Stress	257.7	76.4	-181.3		
	Stress is Pumping minus WWTP and Urban Deep Perc				
Effects of Pumping Stress				***% Chg***	
FHG Deliveries (Mar - Oct)				***Stress***	***% Diff.***
EBID	167.6	202.3	34.7	*-19%*	*21%*
EPCWID (incl. EPW)	139.9	152.1	12.2	*-7%*	*9%*
HCCRD	32.8	34.7	1.9	*-1%*	*6%*
Total	340.3	389.1	48.8	*-27%*	*14%*
FHG Deliveries (Nov - Feb)					
EBID	0.0	0.1	0.1	*0%*	*994%*
EPCWID (incl. EPW)	0.2	0.2	0.0	*0%*	*-3%*
HCCRD	2.4	2.3	-0.1	*0%*	*-6%*
Total	2.6	2.5	-0.1	*0%*	*-3%*
Irrigation Pumping					
EBID	140.4	0.0			
EPCWID (Mesilla Valley)	7.4	0.0			
EPCWID (El Paso Valley)	40.1	31.6	8.5	*-5%*	*21%*
HCCRD	4.2	1.9	2.3	*-1%*	*55%*
	44.3	33.5	-10.8	*6%*	*-24%*
	Pumping turned off.	*Other values are simulated responses and are totaled.*			
Other Inflows/Outflows					
Net Reservoir Evaporation	125.3	142.8	17.5	*-10%*	*14%*
Riparian ET	70.9	77.5	6.6	*-4%*	*9%*
River Evaporation + Incidental Canal Loss	30.3	32.1	1.8	*-1%*	*6%*
Total	226.6	252.5	25.9	*-14%*	*11%*
Rio Grande at Fort Quitman					
Reservoir Spills	33.3	49.3	16.0	*-9%*	*48%*
Nov-Feb Flows	21.4	44.2	22.8	*-13%*	*106%*
Mar - Oct Flows	41.1	58.9	17.8	*-10%*	*43%*
Underflow (GW Model)	0.2	0.3	0.1	*0%*	*25%*
Total	96.0	152.6	56.7	*-31%*	*59%*

Run 6 - RM Pumping Off
Comparison of ILRG Model Runs
Run 6 v. Run 1
1951 - 2017 Annual Average
(1,000 acre-feet)

Run No.	1	6	6 - 1		
Simulated Input or Output	**Run 1**	**Run 6**	**Run 6 minus Run 1**		
Effects of Pumping Stress (continued)				*% Chg*	
Change in Storage				***Stress***	***% Diff.***
Reservoir Storage	-4.7	-3.6	1.1	*-1%*	*-24%*
Alluvial GW Storage (RW Model)	-23.6	-17.6	6.0	*-3%*	*-26%*
Non-alluvial GW Storage (GW Models)	-96.4	-79.2	17.1	*-9%*	*-18%*
Soil Moisture Storage	0.6	0.8	0.2	*0%*	*42%*
Total	-124.0	-99.5	24.5	*-14%*	*-20%*
Summary of Effects					
FHG Deliveries (Mar-Oct)	340.3	389.1	48.8	*-27%*	*14%*
FHG Deliveries (Nov-Feb)	2.6	2.5	-0.1	*0%*	*-3%*
Irrigation Pumping	44.3	33.5	-10.8	*6%*	*-24%*
Riparian ET + Evaporation	226.6	252.5	25.9	*-14%*	*11%*
Fort Quitman Flow	96.0	152.6	56.7	*-31%*	*59%*
Change in Storage	-124.0	-99.5	24.5	*-14%*	*-20%*
Total	585.8	730.7	145.0	*-80%*	*25%*
Other Effects of Pumping Stress				*% Chg*	
Rio Grande at El Paso				***Stress***	***% Diff.***
Reservoir Spills	49.4	67.8	18.4	*-10%*	*37%*
Nov-Feb Flows	22.8	51.3	28.5	*-16%*	*125%*
Mar - Oct Flows	263.8	296.6	32.8	*-18%*	*12%*
Total	336.0	415.7	79.7	*-44%*	*24%*
Rio Grande below Caballo					
Reservoir Spills	65.9	85.0	19.2	*-11%*	*29%*
Nov-Feb Flows	0.5	0.4	-0.1	*0%*	*-22%*
Mar - Oct Flows	541.3	504.1	-37.2	*21%*	*-7%*
Total	607.6	589.5	-18.1	*10%*	*-3%*
Surface Water Diversions (Mar - Oct)					
EBID	366.5	416.1	49.7	*-27%*	*14%*
EPCWID (incl. EPW)	236.8	256.8	20.0	*-11%*	*8%*
HCCRD	67.5	75.1	7.6	*-4%*	*11%*
Total	670.8	748.1	77.3	*-43%*	*12%*
Surface Water Diversions (Nov - Feb)					
EBID	0.0	0.0	0.0	*0%*	*0%*
EPCWID (incl. EPW)	14.3	17.2	2.8	*-2%*	*20%*
HCCRD	14.2	16.8	2.6	*-1%*	*18%*
Total	28.5	34.0	5.4	*-3%*	*19%*

Run 6 - RM Pumping Off
Annual Differences in ILRG Model Outputs
Run 6 minus Run 1
1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1940	-98	-98	3	2	0	1	17	49	4	3	1	1	-137	-28	-61
1941	-304	-304	-6	-9	-2	-2	-47	-10	-1	0	-2	-4	114	291	185
1942	-195	-195	2	-3	2	4	14	53	3	8	1	0	-267	164	172
1943	-236	-236	1	0	3	6	26	65	-8	-8	3	0	-273	119	68
1944	-272	-272	-151	-138	-107	-85	5	45	11	-8	-97	-98	-412	-71	13
1945	-276	-276	-6	40	3	35	24	62	-7	-35	5	4	-428	110	128
1946	-217	-217	17	59	3	24	49	91	17	19	3	3	-393	212	179
1947	-264	-264	-12	77	-2	51	27	71	-5	-15	-6	-6	-478	180	205
1948	-1,052	-1,052	80	126	1	28	484	533	86	78	2	2	-985	68	55
1949	-2,171	-2,171	-90	-65	-18	7	164	218	-48	-53	0	0	-2,971	-66	-55
1950	-267	-267	34	119	-6	104	2,299	2,354	-3	21	0	-1	-1,901	10,379	7,022
1951	439	439	109	144	115	227	3,393	3,450	58	88	85	134	-26,540	13,018	11,025
1952	-337	-337	293	349	180	287	7,337	7,395	112	161	187	278	-41,774	25,550	17,508
1953	-662	-662	-428	-375	372	463	7,413	7,468	-698	-645	122	-134	-47,760	31,274	22,610
1954	34,734	34,734	27,530	34,484	1,179	3,055	26,834	26,871	22,858	22,925	1,946	3,563	225	99,170	30,646
1955	50,428	50,428	39,706	53,127	8,299	11,349	31,349	31,375	27,974	27,828	7,710	10,392	-1,512	116,772	24,785
1956	22,152	22,152	23,380	38,060	5,151	5,753	21,705	21,727	19,277	18,553	5,415	5,498	-49,293	102,633	14,435
1957	66,732	66,732	38,256	50,742	5,029	7,674	24,154	24,192	9,211	8,868	3,345	4,550	-43,129	97,385	9,140
1958	-1,225	-1,225	-14,889	-6,455	6,176	11,995	11,259	11,302	-1,706	-1,717	-1,278	857	-161,801	24,438	35,442
1959	-1,332	-1,332	-3,674	-837	3,027	6,158	7,344	7,393	-392	-315	403	682	-86,238	28,664	36,074
1960	-1,400	-1,400	-1,866	606	1,595	3,136	7,518	7,567	-528	-445	0	0	-83,679	31,404	34,824
1961	-1,309	-1,309	-1,239	946	2,028	3,561	6,935	6,984	916	996	1,249	-815	-72,770	31,581	40,053
1962	-1,328	-1,328	-491	1,588	1,369	2,581	7,063	7,112	-138	-57	313	279	-77,931	34,712	35,598
1963	7,454	7,454	-833	1,771	1,433	2,957	12,598	12,647	-655	-570	651	669	-65,980	43,996	35,168
1964	268,555	268,555	149,321	156,802	14,438	18,938	148,305	148,354	95,955	95,700	12,439	14,921	254,237	232,865	64,719
1965	83,927	83,927	21,142	28,592	8,914	15,277	63,999	64,053	25,553	25,251	9,370	13,144	-96,845	96,942	66,810
1966	-130	-130	30,363	34,348	14,215	18,394	-1,920	-1,872	16,538	16,636	-3,275	-5,164	-72,298	79,587	69,868
1967	186,195	186,195	109,938	116,939	16,505	24,458	106,562	106,611	71,449	71,041	10,241	11,948	134,547	178,759	59,554
1968	37,014	37,014	-5,854	790	10,419	18,764	41,686	41,744	1,589	1,298	9,297	8,014	-98,812	61,998	52,567
1969	705	705	36,273	39,023	19,248	23,692	-2,308	-2,254	20,323	20,400	2,982	-1,561	-66,045	74,431	61,161
1970	-1,492	-1,492	-3,017	-1,558	3,651	6,056	8,549	8,601	-780	-712	-1,274	-2,725	-99,498	32,788	37,710
1971	117,689	117,689	42,737	46,715	12,059	15,637	67,864	67,917	20,910	21,014	9,224	11,184	8,282	119,087	44,665
1972	165,025	165,025	119,306	129,942	18,363	25,619	81,712	81,757	71,075	70,922	11,975	12,028	125,138	202,200	69,019
1973	-2,358	-2,358	-8,330	-723	14,628	20,813	12,937	12,989	76	-66	15,903	16,460	-152,956	41,194	43,000
1974	-1,810	-1,810	-447	2,492	9,209	14,455	13,305	13,360	1,313	1,397	-1,163	-2,482	-87,018	46,816	45,959
1975	-11	-11	35,130	36,785	19,928	24,870	-2,310	-2,263	18,351	18,427	8,132	3,546	-61,526	78,780	48,847
1976	-1,905	-1,905	-412	1,424	6,476	12,016	9,180	9,211	315	362	-1,658	-5,752	-89,122	35,485	38,070
1977	153,121	153,121	40,481	45,887	13,478	19,108	90,216	90,266	18,794	18,894	11,839	12,198	41,815	115,406	35,644
1978	222,159	222,159	58,501	66,235	11,545	19,554	135,079	135,132	37,129	37,252	12,018	11,631	74,681	153,173	66,171

Run 6 - RM Pumping Off
Annual Differences in ILRG Model Outputs
Run 6 minus Run 1
1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1979	1,210	1,210	22,030	26,504	8,765	14,904	11,018	11,073	17,609	17,711	2,413	-213	-113,027	54,647	52,615
1980	-1,414	-1,414	-99	434	3,514	6,186	9,070	9,129	918	997	-3,193	-6,819	-73,339	35,604	55,185
1981	-1,287	-1,287	51	2,329	2,036	4,093	8,997	9,043	824	906	-56	-243	-76,351	39,350	42,823
1982	-1,378	-1,378	230	2,583	1,556	3,344	8,585	8,641	851	934	-369	-1,131	-83,596	38,989	50,617
1983	-1,063	-1,063	355	2,308	1,974	3,522	7,797	7,852	781	857	0	0	-71,021	35,188	39,521
1984	-1,223	-1,223	430	1,959	6,909	8,242	7,841	7,887	713	779	0	0	-42,640	36,343	34,601
1985	1,537	1,537	64,707	64,622	35,413	37,019	-5,051	-4,993	28,709	28,663	0	0	382,997	435,750	387,717
1986	-658	-658	-7,516	-7,493	1,987	3,622	7,240	7,314	-4,041	-3,985	0	0	87,161	151,992	275,056
1987	-1,562	-1,562	460	495	1,179	1,896	4,604	4,673	558	607	0	0	0	55,923	72,818
1988	-1,157	-1,157	450	485	1,028	1,626	5,539	5,605	410	455	0	0	-24,018	35,613	35,409
1989	-939	-939	1,363	1,157	1,034	1,582	6,865	6,920	820	553	0	0	-39,404	30,369	24,238
1990	-676	-676	614	507	3,090	3,504	6,703	6,762	428	244	0	0	-27,120	33,455	24,921
1991	-2,288	-2,288	378	166	804	1,312	3,672	3,739	424	81	0	0	-28,960	23,069	27,436
1992	1,312	1,312	76,069	75,811	35,622	37,102	-5,845	-5,783	34,386	34,089	0	0	94,446	154,612	135,861
1993	-578	-578	-4,821	-4,830	-223	743	7,056	7,127	-2,415	-2,368	0	0	-15,991	43,676	48,947
1994	-1,136	-1,136	1,149	1,169	954	1,538	9,222	9,307	999	1,057	0	0	-16,711	73,803	64,950
1995	-1,364	-1,364	3,779	3,790	3,215	4,010	11,326	11,404	647	670	0	0	34,237	144,612	127,717
1996	-1,504	-1,504	1,003	1,066	909	1,632	11,806	11,891	789	872	0	0	-71,096	55,915	46,149
1997	-843	-843	41	-237	1,095	1,677	8,234	8,295	-359	-970	0	0	-41,169	42,602	29,762
1998	-1,116	-1,116	1,482	1,493	1,477	1,522	8,975	9,055	1,085	1,145	0	0	-18,411	69,356	59,781
1999	-1,876	-1,876	-11,440	-10,929	28,693	28,861	-2,432	-2,372	-14,074	-14,034	0	0	3,446	90,277	89,441
2000	-415	-415	24,104	24,799	3,355	3,403	-1,257	-1,206	2,417	2,450	0	0	-23,155	65,159	49,791
2001	-402	-402	7,627	7,637	2,151	2,503	7,623	7,668	4,859	4,910	0	0	-33,363	42,153	26,688
2002	-769	-769	979	1,574	1,032	1,837	8,576	8,618	333	391	0	0	-47,150	36,645	27,790
2003	115,285	115,285	48,236	48,078	13,821	14,501	70,062	70,125	20,792	20,868	0	0	80,316	118,311	65,139
2004	41,804	41,804	25,747	27,410	5,727	8,163	34,460	34,512	16,803	16,879	0	0	-36,928	78,458	46,282
2005	1,119	1,119	8,274	8,982	4,026	5,517	14,032	14,094	7,585	7,664	0	0	-79,649	39,907	36,848
2006	111,277	111,277	79,160	78,896	19,444	21,433	68,985	69,034	39,341	39,401	0	0	92,843	134,681	67,051
2007	119,778	119,778	10,218	11,470	3,442	5,214	84,639	84,689	9,334	9,418	0	0	-27,098	60,165	38,995
2008	184,130	184,130	3,545	4,666	2,952	4,314	127,162	127,278	3,387	3,585	0	0	23,651	68,345	58,387
2009	171,431	171,431	989	2,764	1,524	3,128	117,388	117,550	380	587	0	0	27,835	81,049	72,070
2010	182,591	182,591	4,295	7,044	2,503	3,802	127,428	127,532	2,613	2,775	0	0	8,631	69,516	56,092
2011	106,343	106,343	63,577	67,243	20,995	27,209	51,441	51,484	43,778	43,887	0	0	7,915	126,802	70,368
2012	105,114	105,114	47,536	49,770	19,581	26,007	56,112	56,144	32,588	32,691	0	0	-43,142	95,684	60,138
2013	70,797	70,797	57,606	60,561	15,744	18,813	37,859	37,890	34,779	34,869	5,926	6,229	32,873	119,482	55,359
2014	77,996	77,996	26,506	28,616	10,409	14,070	37,929	37,951	18,165	18,252	-285	-601	-33,706	84,964	47,985
2015	173,012	173,012	19,108	21,778	5,216	7,677	97,124	97,156	11,788	11,892	-4,348	-3,757	-42,641	62,028	47,821
2016	168,525	168,525	21,562	24,857	4,129	6,342	103,635	103,665	16,014	16,129	0	0	-59,725	74,941	41,903
2017	316,166	316,166	9,667	13,396	2,554	4,233	202,340	202,435	8,509	8,677	0	0	23,278	73,102	50,594
Averages															
1951-2017	49,654	49,654	20,007	22,847	7,592	10,193	34,694	34,750	12,215	12,210	1,885	1,743	-18,110	79,741	56,656
1951-1978	50,037	50,037	26,107	31,352	8,180	12,030	33,848	33,896	16,960	16,910	4,507	4,405	-33,700	79,647	41,110
1979-2005	5,134	5,134	9,840	10,440	6,339	7,550	9,804	9,866	4,550	4,534	-45	-311	-10,389	76,362	73,263
2006-2017	148,930	148,930	28,647	30,922	9,041	11,853	92,670	92,734	18,390	18,514	108	156	893	87,563	55,564
1985-2017	58,513	58,513	17,771	18,691	7,724	9,267	40,105	40,169	9,752	9,770	39	57	5,763	87,043	71,803
1985-2005	6,846	6,846	11,556	11,702	6,971	7,789	10,067	10,131	4,817	4,773	0	0	8,547	86,746	81,083

Notes:

EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

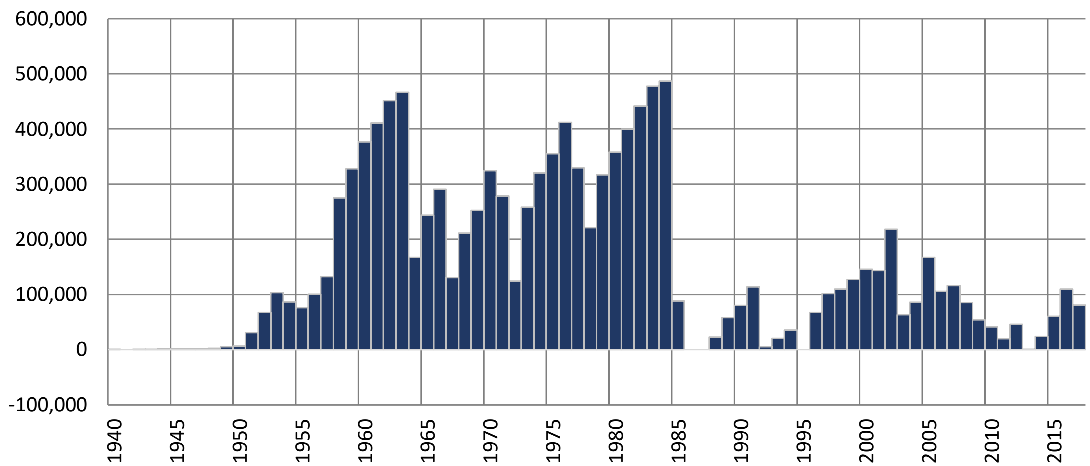
Run 6 - RM Pumping Off

Simulated Differences in ILRG Model Outputs

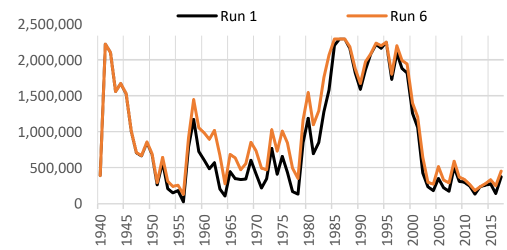
Run 6 minus Run 1

1940 - 2017 (acre-feet)

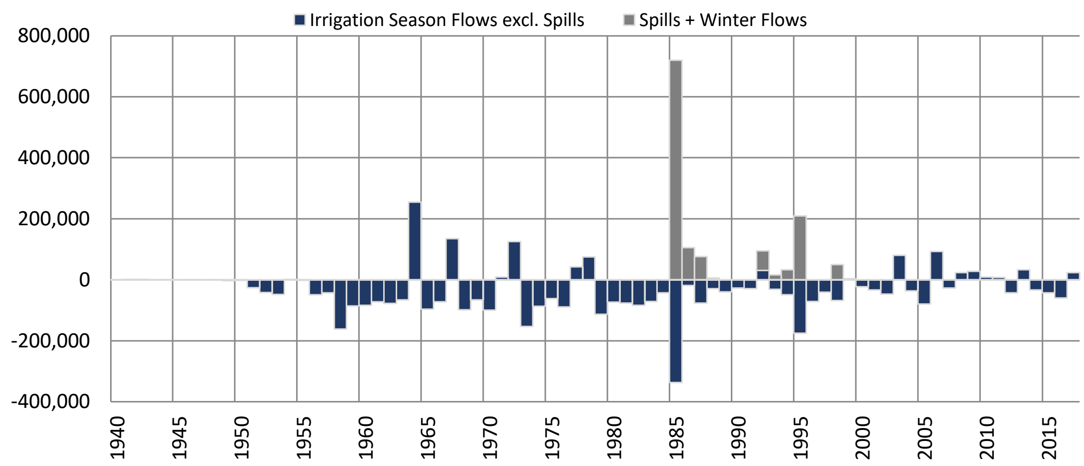
Total Project Storage (Year End)



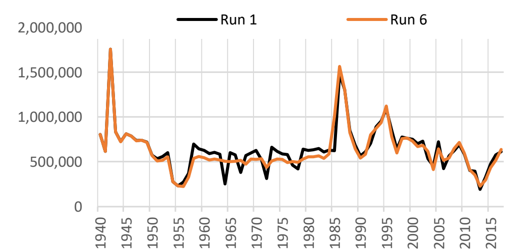
Period	Average Difference
1951-2017	1,108
1951-1978	7,666
1979-2005	-1,995
2006-2017	-7,211
1985-2017	-12,298
1985-2005	-15,205



Caballo Reservoir Outflows (Annual)



	Average Difference		
Period	Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	-37,184	19,074	-18,110
1951-1978	-33,700	0	-33,700
1979-2005	-57,721	47,332	-10,389
2006-2017	893	0	893
1985-2017	-32,963	38,726	5,763
1985-2005	-52,309	60,855	8,547



Notes:

Reservoir storage does not include storage attributed to SJC, CO, or NM credit waters.

Average differences calculated as (Final Storage - Initial Storage)/(no. years).

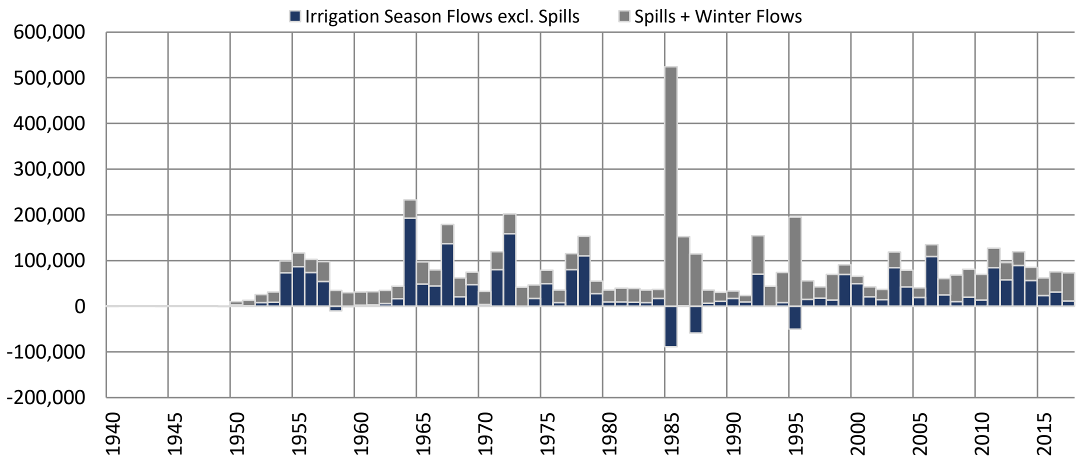
Run 6 - RM Pumping Off

Simulated Differences in ILRG Model Outputs

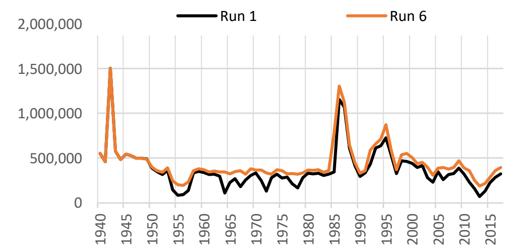
Run 6 minus Run 1

1940 - 2017 (acre-feet)

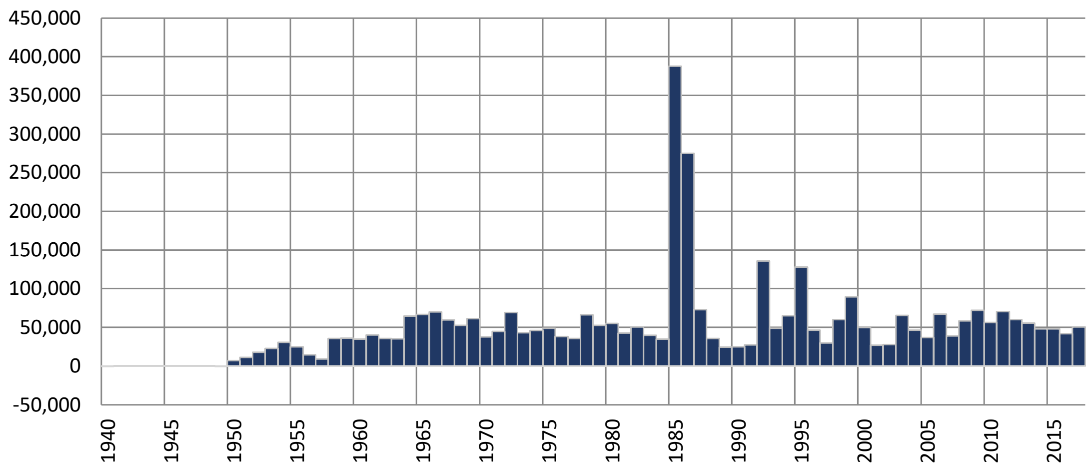
Rio Grande at El Paso (Annual)



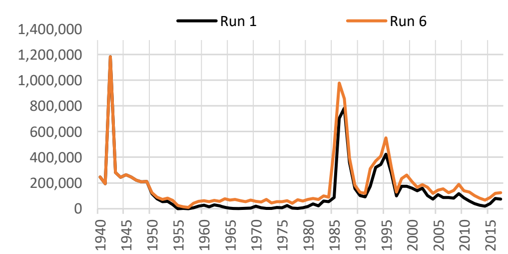
	Average Difference		
Period	Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	32,832	46,909	79,741
1951-1978	47,021	32,626	79,647
1979-2005	13,031	63,332	76,362
2006-2017	44,278	43,285	87,563
1985-2017	24,325	62,718	87,043
1985-2005	12,923	73,823	86,746



Rio Grande at Fort Quitman (Annual)

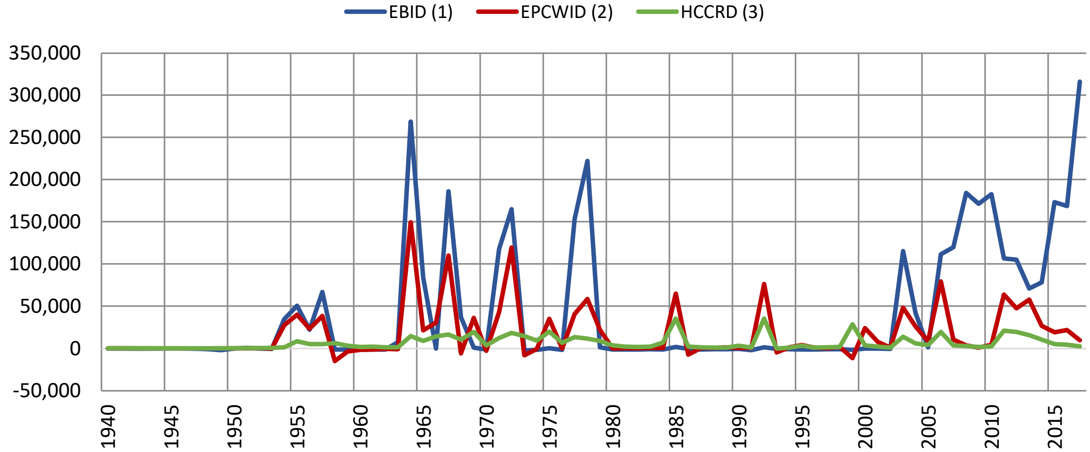


Period	Average Difference
1951-2017	56,602
1951-1978	41,032
1979-2005	73,217
2006-2017	55,549
1985-2017	71,778
1985-2005	81,051



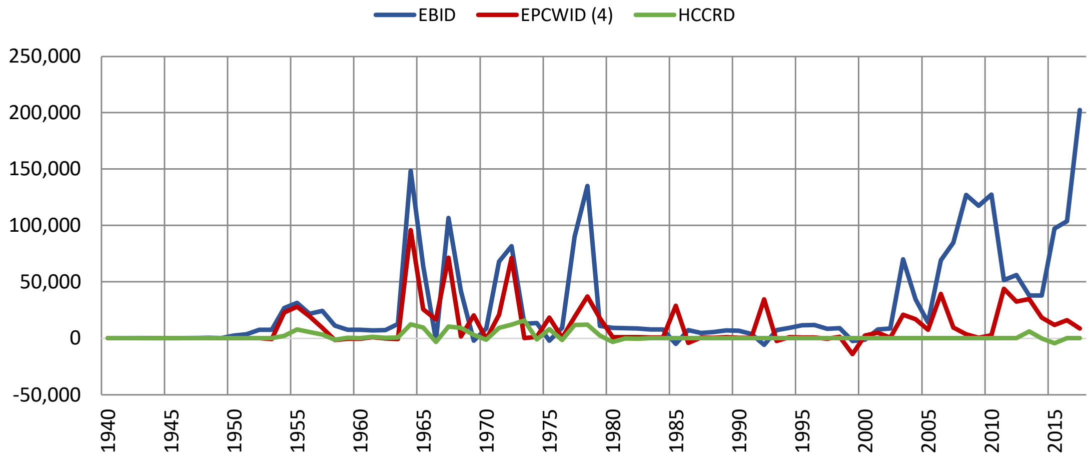
Run 6 - RM Pumping Off
Simulated Differences in ILRG Model Outputs
Run 6 minus Run 1
1940 - 2017 (acre-feet)

River Headgate (RHG) Diversions (Irrigation Season)



	Average Difference		
Period	EBID	EPCWID	HCCRD
1951-2017	49,654	20,007	7,592
1951-1978	50,037	26,107	8,180
1979-2005	5,134	9,840	6,339
2006-2017	148,930	28,647	9,041
1985-2017	58,513	17,771	7,724
1985-2005	6,846	11,556	6,971

Farm Headgate (FHG) Deliveries (Irrigation Season)



	Average Difference		
Period	EBID	EPCWID	HCCRD
1951-2017	34,694	12,215	1,885
1951-1978	33,848	16,960	4,507
1979-2005	9,804	4,550	-45
2006-2017	92,670	18,390	108
1985-2017	40,105	9,752	39
1985-2005	10,067	4,817	0

Notes:
(1) EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).
(2) EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.
(3) HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.
(4) EPCWID FHG values include deliveries to Rogers WTP and R/U WTP.

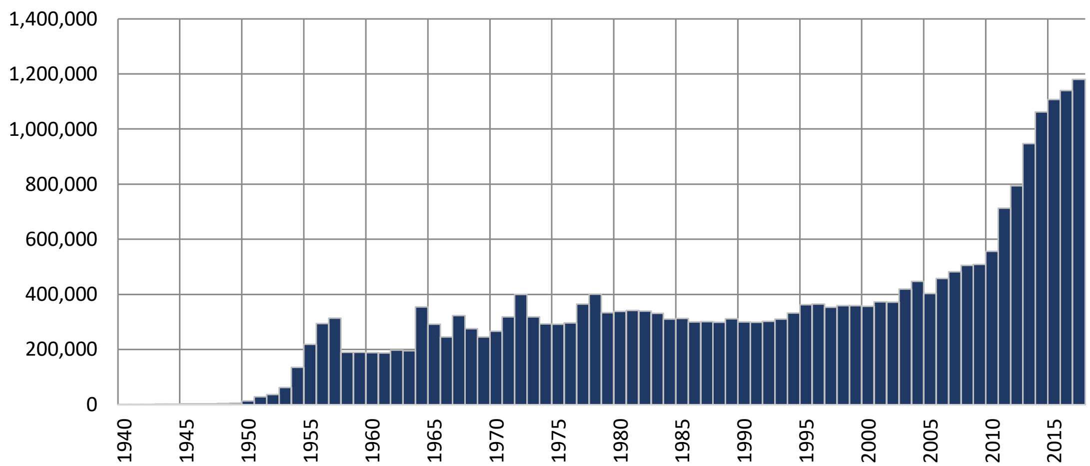
Run 6 - RM Pumping Off

Simulated Differences in ILRG Model Outputs

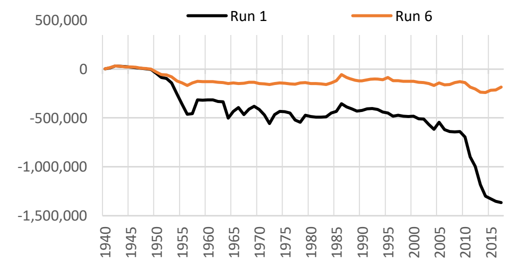
Run 6 minus Run 1

1940 - 2017 (acre-feet)

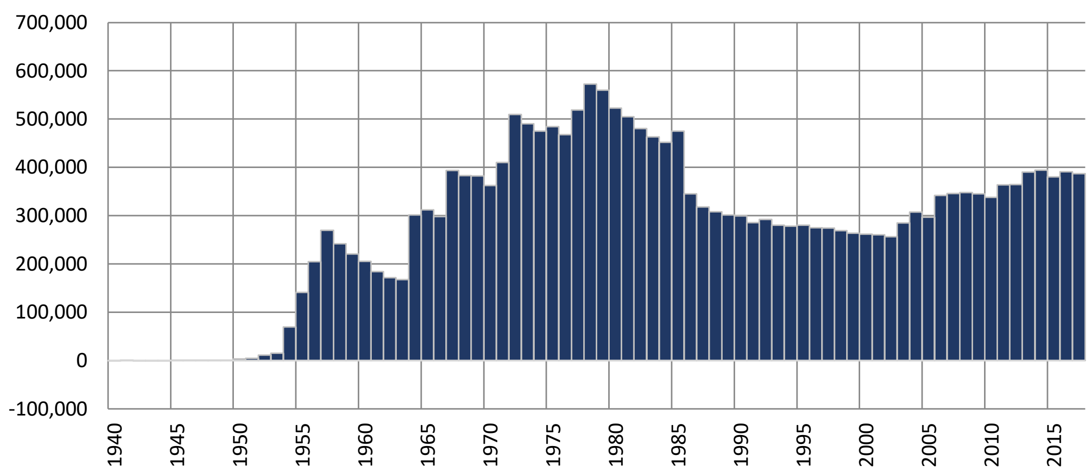
Cumulative Annual Rincon-Mesilla Groundwater Storage



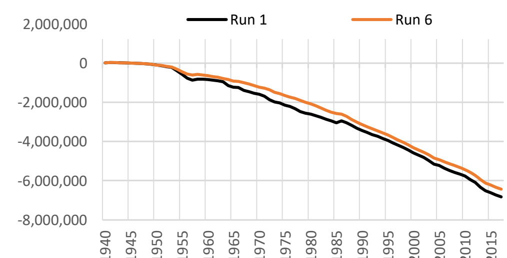
Period	Average Difference
1951-2017	17,414
1951-1978	13,805
1979-2005	102
2006-2017	64,787
1985-2017	26,353
1985-2005	4,391



Cumulative Annual Hueco Groundwater Storage



Period	Average Difference
1951-2017	5,727
1951-1978	20,323
1979-2005	-10,195
2006-2017	7,493
1985-2017	-1,973
1985-2005	-7,382

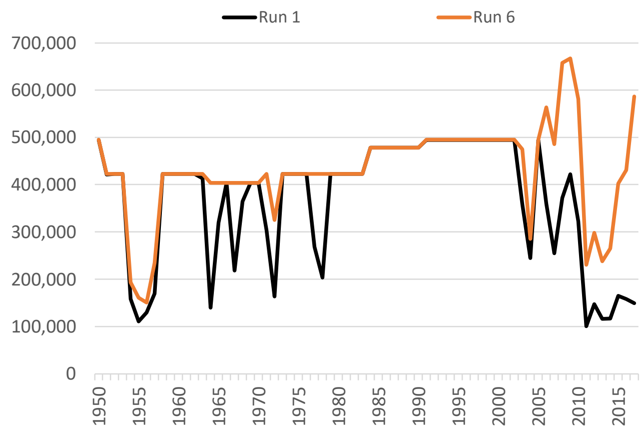


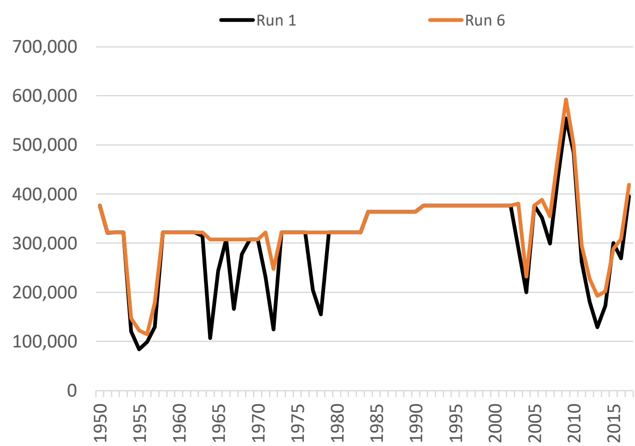
Notes:

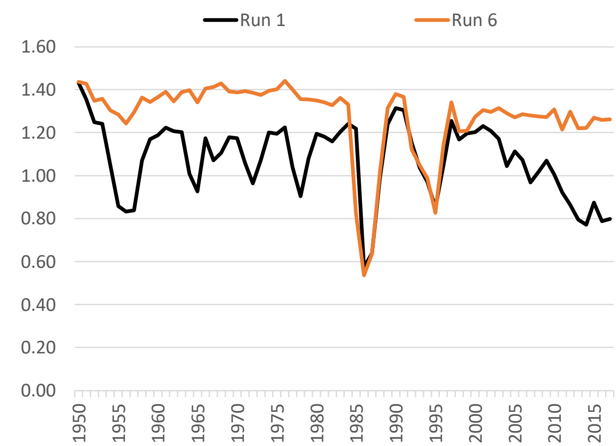
Cumulative storage change in alluvial and non-alluvial aquifers.

Average differences calculated as (Final Storage - Initial Storage)/(no. years).

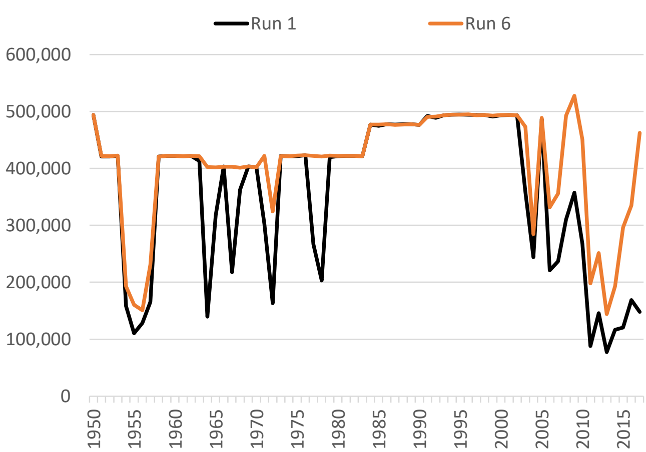
Run 6 - RM Pumping Off
Annual Allocation and Charges
Run 6 v. Run 1
ILRG Model
1950 - 2017 (acre-feet)

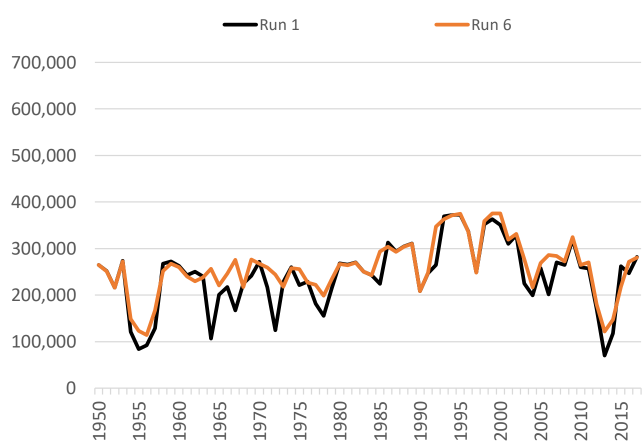
Total Allocation - EBID


Total Allocation - EPCWID


Diversion Ratio


Note:
Computed as Total Charges/Caballo Release.

Annual Delivery Charges - EBID


Annual Delivery Charges - EPCWID


Run 6 - RM Pumping Off

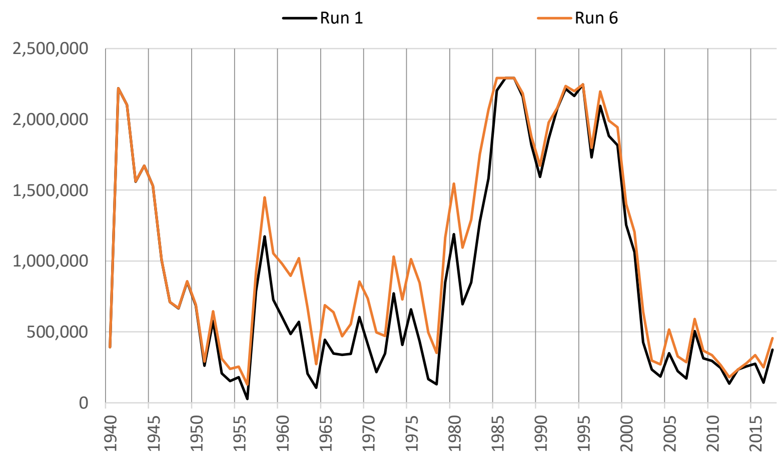
Annual Summary of Project Storage and Rio Grande Flows

Run 6 v. Run 1

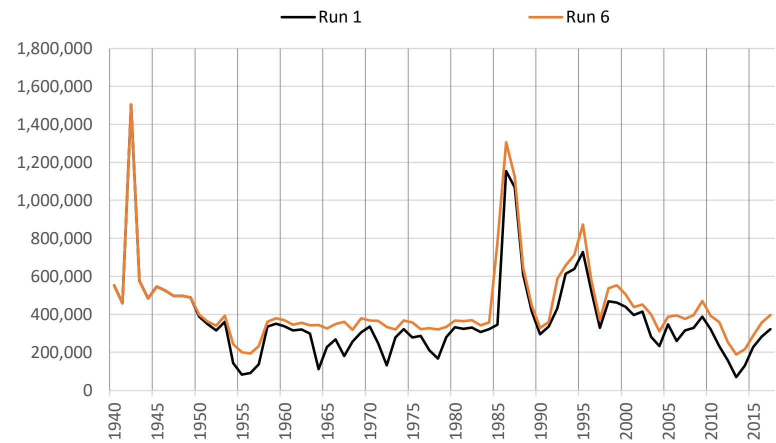
ILRG Model

1940 - 2017 (acre-feet)

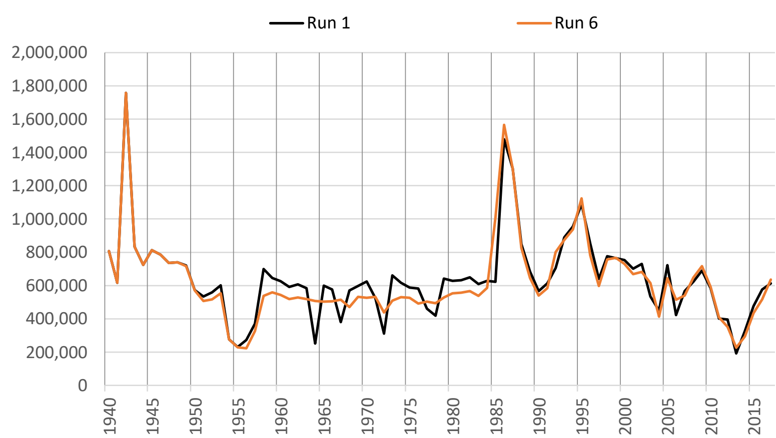
Total Year-End Project Reservoir Storage



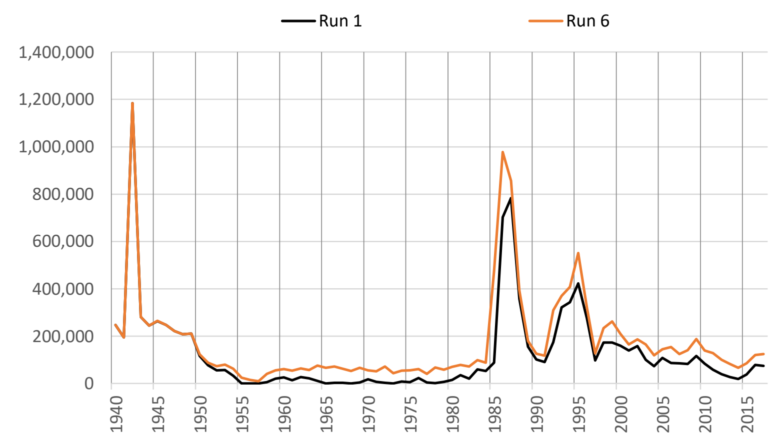
Rio Grande at El Paso



Rio Grande Below Caballo



Rio Grande at Fort Quitman

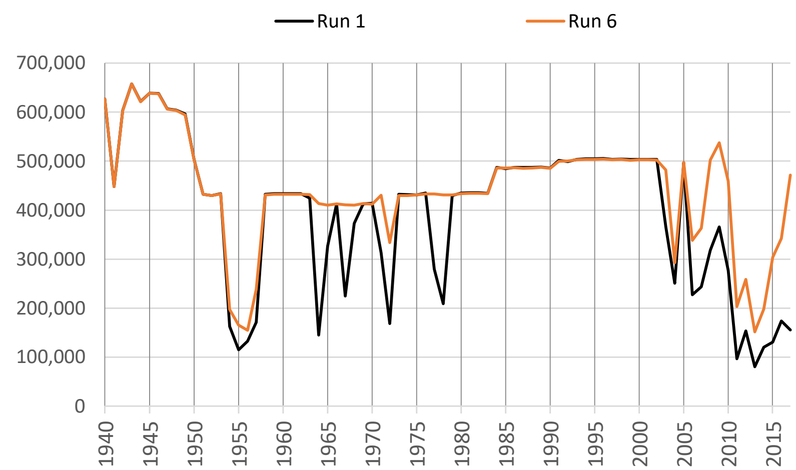


***Note different scales.**

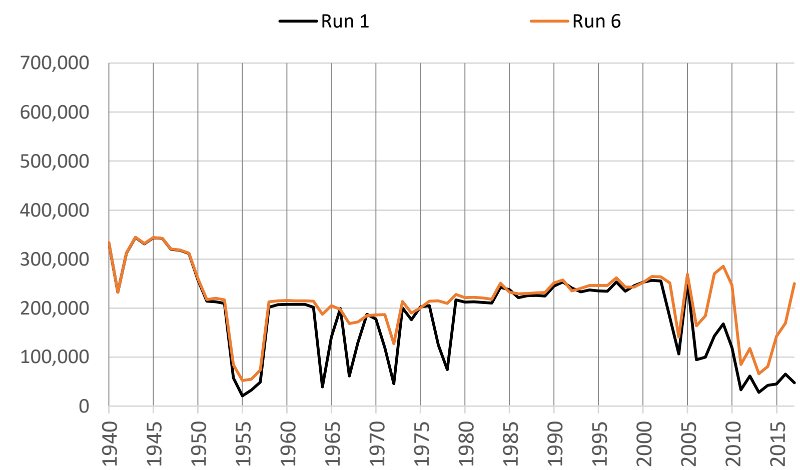
Run 6 - RM Pumping Off
Irrigation Season Summary of Irrigation Operations
Run 6 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

EBID Total

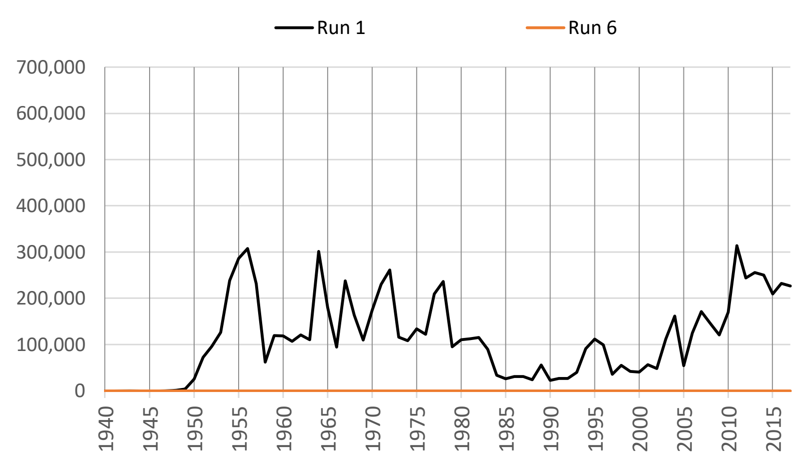
Net River Headgate Diversions



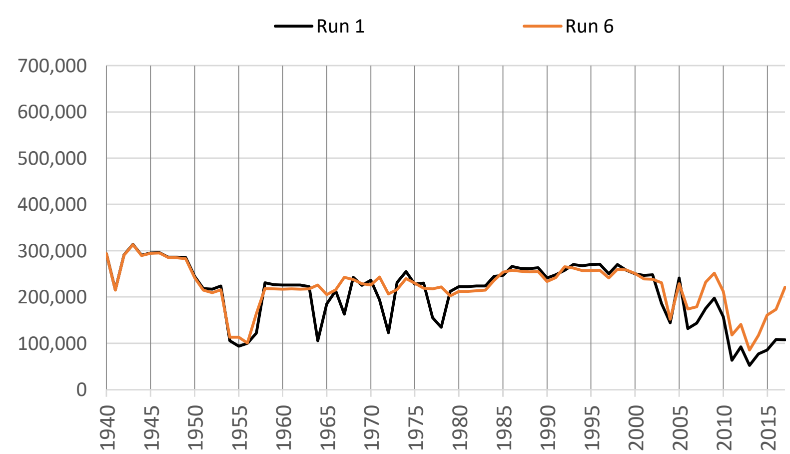
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries

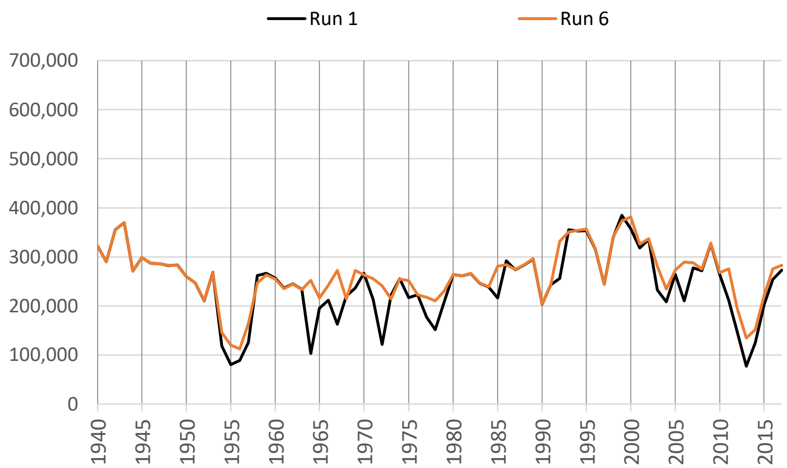


Notes: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).
Pumping includes Supplemental and Primary groundwater pumping.

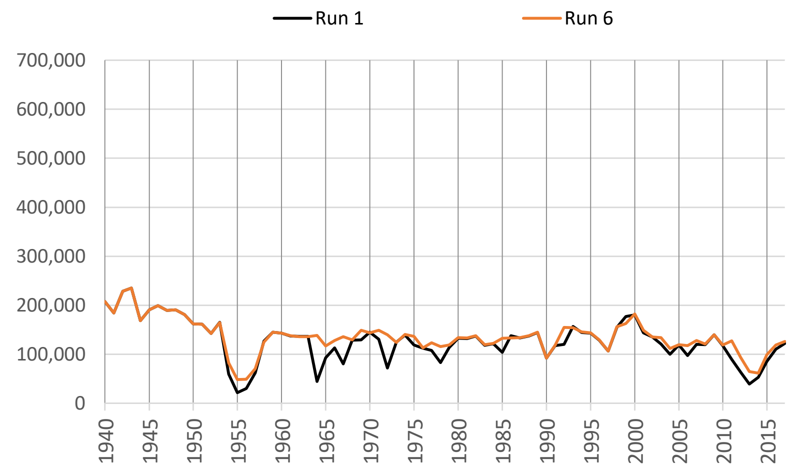
Run 6 - RM Pumping Off
Irrigation Season Summary of Irrigation Operations
Run 6 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

EPCWID Total

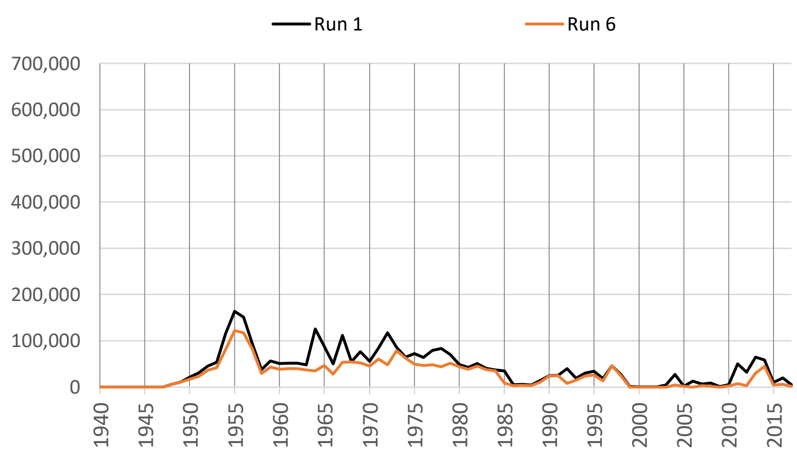
Net River Headgate Diversions



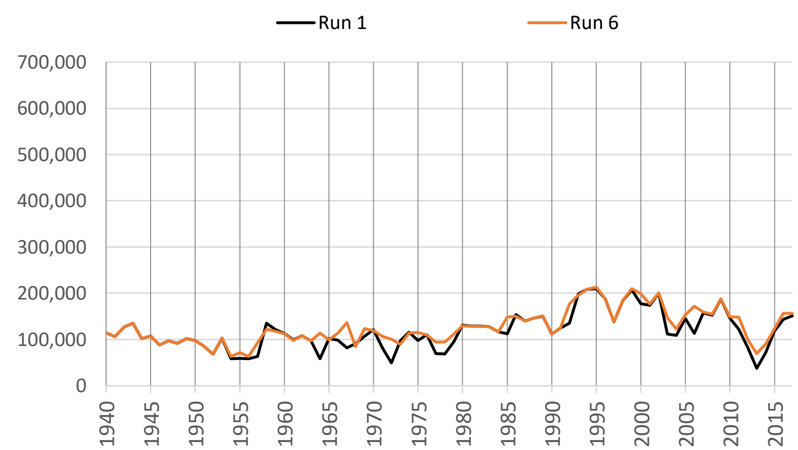
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries

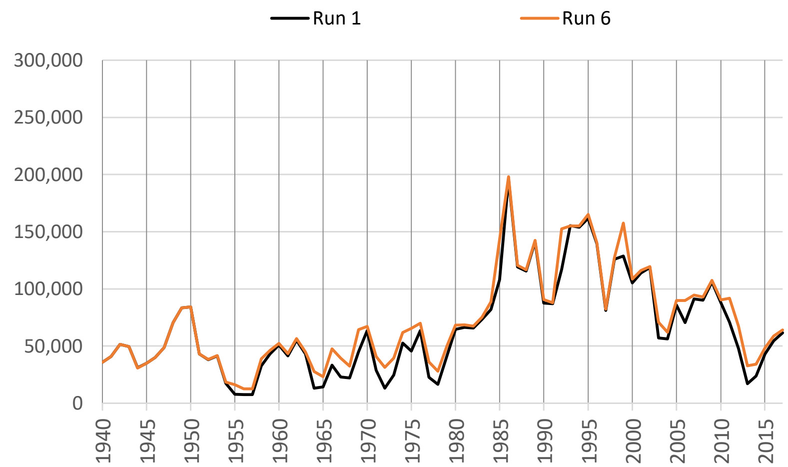


Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

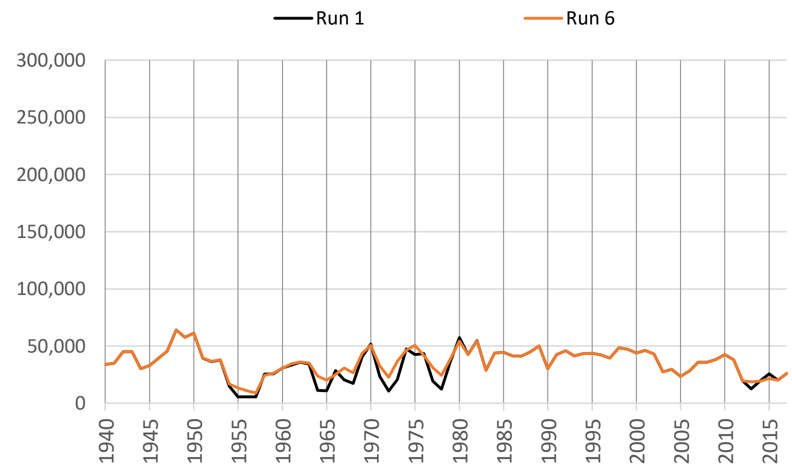
Run 6 - RM Pumping Off
Irrigation Season Summary of Irrigation Operations
Run 6 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

HCCRD Total

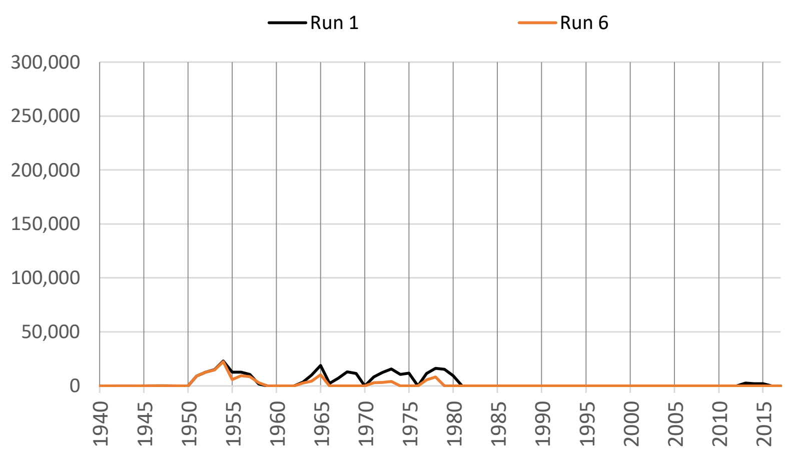
Net River Headgate Diversions



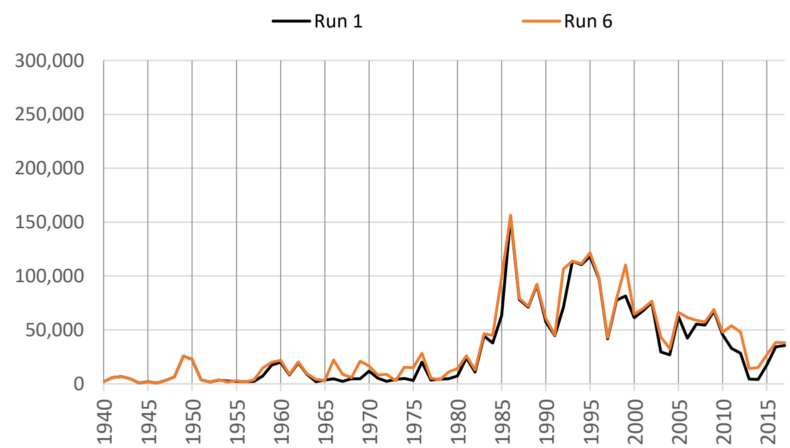
Farm Headgate Deliveries



Pumping



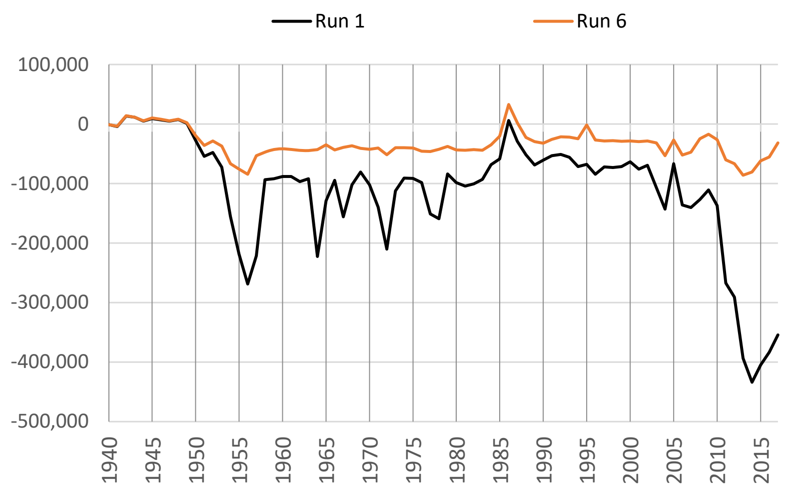
RHG Diversions - FHG Deliveries



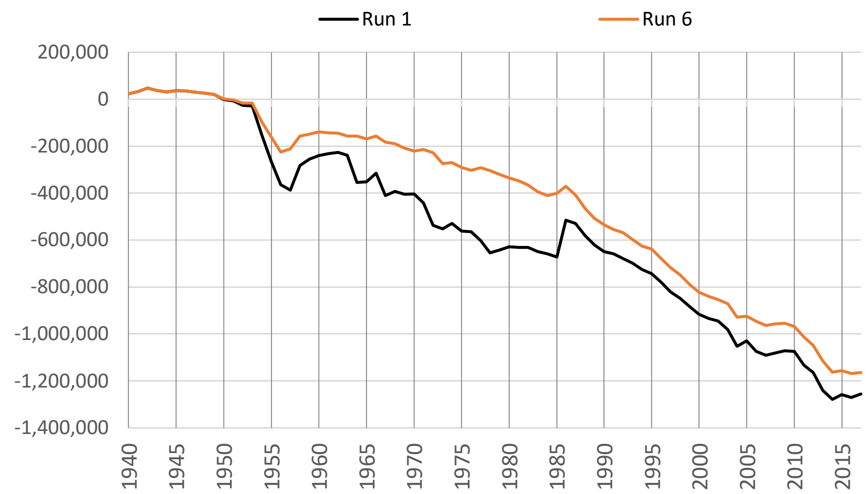
Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

Run 6 - RM Pumping Off
Cumulative Change in Ground Water Storage
Run 6 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

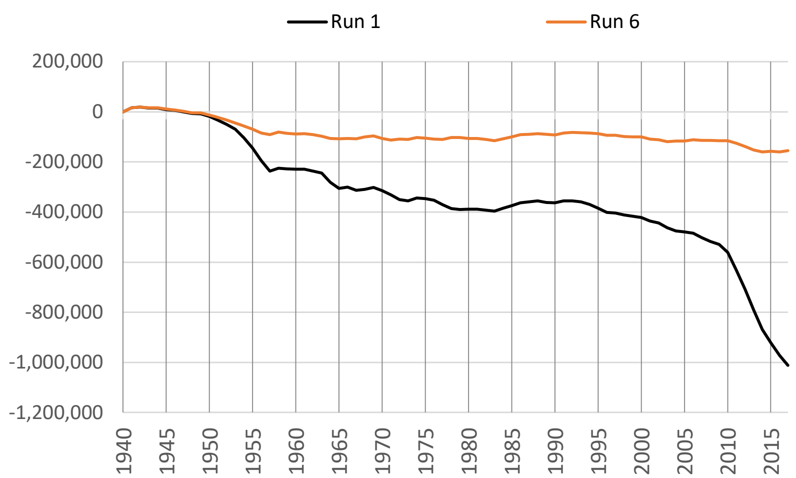
Rincon-Mesilla Alluvial Aquifer



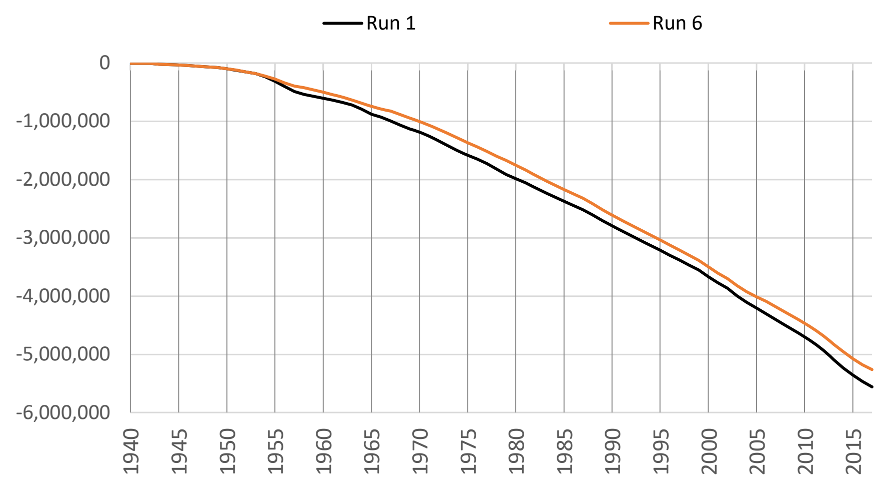
Hueco Alluvial Aquifer



Rincon-Mesilla Non-Alluvial Aquifer

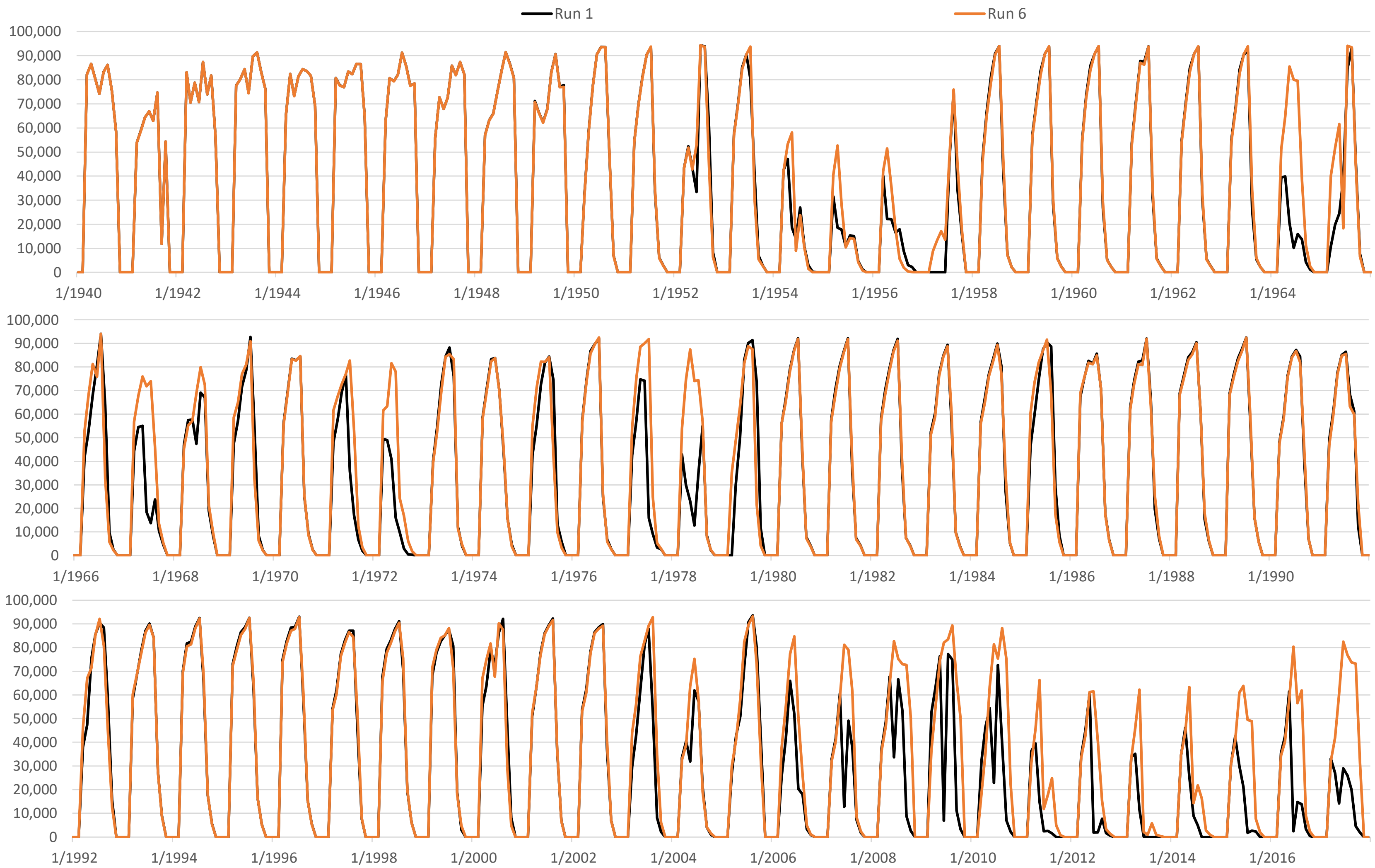


Hueco Non-Alluvial Aquifer



***Note different scales.**

Run 6 - RM Pumping Off
Monthly Net RHG Diversions
Run 6 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
EBID Total

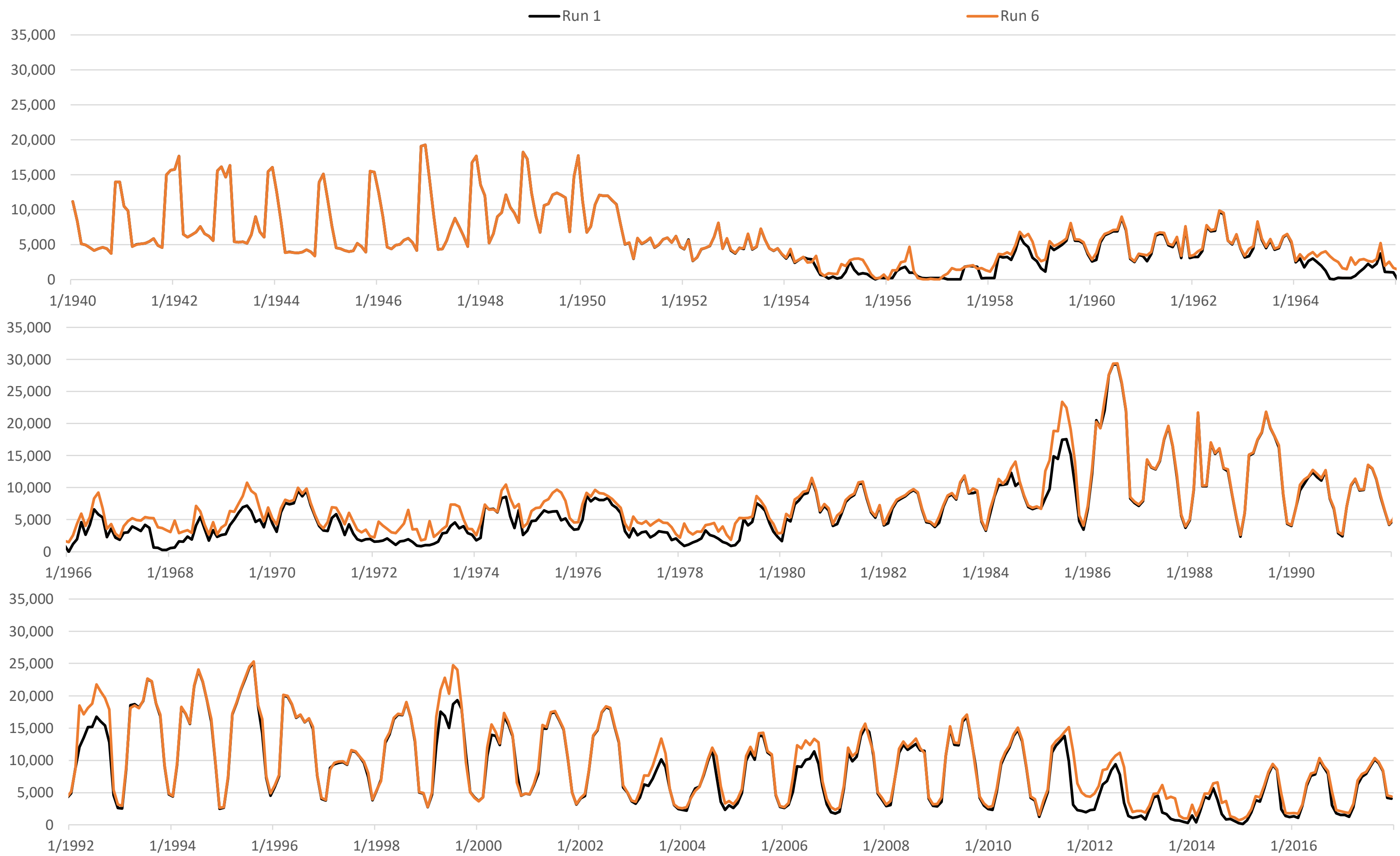


Note: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

Run 6 - RM Pumping Off
Monthly Net RHG Diversions
Run 6 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
EPCWID Total

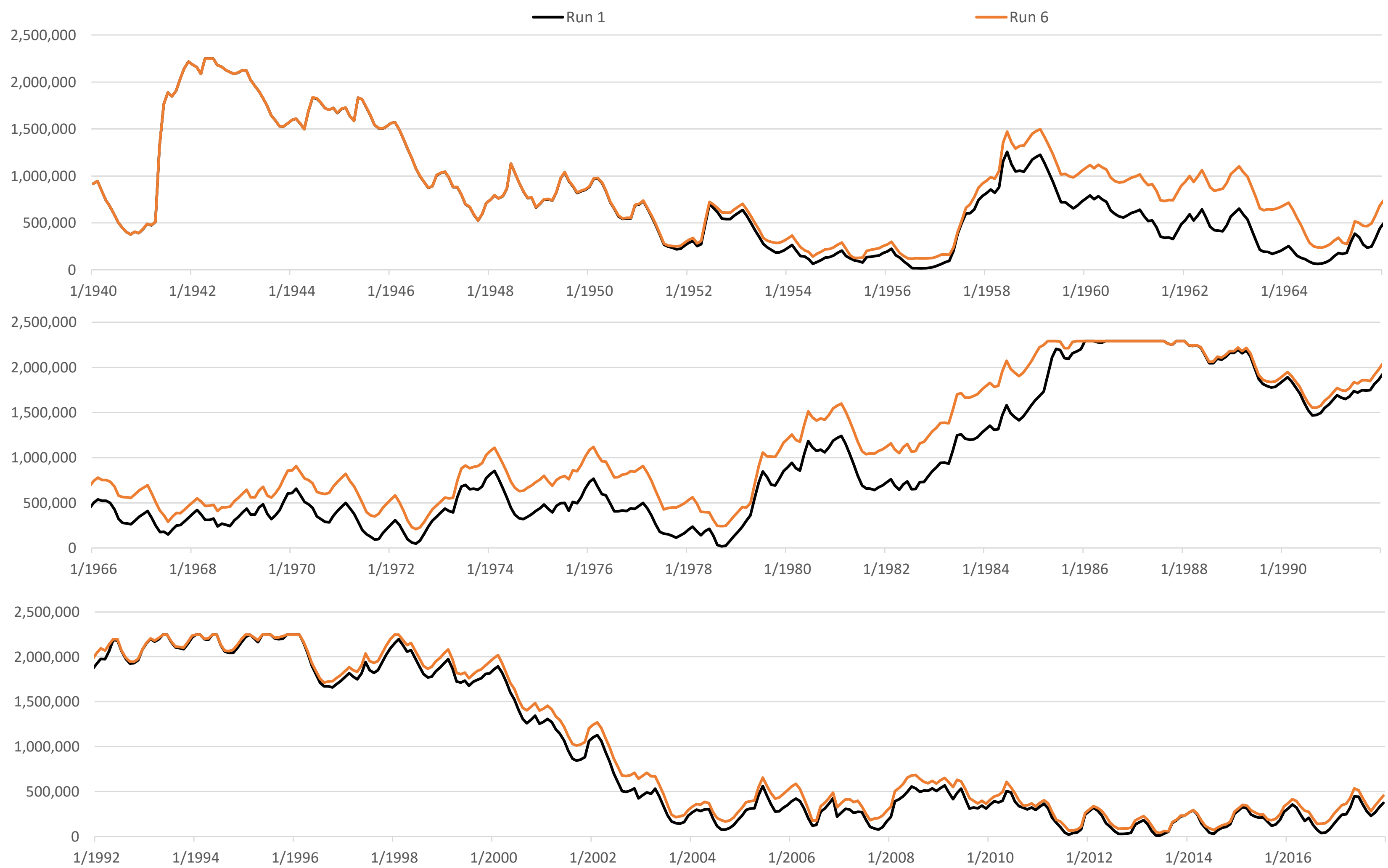
Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

Run 6 - RM Pumping Off
Monthly Net RHG Diversions
Run 6 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
HCCRD Total

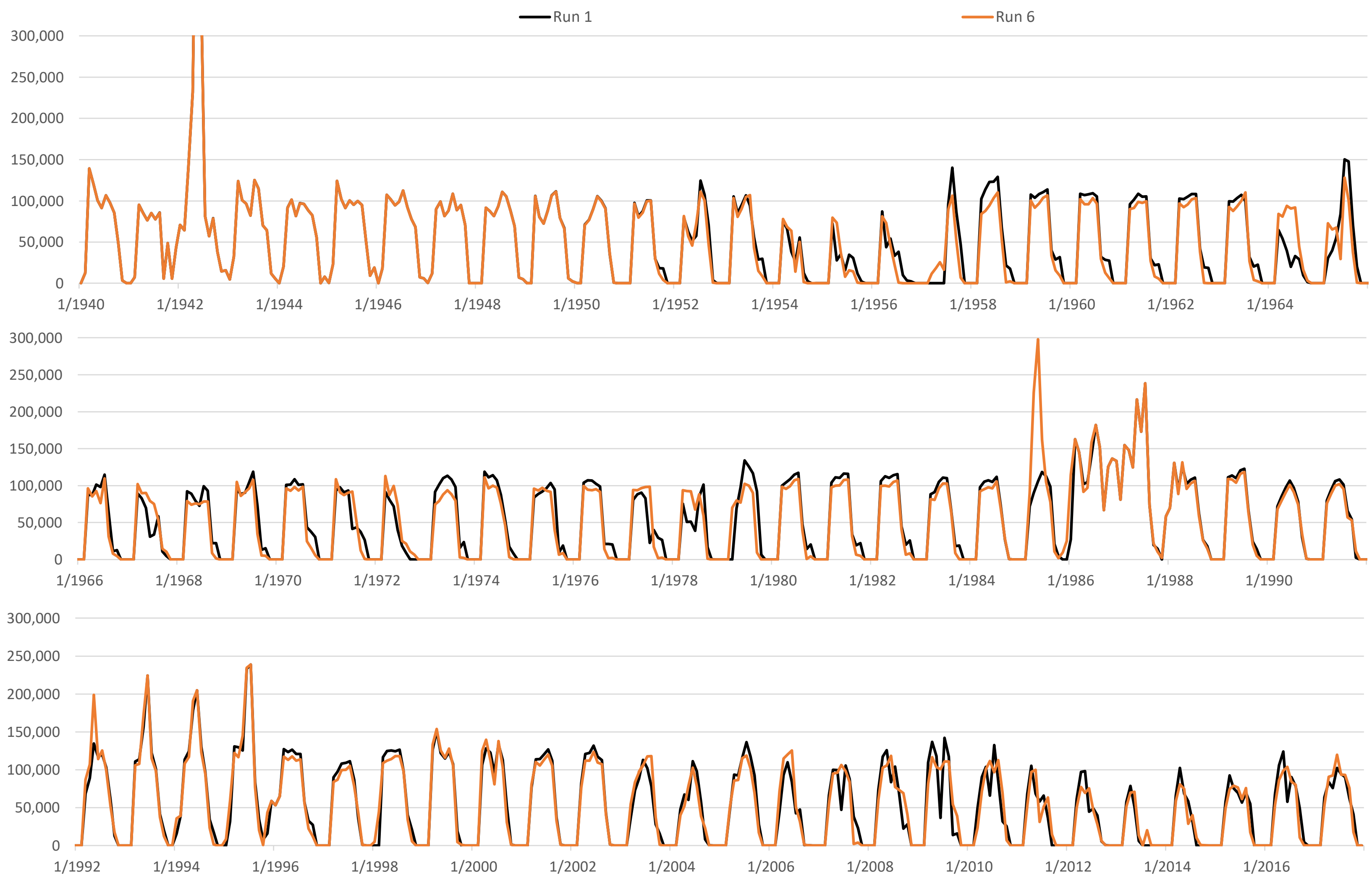


Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

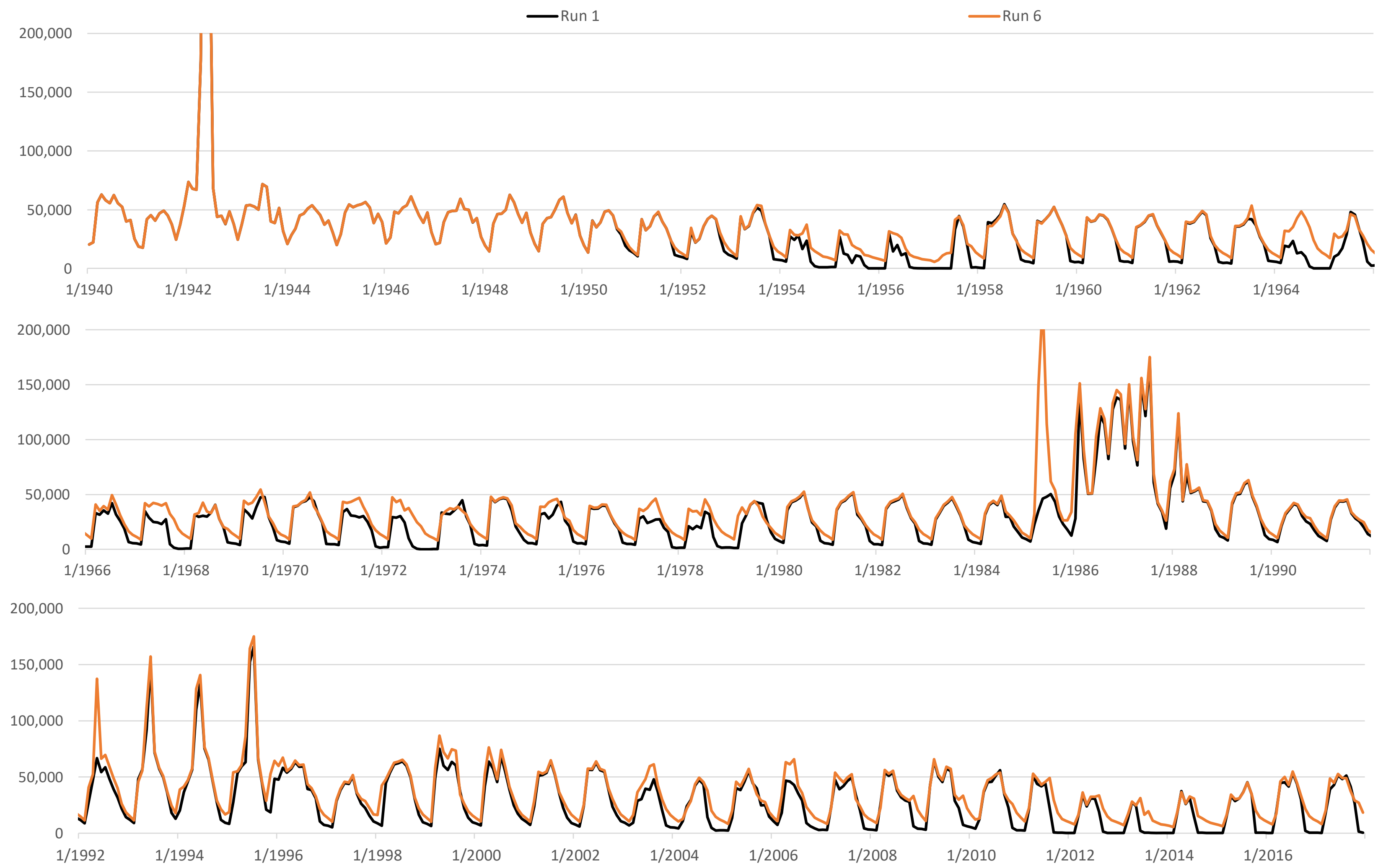
Run 6 - RM Pumping Off
End of Month Reservoir Storage (Elephant Butte + Caballo)
Run 6 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)



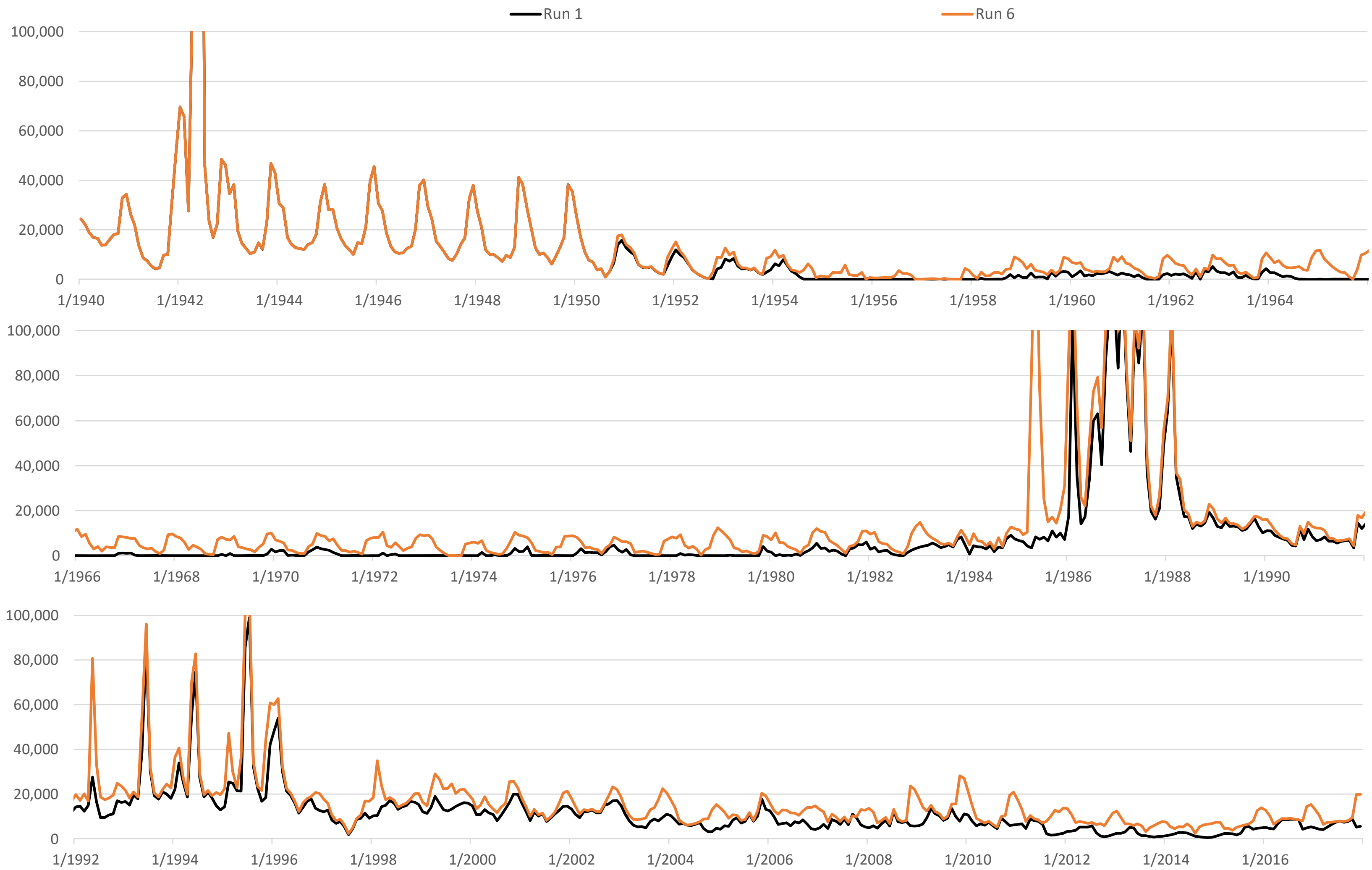
Run 6 - RM Pumping Off
Monthly Caballo Releases
Run 6 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)



Run 6 - RM Pumping Off
Monthly Rio Grande at El Paso Flow
Run 6 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)



Run 6 - RM Pumping Off
Monthly Rio Grande at Fort Quitman Flow
Run 6 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)



Appendix 30G

Comparison of ILRG Model Runs
Run 7 v. Run 1

Model Run Specifications

Model Version: LRG_v116

Name: **Run 7 - TX Mesilla Pumping Off**

Run ID: LRG_v116_Operational_Run7
Date: 8/25/2020

Name: **Run 1 - Historical Base Run**

Run ID: LRG_v116_Operational_Run1
Date: 8/23/2020

Selected Model Inputs

Pumping and Returns	**Run 7**	**Run 1**
Irrigation Pumping	TX Mesilla Off	On
Irrigated Area	Hist	Hist
Non-Irrigation Pumping	TX Mesilla Off	On
Non-Irrigation Pumping Returns	TX Mesilla Off	On
Las Cruces Jornada Pumping Returns	On	On

Project Allocation Rules		
1950-2005	D1/D2	D1/D2
2006-2007	D3	D3
2008-2017	D3 + CO	D3 + CO

EPCWID Operations		
Charge EPCWID for Use of WWTP Returns	Off	Off
ACE and Haskell Credits for EPCWID	On	On
Increased EPCWID Use of Fabens Drain Flows	Off	Off
Charge EPCWID for Fabens Drain Flow Use	Off	Off

Run 7 - TX Mesilla Pumping Off

Comparison of ILRG Model Runs

Run 7 v. Run 1

1951 - 2017 Annual Average

(1,000 acre-feet)

Run No.	1	7	7 - 1		
Simulated Input or Output	**Run 1**	**Run 7**	**Run 7 minus Run 1**		
Pumping Stress					
Irrigation Pumping	7.4	0.0	-7.4		
Non-Irrigation Pumping	181.0	159.3	-21.6		
WWTP Flows	58.0	52.0	-6.1		
Urban Deep Percolation	13.1	10.9	-2.1		
Total Stress	117.2	96.4	-20.8		
	Stress is Pumping minus WWTP and Urban Deep Perc				
Effects of Pumping Stress				***% Chg***	
FHG Deliveries (Mar - Oct)				***Stress***	***% Diff.***
EBID	167.6	173.2	5.6	*-27%*	*3%*
EPCWID (incl. EPW)	139.9	141.7	1.8	*-9%*	*1%*
HCCRD	32.8	33.3	0.4	*-2%*	*1%*
Total	340.3	348.1	7.8	*-38%*	*2%*
FHG Deliveries (Nov - Feb)					
EBID	0.0	0.0	0.0	*0%*	*-2%*
EPCWID (incl. EPW)	0.2	0.1	-0.1	*0%*	*-33%*
HCCRD	2.4	2.5	0.1	*0%*	*2%*
Total	2.6	2.6	0.0	*0%*	*0%*
Irrigation Pumping					
EBID	140.4	135.1	-5.4	*26%*	*-4%*
EPCWID (Mesilla Valley)	7.4	0.0			
EPCWID (El Paso Valley)	40.1	38.8	-1.3	*6%*	*-3%*
HCCRD	4.2	3.6	-0.6	*3%*	*-13%*
	184.8	177.5	-7.2	*35%*	*-4%*
	Pumping turned off.	*Other values are simulated responses and are totaled.*			
Other Inflows/Outflows					
Net Reservoir Evaporation	125.3	127.9	2.6	*-12%*	*2%*
Riparian ET	70.9	72.4	1.5	*-7%*	*2%*
River Evaporation + Incidental Canal Loss	30.3	30.4	0.1	*0%*	*0%*
Total	226.6	230.7	4.1	*-20%*	*2%*
Rio Grande at Fort Quitman					
Reservoir Spills	33.3	36.1	2.8	*-13%*	*8%*
Nov-Feb Flows	21.4	23.0	1.6	*-8%*	*8%*
Mar - Oct Flows	41.1	44.2	3.1	*-15%*	*8%*
Underflow (GW Model)	0.2	0.2	0.0	*0%*	*6%*
Total	96.0	103.5	7.6	*-36%*	*8%*

Run 7 - TX Mesilla Pumping Off
Comparison of ILRG Model Runs
Run 7 v. Run 1
1951 - 2017 Annual Average
(1,000 acre-feet)

Run No.	1	7	7 - 1		
Simulated Input or Output	**Run 1**	**Run 7**	**Run 7 minus Run 1**		
Effects of Pumping Stress (continued)				***% Chg***	
Change in Storage				***Stress***	***% Diff.***
Reservoir Storage	-4.7	-4.7	-0.1	*0%*	*2%*
Alluvial GW Storage (RW Model)	-23.6	-21.8	1.8	*-8%*	*-7%*
Non-alluvial GW Storage (GW Models)	-96.4	-93.6	2.8	*-13%*	*-3%*
Soil Moisture Storage	0.6	0.6	0.0	*0%*	*0%*
Total	-124.0	-119.6	4.4	*-21%*	*-4%*
Summary of Effects					
FHG Deliveries (Mar-Oct)	340.3	348.1	7.8	*-38%*	*2%*
FHG Deliveries (Nov-Feb)	2.6	2.6	0.0	*0%*	*0%*
Irrigation Pumping	184.8	177.5	-7.2	*35%*	*-4%*
Riparian ET + Evaporation	226.6	230.7	4.1	*-20%*	*2%*
Fort Quitman Flow	96.0	103.5	7.6	*-36%*	*8%*
Change in Storage	-124.0	-119.6	4.4	*-21%*	*-4%*
Total	726.2	742.9	16.7	*-80%*	*2%*
Other Effects of Pumping Stress				***% Chg***	
Rio Grande at El Paso				***Stress***	***% Diff.***
Reservoir Spills	49.4	50.6	1.2	*-6%*	*2%*
Nov-Feb Flows	22.8	27.6	4.8	*-23%*	*21%*
Mar - Oct Flows	263.8	276.4	12.6	*-61%*	*5%*
Total	336.0	354.5	18.6	*-89%*	*6%*
Rio Grande below Caballo					
Reservoir Spills	65.9	65.2	-0.6	*3%*	*-1%*
Nov-Feb Flows	0.5	0.3	-0.2	*1%*	*-35%*
Mar - Oct Flows	541.3	539.6	-1.7	*8%*	*0%*
Total	607.6	605.1	-2.5	*12%*	*0%*
Surface Water Diversions (Mar - Oct)					
EBID	366.5	373.7	7.2	*-35%*	*2%*
EPCWID (incl. EPW)	236.8	240.2	3.4	*-17%*	*1%*
HCCRD	67.5	69.1	1.6	*-8%*	*2%*
Total	670.8	683.1	12.2	*-59%*	*2%*
Surface Water Diversions (Nov - Feb)					
EBID	0.0	0.0	0.0	*0%*	*0%*
EPCWID (incl. EPW)	14.3	14.6	0.3	*-1%*	*2%*
HCCRD	14.2	14.5	0.3	*-1%*	*2%*
Total	28.5	29.1	0.5	*-3%*	*2%*

Run 7 - TX Mesilla Pumping Off
Annual Differences in ILRG Model Outputs
Run 7 minus Run 1
1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1940	-55	-55	5	-2	0	-3	-2	-2	3	3	0	0	-58	-23	-58
1941	-163	-163	-2	-5	-2	-2	-3	-3	-1	0	-2	-4	49	86	27
1942	-34	-34	0	-4	-1	0	0	0	3	8	0	-1	27	18	-11
1943	-65	-65	-4	-6	3	3	-14	-14	-12	-12	2	-1	-23	-10	-76
1944	-81	-81	-143	-137	-110	-92	-6	-6	17	-2	-99	-100	-159	-154	-47
1945	-78	-78	-4	24	2	23	1	1	-5	-32	4	4	-91	-1	23
1946	-38	-38	18	32	3	10	5	5	15	15	3	3	-52	67	45
1947	-72	-72	-5	28	-3	16	1	0	-3	-14	-7	-6	-94	36	58
1948	-74	-74	1	19	-1	8	0	0	12	3	1	1	-98	45	45
1949	-102	-102	-9	9	0	12	2	2	0	-2	0	0	-115	26	38
1950	-311	-311	-75	-59	-6	16	380	380	-75	-69	0	-1	-901	1,471	883
1951	280	280	-66	-60	27	41	702	702	-91	-87	21	25	-3,099	1,348	975
1952	-763	-763	-43	-32	45	57	705	705	-210	-201	49	49	-6,155	2,644	659
1953	-750	-750	-267	-255	84	59	1,365	1,365	-560	-551	59	10	-6,341	5,535	1,555
1954	938	938	946	1,945	63	-70	4,735	4,735	4,144	4,161	214	147	-4,262	14,142	2,083
1955	10,196	10,196	7,814	9,558	85	-70	5,747	5,747	5,039	4,833	-155	-293	10,325	16,190	484
1956	4,244	4,244	5,593	6,741	440	418	-454	-454	870	87	345	306	4,155	11,783	46
1957	-434	-434	18	1,712	-26	-28	359	359	-2	-423	-73	-97	-6,093	6,803	1
1958	-855	-855	-2,559	-1,467	635	1,444	1,265	1,264	-306	-384	-80	38	-23,670	5,983	1,305
1959	-1,062	-1,062	-853	-451	303	418	1,234	1,234	-646	-626	2	8	-18,162	7,853	1,330
1960	-1,138	-1,138	-425	-271	124	49	1,331	1,331	-822	-799	0	0	-14,055	9,370	1,127
1961	-1,035	-1,035	-185	-59	361	356	1,359	1,359	-274	-250	298	-300	-14,145	9,129	1,529
1962	-1,108	-1,108	-89	35	153	89	1,358	1,358	-527	-501	-63	-249	-14,889	9,668	4,139
1963	7,675	7,675	-47	177	315	366	6,409	6,409	-790	-759	204	209	-5,532	17,904	4,101
1964	12,132	12,132	8,389	9,495	249	347	18,679	18,679	9,751	9,410	946	878	-4,351	28,238	6,234
1965	41,474	41,474	24,418	25,042	2,832	3,047	23,265	23,265	17,724	17,326	2,941	3,128	41,079	44,649	2,597
1966	-1,133	-1,133	-1,594	-155	2,349	3,337	1,891	1,891	-325	-288	974	-46	-26,853	16,262	4,134
1967	26,715	26,715	21,164	24,315	3,345	5,248	16,171	16,171	16,851	16,365	2,736	3,546	28,728	39,123	2,765
1968	4,327	4,327	-1,993	414	2,963	4,790	5,097	5,097	289	-83	2,887	3,510	-18,416	15,208	1,853
1969	-664	-664	-813	-165	3,247	4,831	1,656	1,656	-226	-205	3,502	2,986	-20,626	9,129	2,430
1970	-953	-953	-170	41	1,076	1,513	1,381	1,381	-41	-22	-745	-1,180	-13,337	11,876	3,492
1971	31,121	31,121	1,212	2,568	474	1,156	20,790	20,790	476	504	438	1,020	9,153	21,127	721
1972	229	229	1,343	2,843	80	832	-2,444	-2,444	-5,528	-5,769	-388	304	-7,947	16,688	-49
1973	-1,460	-1,460	449	986	2,022	2,196	2,691	2,691	666	442	1,986	1,968	-24,113	13,492	135
1974	-1,227	-1,227	197	903	1,343	1,722	1,880	1,880	-231	-209	711	733	-19,723	12,622	1,473
1975	-1,038	-1,038	472	441	2,348	2,320	2,579	2,579	309	327	2,562	2,603	-12,406	13,328	263
1976	-1,343	-1,343	337	336	2,187	2,239	2,459	2,459	-101	-87	-26	-85	-16,802	13,404	2,903
1977	58,722	58,722	36,918	39,473	10,373	11,072	28,037	28,037	15,536	15,565	9,420	10,339	50,270	64,954	6,840
1978	19,351	19,351	13,454	16,799	-1,112	1,424	11,351	11,351	12,149	12,184	-869	1,432	15,835	36,993	2,461

Run 7 - TX Mesilla Pumping Off
Annual Differences in ILRG Model Outputs
Run 7 minus Run 1
1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1979	-850	-850	171	1,249	761	2,834	3,166	3,167	3,288	3,327	790	2,948	-25,529	23,544	3,715
1980	-949	-949	-383	138	1,614	3,331	1,812	1,812	187	213	353	-399	-17,388	16,087	5,456
1981	-911	-911	-117	108	346	660	1,966	1,966	186	206	0	0	-13,693	12,883	2,331
1982	-964	-964	-64	-60	29	164	1,574	1,574	158	176	-29	-85	-12,358	13,052	2,507
1983	-682	-682	41	30	371	466	1,387	1,387	169	186	0	0	-9,967	12,679	1,382
1984	-743	-743	46	283	2,590	2,836	1,493	1,494	134	153	0	0	-6,770	15,793	4,282
1985	-675	-675	24	-41	1,277	1,462	1,768	1,769	14	-58	0	0	-6,864	13,332	4,708
1986	-727	-727	-94	-70	1,127	1,553	1,453	1,463	89	115	0	0	70,618	89,226	160,994
1987	-890	-890	382	398	270	443	953	955	148	165	0	0	8	20,027	30,322
1988	-675	-675	306	320	249	399	1,715	1,716	82	96	0	0	-5,194	16,235	10,396
1989	-802	-802	975	784	343	541	1,673	1,674	388	139	0	0	-5,952	15,959	6,891
1990	-525	-525	302	122	1,515	1,667	1,559	1,559	167	-79	0	0	-4,356	15,268	6,619
1991	-881	-881	229	1	117	367	349	350	175	-198	0	0	-4,441	12,749	8,697
1992	2,068	2,068	74,909	74,752	34,176	35,239	-9,051	-9,062	33,574	33,399	0	0	33,461	56,924	40,586
1993	-38	-38	-5,159	-5,184	-1,070	-422	2,094	2,090	-2,789	-2,787	0	0	-20,236	-5,877	-1,808
1994	-917	-917	774	765	276	457	1,443	1,443	493	499	0	0	470	21,369	12,214
1995	-1,023	-1,023	809	769	339	580	1,633	1,634	461	415	0	0	3,974	29,446	17,882
1996	-1,185	-1,185	391	406	180	362	2,196	2,196	207	224	0	0	-10,192	19,277	7,454
1997	-603	-603	110	-56	336	636	1,468	1,468	-468	-825	0	0	-6,463	17,709	4,267
1998	-781	-781	543	529	241	214	1,672	1,672	289	299	0	0	-9,099	18,151	8,114
1999	-612	-612	-767	-784	259	-20	1,580	1,580	2,033	2,041	0	0	-103	23,524	12,599
2000	-586	-586	-2,190	-2,300	-296	-349	1,753	1,753	-1,881	-1,870	0	0	-11,699	13,008	3,774
2001	-598	-598	608	47	496	484	1,427	1,427	-87	-79	0	0	-7,204	16,044	5,040
2002	-558	-558	1,050	643	525	774	1,670	1,670	89	97	0	0	-8,378	16,084	5,604
2003	29,840	29,840	3,927	2,936	1,038	600	19,729	19,729	2,165	2,180	0	0	13,464	24,112	5,031
2004	12,100	12,100	5,103	4,337	1,502	1,617	8,871	8,871	2,406	2,425	0	0	-1,299	23,151	6,846
2005	1,271	1,271	3,024	2,064	929	988	3,914	3,906	1,536	1,555	0	0	-16,226	16,890	6,009
2006	44,276	44,276	20,324	18,871	8,750	8,837	21,406	21,406	2,088	2,101	0	0	37,556	45,515	24,184
2007	16,218	16,218	562	-192	525	367	9,903	9,903	-306	-287	0	0	-9,419	13,106	3,290
2008	30,040	30,040	1,570	714	820	593	20,700	20,700	168	188	0	0	-2,050	15,960	4,179
2009	44,238	44,238	1,156	511	602	659	25,859	25,859	-283	-261	0	0	-648	16,626	7,742
2010	51,094	51,094	2,159	2,575	929	1,155	33,051	33,051	829	850	0	0	1,782	17,909	6,685
2011	31,586	31,586	6,995	6,924	2,546	2,124	17,664	17,664	4,775	4,794	0	0	19,317	23,326	6,546
2012	-4,968	-4,968	1,997	640	3,840	2,713	-671	-671	863	876	0	0	-12,649	15,103	6,143
2013	1,621	1,621	-2,369	-2,978	249	16	798	798	-1,424	-1,413	316	155	-5,198	10,438	3,092
2014	4,497	4,497	-609	-1,670	38	-362	2,816	2,816	-163	-153	246	-83	2,163	10,794	410
2015	3,926	3,926	282	-249	244	226	2,317	2,317	-251	-241	101	159	134	11,733	2,028
2016	7,709	7,709	-3,364	-3,581	-430	-688	2,478	2,478	-2,878	-2,867	0	0	-9,288	7,132	491
2017	24,900	24,900	2,669	3,015	545	586	13,142	13,142	1,318	1,330	0	0	13,039	15,990	2,282
Averages															
1951-2017	7,249	7,249	3,432	3,697	1,561	1,840	5,557	5,557	1,807	1,745	443	503	-2,509	18,593	7,561
1951-1978	7,230	7,230	4,058	5,032	1,299	1,757	5,771	5,771	2,612	2,499	996	1,107	-4,337	16,980	2,057
1979-2005	1,041	1,041	3,146	3,044	1,835	2,144	2,269	2,269	1,601	1,556	41	91	-3,015	20,987	14,145
2006-2017	21,261	21,261	2,614	2,048	1,555	1,352	12,455	12,455	395	410	55	19	2,895	16,969	5,589
1985-2017	8,738	8,738	3,534	3,182	1,893	1,934	6,040	6,040	1,328	1,293	20	7	1,183	20,492	13,009
1985-2005	1,581	1,581	4,060	3,830	2,087	2,266	2,375	2,374	1,861	1,798	0	0	204	22,505	17,250

Notes:

EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

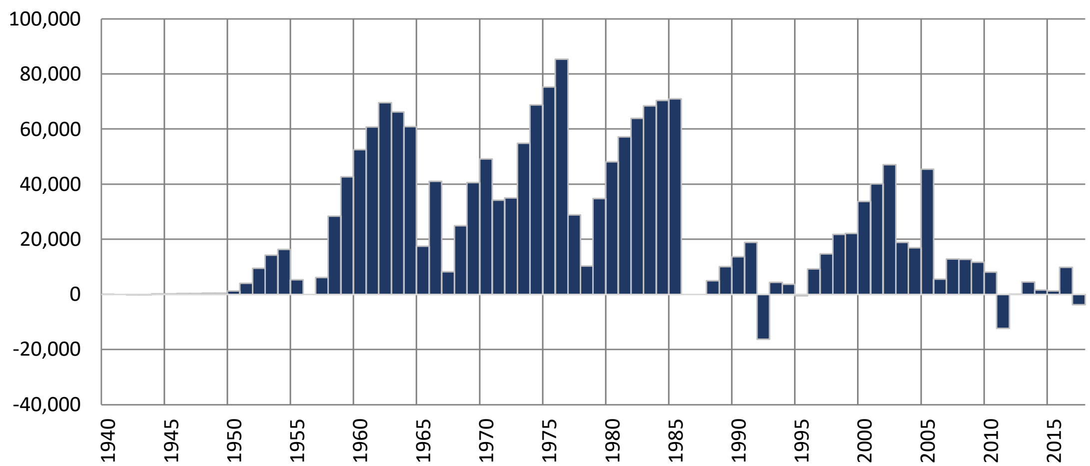
Run 7 - TX Mesilla Pumping Off

Simulated Differences in ILRG Model Outputs

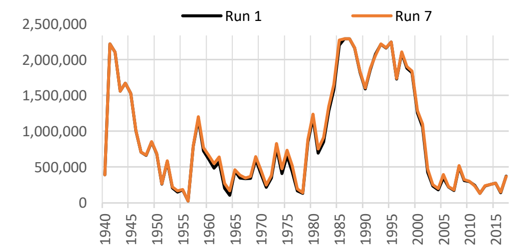
Run 7 minus Run 1

1940 - 2017 (acre-feet)

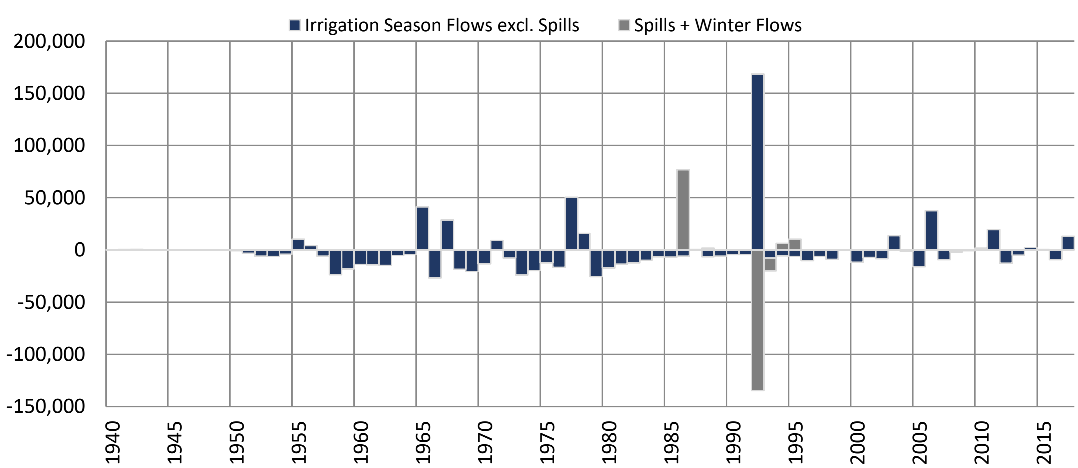
Total Project Storage (Year End)



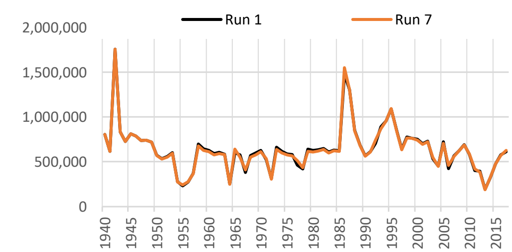
Period	Average Difference
1951-2017	-74
1951-1978	324
1979-2005	1,301
2006-2017	-4,096
1985-2017	-2,245
1985-2005	-1,187



Caballo Reservoir Outflows (Annual)



	Average Difference		
Period	Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	-1,722	-787	-2,509
1951-1978	-4,337	0	-4,337
1979-2005	-1,061	-1,954	-3,015
2006-2017	2,895	0	2,895
1985-2017	2,781	-1,599	1,183
1985-2005	2,716	-2,512	204



Notes:

Reservoir storage does not include storage attributed to SJC, CO, or NM credit waters.

Average differences calculated as (Final Storage - Initial Storage)/(no. years).

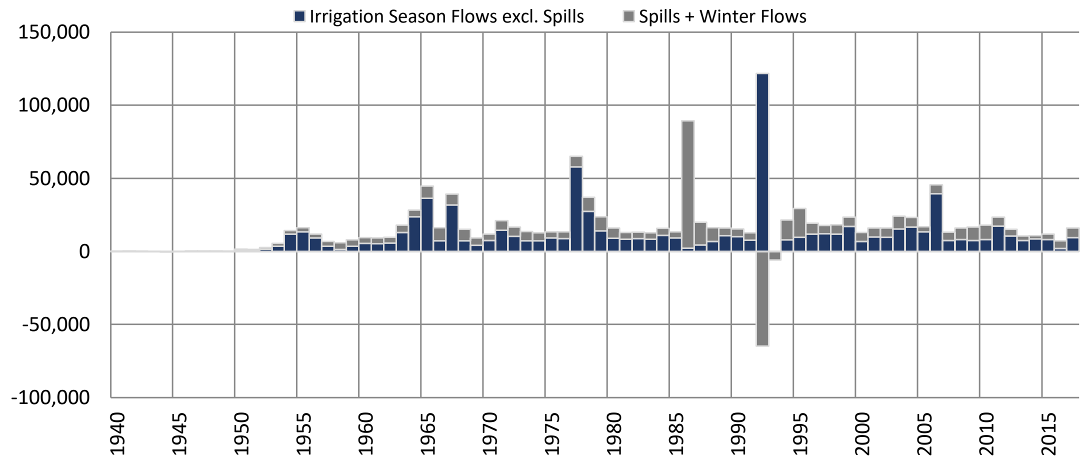
Run 7 - TX Mesilla Pumping Off

Simulated Differences in ILRG Model Outputs

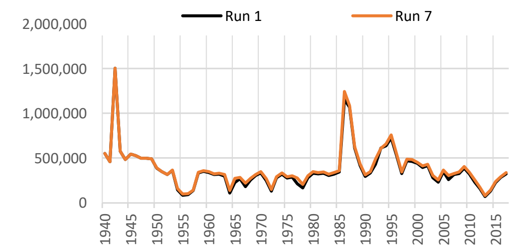
Run 7 minus Run 1

1940 - 2017 (acre-feet)

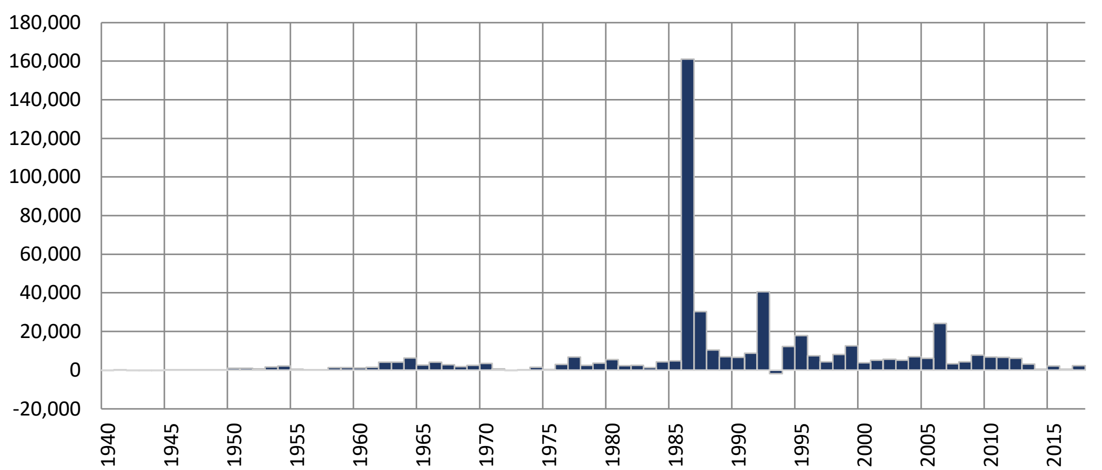
Rio Grande at El Paso (Annual)



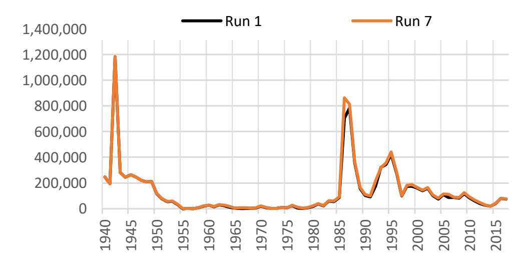
Period	Average Difference: Irr Season (excl. Spills)	Average Difference: Nov-Feb and Spills	Average Difference: Annual
1951-2017	12,613	5,980	18,593
1951-1978	12,051	4,929	16,980
1979-2005	13,849	7,138	20,987
2006-2017	11,144	5,825	16,969
1985-2017	13,586	6,907	20,492
1985-2005	14,981	7,524	22,505



Rio Grande at Fort Quitman (Annual)



Period	Average Difference
1951-2017	7,547
1951-1978	2,042
1979-2005	14,128
2006-2017	5,586
1985-2017	13,001
1985-2005	17,239



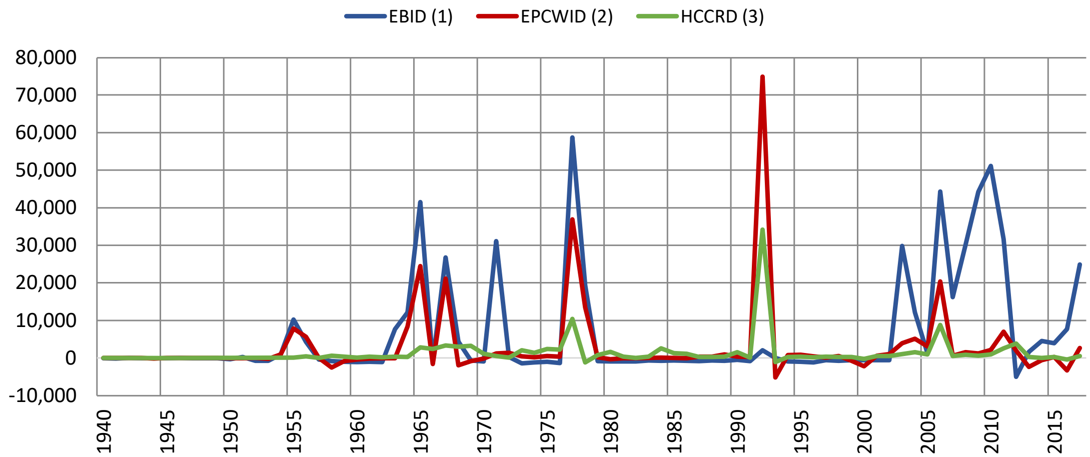
Run 7 - TX Mesilla Pumping Off

Simulated Differences in ILRG Model Outputs

Run 7 minus Run 1

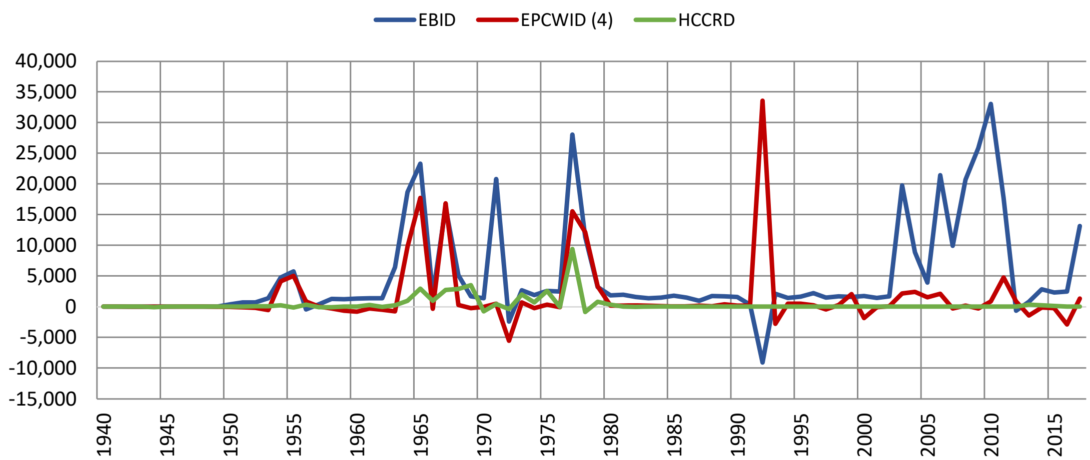
1940 - 2017 (acre-feet)

River Headgate (RHG) Diversions (Irrigation Season)



	Average Difference		
Period	EBID	EPCWID	HCCRD
1951-2017	7,249	3,432	1,561
1951-1978	7,230	4,058	1,299
1979-2005	1,041	3,146	1,835
2006-2017	21,261	2,614	1,555
1985-2017	8,738	3,534	1,893
1985-2005	1,581	4,060	2,087

Farm Headgate (FHG) Deliveries (Irrigation Season)



	Average Difference		
Period	EBID	EPCWID	HCCRD
1951-2017	5,557	1,807	443
1951-1978	5,771	2,612	996
1979-2005	2,269	1,601	41
2006-2017	12,455	395	55
1985-2017	6,040	1,328	20
1985-2005	2,375	1,861	0

Notes:

(1) EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

(2) EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

(3) HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

(4) EPCWID FHG values include deliveries to Rogers WTP and R/U WTP.

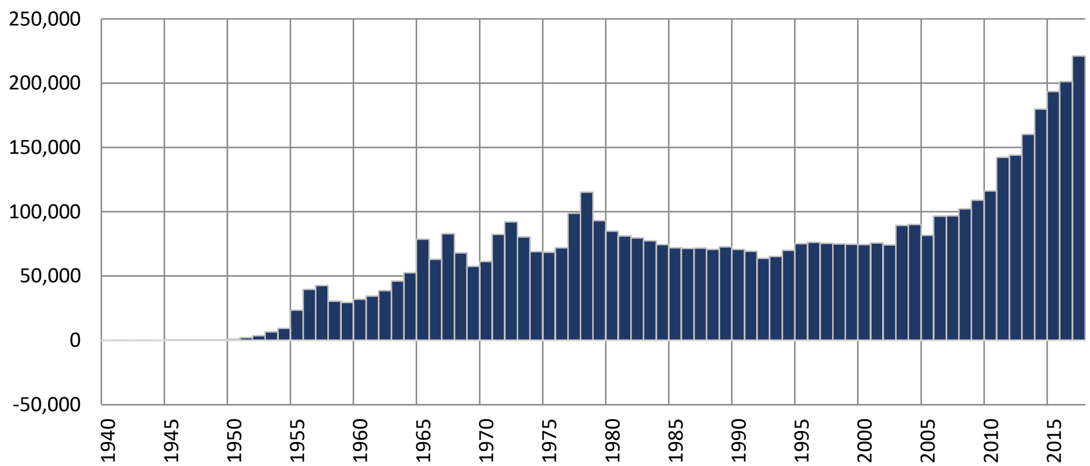
Run 7 - TX Mesilla Pumping Off

Simulated Differences in ILRG Model Outputs

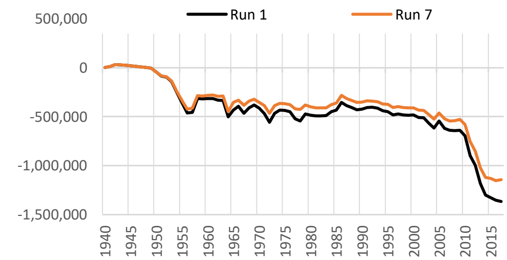
Run 7 minus Run 1

1940 - 2017 (acre-feet)

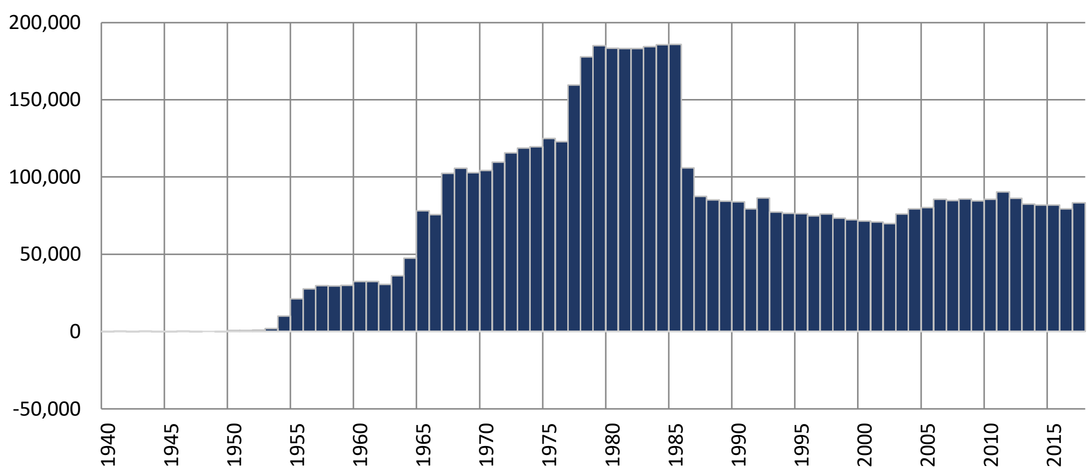
Cumulative Annual Rincon-Mesilla Groundwater Storage



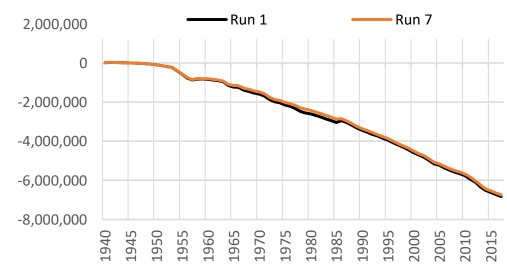
Period	Average Difference
1951-2017	3,285
1951-1978	4,085
1979-2005	-1,246
2006-2017	11,615
1985-2017	4,444
1985-2005	346



Cumulative Annual Hueco Groundwater Storage



Period	Average Difference
1951-2017	1,235
1951-1978	6,331
1979-2005	-3,619
2006-2017	262
1985-2017	-3,102
1985-2005	-5,025



Notes:

Cumulative storage change in alluvial and non-alluvial aquifers.

Average differences calculated as (Final Storage - Initial Storage)/(no. years).

Run 7 - TX Mesilla Pumping Off

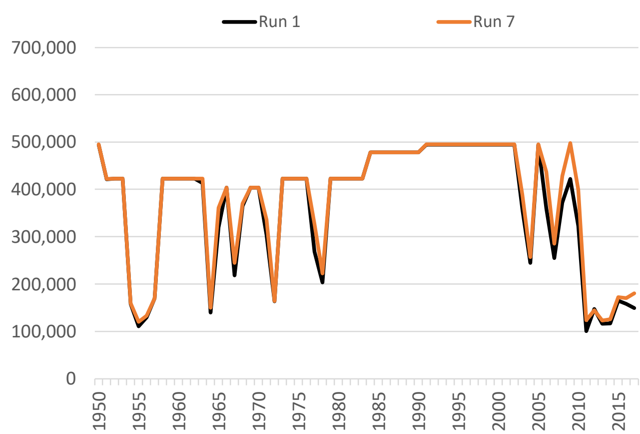
Annual Allocation and Charges

Run 7 v. Run 1

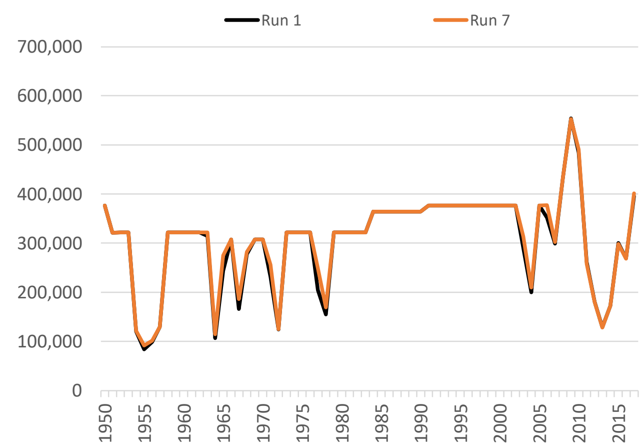
ILRG Model

1950 - 2017 (acre-feet)

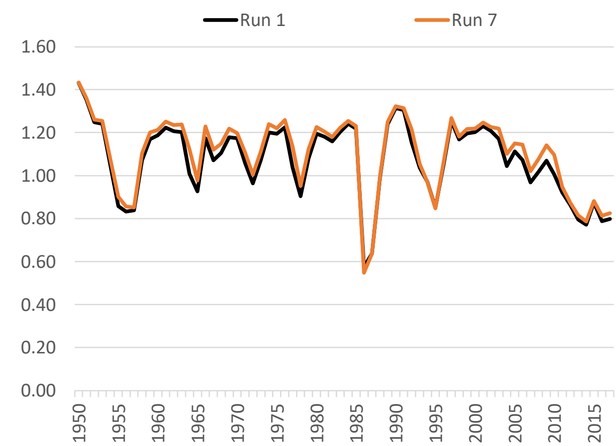
Total Allocation - EBID



Total Allocation - EPCWID



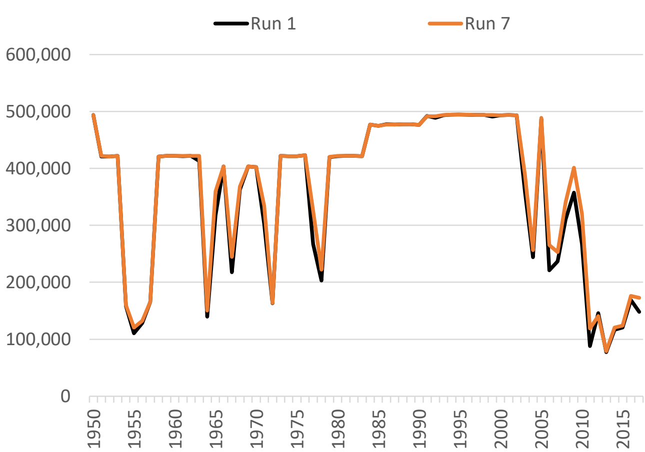
Diversion Ratio



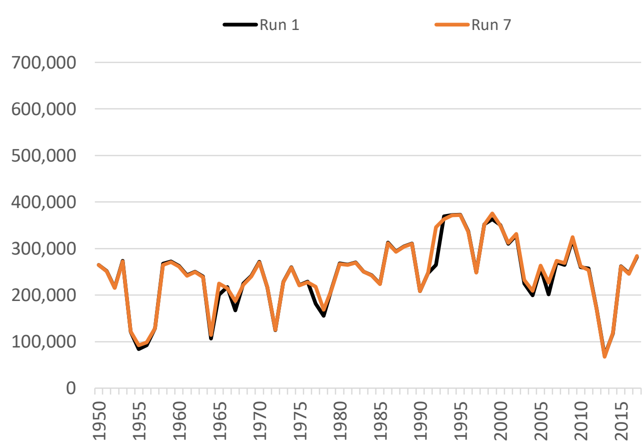
Note:

Computed as Total Charges/Caballo Release.

Annual Delivery Charges - EBID

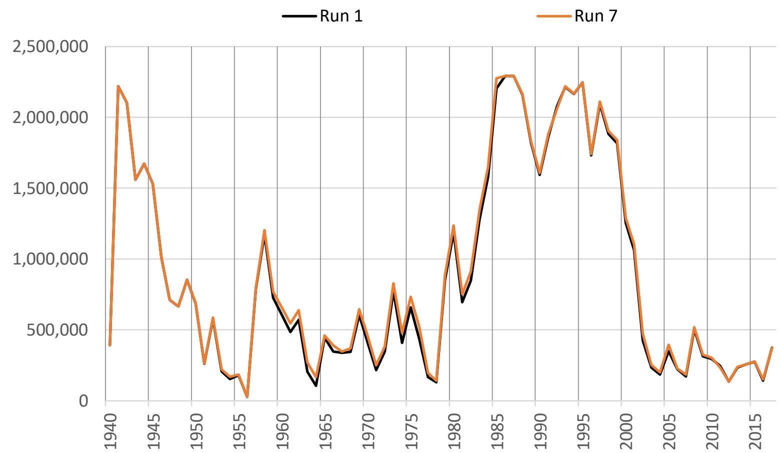


Annual Delivery Charges - EPCWID

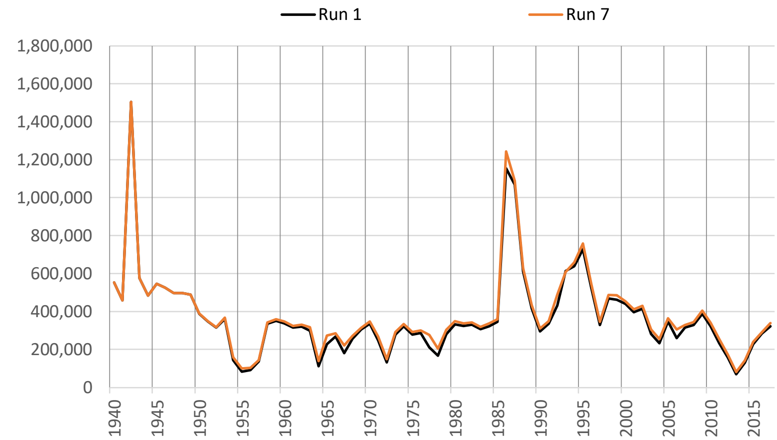


Run 7 - TX Mesilla Pumping Off
Annual Summary of Project Storage and Rio Grande Flows
Run 7 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

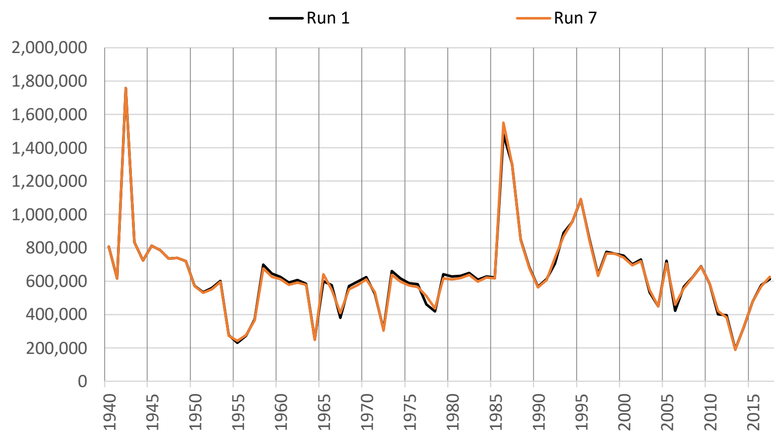
Total Year-End Project Reservoir Storage



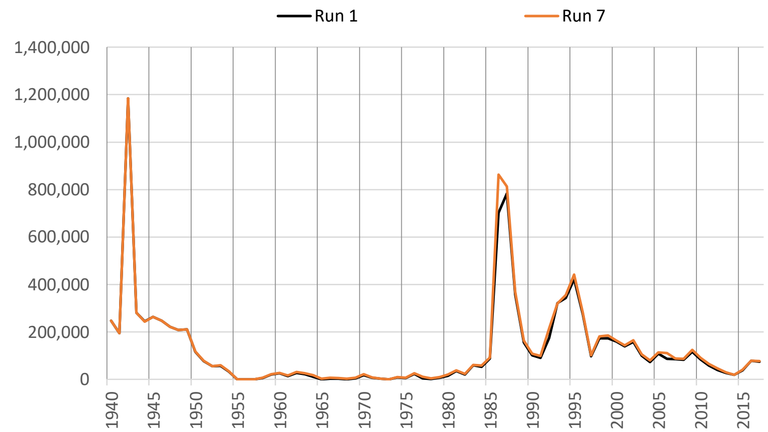
Rio Grande at El Paso



Rio Grande Below Caballo



Rio Grande at Fort Quitman

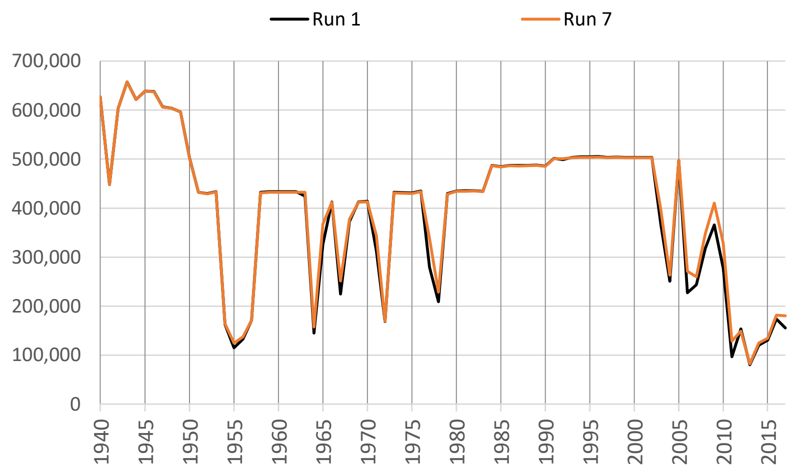


***Note different scales.**

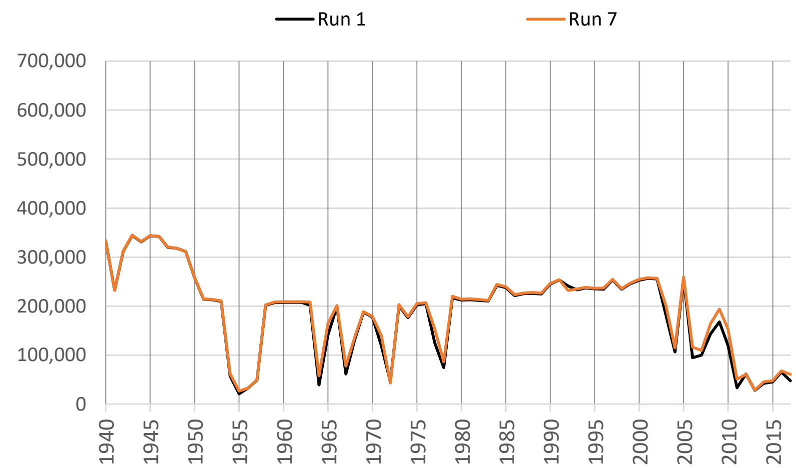
Run 7 - TX Mesilla Pumping Off
Irrigation Season Summary of Irrigation Operations
Run 7 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

EBID Total

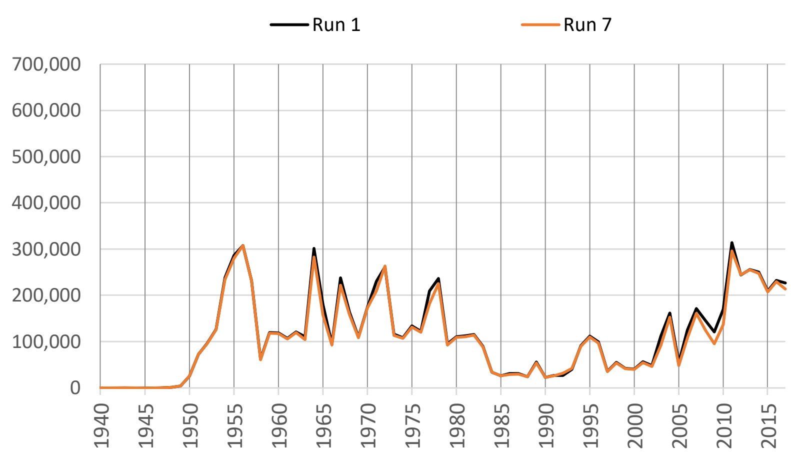
Net River Headgate Diversions



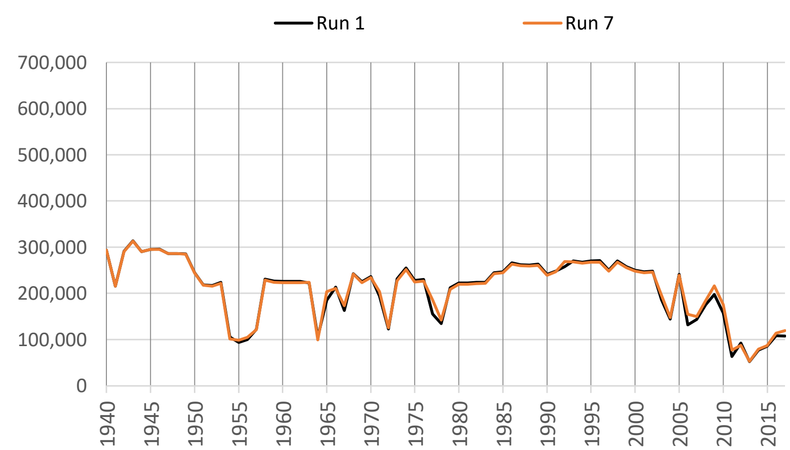
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries



Notes: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).
Pumping includes Supplemental and Primary groundwater pumping.

Run 7 - TX Mesilla Pumping Off

Irrigation Season Summary of Irrigation Operations

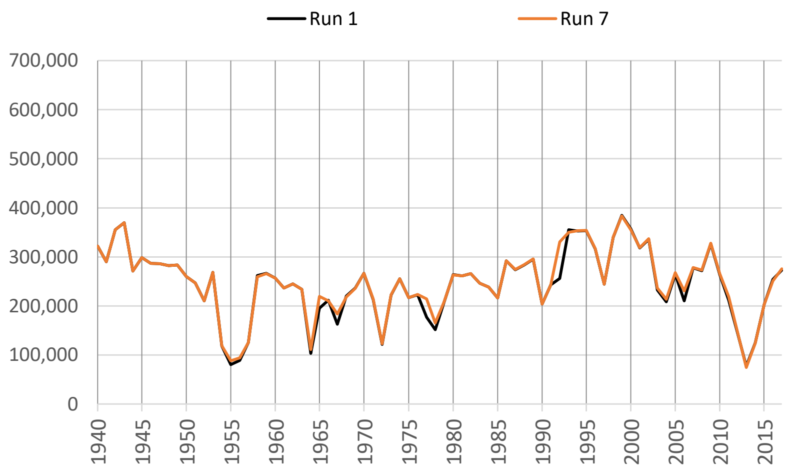
Run 7 v. Run 1

ILRG Model

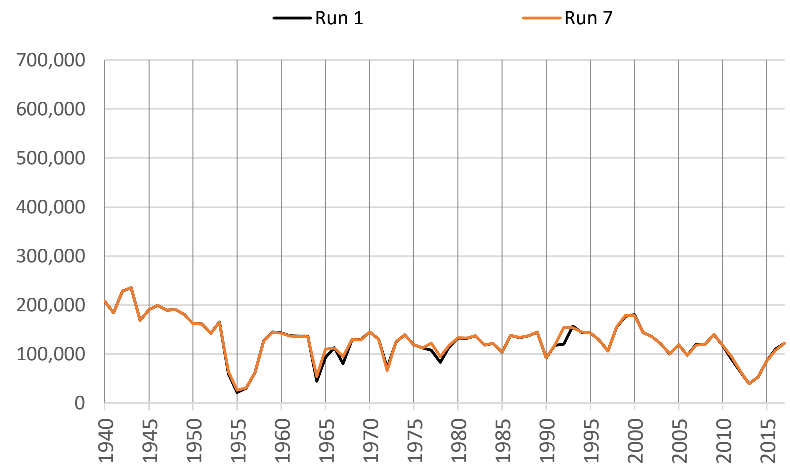
1940 - 2017 (acre-feet)

EPCWID Total

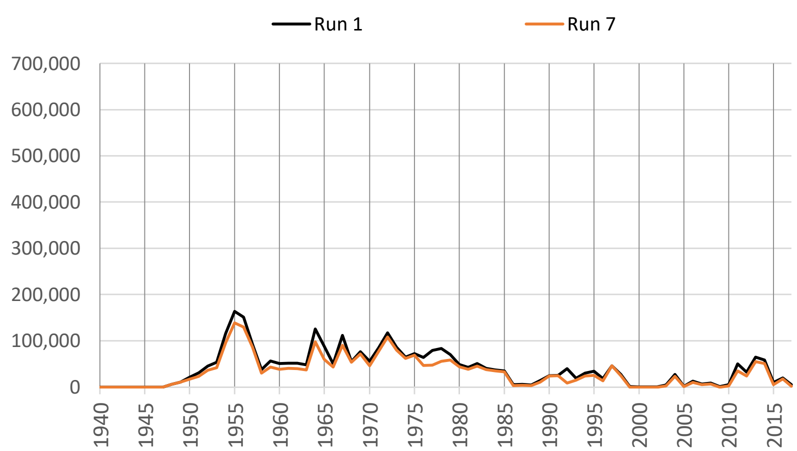
Net River Headgate Diversions



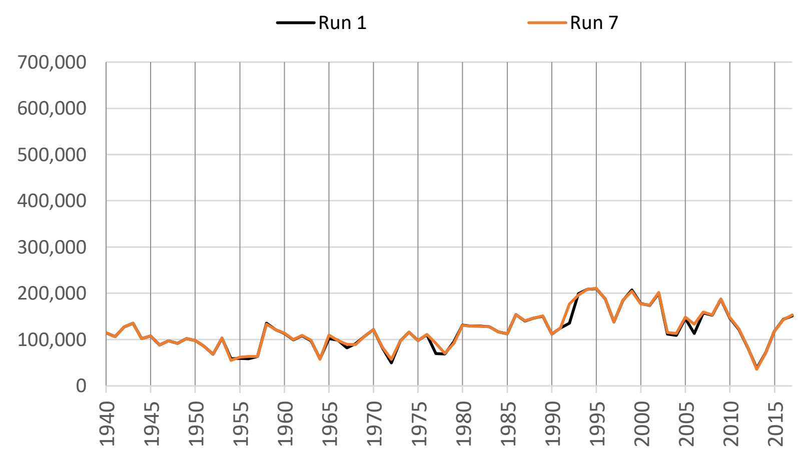
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries

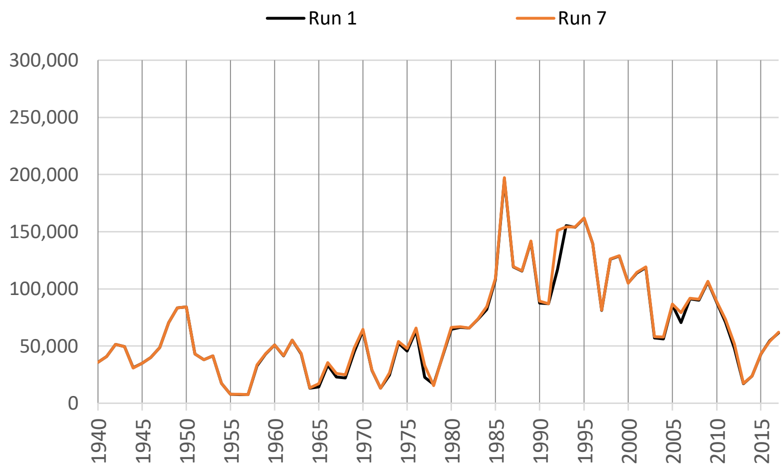


Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

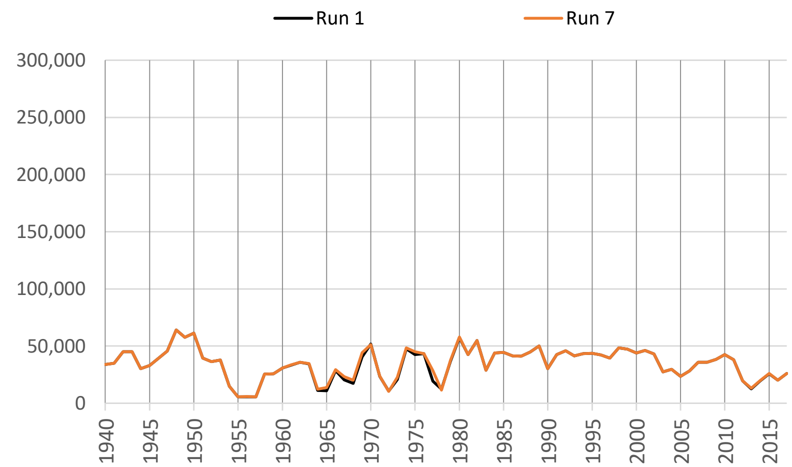
Run 7 - TX Mesilla Pumping Off
Irrigation Season Summary of Irrigation Operations
Run 7 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

HCCRD Total

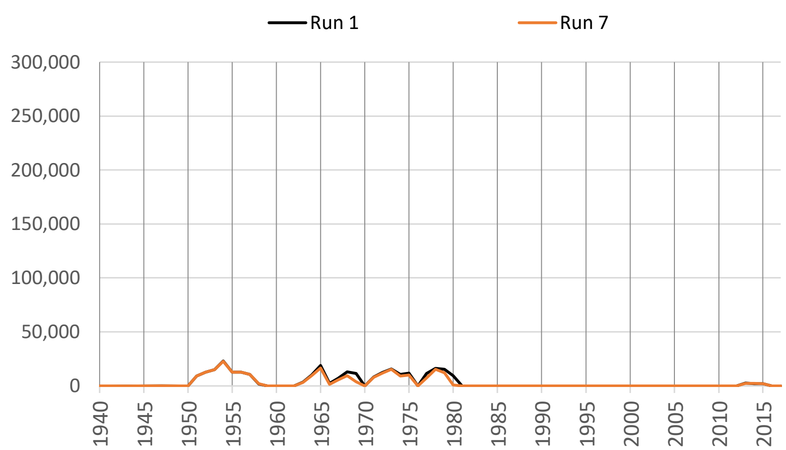
Net River Headgate Diversions



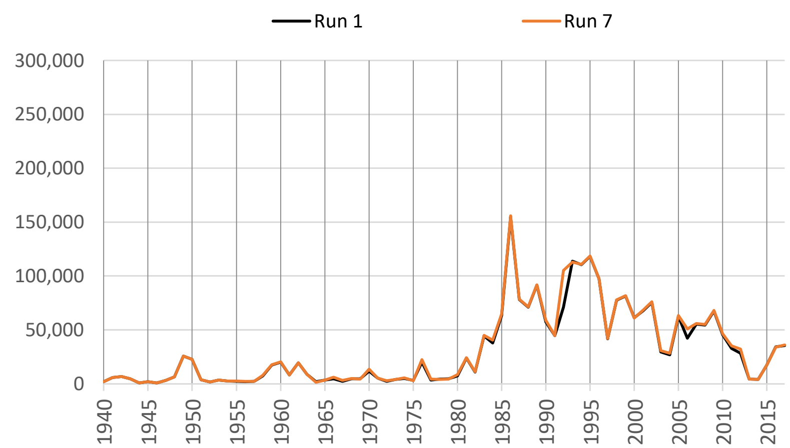
Farm Headgate Deliveries



Pumping



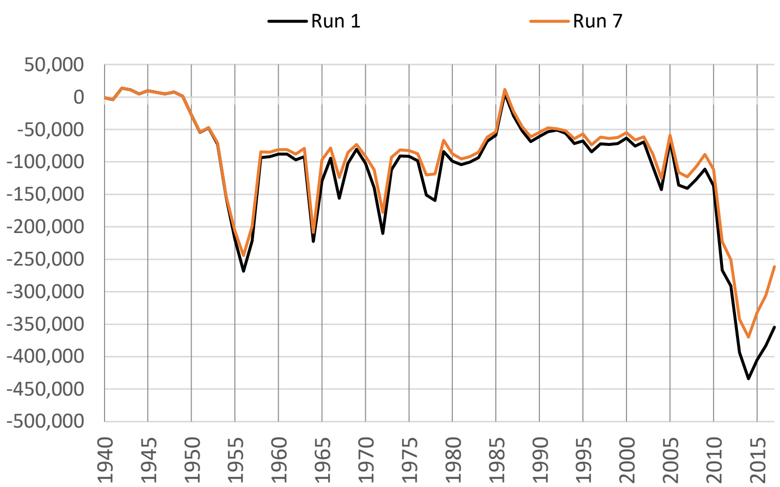
RHG Diversions - FHG Deliveries



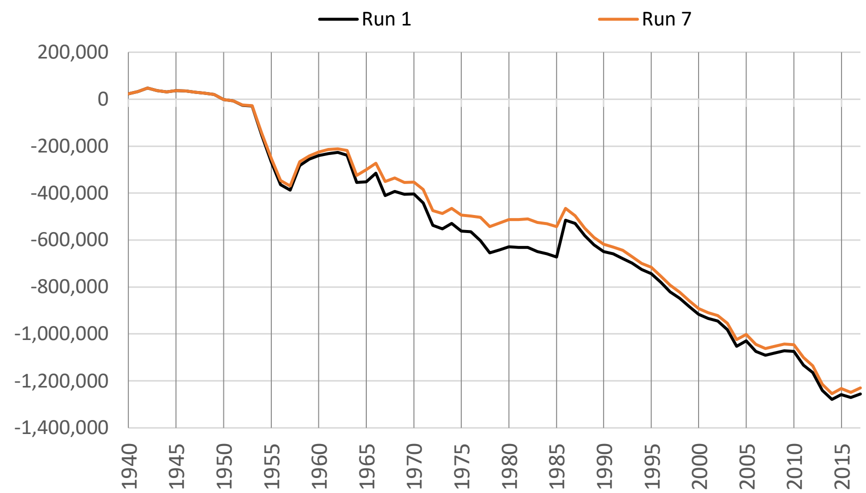
Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

Run 7 - TX Mesilla Pumping Off
Cumulative Change in Ground Water Storage
Run 7 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

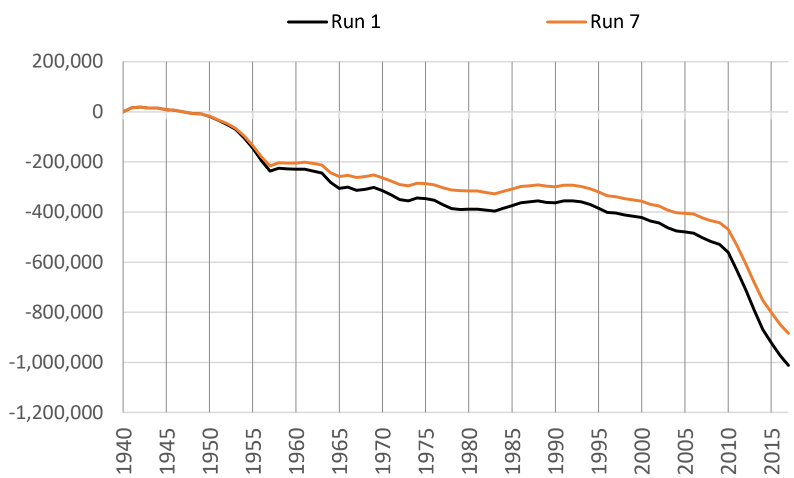
Rincon-Mesilla Alluvial Aquifer



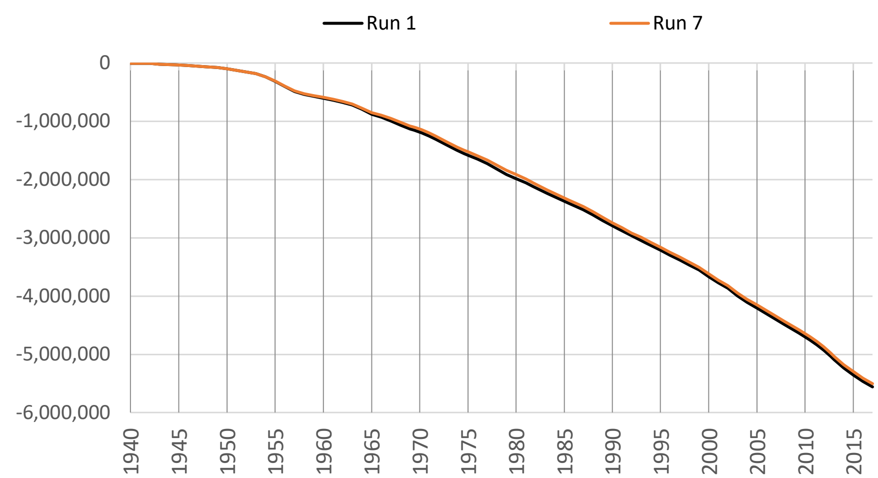
Hueco Alluvial Aquifer



Rincon-Mesilla Non-Alluvial Aquifer

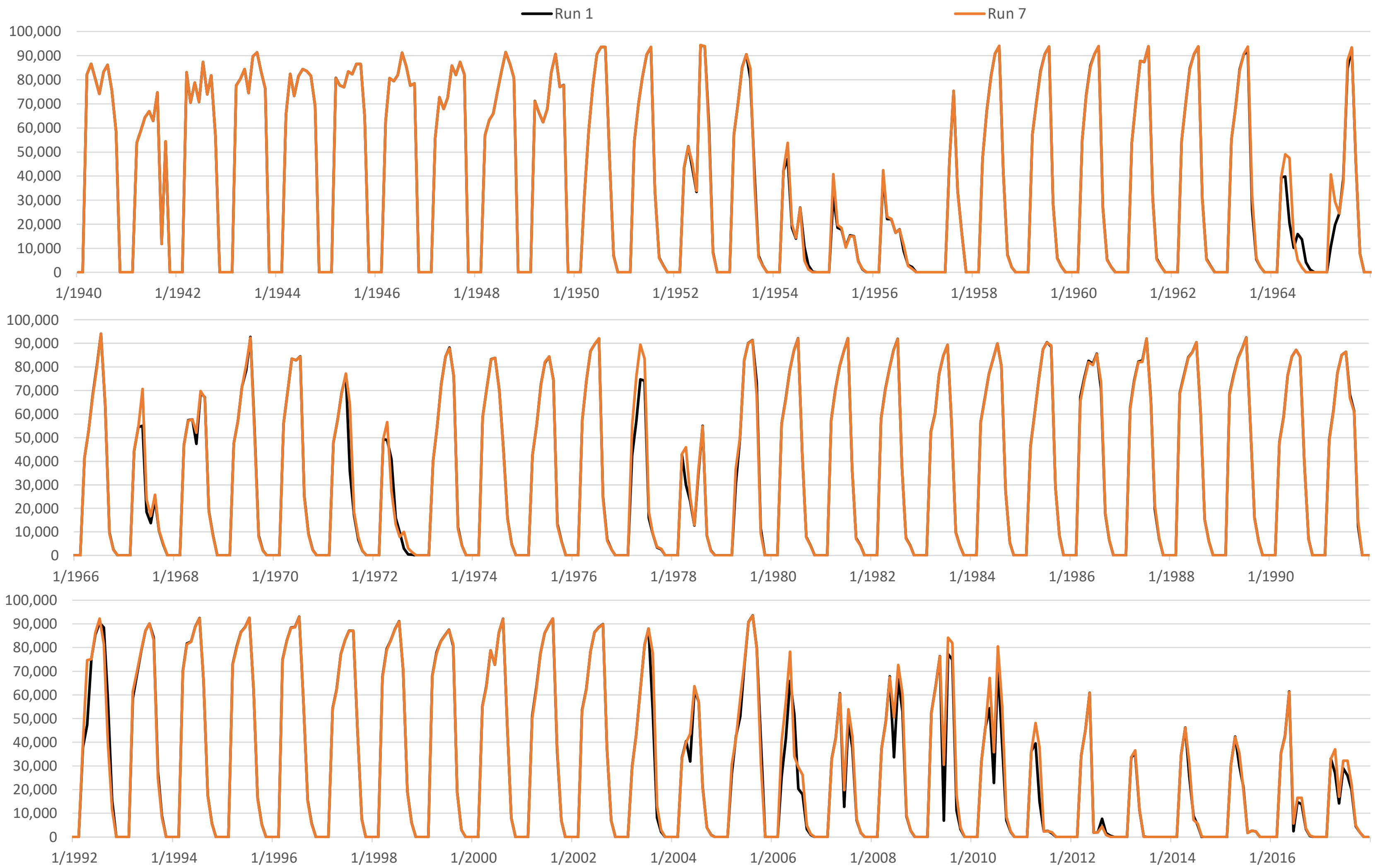


Hueco Non-Alluvial Aquifer



***Note different scales.**

Run 7 - TX Mesilla Pumping Off
Monthly Net RHG Diversions
Run 7 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
EBID Total

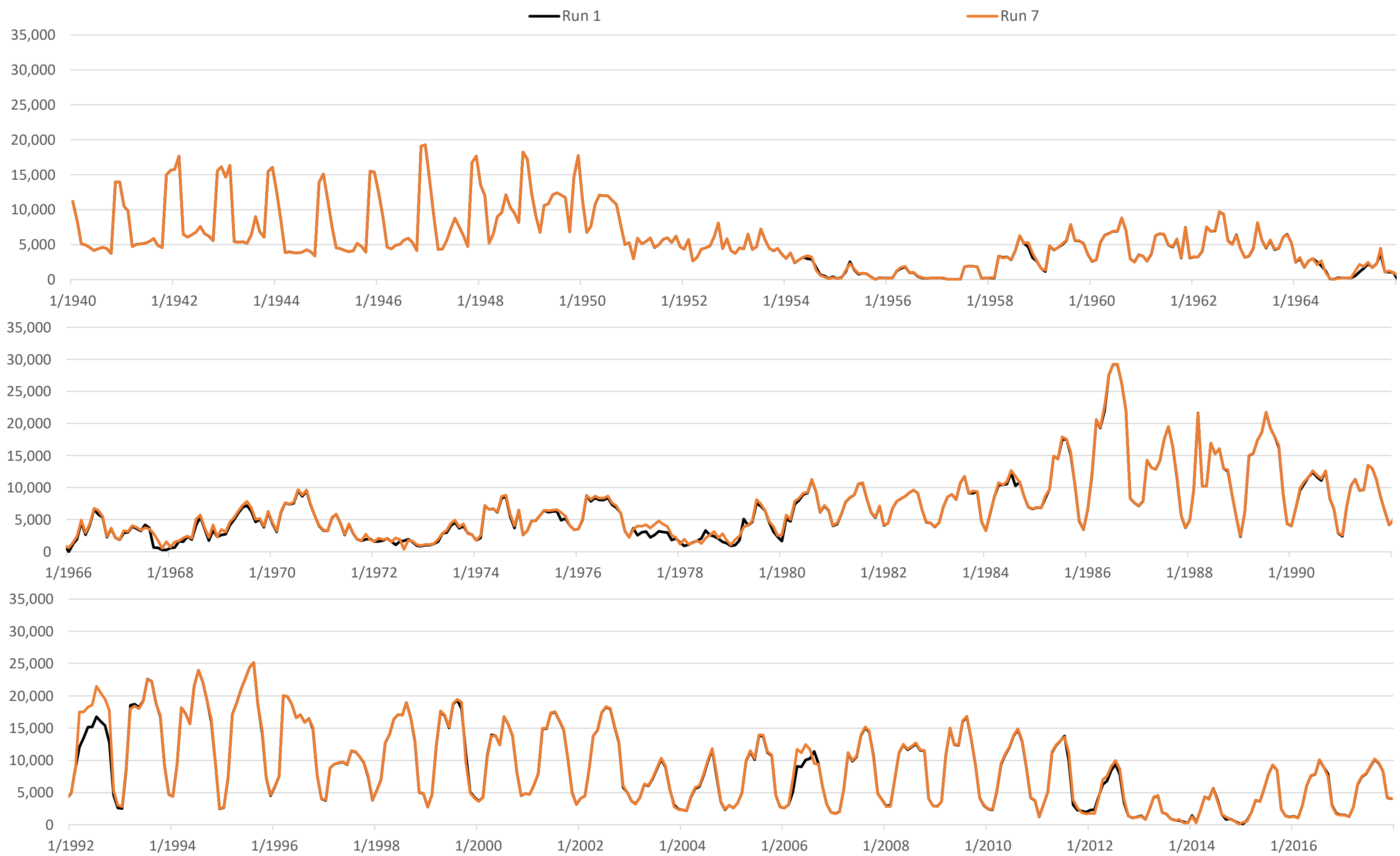


Note: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

Run 7 - TX Mesilla Pumping Off
Monthly Net RHG Diversions
Run 7 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
EPCWID Total

Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

Run 7 - TX Mesilla Pumping Off
Monthly Net RHG Diversions
Run 7 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
HCCRD Total



Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

Run 7 - TX Mesilla Pumping Off

End of Month Reservoir Storage (Elephant Butte + Caballo)

Run 7 v. Run 1

ILRG Model

1940 - 2017 (acre-feet)

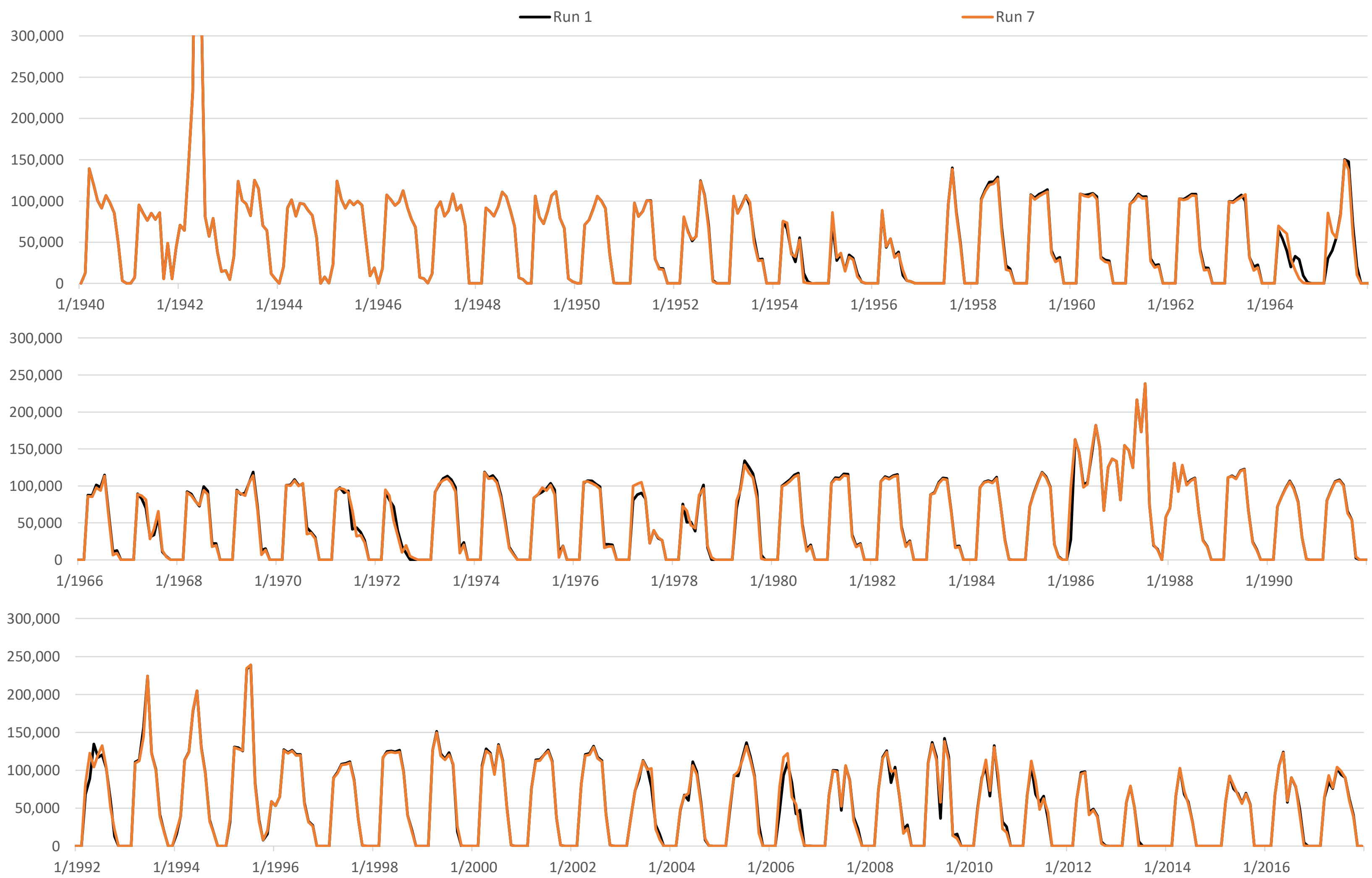
Run 7 - TX Mesilla Pumping Off

Monthly Caballo Releases

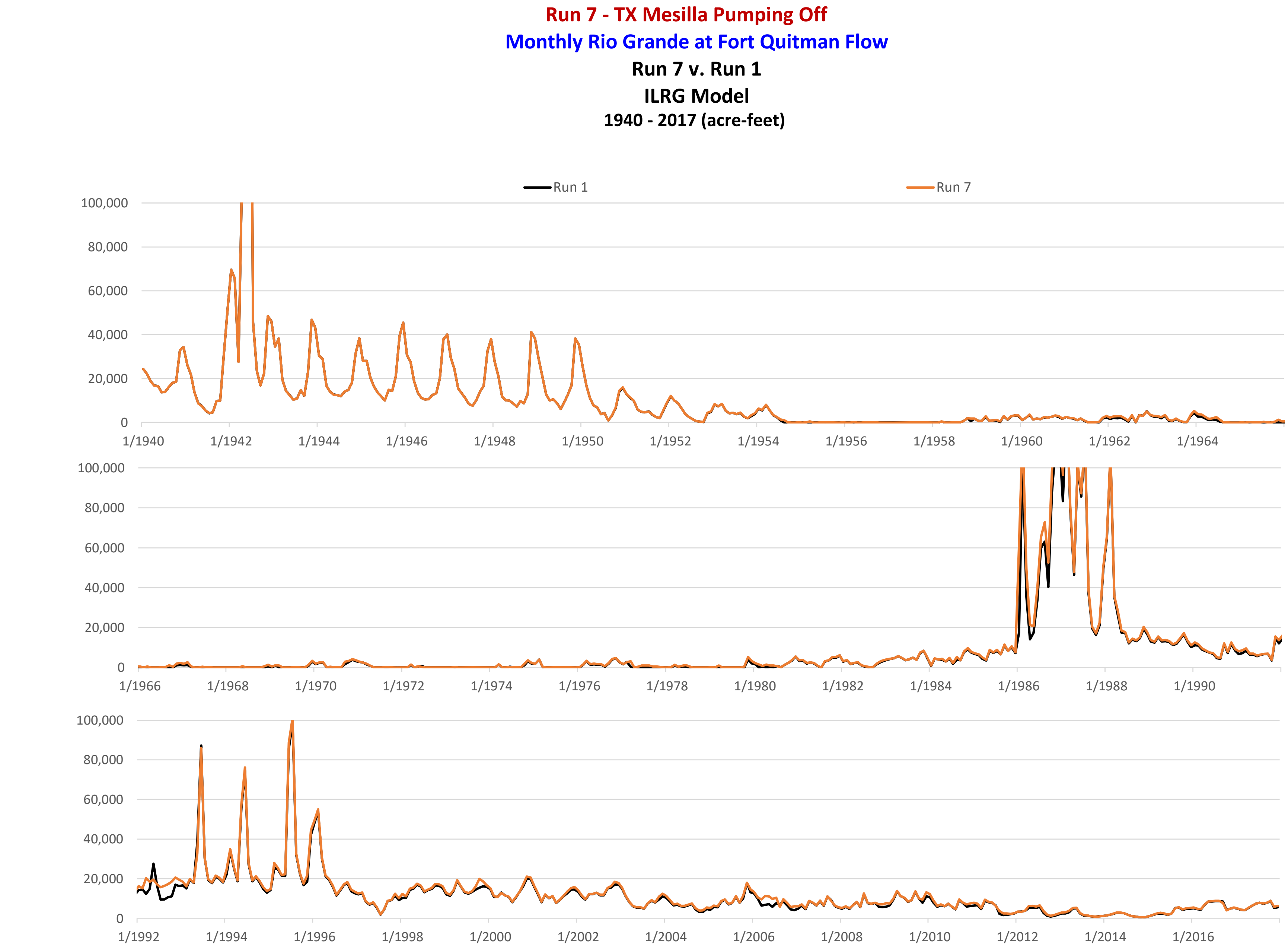
Run 7 v. Run 1

ILRG Model

1940 - 2017 (acre-feet)



Run 7 - TX Mesilla Pumping Off
Monthly Rio Grande at El Paso Flow
Run 7 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)


Run 7 - TX Mesilla Pumping Off
Monthly Rio Grande at Fort Quitman Flow
Run 7 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
Run 1
Run 7
100,000
80,000
60,000
40,000
20,000
0
1/1940
1/1942
1/1944
1/1946
1/1948
1/1950
1/1952
1/1954
1/1956
1/1958
1/1960
1/1962
1/1964
1/1966
1/1968
1/1970
1/1972
1/1974
1/1976
1/1978
1/1980
1/1982
1/1984
1/1986
1/1988
1/1990
1/1992
1/1994
1/1996
1/1998
1/2000
1/2002
1/2004
1/2006
1/2008
1/2010
1/2012
1/2014
1/2016

Appendix 30H

Comparison of ILRG Model Runs
Run 8 v. Run 1

Model Run Specifications

Model Version: LRG_v116

Name: **Run 8 - TX Non-Irrigation Pumping Off**

Run ID: LRG_v116_Operational_Run8
Date: 8/27/2020

Name: **Run 1 - Historical Base Run**

Run ID: LRG_v116_Operational_Run1
Date: 8/23/2020

Selected Model Inputs

Pumping and Returns	Run 8	Run 1
Irrigation Pumping	On	On
Irrigated Area	Hist	Hist
Non-Irrigation Pumping	TX Off	On
Non-Irrigation Pumping Returns	TX Off	On
Las Cruces Jornada Pumping Returns	On	On

Project Allocation Rules		
1950-2005	D1/D2	D1/D2
2006-2007	D3	D3
2008-2017	D3 + CO	D3 + CO

EPCWID Operations		
Charge EPCWID for Use of WWTP Returns	Off	Off
ACE and Haskell Credits for EPCWID	On	On
Increased EPCWID Use of Fabens Drain Flows	Off	Off
Charge EPCWID for Fabens Drain Flow Use	Off	Off

Run 8 - TX Non-Irrigation Pumping Off
Comparison of ILRG Model Runs
Run 8 v. Run 1
1951 - 2017 Annual Average
(1,000 acre-feet)

Run No.	1	8	8 - 1		
Simulated Input or Output	**Run 1**	**Run 8**	**Run 8 minus Run 1**		
Pumping Stress					
Non-Irrigation Pumping	181.0	96.9	-84.1		
WWTP Flows	58.0	40.6	-17.4		
Urban Deep Percolation	13.1	5.7	-7.3		
Total Stress	109.9	50.5	-59.3		
	Stress is Pumping minus WWTP and Urban Deep Perc				
Effects of Pumping Stress				***% Chg***	
FHG Deliveries (Mar - Oct)				***Stress***	***% Diff.***
EBID	167.6	169.1	1.5	*-3%*	*1%*
EPCWID (incl. EPW)	139.9	137.6	-2.2	*4%*	*-2%*
HCCRD	32.8	32.9	0.0	*0%*	*0%*
Total	340.3	339.6	-0.7	*1%*	*0%*
FHG Deliveries (Nov - Feb)					
EBID	0.0	0.0	0.0	*0%*	*2%*
EPCWID (incl. EPW)	0.2	0.1	-0.1	*0%*	*-49%*
HCCRD	2.4	2.1	-0.3	*1%*	*-14%*
Total	2.6	2.2	-0.4	*1%*	*-16%*
Irrigation Pumping					
EBID	140.4	139.0	-1.5	*3%*	*-1%*
EPCWID (Mesilla Valley)	7.4	7.3	0.0	*0%*	*0%*
EPCWID (El Paso Valley)	40.1	42.2	2.1	*-4%*	*5%*
HCCRD	4.2	4.2	0.0	*0%*	*0%*
	192.1	192.8	0.7	*-1%*	*0%*
	Pumping turned off.	*Other values are simulated responses and are totaled.*			
Other Inflows/Outflows					
Net Reservoir Evaporation	125.3	123.7	-1.6	*3%*	*-1%*
Riparian ET	70.9	71.4	0.5	*-1%*	*1%*
River Evaporation + Incidental Canal Loss	30.3	30.0	-0.3	*1%*	*-1%*
Total	226.6	225.2	-1.4	*2%*	*-1%*
Rio Grande at Fort Quitman					
Reservoir Spills	33.3	29.3	-4.0	*7%*	*-12%*
Nov-Feb Flows	21.4	19.0	-2.4	*4%*	*-11%*
Mar - Oct Flows	41.1	42.1	1.0	*-2%*	*3%*
Underflow (GW Model)	0.2	0.2	0.0	*0%*	*2%*
Total	96.0	90.6	-5.4	*9%*	*-6%*

Run 8 - TX Non-Irrigation Pumping Off
Comparison of ILRG Model Runs
Run 8 v. Run 1
1951 - 2017 Annual Average
(1,000 acre-feet)

Run No.	1	8	8 - 1		
Simulated Input or Output	**Run 1**	**Run 8**	**Run 8 minus Run 1**		
Effects of Pumping Stress (continued)				*% Chg*	
Change in Storage				***Stress***	***% Diff.***
Reservoir Storage	-4.7	-4.7	0.0	*0%*	*0%*
Alluvial GW Storage (RW Model)	-23.6	-16.3	7.3	*-12%*	*-31%*
Non-alluvial GW Storage (GW Models)	-96.4	-51.3	45.1	*-76%*	*-47%*
Soil Moisture Storage	0.6	0.6	0.0	*0%*	*-1%*
Total	-124.0	-71.6	52.4	*-88%*	*-42%*
Summary of Effects					
FHG Deliveries (Mar-Oct)	340.3	339.6	-0.7	*1%*	*0%*
FHG Deliveries (Nov-Feb)	2.6	2.2	-0.4	*1%*	*-16%*
Irrigation Pumping	192.1	192.8	0.7	*-1%*	*0%*
Riparian ET + Evaporation	226.6	225.2	-1.4	*2%*	*-1%*
Fort Quitman Flow	96.0	90.6	-5.4	*9%*	*-6%*
Change in Storage	-124.0	-71.6	52.4	*-88%*	*-42%*
Total	733.6	778.7	45.1	*-76%*	*6%*
Other Effects of Pumping Stress				*% Chg*	
Rio Grande at El Paso				***Stress***	***% Diff.***
Reservoir Spills	49.4	44.5	-4.9	*8%*	*-10%*
Nov-Feb Flows	22.8	26.9	4.1	*-7%*	*18%*
Mar - Oct Flows	263.8	282.7	18.9	*-32%*	*7%*
Total	336.0	354.1	18.2	*-31%*	*5%*
Rio Grande below Caballo					
Reservoir Spills	65.9	57.5	-8.4	*14%*	*-13%*
Nov-Feb Flows	0.5	0.4	0.0	*0%*	*-5%*
Mar - Oct Flows	541.3	551.2	9.9	*-17%*	*2%*
Total	607.6	609.1	1.5	*-3%*	*0%*
Surface Water Diversions (Mar - Oct)					
EBID	366.5	366.9	0.4	*-1%*	*0%*
EPCWID (incl. EPW)	236.8	243.9	7.1	*-12%*	*3%*
HCCRD	67.5	68.2	0.7	*-1%*	*1%*
Total	670.8	679.0	8.2	*-14%*	*1%*
Surface Water Diversions (Nov - Feb)					
EBID	0.0	0.0	0.0	*0%*	*0%*
EPCWID (incl. EPW)	14.3	12.3	-2.1	*4%*	*-15%*
HCCRD	14.2	12.6	-1.6	*3%*	*-11%*
Total	28.5	24.8	-3.7	*6%*	*-13%*

Run 8 - TX Non-Irrigation Pumping Off
Annual Differences in ILRG Model Outputs
Run 8 minus Run 1
1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1940	5	5	-620	68	-150	554	-12	-12	377	377	-95	-95	-3,500	-3,375	6,842
1941	1	1	-112	-1,250	219	51	4	4	-2	-199	200	110	3,200	2,929	3,462
1942	-32	-32	-48	-2,055	-175	-176	10	11	464	-154	-197	-219	1,886	1,889	-255
1943	-38	-38	-160	-1,662	-157	-295	23	23	433	189	-100	-403	4,295	4,211	2,315
1944	-41	-41	-487	-1,868	129	-171	0	0	-234	-447	78	-155	1,809	1,798	2,068
1945	-47	-47	-258	-2,171	216	-415	12	12	-298	-698	191	215	2,970	2,926	2,496
1946	-24	-24	52	-2,521	319	-529	25	26	-48	-860	257	180	2,980	3,079	2,616
1947	-43	-43	471	-1,544	209	-441	9	9	643	57	155	186	1,913	2,067	2,790
1948	-35	-35	-98	-1,475	215	-288	-2	-1	352	45	168	-55	95	290	2,463
1949	-44	-44	-619	-2,368	146	-484	4	4	-269	-293	-13	-61	986	1,094	2,067
1950	0	0	-643	-1,519	541	144	4	4	-216	-216	-8	-13	946	1,056	828
1951	-6,969	-6,969	-787	-1,190	71	-16	-3,977	-3,978	-350	-351	31	-26	-768	2,229	1,912
1952	-174	-174	-891	-1,399	-82	-219	-90	-89	-484	-483	-85	-65	5,317	5,594	1,485
1953	-4,058	-4,058	-771	-1,112	187	97	-2,646	-2,646	-778	-774	148	154	-1,976	4,635	3,862
1954	-5,679	-5,679	-4,452	-6,553	-1,333	-1,670	-3,413	-3,413	-3,480	-3,475	-1,484	-1,663	-4,546	1,165	742
1955	-2,787	-2,787	-2,271	-5,623	573	228	-1,937	-1,937	-4,183	-4,404	-41	-203	4,458	2,935	1
1956	-4,961	-4,961	-7,896	-11,988	-272	-1,128	-2,927	-2,927	-4,961	-5,761	-372	-1,174	-8,011	-428	-80
1957	-104	-104	-926	-4,069	97	-421	13	13	-1,371	-1,806	146	-354	2,344	4,863	0
1958	-272	-272	3,820	2,799	1,003	1,035	488	488	621	534	-1,251	-1,734	42	15,216	2,965
1959	-257	-257	486	204	-1,023	-1,792	564	564	-649	-638	18	-79	-4,914	10,157	-1,860
1960	-281	-281	332	-476	79	-626	653	653	-1,210	-1,196	0	0	785	13,981	52
1961	-306	-306	-87	-912	843	437	740	740	-304	-289	809	-633	957	15,227	3,119
1962	-339	-339	-42	-973	278	-271	715	715	-1,261	-1,244	1	-338	1,362	16,011	1,074
1963	-615	-615	332	-424	549	68	736	736	-1,582	-1,562	363	369	1,577	19,191	2,595
1964	-1,152	-1,152	-1,395	-5,832	173	-750	-1,003	-1,003	-3,345	-3,700	-116	-184	6,502	12,503	3,077
1965	-5,562	-5,562	-4,433	-7,085	456	-176	-1,456	-1,456	-4,626	-5,043	648	268	-5,189	15,389	-25
1966	-522	-522	86	-229	-491	-1,098	919	919	-273	-248	-540	-752	-7,469	19,659	-121
1967	3,300	3,300	2,324	142	1,725	826	2,567	2,567	-1,922	-2,420	735	676	-2,093	14,587	309
1968	3,999	3,999	9,214	8,199	1,322	290	4,162	4,162	286	-98	1,213	836	6,632	27,132	5
1969	-432	-432	7,359	6,980	2,945	2,666	940	940	-46	-30	2,958	2,841	-110	22,491	88
1970	-397	-397	7,641	6,801	1,542	938	987	987	-208	-195	-769	-1,192	6,606	24,004	2,563
1971	-4,170	-4,170	9,045	6,562	1,566	336	-1,369	-1,369	-1,572	-1,556	1,376	675	8,145	27,265	440
1972	-7,459	-7,459	-4,947	-8,069	-2,253	-4,570	-4,493	-4,493	-10,843	-11,038	-2,814	-4,985	-15,767	6,516	-140
1973	-580	-580	17,223	14,850	1,270	-504	1,292	1,292	-688	-914	1,155	-391	13,783	33,731	185
1974	-570	-570	15,464	14,864	4,884	3,695	1,107	1,107	275	291	2,704	779	7,465	33,321	2,692
1975	-475	-475	15,129	13,954	4,504	3,342	826	826	178	193	4,419	4,320	11,426	30,786	-851
1976	-316	-316	17,447	16,267	6,548	4,362	1,030	1,030	-100	-91	-10	-33	16,240	33,893	4,746
1977	-25,769	-25,769	3,548	342	1,241	-759	-15,466	-15,466	-9,014	-9,003	1,201	364	-10,165	19,325	-740
1978	-15,073	-15,073	-11,237	-16,380	-2,913	-4,881	-6,248	-6,248	-18,733	-18,724	-2,706	-4,620	-16,297	4,151	-1,061

Run 8 - TX Non-Irrigation Pumping Off
Annual Differences in ILRG Model Outputs
Run 8 minus Run 1
1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1979	-491	-491	14,336	11,557	121	-1,570	888	887	-4,665	-4,645	227	-1,549	17,897	37,958	527
1980	-605	-605	21,066	20,491	1,216	-2,015	1,142	1,143	216	234	1,408	-343	17,020	42,853	-142
1981	-499	-499	22,178	21,171	1,834	-1,343	991	991	143	157	0	0	20,749	40,627	-332
1982	-501	-501	22,122	20,720	2,553	395	1,181	1,181	161	174	-738	-1,883	24,018	42,708	4,168
1983	-457	-457	22,274	20,751	4,257	2,130	1,197	1,197	157	169	0	0	23,014	41,113	1,715
1984	-452	-452	23,845	22,626	6,208	3,659	1,095	1,096	155	169	0	0	20,372	39,947	2,566
1985	1,113	1,113	30,945	30,494	-14,186	-16,828	9,303	9,303	4,902	4,827	0	0	-9,379	6,576	-18,878
1986	-850	-850	24,916	24,802	6,552	3,425	571	565	-361	-359	0	0	-80,808	-60,027	-78,124
1987	-792	-792	27,392	27,278	7,273	4,219	728	728	151	161	0	0	166	18,148	-29,195
1988	-552	-552	28,464	28,342	7,822	4,498	1,558	1,558	77	87	0	0	21,172	36,465	2,204
1989	-530	-530	31,737	31,324	8,858	5,802	1,573	1,574	501	130	0	0	40,111	56,143	13,902
1990	-397	-397	30,059	29,250	7,680	4,566	1,432	1,433	346	-157	0	0	20,681	39,372	1,277
1991	-889	-889	18,017	17,393	2,610	152	-224	-223	13	-763	0	0	18,050	33,669	-3,141
1992	-621	-621	16,284	15,902	847	-1,144	2,721	2,724	-148	-478	0	0	-10,042	4,467	-24,476
1993	-703	-703	714	566	-194	-2,703	814	815	-3,097	-3,096	0	0	-59,280	-41,355	-62,452
1994	-707	-707	1,688	1,545	316	-2,264	1,205	1,204	-968	-968	0	0	-13,467	5,885	-18,259
1995	-562	-562	862	681	-323	-3,670	1,285	1,286	-780	-833	0	0	7,978	26,310	-7,392
1996	-495	-495	5,504	5,379	1,045	-1,354	1,267	1,267	199	209	0	0	6,887	28,980	-6,945
1997	-331	-331	4,549	1,934	493	-2,871	1,201	1,201	-1,295	-2,305	0	0	8,350	30,230	-5,525
1998	-576	-576	9,727	9,371	2,019	-879	1,515	1,515	678	685	0	0	12,259	35,890	4,491
1999	-1,923	-1,923	-4,781	-7,808	1,300	800	9,827	9,832	4,315	4,332	0	0	0	14,462	-13,665
2000	-690	-690	7,157	3,488	1,708	1,543	2,068	2,069	-3,522	-3,507	0	0	-2,004	27,367	-791
2001	-601	-601	9,494	4,927	1,881	1,443	1,416	1,416	-195	-187	0	0	1,558	24,755	-4,359
2002	-471	-471	3,891	794	-201	-695	1,660	1,660	266	273	0	0	-7,289	17,161	-8,292
2003	-8,042	-8,042	19,922	16,491	3,168	2,024	-3,539	-3,539	-839	-834	0	0	16,125	37,345	1,458
2004	-13,719	-13,719	-16,802	-21,110	-3,629	-5,751	-6,560	-6,560	-16,199	-16,194	0	0	-23,843	3,934	-8,780
2005	-127	-127	9,690	5,190	-1,313	-2,842	1,206	1,206	-39	-24	0	0	2,089	21,439	-13,605
2006	4,846	4,846	-5,284	-9,699	-2,018	-3,190	3,337	3,337	-8,839	-8,830	0	0	-10,278	7,688	-9,097
2007	11,344	11,344	4,456	52	-1,656	-2,985	6,662	6,662	-316	-302	0	0	-3,741	12,853	-10,328
2008	24,083	24,083	5,269	1,141	-895	-2,006	16,240	16,240	41	56	0	0	1,809	17,499	-7,341
2009	38,135	38,135	6,178	1,614	235	-649	21,553	21,553	-361	-342	0	0	4,499	20,560	423
2010	40,191	40,191	6,810	2,450	1,235	1,013	25,647	25,647	663	680	0	0	6,745	21,695	2,658
2011	18,671	18,671	2,647	-1,319	-98	-3,321	10,183	10,183	237	247	0	0	7,972	14,598	-2,491
2012	-8,195	-8,195	951	-3,361	-3,713	-7,687	-1,334	-1,334	-9,013	-9,010	0	0	-11,425	15,009	-8,679
2013	3,938	3,938	-7,958	-11,357	-3,904	-6,044	2,238	2,238	-14,131	-14,131	-1,902	-2,184	1,973	9,368	-11,789
2014	3,541	3,541	-3,804	-7,939	-5,744	-8,454	2,173	2,173	-10,212	-10,212	-4,716	-6,311	2,158	6,853	-7,595
2015	259	259	1,650	-2,055	-4,756	-7,247	595	595	-11,430	-11,429	1,280	961	4,289	13,450	-22,469
2016	-4,165	-4,165	-612	-4,627	-4,384	-7,202	-2,941	-2,941	-6,926	-6,923	0	0	-7,101	10,267	-29,243
2017	12,328	12,328	8,356	4,960	-282	-1,438	6,302	6,302	368	373	0	0	16,511	19,818	-11,927
Averages															
1951-2017	411	411	7,063	4,971	708	-911	1,506	1,506	-2,244	-2,337	49	-275	1,524	18,173	-5,416
1951-1978	-2,928	-2,928	2,475	702	839	-20	-974	-974	-2,522	-2,644	276	-255	583	15,555	965
1979-2005	-1,314	-1,314	14,269	12,724	1,849	-418	1,390	1,390	-734	-842	33	-140	2,681	22,682	-10,076
2006-2017	12,081	12,081	1,555	-2,512	-2,165	-4,101	7,555	7,555	-4,993	-4,985	-445	-628	1,117	14,138	-9,823
1985-2017	3,409	3,409	8,427	5,942	235	-1,871	3,687	3,688	-2,300	-2,389	-162	-228	-1,130	16,269	-12,073
1985-2005	-1,546	-1,546	12,354	10,773	1,606	-597	1,477	1,478	-762	-905	0	0	-2,414	17,486	-13,359

Notes:

EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

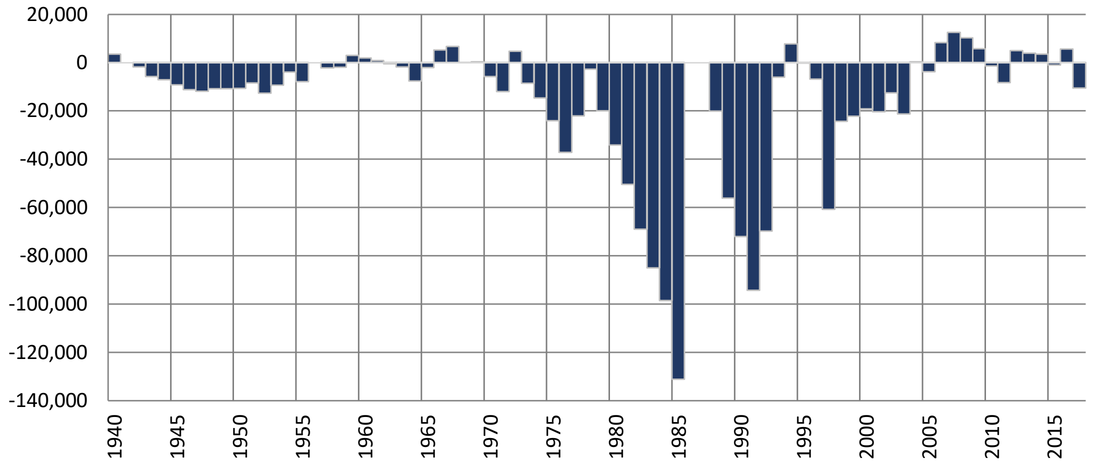
Run 8 - TX Non-Irrigation Pumping Off

Simulated Differences in ILRG Model Outputs

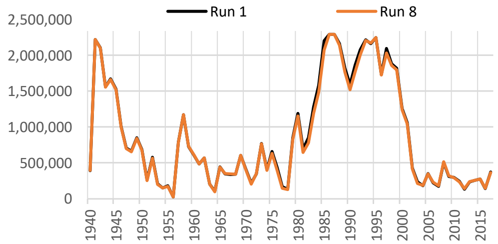
Run 8 minus Run 1

1940 - 2017 (acre-feet)

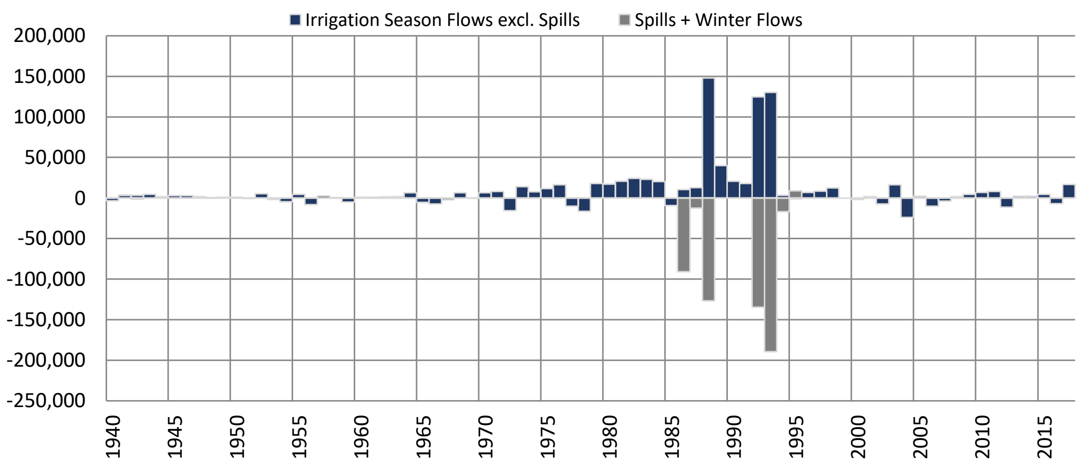
Total Project Storage (Year End)



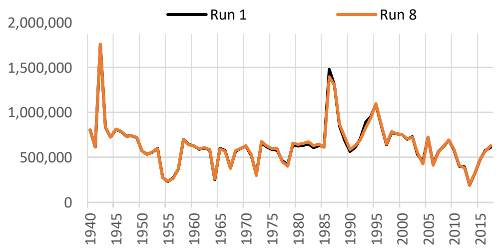
Period	Average Difference
1951-2017	1
1951-1978	284
1979-2005	-44
2006-2017	-558
1985-2017	2,669
1985-2005	4,514



Caballo Reservoir Outflows (Annual)



	Average Difference		
Period	Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	9,918	-8,394	1,524
1951-1978	583	0	583
1979-2005	23,510	-20,829	2,681
2006-2017	1,117	0	1,117
1985-2017	15,912	-17,042	-1,130
1985-2005	24,366	-26,780	-2,414



Notes:

Reservoir storage does not include storage attributed to SJC, CO, or NM credit waters.

Average differences calculated as (Final Storage - Initial Storage)/(no. years).

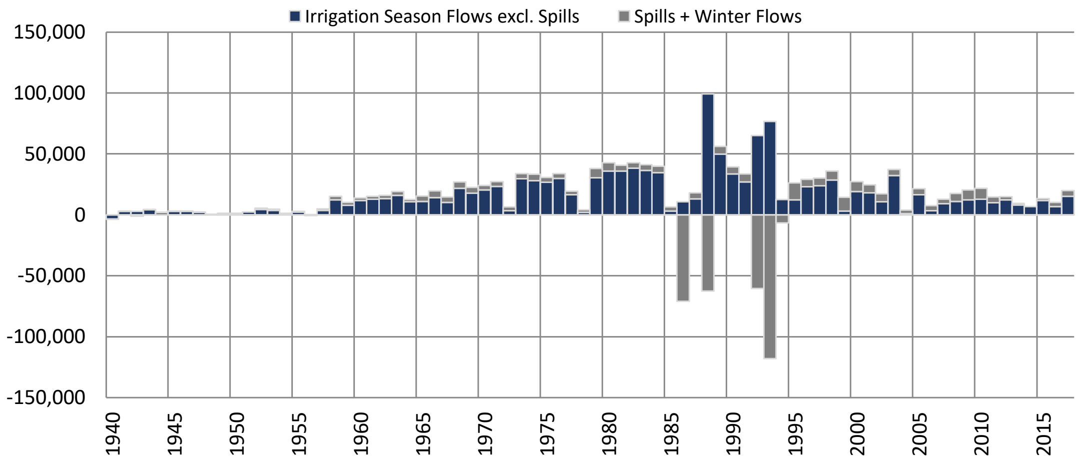
Run 8 - TX Non-Irrigation Pumping Off

Simulated Differences in ILRG Model Outputs

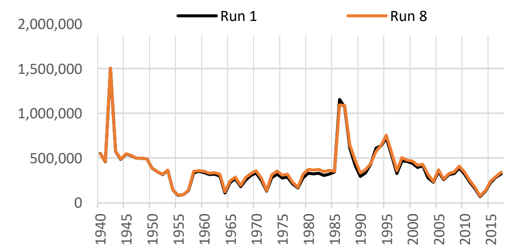
Run 8 minus Run 1

1940 - 2017 (acre-feet)

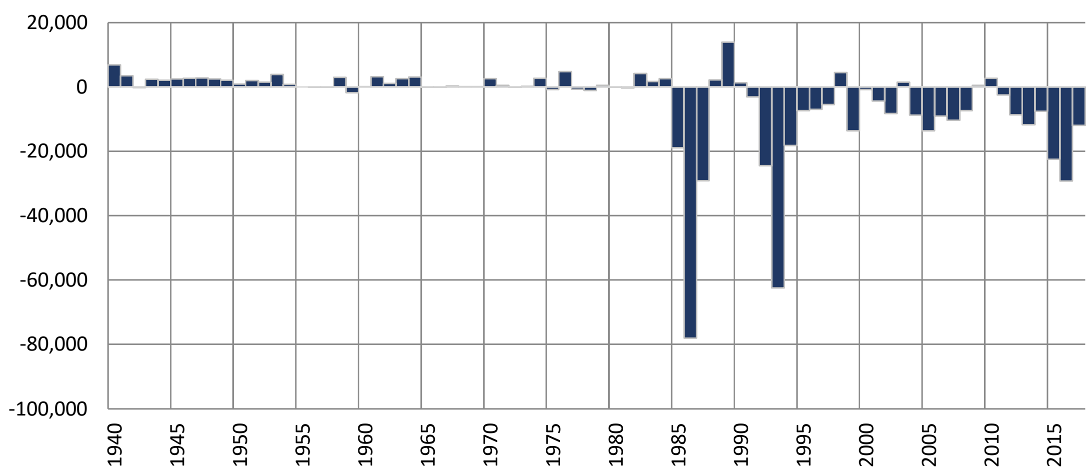
Rio Grande at El Paso (Annual)



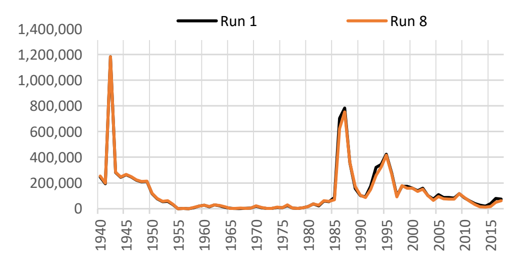
	Average Difference		
Period	Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	18,903	-729	18,173
1951-1978	12,709	2,845	15,555
1979-2005	29,303	-6,621	22,682
2006-2017	9,951	4,187	14,138
1985-2017	21,190	-4,921	16,269
1985-2005	27,612	-10,125	17,486



Rio Grande at Fort Quitman (Annual)



Period	Average Difference
1951-2017	-5,420
1951-1978	960
1979-2005	-10,081
2006-2017	-9,820
1985-2017	-12,075
1985-2005	-13,363



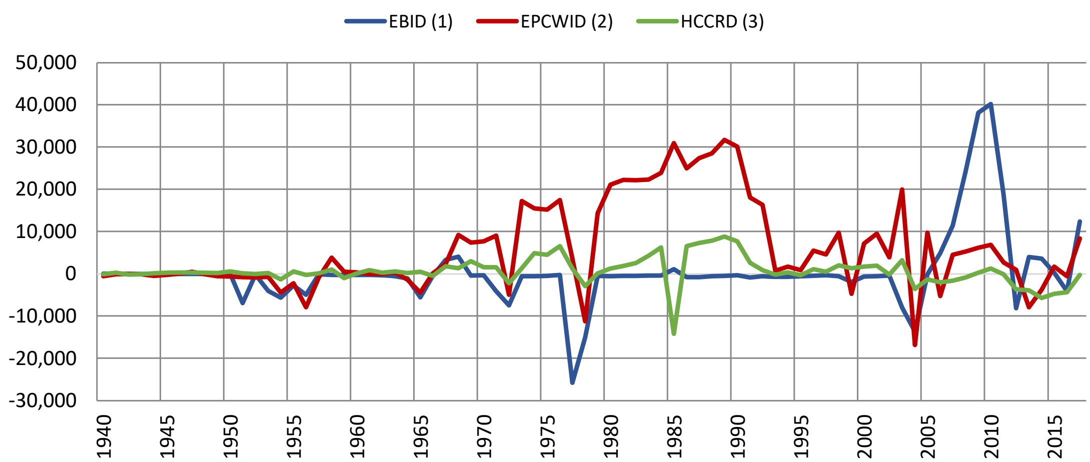
Run 8 - TX Non-Irrigation Pumping Off

Simulated Differences in ILRG Model Outputs

Run 8 minus Run 1

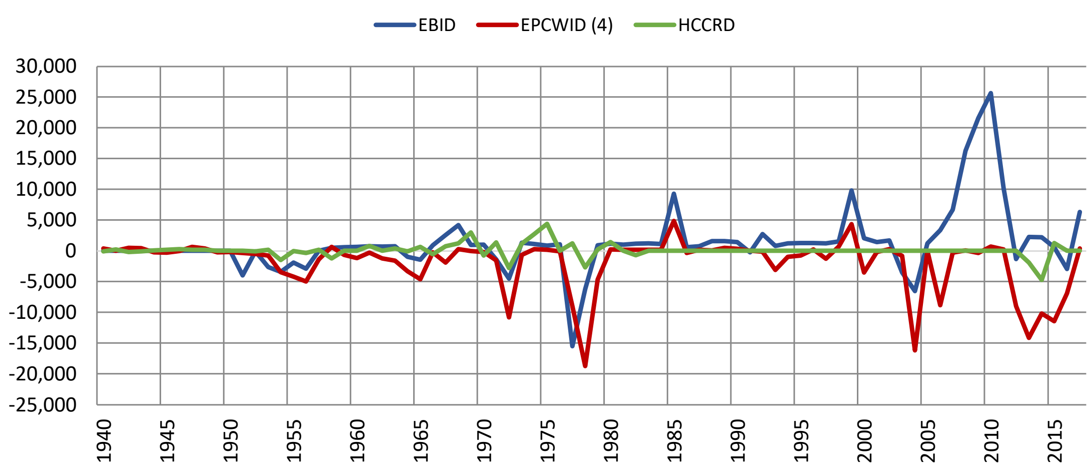
1940 - 2017 (acre-feet)

River Headgate (RHG) Diversions (Irrigation Season)



	Average Difference		
Period	EBID	EPCWID	HCCRD
1951-2017	411	7,063	708
1951-1978	-2,928	2,475	839
1979-2005	-1,314	14,269	1,849
2006-2017	12,081	1,555	-2,165
1985-2017	3,409	8,427	235
1985-2005	-1,546	12,354	1,606

Farm Headgate (FHG) Deliveries (Irrigation Season)



	Average Difference		
Period	EBID	EPCWID	HCCRD
1951-2017	1,506	-2,244	49
1951-1978	-974	-2,522	276
1979-2005	1,390	-734	33
2006-2017	7,555	-4,993	-445
1985-2017	3,687	-2,300	-162
1985-2005	1,477	-762	0

Notes:

(1) EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

(2) EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

(3) HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

(4) EPCWID FHG values include deliveries to Rogers WTP and R/U WTP.

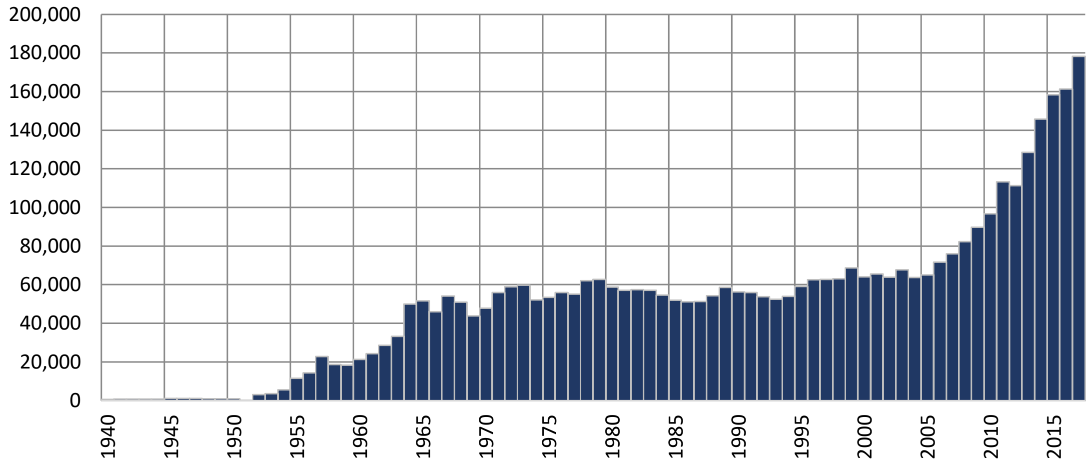
Run 8 - TX Non-Irrigation Pumping Off

Simulated Differences in ILRG Model Outputs

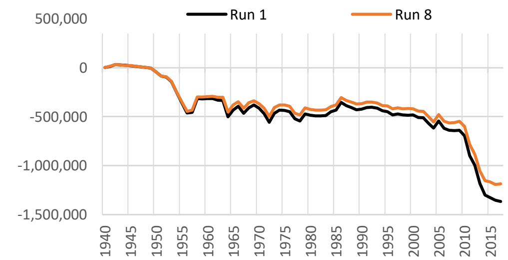
Run 8 minus Run 1

1940 - 2017 (acre-feet)

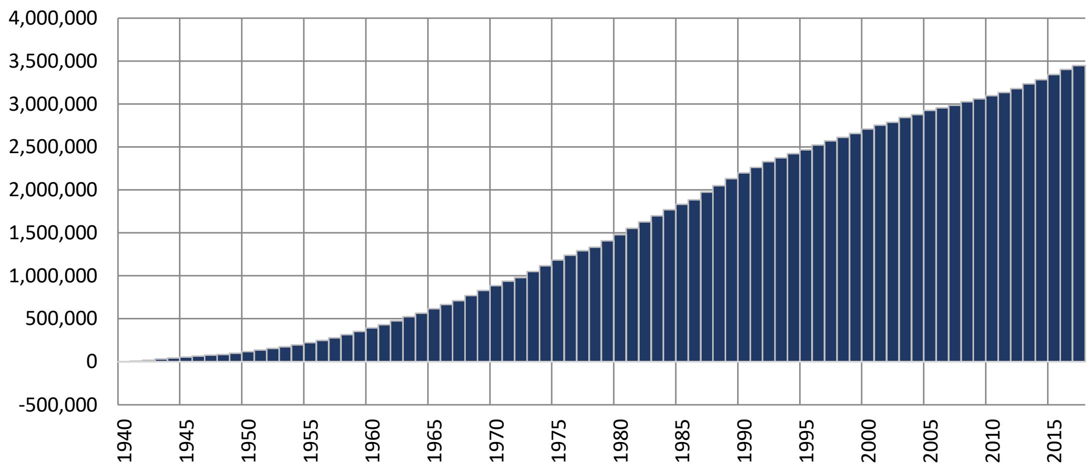
Cumulative Annual Rincon-Mesilla Groundwater Storage



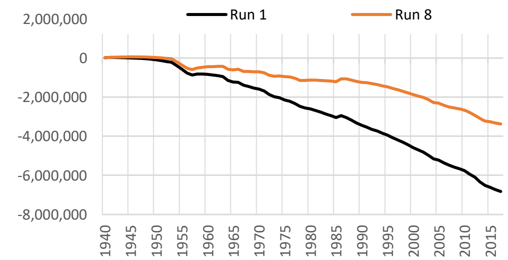
Period	Average Difference
1951-2017	2,646
1951-1978	2,181
1979-2005	109
2006-2017	9,437
1985-2017	3,746
1985-2005	494



Cumulative Annual Hueco Groundwater Storage



Period	Average Difference
1951-2017	49,740
1951-1978	43,453
1979-2005	58,901
2006-2017	43,793
1985-2017	50,923
1985-2005	54,998



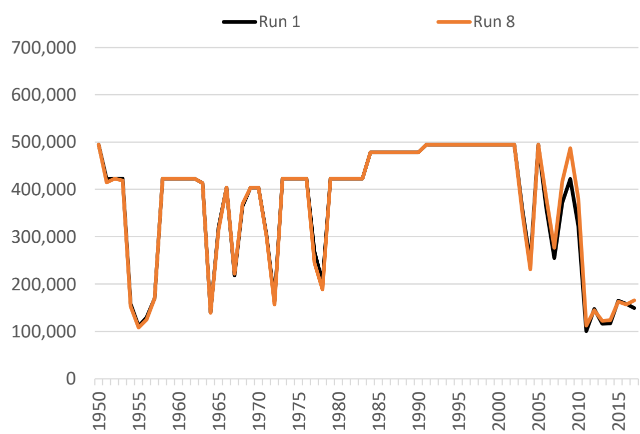
Notes:

Cumulative storage change in alluvial and non-alluvial aquifers.

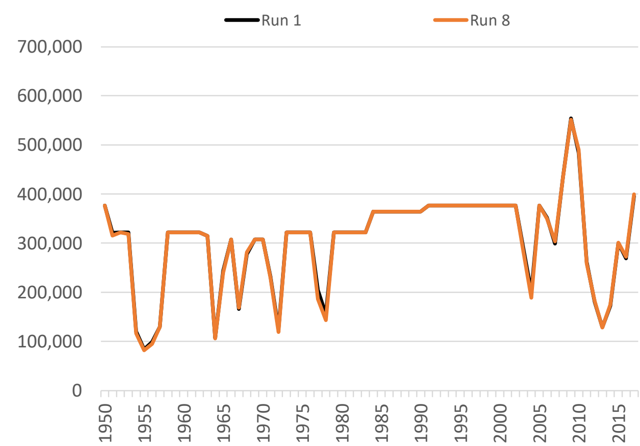
Average differences calculated as (Final Storage - Initial Storage)/(no. years).

Run 8 - TX Non-Irrigation Pumping Off
Annual Allocation and Charges
Run 8 v. Run 1
ILRG Model
1950 - 2017 (acre-feet)

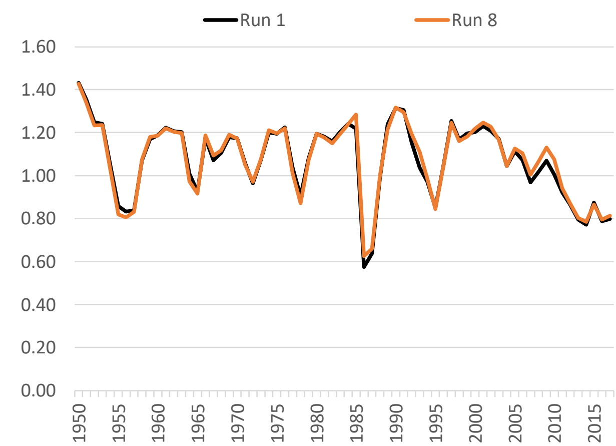
Total Allocation - EBID



Total Allocation - EPCWID

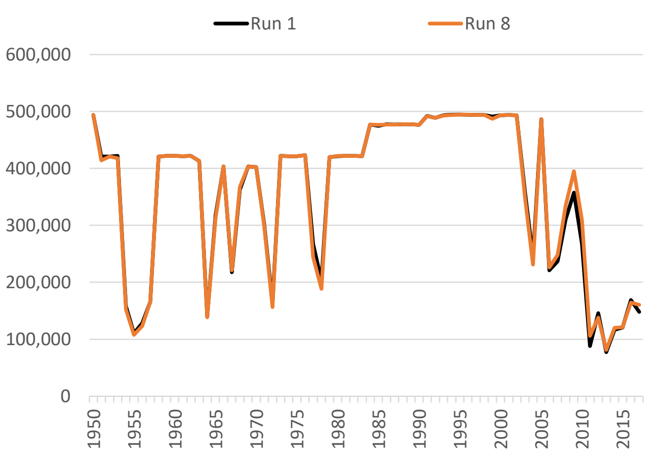


Diversion Ratio

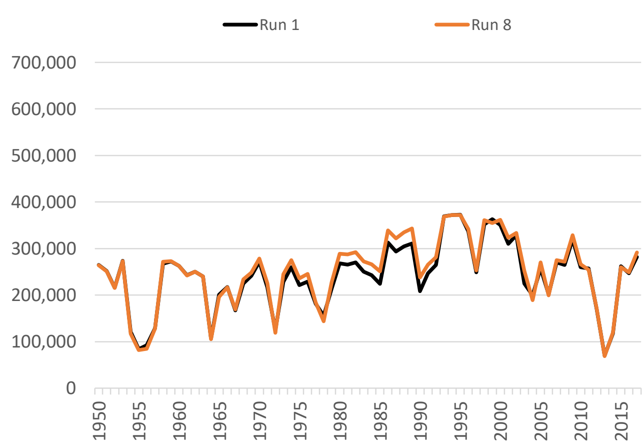


Note:
Computed as Total Charges/Caballo Release.

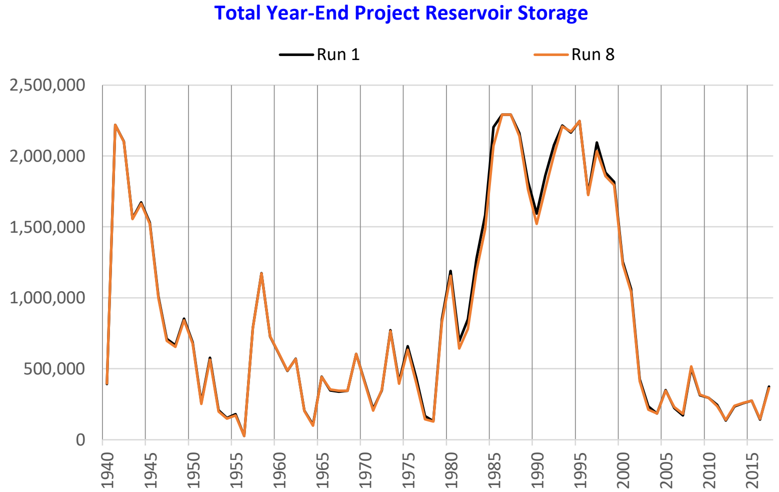
Annual Delivery Charges - EBID

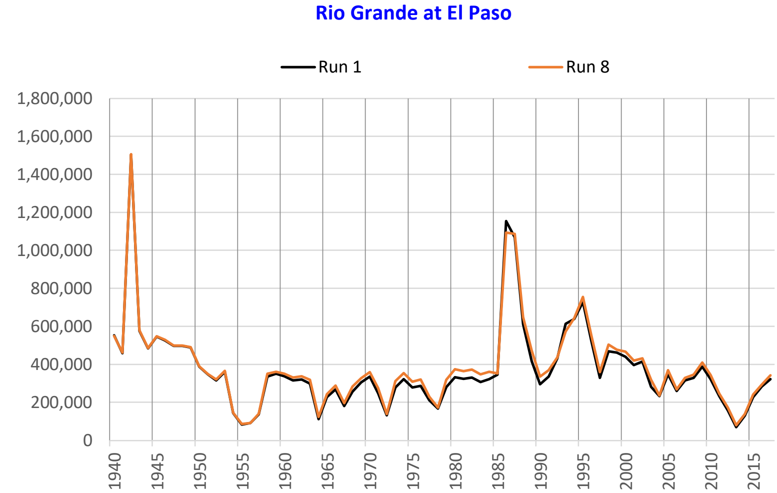


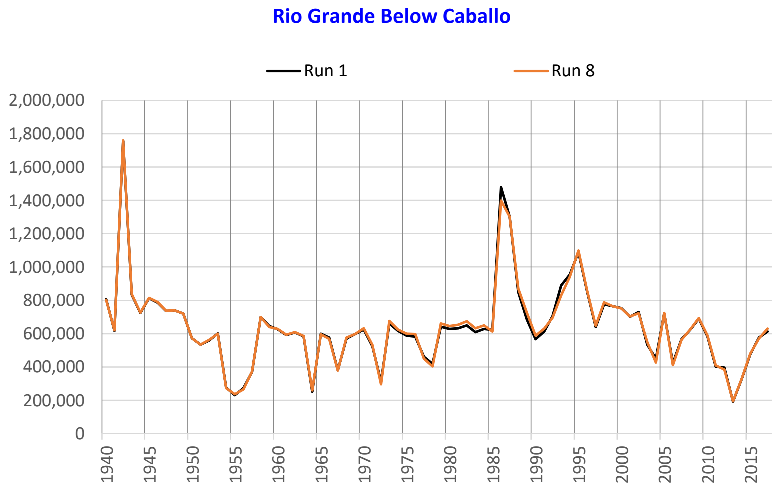
Annual Delivery Charges - EPCWID

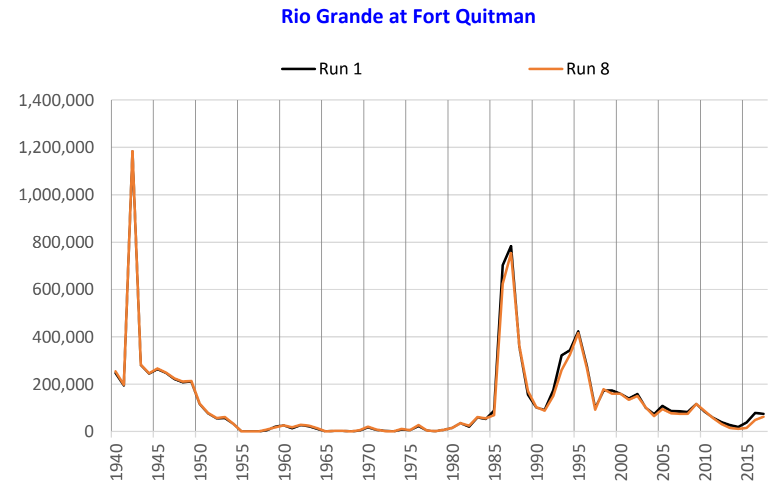


Run 8 - TX Non-Irrigation Pumping Off
Annual Summary of Project Storage and Rio Grande Flows
Run 8 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)







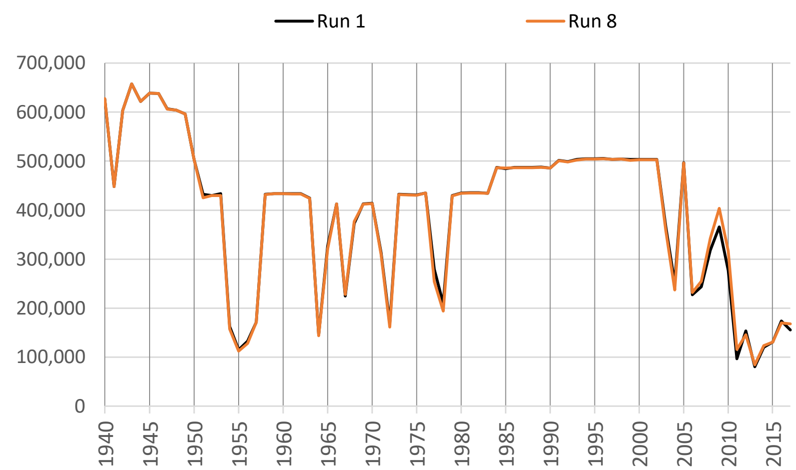


***Note different scales.**

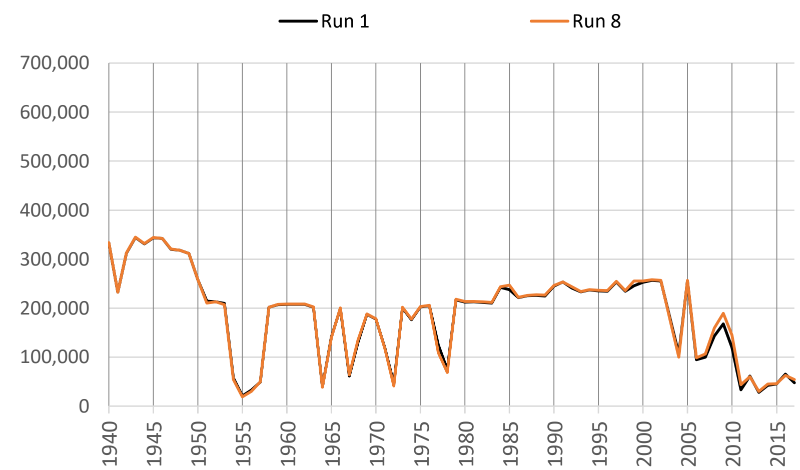
Run 8 - TX Non-Irrigation Pumping Off
Irrigation Season Summary of Irrigation Operations
Run 8 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

EBID Total

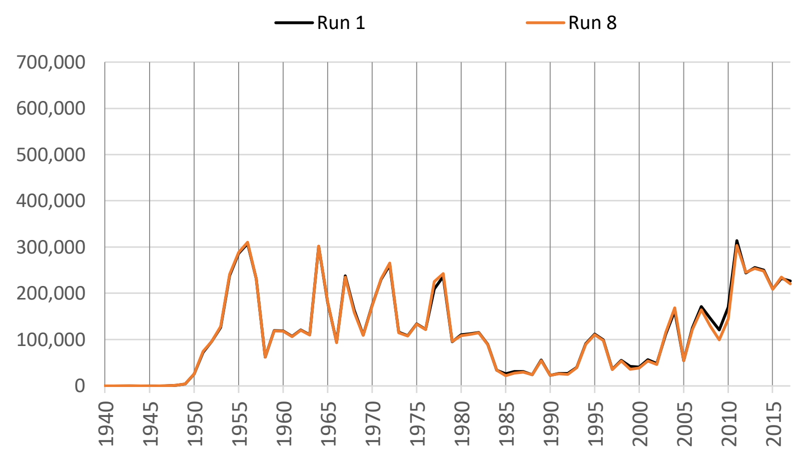
Net River Headgate Diversions



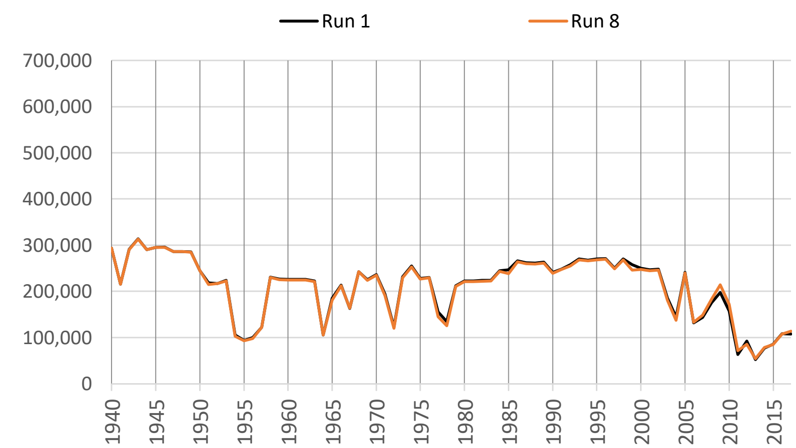
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries

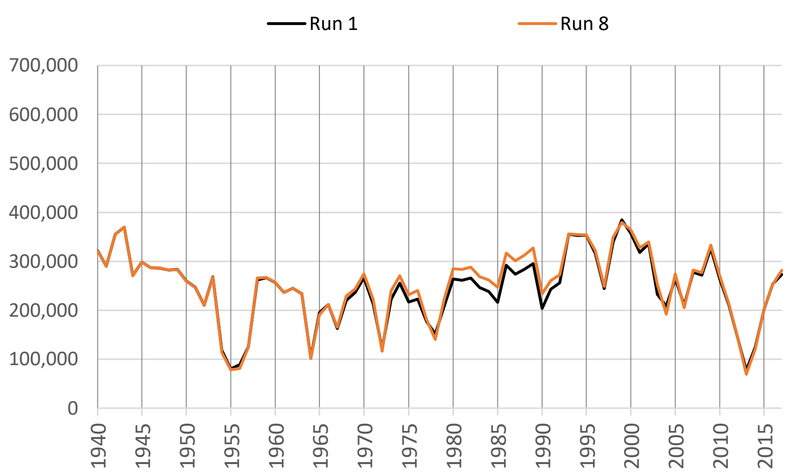


Notes: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).
Pumping includes Supplemental and Primary groundwater pumping.

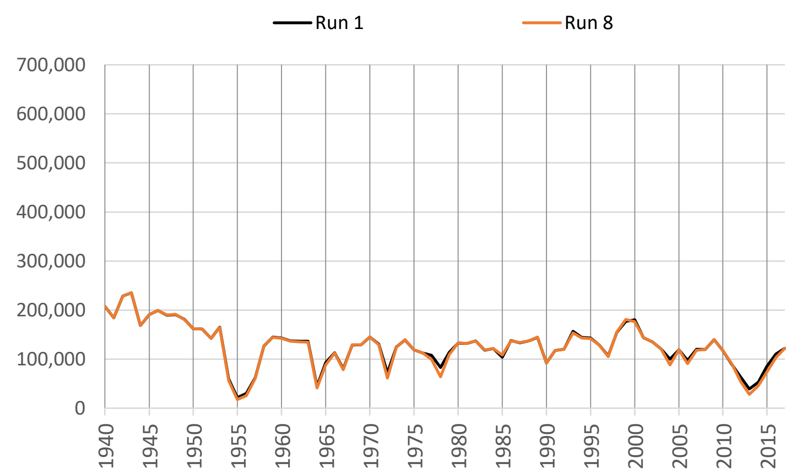
Run 8 - TX Non-Irrigation Pumping Off
Irrigation Season Summary of Irrigation Operations
Run 8 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

EPCWID Total

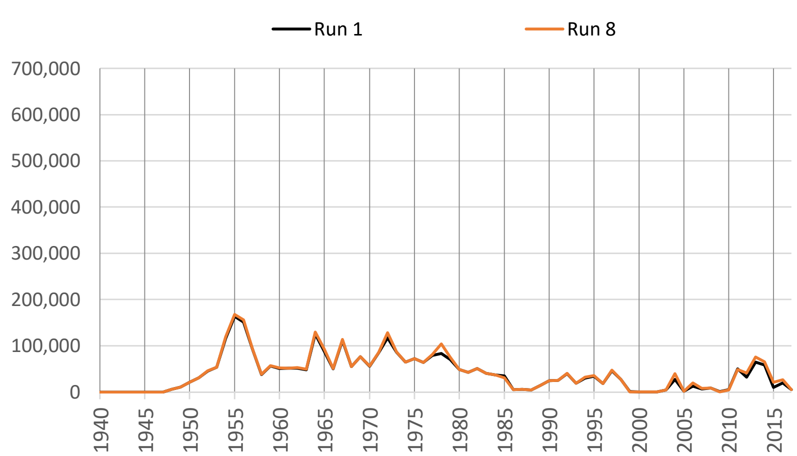
Net River Headgate Diversions



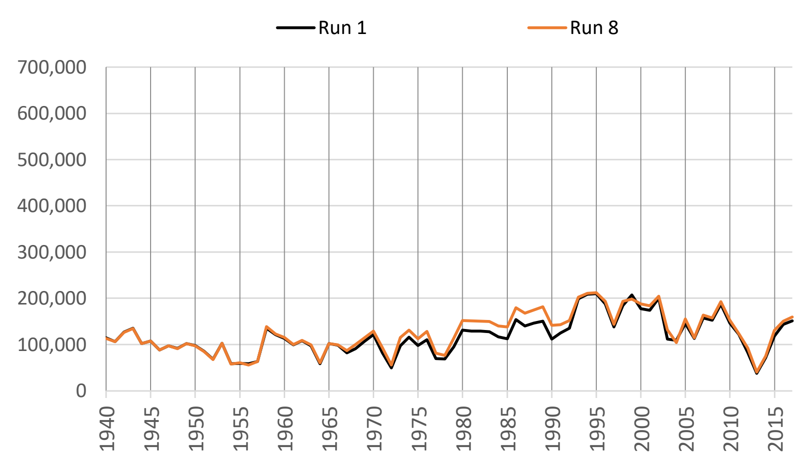
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries

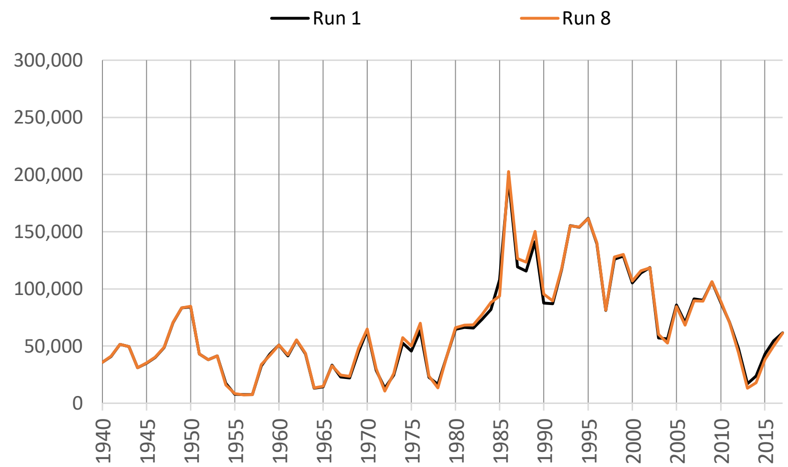


Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

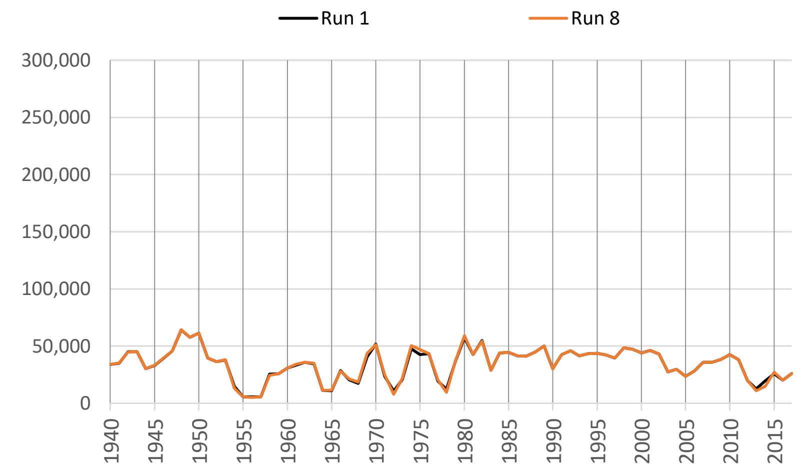
Run 8 - TX Non-Irrigation Pumping Off
Irrigation Season Summary of Irrigation Operations
Run 8 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

HCCRD Total

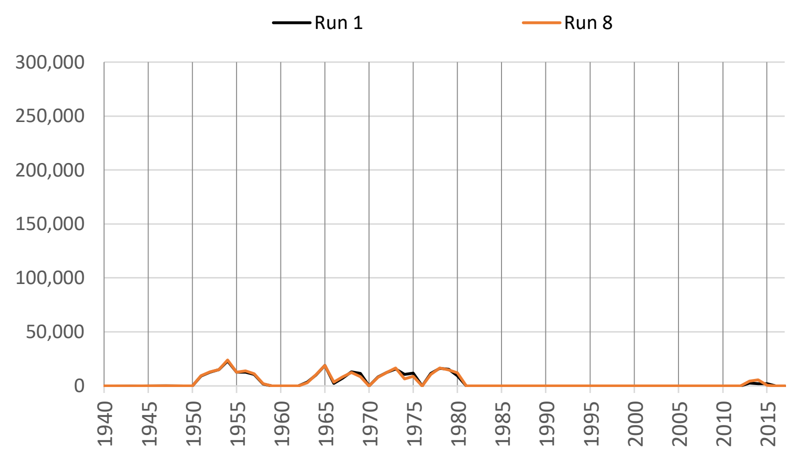
Net River Headgate Diversions



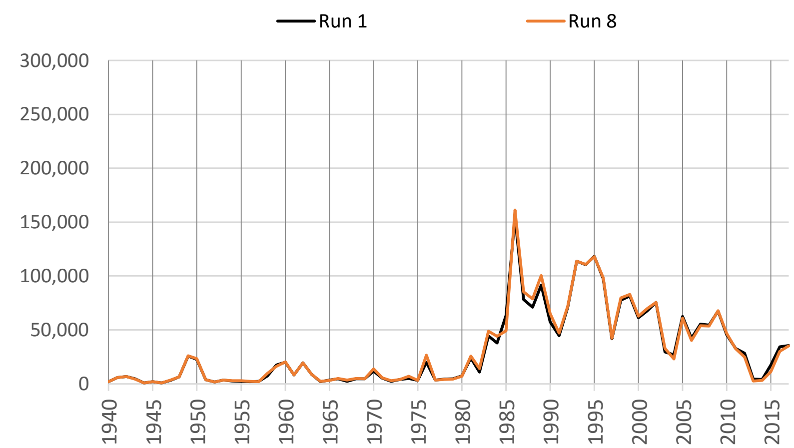
Farm Headgate Deliveries



Pumping



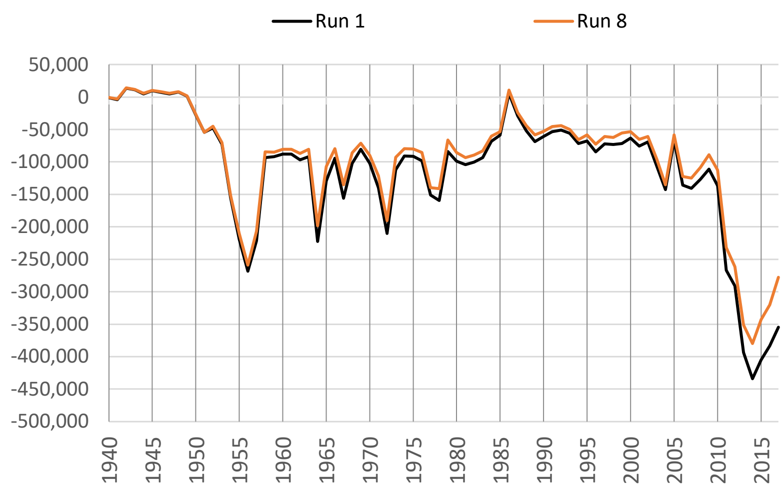
RHG Diversions - FHG Deliveries



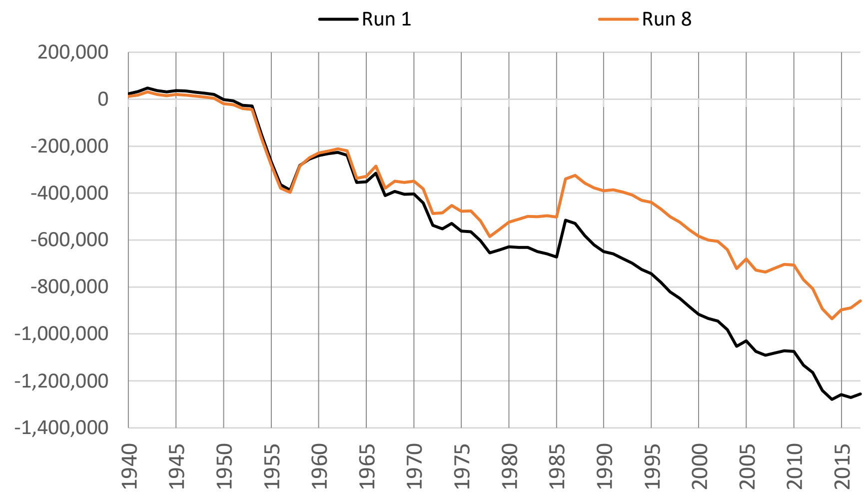
Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

Run 8 - TX Non-Irrigation Pumping Off
Cumulative Change in Ground Water Storage
Run 8 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

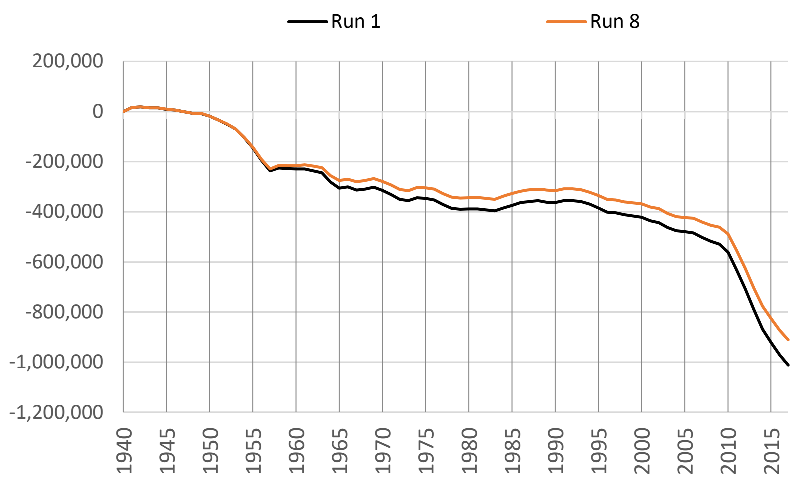
Rincon-Mesilla Alluvial Aquifer



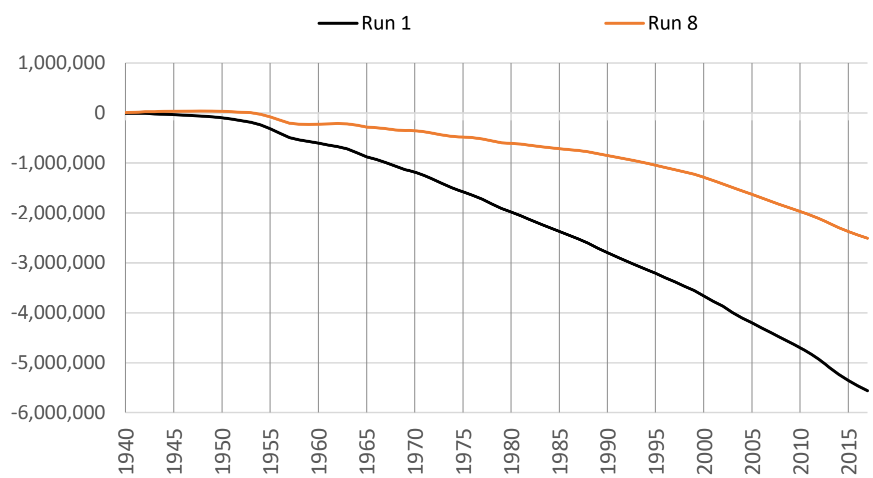
Hueco Alluvial Aquifer



Rincon-Mesilla Non-Alluvial Aquifer



Hueco Non-Alluvial Aquifer



***Note different scales.**

Run 8 - TX Non-Irrigation Pumping Off

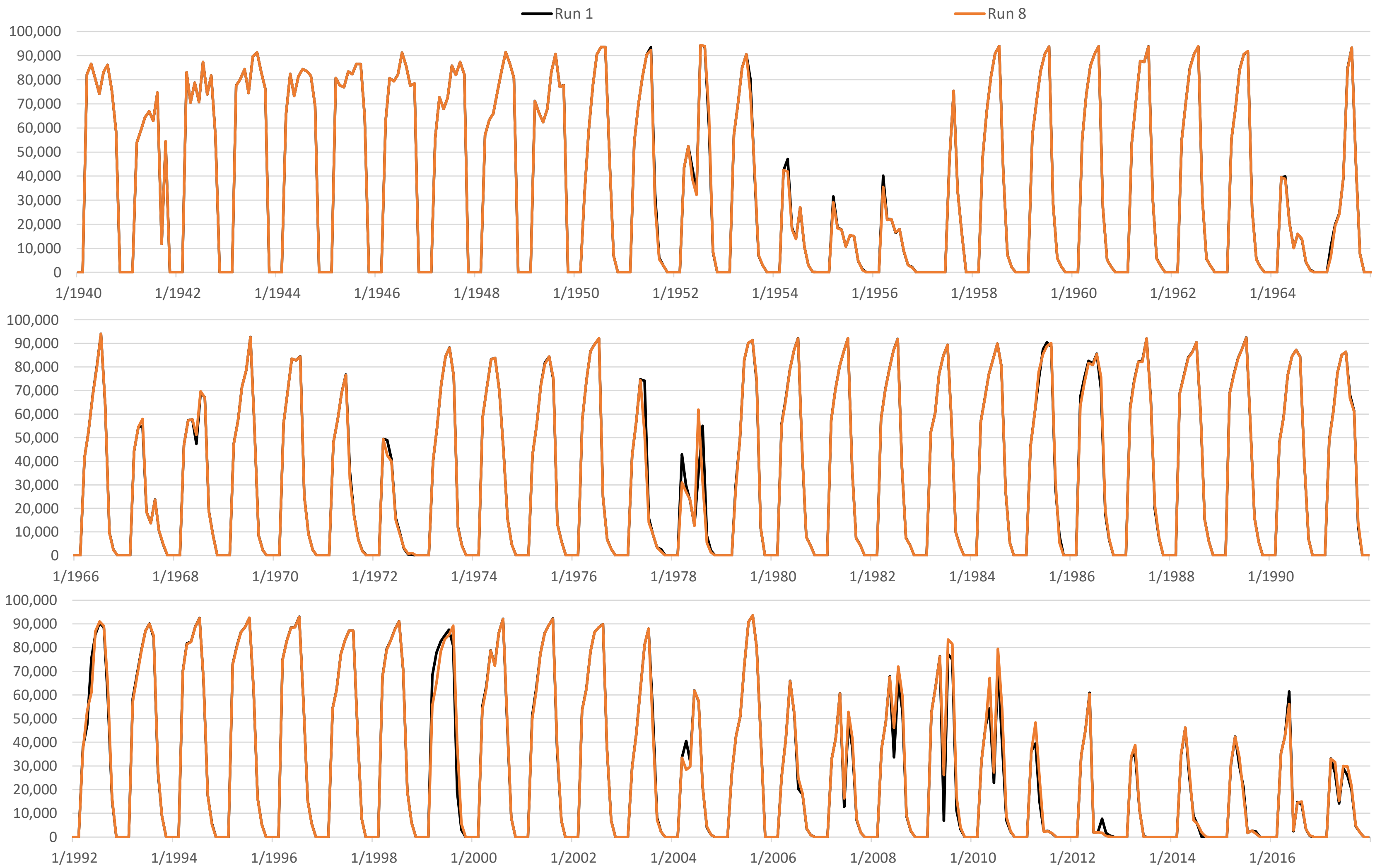
Monthly Net RHG Diversions

Run 8 v. Run 1

ILRG Model

1940 - 2017 (acre-feet)

EBID Total



Note: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

Run 8 - TX Non-Irrigation Pumping Off
Monthly Net RHG Diversions
Run 8 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
EPCWID Total

Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

Run 8 - TX Non-Irrigation Pumping Off

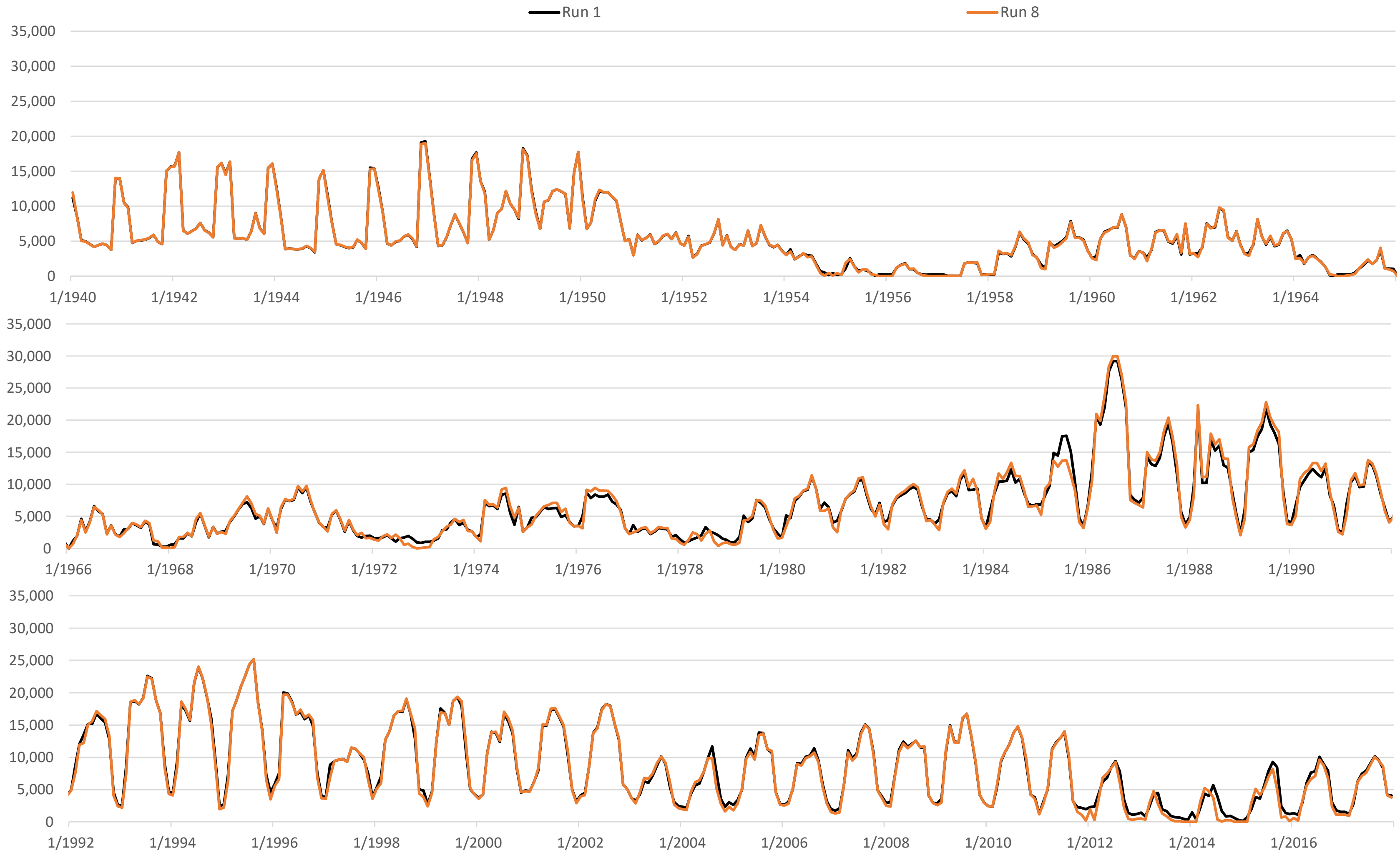
Monthly Net RHG Diversions

Run 8 v. Run 1

ILRG Model

1940 - 2017 (acre-feet)

HCCRD Total



Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

Run 8 - TX Non-Irrigation Pumping Off
End of Month Reservoir Storage (Elephant Butte + Caballo)
Run 8 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

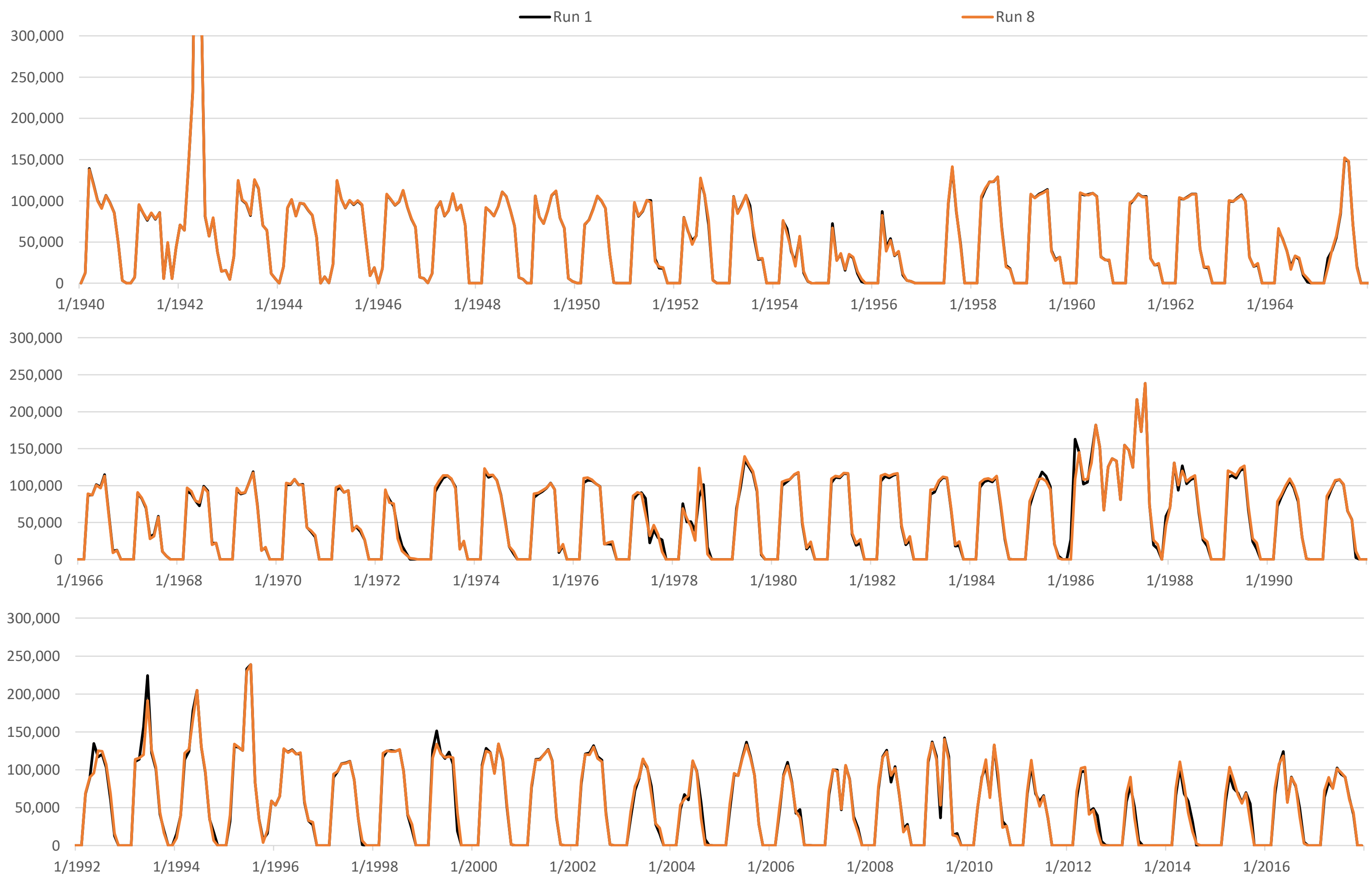
Run 8 - TX Non-Irrigation Pumping Off

Monthly Caballo Releases

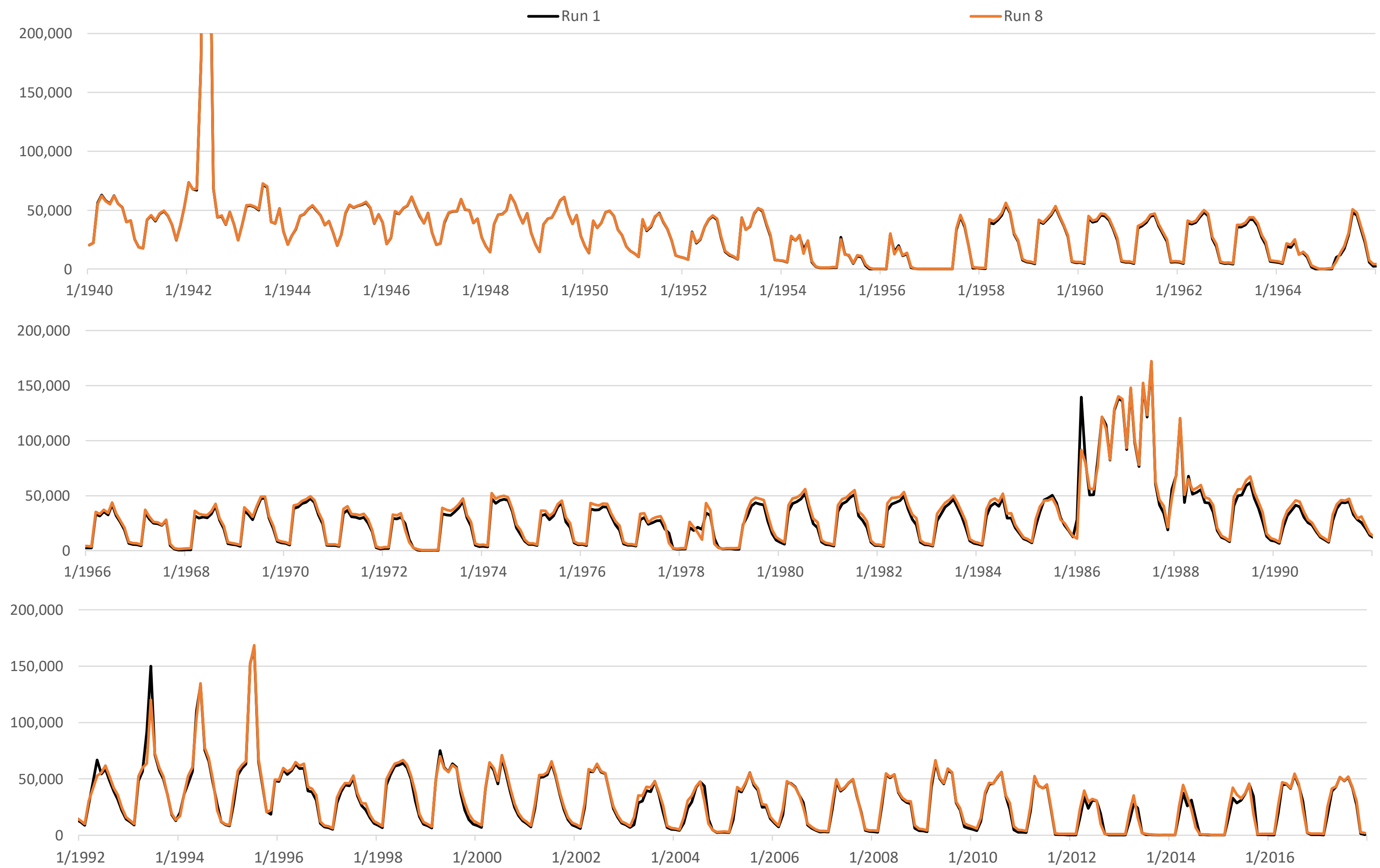
Run 8 v. Run 1

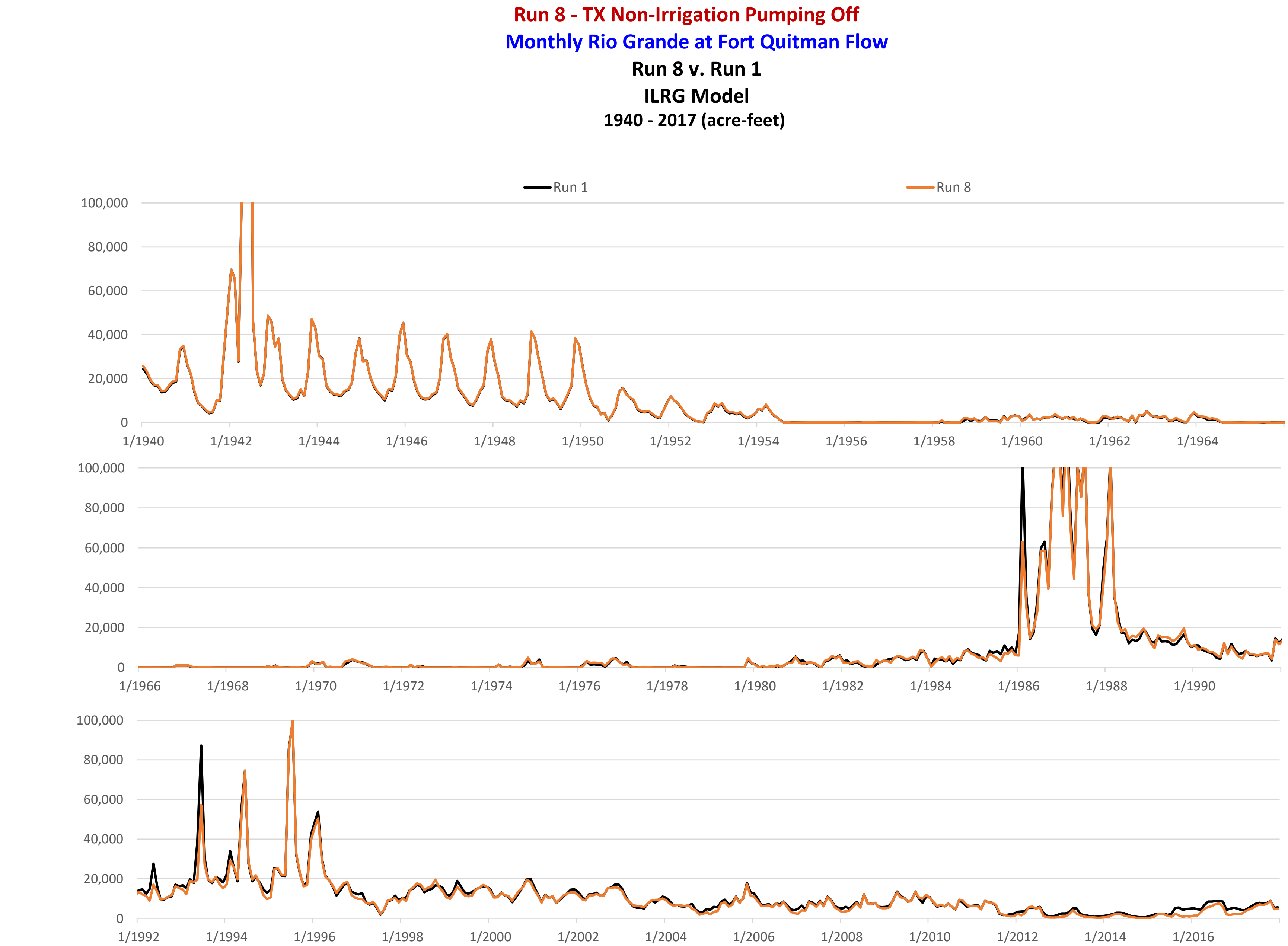
ILRG Model

1940 - 2017 (acre-feet)



Run 8 - TX Non-Irrigation Pumping Off
Monthly Rio Grande at El Paso Flow
Run 8 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)




Run 8 - TX Non-Irrigation Pumping Off
Monthly Rio Grande at Fort Quitman Flow
Run 8 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
Run 1
Run 8
100,000
80,000
60,000
40,000
20,000
0
1/1940
1/1942
1/1944
1/1946
1/1948
1/1950
1/1952
1/1954
1/1956
1/1958
1/1960
1/1962
1/1964
1/1966
1/1968
1/1970
1/1972
1/1974
1/1976
1/1978
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1/1982
1/1984
1/1986
1/1988
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1/1994
1/1996
1/1998
1/2000
1/2002
1/2004
1/2006
1/2008
1/2010
1/2012
1/2014
1/2016

Appendix 30I

Comparison of ILRG Model Runs
Run 9 v. Run 1

Model Run Specifications

Model Version: LRG_v116

Name: **Run 9 - NM Non-Irrigation Pumping Off**

Run ID: LRG_v116_Operational_Run9
Date: 8/26/2020

Name: **Run 1 - Historical Base Run**

Run ID: LRG_v116_Operational_Run1
Date: 8/23/2020

Selected Model Inputs

Pumping and Returns	Run 9	Run 1
Irrigation Pumping	On	On
Irrigated Area	Hist	Hist
Non-Irrigation Pumping	NM Off	On
Non-Irrigation Pumping Returns	NM Off	On
Las Cruces Jornada Pumping Returns	Off	On

Project Allocation Rules		
1950-2005	D1/D2	D1/D2
2006-2007	D3	D3
2008-2017	D3 + CO	D3 + CO

EPCWID Operations		
Charge EPCWID for Use of WWTP Returns	Off	Off
ACE and Haskell Credits for EPCWID	On	On
Increased EPCWID Use of Fabens Drain Flows	Off	Off
Charge EPCWID for Fabens Drain Flow Use	Off	Off

Run 9 - NM Non-Irrigation Pumping Off
Comparison of ILRG Model Runs
Run 9 v. Run 1
1951 - 2017 Annual Average
(1,000 acre-feet)

Run No.	1	9	9 - 1		
Simulated Input or Output	**Run 1**	**Run 9**	**Run 9 minus Run 1**		
Pumping Stress					
Non-Irrigation Pumping	181.0	155.5	-25.4		
WWTP Flows	58.0	52.3	-5.7		
Urban Deep Percolation	13.1	10.0	-3.0		
Total Stress	109.9	93.2	-16.7		
	Stress is Pumping minus WWTP and Urban Deep Perc				
Effects of Pumping Stress				***% Chg***	
FHG Deliveries (Mar - Oct)				***Stress***	***% Diff.***
EBID	167.6	171.7	4.1	*-24%*	*2%*
EPCWID (incl. EPW)	139.9	141.2	1.3	*-8%*	*1%*
HCCRD	32.8	33.0	0.1	*-1%*	*0%*
Total	340.3	345.8	5.5	*-33%*	*2%*
FHG Deliveries (Nov - Feb)					
EBID	0.0	0.0	0.0	*0%*	*561%*
EPCWID (incl. EPW)	0.2	0.2	0.0	*0%*	*8%*
HCCRD	2.4	2.4	0.0	*0%*	*-1%*
Total	2.6	2.6	0.0	*0%*	*1%*
Irrigation Pumping					
EBID	140.4	136.4	-4.0	*24%*	*-3%*
EPCWID (Mesilla Valley)	7.4	7.2	-0.2	*1%*	*-2%*
EPCWID (El Paso Valley)	40.1	39.1	-1.0	*6%*	*-3%*
HCCRD	4.2	4.0	-0.2	*1%*	*-4%*
	192.1	186.8	-5.4	*32%*	*-3%*
	Pumping turned off.	*Other values are simulated responses and are totaled.*			
Other Inflows/Outflows					
Net Reservoir Evaporation	125.3	126.5	1.2	*-7%*	*1%*
Riparian ET	70.9	71.4	0.5	*-3%*	*1%*
River Evaporation + Incidental Canal Loss	30.3	30.4	0.1	*0%*	*0%*
Total	226.6	228.3	1.8	*-11%*	*1%*
Rio Grande at Fort Quitman					
Reservoir Spills	33.3	34.6	1.3	*-8%*	*4%*
Nov-Feb Flows	21.4	22.8	1.4	*-9%*	*7%*
Mar - Oct Flows	41.1	43.4	2.3	*-14%*	*6%*
Underflow (GW Model)	0.2	0.2	0.0	*0%*	*2%*
Total	96.0	101.0	5.1	*-30%*	*5%*

Run 9 - NM Non-Irrigation Pumping Off
Comparison of ILRG Model Runs
Run 9 v. Run 1
1951 - 2017 Annual Average
(1,000 acre-feet)

Run No.	1	9	9 - 1		
Simulated Input or Output	**Run 1**	**Run 9**	**Run 9 minus Run 1**		
Effects of Pumping Stress (continued)				***% Chg***	
Change in Storage				***Stress***	***% Diff.***
Reservoir Storage	-4.7	-4.7	-0.1	*0%*	*1%*
Alluvial GW Storage (RW Model)	-23.6	-21.2	2.3	*-14%*	*-10%*
Non-alluvial GW Storage (GW Models)	-96.4	-91.7	4.6	*-28%*	*-5%*
Soil Moisture Storage	0.6	0.6	0.0	*0%*	*1%*
Total	-124.0	-117.1	6.9	*-41%*	*-6%*
Summary of Effects					
FHG Deliveries (Mar-Oct)	340.3	345.8	5.5	*-33%*	*2%*
FHG Deliveries (Nov-Feb)	2.6	2.6	0.0	*0%*	*1%*
Irrigation Pumping	192.1	186.8	-5.4	*32%*	*-3%*
Riparian ET + Evaporation	226.6	228.3	1.8	*-11%*	*1%*
Fort Quitman Flow	96.0	101.0	5.1	*-30%*	*5%*
Change in Storage	-124.0	-117.1	6.9	*-41%*	*-6%*
Total	733.6	747.5	13.9	*-84%*	*2%*
Other Effects of Pumping Stress				***% Chg***	
Rio Grande at El Paso				***Stress***	***% Diff.***
Reservoir Spills	49.4	49.8	0.4	*-2%*	*1%*
Nov-Feb Flows	22.8	24.5	1.7	*-10%*	*8%*
Mar - Oct Flows	263.8	267.8	4.0	*-24%*	*2%*
Total	336.0	342.1	6.1	*-37%*	*2%*
Rio Grande below Caballo					
Reservoir Spills	65.9	64.8	-1.1	*6%*	*-2%*
Nov-Feb Flows	0.5	0.4	-0.1	*1%*	*-25%*
Mar - Oct Flows	541.3	541.3	0.1	*0%*	*0%*
Total	607.6	606.5	-1.1	*7%*	*0%*
Surface Water Diversions (Mar - Oct)					
EBID	366.5	372.5	6.0	*-36%*	*2%*
EPCWID (incl. EPW)	236.8	239.3	2.6	*-15%*	*1%*
HCCRD	67.5	68.7	1.1	*-7%*	*2%*
Total	670.8	680.5	9.7	*-58%*	*1%*
Surface Water Diversions (Nov - Feb)					
EBID	0.0	0.0	0.0	*0%*	*0%*
EPCWID (incl. EPW)	14.3	14.6	0.3	*-2%*	*2%*
HCCRD	14.2	14.4	0.2	*-1%*	*1%*
Total	28.5	29.0	0.4	*-3%*	*2%*

Run 9 - NM Non-Irrigation Pumping Off
Annual Differences in ILRG Model Outputs
Run 9 minus Run 1
1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1940	-55	-55	4	7	1	4	18	51	2	2	1	1	-85	-6	-31
1941	-193	-193	-1	-1	1	2	-44	-7	0	1	1	0	70	228	134
1942	-162	-162	-4	-2	2	4	15	54	-2	-4	1	1	-282	146	135
1943	-186	-186	7	12	0	4	37	77	7	-7	0	-1	-252	133	59
1944	-207	-207	-144	-131	-102	-81	9	50	4	-8	-93	-93	-398	-59	29
1945	-215	-215	9	37	-103	-41	22	59	8	0	-104	27	-323	124	53
1946	-186	-186	10	39	11	37	44	86	7	9	-7	-68	-326	158	180
1947	-207	-207	-4	56	-33	14	26	70	-1	-23	-33	-33	-378	152	158
1948	-248	-248	13	36	5	23	24	69	16	12	1	1	-334	146	136
1949	-277	-277	0	26	-17	7	20	67	3	2	0	0	-411	156	115
1950	-11	-11	21	54	8	33	222	269	14	15	0	0	-141	436	334
1951	1,010	1,010	37	38	6	10	720	767	25	26	4	6	75	449	327
1952	13	13	47	48	10	12	244	287	31	32	11	9	-1,647	120	88
1953	44	44	10	10	6	3	423	465	9	9	3	-4	-1,085	461	171
1954	2,181	2,181	1,757	2,011	368	350	1,505	1,530	1,081	1,081	547	527	1,910	2,449	186
1955	845	845	613	439	218	61	464	478	262	522	133	-42	1,510	866	0
1956	108	108	-275	-961	-312	-556	-959	-949	-22	364	-324	-568	-658	-1,070	-5
1957	-6	-6	-22	237	-16	-147	32	48	36	223	72	-62	-1,233	-416	0
1958	2	2	-511	-145	-61	243	223	249	49	-49	54	121	-9,208	547	97
1959	1	1	-131	116	50	144	281	312	8	9	3	12	-3,939	816	273
1960	1	1	-54	112	31	105	280	312	6	6	0	0	-3,194	652	366
1961	1	1	8	158	19	89	240	272	-14	-13	-6	5	-3,159	707	212
1962	3	3	18	171	26	87	279	311	28	28	1	5	-3,218	742	437
1963	8,871	8,871	185	354	43	117	5,082	5,114	145	147	14	15	2,234	2,927	476
1964	7,813	7,813	5,740	5,733	692	727	4,593	4,612	3,548	3,789	643	575	8,610	6,837	1,276
1965	2,159	2,159	997	690	113	61	1,208	1,230	1,288	1,458	-10	47	-4,893	2,117	25
1966	-18	-18	-244	318	666	748	495	522	28	31	591	-554	-5,206	2,480	749
1967	8,073	8,073	6,113	7,294	1,523	2,107	5,525	5,545	3,727	3,432	1,259	1,343	7,924	8,114	1,068
1968	1,770	1,770	-18	1,355	769	636	1,790	1,814	249	-151	723	300	-3,477	3,683	420
1969	-3	-3	-196	70	1,112	1,862	759	789	-34	-33	1,382	1,015	-5,251	947	841
1970	-9	-9	-41	192	286	547	480	511	41	42	-256	-410	-3,961	946	1,143
1971	8,102	8,102	81	686	108	413	5,197	5,223	210	211	94	210	1,084	2,220	370
1972	-99	-99	453	513	295	490	6,908	6,925	1,167	1,225	324	517	-5,130	1,541	95
1973	-47	-47	585	70	389	321	150	174	208	284	336	341	-6,750	472	4
1974	-10	-10	132	390	53	199	521	552	56	57	-1	94	-5,043	1,250	278
1975	-227	-227	316	579	111	248	1,390	1,417	261	262	47	35	-5,762	1,053	156
1976	-18	-18	168	421	223	446	770	790	101	101	-1	-3	-4,111	1,153	544
1977	18,024	18,024	431	1,815	26	264	10,787	10,815	373	376	54	144	6,622	4,216	269
1978	11,916	11,916	8,363	10,146	-1,797	-1,221	6,398	6,419	9,333	9,338	-1,620	-1,129	16,948	17,519	1,027

Run 9 - NM Non-Irrigation Pumping Off
Annual Differences in ILRG Model Outputs
Run 9 minus Run 1
1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1979	-156	-156	-664	59	1,052	2,023	1,095	1,127	89	96	1,130	2,089	-11,011	2,734	1,133
1980	-102	-102	-152	355	1,104	2,322	638	678	82	88	1,156	1,098	-7,527	1,872	1,395
1981	-66	-66	-57	308	349	633	759	788	58	62	0	0	-6,552	1,545	1,194
1982	-58	-58	-13	372	169	425	577	613	62	66	-39	-121	-6,895	1,590	1,277
1983	-53	-53	8	402	165	411	633	670	60	64	0	0	-6,552	1,724	840
1984	-100	-100	104	576	809	1,116	774	807	122	127	0	0	-5,311	3,613	2,110
1985	-131	-131	42	77	660	708	922	967	39	63	0	0	-6,521	2,938	1,868
1986	-128	-128	-37	-27	554	795	963	1,018	7	18	0	0	36,392	45,540	51,794
1987	-211	-211	77	83	141	215	698	748	83	89	0	0	-6	8,736	24,265
1988	-74	-74	49	54	115	172	988	1,038	56	61	0	0	-5,148	4,834	5,372
1989	-46	-46	70	103	114	123	963	1,001	51	70	0	0	-7,747	2,654	2,744
1990	-99	-99	92	126	589	564	1,191	1,237	80	89	0	0	-6,353	5,552	4,264
1991	-398	-398	111	161	138	127	726	778	101	187	0	0	-8,208	3,935	5,020
1992	2,358	2,358	74,380	74,340	34,132	35,125	-9,209	-9,165	33,305	33,289	0	0	37,324	56,397	43,904
1993	401	401	-5,547	-5,567	-1,093	-491	1,908	1,959	-2,887	-2,885	0	0	-20,136	-10,089	822
1994	-67	-67	55	57	166	314	1,375	1,434	267	274	0	0	2,221	14,892	14,465
1995	-74	-74	81	48	246	359	1,520	1,563	144	102	0	0	4,391	18,003	17,397
1996	-124	-124	90	96	130	234	1,871	1,925	147	154	0	0	-12,599	4,235	4,801
1997	-97	-97	-29	36	250	229	1,410	1,453	81	120	0	0	-8,700	5,741	3,651
1998	-124	-124	-8	-5	178	81	1,552	1,607	103	114	0	0	-14,768	4,010	5,841
1999	85	85	863	1,030	-210	-111	1,297	1,341	2,444	2,454	0	0	-799	13,626	10,914
2000	-105	-105	-3,250	-2,941	-522	-384	1,470	1,514	-2,195	-2,184	0	0	-15,053	2,280	4,502
2001	-169	-169	-37	275	121	276	1,486	1,521	61	73	0	0	-12,379	5,858	5,399
2002	-116	-116	-37	361	127	306	1,602	1,631	92	105	0	0	-12,034	6,326	6,153
2003	44,077	44,077	38,625	39,031	11,517	12,020	21,207	21,243	14,654	14,667	0	0	38,338	48,057	27,060
2004	8,023	8,023	5,803	6,425	1,329	2,257	5,720	5,752	4,085	4,096	0	0	422	11,793	8,882
2005	953	953	8	379	826	1,387	3,123	3,162	842	858	0	0	-21,164	5,905	10,463
2006	44,945	44,945	23,290	23,905	8,757	9,348	21,509	21,542	5,634	5,648	0	0	33,335	36,410	26,116
2007	21,861	21,861	2,575	3,151	901	1,307	13,174	13,200	2,226	2,242	0	0	-7,898	6,622	5,488
2008	35,455	35,455	184	715	307	612	24,350	24,379	251	269	0	0	-6,138	5,005	5,430
2009	48,801	48,801	138	603	179	437	28,864	28,900	188	212	0	0	-3,238	6,885	7,159
2010	59,142	59,142	1,148	2,192	381	737	38,756	38,787	922	946	0	0	-1,056	8,237	7,264
2011	42,865	42,865	12,729	13,289	4,212	4,217	24,235	24,250	9,286	9,306	0	0	28,272	17,607	9,293
2012	-2,421	-2,421	3,532	3,529	4,016	3,703	1,306	1,316	2,590	2,602	0	0	-8,053	2,622	5,448
2013	-5,133	-5,133	-818	-873	67	-15	-2,691	-2,682	-629	-621	253	0	-7,472	-2,788	1,720
2014	-1,870	-1,870	510	349	456	8	-674	-670	317	324	385	-92	-331	-1,340	589
2015	-1,612	-1,612	-126	-211	80	-86	-548	-540	16	24	18	-170	-1,489	-704	-232
2016	20,288	20,288	-9,189	-9,142	-1,780	-2,161	10,461	10,470	-6,065	-6,055	0	0	-3,636	-9,976	-4,675
2017	18,257	18,257	1,767	1,865	-177	-359	10,090	10,103	919	930	0	-22	8,356	2,545	-1,991
Averages															
1951-2017	6,037	6,037	2,551	2,813	1,127	1,304	4,058	4,090	1,342	1,357	104	80	-1,130	6,108	5,075
1951-1978	2,518	2,518	877	1,174	177	299	1,992	2,019	793	814	146	91	-1,072	2,279	389
1979-2005	1,978	1,978	4,097	4,304	1,969	2,268	1,750	1,793	1,927	1,938	83	114	-2,829	10,159	9,908
2006-2017	23,381	23,381	2,978	3,281	1,450	1,479	14,069	14,088	1,305	1,319	55	-24	2,554	5,927	5,134
1985-2017	10,137	10,137	4,459	4,652	2,027	2,183	6,413	6,448	2,037	2,050	20	-9	-57	10,071	9,733
1985-2005	2,568	2,568	5,305	5,435	2,358	2,586	2,037	2,082	2,455	2,467	0	0	-1,549	12,439	12,361

Notes:

EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

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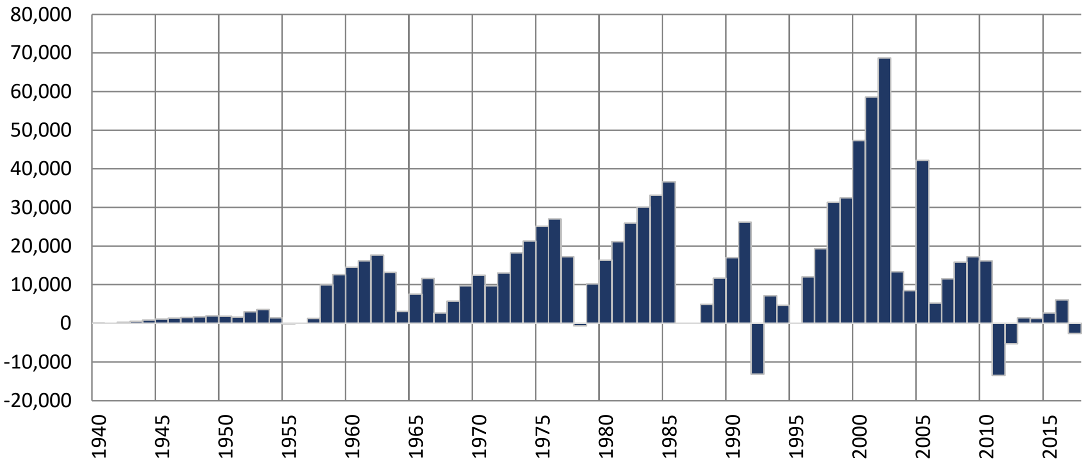
Run 9 - NM Non-Irrigation Pumping Off

Simulated Differences in ILRG Model Outputs

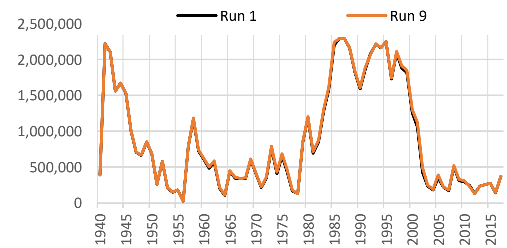
Run 9 minus Run 1

1940 - 2017 (acre-feet)

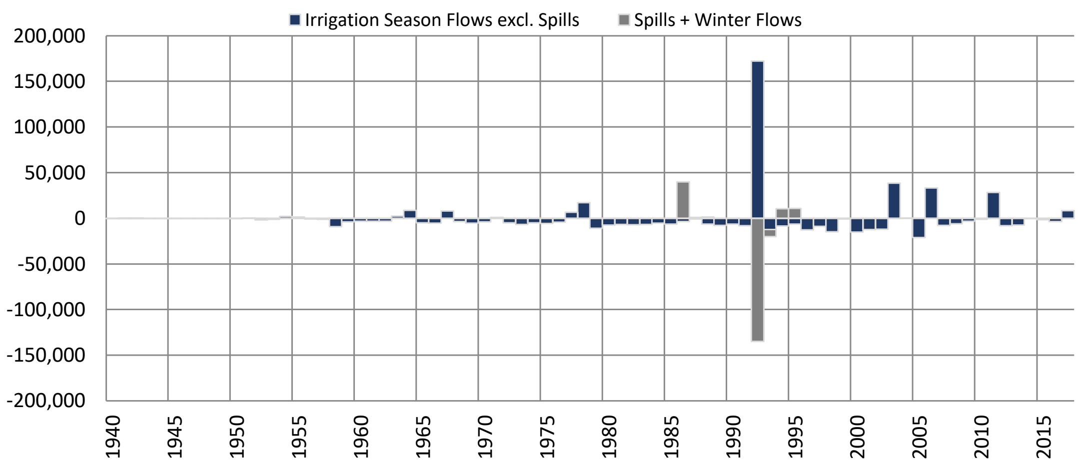
Total Project Storage (Year End)



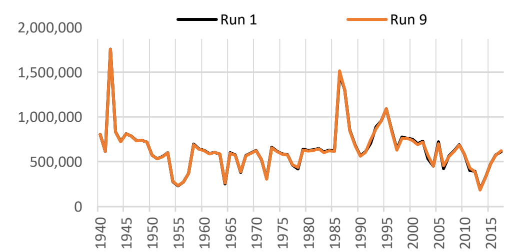
Period	Average Difference
1951-2017	-67
1951-1978	-89
1979-2005	1,587
2006-2017	-3,736
1985-2017	-1,085
1985-2005	430



Caballo Reservoir Outflows (Annual)



	Average Difference		
Period	Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	54	-1,185	-1,130
1951-1978	-1,072	0	-1,072
1979-2005	111	-2,940	-2,829
2006-2017	2,554	0	2,554
1985-2017	2,349	-2,405	-57
1985-2005	2,231	-3,780	-1,549



Notes:

Reservoir storage does not include storage attributed to SJC, CO, or NM credit waters.

Average differences calculated as (Final Storage - Initial Storage)/(no. years).

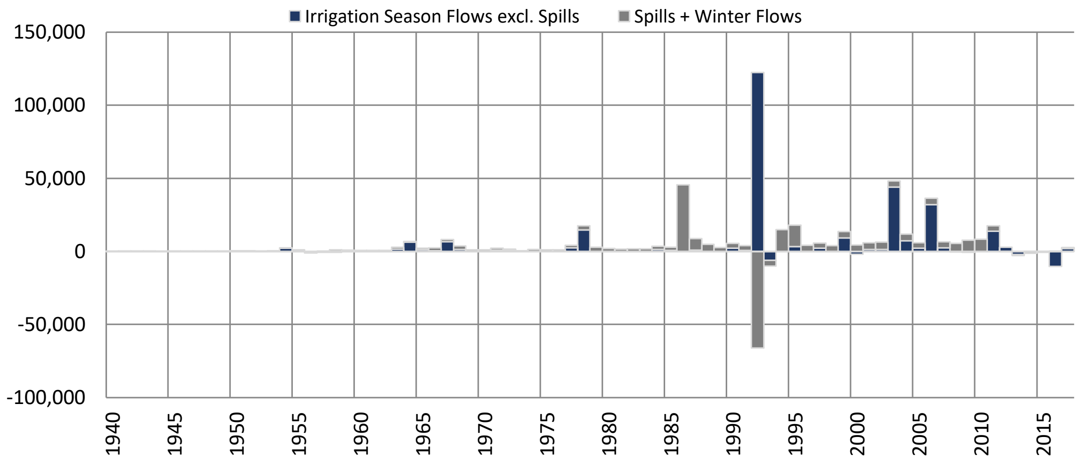
Run 9 - NM Non-Irrigation Pumping Off

Simulated Differences in ILRG Model Outputs

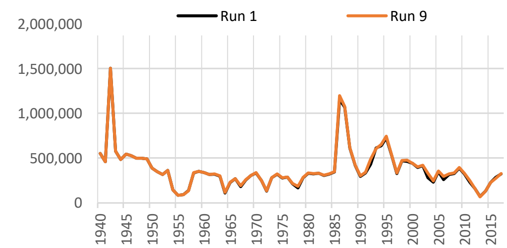
Run 9 minus Run 1

1940 - 2017 (acre-feet)

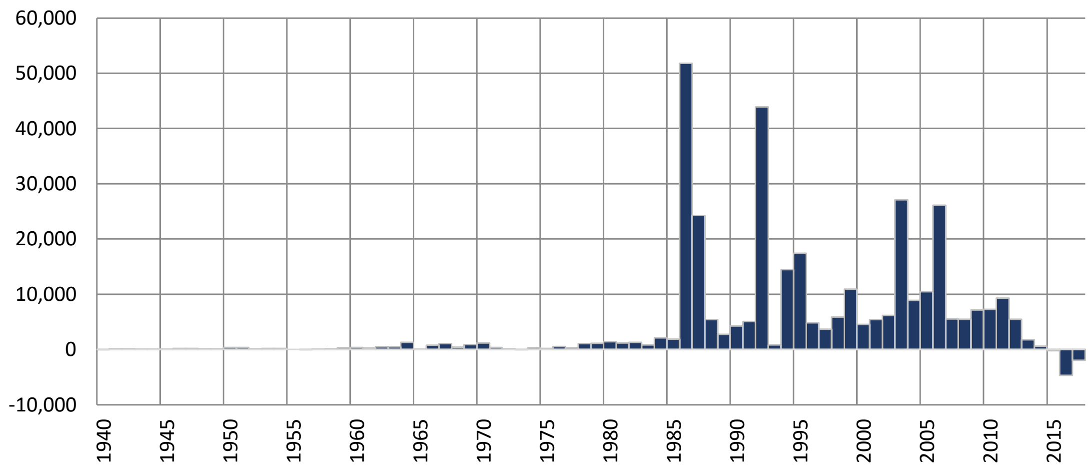
Rio Grande at El Paso (Annual)



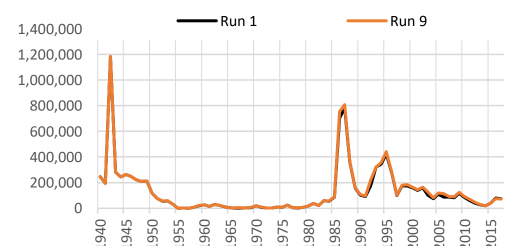
	Average Difference		
Period	Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	4,003	2,105	6,108
1951-1978	1,364	914	2,279
1979-2005	7,067	3,092	10,159
2006-2017	3,267	2,661	5,927
1985-2017	6,942	3,129	10,071
1985-2005	9,043	3,396	12,439



Rio Grande at Fort Quitman (Annual)



Period	Average Difference
1951-2017	5,072
1951-1978	386
1979-2005	9,904
2006-2017	5,132
1985-2017	9,730
1985-2005	12,358



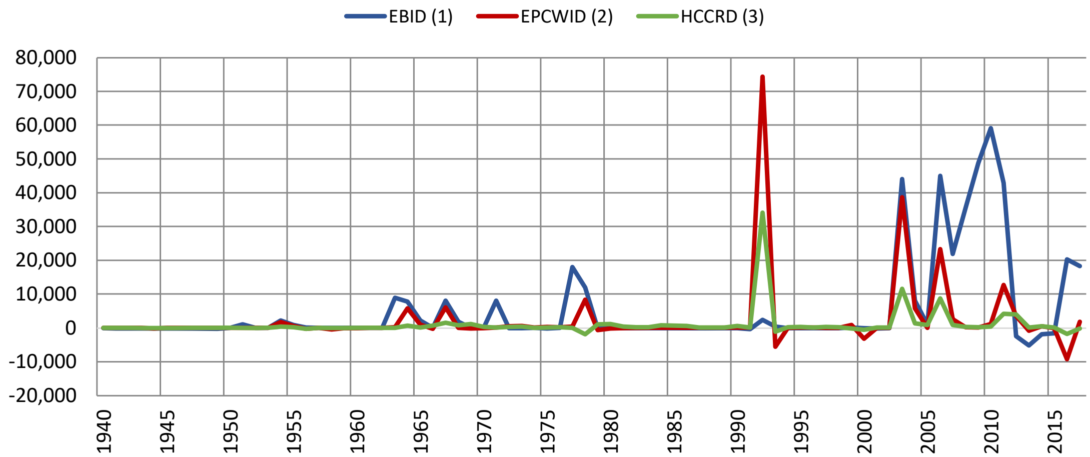
Run 9 - NM Non-Irrigation Pumping Off

Simulated Differences in ILRG Model Outputs

Run 9 minus Run 1

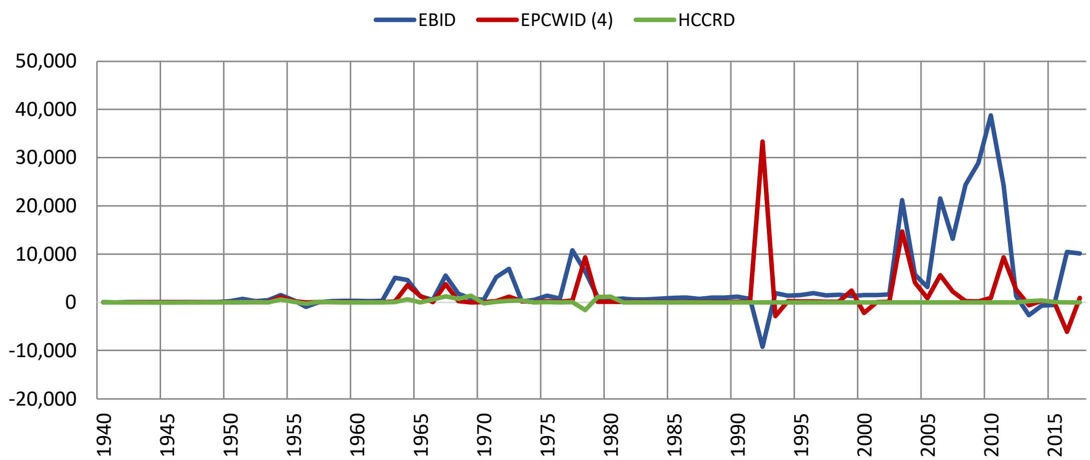
1940 - 2017 (acre-feet)

River Headgate (RHG) Diversions (Irrigation Season)



	Average Difference		
Period	EBID	EPCWID	HCCRD
1951-2017	6,037	2,551	1,127
1951-1978	2,518	877	177
1979-2005	1,978	4,097	1,969
2006-2017	23,381	2,978	1,450
1985-2017	10,137	4,459	2,027
1985-2005	2,568	5,305	2,358

Farm Headgate (FHG) Deliveries (Irrigation Season)



	Average Difference		
Period	EBID	EPCWID	HCCRD
1951-2017	4,058	1,342	104
1951-1978	1,992	793	146
1979-2005	1,750	1,927	83
2006-2017	14,069	1,305	55
1985-2017	6,413	2,037	20
1985-2005	2,037	2,455	0

Notes:

(1) EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

(2) EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

(3) HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

(4) EPCWID FHG values include deliveries to Rogers WTP and R/U WTP.

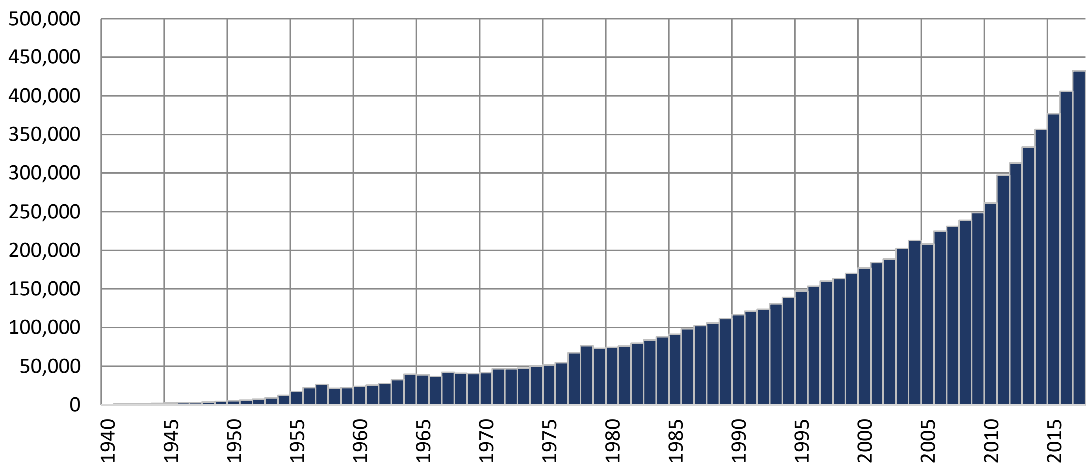
Run 9 - NM Non-Irrigation Pumping Off

Simulated Differences in ILRG Model Outputs

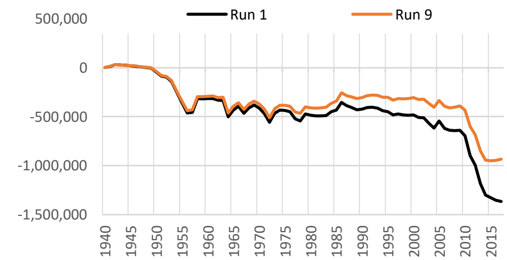
Run 9 minus Run 1

1940 - 2017 (acre-feet)

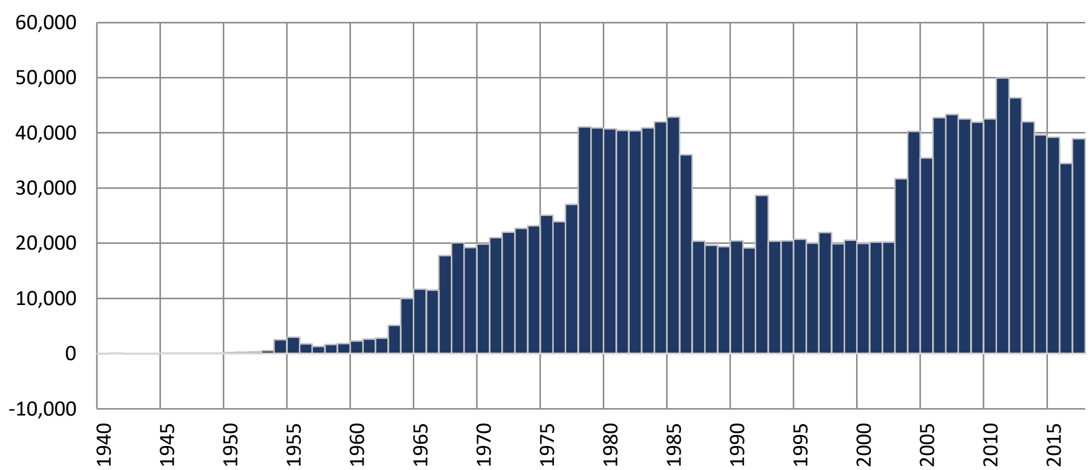
Cumulative Annual Rincon-Mesilla Groundwater Storage



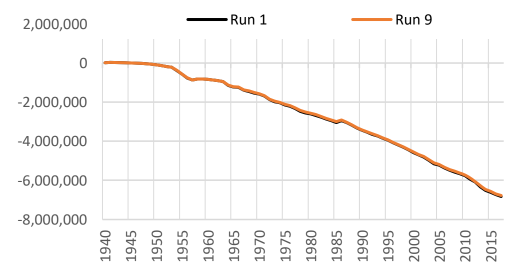
Period	Average Difference
1951-2017	6,373
1951-1978	2,547
1979-2005	4,875
2006-2017	18,673
1985-2017	10,432
1985-2005	5,723



Cumulative Annual Hueco Groundwater Storage



Period	Average Difference
1951-2017	579
1951-1978	1,461
1979-2005	-209
2006-2017	293
1985-2017	-93
1985-2005	-313



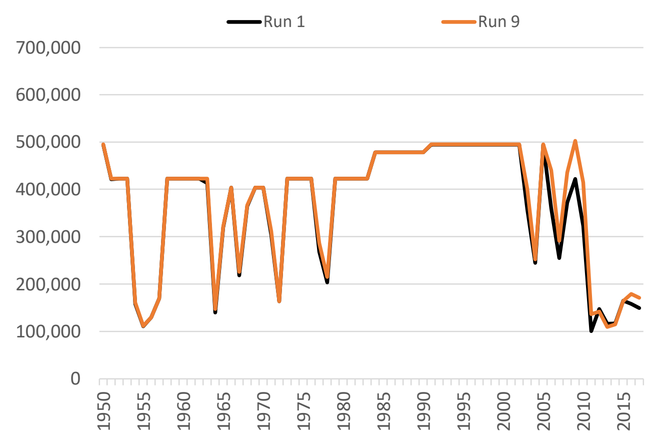
Notes:

Cumulative storage change in alluvial and non-alluvial aquifers.

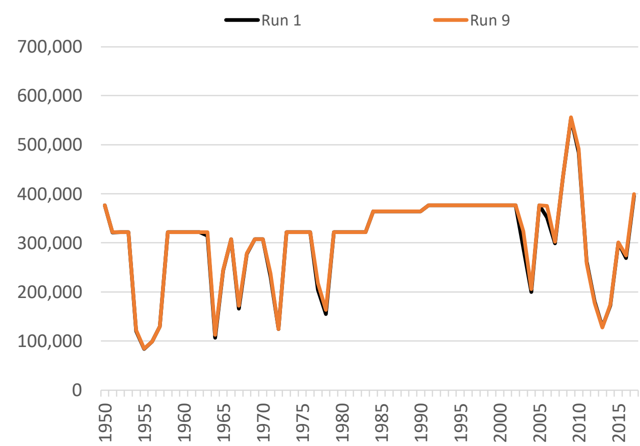
Average differences calculated as (Final Storage - Initial Storage)/(no. years).

Run 9 - NM Non-Irrigation Pumping Off
Annual Allocation and Charges
Run 9 v. Run 1
ILRG Model
1950 - 2017 (acre-feet)

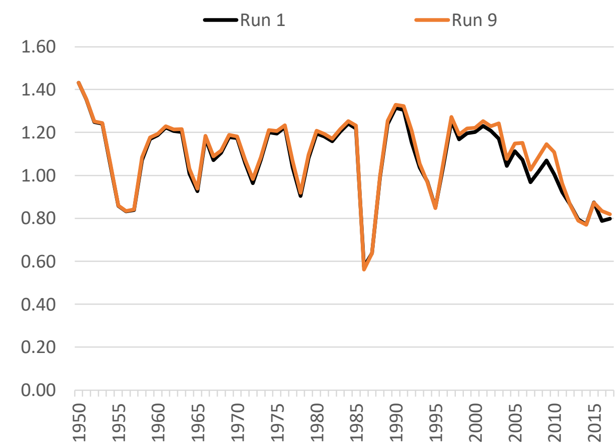
Total Allocation - EBID



Total Allocation - EPCWID

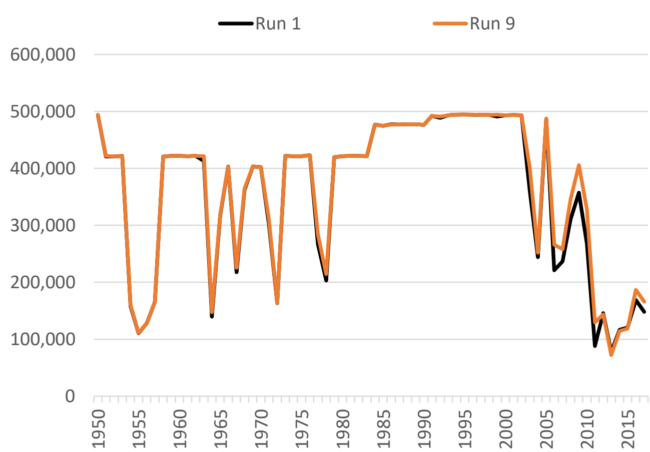


Diversion Ratio

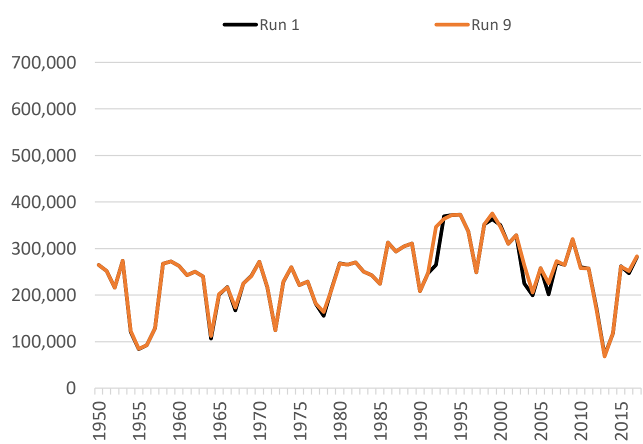


Note:
Computed as Total Charges/Caballo Release.

Annual Delivery Charges - EBID

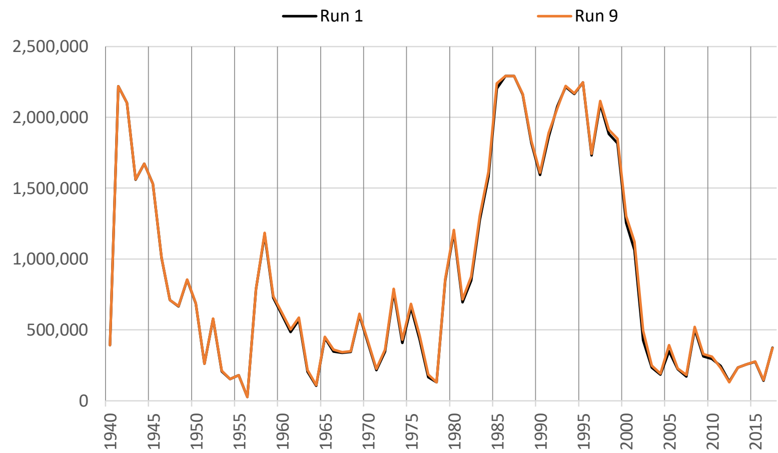


Annual Delivery Charges - EPCWID

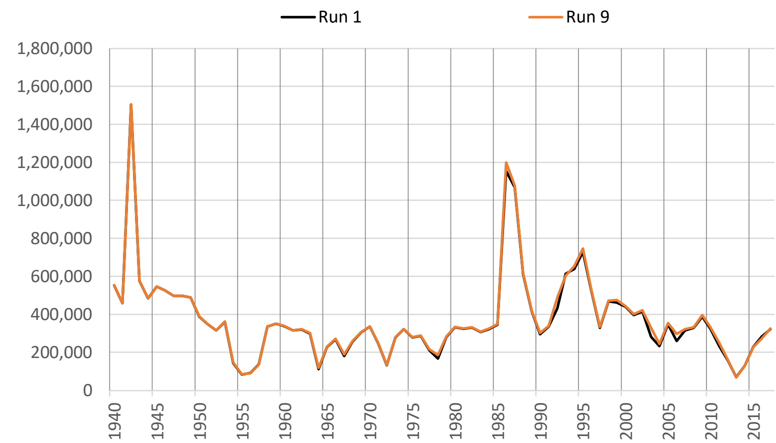


Run 9 - NM Non-Irrigation Pumping Off
Annual Summary of Project Storage and Rio Grande Flows
Run 9 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

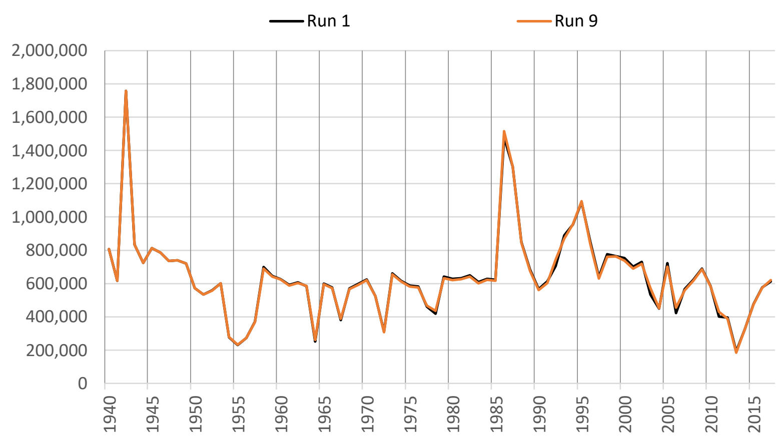
Total Year-End Project Reservoir Storage



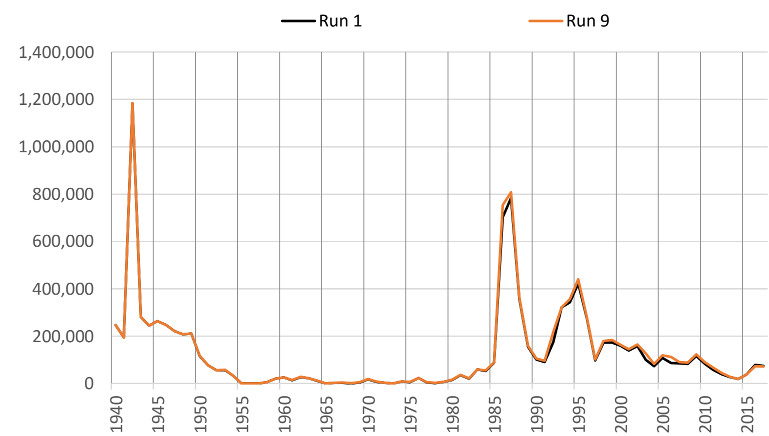
Rio Grande at El Paso



Rio Grande Below Caballo



Rio Grande at Fort Quitman

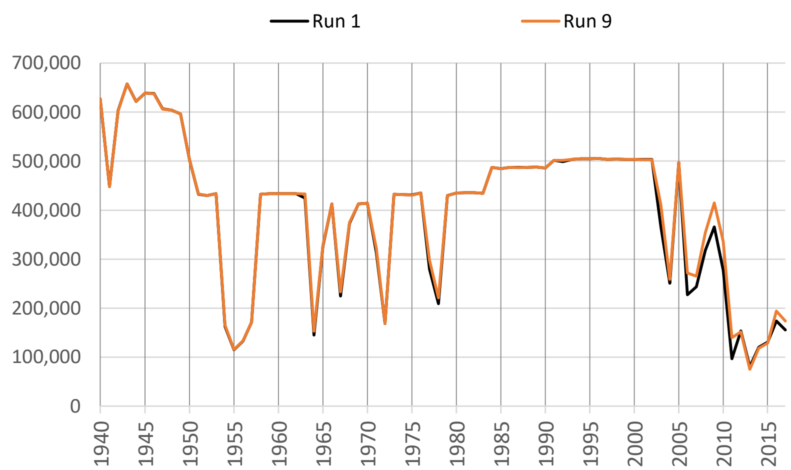


***Note different scales.**

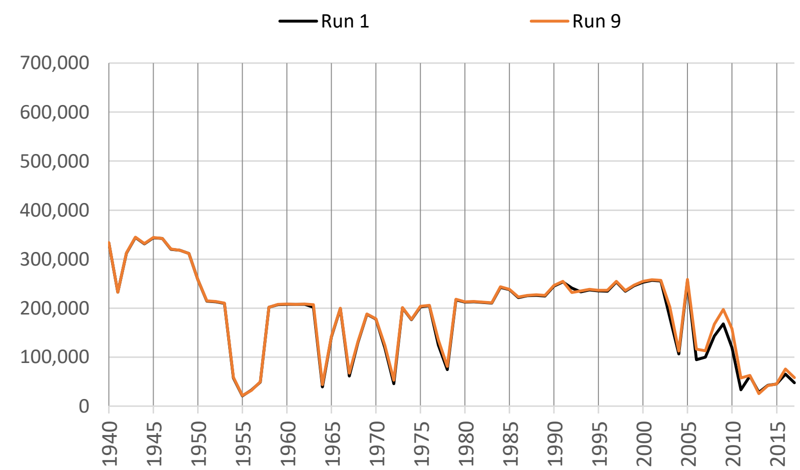
Run 9 - NM Non-Irrigation Pumping Off
Irrigation Season Summary of Irrigation Operations
Run 9 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

EBID Total

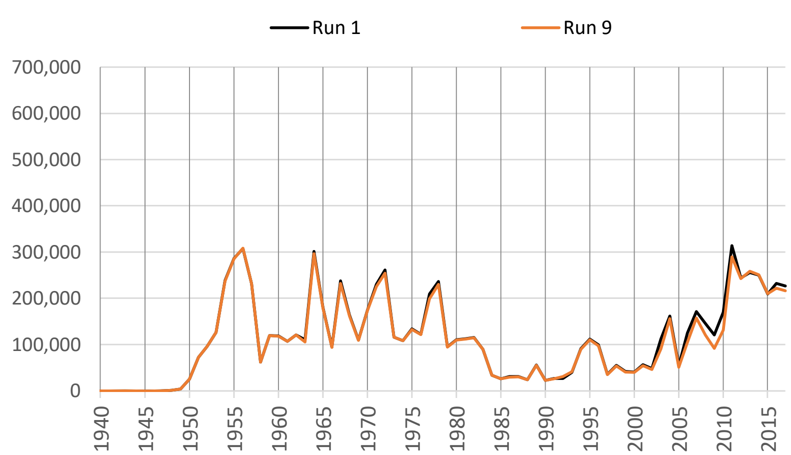
Net River Headgate Diversions



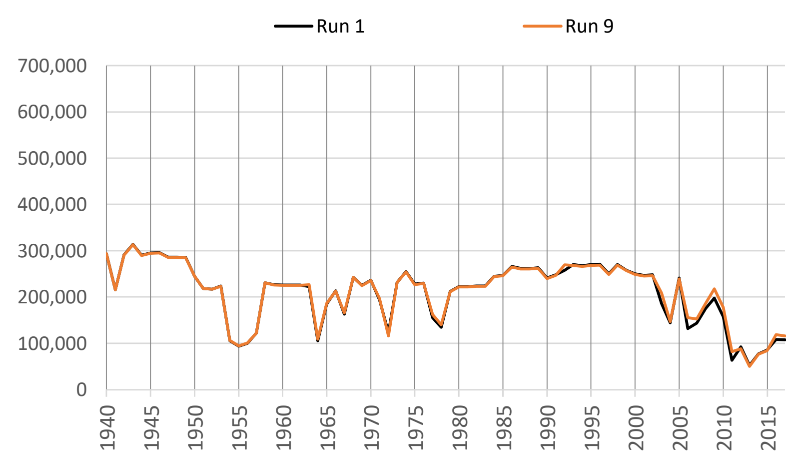
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries

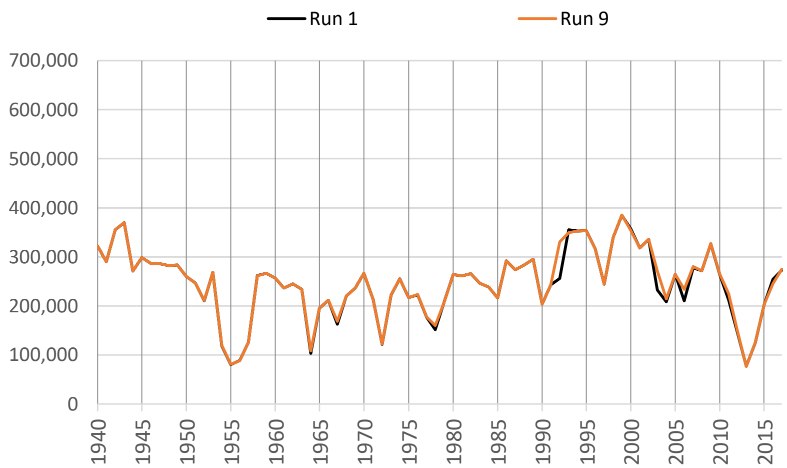


Notes: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).
Pumping includes Supplemental and Primary groundwater pumping.

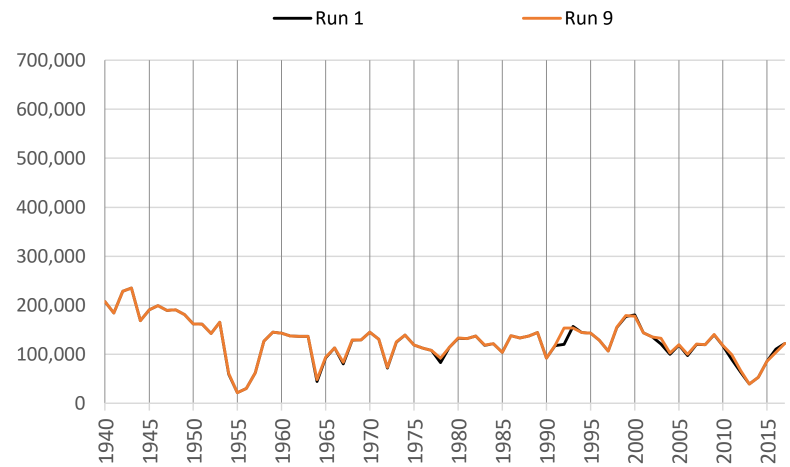
Run 9 - NM Non-Irrigation Pumping Off
Irrigation Season Summary of Irrigation Operations
Run 9 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

EPCWID Total

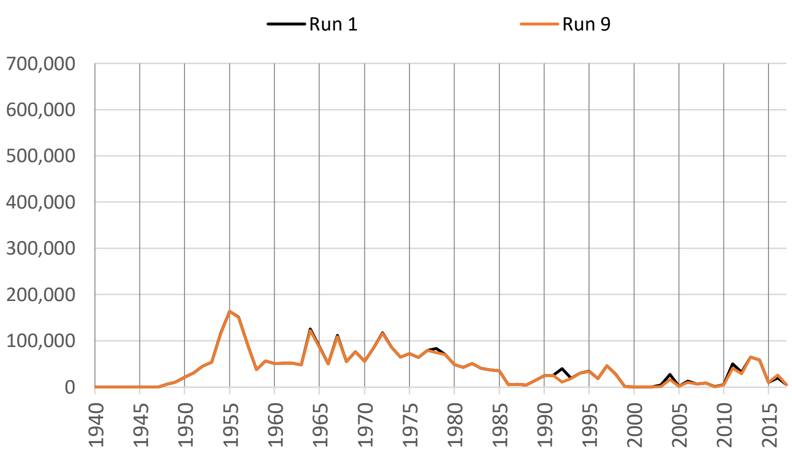
Net River Headgate Diversions



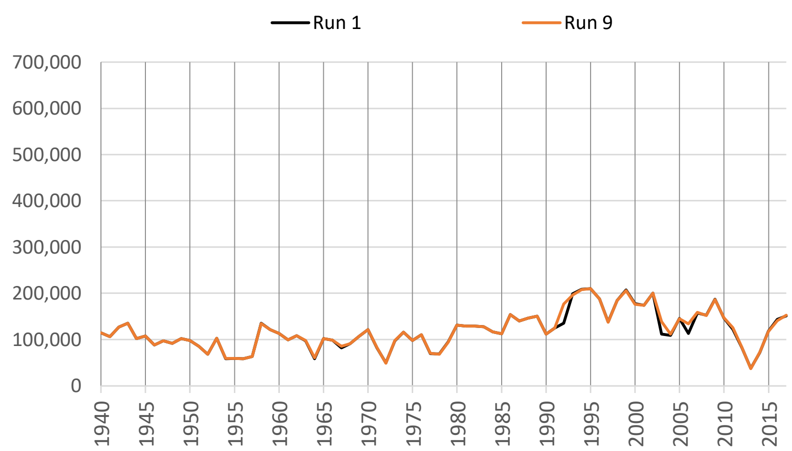
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries

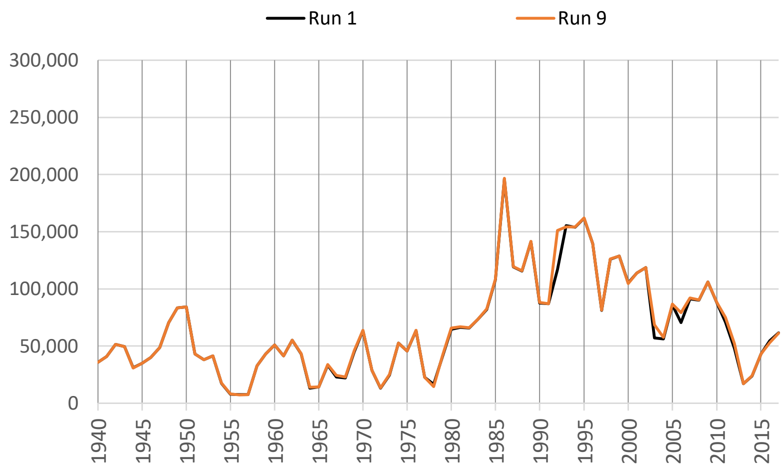


Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

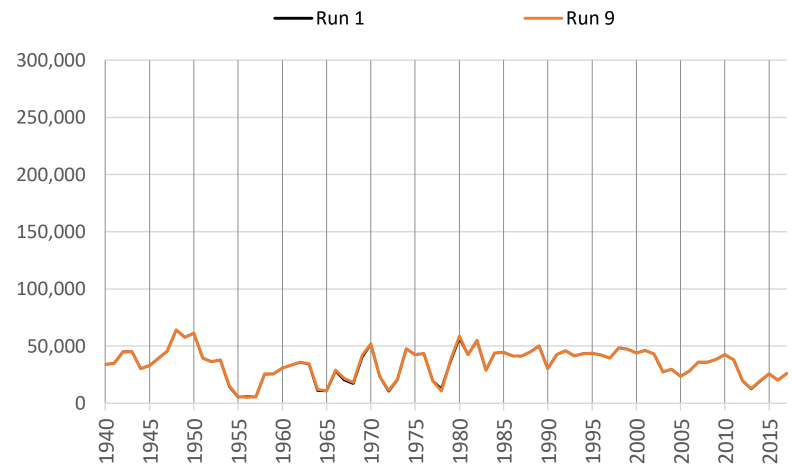
Run 9 - NM Non-Irrigation Pumping Off
Irrigation Season Summary of Irrigation Operations
Run 9 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

HCCRD Total

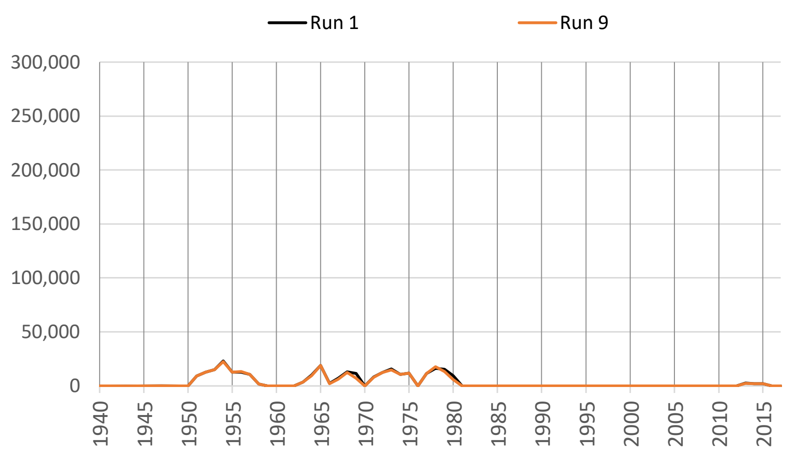
Net River Headgate Diversions



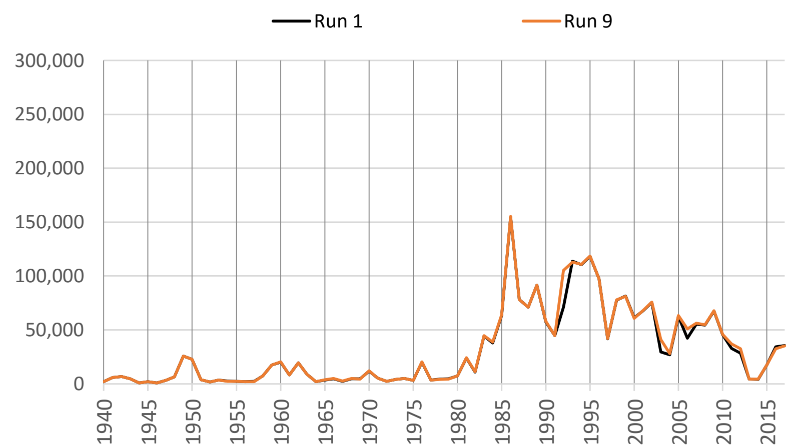
Farm Headgate Deliveries



Pumping



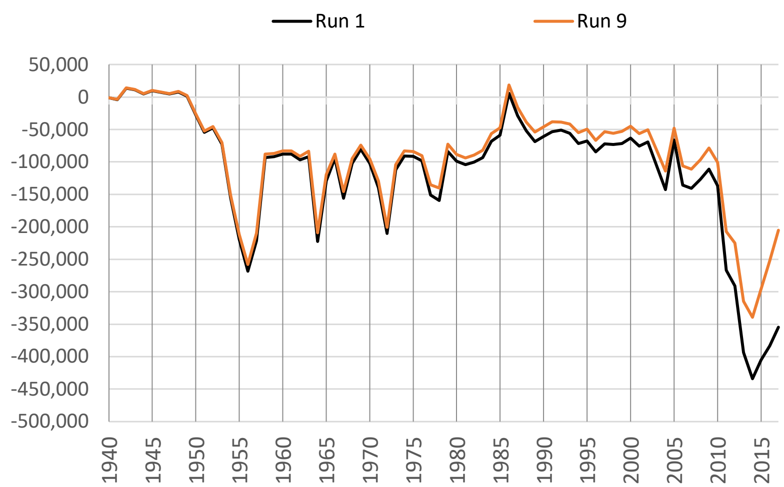
RHG Diversions - FHG Deliveries



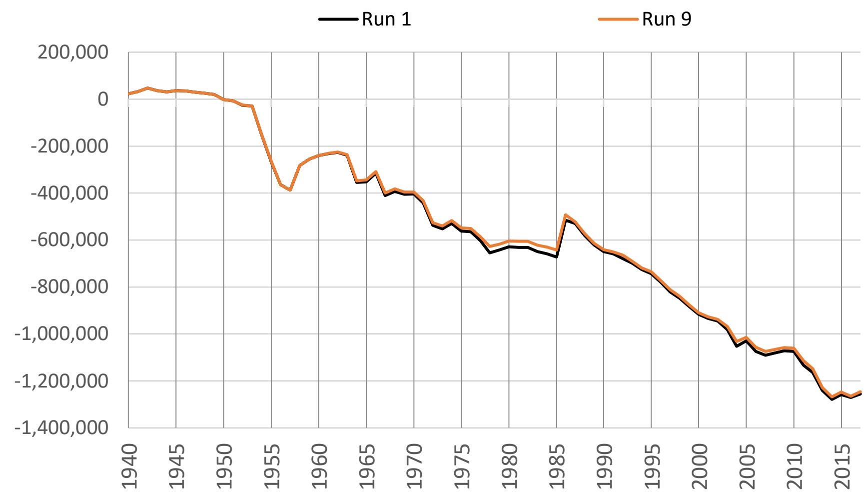
Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

Run 9 - NM Non-Irrigation Pumping Off
Cumulative Change in Ground Water Storage
Run 9 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

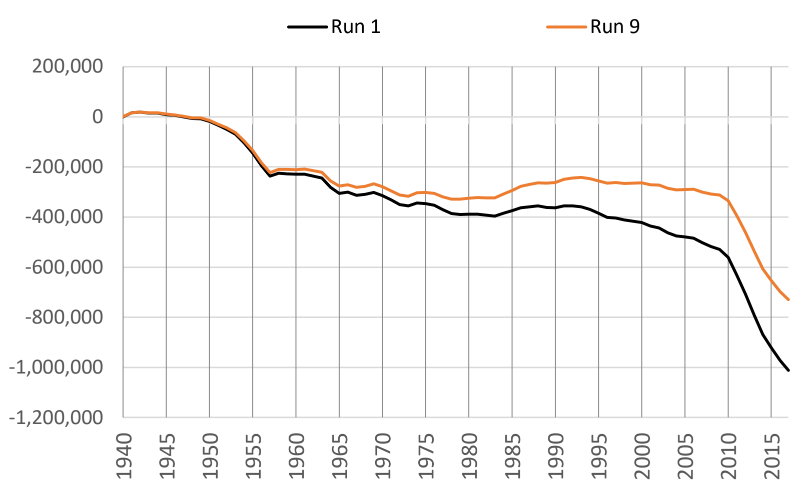
Rincon-Mesilla Alluvial Aquifer



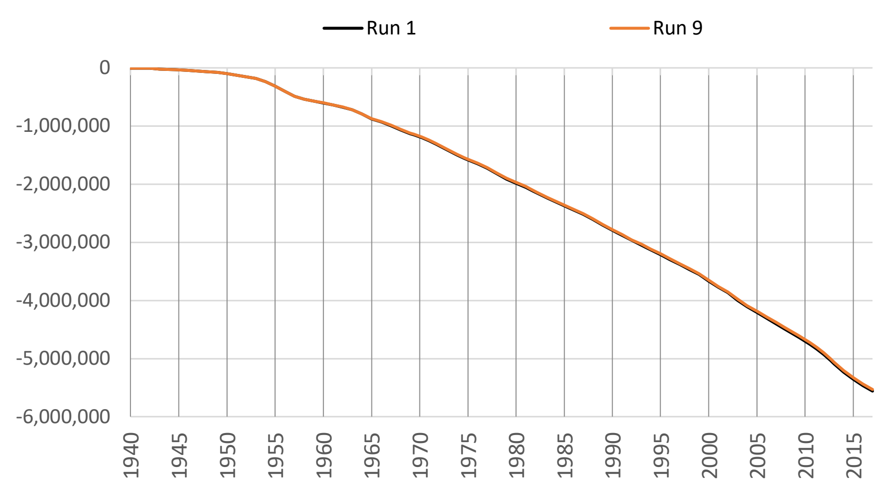
Hueco Alluvial Aquifer



Rincon-Mesilla Non-Alluvial Aquifer



Hueco Non-Alluvial Aquifer



***Note different scales.**

Run 9 - NM Non-Irrigation Pumping Off

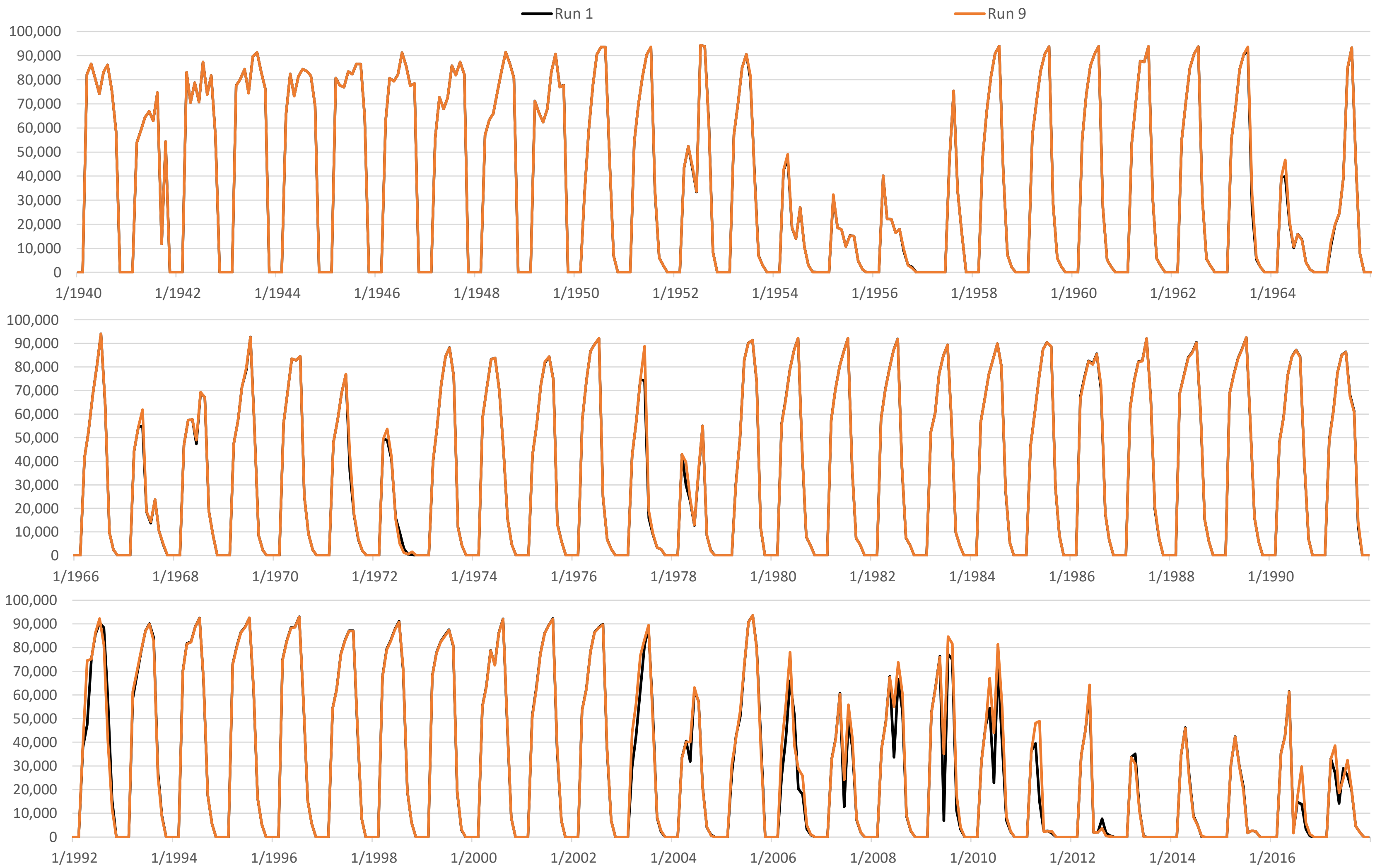
Monthly Net RHG Diversions

Run 9 v. Run 1

ILRG Model

1940 - 2017 (acre-feet)

EBID Total



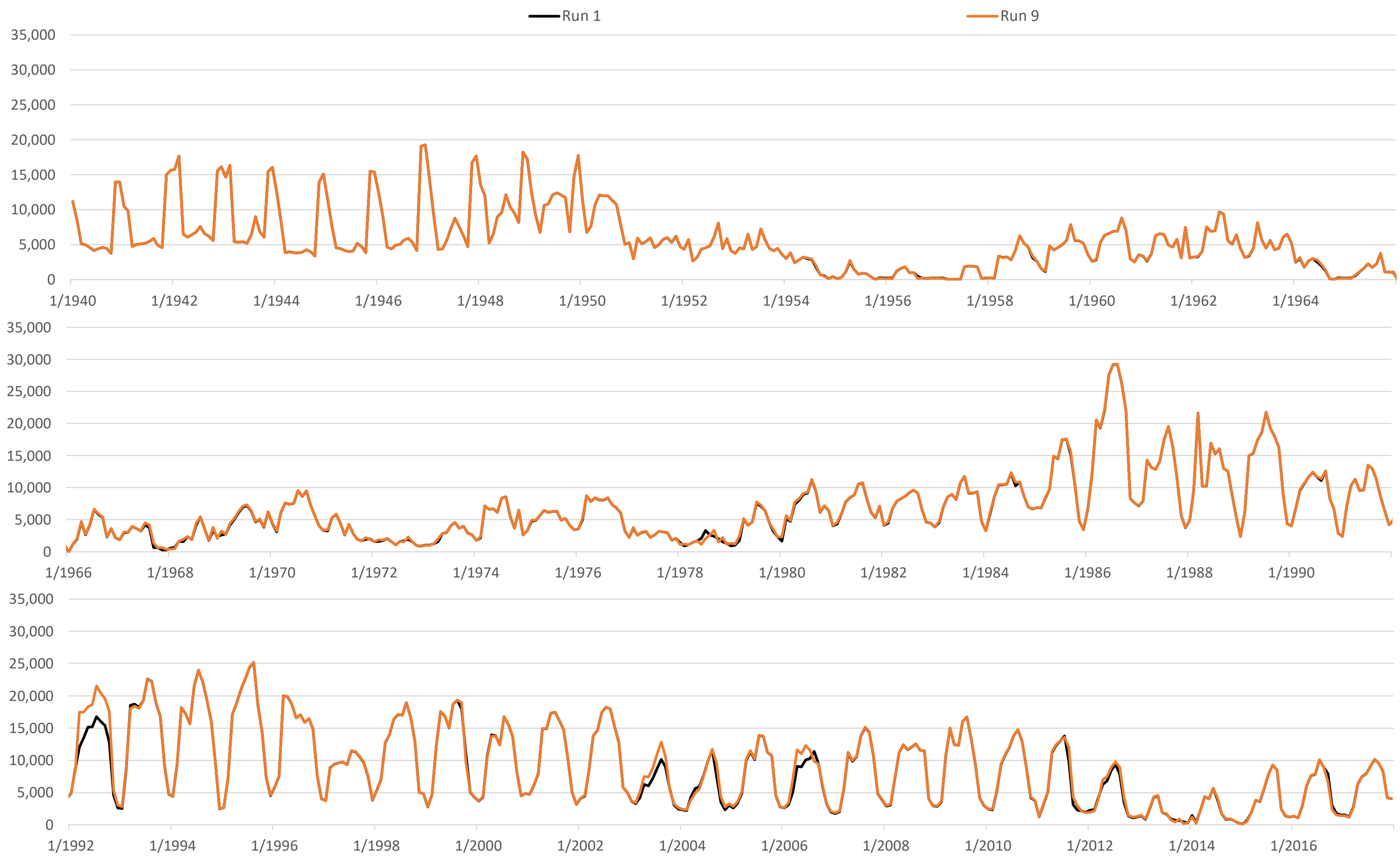
Note: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

Run 9 - NM Non-Irrigation Pumping Off
Monthly Net RHG Diversions
Run 9 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

EPCWID Total

Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

Run 9 - NM Non-Irrigation Pumping Off
Monthly Net RHG Diversions
Run 9 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
HCCRD Total



Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

Run 9 - NM Non-Irrigation Pumping Off
End of Month Reservoir Storage (Elephant Butte + Caballo)
Run 9 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

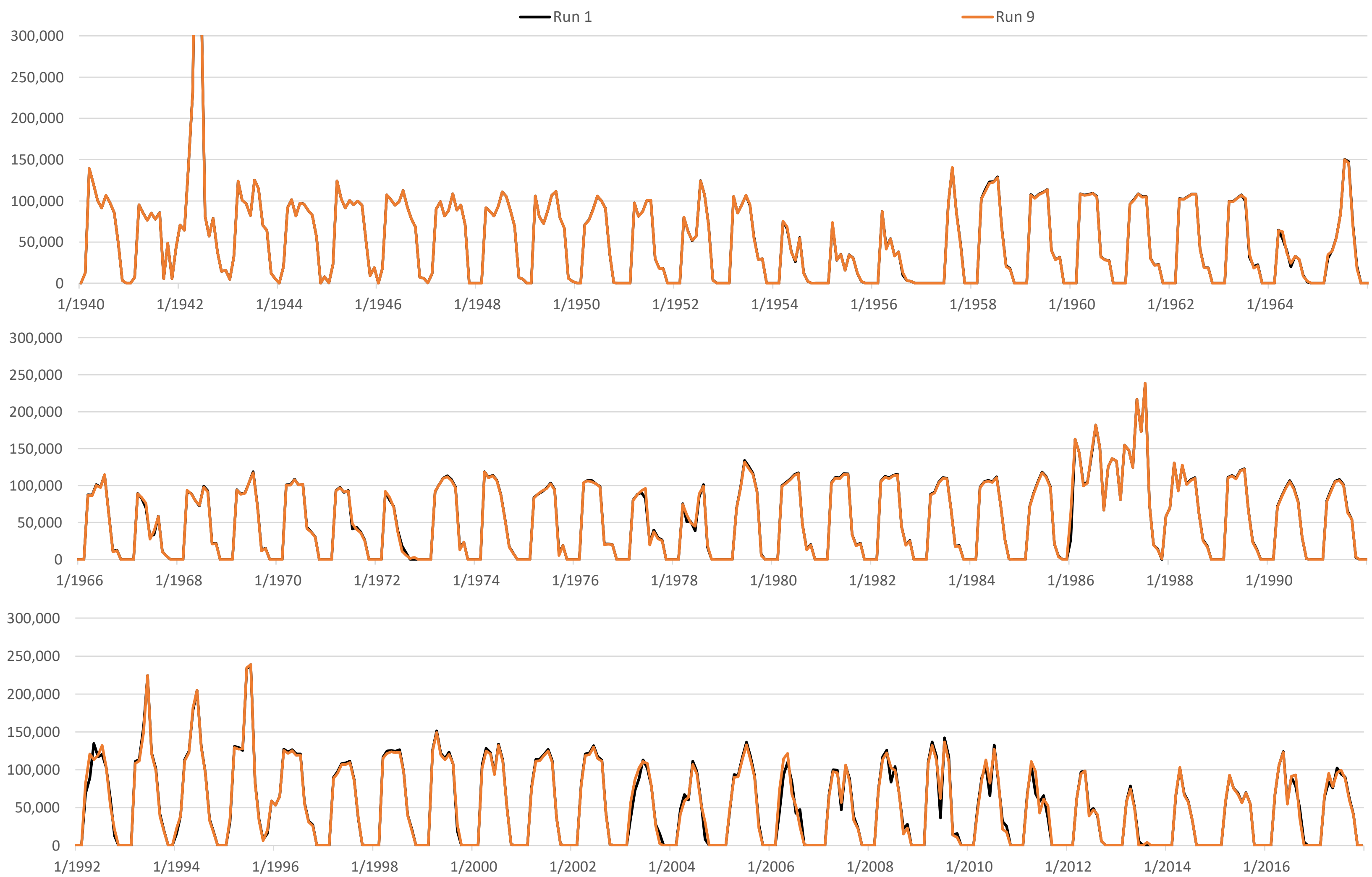
Run 9 - NM Non-Irrigation Pumping Off

Monthly Caballo Releases

Run 9 v. Run 1

ILRG Model

1940 - 2017 (acre-feet)



Run 9 - NM Non-Irrigation Pumping Off
Monthly Rio Grande at El Paso Flow
Run 9 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

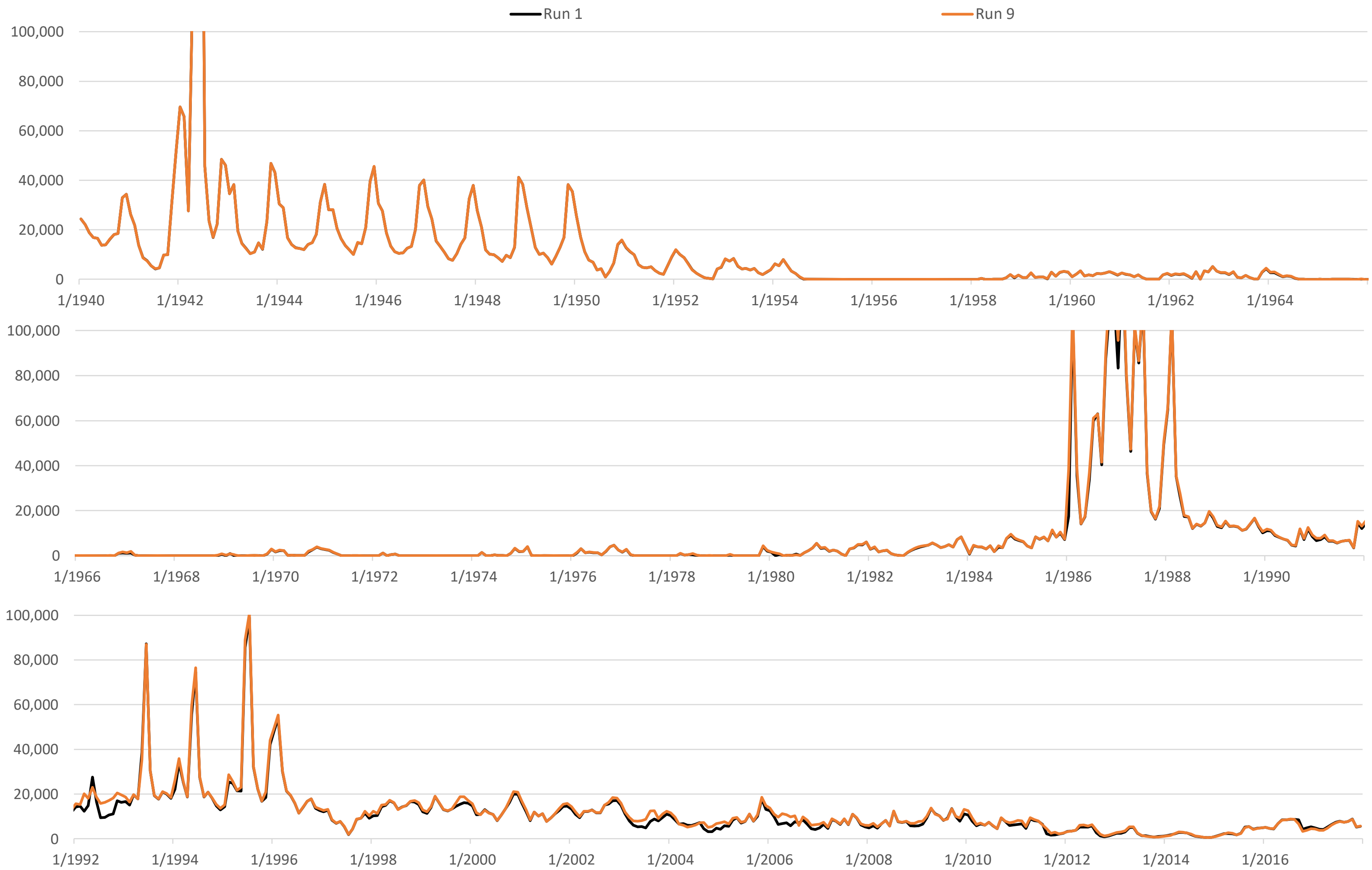
Run 9 - NM Non-Irrigation Pumping Off

Monthly Rio Grande at Fort Quitman Flow

Run 9 v. Run 1

ILRG Model

1940 - 2017 (acre-feet)



Appendix 30J

Comparison of ILRG Model Runs
Run 10 v. Run 1

Model Run Specifications

Model Version: LRG_v116

Name: **Run 10 - MX Non-Irrigation Pumping Off**

Run ID: LRG_v116_Operational_Run10
Date: 8/27/2020

Name: **Run 1 - Historical Base Run**

Run ID: LRG_v116_Operational_Run1
Date: 8/23/2020

Selected Model Inputs

Pumping and Returns	Run 10	Run 1
Irrigation Pumping	On	On
Irrigated Area	Hist	Hist
Non-Irrigation Pumping	MX Off	On
Non-Irrigation Pumping Returns	MX Off	On
Las Cruces Jornada Pumping Returns	On	On

Project Allocation Rules		
1950-2005	D1/D2	D1/D2
2006-2007	D3	D3
2008-2017	D3 + CO	D3 + CO

EPCWID Operations		
Charge EPCWID for Use of WWTP Returns	Off	Off
ACE and Haskell Credits for EPCWID	On	On
Increased EPCWID Use of Fabens Drain Flows	Off	Off
Charge EPCWID for Fabens Drain Flow Use	Off	Off

Run 10 - MX Non-Irrigation Pumping Off
Comparison of ILRG Model Runs
Run 10 v. Run 1
1951 - 2017 Annual Average
(1,000 acre-feet)

Run No.	1	10	10 - 1		
Simulated Input or Output	**Run 1**	**Run 10**	**Run 10 minus Run 1**		
Pumping Stress					
Non-Irrigation Pumping	181.0	109.4	-71.6		
WWTP Flows	58.0	34.3	-23.8		
Urban Deep Percolation	13.1	13.1	0.0		
Total Stress	109.9	62.0	-47.8		
	Stress is Pumping minus WWTP and Urban Deep Perc				
Effects of Pumping Stress				***% Chg***	
FHG Deliveries (Mar - Oct)				***Stress***	***% Diff.***
EBID	167.6	168.0	0.3	*-1%*	*0%*
EPCWID (incl. EPW)	139.9	140.1	0.2	*0%*	*0%*
HCCRD	32.8	32.7	-0.2	*0%*	*0%*
Total	340.3	340.7	0.4	*-1%*	*0%*
FHG Deliveries (Nov - Feb)					
EBID	0.0	0.0	0.0	*0%*	*0%*
EPCWID (incl. EPW)	0.2	0.2	0.0	*0%*	*-4%*
HCCRD	2.4	2.4	0.0	*0%*	*-1%*
Total	2.6	2.6	0.0	*0%*	*-1%*
Irrigation Pumping					
EBID	140.4	140.1	-0.3	*1%*	*0%*
EPCWID (Mesilla Valley)	7.4	7.3	0.0	*0%*	*0%*
EPCWID (El Paso Valley)	40.1	39.9	-0.2	*0%*	*0%*
HCCRD	4.2	4.4	0.2	*0%*	*5%*
	192.1	191.8	-0.3	*1%*	*0%*
	Pumping turned off.	*Other values are simulated responses and are totaled.*			
Other Inflows/Outflows					
Net Reservoir Evaporation	125.3	125.4	0.0	*0%*	*0%*
Riparian ET	70.9	69.8	-1.1	*2%*	*-2%*
River Evaporation + Incidental Canal Loss	30.3	30.2	-0.1	*0%*	*0%*
Total	226.6	225.4	-1.2	*3%*	*-1%*
Rio Grande at Fort Quitman					
Reservoir Spills	33.3	32.0	-1.2	*3%*	*-4%*
Nov-Feb Flows	21.4	19.3	-2.1	*4%*	*-10%*
Mar - Oct Flows	41.1	36.9	-4.1	*9%*	*-10%*
Underflow (GW Model)	0.2	0.2	0.0	*0%*	*-1%*
Total	96.0	88.5	-7.5	*16%*	*-8%*

Run 10 - MX Non-Irrigation Pumping Off
Comparison of ILRG Model Runs
Run 10 v. Run 1
1951 - 2017 Annual Average
(1,000 acre-feet)

Run No.	1	10	10 - 1		
Simulated Input or Output	**Run 1**	**Run 10**	**Run 10 minus Run 1**		
Effects of Pumping Stress (continued)				*% Chg*	
Change in Storage				*Stress*	*% Diff.*
Reservoir Storage	-4.7	-4.8	-0.2	*0%*	*3%*
Alluvial GW Storage (RW Model)	-23.6	-15.4	8.2	*-17%*	*-35%*
Non-alluvial GW Storage (GW Models)	-96.4	-59.7	36.7	*-77%*	*-38%*
Soil Moisture Storage	0.6	0.4	-0.2	*0%*	*-29%*
Total	-124.0	-79.5	44.5	*-93%*	*-36%*
Summary of Effects					
FHG Deliveries (Mar-Oct)	340.3	340.7	0.4	*-1%*	*0%*
FHG Deliveries (Nov-Feb)	2.6	2.6	0.0	*0%*	*-1%*
Irrigation Pumping	192.1	191.8	-0.3	*1%*	*0%*
Riparian ET + Evaporation	226.6	225.4	-1.2	*3%*	*-1%*
Fort Quitman Flow	96.0	88.5	-7.5	*16%*	*-8%*
Change in Storage	-124.0	-79.5	44.5	*-93%*	*-36%*
Total	733.6	769.5	35.9	*-75%*	*5%*
Other Effects of Pumping Stress				*% Chg*	
Rio Grande at El Paso				*Stress*	*% Diff.*
Reservoir Spills	49.4	49.6	0.2	*0%*	*0%*
Nov-Feb Flows	22.8	22.5	-0.3	*1%*	*-1%*
Mar - Oct Flows	263.8	263.9	0.1	*0%*	*0%*
Total	336.0	336.0	0.1	*0%*	*0%*
Rio Grande below Caballo					
Reservoir Spills	65.9	65.7	-0.1	*0%*	*0%*
Nov-Feb Flows	0.5	0.3	-0.2	*0%*	*-43%*
Mar - Oct Flows	541.3	541.7	0.4	*-1%*	*0%*
Total	607.6	607.7	0.1	*0%*	*0%*
Surface Water Diversions (Mar - Oct)					
EBID	366.5	366.7	0.3	*-1%*	*0%*
EPCWID (incl. EPW)	236.8	237.5	0.7	*-2%*	*0%*
HCCRD	67.5	66.1	-1.5	*3%*	*-2%*
Total	670.8	670.3	-0.5	*1%*	*0%*
Surface Water Diversions (Nov - Feb)					
EBID	0.0	0.0	0.0	*0%*	*0%*
EPCWID (incl. EPW)	14.3	14.3	0.0	*0%*	*0%*
HCCRD	14.2	13.3	-0.9	*2%*	*-6%*
Total	28.5	27.7	-0.9	*2%*	*-3%*

Run 10 - MX Non-Irrigation Pumping Off

Annual Differences in ILRG Model Outputs

Run 10 minus Run 1

1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1940	3	3	-154	465	-246	79	-13	-13	464	514	-223	-223	-4,020	-3,820	144
1941	-110	-110	-662	84	-255	34	0	1	-34	97	-223	-157	3,492	2,242	4,426
1942	-4	-4	-302	480	108	100	3	4	-273	116	70	87	-682	492	3,928
1943	6	6	-310	268	45	159	-10	-10	-257	-158	78	236	-1,902	-1,842	210
1944	14	14	-294	87	-215	-113	-7	-7	154	240	-178	-70	-2,066	-2,001	23
1945	11	11	-224	208	-258	-53	-8	-8	148	258	-239	-85	-2,041	-2,004	-74
1946	5	5	-299	319	-157	29	-11	-11	101	389	-156	-203	-2,077	-2,041	-57
1947	8	8	-552	-6	-189	-166	-10	-10	-89	261	-159	-170	-2,331	-2,289	-249
1948	13	13	-398	130	-181	-63	-8	-8	61	295	-76	-45	-2,302	-2,263	-630
1949	13	13	-192	383	-193	19	-5	-5	239	367	13	28	-2,220	-2,190	-503
1950	1	1	-286	-97	-116	17	-6	-6	97	97	12	21	-2,051	-2,013	586
1951	1,018	1,018	-123	-139	-97	-98	554	555	224	224	-73	-68	-1,130	-1,431	-453
1952	172	172	146	137	9	9	315	314	237	235	7	42	-4,893	-3,444	-65
1953	157	157	-84	-85	-99	-74	960	959	256	255	-60	-41	-1,209	-2,102	-837
1954	1,308	1,308	1,060	840	316	99	4,685	4,685	4,299	4,298	265	136	-412	4,551	961
1955	8,538	8,538	6,125	5,932	-793	-1,045	4,405	4,405	4,220	4,166	-746	-880	18,980	9,096	306
1956	-3,239	-3,239	-1,878	-1,878	-494	-515	-2,376	-2,376	-1,642	-1,753	-683	-703	-5,511	-2,335	2
1957	-6	-6	102	101	61	-36	-13	-13	-119	-174	-21	-116	79	14	0
1958	-3	-3	807	785	91	-30	5	5	123	68	-19	-13	5	839	-197
1959	-1	-1	433	444	-1,165	-2,028	6	6	16	16	4	14	297	462	-2,015
1960	1	1	364	438	-461	-681	-2	-2	163	163	0	0	-1,890	-1,625	-965
1961	1	1	177	304	-374	-477	-4	-4	807	807	-116	223	-2,950	-2,641	-452
1962	0	0	344	462	-339	-469	-8	-8	264	264	40	157	-3,412	-3,184	-585
1963	4,694	4,694	340	520	-559	-699	2,615	2,615	450	451	-318	-320	-740	-2,562	76
1964	4,098	4,098	2,985	3,194	-69	-118	2,402	2,402	1,862	1,689	25	15	4,244	2,564	-973
1965	1,340	1,340	838	840	103	-351	626	626	-15	-148	-50	-473	614	1,284	36
1966	-7	-7	564	850	-819	-1,633	47	47	5	5	-969	-98	-969	76	-1,004
1967	1,308	1,308	1,282	1,425	-183	-309	784	784	533	430	-775	-536	554	269	-406
1968	831	831	283	305	220	-87	615	615	80	-27	198	312	418	528	-222
1969	0	0	566	619	-455	-1,127	44	44	2	2	-497	-364	-597	-123	-901
1970	-1	-1	681	730	-629	-1,358	10	10	3	3	308	491	-907	-688	-1,767
1971	1,289	1,289	375	582	-665	-797	827	827	182	182	-419	-285	-108	-544	-400
1972	-4,722	-4,722	-3,322	-3,305	-474	-737	594	594	-1,532	-1,571	-441	-687	-9,520	-3,062	163
1973	-2	-2	1,267	1,265	-555	-572	-302	-302	-171	-218	-655	-547	4,867	1,081	9
1974	7	7	927	905	16	-66	-74	-74	66	66	-53	-188	604	86	-465
1975	-10	-10	832	856	627	579	71	71	3	3	584	560	120	3	-141
1976	-2	-2	952	986	997	985	143	143	59	59	-4	-15	-116	-173	582
1977	2,364	2,364	688	966	11	-156	1,493	1,493	158	158	-54	-185	1,254	198	42
1978	1,319	1,319	940	1,129	189	-1,010	728	728	516	516	131	-1,130	1,701	1,358	206

Run 10 - MX Non-Irrigation Pumping Off
Annual Differences in ILRG Model Outputs
Run 10 minus Run 1
1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1979	9	9	584	790	221	-1,222	25	25	-42	-42	49	-1,442	978	1,292	65
1980	-4	-4	1,162	1,197	-1,776	-4,534	14	14	0	0	-1,055	-1,613	531	787	-4,135
1981	-1	-1	1,122	1,137	-3,504	-6,660	-12	-12	-2	-2	287	287	1,029	994	-7,234
1982	-3	-3	1,094	1,110	-2,613	-4,142	9	9	0	0	-43	1,617	1,178	1,153	-5,834
1983	-4	-4	1,185	1,203	-1,573	-2,636	11	11	0	0	0	0	1,184	1,263	-3,619
1984	-7	-7	1,790	1,810	-749	-1,912	10	10	0	0	0	0	2,456	2,305	-2,039
1985	22	22	2,268	2,272	-4,681	-5,751	1,550	1,549	296	255	0	0	-5,152	-4,601	-5,735
1986	14	14	1,835	1,853	-1,201	-2,186	90	90	-13	-13	0	0	-399	-593	-9,577
1987	8	8	1,767	1,778	-1,387	-2,360	3	3	-4	-4	0	0	-4	-130	-67,805
1988	-2	-2	2,437	2,449	-1,184	-2,154	12	12	1	1	0	0	1,607	1,531	-7,888
1989	-5	-5	3,099	3,074	-1,016	-1,980	22	22	71	-6	0	0	4,285	4,021	-5,392
1990	-40	-40	3,135	3,062	440	-623	156	156	72	-76	0	0	2,986	3,407	-2,116
1991	-47	-47	2,997	2,935	-1,530	-2,531	-144	-144	5	-48	0	0	2,782	2,808	-7,353
1992	-367	-367	2,573	2,551	-3,455	-4,556	1,725	1,726	-246	-246	0	0	2,406	1,009	-14,524
1993	-183	-183	923	881	-2,052	-3,218	115	115	-1,524	-1,526	0	0	-12,942	-11,251	-25,494
1994	-203	-203	947	896	-2,094	-3,438	-23	-23	-970	-972	0	0	-4,963	-3,882	-20,135
1995	-287	-287	1,076	1,064	-2,264	-3,756	101	101	-900	-838	0	0	7,215	5,918	-11,530
1996	-33	-33	3,381	3,316	-1,636	-2,788	344	344	32	32	0	0	766	1,649	-9,785
1997	-4	-4	2,537	2,789	-2,053	-3,492	3	3	162	702	0	0	1,481	1,505	-9,453
1998	-5	-5	2,349	2,242	-1,981	-3,231	17	17	-357	-272	0	0	1,251	1,253	-8,242
1999	-69	-69	90	20	-2,701	-3,980	5	5	-1,339	-1,294	0	0	0	179	-8,171
2000	-3	-3	3,621	3,543	-2,356	-3,643	14	14	1,118	1,118	0	0	4,173	3,877	-8,345
2001	-10	-10	1,330	1,255	-2,768	-4,029	5	5	1	1	0	0	1,554	1,546	-8,225
2002	-7	-7	1,127	1,050	-2,732	-4,027	7	7	3	2	0	0	1,397	1,375	-10,153
2003	-6,085	-6,085	-327	-463	-2,925	-4,179	-3,695	-3,695	-417	-419	0	0	-3,391	-1,207	-15,266
2004	-1,819	-1,819	-1,429	-1,560	-3,181	-4,585	-1,160	-1,160	-513	-514	0	0	-1,782	-1,905	-16,014
2005	-58	-58	38	-56	-3,324	-4,799	-99	-99	-68	-69	0	0	1,110	183	-10,936
2006	-1,098	-1,098	-2,202	-2,325	-3,411	-4,759	-585	-585	-1,363	-1,364	0	0	-4,167	-3,135	-9,904
2007	-880	-880	156	42	-3,421	-4,825	-497	-497	714	713	0	0	1,266	482	-14,871
2008	1,097	1,097	-1,520	-1,644	-2,289	-3,446	737	737	-377	-377	0	0	-1,241	-1,360	-9,883
2009	1,732	1,732	-922	-1,050	-3,179	-4,435	666	666	-195	-195	0	0	-125	-631	-7,422
2010	2,796	2,796	-868	-990	-3,040	-4,194	1,846	1,846	-5	-5	0	0	357	-486	-7,871
2011	1,737	1,737	296	182	1,617	-347	929	929	1,018	1,018	0	0	1,968	821	-7,858
2012	-5	-5	192	76	468	-1,081	108	108	1,615	1,615	0	0	614	399	-14,424
2013	-1,147	-1,147	-268	-380	-4,022	-4,980	-625	-625	1,172	1,172	-2,418	-2,710	-397	-27	-19,363
2014	773	773	-1,407	-1,520	-3,409	-2,989	741	741	216	216	-4,122	-3,947	-241	-1,012	-16,029
2015	-603	-603	-3,312	-3,433	-6,397	-8,128	-794	-794	-7	-7	753	645	-4,661	-3,120	-30,741
2016	-555	-555	2,429	2,298	-5,537	-7,591	-115	-115	4,186	4,187	0	0	6,748	3,557	-27,554
2017	3,353	3,353	-4,895	-5,038	-5,003	-6,610	2,018	2,018	-274	-274	0	0	-4,347	-4,956	-21,492
Averages															
1951-2017	275	275	717	711	-1,482	-2,367	339	339	196	189	-163	-177	103	52	-7,490
1951-1978	730	730	631	686	-200	-457	684	684	395	363	-157	-168	-22	-54	-338
1979-2005	-340	-340	1,582	1,563	-2,077	-3,423	-33	-33	-172	-157	-28	-43	435	536	-11,294
2006-2017	600	600	-1,027	-1,149	-3,135	-4,449	369	369	558	558	-482	-501	-352	-789	-15,618
1985-2017	-60	-60	711	641	-2,536	-3,779	105	105	64	76	-175	-182	5	-84	-14,229
1985-2005	-437	-437	1,704	1,664	-2,194	-3,396	-45	-45	-219	-199	0	0	209	319	-13,435

Notes:

EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

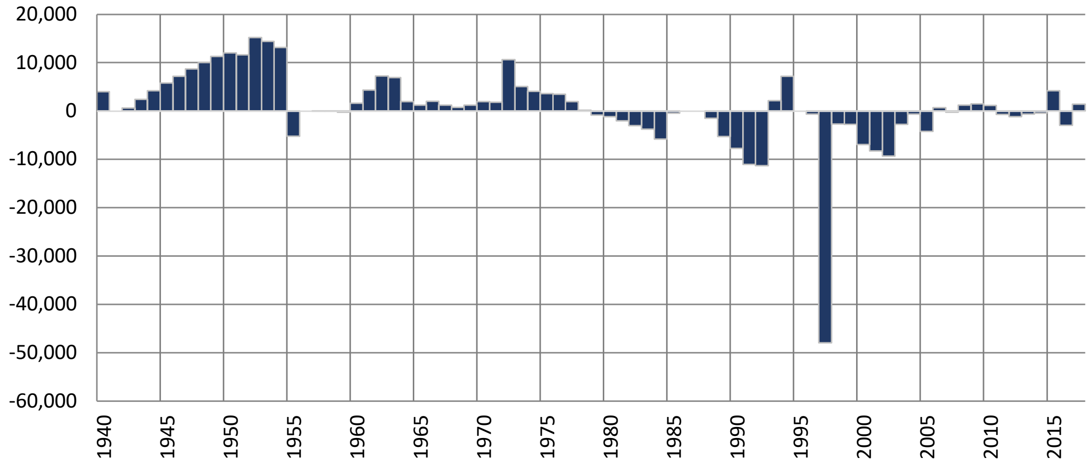
Run 10 - MX Non-Irrigation Pumping Off

Simulated Differences in ILRG Model Outputs

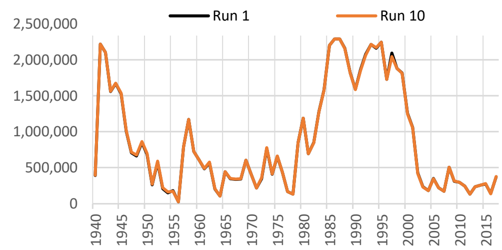
Run 10 minus Run 1

1940 - 2017 (acre-feet)

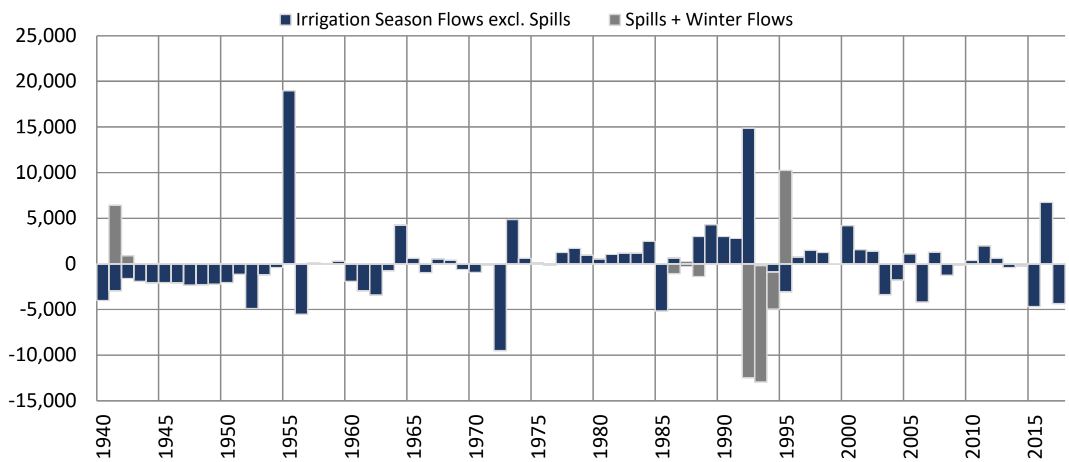
Total Project Storage (Year End)



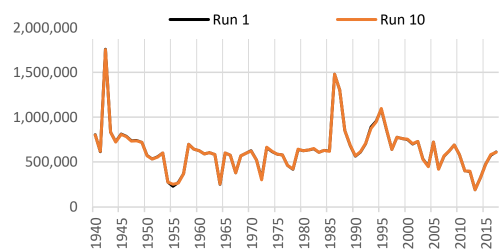
Period	Average Difference
1951-2017	-158
1951-1978	-425
1979-2005	-160
2006-2017	469
1985-2017	220
1985-2005	78



Caballo Reservoir Outflows (Annual)



	Average Difference		
Period	Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	419	-317	103
1951-1978	-22	0	-22
1979-2005	1,220	-785	435
2006-2017	-352	0	-352
1985-2017	647	-643	5
1985-2005	1,218	-1,010	209



Notes:

Reservoir storage does not include storage attributed to SJC, CO, or NM credit waters.

Average differences calculated as (Final Storage - Initial Storage)/(no. years).

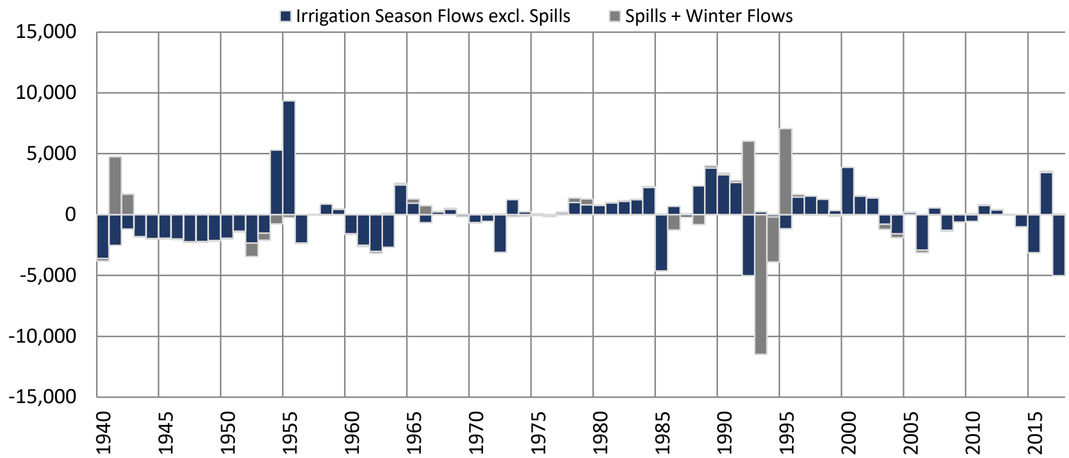
Run 10 - MX Non-Irrigation Pumping Off

Simulated Differences in ILRG Model Outputs

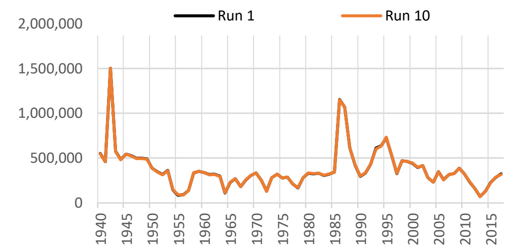
Run 10 minus Run 1

1940 - 2017 (acre-feet)

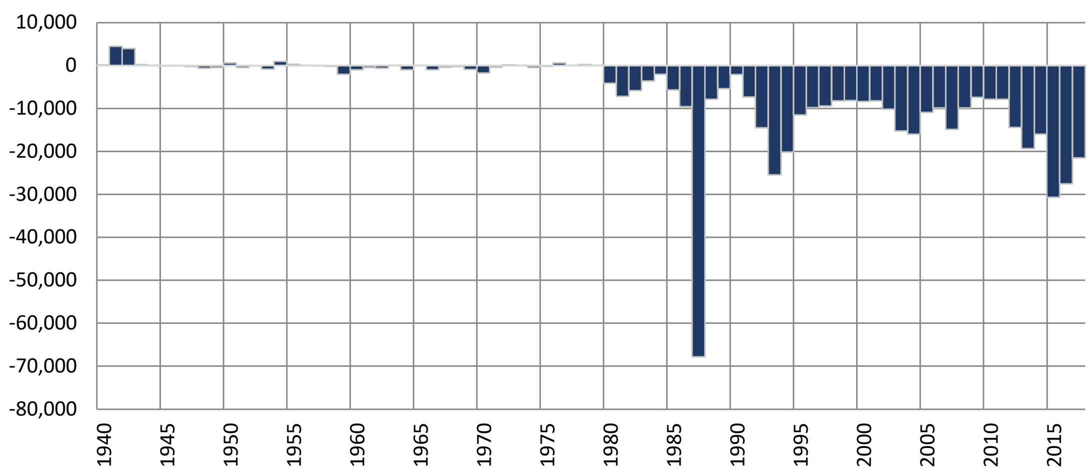
Rio Grande at El Paso (Annual)



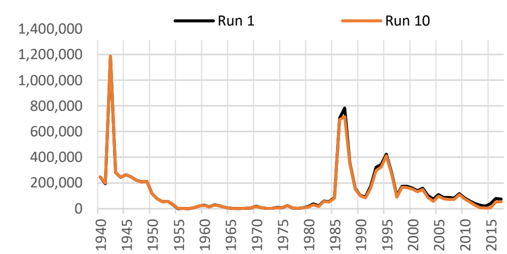
Period	Average Difference Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	130	-78	52
1951-1978	3	-57	-54
1979-2005	667	-131	536
2006-2017	-781	-8	-789
1985-2017	47	-131	-84
1985-2005	520	-201	319



Rio Grande at Fort Quitman (Annual)



Period	Average Difference
1951-2017	-7,487
1951-1978	-340
1979-2005	-11,290
2006-2017	-15,609
1985-2017	-14,224
1985-2005	-13,433



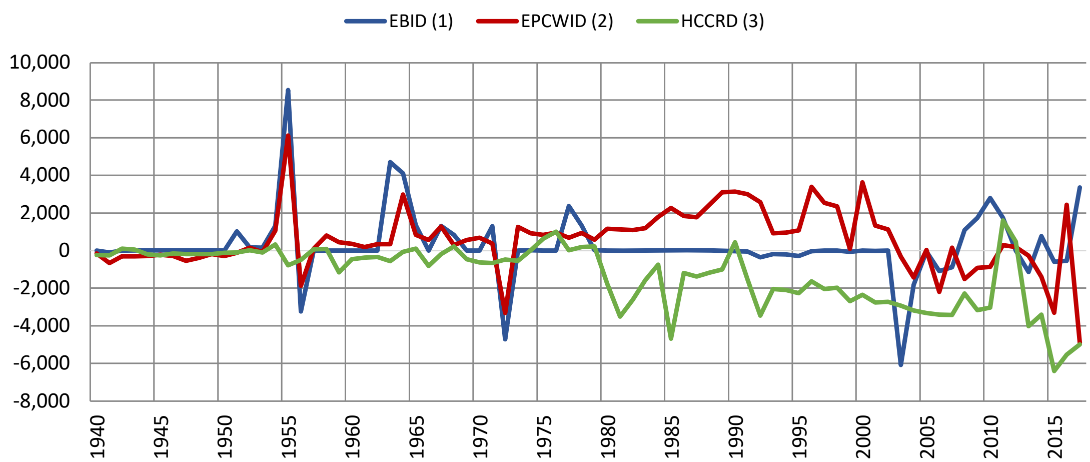
Run 10 - MX Non-Irrigation Pumping Off

Simulated Differences in ILRG Model Outputs

Run 10 minus Run 1

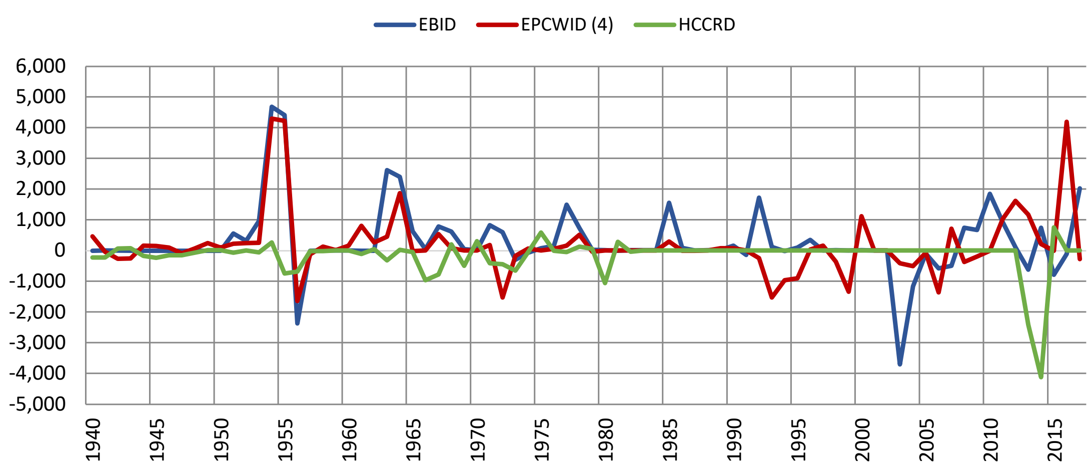
1940 - 2017 (acre-feet)

River Headgate (RHG) Diversions (Irrigation Season)



	Average Difference		
Period	EBID	EPCWID	HCCRD
1951-2017	275	717	-1,482
1951-1978	730	631	-200
1979-2005	-340	1,582	-2,077
2006-2017	600	-1,027	-3,135
1985-2017	-60	711	-2,536
1985-2005	-437	1,704	-2,194

Farm Headgate (FHG) Deliveries (Irrigation Season)



	Average Difference		
Period	EBID	EPCWID	HCCRD
1951-2017	339	196	-163
1951-1978	684	395	-157
1979-2005	-33	-172	-28
2006-2017	369	558	-482
1985-2017	105	64	-175
1985-2005	-45	-219	0

Notes:

(1) EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

(2) EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

(3) HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

(4) EPCWID FHG values include deliveries to Rogers WTP and R/U WTP.

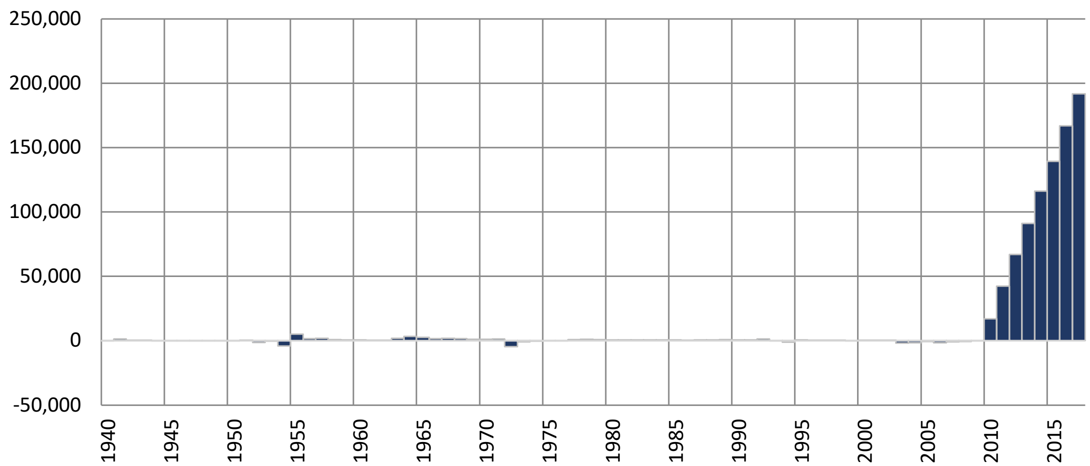
Run 10 - MX Non-Irrigation Pumping Off

Simulated Differences in ILRG Model Outputs

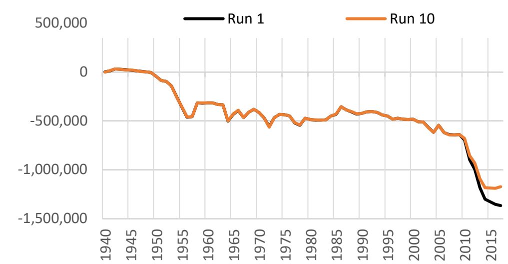
Run 10 minus Run 1

1940 - 2017 (acre-feet)

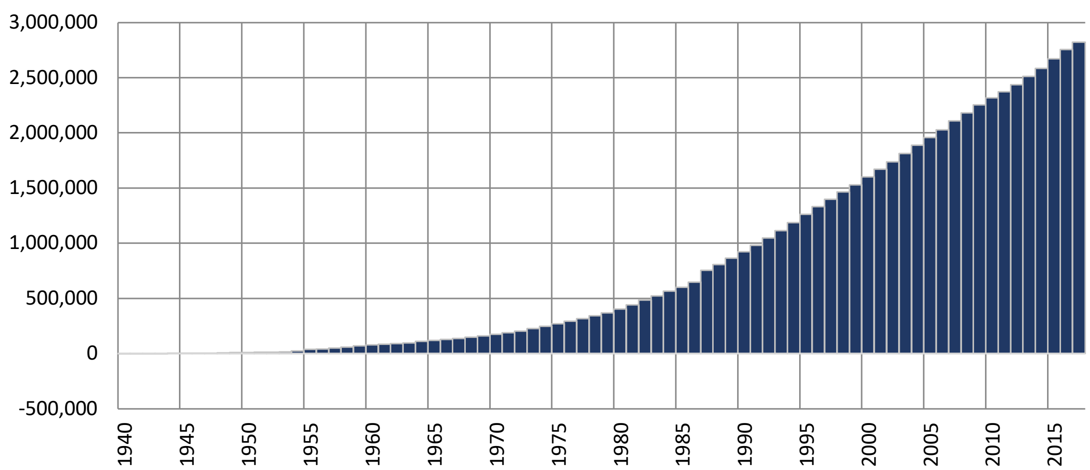
Cumulative Annual Rincon-Mesilla Groundwater Storage



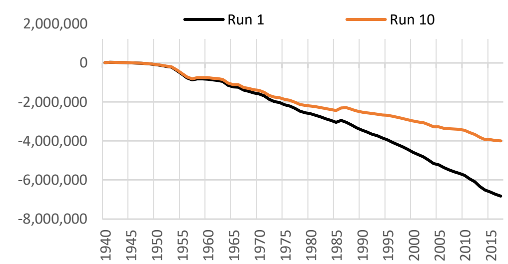
Period	Average Difference
1951-2017	2,863
1951-1978	41
1979-2005	-69
2006-2017	16,044
1985-2017	5,794
1985-2005	-63



Cumulative Annual Hueco Groundwater Storage



Period	Average Difference
1951-2017	42,005
1951-1978	11,923
1979-2005	59,878
2006-2017	71,980
1985-2017	68,434
1985-2005	66,408



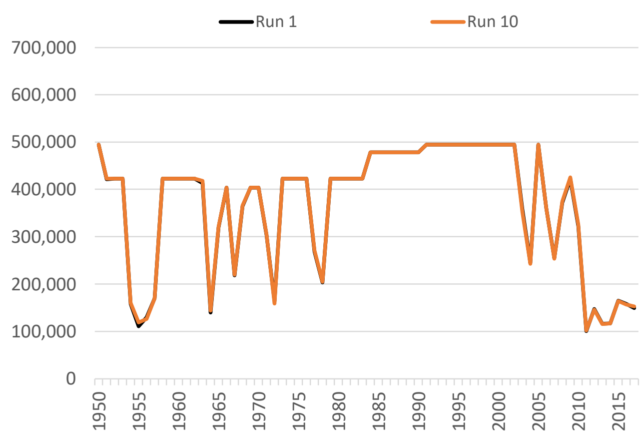
Notes:

Cumulative storage change in alluvial and non-alluvial aquifers.

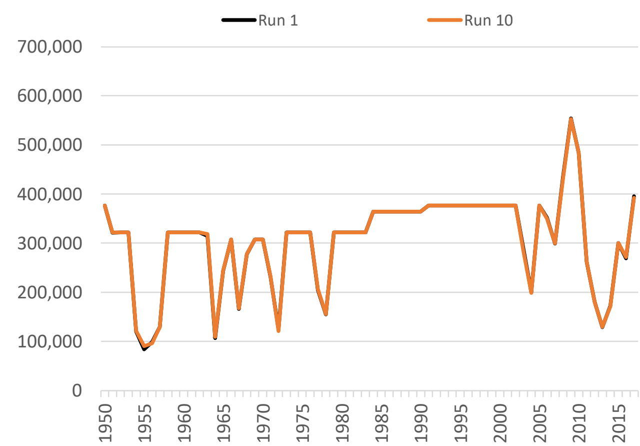
Average differences calculated as (Final Storage - Initial Storage)/(no. years).

Run 10 - MX Non-Irrigation Pumping Off
Annual Allocation and Charges
Run 10 v. Run 1
ILRG Model
1950 - 2017 (acre-feet)

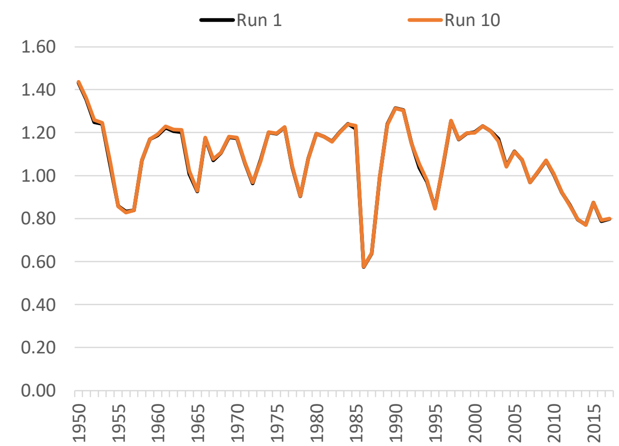
Total Allocation - EBID



Total Allocation - EPCWID

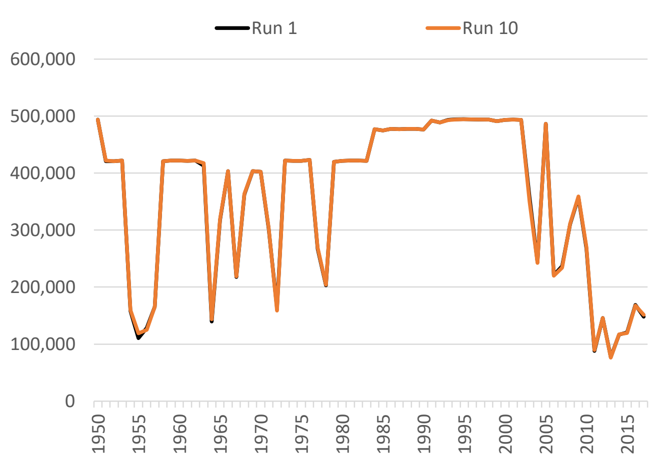


Diversion Ratio

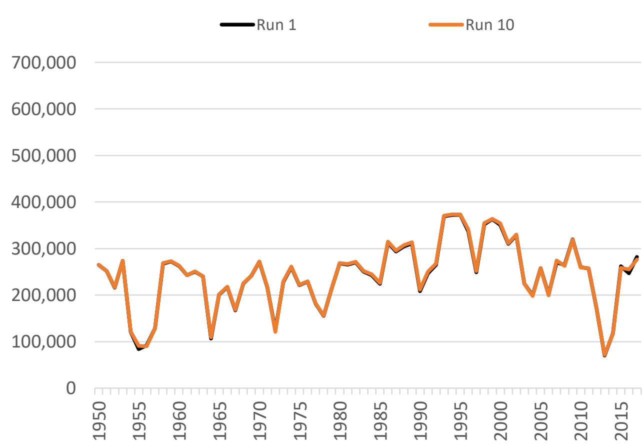


Note:
Computed as Total Charges/Caballo Release.

Annual Delivery Charges - EBID



Annual Delivery Charges - EPCWID



Run 10 - MX Non-Irrigation Pumping Off

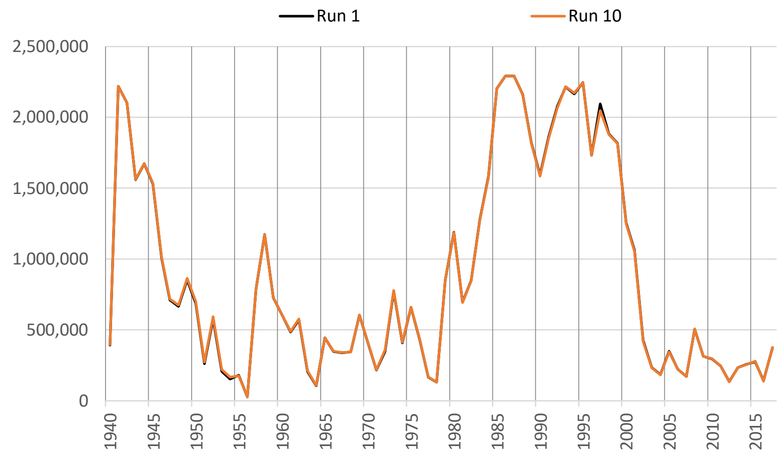
Annual Summary of Project Storage and Rio Grande Flows

Run 10 v. Run 1

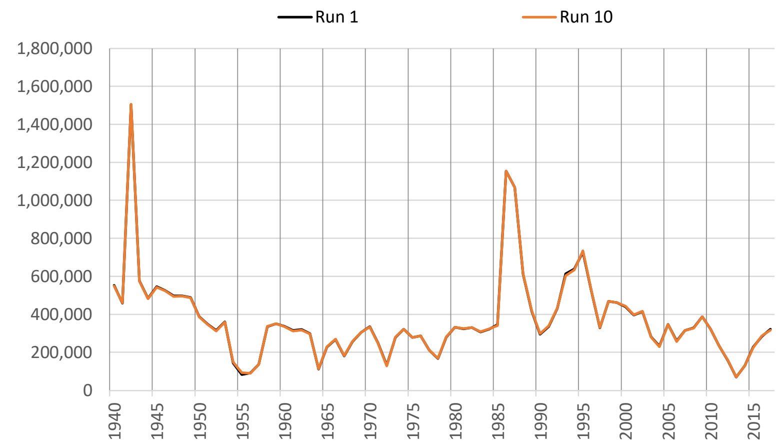
ILRG Model

1940 - 2017 (acre-feet)

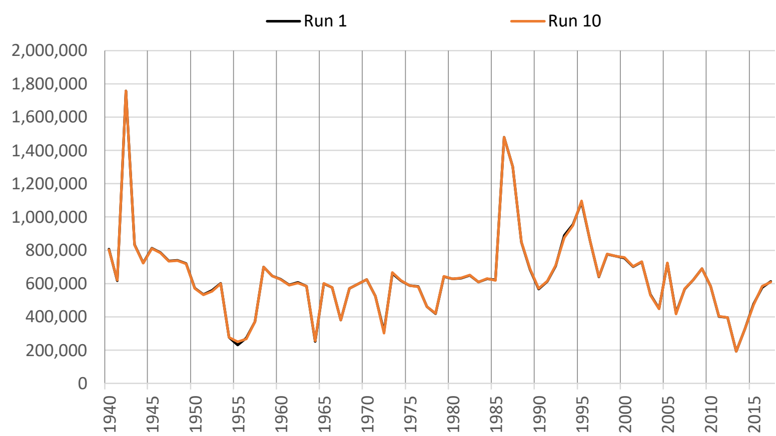
Total Year-End Project Reservoir Storage



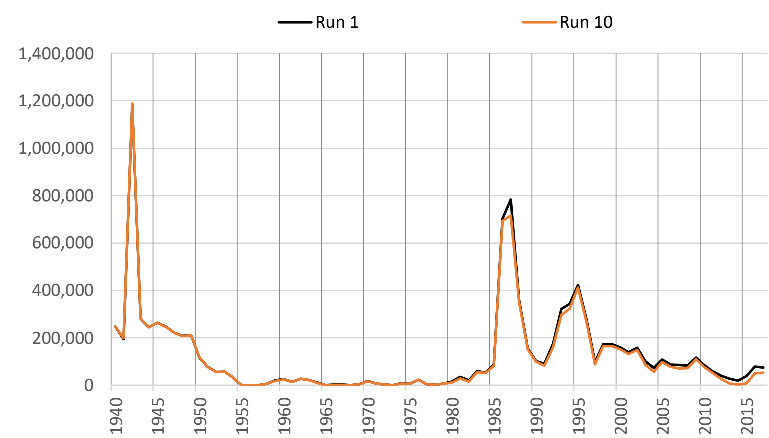
Rio Grande at El Paso



Rio Grande Below Caballo



Rio Grande at Fort Quitman



***Note different scales.**

Run 10 - MX Non-Irrigation Pumping Off

Irrigation Season Summary of Irrigation Operations

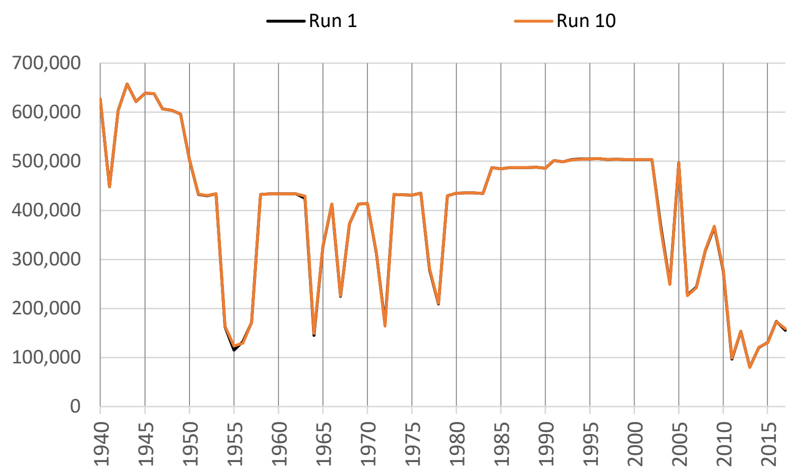
Run 10 v. Run 1

ILRG Model

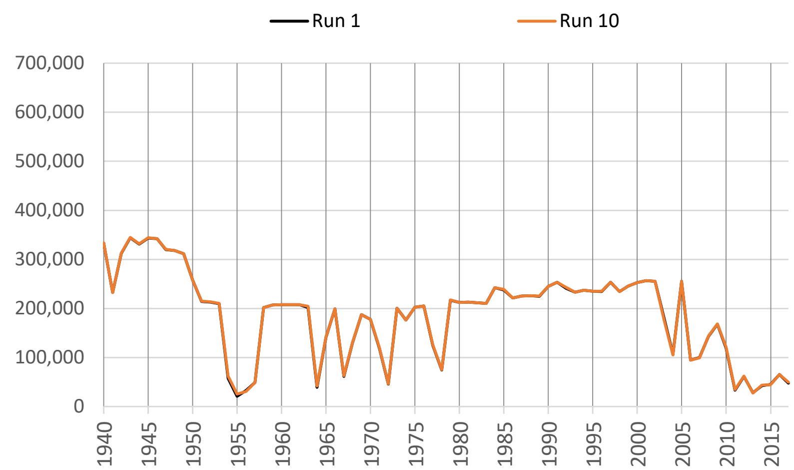
1940 - 2017 (acre-feet)

EBID Total

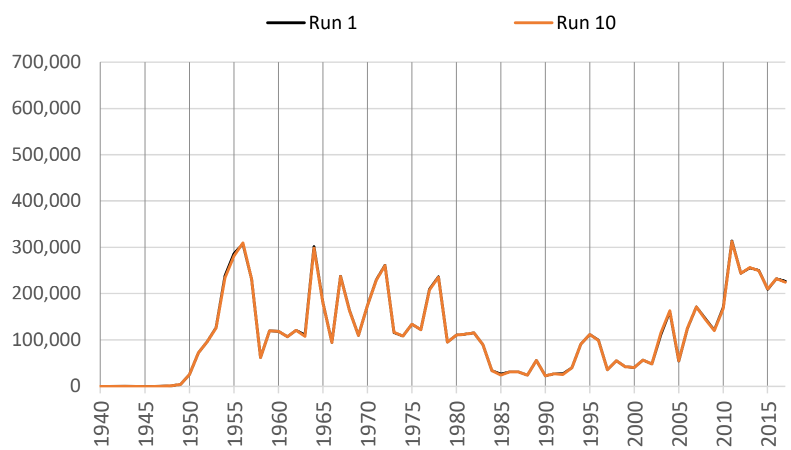
Net River Headgate Diversions



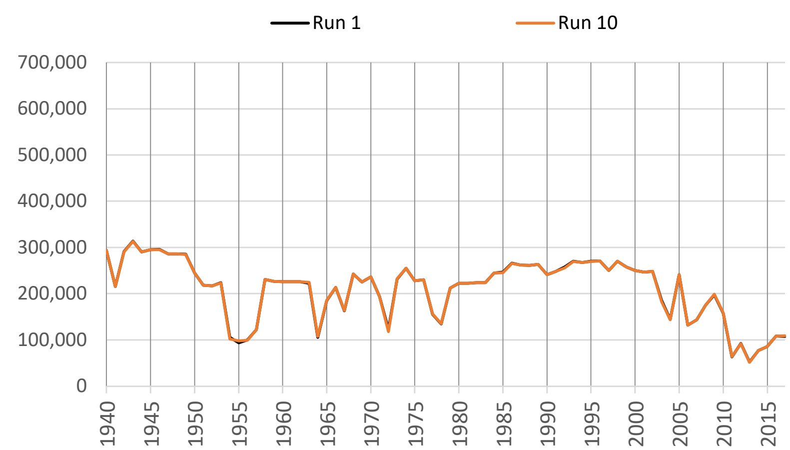
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries



Notes: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).
Pumping includes Supplemental and Primary groundwater pumping.

Run 10 - MX Non-Irrigation Pumping Off

Irrigation Season Summary of Irrigation Operations

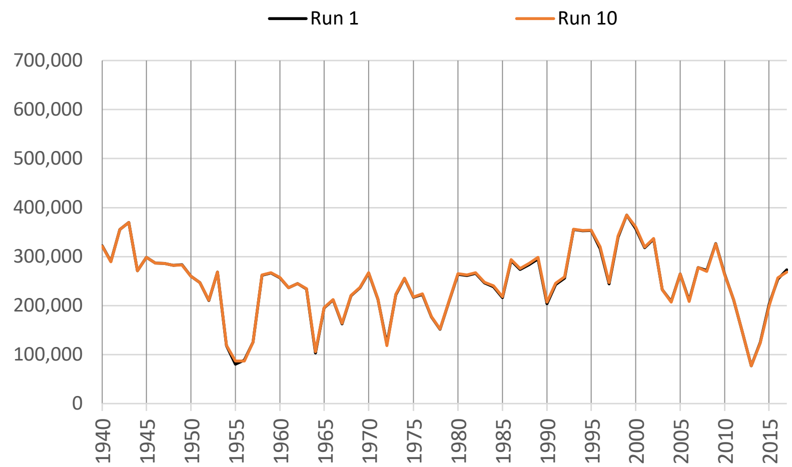
Run 10 v. Run 1

ILRG Model

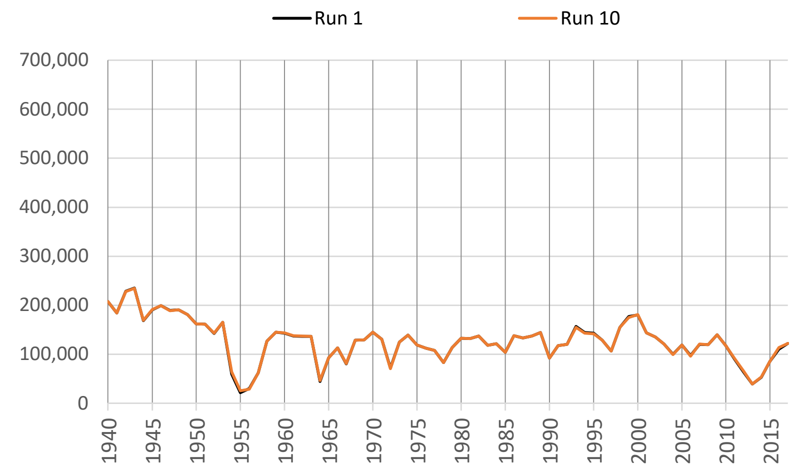
1940 - 2017 (acre-feet)

EPCWID Total

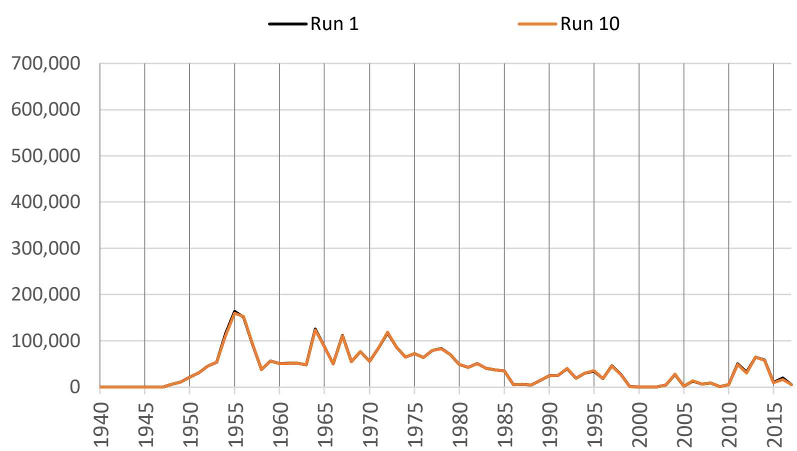
Net River Headgate Diversions



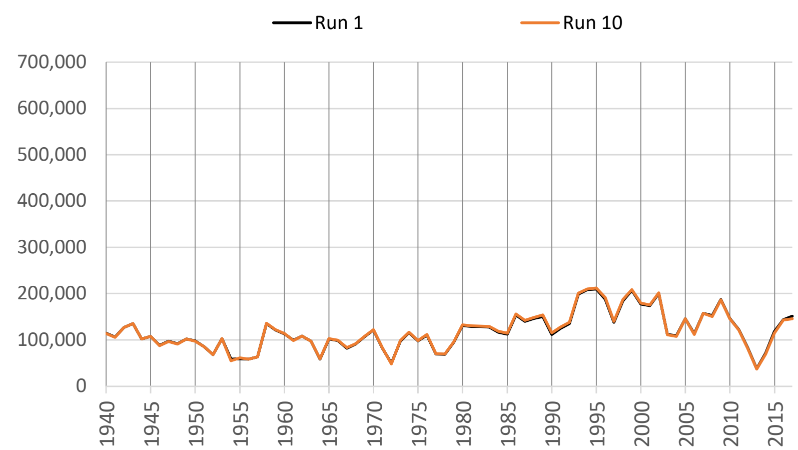
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries

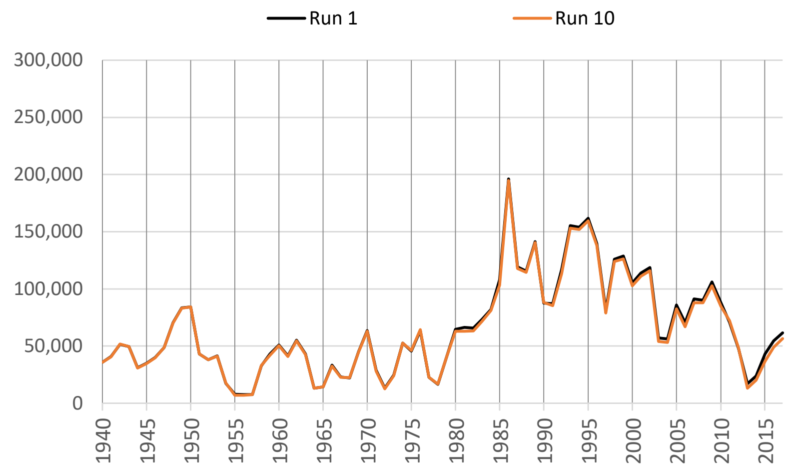


Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

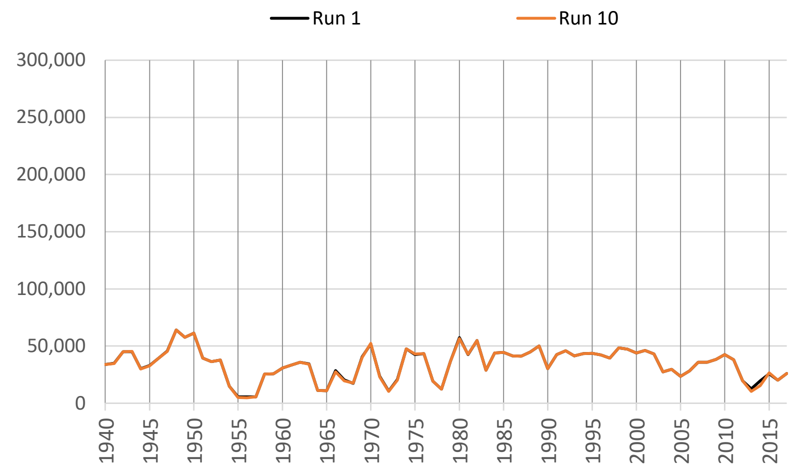
Run 10 - MX Non-Irrigation Pumping Off
Irrigation Season Summary of Irrigation Operations
Run 10 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

HCCRD Total

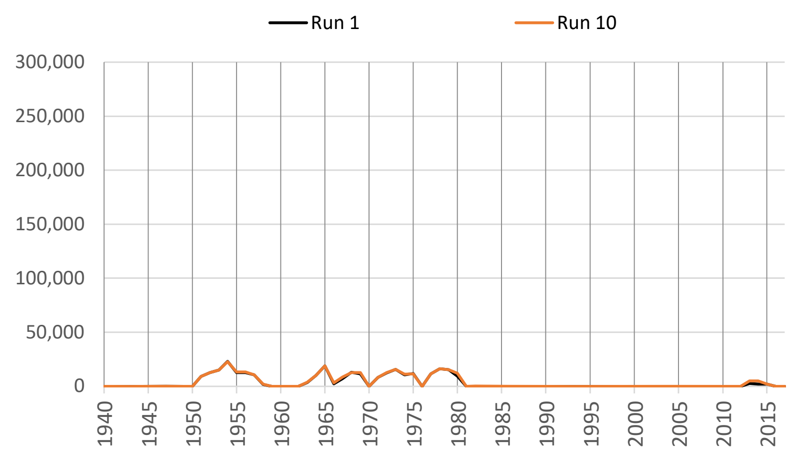
Net River Headgate Diversions



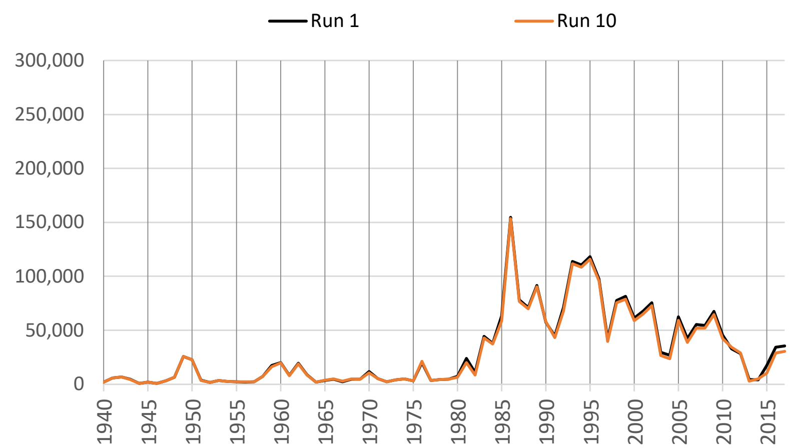
Farm Headgate Deliveries



Pumping



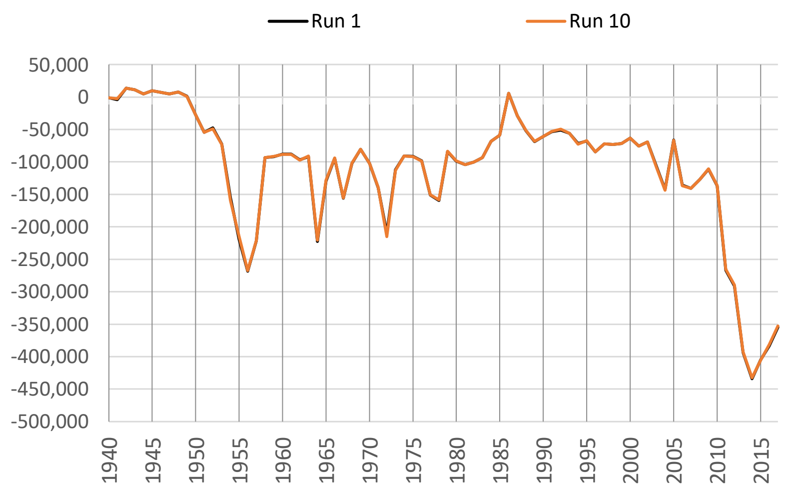
RHG Diversions - FHG Deliveries



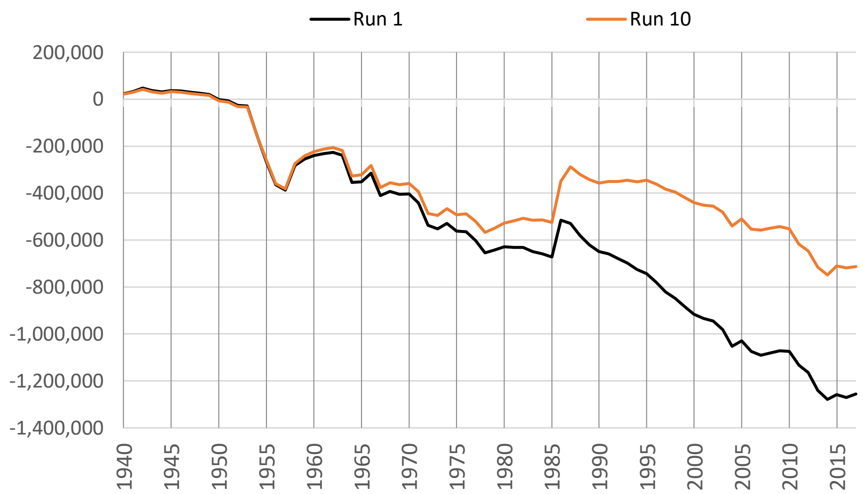
Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

Run 10 - MX Non-Irrigation Pumping Off
Cumulative Change in Ground Water Storage
Run 10 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

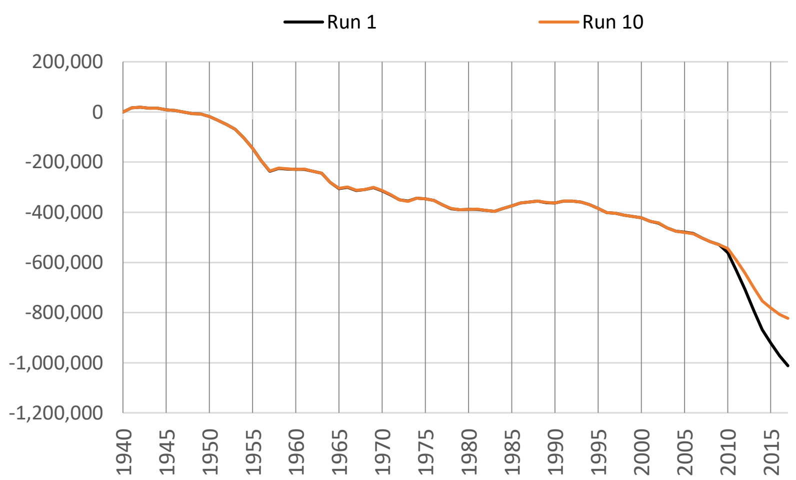
Rincon-Mesilla Alluvial Aquifer



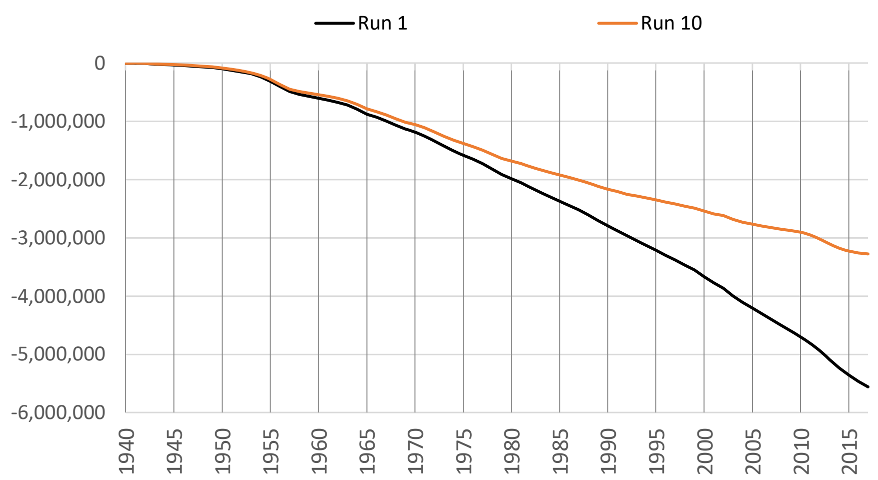
Hueco Alluvial Aquifer



Rincon-Mesilla Non-Alluvial Aquifer

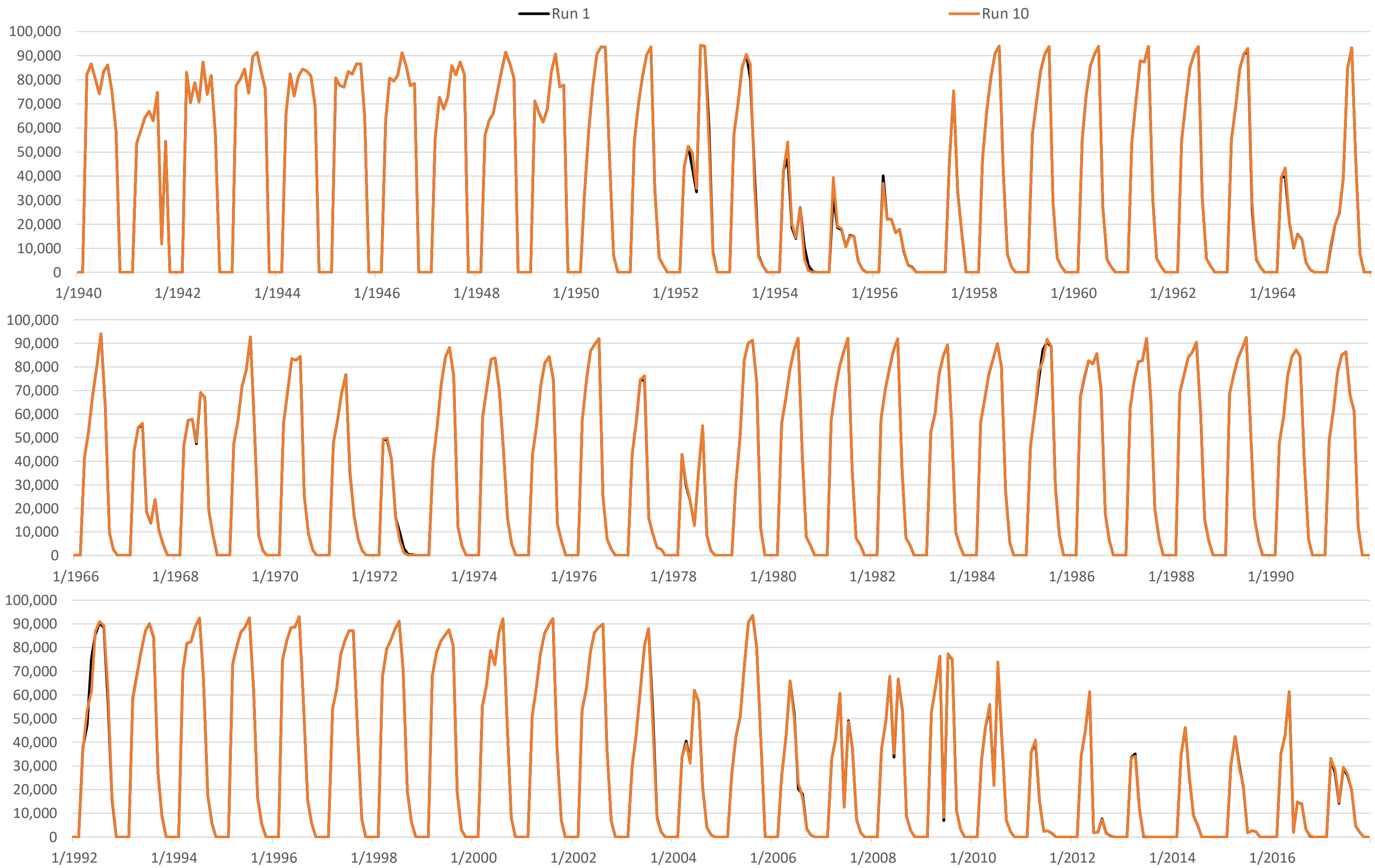


Hueco Non-Alluvial Aquifer



***Note different scales.**

Run 10 - MX Non-Irrigation Pumping Off
Monthly Net RHG Diversions
Run 10 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
EBID Total



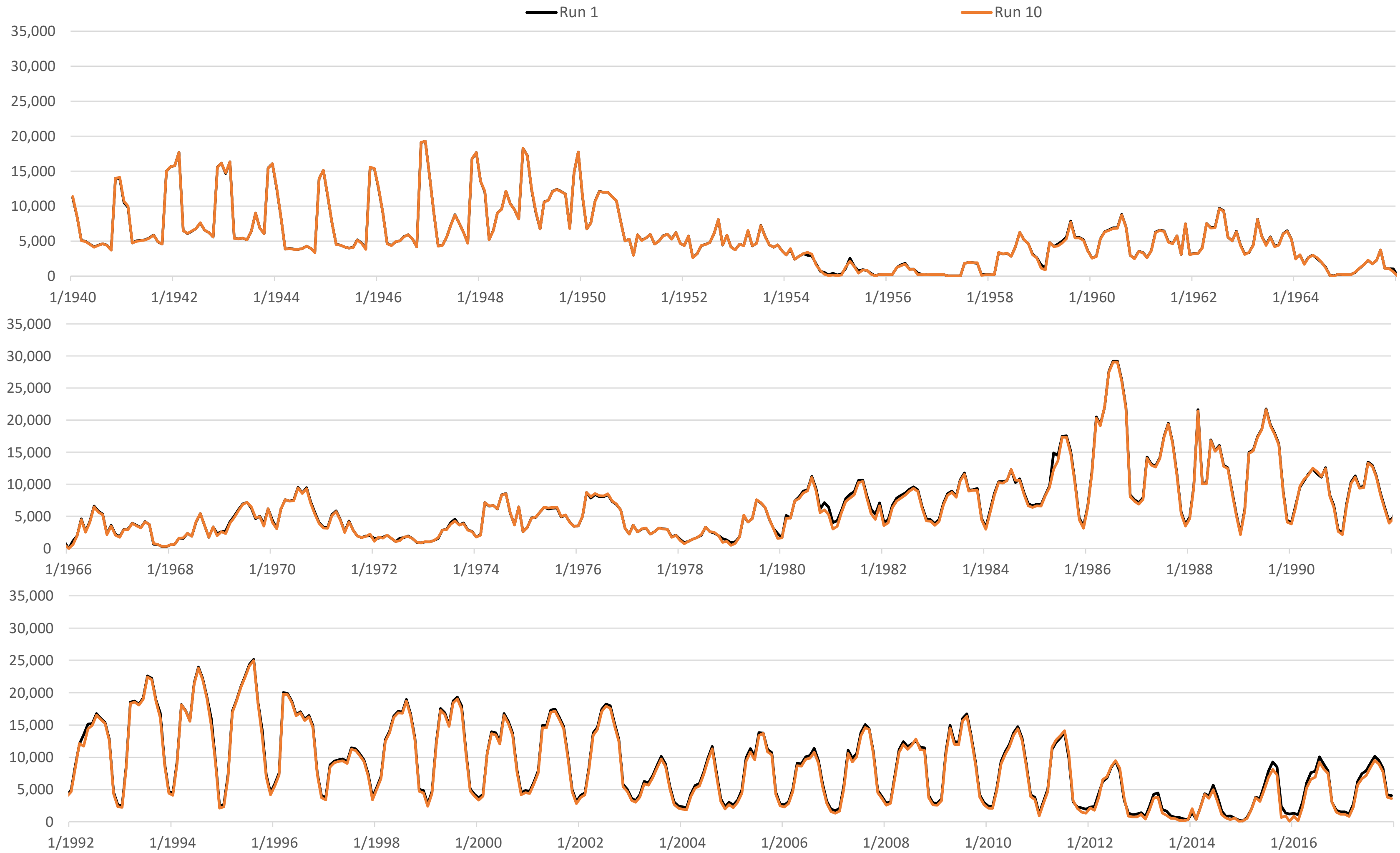
Note: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

Run 10 - MX Non-Irrigation Pumping Off
Monthly Net RHG Diversions
Run 10 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

EPCWID Total

Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

Run 10 - MX Non-Irrigation Pumping Off
Monthly Net RHG Diversions
Run 10 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
HCCRD Total



Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

Run 10 - MX Non-Irrigation Pumping Off
End of Month Reservoir Storage (Elephant Butte + Caballo)
Run 10 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

Run 10 - MX Non-Irrigation Pumping Off
Monthly Caballo Releases
Run 10 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

Run 10 - MX Non-Irrigation Pumping Off
Monthly Rio Grande at El Paso Flow
Run 10 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

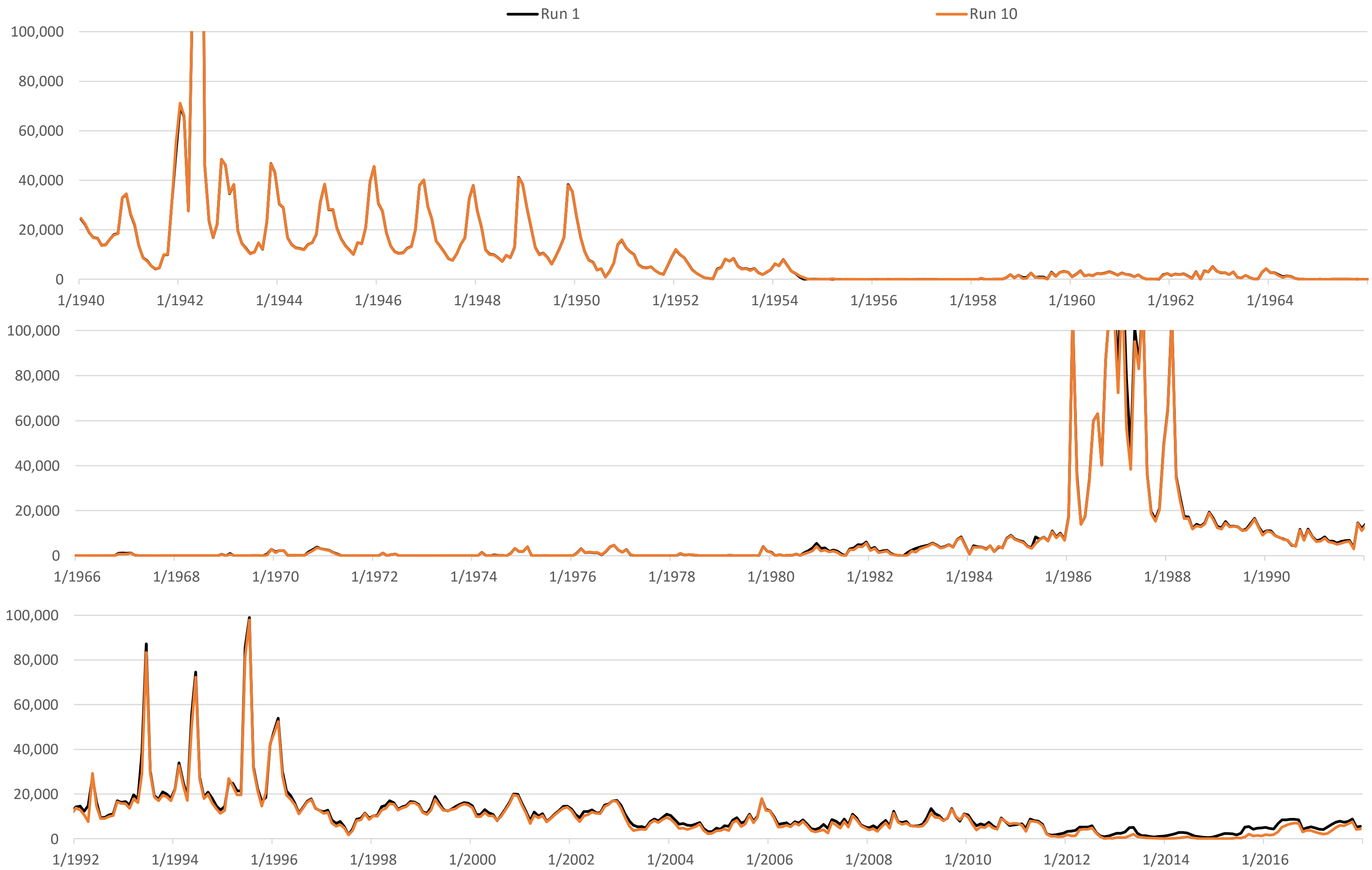
Run 10 - MX Non-Irrigation Pumping Off

Monthly Rio Grande at Fort Quitman Flow

Run 10 v. Run 1

ILRG Model

1940 - 2017 (acre-feet)



Appendix 30K

Comparison of ILRG Model Runs
Run 11 v. Run 1

Model Run Specifications

Model Version: LRG_v116

Name: **Run 11 - D1/D2**

Run ID: LRG_v116_Operational_Run11
Date: 8/25/2020

Name: **Run 1 - Historical Base Run (All Pumping On)**

Run ID: LRG_v116_Operational_Run1
Date: 8/23/2020

Selected Model Inputs

Pumping and Returns	Run 11	Run 1
Irrigation Pumping	On	On
Irrigated Area	Hist	Hist
Non-Irrigation Pumping	On	On
Non-Irrigation Pumping Returns	On	On
Las Cruces Jornada Pumping Returns	On	On

Project Allocation Rules		
1950-2005	D1/D2	D1/D2
2006-2007	D1/D2	D3
2008-2017	D1/D2	D3 + CO

EPCWID Operations		
Charge EPCWID for Use of WWTP Returns	Off	Off
ACE and Haskell Credits for EPCWID	On	On
Increased EPCWID Use of Fabens Drain Flows	Off	Off
Charge EPCWID for Fabens Drain Flow Use	Off	Off

Run 11 - D1/D2

Comparison of ILRG Model Runs

Run 11 v. Run 1

2006 - 2017 Annual Average

(1,000 acre-feet)

Run No.	1	11	11 - 1	
Simulated Input or Output	**Run 1**	**Run 11**	**Run 11 minus Run 1**	
Effects of Alternate Scenario				
FHG Deliveries (Mar - Oct)				***% Diff.***
EBID	79.2	133.8	54.6	*69%*
EPCWID (incl. EPW)	138.0	120.8	-17.2	*-12%*
HCCRD	28.6	27.5	-1.0	*-4%*
Total	245.8	282.1	36.4	*15%*
FHG Deliveries (Nov - Feb)				
EBID	0.0	0.0	0.0	*17091%*
EPCWID (incl. EPW)	0.0	0.1	0.0	*80%*
HCCRD	1.1	1.2	0.1	*10%*
Total	1.2	1.3	0.2	*13%*
Irrigation Pumping				
EBID	215.4	164.0	-51.4	*-24%*
EPCWID (Mesilla Valley)	5.3	4.0	-1.4	*-25%*
EPCWID (El Paso Valley)	20.0	29.6	9.7	*48%*
HCCRD	0.6	1.2	0.7	*124%*
Total	241.2	198.8	-42.4	*-18%*
Other Inflows/Outflows				
Net Reservoir Evaporation	97.1	96.7	-0.4	*0%*
Riparian ET	58.0	56.3	-1.7	*-3%*
River Evaporation + Incidental Canal Loss	24.0	26.3	2.3	*10%*
Total	179.2	179.4	0.2	*0%*
Rio Grande at Fort Quitman				
Reservoir Spills	0.0	0.0	0.0	*0%*
Nov-Feb Flows	19.0	25.9	6.9	*36%*
Mar - Oct Flows	46.8	38.6	-8.2	*-18%*
Underflow (GW Model)	0.3	0.3	0.0	*-1%*
Total	66.1	64.8	-1.4	*-2%*

Run 11 - D1/D2
Comparison of ILRG Model Runs
Run 11 v. Run 1
2006 - 2017 Annual Average
(1,000 acre-feet)

Run No.	1	11	11 - 1	
Simulated Input or Output	**Run 1**	**Run 11**	**Run 11 minus Run 1**	
Effects of Alternate Scenario (continued)				
Change in Storage				***% Diff.***
Reservoir Storage	2.1	-8.8	-10.9	*-519%*
Alluvial GW Storage (RW Model)	-42.8	-30.6	12.3	*-29%*
Non-alluvial GW Storage (GW Models)	-157.5	-159.1	-1.6	*1%*
Soil Moisture Storage	-1.6	-0.8	0.8	*-52%*
Total	-199.8	-199.2	0.6	*0%*
Summary of Effects				
FHG Deliveries (Mar-Oct)	245.8	282.1	36.4	*15%*
FHG Deliveries (Nov-Feb)	1.2	1.3	0.2	*13%*
Irrigation Pumping	241.2	198.8	-42.4	*-18%*
Riparian ET + Evaporation	179.2	179.4	0.2	*0%*
Fort Quitman Flow	66.1	64.8	-1.4	*-2%*
Change in Storage	-199.8	-199.2	0.6	*0%*
Total	533.6	527.2	-6.4	*-1%*
Other Effects of Alternate Scenario				
Rio Grande at El Paso				***% Diff.***
Reservoir Spills	0.0	0.0	0.0	*0%*
Nov-Feb Flows	9.2	21.5	12.4	*135%*
Mar - Oct Flows	243.9	212.1	-31.9	*-13%*
Total	253.1	233.6	-19.5	*-8%*
Rio Grande below Caballo				
Reservoir Spills	0.0	0.0	0.0	*0%*
Nov-Feb Flows	0.0	0.0	0.0	*0%*
Mar - Oct Flows	489.2	499.7	10.5	*2%*
Total	489.2	499.7	10.5	*2%*
Surface Water Diversions (Mar - Oct)				
EBID	195.2	289.5	94.2	*48%*
EPCWID (incl. EPW)	220.0	197.1	-23.0	*-10%*
HCCRD	63.7	56.6	-7.1	*-11%*
Total	479.0	543.1	64.1	*13%*
Surface Water Diversions (Nov - Feb)				
EBID	0.0	0.0	0.0	*0%*
EPCWID (incl. EPW)	6.3	7.1	0.7	*12%*
HCCRD	8.7	8.1	-0.6	*-7%*
Total	15.1	15.2	0.1	*1%*

Run 11 - D1/D2
Annual Differences in ILRG Model Outputs
Run 11 minus Run 1
1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1940															
1941															
1942															
1943															
1944															
1945															
1946															
1947															
1948															
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1969															
1970															
1971															
1972															
1973															
1974															
1975															
1976															
1977															
1978															

Run 11 - D1/D2

Annual Differences in ILRG Model Outputs

Run 11 minus Run 1

1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1979															
1980															
1981															
1982															
1983															
1984															
1985															
1986															
1987															
1988															
1989															
1990															
1991															
1992															
1993															
1994															
1995															
1996															
1997															
1998															
1999															
2000															
2001															
2002															
2003															
2004															
2005															
2006	-2,318	-2,318	-21,840	-22,016	-3,624	-4,032	1,147	1,147	-16,792	-16,795	0	0	-40,298	-32,575	-7,891
2007	105,518	105,518	1,611	2,044	-774	-1,064	65,944	65,944	-73	-58	0	0	40,410	727	-3,346
2008	175,741	175,741	-4,880	-4,055	-1,238	-946	110,051	110,084	-4,269	-4,187	0	0	100,466	26,446	24,011
2009	128,086	128,086	-60,467	-58,754	-16,601	-16,208	89,124	89,180	-28,590	-28,501	0	0	-14,061	-23,199	4,308
2010	141,743	141,743	-6,682	-4,476	-551	-52	91,927	91,930	-6,891	-6,821	0	0	4,213	9,211	25,221
2011	37,824	37,824	-104,867	-103,646	-34,648	-38,314	8,843	8,843	-76,777	-76,743	-10,844	-10,982	-135,777	-113,986	-14,325
2012	72,262	72,262	21,557	21,691	-1,824	-5,752	29,618	29,618	13,160	13,174	3,877	3,994	73,942	16,011	-14,434
2013	-64,871	-64,871	-53,898	-53,822	-11,112	-11,127	-22,953	-22,953	-39,147	-39,142	-6,363	-6,601	-150,058	-57,269	-8,516
2014	95,057	95,057	51,805	51,821	7,587	7,963	41,984	41,984	30,982	30,986	4,187	4,956	170,150	52,864	-982
2015	92,044	92,044	-18,815	-18,534	-3,665	-3,260	38,865	38,865	-14,008	-13,996	-3,981	-3,186	21,403	-34,637	3,112
2016	77,151	77,151	-61,804	-61,395	-12,527	-13,555	35,806	35,806	-47,324	-47,309	0	0	-55,466	-73,162	-24,959
2017	272,360	272,360	-17,385	-15,748	-6,295	-6,492	164,455	164,473	-16,423	-16,366	698	715	110,551	-4,466	1,585
Averages															
1951-2017															
1951-1978															
1979-2005															
2006-2017	94,216	94,216	-22,972	-22,241	-7,106	-7,737	54,568	54,577	-17,179	-17,147	-1,035	-925	10,456	-19,503	-1,351
1985-2017															
1985-2005															

Notes:

EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

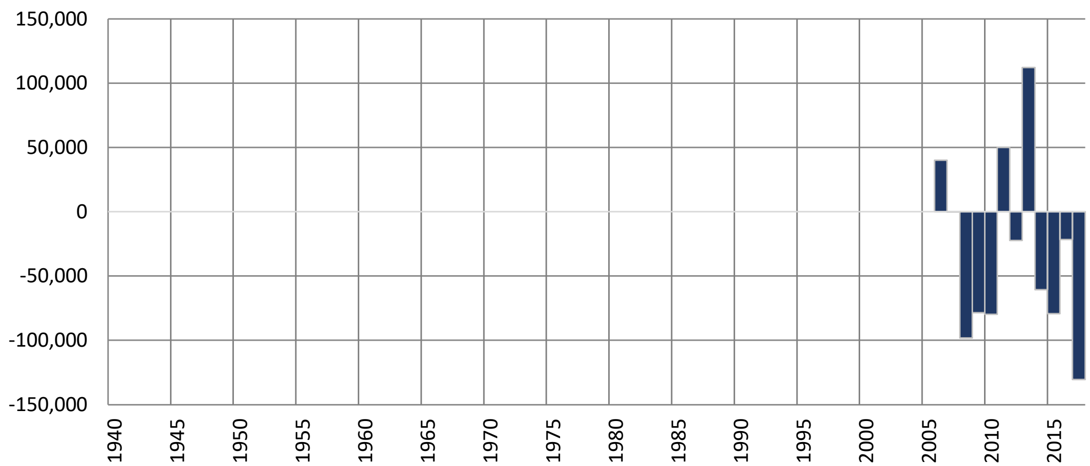
Run 11 - D1/D2

Simulated Differences in ILRG Model Outputs

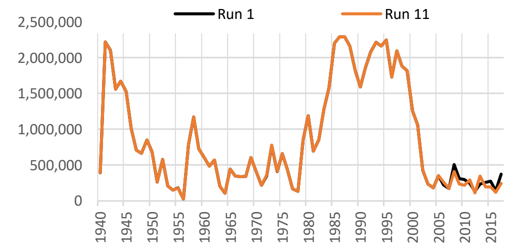
Run 11 minus Run 1

1940 - 2017 (acre-feet)

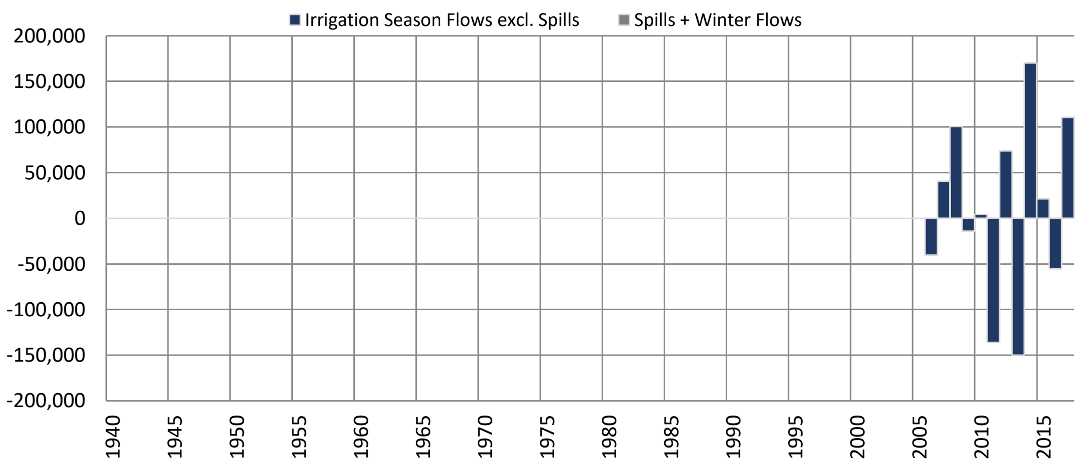
Total Project Storage (Year End)



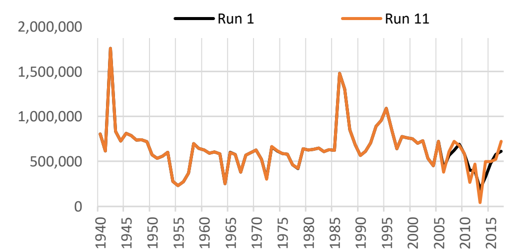
Period	Average Difference
1951-2017	
1951-1978	
1979-2005	
2006-2017	-10,874
1985-2017	
1985-2005	



Caballo Reservoir Outflows (Annual)



Period	Average Difference: Irr Season (excl. Spills)	Average Difference: Nov-Feb and Spills	Annual
1951-2017			
1951-1978			
1979-2005			
2006-2017	10,456	0	10,456
1985-2017			
1985-2005			



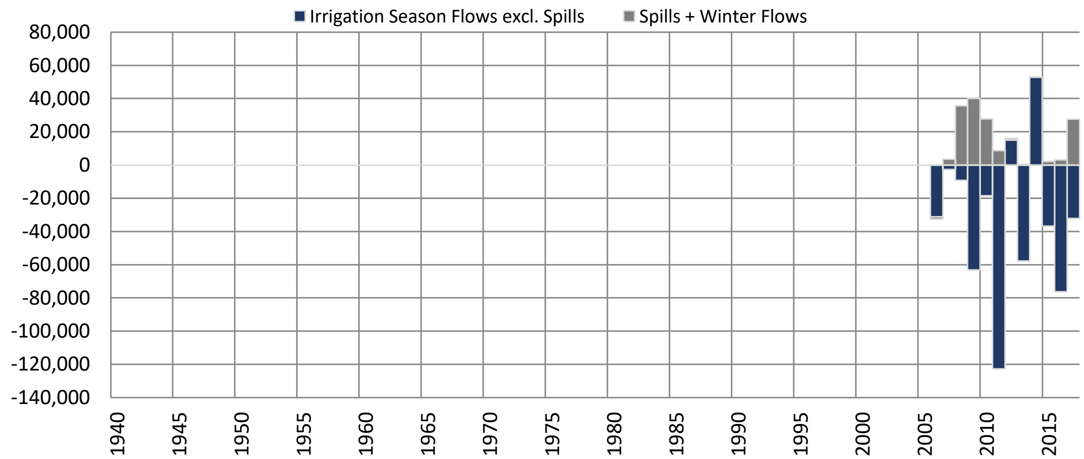
Notes:

Reservoir storage does not include storage attributed to SJC, CO, or NM credit waters.

Average differences calculated as (Final Storage - Initial Storage)/(no. years).

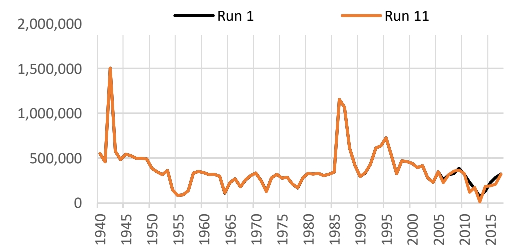
Run 11 - D1/D2
Simulated Differences in ILRG Model Outputs
Run 11 minus Run 1
1940 - 2017 (acre-feet)

Rio Grande at El Paso (Annual)

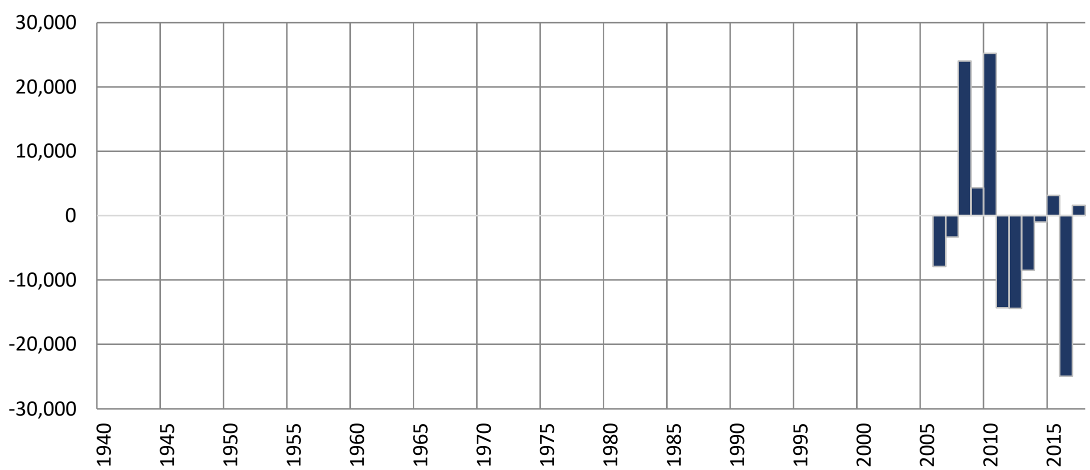


Average Difference

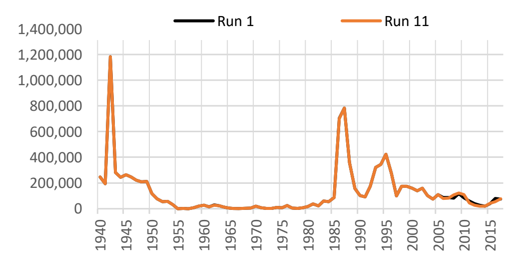
Period	Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017			
1951-1978			
1979-2005			
2006-2017	-31,871	12,368	-19,503
1985-2017			
1985-2005			



Rio Grande at Fort Quitman (Annual)



Period	Average Difference
1951-2017	
1951-1978	
1979-2005	
2006-2017	-1,349
1985-2017	
1985-2005	



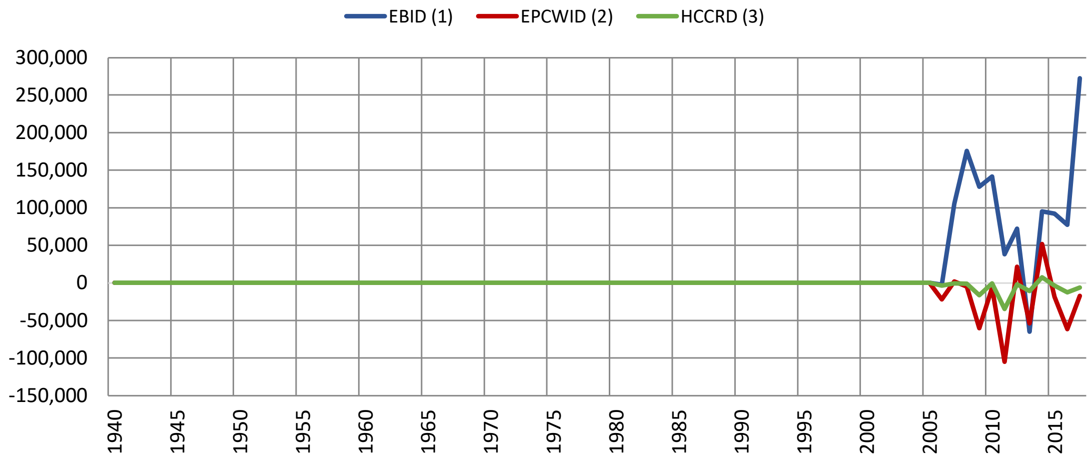
Run 11 - D1/D2

Simulated Differences in ILRG Model Outputs

Run 11 minus Run 1

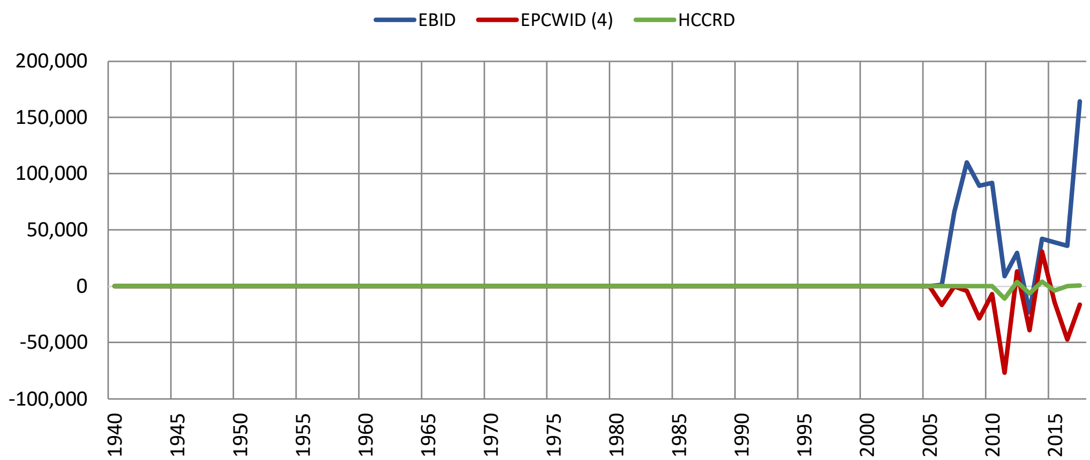
1940 - 2017 (acre-feet)

River Headgate (RHG) Diversions (Irrigation Season)



	Average Difference		
Period	EBID	EPCWID	HCCRD
1951-2017			
1951-1978			
1979-2005			
2006-2017	94,216	-22,972	-7,106
1985-2017			
1985-2005			

Farm Headgate (FHG) Deliveries (Irrigation Season)



	Average Difference		
Period	EBID	EPCWID	HCCRD
1951-2017			
1951-1978			
1979-2005			
2006-2017	54,568	-17,179	-1,035
1985-2017			
1985-2005			

Notes:

(1) EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

(2) EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

(3) HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

(4) EPCWID FHG values include deliveries to Rogers WTP and R/U WTP.

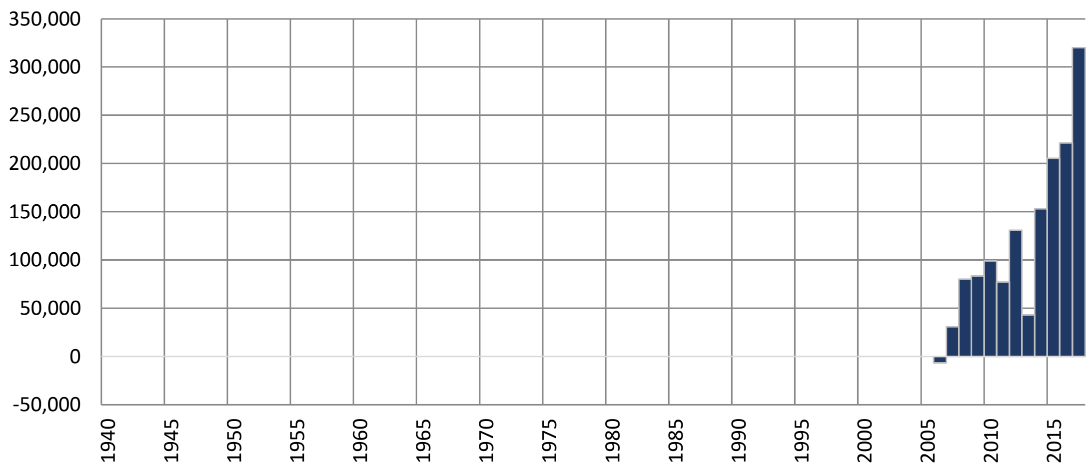
Run 11 - D1/D2

Simulated Differences in ILRG Model Outputs

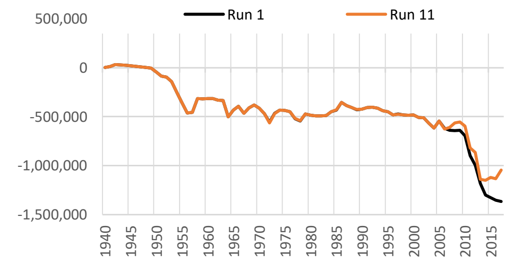
Run 11 minus Run 1

1940 - 2017 (acre-feet)

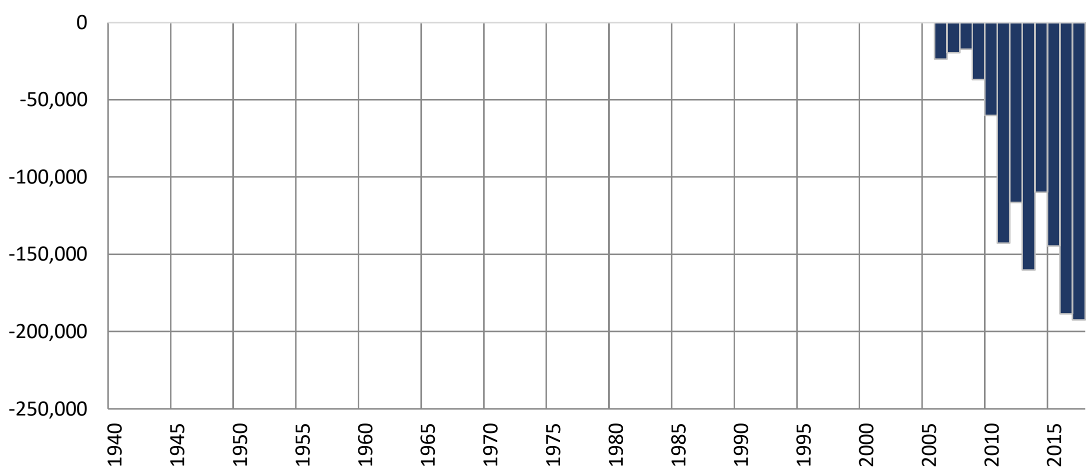
Cumulative Annual Rincon-Mesilla Groundwater Storage



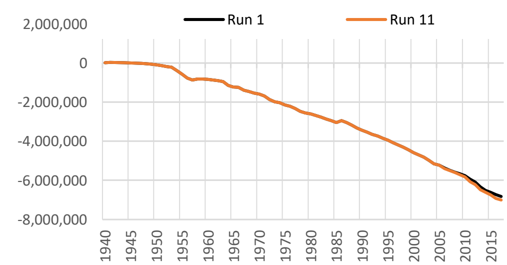
Period	Average Difference
1951-2017	
1951-1978	
1979-2005	
2006-2017	26,667
1985-2017	
1985-2005	



Cumulative Annual Hueco Groundwater Storage



Period	Average Difference
1951-2017	
1951-1978	
1979-2005	
2006-2017	-16,051
1985-2017	
1985-2005	



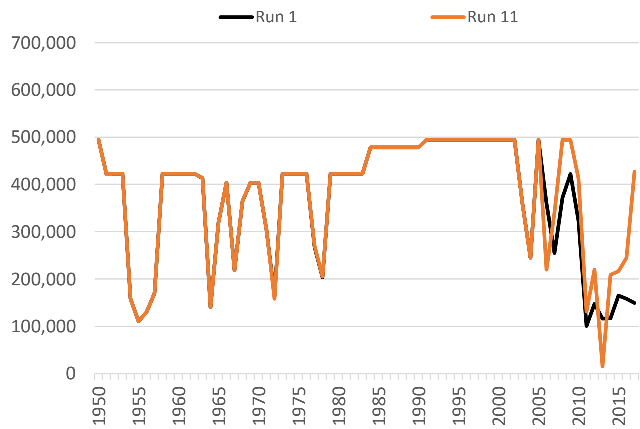
Notes:

Cumulative storage change in alluvial and non-alluvial aquifers.

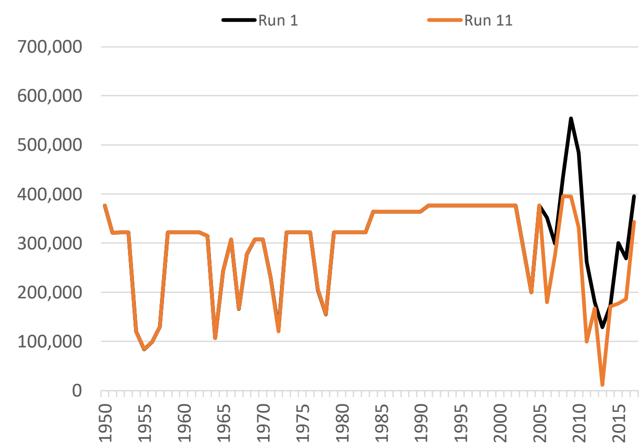
Average differences calculated as (Final Storage - Initial Storage)/(no. years).

Run 11 - D1/D2
Annual Allocation and Charges
Run 11 v. Run 1
ILRG Model
1950 - 2017 (acre-feet)

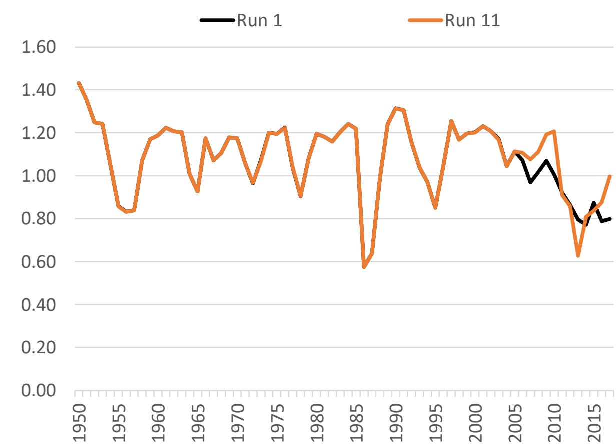
Total Allocation - EBID



Total Allocation - EPCWID

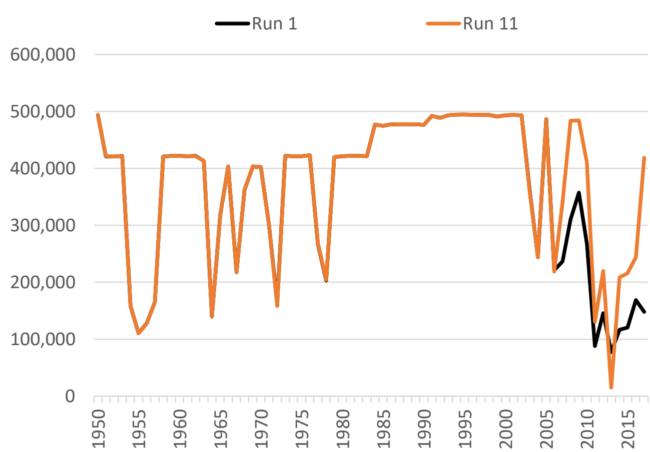


Diversion Ratio

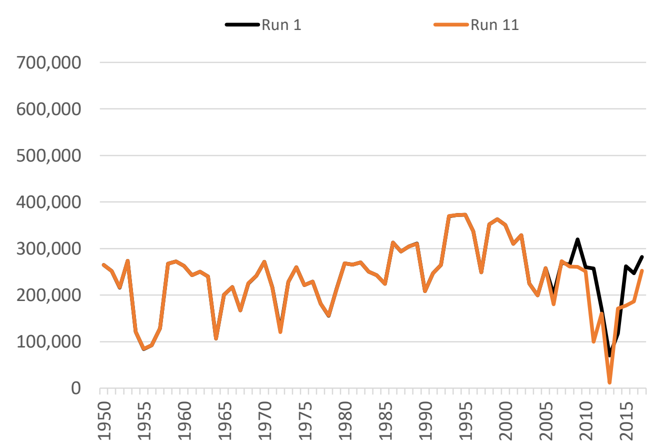


Note:
Computed as Total Charges/Caballo Release.

Annual Delivery Charges - EBID

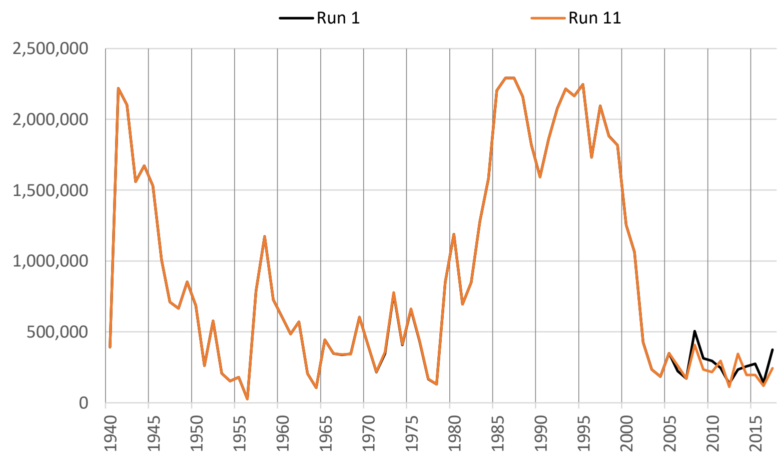


Annual Delivery Charges - EPCWID

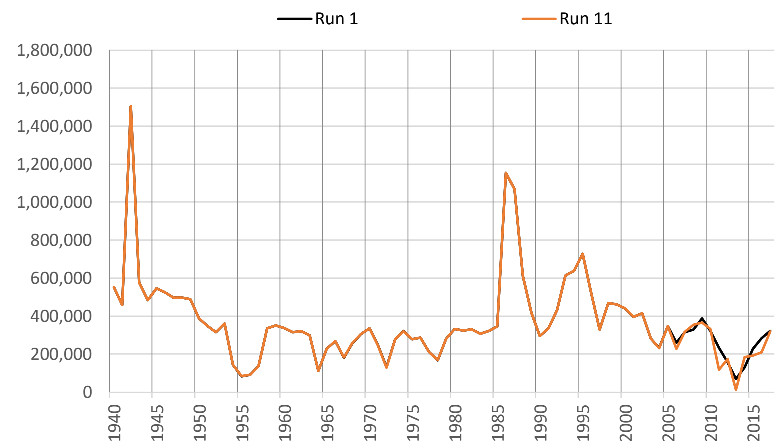


Run 11 - D1/D2
Annual Summary of Project Storage and Rio Grande Flows
Run 11 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

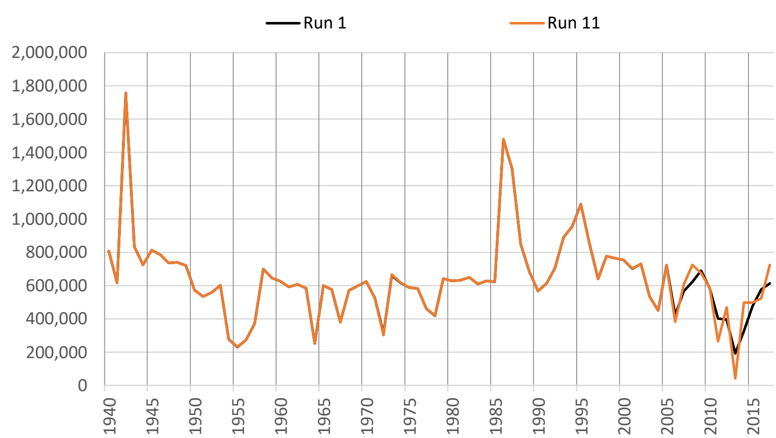
Total Year-End Project Reservoir Storage



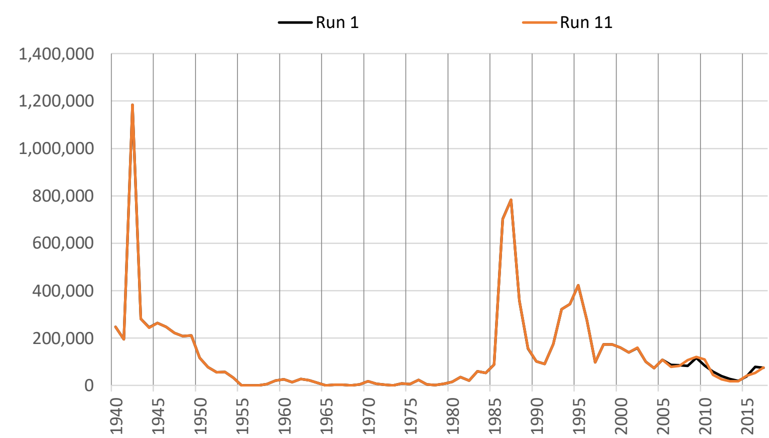
Rio Grande at El Paso



Rio Grande Below Caballo



Rio Grande at Fort Quitman

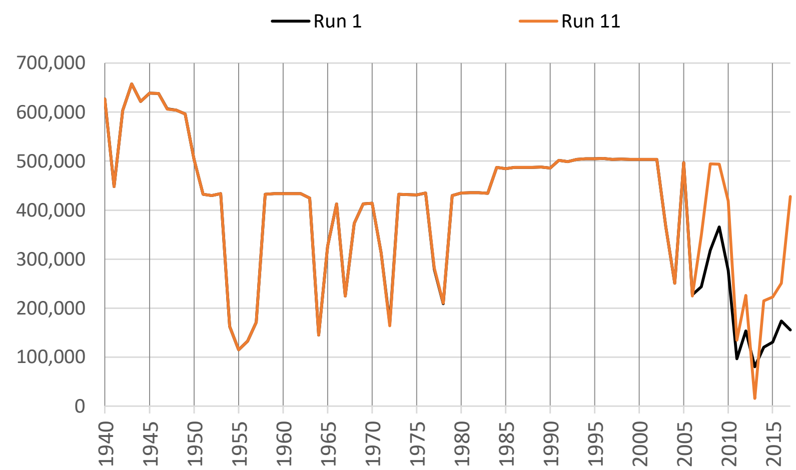


***Note different scales.**

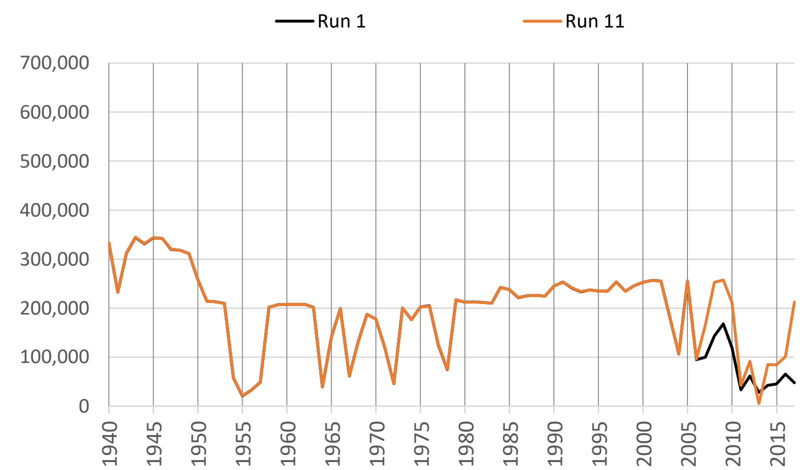
Run 11 - D1/D2
Irrigation Season Summary of Irrigation Operations
Run 11 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

EBID Total

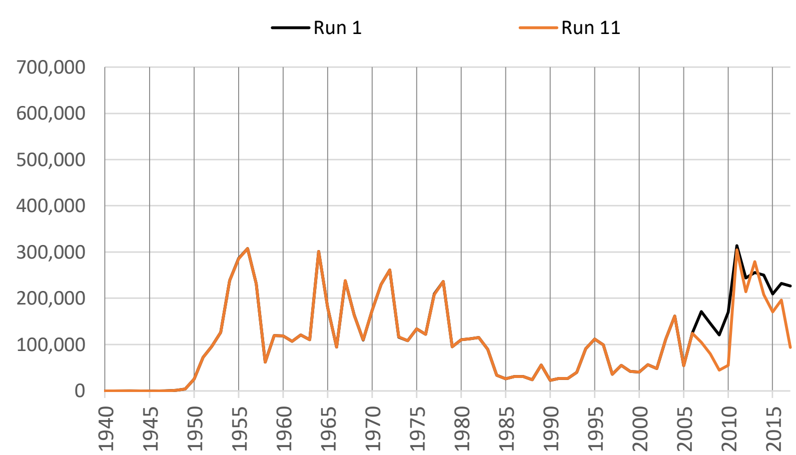
Net River Headgate Diversions



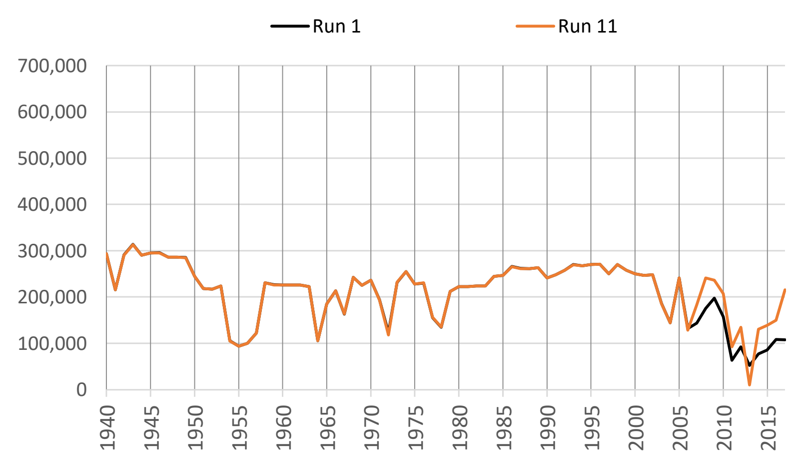
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries

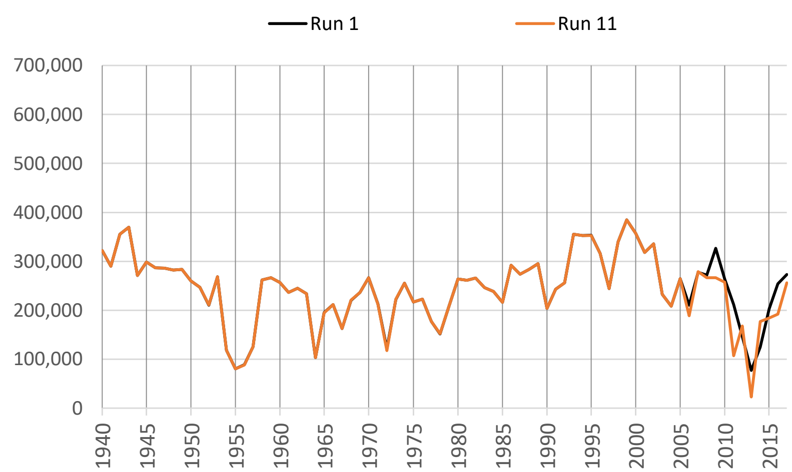


Notes: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).
Pumping includes Supplemental and Primary groundwater pumping.

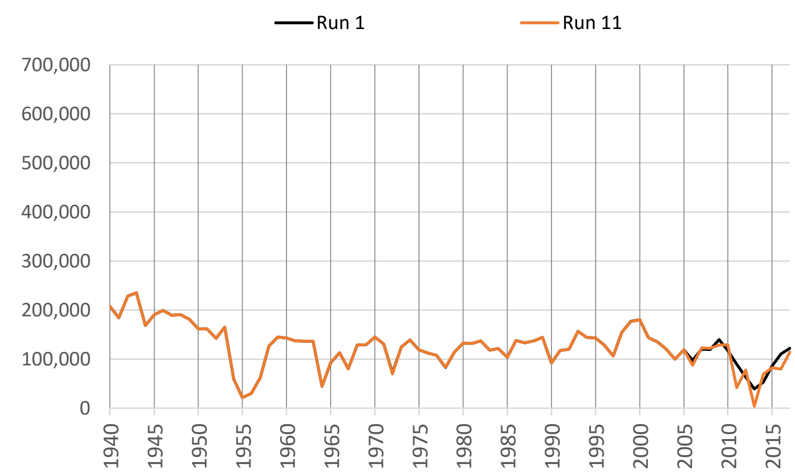
Run 11 - D1/D2
Irrigation Season Summary of Irrigation Operations
Run 11 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

EPCWID Total

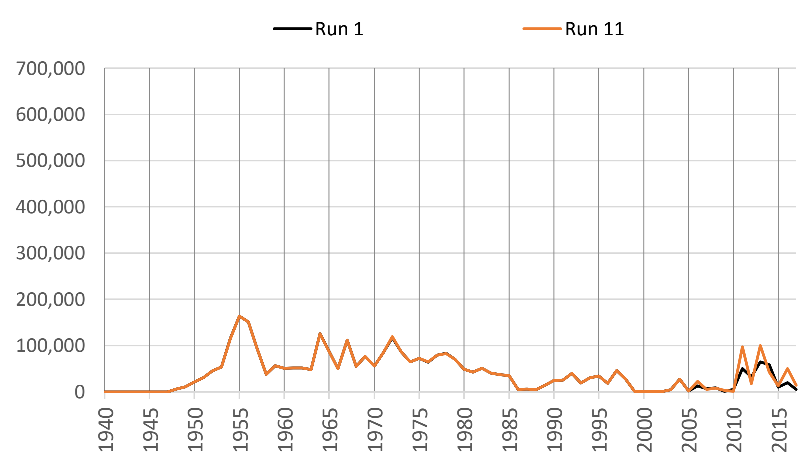
Net River Headgate Diversions



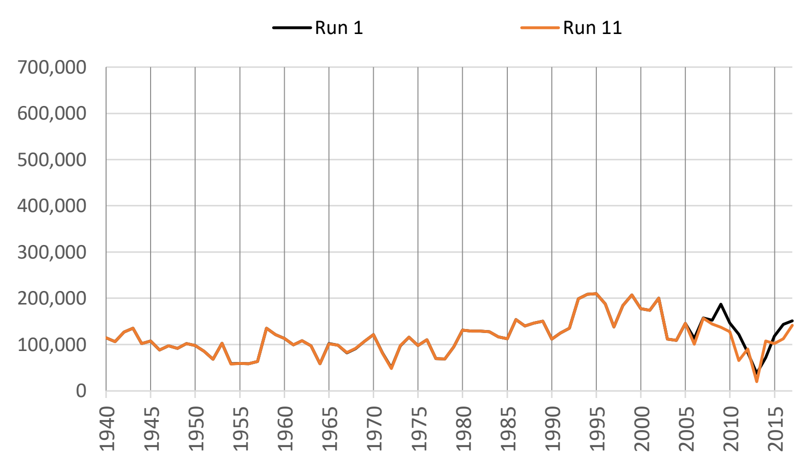
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries

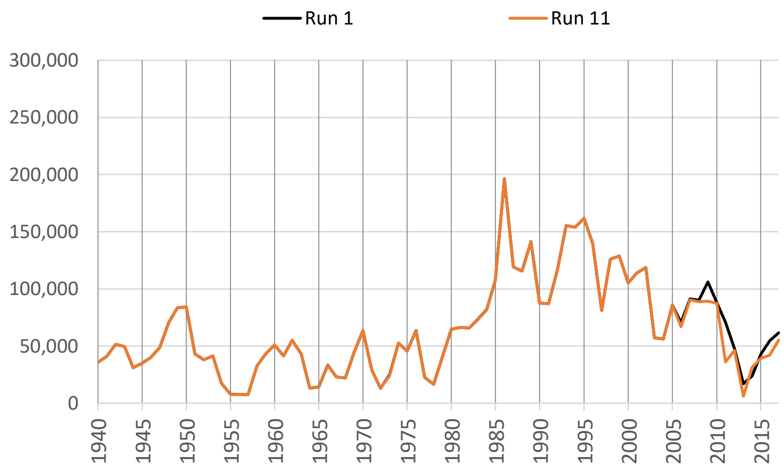


Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

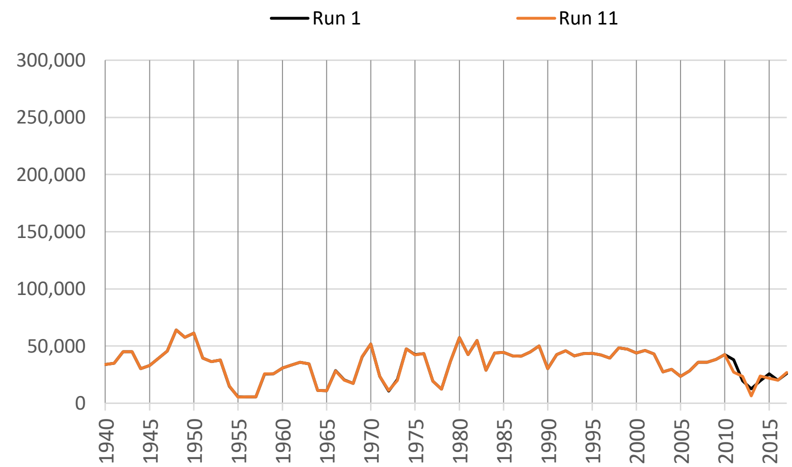
Run 11 - D1/D2
Irrigation Season Summary of Irrigation Operations
Run 11 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

HCCRD Total

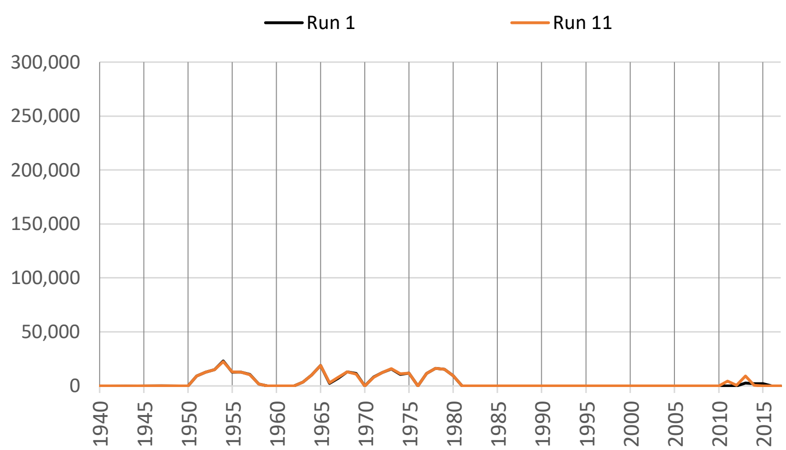
Net River Headgate Diversions



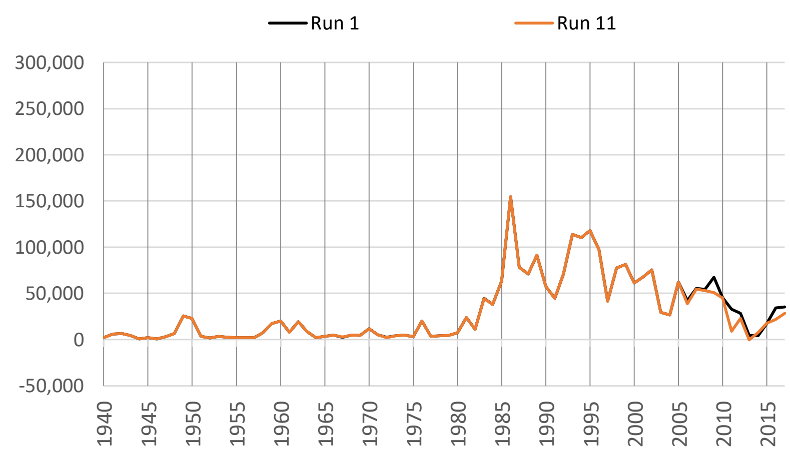
Farm Headgate Deliveries



Pumping



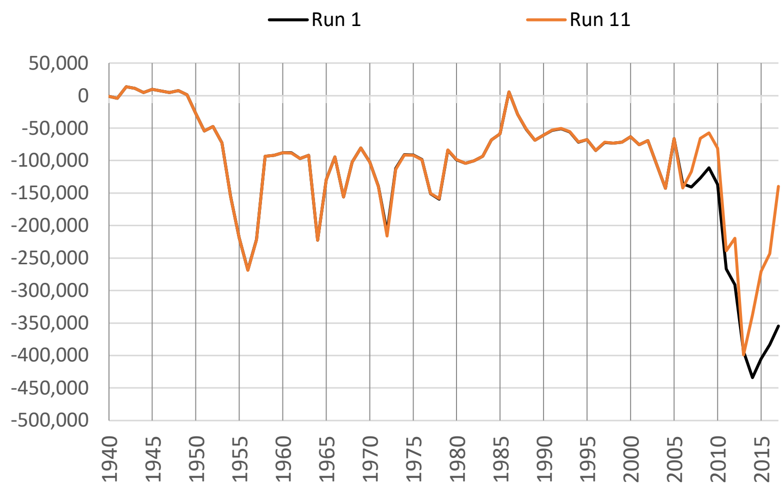
RHG Diversions - FHG Deliveries



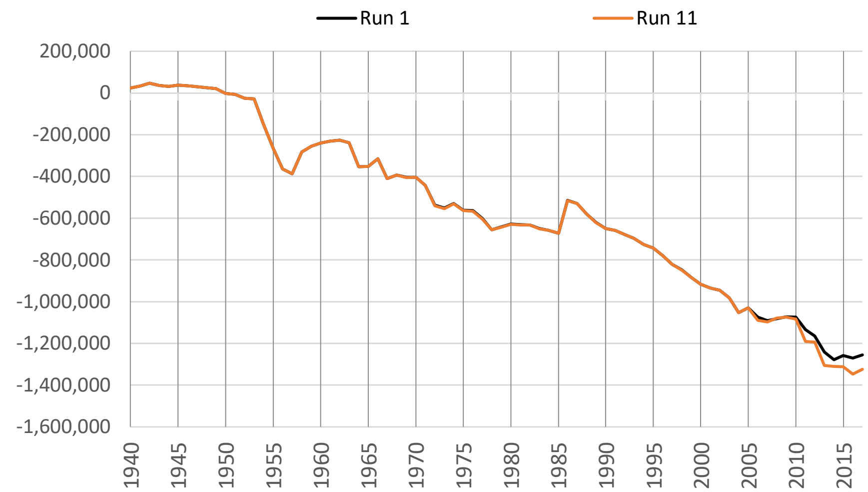
Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

Run 11 - D1/D2
Cumulative Change in Ground Water Storage
Run 11 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

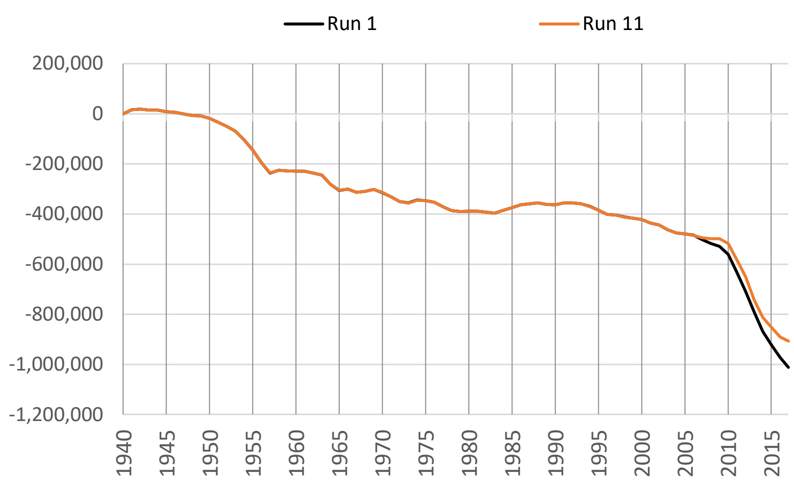
Rincon-Mesilla Alluvial Aquifer



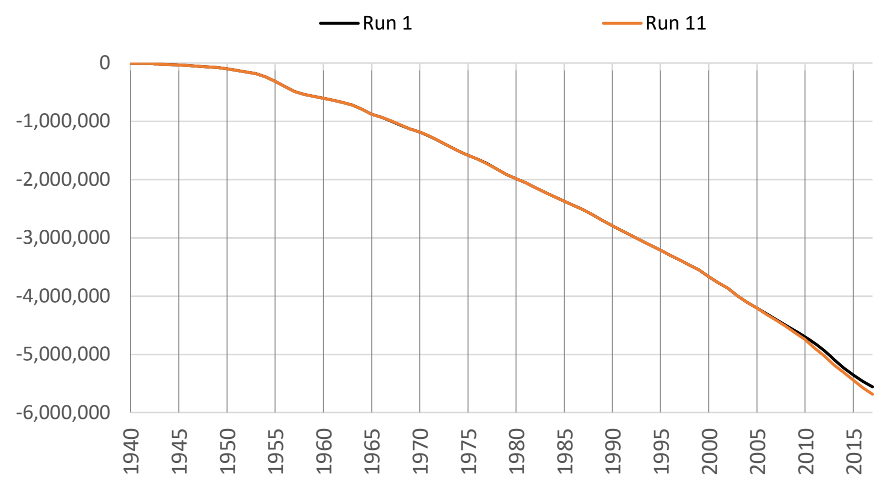
Hueco Alluvial Aquifer



Rincon-Mesilla Non-Alluvial Aquifer

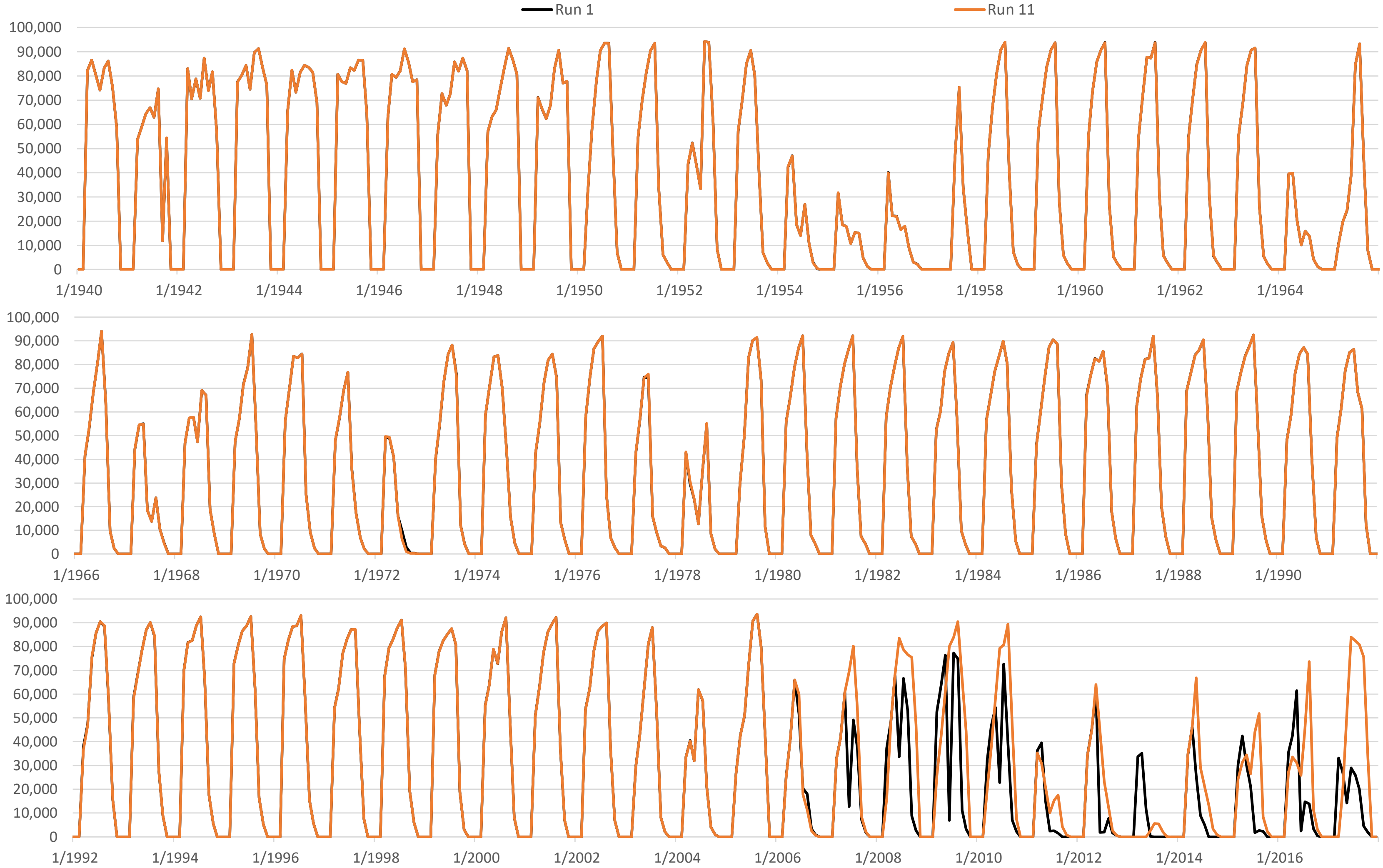


Hueco Non-Alluvial Aquifer



***Note different scales.**

Run 11 - D1/D2
Monthly Net RHG Diversions
Run 11 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
EBID Total

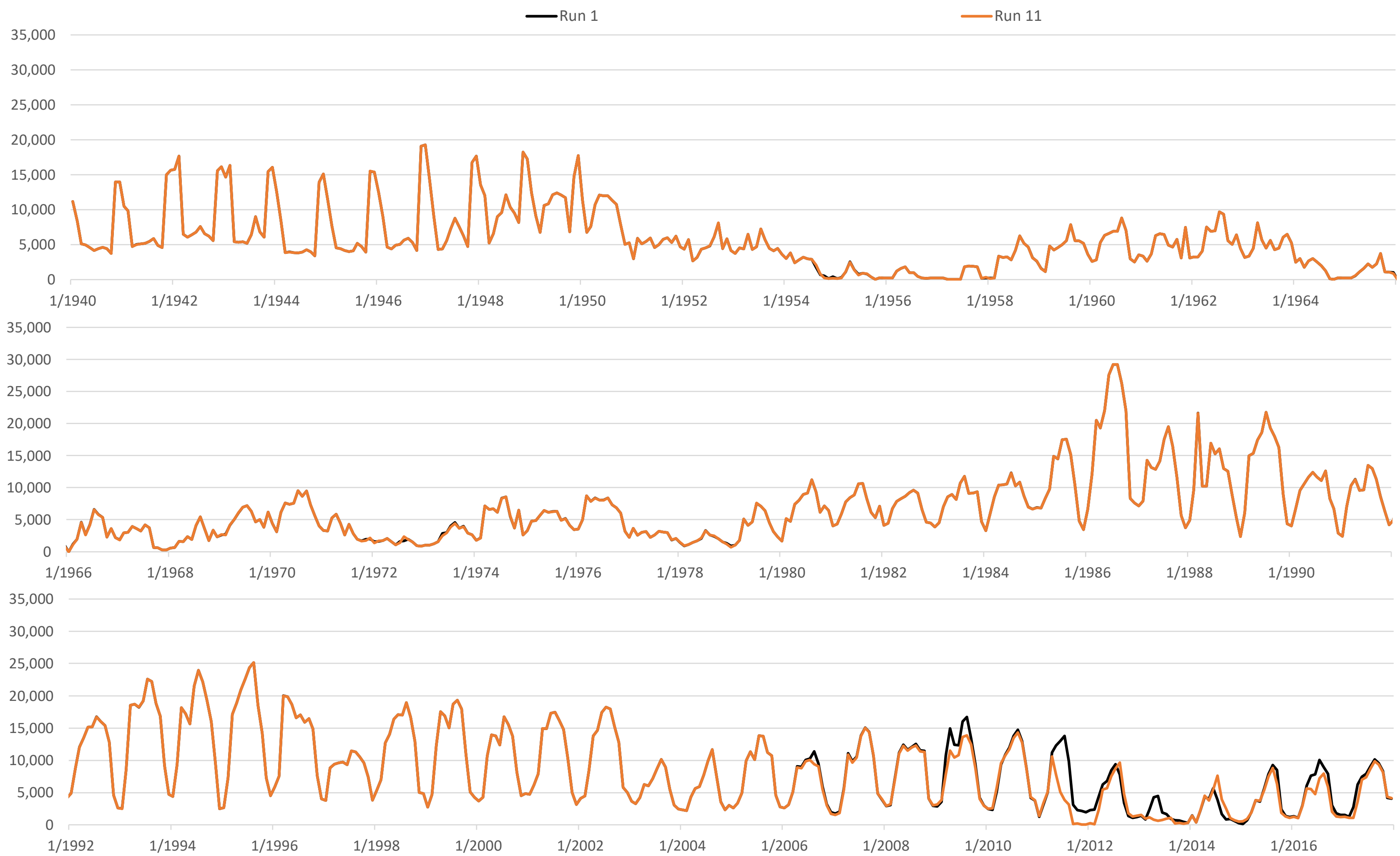


Note: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

Run 11 - D1/D2
Monthly Net RHG Diversions
Run 11 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
EPCWID Total

Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

Run 11 - D1/D2
Monthly Net RHG Diversions
Run 11 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
HCCRD Total



Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

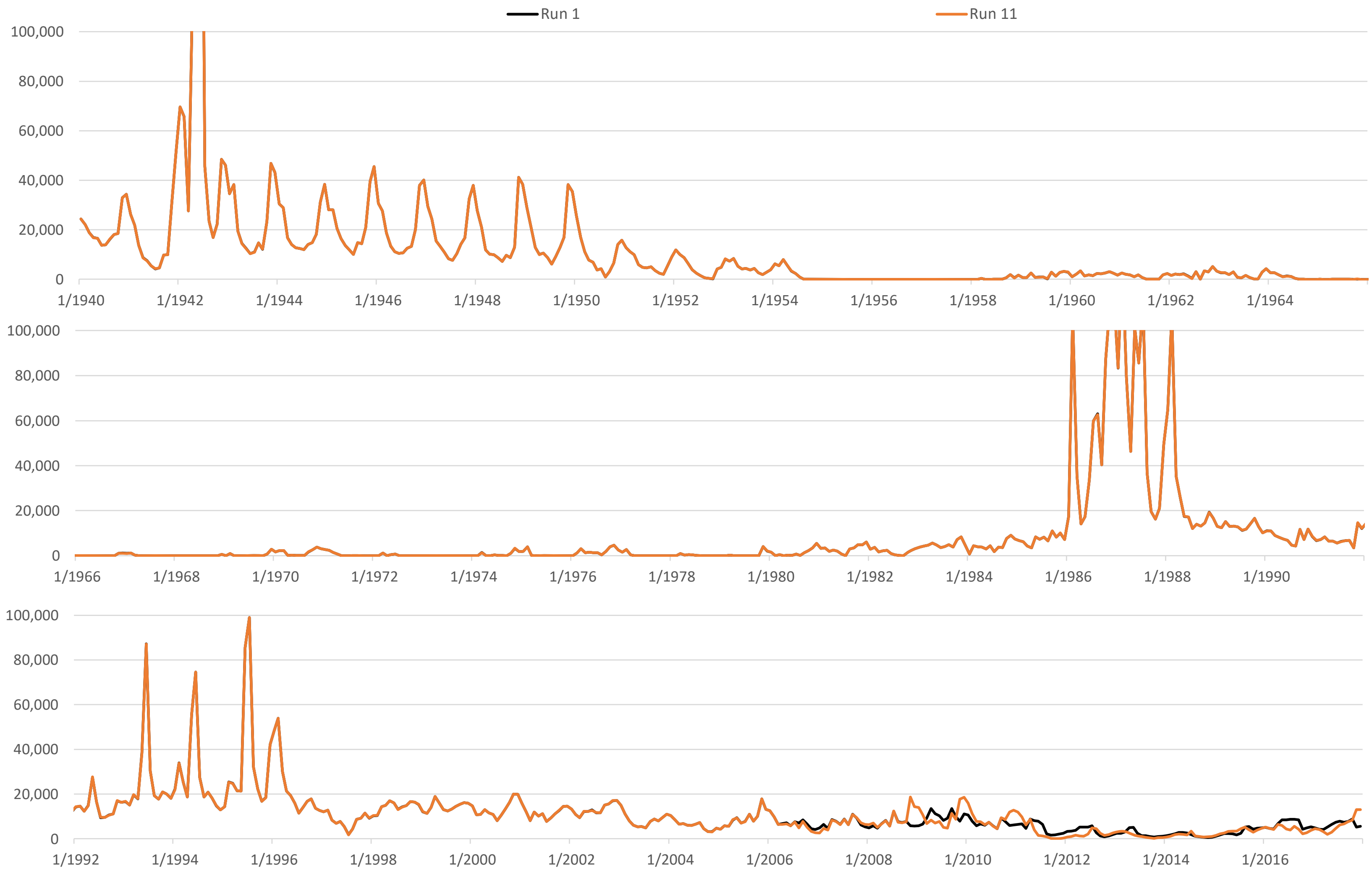
Run 11 - D1/D2
End of Month Reservoir Storage (Elephant Butte + Caballo)
Run 11 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

US_MSJ_00003205

Run 11 - D1/D2
Monthly Caballo Releases
Run 11 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

Run 11 - D1/D2
Monthly Rio Grande at El Paso Flow
Run 11 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

Run 11 - D1/D2
Monthly Rio Grande at Fort Quitman Flow
Run 11 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)



Appendix 30L

Comparison of ILRG Model Runs
Run 12 v. Run 11

Model Run Specifications

Model Version: LRG_v116

Name: **Run 12 - D3 + Carryover Allocation (All Pumping On)**

Run ID: LRG_v116_Operational_Run12
Date: 8/31/2020

Name: **Run 11 - D1/D2 Allocation (All Pumping On)**

Run ID: LRG_v116_Operational_Run11
Date: 8/25/2020

Selected Model Inputs

Pumping and Returns	Run 12	Run 11
Irrigation Pumping	On	On
Irrigated Area	Hist	Hist
Non-Irrigation Pumping	On	On
Non-Irrigation Pumping Returns	On	On
Las Cruces Jornada Pumping Returns	On	On

Project Allocation Rules		
1950-2005	D3 + CO	D1/D2
2006-2007	D3 + CO	D1/D2
2008-2017	D3 + CO	D1/D2

EPCWID Operations		
Charge EPCWID for Use of WWTP Returns	Off	Off
ACE and Haskell Credits for EPCWID	On	On
Increased EPCWID Use of Fabens Drain Flows	Off	Off
Charge EPCWID for Fabens Drain Flow Use	Off	Off

Run 12 - D3 + Carryover Allocation (All Pumping On)
Comparison of ILRG Model Runs
Run 12 v. Run 11
1951 - 2017 Annual Average
(1,000 acre-feet)

Run No.	11	12	12 - 11	
Simulated Input or Output	**Run 11**	**Run 12**	**Run 12 minus Run 11**	
Effects of Alternate Scenario				
FHG Deliveries (Mar - Oct)				***% Diff.***
EBID	177.4	157.6	-19.8	*-11%*
EPCWID (incl. EPW)	136.8	145.0	8.2	*6%*
HCCRD	32.7	33.4	0.7	*2%*
Total	346.9	335.9	-10.9	*-3%*
FHG Deliveries (Nov - Feb)				
EBID	0.0	0.0	0.0	*377%*
EPCWID (incl. EPW)	0.2	0.2	0.0	*17%*
HCCRD	2.4	2.3	-0.1	*-6%*
Total	2.6	2.5	-0.1	*-3%*
Irrigation Pumping				
EBID	131.2	153.3	22.1	*17%*
EPCWID (Mesilla Valley)	7.1	7.9	0.8	*12%*
EPCWID (El Paso Valley)	41.8	40.2	-1.6	*-4%*
HCCRD	4.3	3.7	-0.6	*-15%*
Total	184.5	205.2	20.7	*11%*
Other Inflows/Outflows				
Net Reservoir Evaporation	125.3	119.8	-5.5	*-4%*
Riparian ET	70.6	71.4	0.8	*1%*
River Evaporation + Incidental Canal Loss	30.8	29.7	-1.1	*-3%*
Total	226.6	220.9	-5.8	*-3%*
Rio Grande at Fort Quitman				
Reservoir Spills	33.3	23.2	-10.0	*-30%*
Nov-Feb Flows	22.6	29.5	6.9	*30%*
Mar - Oct Flows	39.6	44.0	4.4	*11%*
Underflow (GW Model)	0.2	0.2	0.0	*2%*
Total	95.7	97.0	1.3	*1%*

Run 12 - D3 + Carryover Allocation (All Pumping On)

Comparison of ILRG Model Runs

Run 12 v. Run 11

1951 - 2017 Annual Average

(1,000 acre-feet)

Run No.	11	12	12 - 11	
Simulated Input or Output	**Run 11**	**Run 12**	**Run 12 minus Run 11**	
Effects of Alternate Scenario (continued)				
Change in Storage				***% Diff.***
Reservoir Storage	-6.6	-4.3	2.4	*-36%*
Alluvial GW Storage (RW Model)	-21.4	-23.6	-2.2	*10%*
Non-alluvial GW Storage (GW Models)	-96.6	-92.5	4.1	*-4%*
Soil Moisture Storage	0.7	0.7	0.0	*-6%*
Total	-123.9	-119.7	4.3	*-3%*
Summary of Effects				
FHG Deliveries (Mar-Oct)	346.9	335.9	-10.9	*-3%*
FHG Deliveries (Nov-Feb)	2.6	2.5	-0.1	*-3%*
Irrigation Pumping	184.5	205.2	20.7	*11%*
Riparian ET + Evaporation	226.6	220.9	-5.8	*-3%*
Fort Quitman Flow	95.7	97.0	1.3	*1%*
Change in Storage	-123.9	-119.7	4.3	*-3%*
Total	732.4	741.8	9.4	*1%*
Other Effects of Alternate Scenario				
Rio Grande at El Paso				***% Diff.***
Reservoir Spills	49.4	35.5	-13.9	*-28%*
Nov-Feb Flows	25.0	29.9	4.9	*20%*
Mar - Oct Flows	258.0	277.7	19.6	*8%*
Total	332.4	343.1	10.7	*3%*
Rio Grande below Caballo				
Reservoir Spills	65.9	46.7	-19.1	*-29%*
Nov-Feb Flows	0.5	0.1	-0.3	*-69%*
Mar - Oct Flows	543.1	565.9	22.7	*4%*
Total	609.5	612.7	3.3	*1%*
Surface Water Diversions (Mar - Oct)				
EBID	383.3	348.9	-34.4	*-9%*
EPCWID (incl. EPW)	232.6	245.7	13.1	*6%*
HCCRD	66.3	69.3	3.0	*5%*
Total	682.2	663.9	-18.3	*-3%*
Surface Water Diversions (Nov - Feb)				
EBID	0.0	0.0	0.0	*0%*
EPCWID (incl. EPW)	14.5	13.4	-1.1	*-8%*
HCCRD	14.1	14.0	-0.1	*-1%*
Total	28.6	27.4	-1.2	*-4%*

Run 12 - D3 + Carryover Allocation (All Pumping On)
Annual Differences in ILRG Model Outputs
Run 12 minus Run 11
1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1940	52	52	-3	4	0	4	2	2	-2	-1	0	0	51	26	75
1941	162	162	6	11	2	4	4	4	1	2	2	4	-42	-69	-18
1942	33	33	0	4	1	1	0	0	-4	-9	0	1	-27	-10	13
1943	64	64	4	11	-2	-1	14	14	12	2	-2	1	23	11	64
1944	81	81	11	10	-28	-12	4	4	-11	-6	-30	-28	19	16	3
1945	70	70	19	9	5	1	0	0	19	35	0	0	60	50	30
1946	33	33	-5	-7	-1	-3	3	3	-7	-7	-1	-1	-3	-2	-4
1947	51	51	4	-4	2	-3	3	3	4	-3	5	5	7	9	0
1948	52	52	10	12	1	3	0	0	1	5	-3	-3	19	20	19
1949	80	80	10	14	3	2	-2	-2	2	3	0	0	22	20	20
1950	30,829	30,829	1,266	1,298	66	166	18,515	18,528	776	802	0	-1	29,277	12,269	7,978
1951	26,584	26,584	1,318	1,327	136	234	16,194	16,201	1,060	1,074	106	138	13,490	7,710	5,889
1952	111,891	111,891	1,890	2,017	227	508	74,596	74,746	1,199	1,316	226	408	103,759	47,194	31,334
1953	-80,311	-80,311	-63	-34	637	846	-53,275	-53,266	97	119	350	-117	-50,822	3,937	21,289
1954	-78,743	-78,743	11,604	10,069	818	1,110	-30,809	-30,809	13,519	13,569	1,047	1,215	-30,849	16,265	2,777
1955	-7,081	-7,081	-8,553	-9,509	-1,415	-1,309	10,710	10,710	8,851	8,875	-509	-300	-10,273	-1,666	684
1956	-24,496	-24,496	-2,766	-2,789	-1,503	-1,450	-3,158	-3,158	6,590	6,515	-690	-570	-9,547	4,770	0
1957	-52,309	-52,309	-6,266	-7,519	1,980	1,831	-39,066	-39,066	-20,178	-20,045	2,350	2,220	-25,035	2,024	0
1958	-72,569	-72,569	7,554	6,430	1,179	-1,906	-47,425	-47,425	4,745	5,005	-744	-1,271	26,874	2,490	103
1959	103,855	103,855	9,707	8,121	-138	-1,925	55,476	55,484	5,671	5,681	-52	-203	84,645	10,009	980
1960	153,259	153,259	8,358	10,056	800	1,508	88,827	88,853	5,179	5,241	0	0	75,841	32,148	15,035
1961	-972	-972	1,028	3,202	624	1,514	-1,742	-1,735	1,405	1,443	335	-325	-30,283	8,918	7,770
1962	27,179	27,179	3,574	4,201	569	838	12,859	12,862	2,685	2,701	-71	-280	9,885	5,201	5,602
1963	-117,287	-117,287	-1,826	-1,349	262	656	-73,442	-73,443	-774	-779	89	91	-47,901	-4,334	2,650
1964	-76,720	-76,720	13,824	12,622	509	-60	-28,167	-28,167	19,122	19,054	1,644	1,575	-17,463	24,682	3,598
1965	-183,009	-183,009	-5,191	-10,167	593	-398	-100,610	-100,610	-3,263	-3,144	678	-36	-103,844	-810	-36
1966	-123,581	-123,581	35,625	29,691	9,934	8,964	-93,472	-93,472	15,707	16,051	709	-2,401	63,606	31,208	9,875
1967	-100,411	-100,411	48,775	45,832	5,419	7,772	-40,983	-40,983	32,693	32,157	4,398	7,027	67,665	59,222	-36
1968	-156,391	-156,391	-13,400	-18,056	4,442	6,892	-89,425	-89,425	-6,588	-6,901	4,383	6,659	-51,952	-14,832	-174
1969	-152,598	-152,598	-2,081	-6,947	1,576	-2,836	-102,936	-102,937	-2,322	-2,366	1,524	1,188	-10,606	-15,018	-3,509
1970	-31,586	-31,586	5,280	1,875	469	-2,514	-30,258	-30,258	3,021	3,004	7	-50	35,155	-7,058	-2,952
1971	-122,803	-122,803	32,591	29,256	10,277	9,965	-69,136	-69,136	13,408	13,427	7,744	8,136	3,360	46,389	6,310
1972	-49,146	-49,146	6,259	3,264	1,164	2,327	-22,057	-22,057	4,580	4,762	921	1,943	6,419	12,283	128
1973	-176,222	-176,222	-5,237	-9,279	2,045	1,155	-107,769	-107,769	-3,180	-3,209	1,925	903	-54,117	-7,185	-5
1974	-107,244	-107,244	6,069	2,496	696	-1,486	-73,676	-73,676	1,476	1,448	729	1,077	13,899	-8,092	-2,659
1975	-79,664	-79,664	39,530	36,616	18,246	16,402	-68,710	-68,710	19,701	19,667	8,292	3,702	44,681	33,014	11,103
1976	45,284	45,284	4,546	2,385	1,187	7	20,705	20,706	2,740	2,743	-1,658	-5,752	48,398	-2,684	6,547
1977	-82,332	-82,332	-3,061	-4,530	286	724	-42,717	-42,717	-2,527	-2,532	288	668	-37,475	-293	218
1978	-86,422	-86,422	15,261	11,226	-1,932	-417	-40,207	-40,207	13,455	13,891	-1,719	-145	-5,689	22,294	-44

Run 12 - D3 + Carryover Allocation (All Pumping On)
Annual Differences in ILRG Model Outputs
Run 12 minus Run 11
1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1979	-242,940	-242,940	14,971	10,250	1,356	1,835	-156,411	-156,421	10,865	11,121	883	1,513	-79,820	-6,878	-6,271
1980	-57,521	-57,521	12,992	7,840	2,657	-271	-45,374	-45,375	5,690	5,722	2,749	1,535	50,842	-10,431	-3,544
1981	-748	-748	18,265	16,460	3,544	1,830	-5,809	-5,809	7,694	7,675	0	0	42,949	5,862	575
1982	104,358	104,358	13,207	12,473	2,894	2,147	60,225	60,234	5,313	5,332	-1,707	-3,455	74,615	17,105	8,645
1983	170,632	170,632	17,092	18,975	7,635	8,539	104,548	104,634	6,781	6,900	0	0	133,843	61,115	27,926
1984	35,030	35,030	14,349	15,942	1,945	2,596	24,687	24,721	5,912	6,017	0	0	17,038	38,153	14,801
1985	6,224	6,224	20,411	20,491	-18,515	-18,898	13,078	13,095	10,574	10,599	0	0	-19,916	-6,599	-14,535
1986	89,043	89,043	20,391	20,515	1,458	331	48,157	48,259	10,093	10,193	0	0	-184,856	-209,916	-170,620
1987	64,788	64,788	21,344	21,499	6,046	5,967	34,901	35,030	9,499	9,636	0	0	42,456	40,189	17,285
1988	54,473	54,473	21,898	22,008	5,315	5,043	25,545	25,632	10,639	10,735	0	0	46,971	30,948	6,113
1989	105,248	105,248	26,533	26,610	6,905	7,176	62,153	62,269	12,555	12,573	0	0	98,846	67,520	44,485
1990	17,227	17,227	20,147	20,216	4,471	4,503	9,923	9,994	9,154	9,100	0	0	26,132	47,336	30,703
1991	12,089	12,089	15,726	15,769	3,713	3,497	6,353	6,416	6,052	6,099	0	0	23,248	31,909	21,446
1992	39,535	39,535	20,145	20,169	710	383	31,853	31,945	7,828	7,839	0	0	13,262	1,908	-11,486
1993	56,305	56,305	10,680	11,014	-5,873	-6,338	36,926	37,056	3,396	3,871	0	0	-61,025	-77,452	-87,516
1994	117,979	117,979	16,860	16,986	2,585	2,904	71,694	71,834	7,618	7,756	0	0	2,660	-24,835	-38,838
1995	131,993	131,993	10,952	11,028	886	1,942	82,128	82,277	4,619	4,693	0	0	-61,578	-56,465	-50,980
1996	146,042	146,042	9,917	10,080	793	972	90,723	90,865	3,799	3,959	0	0	51,975	19,613	2,113
1997	55,506	55,506	3,912	4,061	-439	-286	36,960	37,060	1,900	1,913	0	0	46,476	61,669	44,636
1998	84,253	84,253	6,290	6,357	1,596	1,713	51,308	51,406	1,999	2,124	0	0	44,739	37,759	33,955
1999	43,156	43,156	6,649	7,382	2,880	3,596	37,267	37,333	19,325	19,416	0	0	37,842	36,998	21,371
2000	39,017	39,017	8,726	9,939	1,802	2,389	26,263	26,320	6,525	6,593	0	0	33,339	40,172	32,565
2001	64,767	64,767	20,040	20,866	3,869	4,408	40,984	41,085	14,015	14,117	0	0	85,456	69,677	49,561
2002	-81,134	-81,134	465	1,904	1,207	1,739	-45,642	-45,641	923	934	0	0	-75,916	3,212	9,507
2003	-171,521	-171,521	-12,182	-13,689	-1,146	-1,838	-103,803	-103,803	-9,180	-9,213	0	0	-93,896	-33,791	-7,607
2004	-61,471	-61,471	-3,524	-4,646	-625	-1,084	-32,540	-32,540	-1,631	-1,661	0	0	-5,144	-9,344	-8,898
2005	-254,960	-254,960	2,796	1,921	584	128	-159,228	-159,263	2,365	2,293	0	0	-122,256	-28,376	-23,335
2006	-64,437	-64,437	71,350	69,120	16,825	17,365	-35,240	-35,241	39,361	39,311	0	0	103,380	63,812	10,643
2007	-161,645	-161,645	-5,201	-6,645	820	1,171	-99,591	-99,591	-1,820	-1,858	0	0	-44,861	-11,410	63
2008	-204,071	-204,071	2,692	1,152	595	-66	-128,644	-128,677	2,651	2,547	0	0	-98,995	-33,272	-29,321
2009	-144,518	-144,518	58,899	56,730	16,250	15,737	-98,878	-98,935	27,421	27,316	0	0	22,399	18,220	-8,941
2010	-176,701	-176,701	5,848	3,188	352	-190	-113,110	-113,114	6,358	6,273	0	0	-9,069	-12,390	-28,117
2011	-53,706	-53,706	103,760	102,380	34,226	37,633	-17,354	-17,354	76,088	76,048	10,844	10,982	131,185	112,180	12,517
2012	-59,293	-59,293	-8,002	-8,136	5,695	9,903	-25,723	-25,723	-3,345	-3,360	-3,877	-3,994	-40,374	-2,252	19,534
2013	36,192	36,192	45,941	45,865	10,634	10,857	9,211	9,211	33,667	33,662	6,317	6,474	107,830	48,863	11,247
2014	-116,483	-116,483	-28,176	-28,193	-1,382	-1,383	-51,818	-51,818	-16,049	-16,054	63	104	-154,243	-25,601	5,123
2015	-80,123	-80,123	9,829	9,535	3,064	2,772	-31,264	-31,264	8,168	8,155	548	-8	-20,981	25,072	4,469
2016	-79,576	-79,576	59,981	59,552	12,162	13,041	-36,555	-36,555	46,029	46,012	0	0	53,720	71,287	23,793
2017	-275,637	-275,637	17,199	15,537	6,251	6,418	-166,196	-166,214	16,343	16,285	-698	-715	-110,047	4,293	-1,681
Averages															
1951-2017	-34,425	-34,425	13,097	11,985	3,027	2,942	-19,820	-19,793	8,168	8,201	708	566	3,284	10,651	1,252
1951-1978	-53,352	-53,352	7,298	5,375	2,110	1,748	-31,417	-31,409	4,931	4,956	1,154	911	3,994	10,992	4,374
1979-2005	21,014	21,014	12,557	12,312	1,417	1,293	12,847	12,912	6,456	6,531	71	-15	6,233	5,447	-2,146
2006-2017	-115,000	-115,000	27,843	26,674	8,791	9,438	-66,264	-66,273	19,573	19,528	1,100	1,070	-5,005	21,567	1,611
1985-2017	-24,892	-24,892	17,645	17,290	3,749	3,985	-13,035	-12,989	11,119	11,149	400	389	-3,977	9,119	-2,447
1985-2005	26,598	26,598	11,818	11,928	868	869	17,381	17,459	6,289	6,360	0	0	-3,390	2,006	-4,765

Notes:

EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

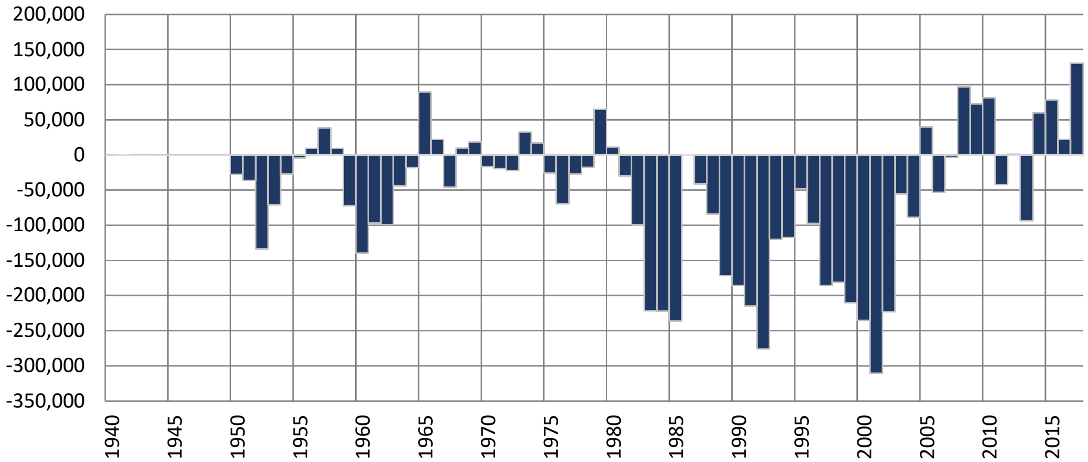
Run 12 - D3 + Carryover Allocation (All Pumping On)

Simulated Differences in ILRG Model Outputs

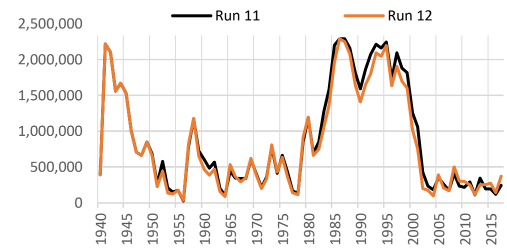
Run 12 minus Run 11

1940 - 2017 (acre-feet)

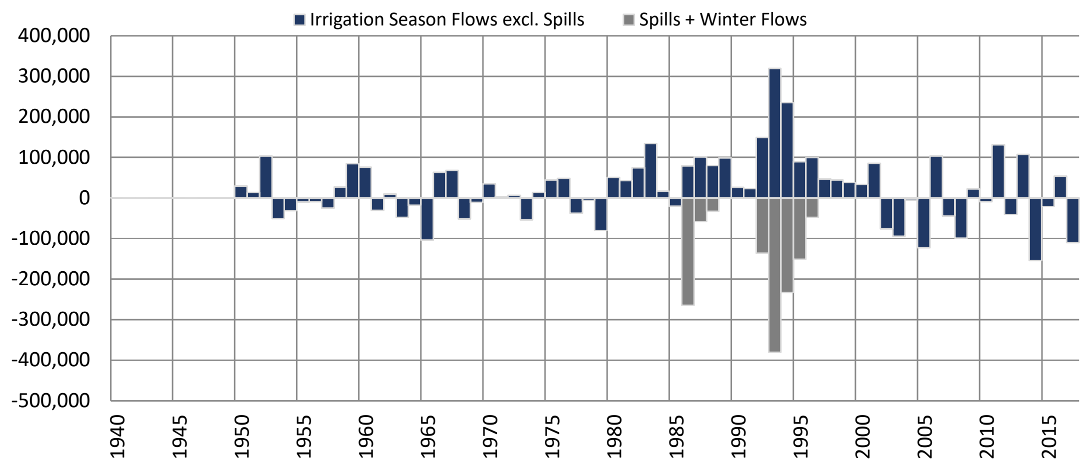
Total Project Storage (Year End)



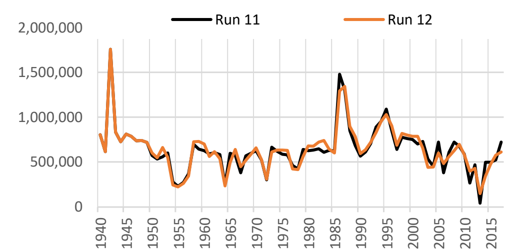
Period	Average Difference
1951-2017	2,357
1951-1978	356
1979-2005	2,125
2006-2017	7,550
1985-2017	10,688
1985-2005	12,482



Caballo Reservoir Outflows (Annual)



	Average Difference		
Period	Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	22,740	-19,455	3,284
1951-1978	3,994	0	3,994
1979-2005	54,511	-48,278	6,233
2006-2017	-5,005	0	-5,005
1985-2017	35,523	-39,500	-3,977
1985-2005	58,682	-62,072	-3,390



Notes:

Reservoir storage does not include storage attributed to SJC, CO, or NM credit waters.

Average differences calculated as (Final Storage - Initial Storage)/(no. years).

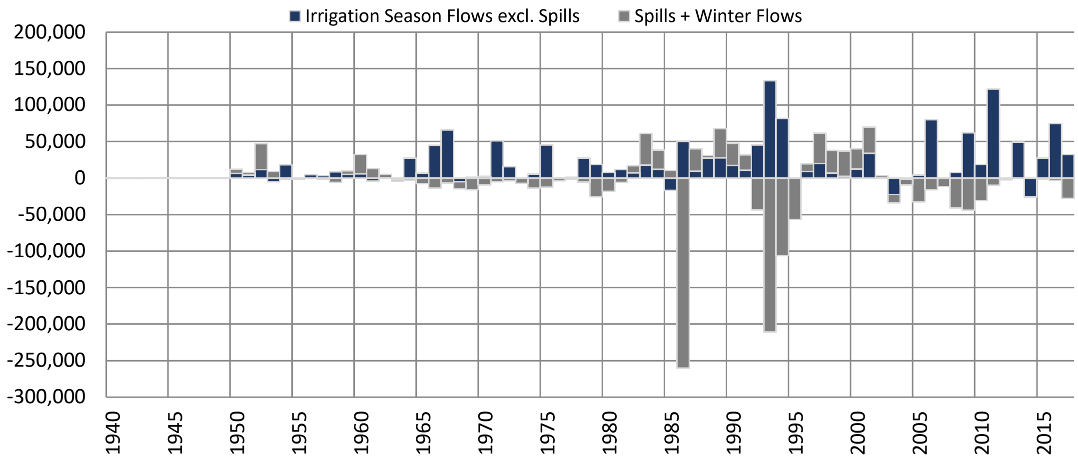
Run 12 - D3 + Carryover Allocation (All Pumping On)

Simulated Differences in ILRG Model Outputs

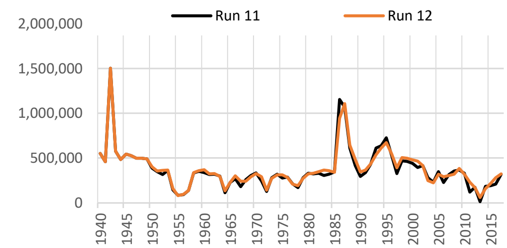
Run 12 minus Run 11

1940 - 2017 (acre-feet)

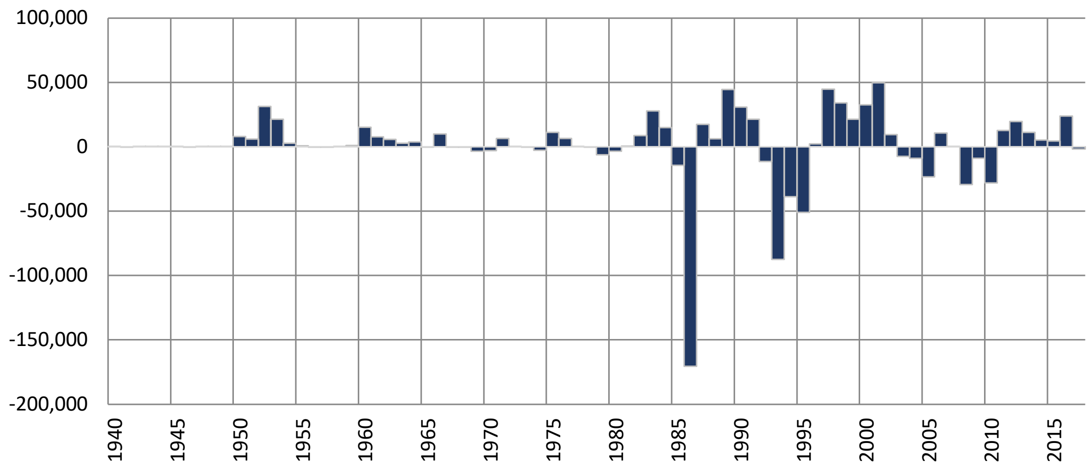
Rio Grande at El Paso (Annual)



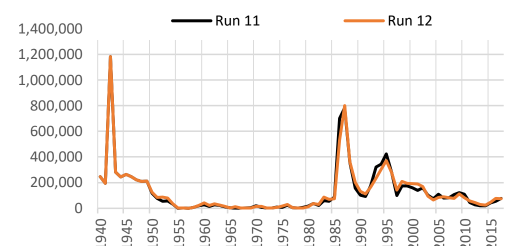
	Average Difference		
Period	Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	19,634	-8,983	10,651
1951-1978	12,214	-1,221	10,992
1979-2005	19,551	-14,104	5,447
2006-2017	37,136	-15,569	21,567
1985-2017	27,217	-18,097	9,119
1985-2005	21,549	-19,542	2,006



Rio Grande at Fort Quitman (Annual)



Period	Average Difference
1951-2017	1,247
1951-1978	4,367
1979-2005	-2,150
2006-2017	1,607
1985-2017	-2,450
1985-2005	-4,768



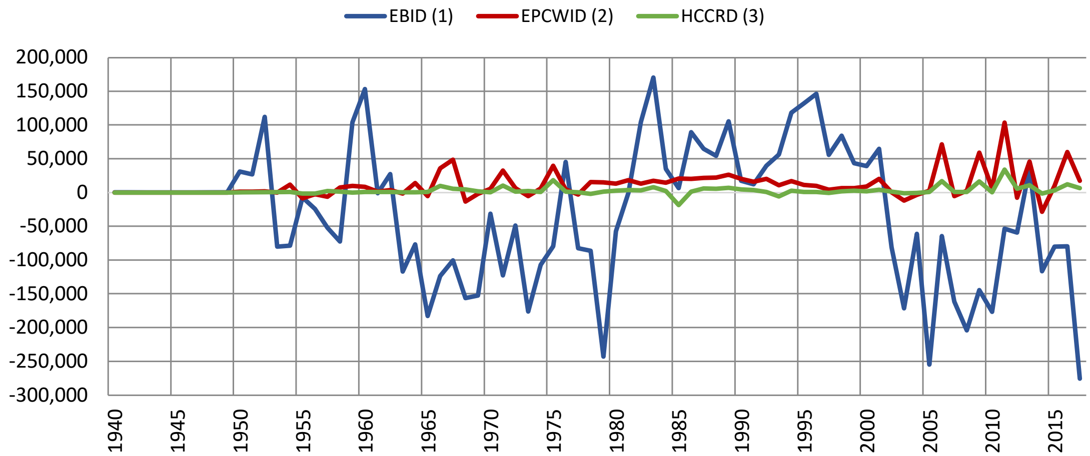
Run 12 - D3 + Carryover Allocation (All Pumping On)

Simulated Differences in ILRG Model Outputs

Run 12 minus Run 11

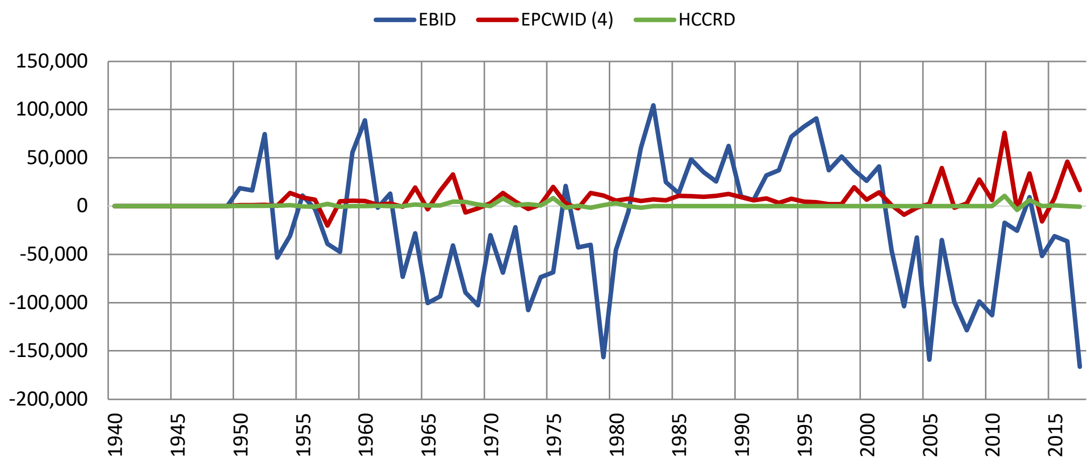
1940 - 2017 (acre-feet)

River Headgate (RHG) Diversions (Irrigation Season)



	Average Difference		
Period	EBID	EPCWID	HCCRD
1951-2017	-34,425	13,097	3,027
1951-1978	-53,352	7,298	2,110
1979-2005	21,014	12,557	1,417
2006-2017	-115,000	27,843	8,791
1985-2017	-24,892	17,645	3,749
1985-2005	26,598	11,818	868

Farm Headgate (FHG) Deliveries (Irrigation Season)



	Average Difference		
Period	EBID	EPCWID	HCCRD
1951-2017	-19,820	8,168	708
1951-1978	-31,417	4,931	1,154
1979-2005	12,847	6,456	71
2006-2017	-66,264	19,573	1,100
1985-2017	-13,035	11,119	400
1985-2005	17,381	6,289	0

Notes:

(1) EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

(2) EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

(3) HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

(4) EPCWID FHG values include deliveries to Rogers WTP and R/U WTP.

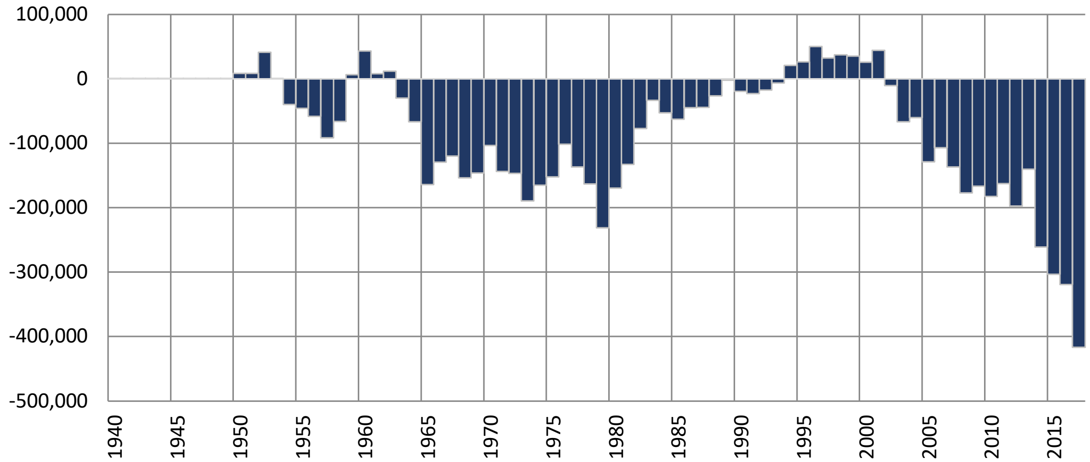
Run 12 - D3 + Carryover Allocation (All Pumping On)

Simulated Differences in ILRG Model Outputs

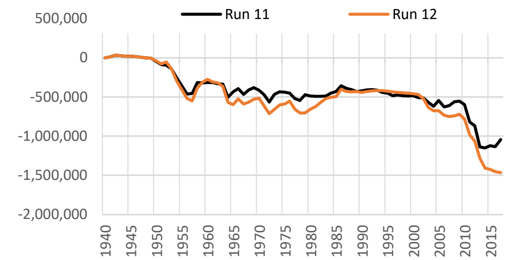
Run 12 minus Run 11

1940 - 2017 (acre-feet)

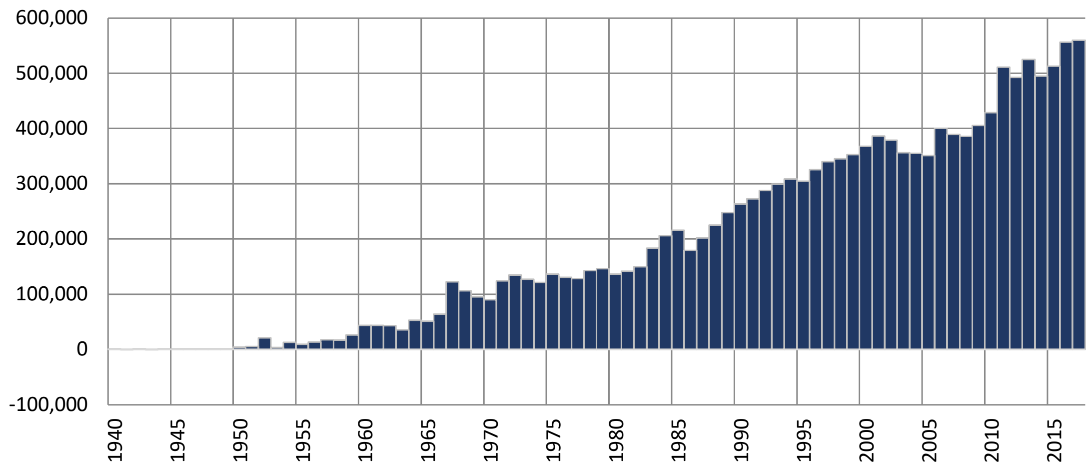
Cumulative Annual Rincon-Mesilla Groundwater Storage



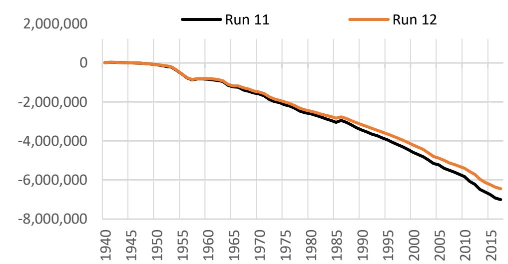
Period	Average Difference
1951-2017	-6,349
1951-1978	-6,126
1979-2005	1,264
2006-2017	-23,995
1985-2017	-11,029
1985-2005	-3,620



Cumulative Annual Hueco Groundwater Storage



Period	Average Difference
1951-2017	8,297
1951-1978	4,943
1979-2005	7,708
2006-2017	17,444
1985-2017	10,723
1985-2005	6,883



Notes:

Cumulative storage change in alluvial and non-alluvial aquifers.

Average differences calculated as (Final Storage - Initial Storage)/(no. years).

Run 12 - D3 + Carryover Allocation (All Pumping On)

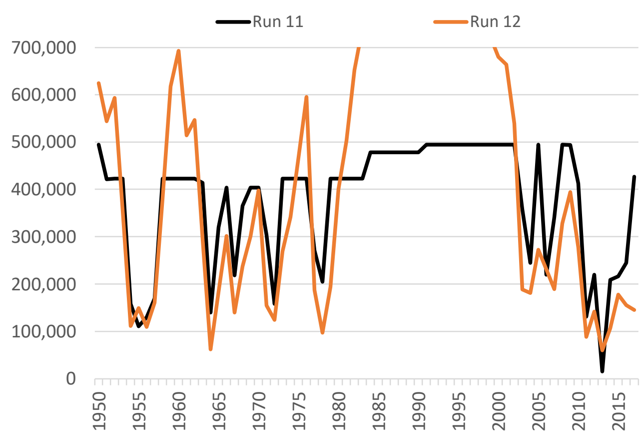
Annual Allocation and Charges

Run 12 v. Run 11

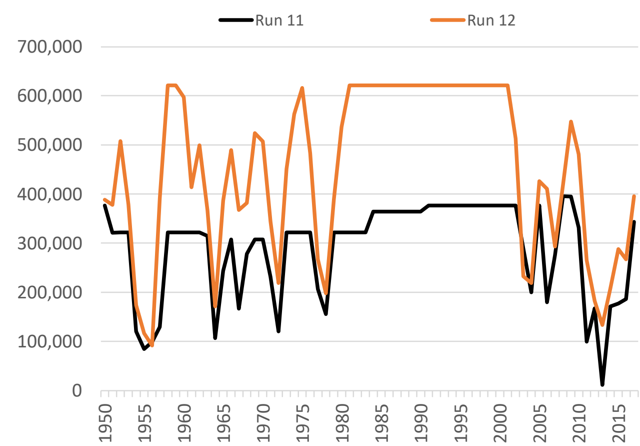
ILRG Model

1950 - 2017 (acre-feet)

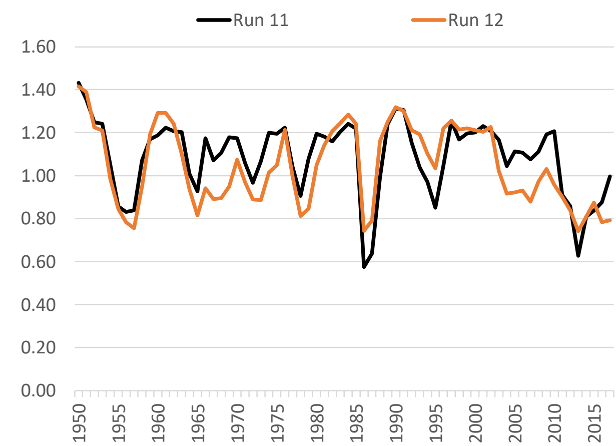
Total Allocation - EBID



Total Allocation - EPCWID



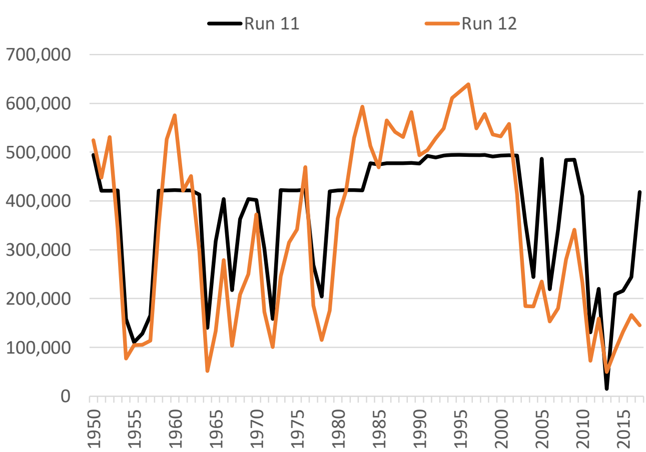
Diversion Ratio



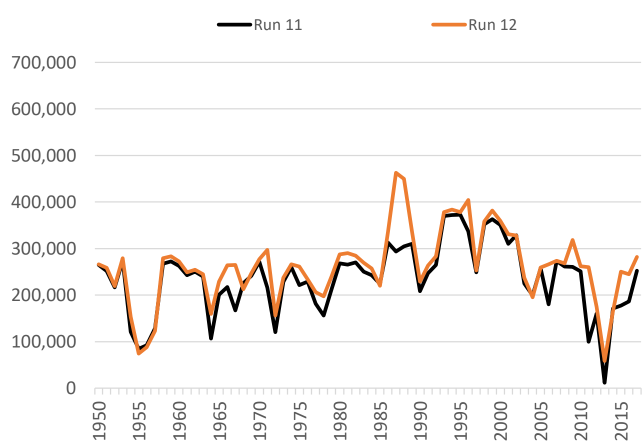
Note:

Computed as Total Charges/Caballo Release.

Annual Delivery Charges - EBID



Annual Delivery Charges - EPCWID



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Run 12 - D3 + Carryover Allocation (All Pumping On)

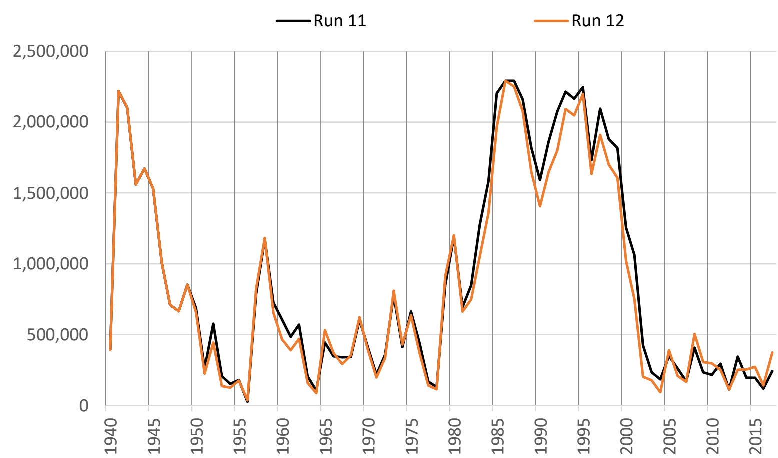
Annual Summary of Project Storage and Rio Grande Flows

Run 12 v. Run 11

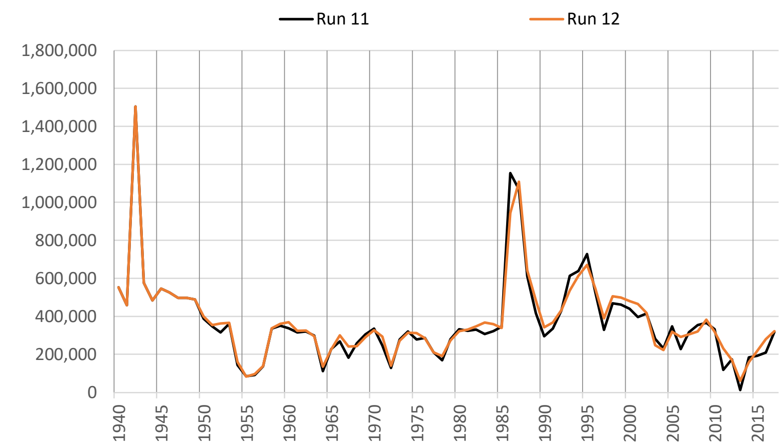
ILRG Model

1940 - 2017 (acre-feet)

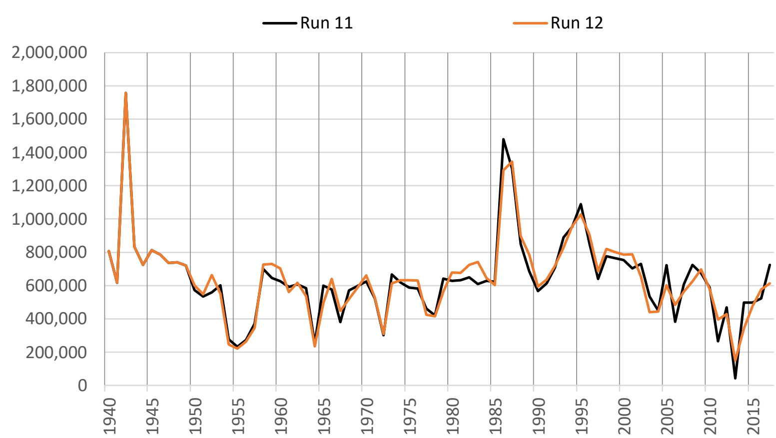
Total Year-End Project Reservoir Storage



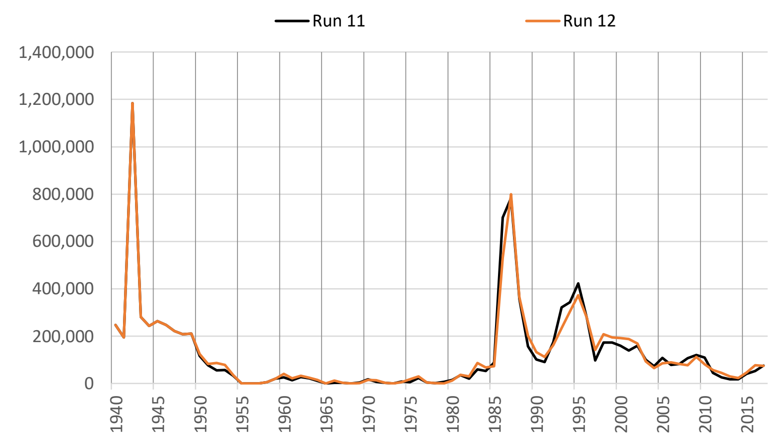
Rio Grande at El Paso



Rio Grande Below Caballo



Rio Grande at Fort Quitman



***Note different scales.**

Run 12 - D3 + Carryover Allocation (All Pumping On)

Irrigation Season Summary of Irrigation Operations

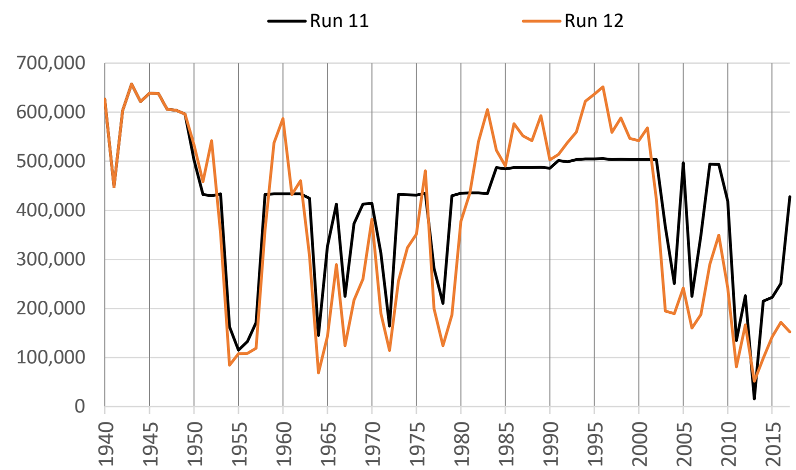
Run 12 v. Run 11

ILRG Model

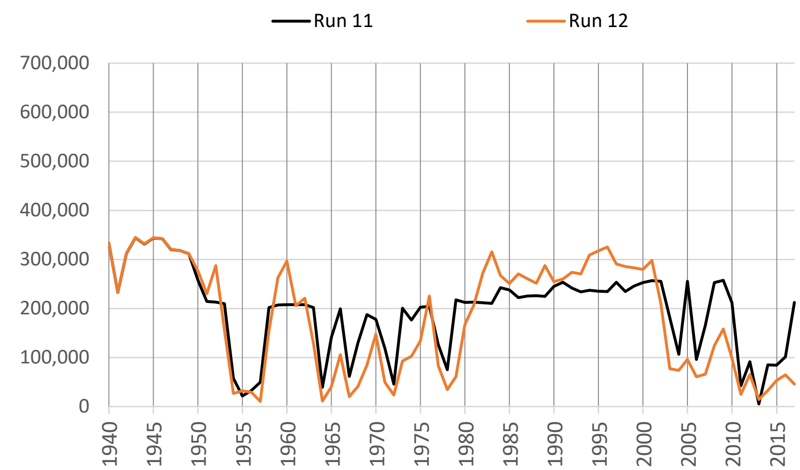
1940 - 2017 (acre-feet)

EBID Total

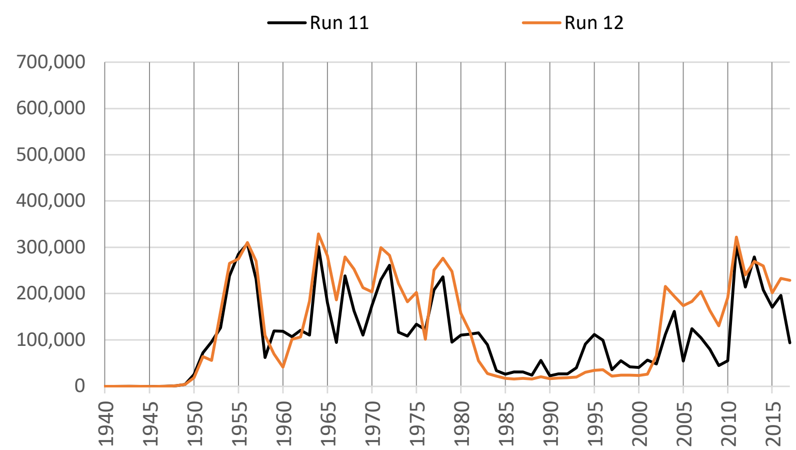
Net River Headgate Diversions



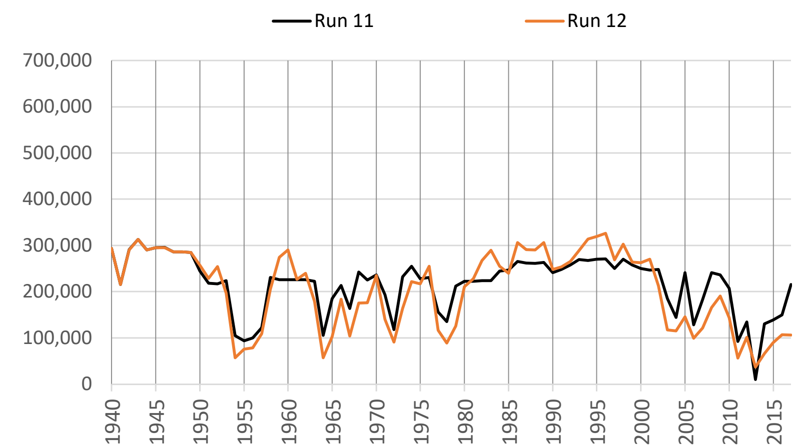
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries

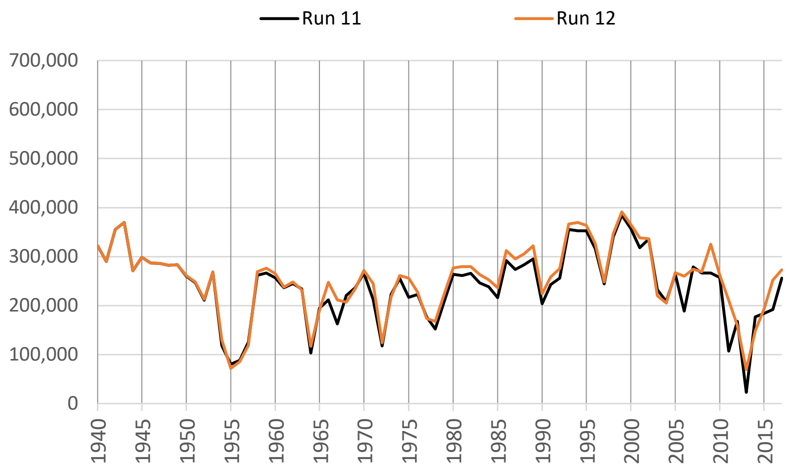


Notes: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).
Pumping includes Supplemental and Primary groundwater pumping.

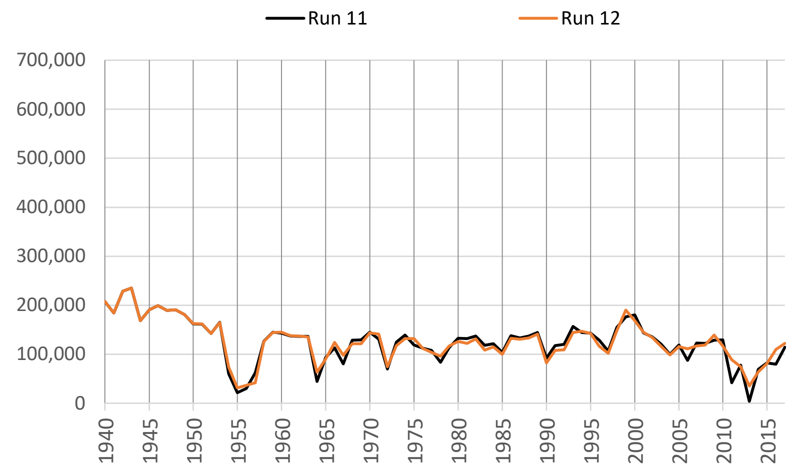
Run 12 - D3 + Carryover Allocation (All Pumping On)
Irrigation Season Summary of Irrigation Operations
Run 12 v. Run 11
ILRG Model
1940 - 2017 (acre-feet)

EPCWID Total

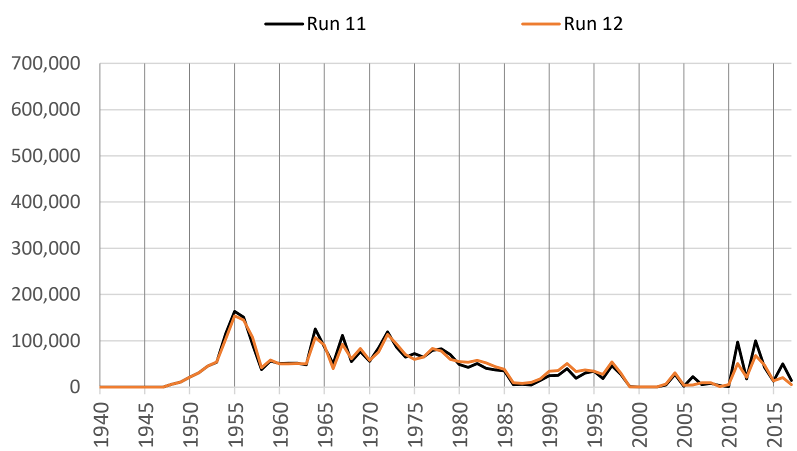
Net River Headgate Diversions



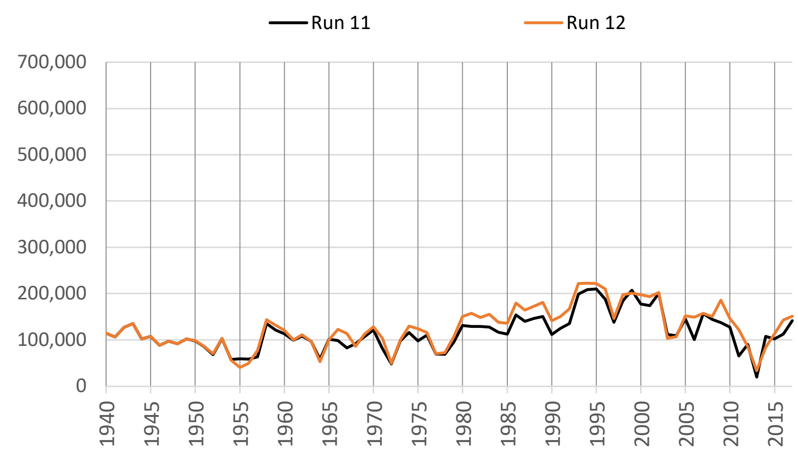
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries



Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

Run 12 - D3 + Carryover Allocation (All Pumping On)

Irrigation Season Summary of Irrigation Operations

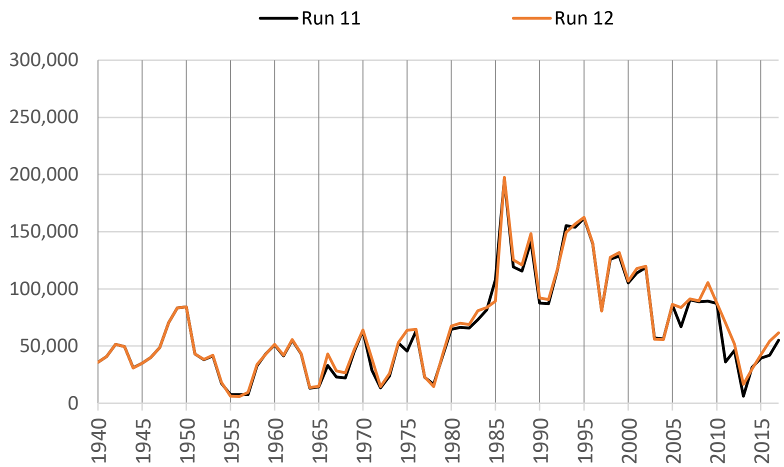
Run 12 v. Run 11

ILRG Model

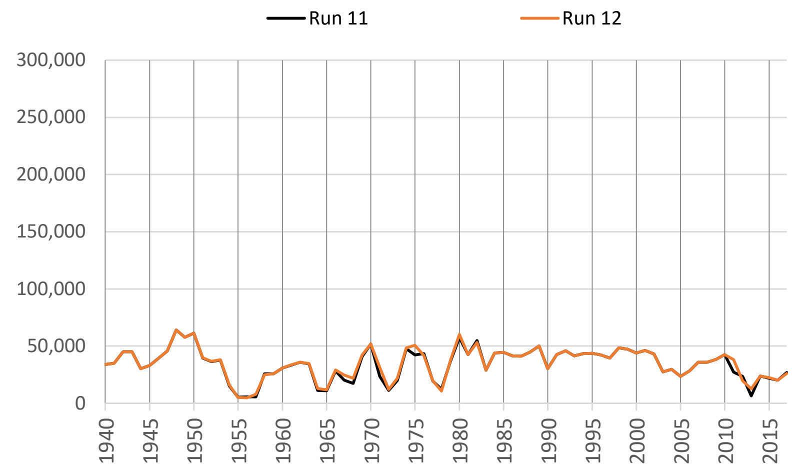
1940 - 2017 (acre-feet)

HCCRD Total

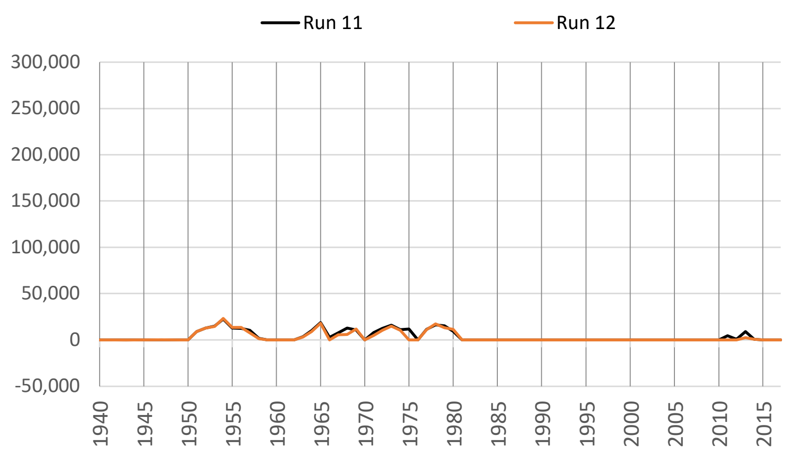
Net River Headgate Diversions



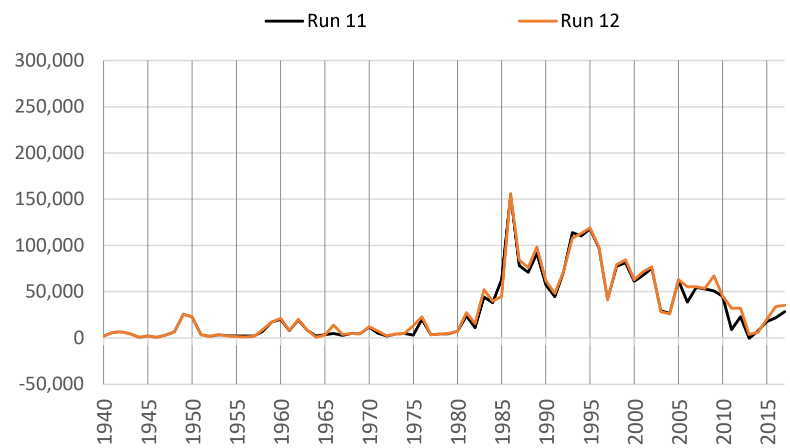
Farm Headgate Deliveries



Pumping



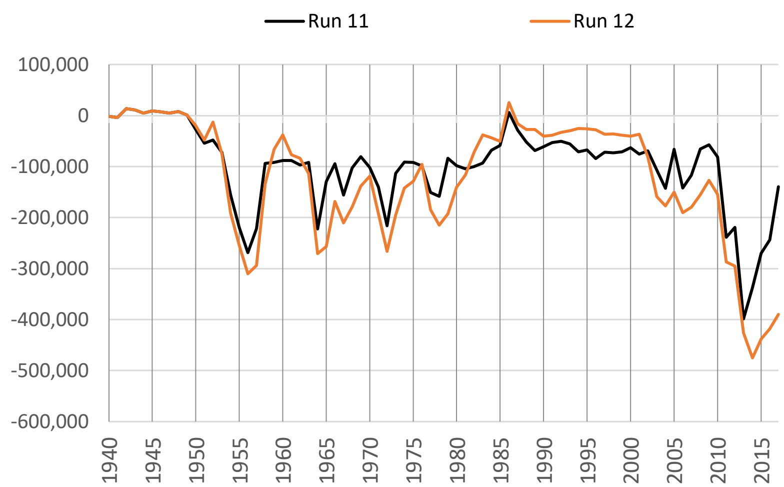
RHG Diversions - FHG Deliveries



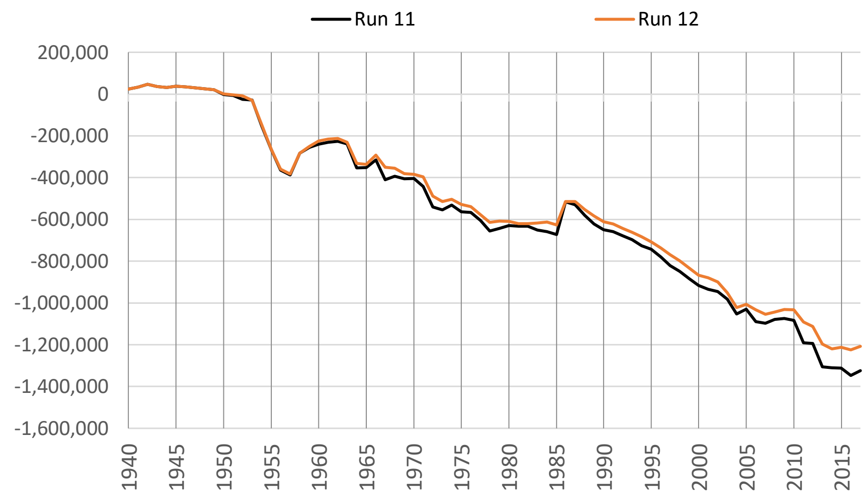
Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

Run 12 - D3 + Carryover Allocation (All Pumping On)
Cumulative Change in Ground Water Storage
Run 12 v. Run 11
ILRG Model
1940 - 2017 (acre-feet)

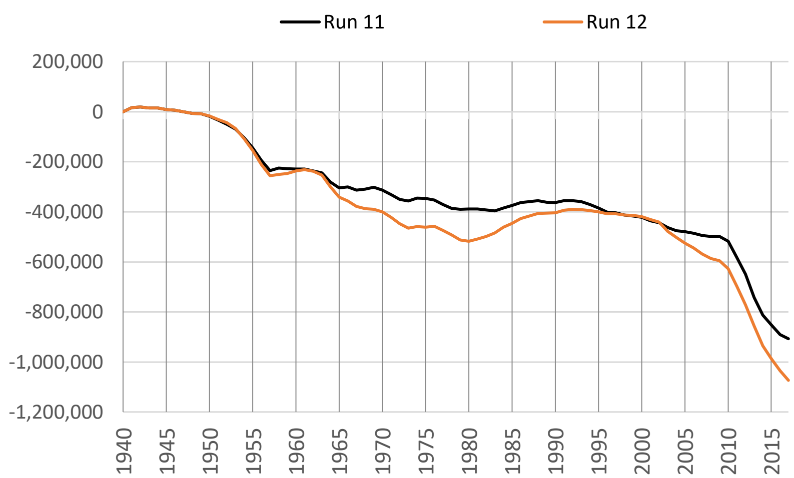
Rincon-Mesilla Alluvial Aquifer



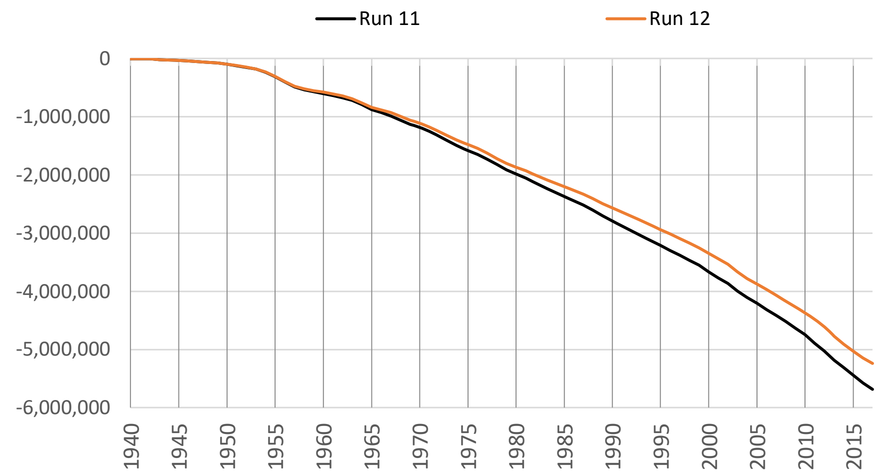
Hueco Alluvial Aquifer



Rincon-Mesilla Non-Alluvial Aquifer

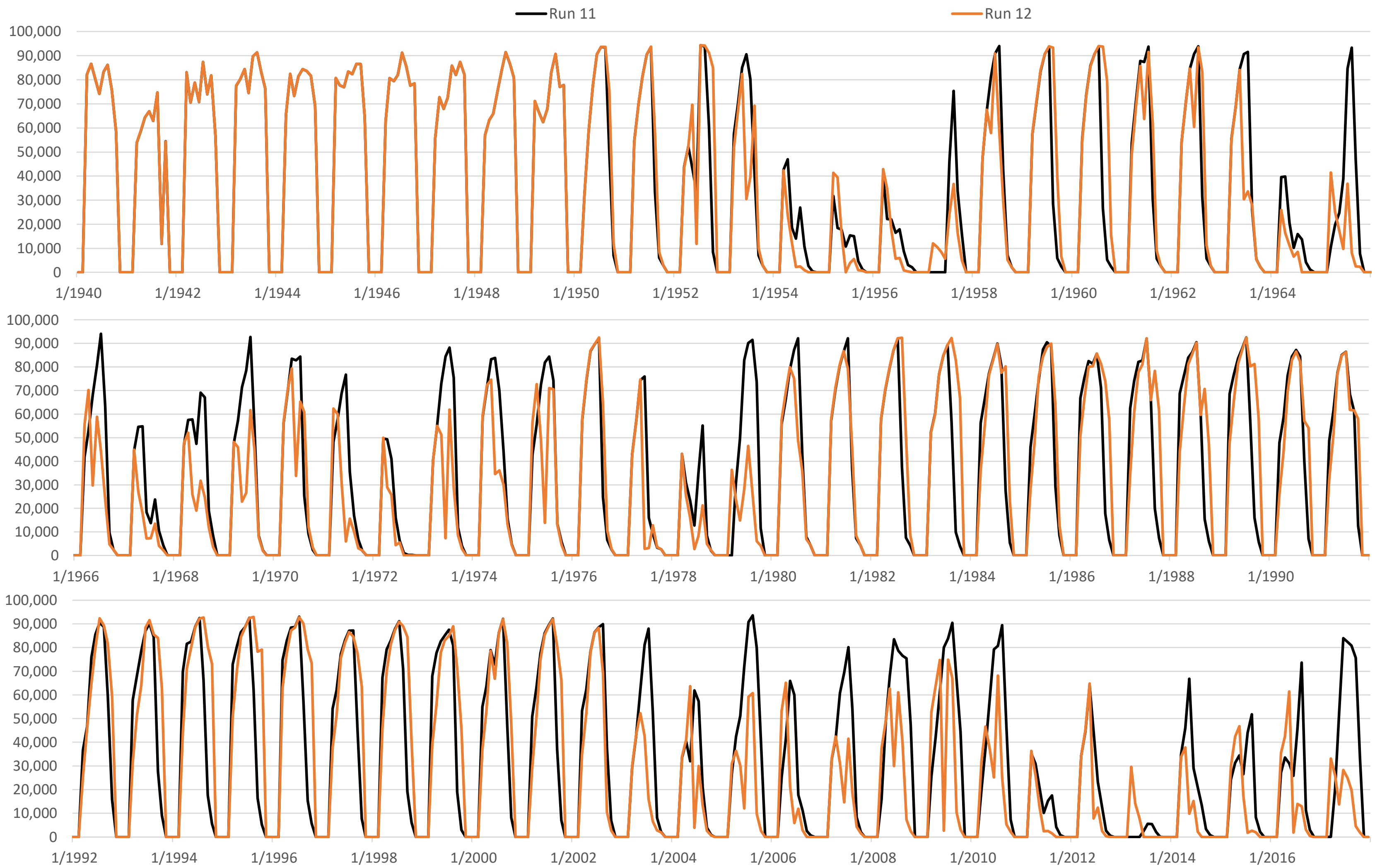


Hueco Non-Alluvial Aquifer



***Note different scales.**

Run 12 - D3 + Carryover Allocation (All Pumping On)
Monthly Net RHG Diversions
Run 12 v. Run 11
ILRG Model
1940 - 2017 (acre-feet)
EBID Total

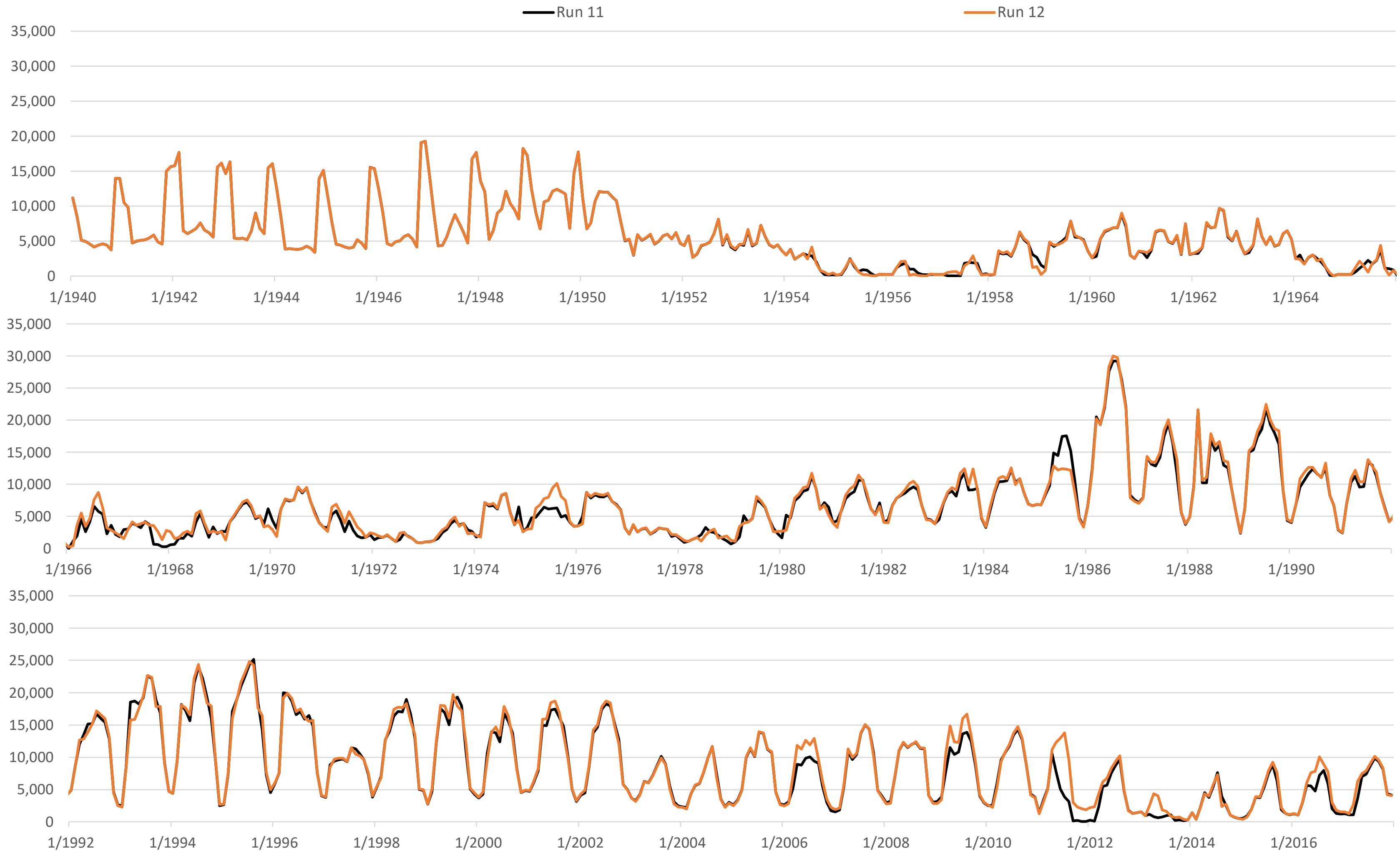


Note: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

Run 12 - D3 + Carryover Allocation (All Pumping On)
Monthly Net RHG Diversions
Run 12 v. Run 11
ILRG Model
1940 - 2017 (acre-feet)
EPCWID Total

Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

Run 12 - D3 + Carryover Allocation (All Pumping On)
Monthly Net RHG Diversions
Run 12 v. Run 11
ILRG Model
1940 - 2017 (acre-feet)
HCCRD Total



Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

Run 12 - D3 + Carryover Allocation (All Pumping On)

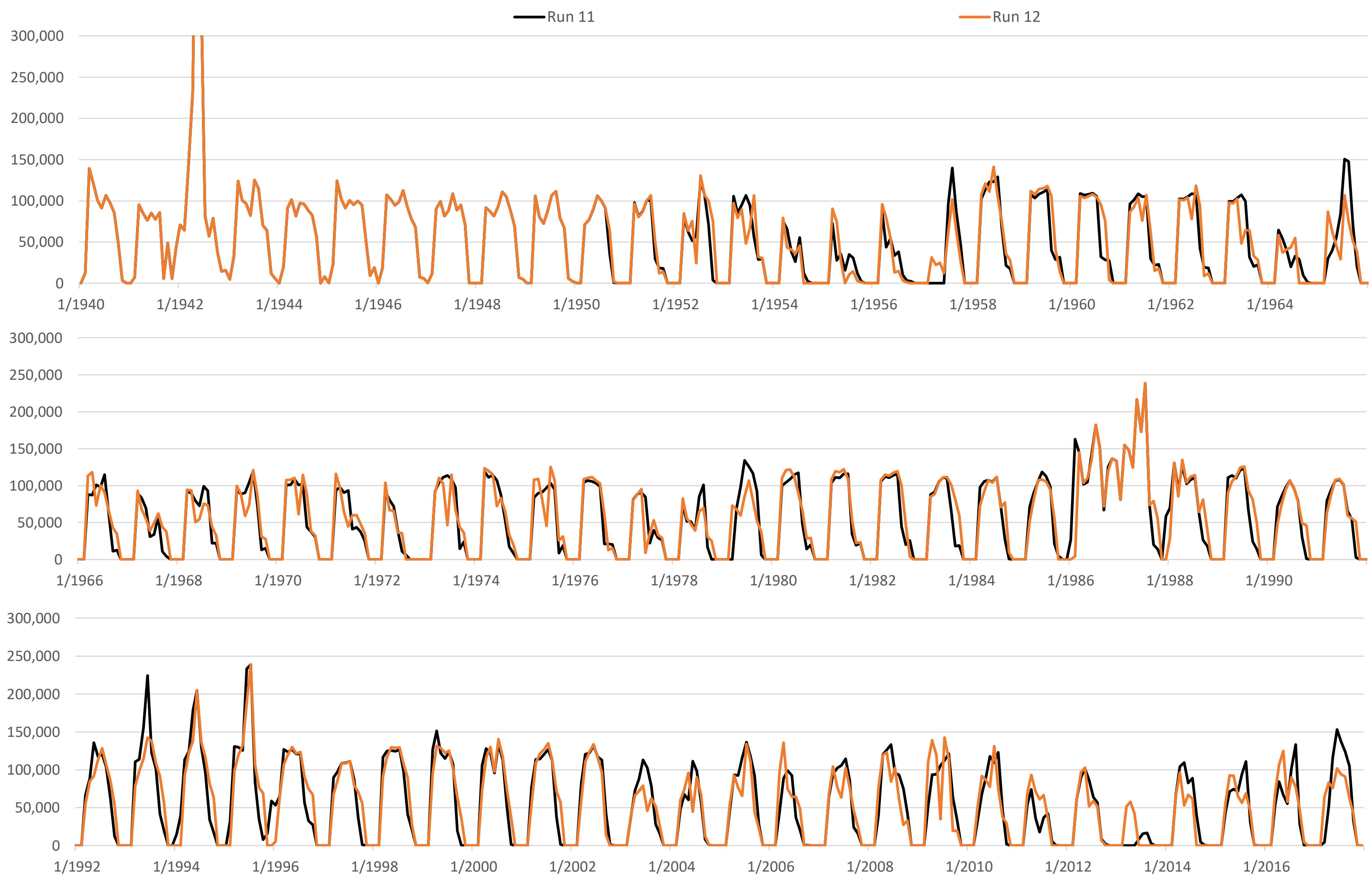
End of Month Reservoir Storage (Elephant Butte + Caballo)

Run 12 v. Run 11

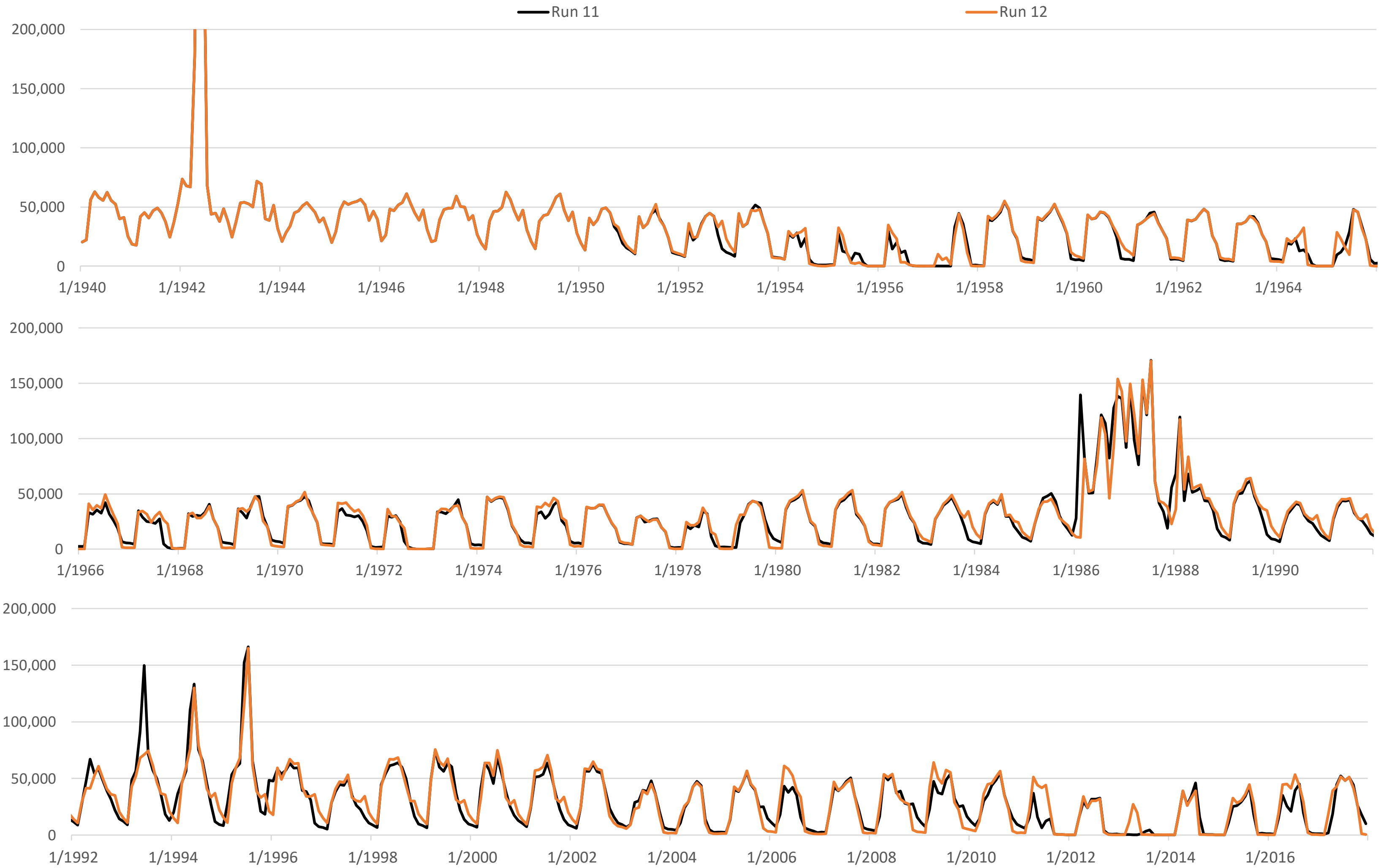
ILRG Model

1940 - 2017 (acre-feet)

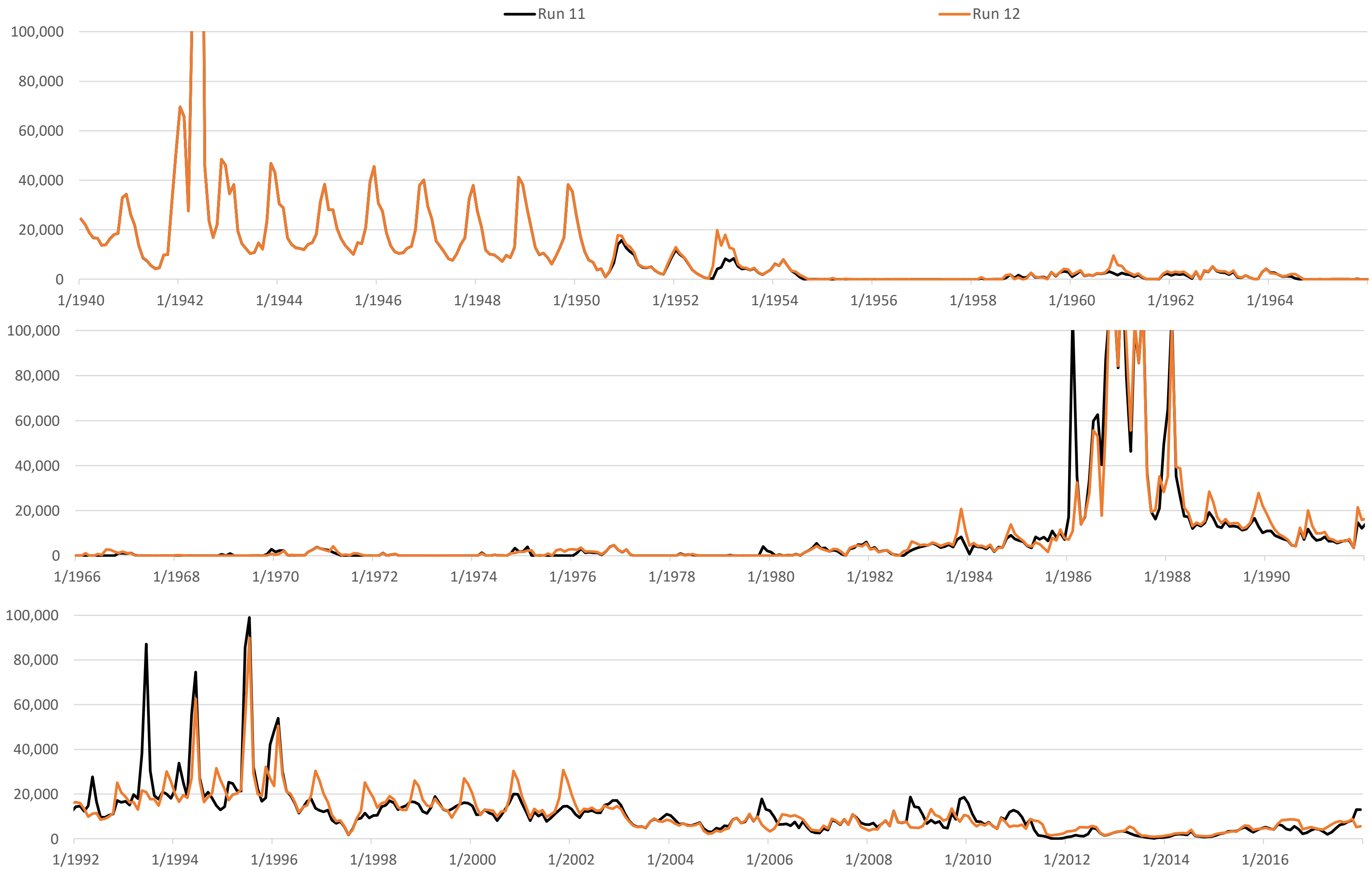
Run 12 - D3 + Carryover Allocation (All Pumping On)
Monthly Caballo Releases
Run 12 v. Run 11
ILRG Model
1940 - 2017 (acre-feet)



Run 12 - D3 + Carryover Allocation (All Pumping On)
Monthly Rio Grande at El Paso Flow
Run 12 v. Run 11
ILRG Model
1940 - 2017 (acre-feet)



Run 12 - D3 + Carryover Allocation (All Pumping On)
Monthly Rio Grande at Fort Quitman Flow
Run 12 v. Run 11
ILRG Model
1940 - 2017 (acre-feet)



Appendix 30M

Comparison of ILRG Model Runs
Run 13 v. Run 1

Model Run Specifications

Model Version: LRG_v116

Name: **Run 13 - Reduced Waste**

Run ID: LRG_v116_Operational_Run13
Date: 8/27/2020

Name: **Run 1 - Historical Base Run (All Pumping On)**

Run ID: LRG_v116_Operational_Run1
Date: 8/23/2020

Selected Model Inputs

Pumping and Returns	**Run 13**	**Run 1**
Irrigation Pumping	On	On
Irrigated Area	Hist	Hist
Non-Irrigation Pumping	On	On
Non-Irrigation Pumping Returns	On	On
Las Cruces Jornada Pumping Returns	On	On

Project Allocation Rules		
1950-2005	D1/D2	D1/D2
2006-2007	D3	D3
2008-2017	D3 + CO	D3 + CO

EPCWID Operations		
Charge EPCWID for Use of WWTP Returns	Off	Off
ACE and Haskell Credits for EPCWID	On	On
Increased EPCWID Use of Fabens Drain Flows	Off	Off
Charge EPCWID for Fabens Drain Flow Use	Off	Off

Notes:
(1) Limit waste to minimum of tuned percentage or 10% of diversion.

Run 13 - Reduced Waste

Comparison of ILRG Model Runs

Run 13 v. Run 1

1951 - 2017 Annual Average

(1,000 acre-feet)

Run No.	1	13	13 - 1	
Simulated Input or Output	**Run 1**	**Run 13**	**Run 13 minus Run 1**	
Effects of Alternate Scenario				
FHG Deliveries (Mar - Oct)				***% Diff.***
EBID	167.6	201.8	34.2	*20%*
EPCWID (incl. EPW)	139.9	151.1	11.3	*8%*
HCCRD	32.8	28.5	-4.3	*-13%*
Total	340.3	381.4	41.1	*12%*
FHG Deliveries (Nov - Feb)				
EBID	0.0	0.0	0.0	*123%*
EPCWID (incl. EPW)	0.2	5.0	4.8	*2564%*
HCCRD	2.4	3.6	1.2	*49%*
Total	2.6	8.6	6.0	*231%*
Irrigation Pumping				
EBID	140.4	108.7	-31.7	*-23%*
EPCWID (Mesilla Valley)	7.4	5.1	-2.2	*-31%*
EPCWID (El Paso Valley)	40.1	28.6	-11.6	*-29%*
HCCRD	4.2	8.5	4.3	*101%*
Total	192.1	150.9	-41.2	*-21%*
Other Inflows/Outflows				
Net Reservoir Evaporation	125.3	139.7	14.4	*12%*
Riparian ET	70.9	68.9	-2.0	*-3%*
River Evaporation + Incidental Canal Loss	30.3	29.9	-0.4	*-1%*
Total	226.6	238.5	12.0	*5%*
Rio Grande at Fort Quitman				
Reservoir Spills	33.3	45.1	11.8	*35%*
Nov-Feb Flows	21.4	17.3	-4.1	*-19%*
Mar - Oct Flows	41.1	18.9	-22.2	*-54%*
Underflow (GW Model)	0.2	0.2	0.0	*-16%*
Total	96.0	81.4	-14.5	*-15%*

Run 13 - Reduced Waste
Comparison of ILRG Model Runs
Run 13 v. Run 1
1951 - 2017 Annual Average
(1,000 acre-feet)

Run No.	1	13	13 - 1	
Simulated Input or Output	**Run 1**	**Run 13**	**Run 13 minus Run 1**	
Effects of Alternate Scenario (continued)				
Change in Storage				***% Diff.***
Reservoir Storage	-4.7	-9.4	-4.7	*102%*
Alluvial GW Storage (RW Model)	-23.6	-22.0	1.6	*-7%*
Non-alluvial GW Storage (GW Models)	-96.4	-91.7	4.7	*-5%*
Soil Moisture Storage	0.6	0.7	0.1	*25%*
Total	-124.0	-122.3	1.7	*-1%*
Summary of Effects				
FHG Deliveries (Mar-Oct)	340.3	381.4	41.1	*12%*
FHG Deliveries (Nov-Feb)	2.6	8.6	6.0	*231%*
Irrigation Pumping	192.1	150.9	-41.2	*-21%*
Riparian ET + Evaporation	226.6	238.5	12.0	*5%*
Fort Quitman Flow	96.0	81.4	-14.5	*-15%*
Change in Storage	-124.0	-122.3	1.7	*-1%*
Total	733.6	738.6	5.0	*1%*
Other Effects of Alternate Scenario				
Rio Grande at El Paso				***% Diff.***
Reservoir Spills	49.4	71.1	21.7	*44%*
Nov-Feb Flows	22.8	28.0	5.2	*23%*
Mar - Oct Flows	263.8	223.0	-40.8	*-15%*
Total	336.0	322.0	-13.9	*-4%*
Rio Grande below Caballo				
Reservoir Spills	65.9	96.3	30.4	*46%*
Nov-Feb Flows	0.5	0.7	0.2	*52%*
Mar - Oct Flows	541.3	500.9	-40.3	*-7%*
Total	607.6	598.0	-9.6	*-2%*
Surface Water Diversions (Mar - Oct)				
EBID	366.5	399.3	32.8	*9%*
EPCWID (incl. EPW)	236.8	203.3	-33.5	*-14%*
HCCRD	67.5	47.3	-20.3	*-30%*
Total	670.8	649.9	-20.9	*-3%*
Surface Water Diversions (Nov - Feb)				
EBID	0.0	0.0	0.0	*0%*
EPCWID (incl. EPW)	14.3	15.2	0.8	*6%*
HCCRD	14.2	11.6	-2.6	*-19%*
Total	28.5	26.7	-1.8	*-6%*

Run 13 - Reduced Waste
Annual Differences in ILRG Model Outputs
Run 13 minus Run 1
1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1940	-35,290	-35,290	-78,398	-69,876	-26,983	-56,255	9,057	9,062	-4,197	53,068	-25,007	-24,622	-114,402	-113,176	-126,923
1941	-18,177	-18,177	-114,977	-115,869	-30,632	-47,816	-5,618	-5,595	-46,587	-20,787	-25,555	-24,328	98,482	82,086	93,807
1942	-57,582	-57,582	-92,628	-97,834	-26,493	-33,919	890	822	-21,207	-15,874	-21,688	-16,092	-36,516	-16,644	25,501
1943	-44,422	-44,422	-70,399	-72,947	-22,798	-28,742	13,171	13,182	-5,977	-716	-21,241	-21,935	-24,940	-32,320	-14,851
1944	-43,709	-43,709	-51,678	-48,747	-20,483	-35,653	1,267	1,244	6,915	37,450	-19,696	-19,746	-66,808	-64,986	-82,464
1945	-40,911	-40,911	-73,157	-71,353	-23,855	-38,413	4,475	4,463	-6,075	21,649	-21,875	-20,788	-102,673	-101,799	-101,548
1946	-39,172	-39,172	-70,441	-78,221	-23,932	-40,349	5,602	5,602	-3,692	18,201	-23,569	-23,076	-97,866	-99,501	-94,810
1947	-39,125	-39,125	-71,355	-69,319	-23,935	-39,885	3,489	3,495	-3,185	25,752	-23,462	-20,369	-80,999	-82,709	-86,369
1948	-38,925	-38,925	-69,801	-68,341	-22,090	-36,420	3,851	3,819	-4,378	21,384	-17,832	-12,026	-79,936	-80,965	-76,334
1949	-55,167	-55,167	-74,184	-72,469	-22,627	-36,212	-7,650	-7,688	-5,836	20,027	-4,170	6,057	-95,748	-85,544	-87,416
1950	-1,520	-1,520	-62,984	-63,472	-28,555	-32,161	23,361	23,371	-9,397	-3,033	-7,885	1,032	-38,075	-56,880	-31,366
1951	-933	-933	-52,876	-50,976	-14,249	-21,670	21,181	21,186	-1,084	11,824	-14,925	-14,977	-52,108	-56,798	-40,236
1952	1,598	1,598	-9,435	-8,415	-5,069	-11,100	19,170	19,165	18,476	28,403	-7,302	-7,701	-42,429	-28,613	-31,164
1953	-1,571	-1,571	-54,995	-55,160	-15,135	-20,384	21,645	21,645	2,814	10,910	-15,858	-17,357	-46,562	-65,808	-41,118
1954	248,417	248,417	88,676	94,047	523	828	162,892	162,892	87,135	93,247	-204	162	250,386	129,033	-16,754
1955	48,707	48,707	37,108	42,874	3,517	5,793	43,591	43,591	48,983	51,419	3,726	5,504	25,188	54,523	8,465
1956	32,089	32,089	27,407	28,124	-1,420	-1,626	25,632	25,632	35,607	35,668	-1,227	-1,887	55,345	32,974	-96
1957	12,068	12,068	-16,175	-14,894	-4,547	-4,562	10,753	10,754	3,301	3,427	-3,267	-3,949	-2,020	-13,951	2
1958	-1,356	-1,356	-59,290	-58,000	-19,070	-19,930	22,144	22,146	427	3,604	-16,291	-14,102	-107,444	-62,867	-5,170
1959	-1,940	-1,940	-53,119	-52,450	-14,433	-16,580	20,926	20,928	-210	3,956	-2,041	1,755	-72,904	-61,204	-17,852
1960	-1,855	-1,855	-49,261	-48,899	-18,748	-23,424	20,737	20,739	-88	5,126	-3,210	-927	-62,018	-58,470	-23,419
1961	-1,972	-1,972	-50,904	-50,479	-16,136	-21,240	20,987	20,989	1,277	6,668	-12,812	-8,362	-63,089	-60,239	-12,660
1962	-1,879	-1,879	-48,380	-48,198	-19,356	-23,949	20,683	20,685	232	5,974	-4,796	-422	-59,998	-58,256	-25,363
1963	7,108	7,108	-49,413	-48,994	-15,550	-20,190	26,417	26,419	451	6,823	-10,782	-5,946	-44,867	-46,724	-17,262
1964	170,840	170,840	91,204	94,468	-980	-1,452	104,329	104,329	90,108	92,922	-1,527	1,043	218,972	115,755	-3,100
1965	38,445	38,445	-14,103	-11,546	-1,870	-2,168	31,677	31,678	24,952	29,061	-1,831	-1,351	-52,801	-4,096	3,816
1966	-716	-716	-15,762	-14,048	-2,834	-5,390	10,853	10,855	14,633	20,301	-2,788	-3,047	-42,808	-12,274	-718
1967	88,267	88,267	30,946	35,362	-1,807	-358	58,628	58,628	43,777	47,610	-3,762	-57	93,593	43,870	-1,250
1968	17,849	17,849	-29,046	-25,901	-508	-420	27,397	27,399	1,986	5,742	-357	-295	-47,989	-18,956	1,184
1969	-1,040	-1,040	-29,376	-28,329	-9,819	-12,699	12,489	12,490	-474	4,789	-9,997	-6,921	-47,161	-30,901	-4,398
1970	-1,695	-1,695	-42,191	-42,246	-20,090	-22,909	23,372	23,373	636	4,214	-12,731	-6,400	-56,523	-51,980	-16,416
1971	99,219	99,219	2,060	2,957	-4,467	-8,872	68,669	68,670	27,153	31,625	-4,051	-3,739	45,528	12,567	-5,338
1972	37,411	37,411	27,087	29,045	-1,757	-1,482	22,008	22,008	32,903	34,531	-3,093	-3,578	62,263	37,788	-1,261
1973	-1,895	-1,895	-25,675	-25,000	-8,211	-8,332	12,842	12,842	3,808	5,919	-8,448	-9,329	-60,326	-26,830	-96
1974	-1,561	-1,561	-34,570	-34,186	-21,183	-22,944	28,072	28,074	3,745	8,978	-21,262	-17,001	-49,774	-40,105	-7,271
1975	-192	-192	-3,354	-3,297	-6,423	-8,415	12,470	12,471	18,413	24,183	-7,470	-4,669	-23,259	-7,817	-5,699
1976	-2,691	-2,691	-32,764	-33,366	-23,773	-25,876	22,075	22,076	2,227	7,373	-8,238	-1,493	-36,647	-41,087	-22,678
1977	99,951	99,951	-1,104	1,110	-3,574	-5,299	69,734	69,734	19,511	23,253	-3,513	-2,951	39,537	8,532	-2,977
1978	64,167	64,167	-2,345	654	-6,930	-7,881	45,706	45,706	18,414	22,066	-6,810	-7,899	27,220	12,268	-765

Run 13 - Reduced Waste

Annual Differences in ILRG Model Outputs

Run 13 minus Run 1

1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1979	797	797	-27,278	-26,130	-19,289	-21,579	5,175	5,171	12,243	17,742	-19,739	-22,172	-68,735	-35,812	-2,561
1980	-2,789	-2,789	-61,823	-62,355	-32,388	-38,368	16,721	16,722	-643	6,518	-30,230	-26,216	-80,255	-77,168	-14,394
1981	-2,640	-2,640	-61,340	-61,557	-34,081	-41,371	16,347	16,348	-1,461	4,478	-15,142	-5,783	-77,818	-73,294	-35,450
1982	-2,513	-2,513	-61,635	-61,821	-29,687	-36,701	15,526	15,526	-1,398	4,686	-23,774	-18,856	-79,413	-75,568	-20,088
1983	-2,478	-2,478	-59,760	-59,754	-38,563	-46,150	16,017	16,019	-3,188	3,583	-608	6,615	-73,581	-71,443	-54,057
1984	-2,201	-2,201	-59,796	-59,929	-45,979	-53,585	16,009	16,016	-3,518	4,859	-11,417	-8,851	-52,572	-59,596	-42,024
1985	-933	-933	-7,060	-7,340	-7,253	-14,024	12,315	12,324	21,243	30,151	0	0	265,727	254,055	168,627
1986	-5,011	-5,011	-84,944	-85,405	-33,888	-39,189	18,882	18,912	-14,148	-5,481	0	0	87,161	89,370	71,475
1987	-5,769	-5,769	-70,732	-70,997	-33,189	-39,121	18,319	18,342	-6,811	2,421	0	0	400	2,357	-120,246
1988	-5,658	-5,658	-80,122	-80,241	-36,895	-44,194	16,636	16,656	-10,873	-169	0	0	-60,716	-58,492	-55,578
1989	-4,009	-4,009	-78,561	-78,608	-45,339	-52,468	23,603	23,619	-8,717	1,608	0	0	-65,194	-58,618	-45,194
1990	-1,565	-1,565	-21,373	-21,537	-25,010	-31,527	12,922	12,930	14,892	24,228	0	0	-35,983	-28,884	-39,641
1991	-5,916	-5,916	-65,048	-65,559	-32,102	-39,883	11,514	11,541	-10,317	-145	0	0	-59,438	-65,062	-46,111
1992	-2,854	-2,854	-11,166	-11,548	-11,034	-18,057	12,647	12,664	25,971	35,564	0	0	154,881	156,807	125,813
1993	-4,934	-4,934	-98,794	-98,731	-48,656	-55,772	21,643	21,664	-11,250	278	0	0	-8,245	-10,832	-851
1994	-2,245	-2,245	-90,522	-90,497	-48,162	-55,295	26,310	26,329	-3,383	8,381	0	0	-14,314	-7,216	-2,866
1995	-1,419	-1,419	-87,487	-87,390	-47,559	-54,444	27,612	27,623	-1,602	11,123	0	0	41,059	36,308	26,104
1996	-2,217	-2,217	-93,368	-93,433	-45,352	-52,224	26,499	26,500	-9,675	1,914	0	0	-123,397	-112,183	-86,834
1997	-2,794	-2,794	-69,226	-69,894	-28,524	-37,109	16,169	16,178	-12,075	-1,340	2,924	4,656	-47,636	-52,295	-45,462
1998	-2,465	-2,465	-90,372	-90,368	-45,958	-54,742	24,296	24,307	-7,322	4,961	0	191	-45,974	-40,891	-33,577
1999	-1,498	-1,498	-82,123	-81,876	-21,065	-23,383	12,013	12,016	5,967	8,031	0	0	-61,869	-61,220	-60,524
2000	-1,866	-1,866	-88,078	-87,792	-22,645	-23,593	3,736	3,737	-11,976	-11,971	0	0	-78,031	-66,274	-51,508
2001	-1,186	-1,186	-69,935	-69,976	-44,124	-45,070	17,557	17,559	821	1,019	0	0	-64,682	-69,323	-59,605
2002	-1,211	-1,211	-73,705	-73,441	-39,304	-40,352	18,777	18,778	465	783	0	0	-74,260	-73,819	-68,834
2003	134,326	134,326	-14,539	-14,157	-18,556	-18,731	90,606	90,619	23,290	23,677	0	0	83,308	31,106	-12,243
2004	149,456	149,456	11,872	14,259	-14,268	-12,159	102,298	102,299	42,033	42,447	0	0	73,816	43,082	-8,210
2005	135	135	-42,108	-40,718	-26,848	-25,589	13,958	13,964	4,665	4,882	0	0	-89,756	-34,658	-18,890
2006	101,477	101,477	26,324	27,162	-16,233	-14,439	69,051	69,051	49,963	50,057	0	0	60,724	32,432	-19,830
2007	136,295	136,295	-40,113	-39,104	-30,075	-28,984	95,009	95,009	10,261	10,329	0	0	-11,667	-24,315	-29,651
2008	157,614	157,614	-40,277	-39,435	-27,651	-27,573	109,574	109,582	5,822	6,243	0	0	6,625	-22,648	-24,262
2009	183,751	183,751	-82,015	-80,806	-42,736	-42,425	132,674	132,767	-8,744	-8,522	0	0	18,115	-32,629	-18,582
2010	239,134	239,134	-26,068	-23,553	-25,415	-25,096	161,956	162,036	15,583	15,715	0	0	69,996	31,395	19,912
2011	172,338	172,338	35,867	38,704	-10,889	-4,280	93,337	93,341	59,523	59,592	0	0	90,114	47,702	11,664
2012	27,076	27,076	-3,266	-2,610	-8,290	-3,102	9,184	9,184	23,755	24,215	0	0	-17,635	-8,279	2,543
2013	-33,689	-33,689	-721	-548	-425	938	-16,856	-16,856	10,818	10,998	3,107	3,256	-36,282	-2,184	3,964
2014	11,773	11,773	-8,215	-8,210	-5,521	-4,203	8,288	8,288	15,876	15,879	-5,250	-4,438	-1,185	-12,443	-5,542
2015	806	806	-24,419	-24,405	-16,592	-15,445	2,303	2,303	13,832	13,836	-4,967	-3,794	-34,295	-34,049	-20,721
2016	8,360	8,360	-23,159	-23,074	-20,670	-19,768	3,723	3,723	20,166	20,172	952	1,017	-29,928	-31,265	-34,275
2017	30,645	30,645	-46,459	-46,314	-23,471	-23,411	19,252	19,252	4,882	4,887	-64	-64	-52,743	-56,415	-36,769
Averages															
1951-2017	32,820	32,820	-33,451	-32,608	-20,262	-22,910	34,159	34,166	11,255	16,078	-4,315	-3,139	-9,647	-13,909	-14,535
1951-1978	33,744	33,744	-13,202	-11,634	-9,068	-11,162	35,253	35,254	17,825	22,486	-6,603	-4,853	-5,453	-10,702	-10,343
1979-2005	8,094	8,094	-60,705	-60,622	-32,434	-37,581	22,745	22,754	1,231	8,305	-3,629	-2,608	-20,575	-19,243	-19,731
2006-2017	86,298	86,298	-19,377	-18,516	-18,997	-17,316	57,291	57,307	18,478	18,617	-519	-335	5,153	-9,391	-12,629
1985-2017	38,362	38,362	-46,664	-46,286	-27,385	-29,840	36,843	36,856	7,665	12,296	-100	25	-1,858	-7,254	-15,627
1985-2005	10,970	10,970	-62,257	-62,155	-32,178	-36,996	25,158	25,170	1,486	8,684	139	231	-5,864	-6,032	-17,341

Notes:

EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

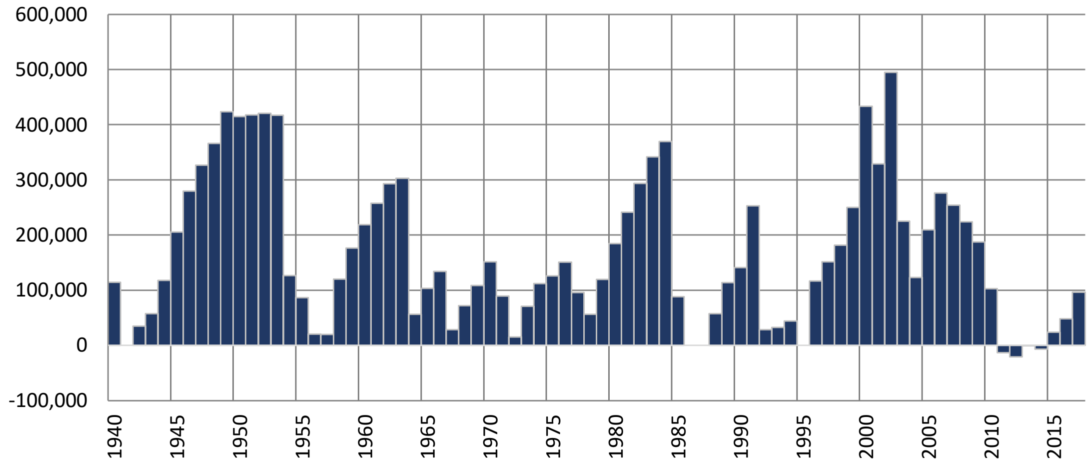
Run 13 - Reduced Waste

Simulated Differences in ILRG Model Outputs

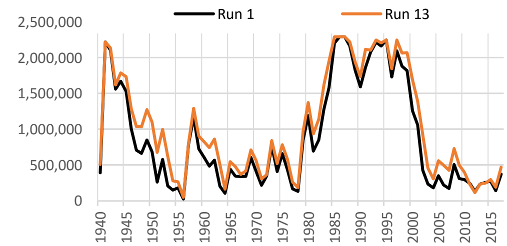
Run 13 minus Run 1

1940 - 2017 (acre-feet)

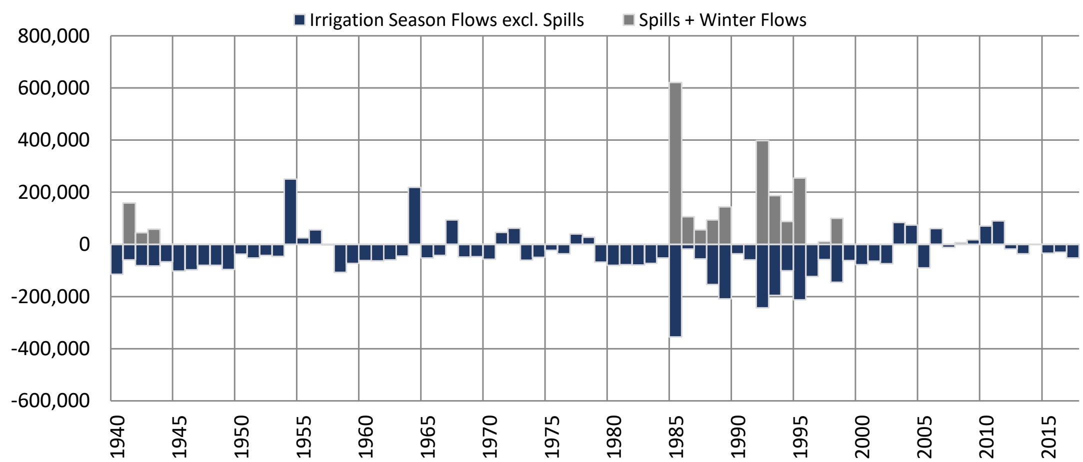
Total Project Storage (Year End)



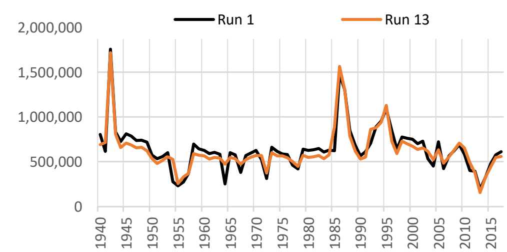
Period	Average Difference
1951-2017	-4,748
1951-1978	-12,793
1979-2005	5,676
2006-2017	-9,431
1985-2017	-8,276
1985-2005	-7,617



Caballo Reservoir Outflows (Annual)



Period	Average Difference Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	-40,335	30,688	-9,647
1951-1978	-5,453	0	-5,453
1979-2005	-96,725	76,151	-20,575
2006-2017	5,153	0	5,153
1985-2017	-64,163	62,305	-1,858
1985-2005	-103,772	97,908	-5,864



Notes:

Reservoir storage does not include storage attributed to SJC, CO, or NM credit waters.

Average differences calculated as (Final Storage - Initial Storage)/(no. years).

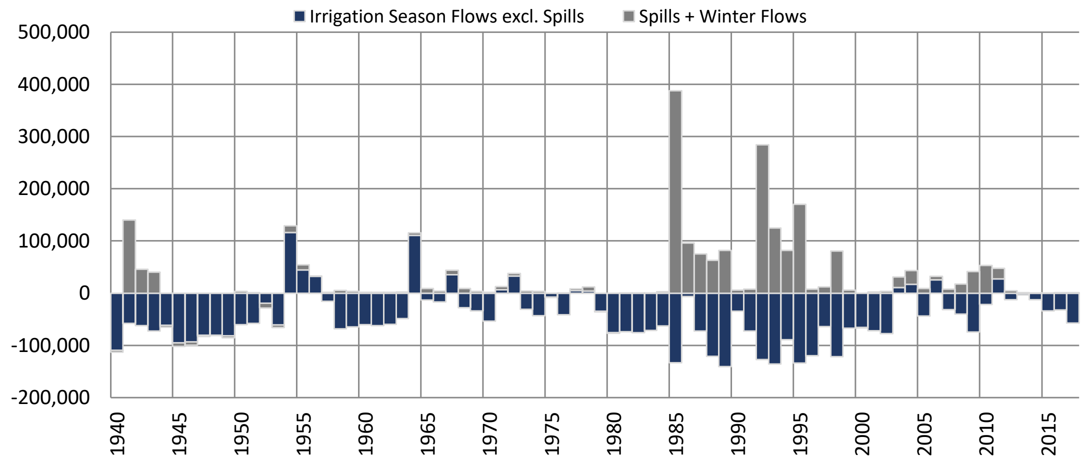
Run 13 - Reduced Waste

Simulated Differences in ILRG Model Outputs

Run 13 minus Run 1

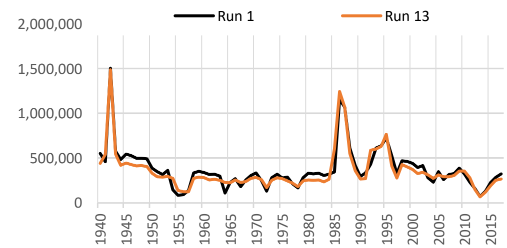
1940 - 2017 (acre-feet)

Rio Grande at El Paso (Annual)

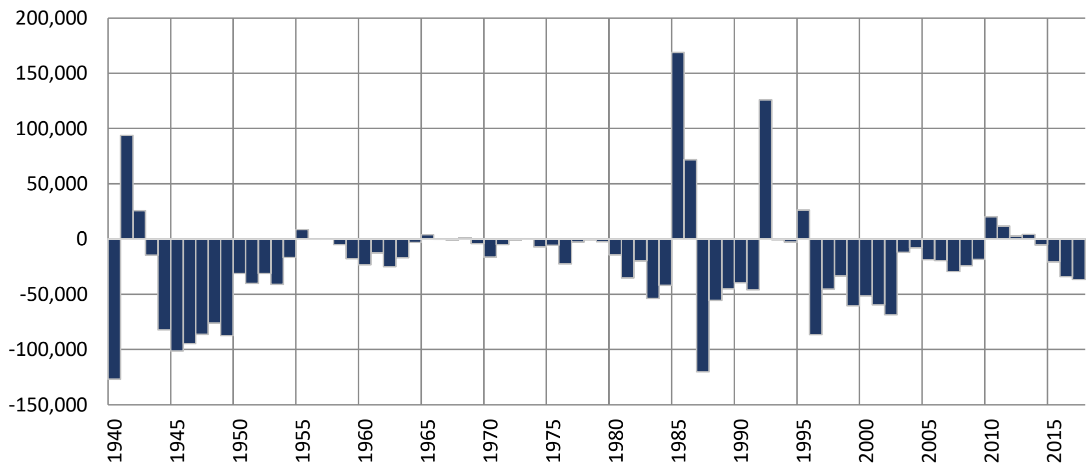


Average Difference

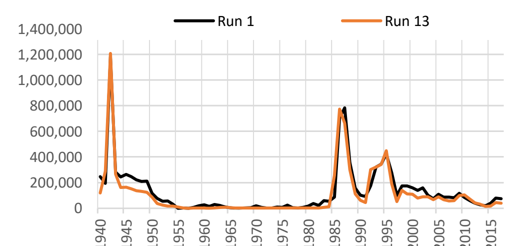
Period	Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	-40,751	26,842	-13,909
1951-1978	-14,267	3,565	-10,702
1979-2005	-76,428	57,184	-19,243
2006-2017	-22,276	12,885	-9,391
1985-2017	-58,703	51,449	-7,254
1985-2005	-79,518	73,485	-6,032



Rio Grande at Fort Quitman (Annual)



Period	Average Difference
1951-2017	-14,502
1951-1978	-10,313
1979-2005	-19,684
2006-2017	-12,616
1985-2017	-15,598
1985-2005	-17,303



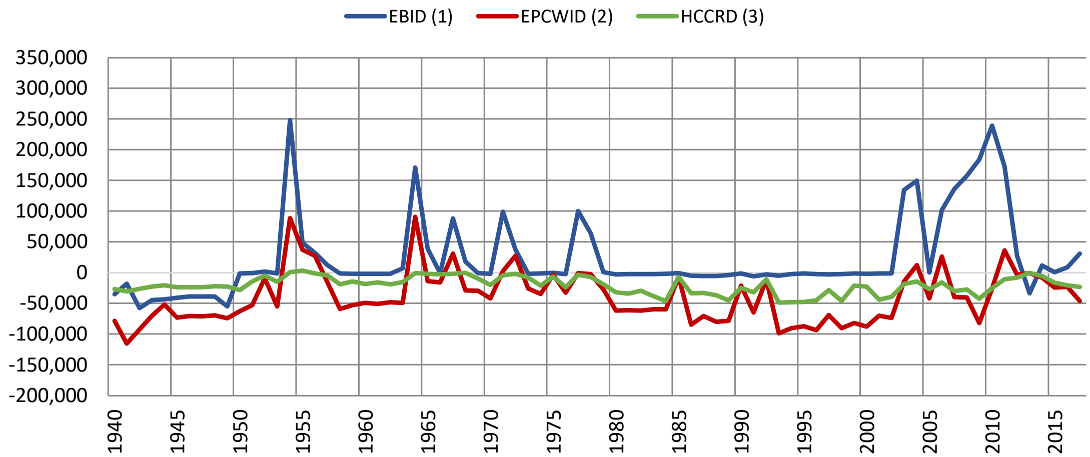
Run 13 - Reduced Waste

Simulated Differences in ILRG Model Outputs

Run 13 minus Run 1

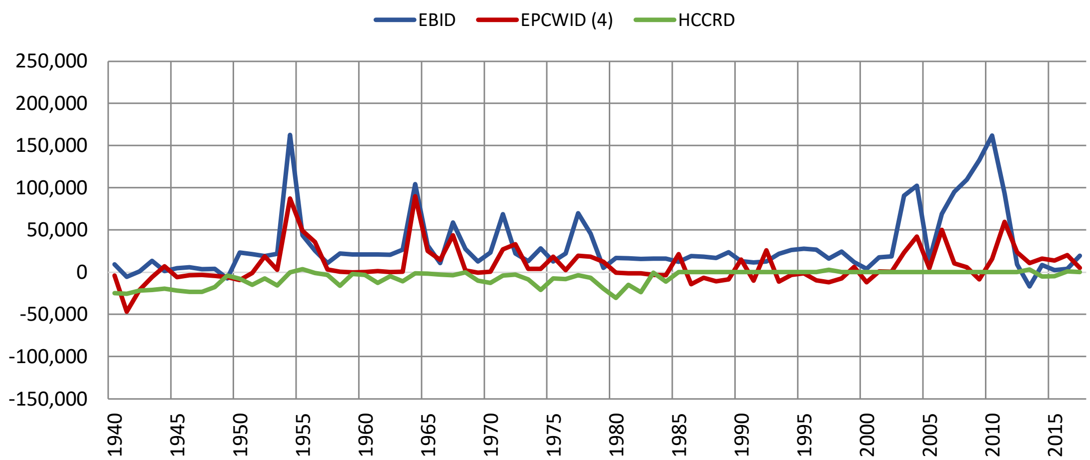
1940 - 2017 (acre-feet)

River Headgate (RHG) Diversions (Irrigation Season)



	Average Difference		
Period	EBID	EPCWID	HCCRD
1951-2017	32,820	-33,451	-20,262
1951-1978	33,744	-13,202	-9,068
1979-2005	8,094	-60,705	-32,434
2006-2017	86,298	-19,377	-18,997
1985-2017	38,362	-46,664	-27,385
1985-2005	10,970	-62,257	-32,178

Farm Headgate (FHG) Deliveries (Irrigation Season)



	Average Difference		
Period	EBID	EPCWID	HCCRD
1951-2017	34,159	11,255	-4,315
1951-1978	35,253	17,825	-6,603
1979-2005	22,745	1,231	-3,629
2006-2017	57,291	18,478	-519
1985-2017	36,843	7,665	-100
1985-2005	25,158	1,486	139

Notes:

(1) EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

(2) EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

(3) HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

(4) EPCWID FHG values include deliveries to Rogers WTP and R/U WTP.

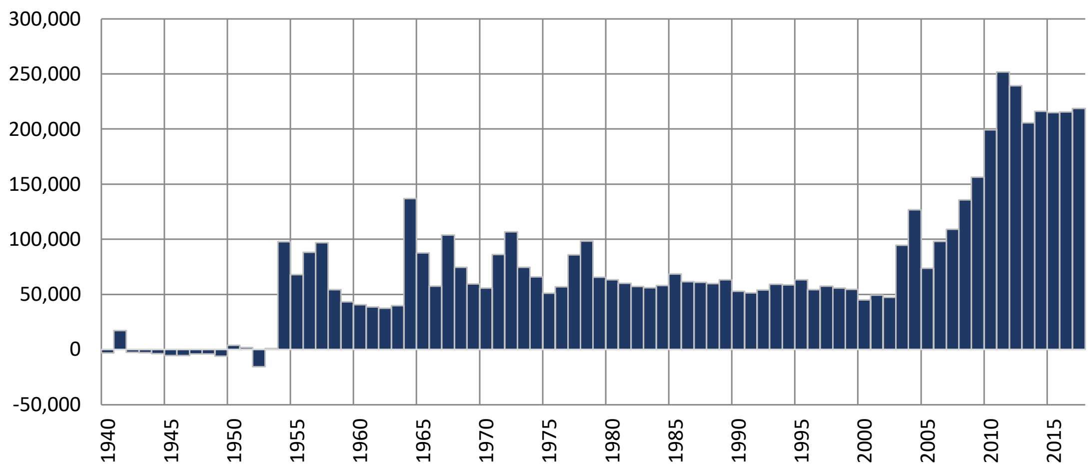
Run 13 - Reduced Waste

Simulated Differences in ILRG Model Outputs

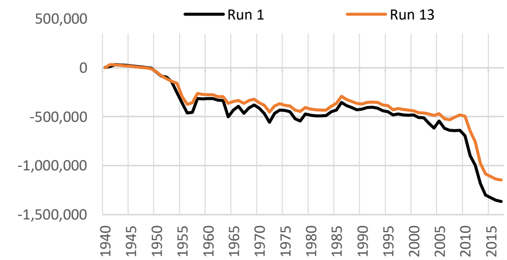
Run 13 minus Run 1

1940 - 2017 (acre-feet)

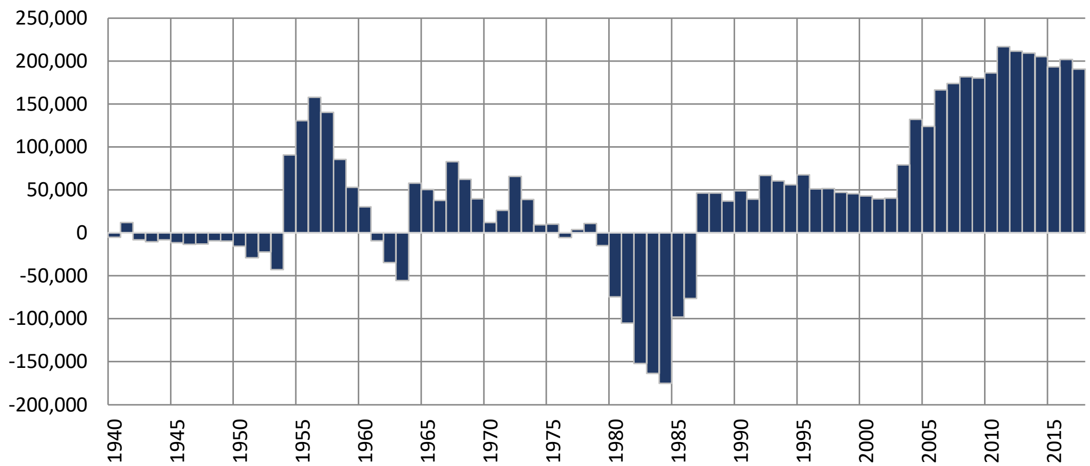
Cumulative Annual Rincon-Mesilla Groundwater Storage



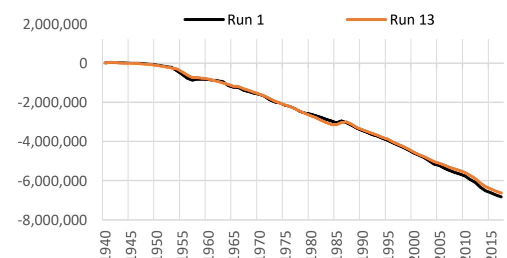
Period	Average Difference
1951-2017	3,209
1951-1978	3,375
1979-2005	-911
2006-2017	12,092
1985-2017	4,870
1985-2005	744



Cumulative Annual Hueco Groundwater Storage



Period	Average Difference
1951-2017	3,078
1951-1978	946
1979-2005	4,181
2006-2017	5,572
1985-2017	11,084
1985-2005	14,234



Notes:

Cumulative storage change in alluvial and non-alluvial aquifers.

Average differences calculated as (Final Storage - Initial Storage)/(no. years).

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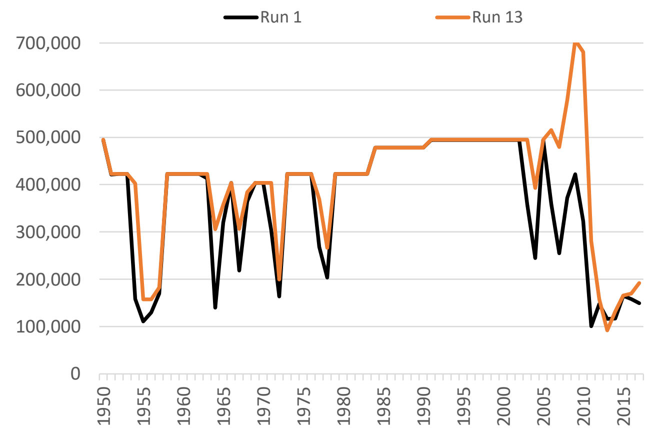
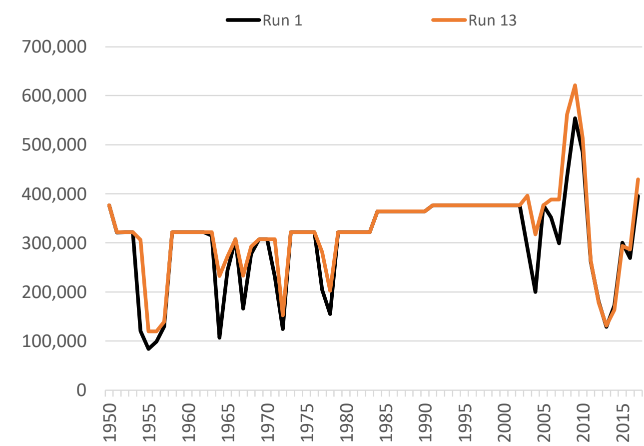
Run 13 - Reduced Waste
Annual Allocation and Charges
Run 13 v. Run 1
ILRG Model
1950 - 2017 (acre-feet)

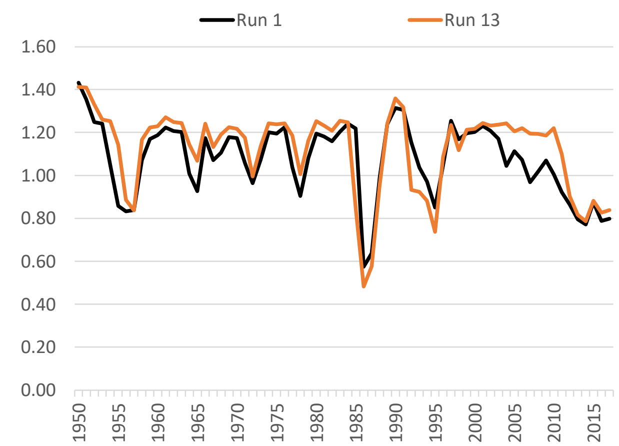
Total Allocation - EBID



Total Allocation - EPCWID

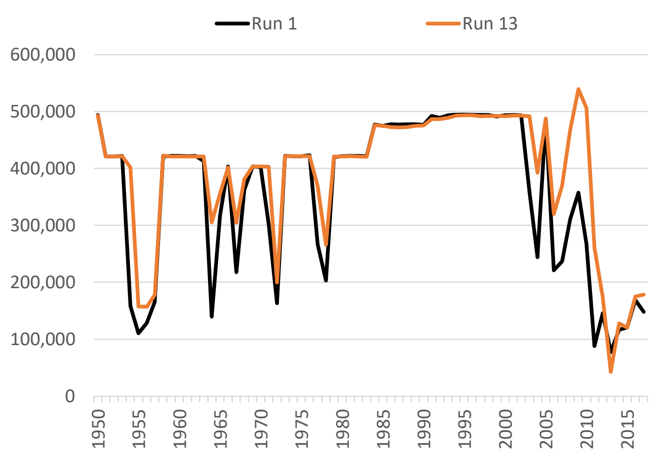


Diversion Ratio

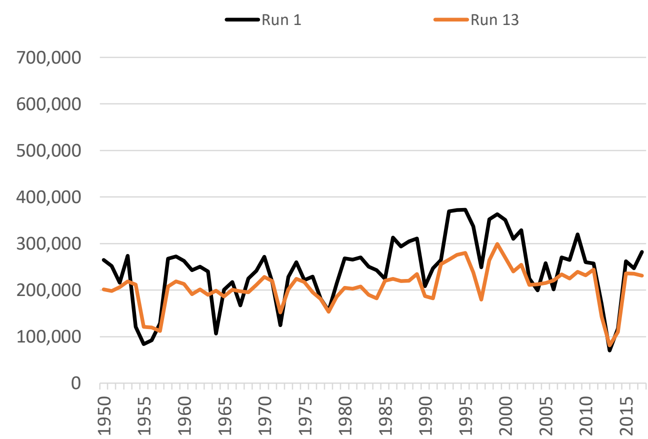


Note:
Computed as Total Charges/Caballo Release.

Annual Delivery Charges - EBID



Annual Delivery Charges - EPCWID



Run 13 - Reduced Waste

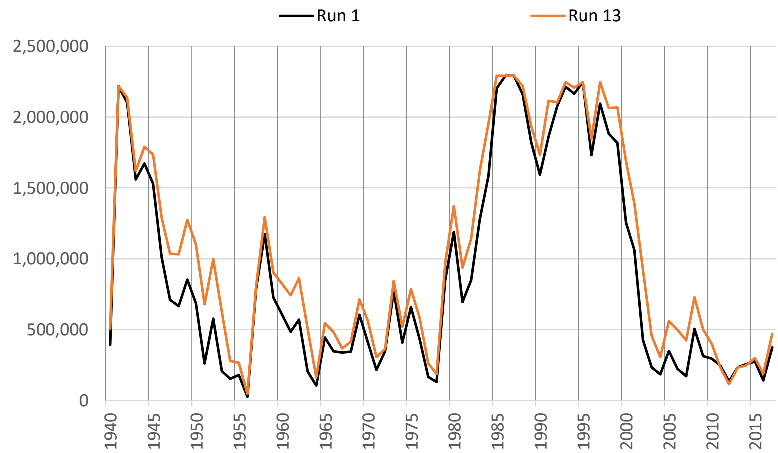
Annual Summary of Project Storage and Rio Grande Flows

Run 13 v. Run 1

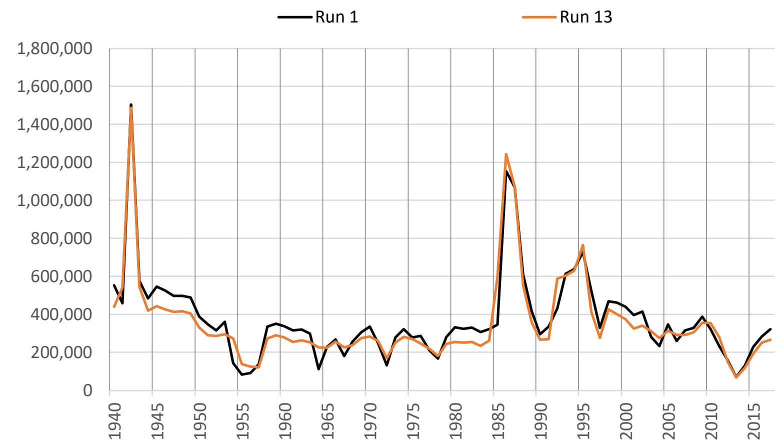
ILRG Model

1940 - 2017 (acre-feet)

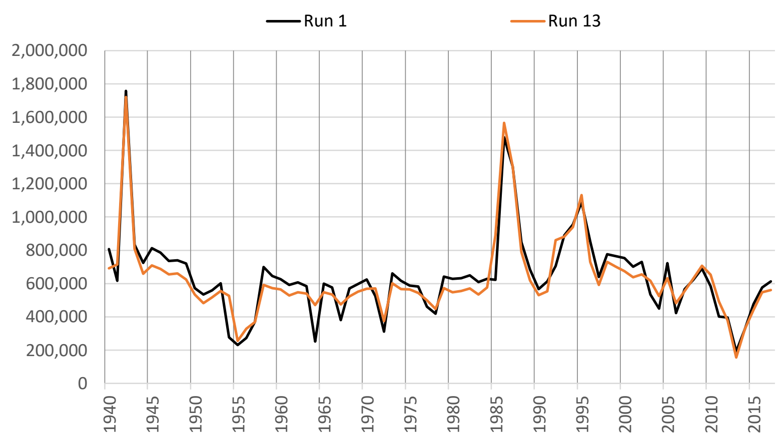
Total Year-End Project Reservoir Storage



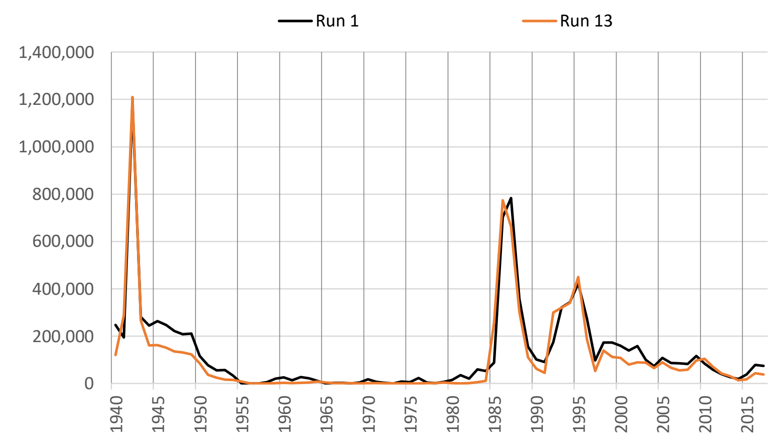
Rio Grande at El Paso



Rio Grande Below Caballo



Rio Grande at Fort Quitman

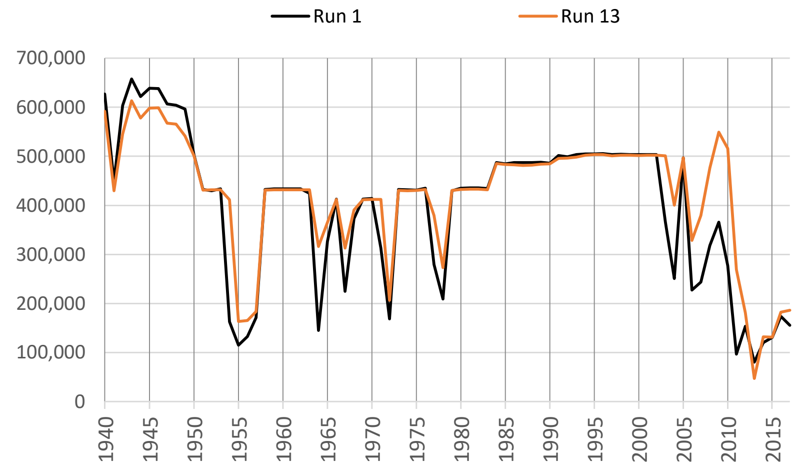


***Note different scales.**

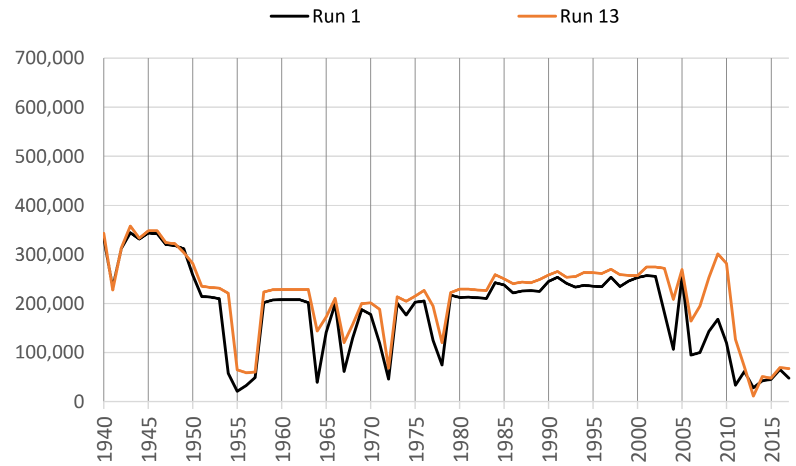
Run 13 - Reduced Waste
Irrigation Season Summary of Irrigation Operations
Run 13 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

EBID Total

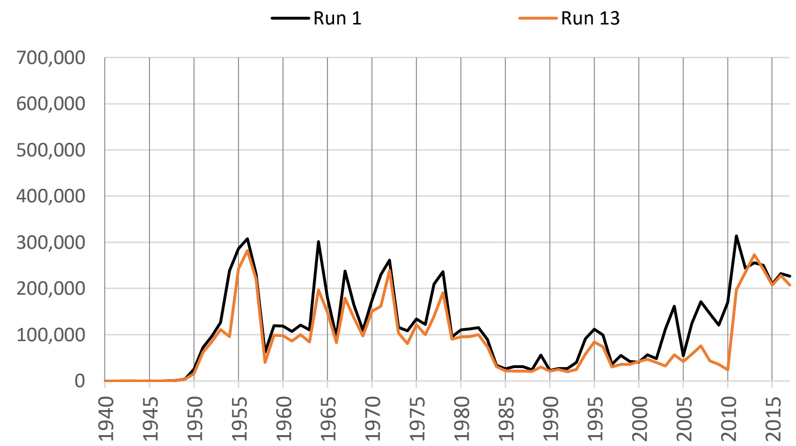
Net River Headgate Diversions



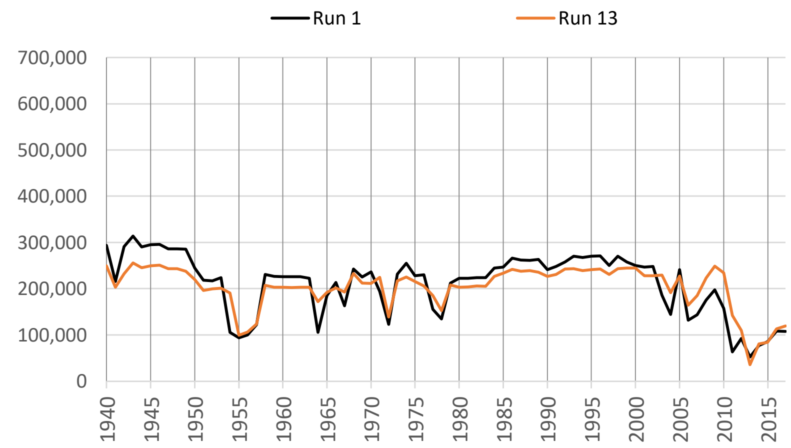
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries

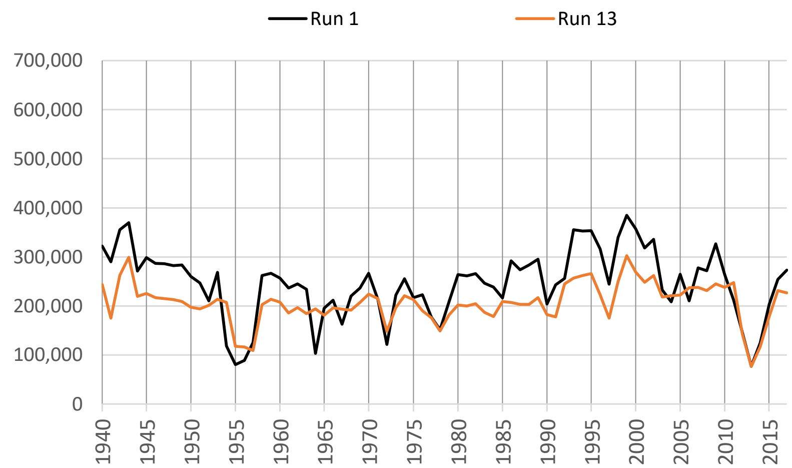


Notes: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).
Pumping includes Supplemental and Primary groundwater pumping.

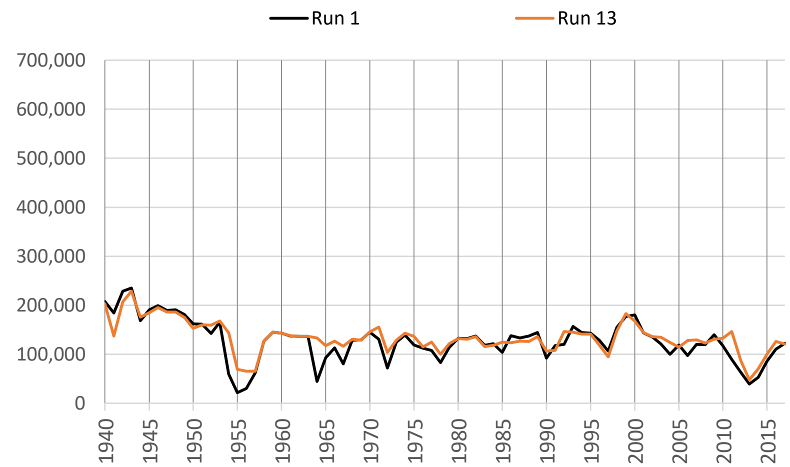
Run 13 - Reduced Waste
Irrigation Season Summary of Irrigation Operations
Run 13 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

EPCWID Total

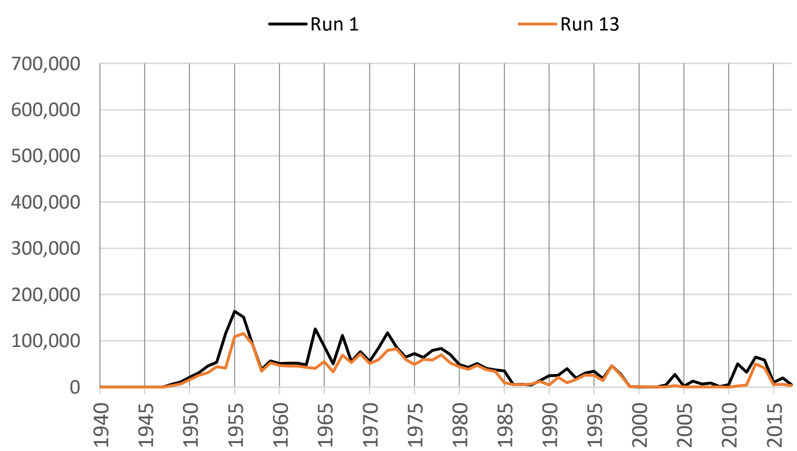
Net River Headgate Diversions



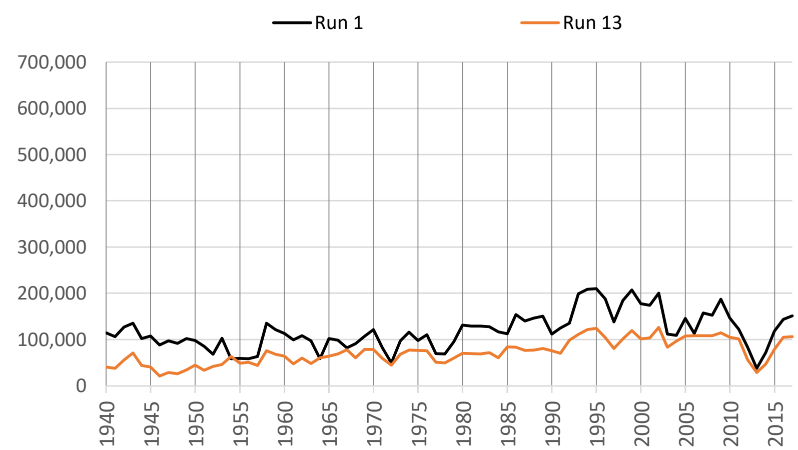
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries

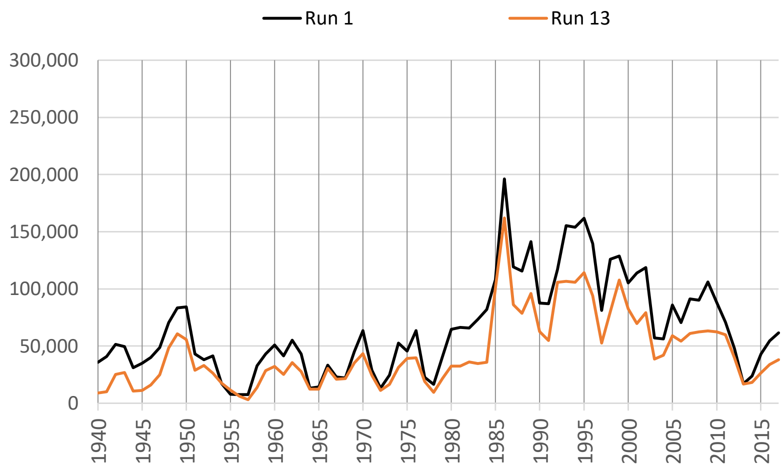


Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

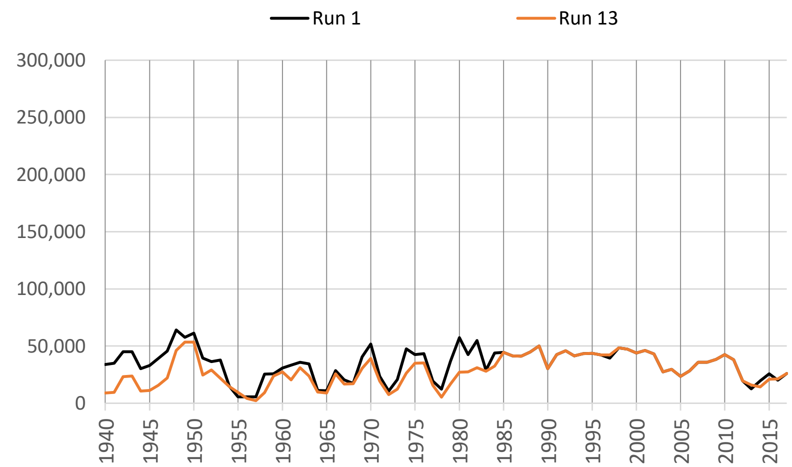
Run 13 - Reduced Waste
Irrigation Season Summary of Irrigation Operations
Run 13 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

HCCRD Total

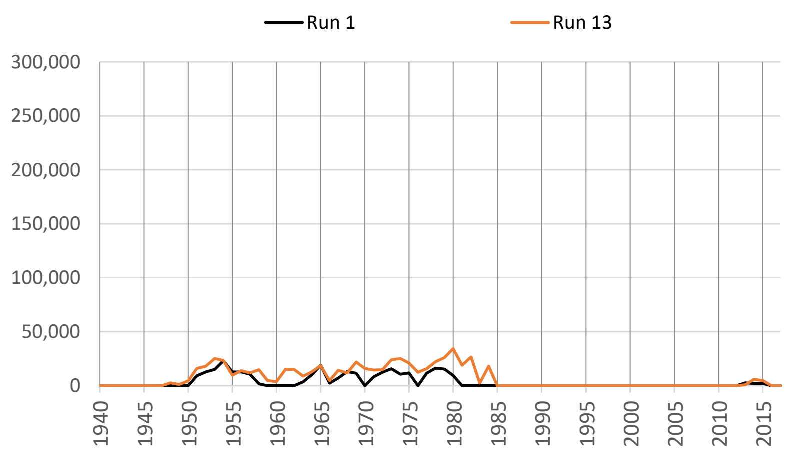
Net River Headgate Diversions



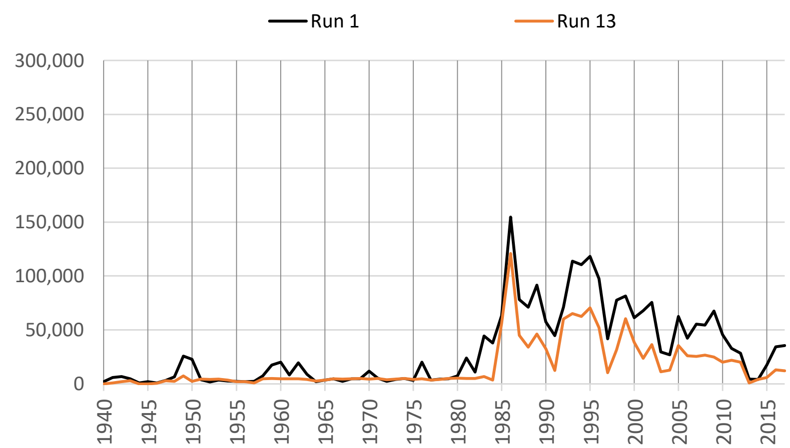
Farm Headgate Deliveries



Pumping



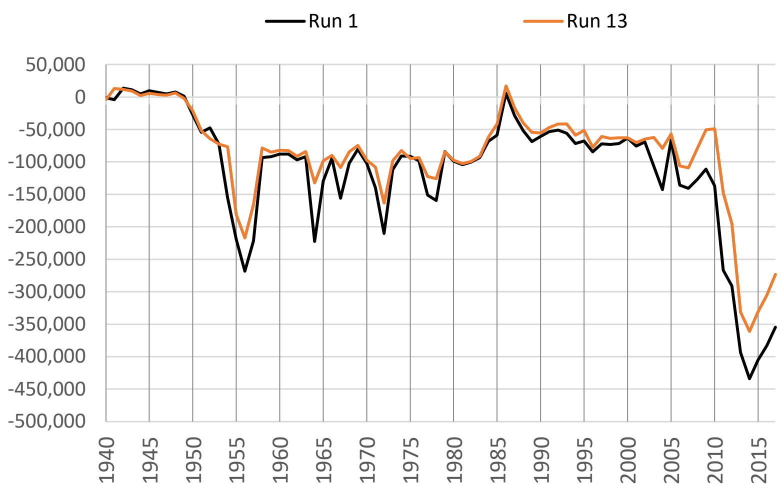
RHG Diversions - FHG Deliveries



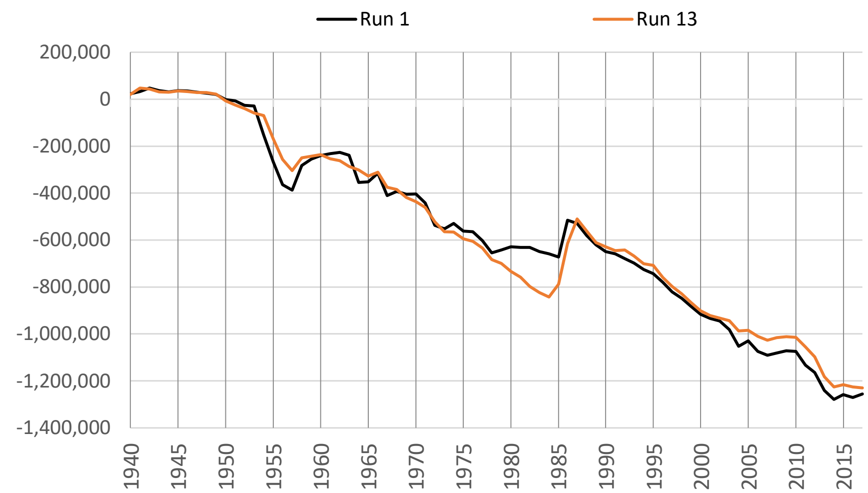
Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

Run 13 - Reduced Waste
Cumulative Change in Ground Water Storage
Run 13 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

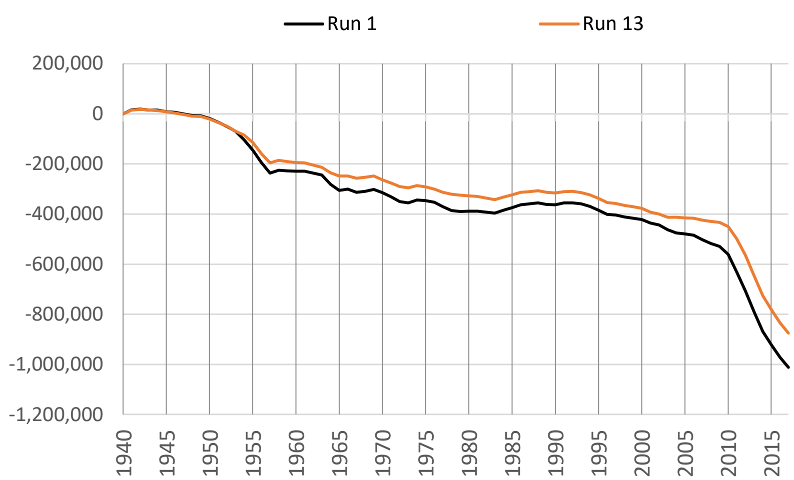
Rincon-Mesilla Alluvial Aquifer



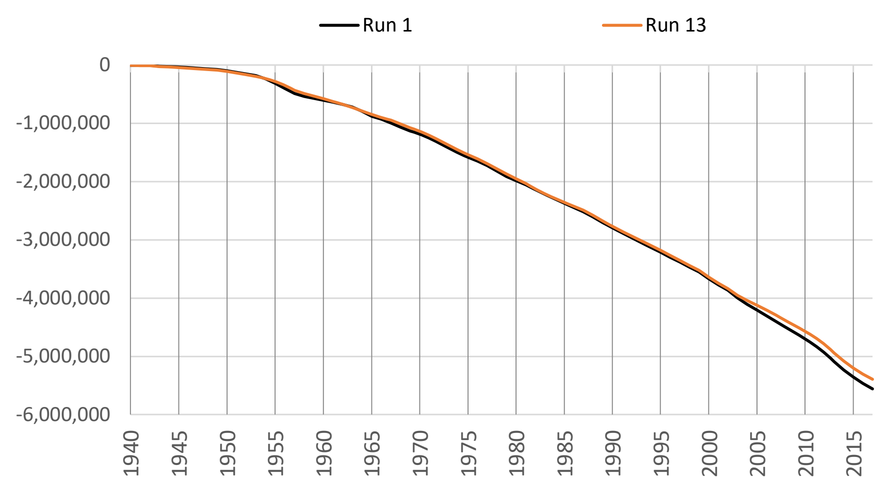
Hueco Alluvial Aquifer



Rincon-Mesilla Non-Alluvial Aquifer

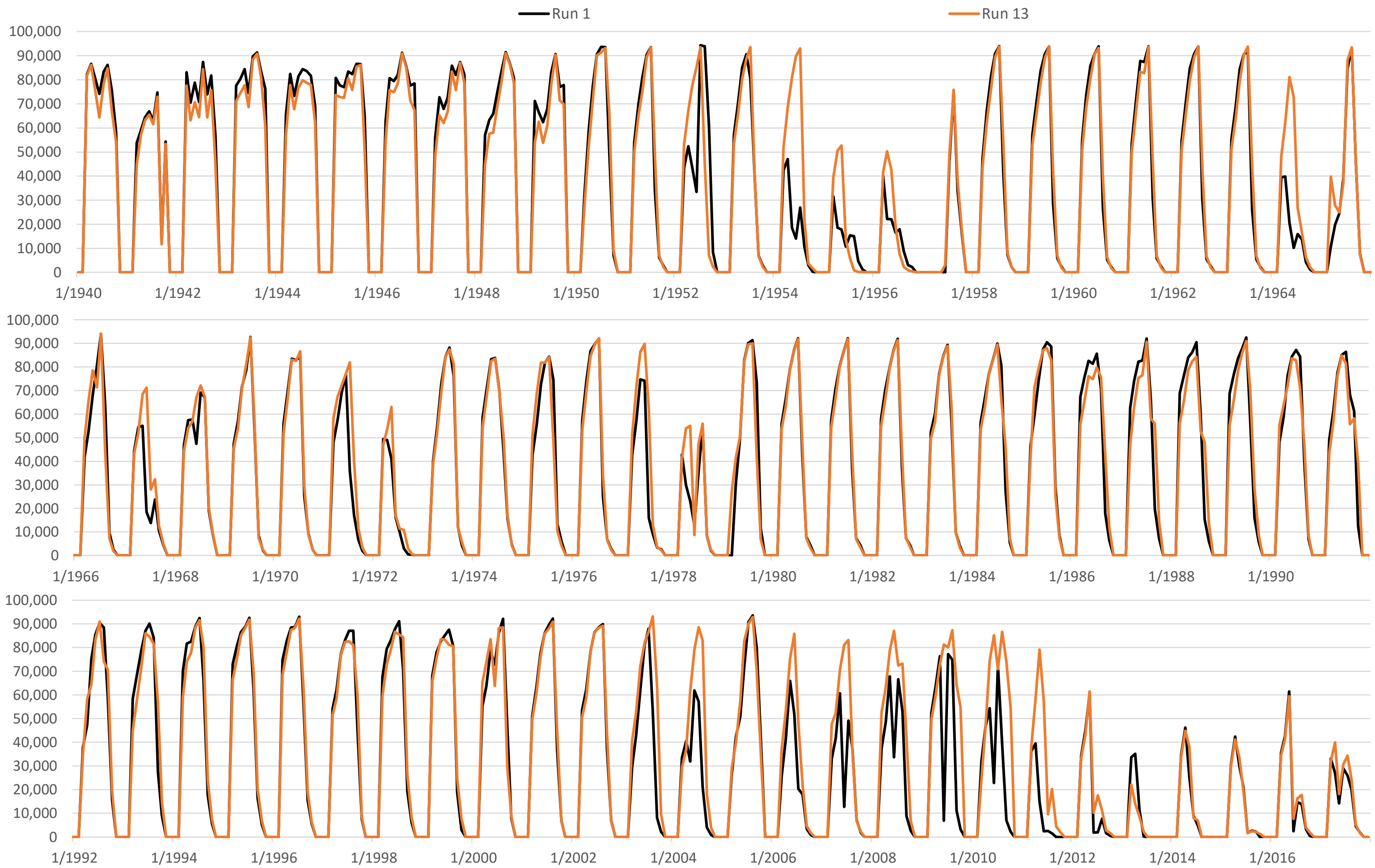


Hueco Non-Alluvial Aquifer



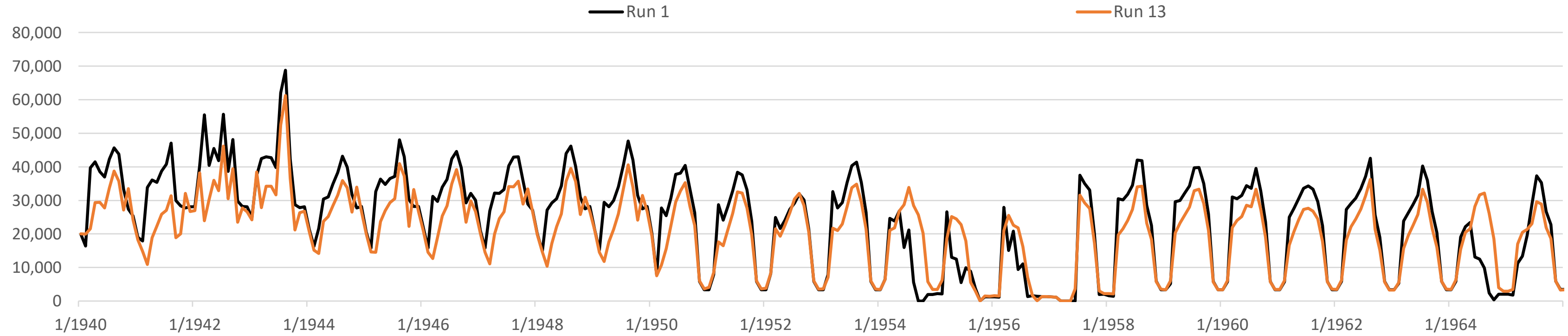
***Note different scales.**

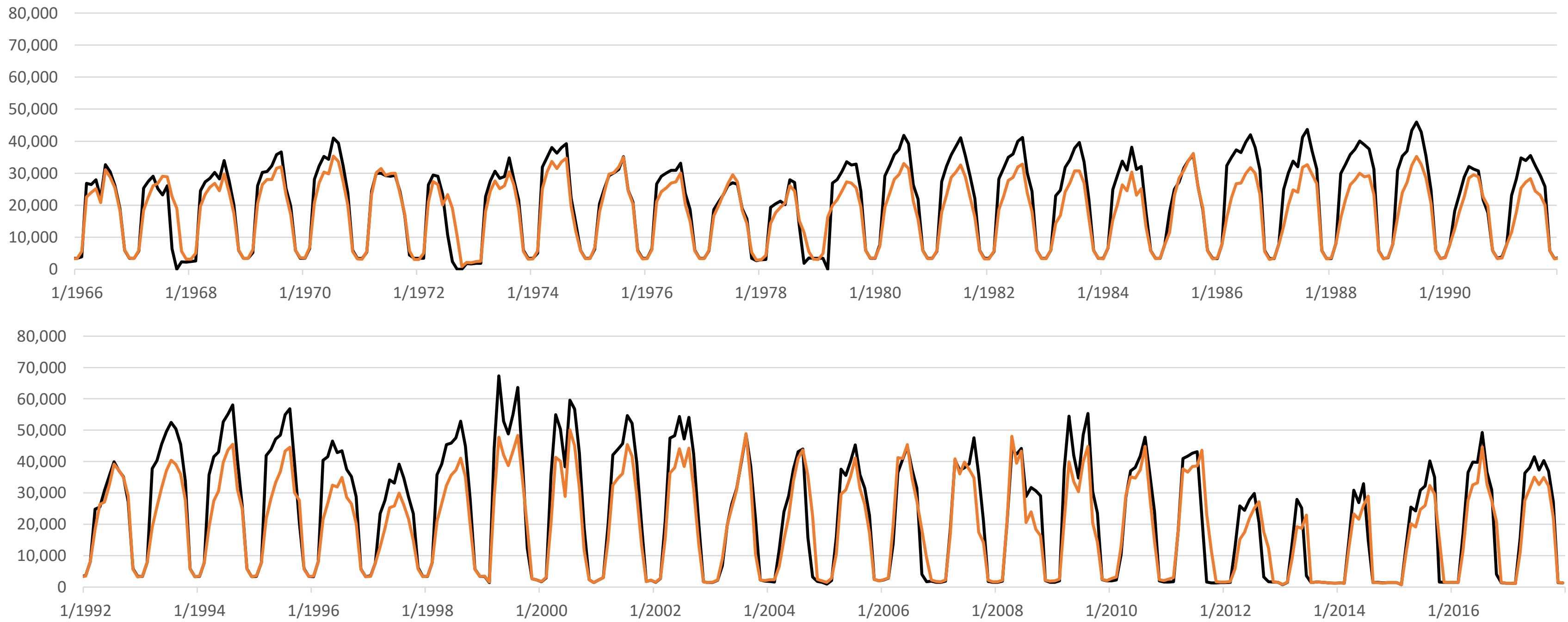
Run 13 - Reduced Waste
Monthly Net RHG Diversions
Run 13 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
EBID Total



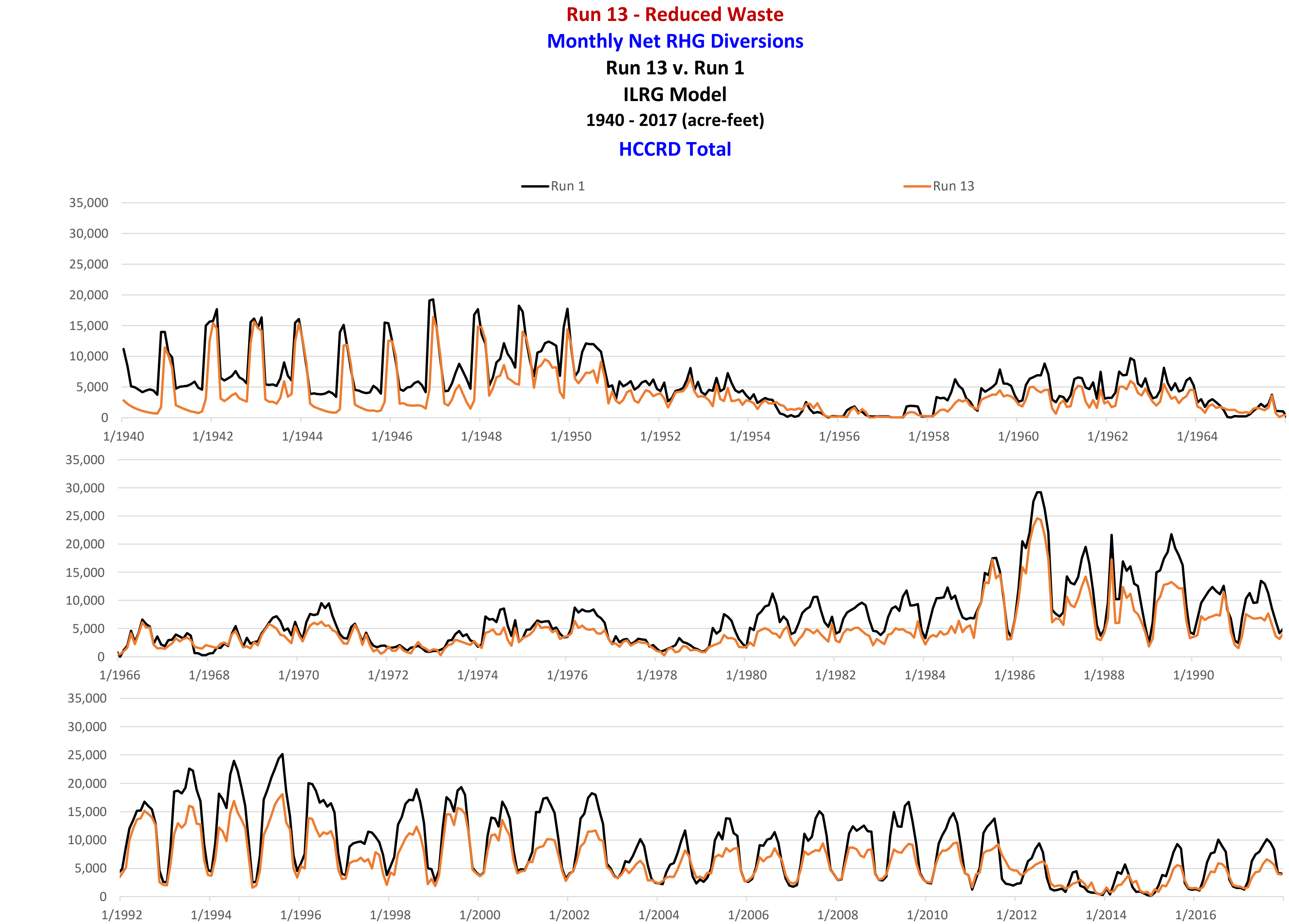
Note: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

Run 13 - Reduced Waste
Monthly Net RHG Diversions
Run 13 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
EPCWID Total



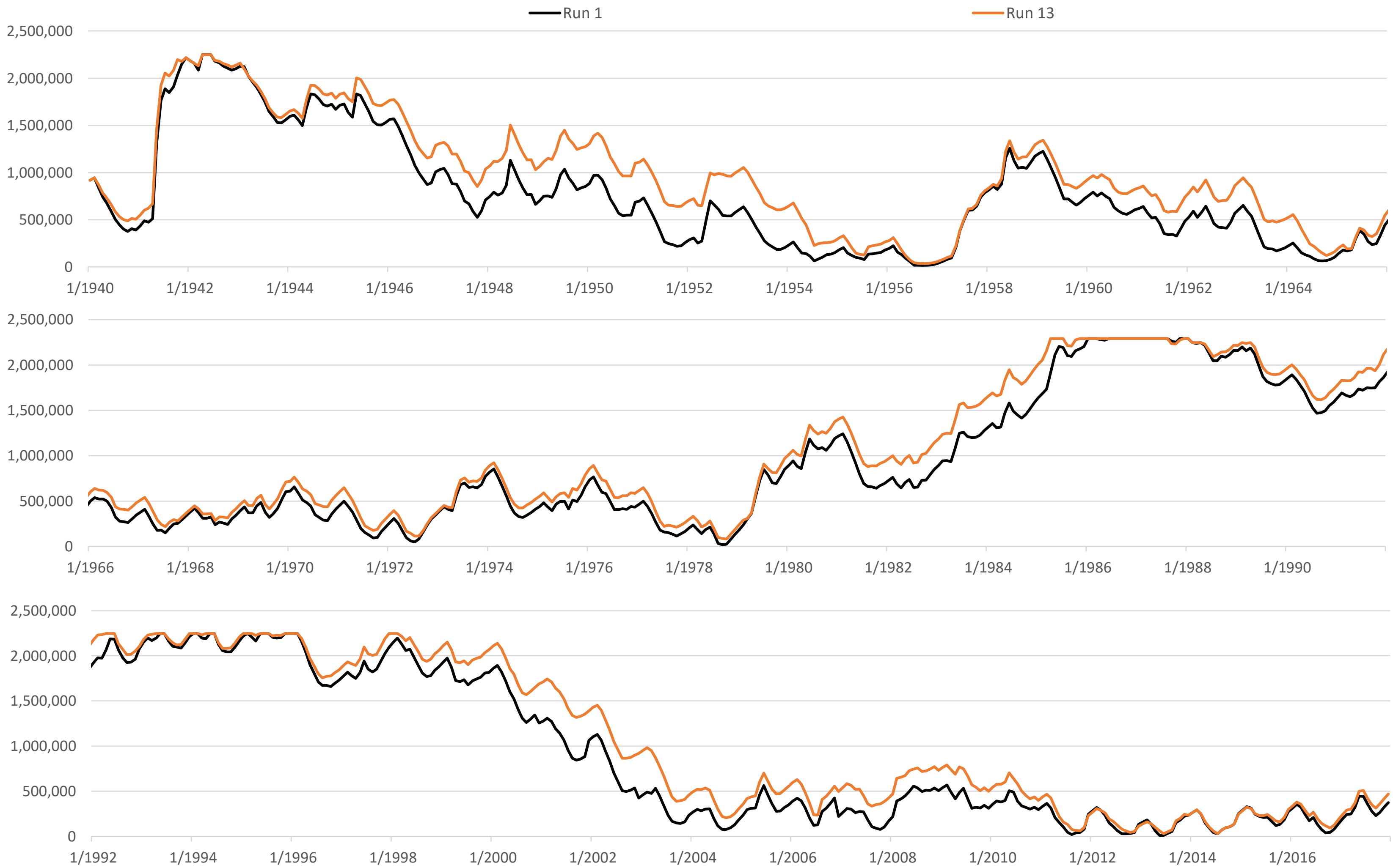


Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

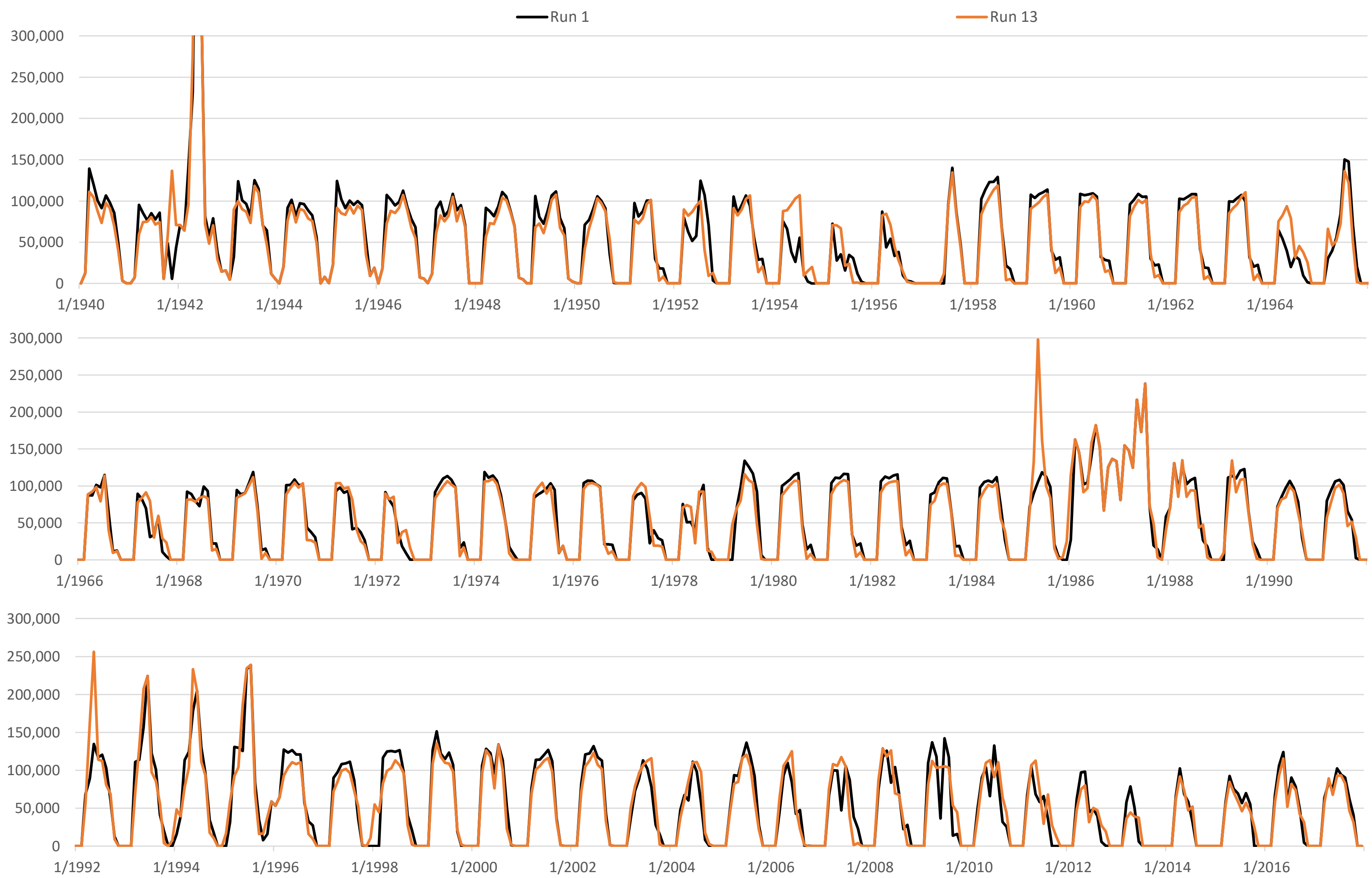


Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

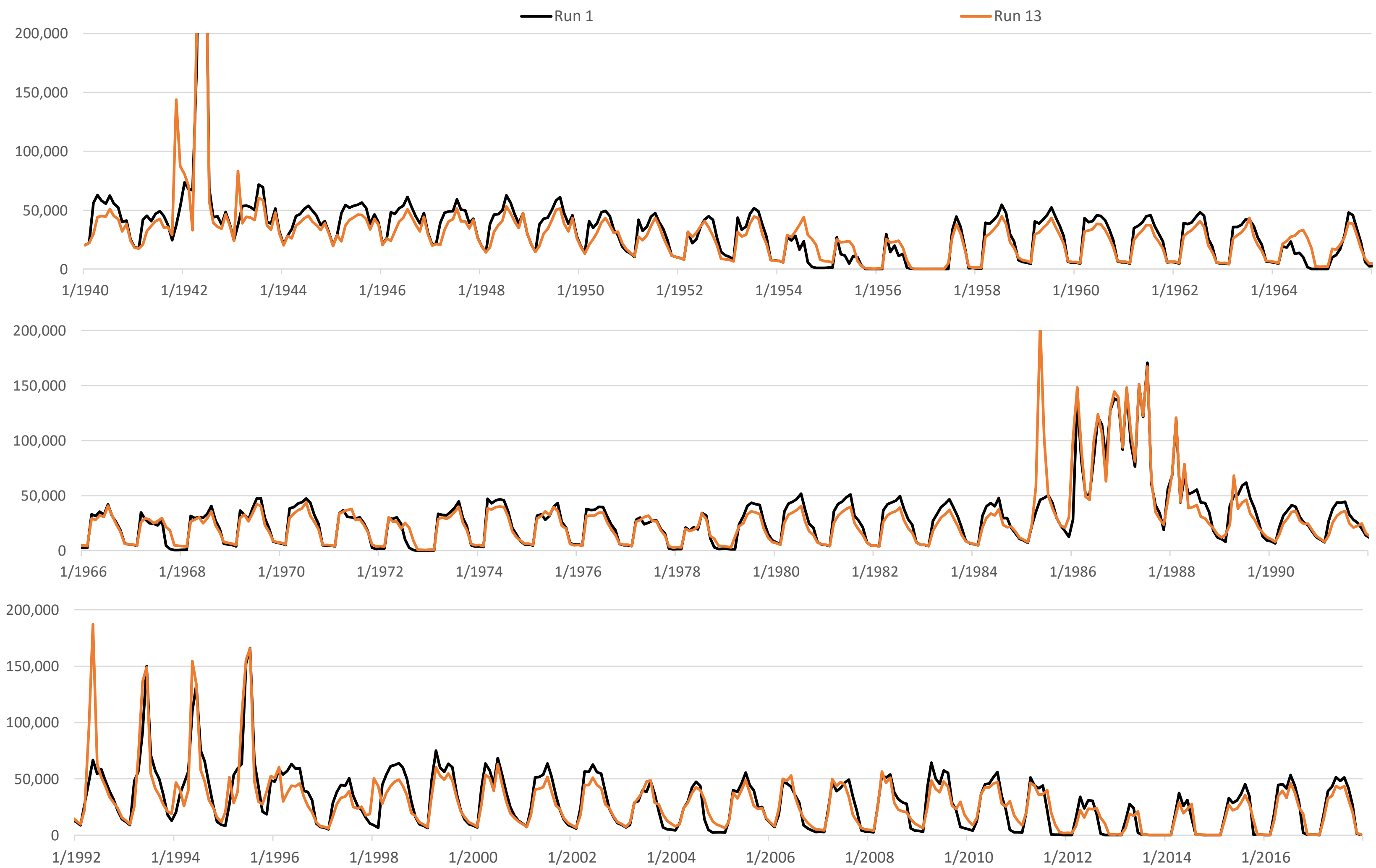
Run 13 - Reduced Waste
End of Month Reservoir Storage (Elephant Butte + Caballo)
Run 13 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)



Run 13 - Reduced Waste
Monthly Caballo Releases
Run 13 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)



Run 13 - Reduced Waste
Monthly Rio Grande at El Paso Flow
Run 13 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)



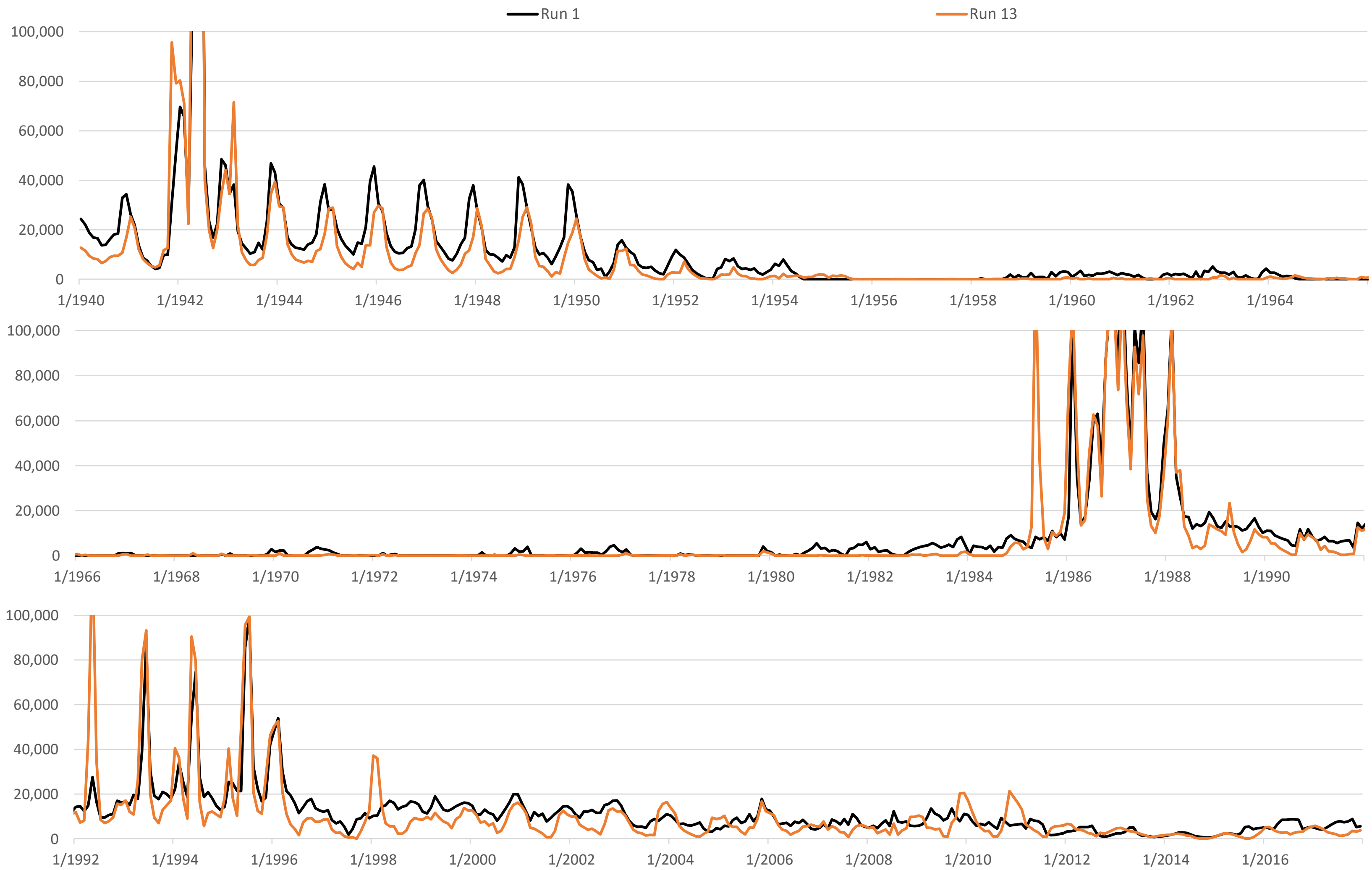
Run 13 - Reduced Waste

Monthly Rio Grande at Fort Quitman Flow

Run 13 v. Run 1

ILRG Model

1940 - 2017 (acre-feet)



Appendix 30N

Comparison of ILRG Model Runs
Run 14 v. Run 1

Model Run Specifications

Model Version: LRG_v116

Name: **Run 14 - All Hueco Pumping Off**

Run ID: LRG_v116_Operational_Run14
Date: 8/24/2020

Name: **Run 1 - Historical Base Run (All Pumping On)**

Run ID: LRG_v116_Operational_Run1
Date: 8/23/2020

Selected Model Inputs

Pumping and Returns	Run 14	Run 1
Irrigation Pumping	Hueco Off	On
Irrigated Area	Hist	Hist
Non-Irrigation Pumping	Hueco Off	On
Non-Irrigation Pumping Returns	Hueco Off	On
Las Cruces Jornada Pumping Returns	On	On

Project Allocation Rules		
1950-2005	D1/D2	D1/D2
2006-2007	D3	D3
2008-2017	D3 + CO	D3 + CO

EPCWID Operations		
Charge EPCWID for Use of WWTP Returns	Off	Off
ACE and Haskell Credits for EPCWID	On	On
Increased EPCWID Use of Fabens Drain Flows	Off	Off
Charge EPCWID for Fabens Drain Flow Use	Off	Off

Run 14 - All Hueco Pumping Off
Comparison of ILRG Model Runs
Run 14 v. Run 1
1951 - 2017 Annual Average
(1,000 acre-feet)

Run No.	1	14	14 - 1		
Simulated Input or Output	**Run 1**	**Run 14**	**Run 14 minus Run 1**		
Pumping Stress					
Irrigation Pumping	107.1	0.0	-107.1		
Non-Irrigation Pumping	181.0	49.5	-131.5		
WWTP Flows	58.0	24.0	-34.1		
Urban Deep Percolation	13.1	7.8	-5.3		
Total Stress	217.0	17.7	-199.3		
	Stress is Pumping minus WWTP and Urban Deep Perc				
Effects of Pumping Stress				***% Chg***	
FHG Deliveries (Mar - Oct)				***Stress***	***% Diff.***
EBID	167.6	169.1	1.5	*-1%*	*1%*
EPCWID (incl. EPW)	139.9	140.6	0.8	*0%*	*1%*
HCCRD	32.8	34.7	1.9	*-1%*	*6%*
Total	340.3	344.5	4.2	*-2%*	*1%*
FHG Deliveries (Nov - Feb)					
EBID	0.0	0.0	0.0	*0%*	*0%*
EPCWID (incl. EPW)	0.2	0.1	-0.1	*0%*	*-31%*
HCCRD	2.4	2.2	-0.2	*0%*	*-8%*
Total	2.6	2.3	-0.2	*0%*	*-10%*
Irrigation Pumping					
EBID	140.4	138.9	-1.5	*1%*	*-1%*
EPCWID (Mesilla Valley)	7.4	7.2	-0.1	*0%*	*-2%*
EPCWID (El Paso Valley)	40.1	0.0	-40.1		
HCCRD	4.2	0.0	-4.2		
Total	147.8	146.1	-1.7	*1%*	*-1%*
	Pumping turned off.	*Other values are simulated responses and are totaled.*			
Other Inflows/Outflows					
Net Reservoir Evaporation	125.3	126.4	1.1	*-1%*	*1%*
Riparian ET	70.9	80.7	9.8	*-5%*	*14%*
River Evaporation + Incidental Canal Loss	30.3	29.6	-0.7	*0%*	*-2%*
Total	226.6	236.7	10.2	*-5%*	*4%*
Rio Grande at Fort Quitman					
Reservoir Spills	33.3	35.3	2.0	*-1%*	*6%*
Nov-Feb Flows	21.4	37.1	15.7	*-8%*	*73%*
Mar - Oct Flows	41.1	67.8	26.7	*-13%*	*65%*
Underflow (GW Model)	0.2	0.3	0.1	*0%*	*28%*
Total	96.0	140.5	44.5	*-22%*	*46%*

Run 14 - All Hueco Pumping Off
Comparison of ILRG Model Runs
Run 14 v. Run 1
1951 - 2017 Annual Average
(1,000 acre-feet)

Run No.	1	14	14 - 1		
Simulated Input or Output	**Run 1**	**Run 14**	**Run 14 minus Run 1**		
Effects of Pumping Stress (continued)				***% Chg***	
Change in Storage				***Stress***	***% Diff.***
Reservoir Storage	-4.7	-4.7	0.0	*0%*	*0%*
Alluvial GW Storage (RW Model)	-23.6	-5.2	18.4	*-9%*	*-78%*
Non-alluvial GW Storage (GW Models)	-96.4	-13.0	83.4	*-42%*	*-87%*
Soil Moisture Storage	0.6	0.5	-0.1	*0%*	*-18%*
Total	-124.0	-22.4	101.6	*-51%*	*-82%*
Summary of Effects					
FHG Deliveries (Mar-Oct)	340.3	344.5	4.2	*-2%*	*1%*
FHG Deliveries (Nov-Feb)	2.6	2.3	-0.2	*0%*	*-10%*
Irrigation Pumping	147.8	146.1	-1.7	*1%*	*-1%*
Riparian ET + Evaporation	226.6	236.7	10.2	*-5%*	*4%*
Fort Quitman Flow	96.0	140.5	44.5	*-22%*	*46%*
Change in Storage	-124.0	-22.4	101.6	*-51%*	*-82%*
Total	689.2	847.8	158.6	*-80%*	*23%*
Other Effects of Pumping Stress				***% Chg***	
Rio Grande at El Paso				***Stress***	***% Diff.***
Reservoir Spills	49.4	46.6	-2.7	*1%*	*-6%*
Nov-Feb Flows	22.8	23.2	0.4	*0%*	*2%*
Mar - Oct Flows	263.8	265.1	1.4	*-1%*	*1%*
Total	336.0	335.0	-0.9	*0%*	*0%*
Rio Grande below Caballo					
Reservoir Spills	65.9	61.3	-4.6	*2%*	*-7%*
Nov-Feb Flows	0.5	0.5	0.1	*0%*	*13%*
Mar - Oct Flows	541.3	544.8	3.6	*-2%*	*1%*
Total	607.6	606.6	-1.0	*0%*	*0%*
Surface Water Diversions (Mar - Oct)					
EBID	366.5	368.4	2.0	*-1%*	*1%*
EPCWID (incl. EPW)	236.8	237.0	0.2	*0%*	*0%*
HCCRD	67.5	75.0	7.5	*-4%*	*11%*
Total	670.8	680.4	9.6	*-5%*	*1%*
Surface Water Diversions (Nov - Feb)					
EBID	0.0	0.0	0.0	*0%*	*0%*
EPCWID (incl. EPW)	14.3	12.6	-1.8	*1%*	*-12%*
HCCRD	14.2	16.3	2.1	*-1%*	*15%*
Total	28.5	28.9	0.3	*0%*	*1%*

Run 14 - All Hueco Pumping Off

Annual Differences in ILRG Model Outputs

Run 14 minus Run 1

1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1940	14	14	-833	530	-407	698	-25	-25	845	902	-322	-322	-7,588	-7,284	7,183
1941	-15	-15	-767	-1,279	-1	84	5	5	-43	-104	12	-22	6,749	5,202	7,787
1942	-37	-37	-305	-2,116	-89	-109	13	13	276	-185	-114	-123	1,220	2,376	3,556
1943	-28	-28	-353	-1,483	-100	-122	12	12	325	141	-86	-303	2,571	2,528	2,813
1944	-21	-21	-728	-2,069	-12	-235	-7	-7	-96	-309	-37	-199	-184	-152	2,166
1945	-21	-21	-468	-2,114	55	-501	0	0	-74	-340	48	106	935	868	2,557
1946	-7	-7	-378	-2,349	138	-564	-2	-2	50	-428	94	28	755	716	2,626
1947	-3	-3	-111	-1,571	5	-366	-6	-7	645	196	-19	-1	-512	-497	2,964
1948	13	13	-1,506	-2,685	370	185	-20	-21	439	276	378	155	-3,573	-3,442	7,847
1949	23	23	-2,763	-4,080	1,432	1,684	-8	-9	-58	-83	-138	-281	-3,148	-3,174	13,461
1950	10	10	-4,064	-4,883	1,626	1,968	-44	-44	-99	-100	-27	-47	-3,630	-3,585	10,287
1951	1,028	1,028	-4,701	-5,308	1,593	2,279	555	556	6	5	1,704	1,239	-3,394	-3,479	25,964
1952	86	86	-7,108	-7,724	1,823	2,664	395	394	-442	-444	1,657	933	-9,670	-8,054	24,226
1953	179	179	-8,220	-8,870	3,129	4,635	1,088	1,087	-49	-51	3,522	4,034	-8,077	-8,391	42,118
1954	-17,710	-17,710	-12,313	-14,153	1,122	3,272	-2,036	-2,036	710	706	2,136	3,844	-33,072	-8,404	24,621
1955	32,323	32,323	24,036	20,802	8,932	12,135	16,239	16,239	21,900	22,065	8,565	11,417	66,243	28,186	19,078
1956	-8,443	-8,443	-8,084	-10,443	7,558	10,233	-7,008	-7,008	-464	-752	7,087	9,245	-15,612	-6,786	8,350
1957	42	42	-8,946	-11,312	2,395	6,191	14	14	1,764	1,448	3,075	4,936	-7,152	-5,662	6,336
1958	-5	-5	-22,873	-24,299	7,547	13,212	-98	-98	-1,713	-1,811	-1,169	570	-27,008	-23,145	46,574
1959	6	6	-14,880	-15,728	6,169	9,923	-56	-56	-345	-345	403	682	-19,692	-18,776	55,810
1960	7	7	-13,032	-14,048	4,967	7,439	-50	-51	-779	-779	0	0	-14,804	-14,797	52,470
1961	10	10	-12,889	-13,840	5,145	7,485	-22	-22	618	617	1,527	-417	-13,799	-13,520	54,683
1962	12	12	-12,111	-13,142	4,709	6,988	-31	-31	-170	-170	794	1,225	-13,492	-12,938	51,440
1963	8,881	8,881	-12,259	-13,225	4,725	6,861	4,805	4,805	-455	-453	2,584	2,360	-967	-4,876	54,188
1964	12,029	12,029	7,126	5,110	6,022	8,896	17,743	17,743	11,654	11,852	6,036	7,889	11,142	17,345	41,745
1965	31,802	31,802	5,179	3,068	10,116	14,599	15,775	15,775	16,759	16,798	10,941	13,271	37,909	18,873	45,430
1966	-69	-69	-13,553	-14,249	9,180	13,109	198	198	-254	-250	-2,779	-4,910	-18,684	-9,944	55,788
1967	15,818	15,818	10,877	10,360	8,536	14,595	11,473	11,473	16,071	15,556	6,960	10,714	20,437	12,750	42,262
1968	230	230	-11,091	-11,781	12,756	18,842	127	127	526	126	10,106	7,733	-12,554	-5,021	46,007
1969	2	2	-11,373	-12,396	14,942	19,644	317	317	-218	-217	2,911	-1,892	-13,203	-10,314	59,775
1970	3	3	-8,998	-9,979	8,374	11,883	-1	-1	15	15	-1,274	-2,725	-11,872	-10,703	62,623
1971	20,912	20,912	-8,450	-9,092	9,667	14,109	12,713	12,713	-332	-330	7,941	11,107	2,710	-5,526	54,950
1972	-4,887	-4,887	-3,665	-4,513	13,426	17,542	-5,165	-5,165	-5,841	-5,474	10,467	9,332	-4,162	-2,542	45,402
1973	-186	-186	-7,372	-8,963	22,061	27,344	918	918	421	608	17,776	15,095	-11,386	-7,996	38,170
1974	-48	-48	-4,896	-6,102	19,818	26,111	328	328	673	673	-3,918	-6,168	-6,133	-6,074	74,491
1975	-246	-246	-1,901	-2,999	19,415	25,555	1,129	1,129	155	155	8,282	3,832	-6,108	-3,910	58,376
1976	-15	-15	2,954	1,826	17,146	23,660	718	718	216	216	-1,658	-5,752	53	-345	59,161
1977	23,989	23,989	1,532	1,567	11,908	17,427	14,543	14,543	288	290	11,072	11,094	15,943	6,178	54,566
1978	11,641	11,641	8,133	7,828	11,682	16,655	6,494	6,494	6,106	6,108	11,342	9,864	20,417	17,073	52,161

Run 14 - All Hueco Pumping Off

Annual Differences in ILRG Model Outputs

Run 14 minus Run 1

1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1979	-320	-320	-2,957	-3,985	10,541	15,757	-67	-66	-2,755	-2,751	2,790	-150	-1,578	2,941	63,217
1980	-36	-36	3,953	2,840	10,476	13,957	153	153	19	22	-4,659	-9,146	157	2,797	92,428
1981	-21	-21	7,703	6,626	8,970	10,427	192	192	7	7	-56	-413	5,388	6,000	65,726
1982	-16	-16	6,755	5,509	8,448	9,689	81	81	3	4	-2,064	-4,042	6,107	6,895	78,392
1983	-18	-18	10,068	8,682	11,713	13,006	77	77	2	3	0	0	7,842	8,279	58,009
1984	-19	-19	11,784	10,530	14,977	15,774	71	71	7	8	0	0	7,050	7,586	54,871
1985	1	1	14,484	13,837	9,635	10,270	1,612	1,612	277	192	0	0	5,315	5,236	58,414
1986	11	11	19,575	18,988	11,381	10,762	80	76	-9	-11	0	0	-25,668	-23,770	138,291
1987	-15	-15	21,479	20,858	9,642	8,432	4	3	-13	-13	0	0	53	314	70,775
1988	-10	-10	22,771	22,147	9,603	7,884	58	58	1	2	0	0	7,629	6,710	51,845
1989	-18	-18	24,355	23,461	10,677	9,239	101	102	350	-29	0	0	23,502	22,123	53,669
1990	-55	-55	23,467	22,503	13,434	12,257	242	242	326	-190	0	0	11,638	13,047	38,572
1991	-163	-163	10,946	9,864	6,273	5,642	-689	-688	147	-650	0	0	6,321	6,573	46,726
1992	-290	-290	7,216	6,372	4,475	4,511	1,601	1,603	94	-250	0	0	-28,822	-28,584	20,532
1993	-33	-33	-2,073	-2,712	2,806	2,136	187	187	18	15	0	0	-14,909	-14,281	30,195
1994	194	194	-936	-1,626	3,370	2,938	11	11	2,318	2,318	0	0	-1,495	-1,588	47,276
1995	416	416	-1,738	-2,514	2,644	1,837	56	56	2,583	2,525	0	0	5,341	4,358	52,828
1996	-51	-51	-2,925	-3,652	2,297	1,618	313	313	29	29	0	0	-11,095	-8,786	39,048
1997	122	122	-7,251	-9,774	4,329	3,034	-222	-222	-1,092	-2,115	0	0	-5,176	-5,318	44,036
1998	5	5	-585	-1,401	3,391	2,400	-3	-3	539	539	0	0	-4,892	-4,823	49,623
1999	-172	-172	-1,492	-4,668	2,506	3,123	-2	-2	-3,093	-3,093	0	0	0	562	44,877
2000	-1,250	-1,250	10,392	6,623	5,134	6,228	-113	-113	2,648	2,647	0	0	11,450	11,513	38,594
2001	-33	-33	4,631	618	4,029	5,095	-64	-64	-9	-9	0	0	4,629	4,117	33,350
2002	-15	-15	-1,665	-4,332	1,736	2,771	-24	-24	166	166	0	0	-3,922	-3,433	28,007
2003	3,973	3,973	15,245	12,976	4,879	5,206	2,577	2,577	101	102	0	0	25,330	21,301	31,739
2004	-12,540	-12,540	-11,360	-14,585	752	1,456	-6,490	-6,490	-8,003	-8,005	0	0	-12,256	-3,371	28,014
2005	-395	-395	201	-3,350	3,602	5,026	-379	-376	-273	-273	0	0	1,827	-1,589	29,676
2006	-1,769	-1,769	-2,784	-5,594	1,597	2,853	-1,371	-1,371	-2,439	-2,440	0	0	-6,577	-5,451	33,036
2007	-248	-248	1,392	-2,009	3,211	4,643	-199	-199	4,151	4,152	0	0	722	-958	27,667
2008	3,366	3,366	-5,202	-8,453	3,071	3,952	2,192	2,192	-1,295	-1,294	0	0	-6,375	-6,185	34,982
2009	3,986	3,986	-858	-4,740	1,838	2,639	1,867	1,867	213	213	0	0	-56	-978	39,824
2010	13,099	13,099	-957	-5,606	2,560	3,613	8,182	8,182	92	94	0	0	3,438	-716	37,321
2011	7,635	7,635	1,015	-3,280	12,714	17,489	4,234	4,234	3,569	3,571	0	0	4,704	1,608	32,950
2012	-2,798	-2,798	491	-3,334	12,969	16,137	480	480	-4,792	-4,792	0	0	-658	3,703	21,497
2013	-1,109	-1,109	-6,109	-9,574	6,528	8,575	-498	-498	-9,905	-9,905	5,173	6,466	-1,752	2,560	10,859
2014	-2,258	-2,258	-839	-4,572	8,726	13,067	-1,395	-1,395	-52	-52	1,263	3,346	864	3,378	17,223
2015	-868	-868	155	-3,669	6,164	8,373	-600	-600	383	383	-3,308	-2,165	4,184	3,195	32,274
2016	-5,454	-5,454	-774	-5,049	2,828	4,542	-2,674	-2,674	1,254	1,254	0	0	336	716	18,059
2017	848	848	-6,775	-10,554	2,832	4,453	797	797	-435	-435	0	0	-7,871	-7,309	29,379
Averages															
1951-2017	1,956	1,956	178	-1,615	7,487	9,613	1,515	1,515	775	718	1,869	1,678	-974	-932	44,486
1951-1978	4,550	4,550	-5,317	-6,486	9,102	12,975	3,254	3,254	2,386	2,363	4,503	4,234	-2,714	-3,243	44,884
1979-2005	-398	-398	6,742	5,179	6,730	7,055	-24	-23	-208	-326	-148	-509	732	1,289	51,434
2006-2017	1,203	1,203	-1,770	-5,536	5,420	7,528	918	918	-771	-771	261	637	-753	-536	27,923
1985-2017	125	125	3,742	1,309	5,504	6,127	299	299	-368	-465	95	232	-432	-186	39,732
1985-2005	-491	-491	6,892	5,221	5,552	5,327	-54	-54	-138	-291	0	0	-248	15	46,480

Notes:

EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

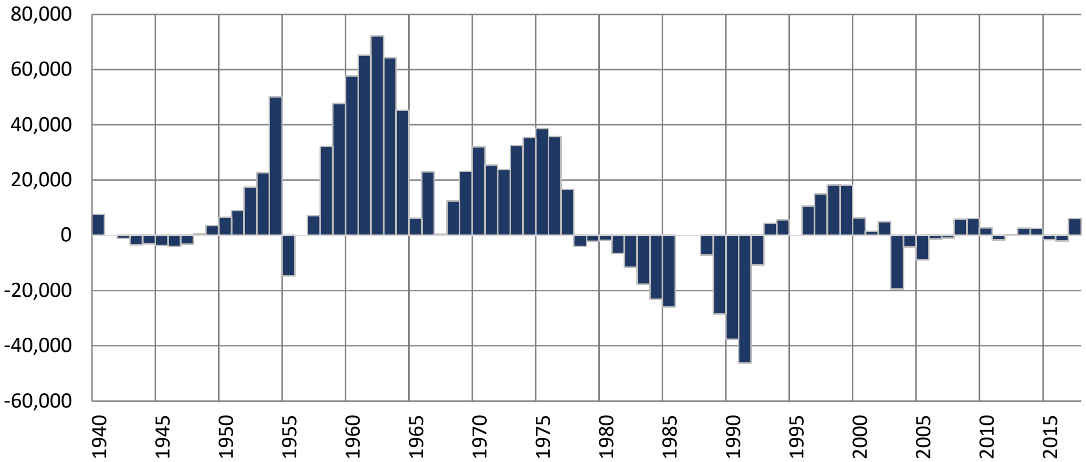
Run 14 - All Hueco Pumping Off

Simulated Differences in ILRG Model Outputs

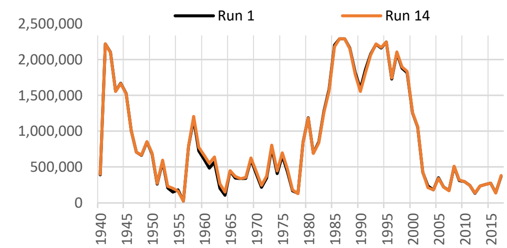
Run 14 minus Run 1

1940 - 2017 (acre-feet)

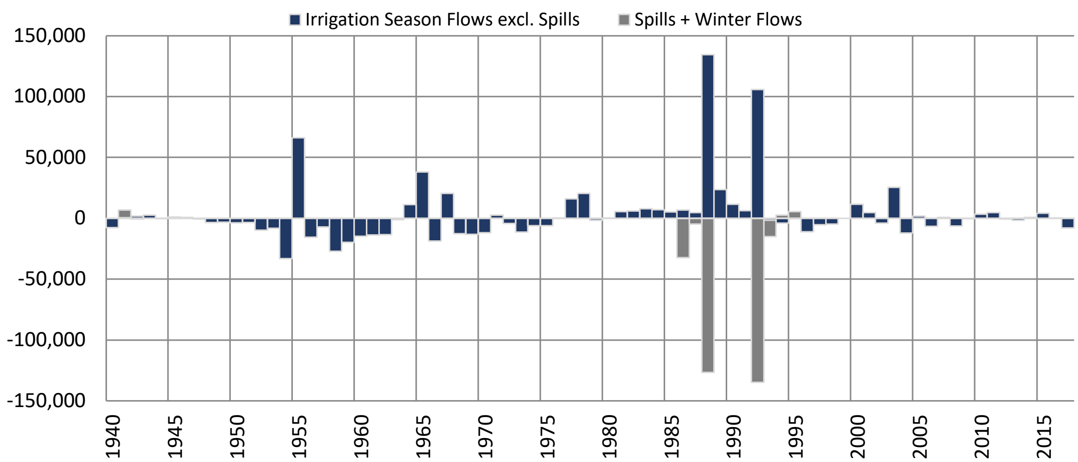
Total Project Storage (Year End)



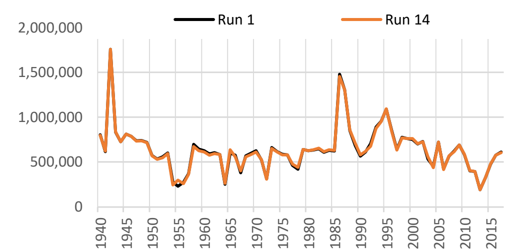
Period	Average Difference
1951-2017	-8
1951-1978	-378
1979-2005	-180
2006-2017	1,243
1985-2017	885
1985-2005	681



Caballo Reservoir Outflows (Annual)



	Average Difference		
Period	Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	3,556	-4,530	-974
1951-1978	-2,714	0	-2,714
1979-2005	11,974	-11,242	732
2006-2017	-753	0	-753
1985-2017	8,767	-9,198	-432
1985-2005	14,207	-14,454	-248



Notes:

Reservoir storage does not include storage attributed to SJC, CO, or NM credit waters.

Average differences calculated as (Final Storage - Initial Storage)/(no. years).

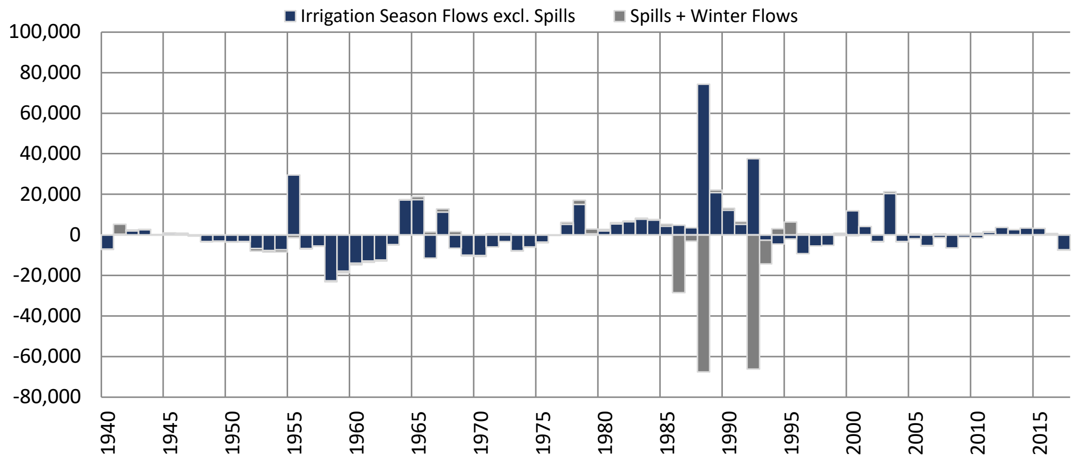
Run 14 - All Hueco Pumping Off

Simulated Differences in ILRG Model Outputs

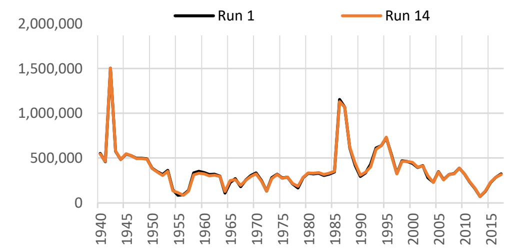
Run 14 minus Run 1

1940 - 2017 (acre-feet)

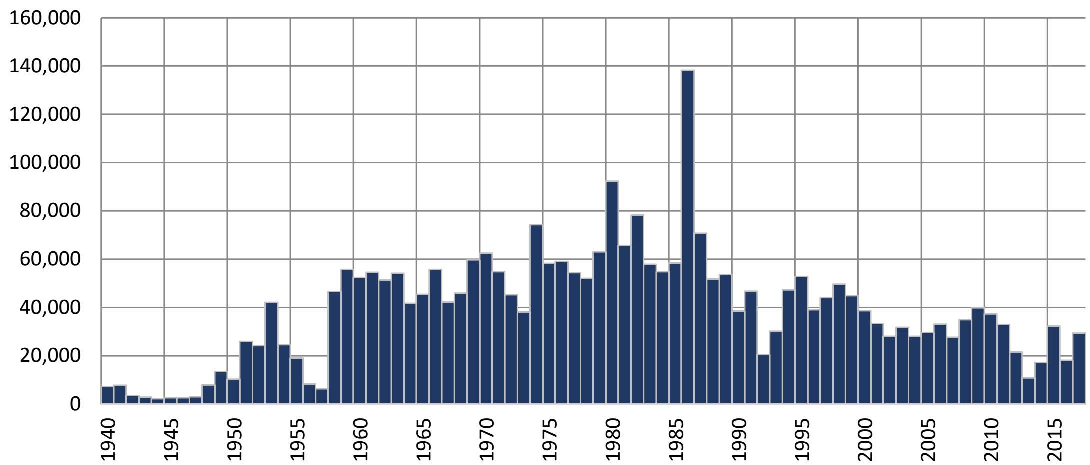
Rio Grande at El Paso (Annual)



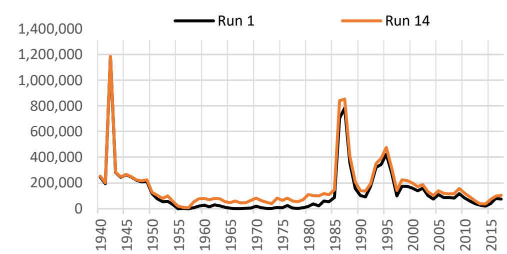
	Average Difference		
Period	Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	1,375	-2,307	-932
1951-1978	-3,254	11	-3,243
1979-2005	7,099	-5,810	1,289
2006-2017	-705	168	-536
1985-2017	4,662	-4,847	-186
1985-2005	7,728	-7,713	15



Rio Grande at Fort Quitman (Annual)

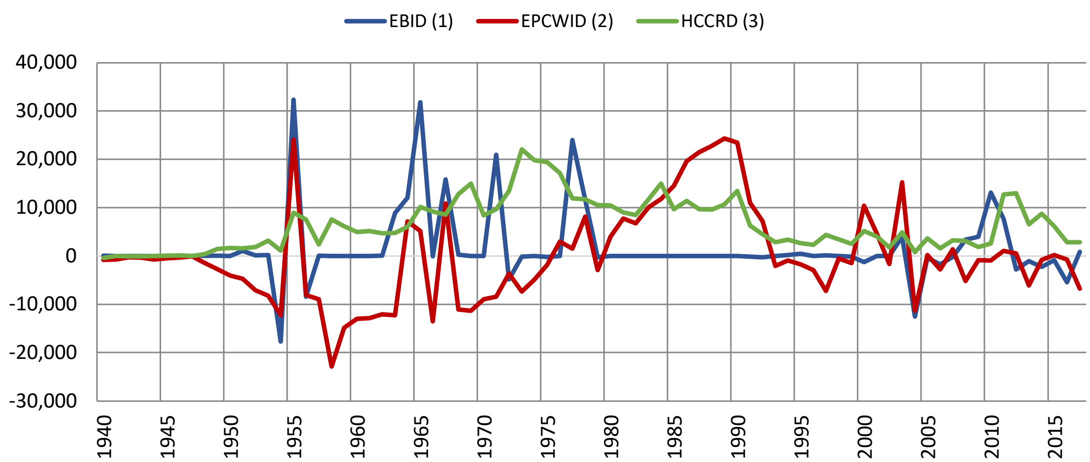


Period	Average Difference
1951-2017	44,426
1951-1978	44,797
1979-2005	51,382
2006-2017	27,909
1985-2017	39,705
1985-2005	46,445



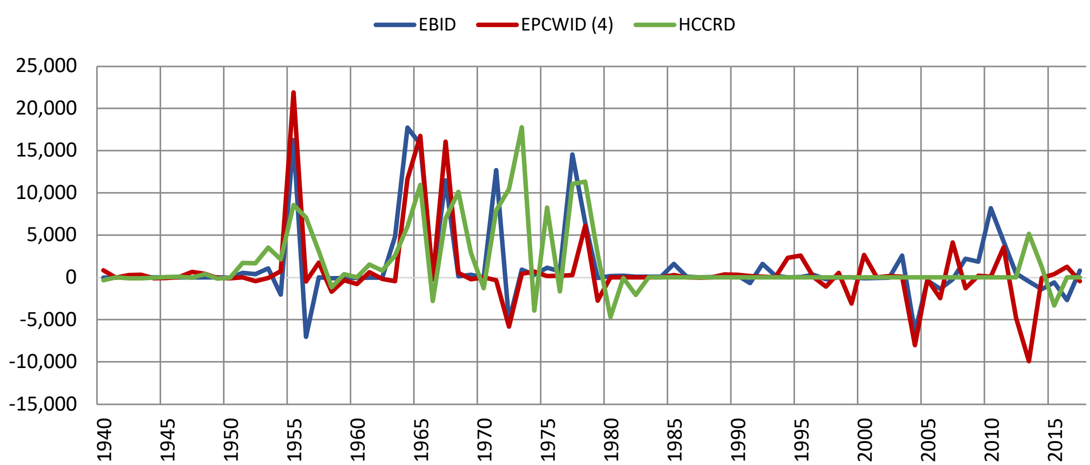
Run 14 - All Hueco Pumping Off
Simulated Differences in ILRG Model Outputs
Run 14 minus Run 1
1940 - 2017 (acre-feet)

River Headgate (RHG) Diversions (Irrigation Season)



	Average Difference		
Period	EBID	EPCWID	HCCRD
1951-2017	1,956	178	7,487
1951-1978	4,550	-5,317	9,102
1979-2005	-398	6,742	6,730
2006-2017	1,203	-1,770	5,420
1985-2017	125	3,742	5,504
1985-2005	-491	6,892	5,552

Farm Headgate (FHG) Deliveries (Irrigation Season)



	Average Difference		
Period	EBID	EPCWID	HCCRD
1951-2017	1,515	775	1,869
1951-1978	3,254	2,386	4,503
1979-2005	-24	-208	-148
2006-2017	918	-771	261
1985-2017	299	-368	95
1985-2005	-54	-138	0

Notes:
(1) EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).
(2) EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.
(3) HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.
(4) EPCWID FHG values include deliveries to Rogers WTP and R/U WTP.

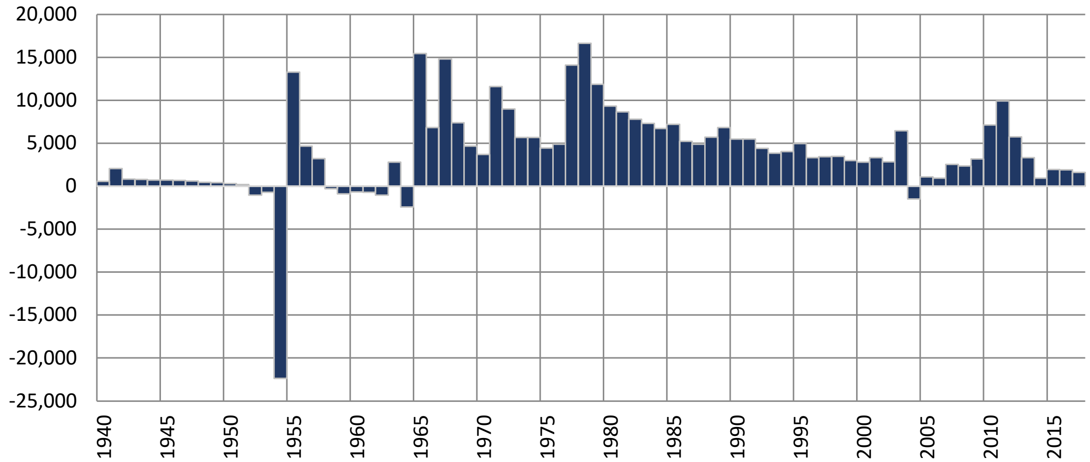
Run 14 - All Hueco Pumping Off

Simulated Differences in ILRG Model Outputs

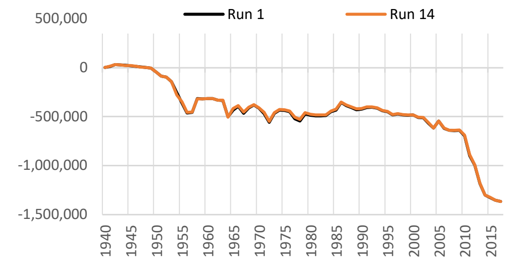
Run 14 minus Run 1

1940 - 2017 (acre-feet)

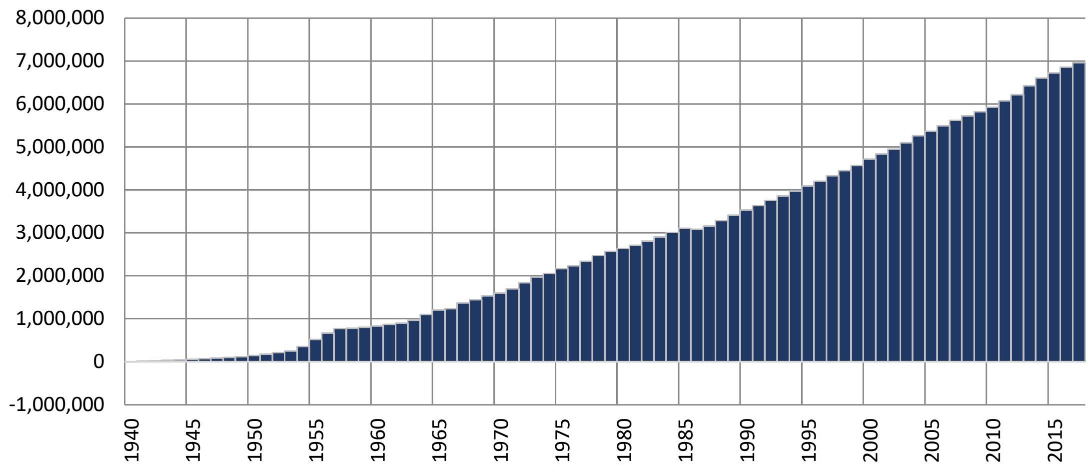
Cumulative Annual Rincon-Mesilla Groundwater Storage



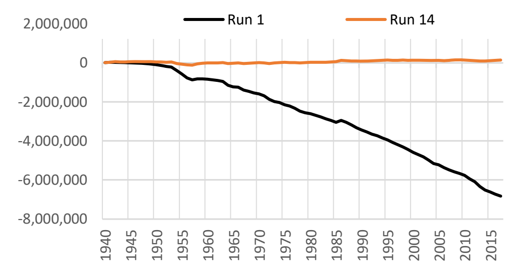
Period	Average Difference
1951-2017	20
1951-1978	584
1979-2005	-575
2006-2017	43
1985-2017	-154
1985-2005	-267



Cumulative Annual Hueco Groundwater Storage



Period	Average Difference
1951-2017	101,742
1951-1978	83,168
1979-2005	107,121
2006-2017	132,976
1985-2017	119,828
1985-2005	112,314



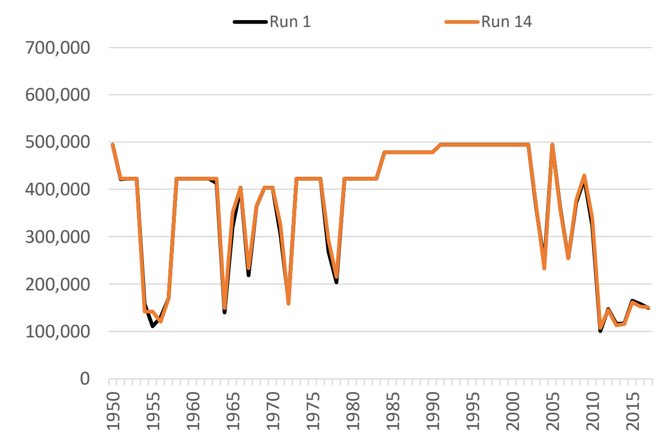
Notes:

Cumulative storage change in alluvial and non-alluvial aquifers.

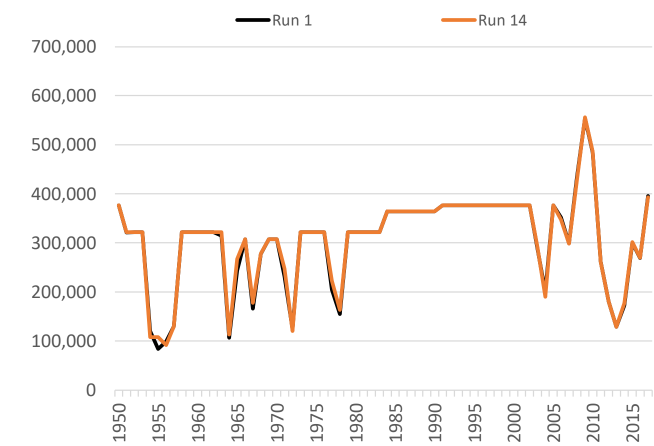
Average differences calculated as (Final Storage - Initial Storage)/(no. years).

Run 14 - All Hueco Pumping Off
Annual Allocation and Charges
Run 14 v. Run 1
ILRG Model
1950 - 2017 (acre-feet)

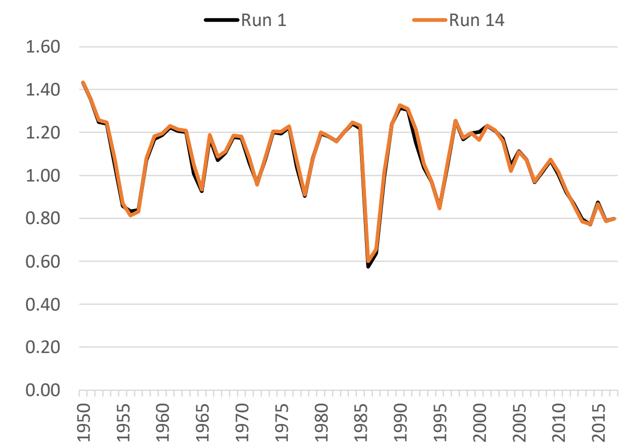
Total Allocation - EBID



Total Allocation - EPCWID

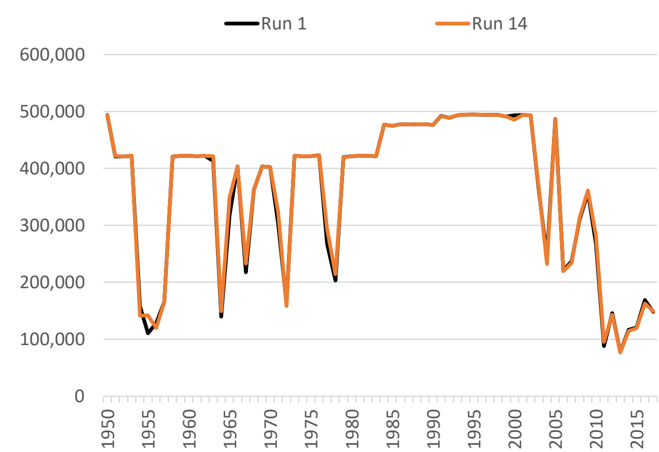


Diversion Ratio

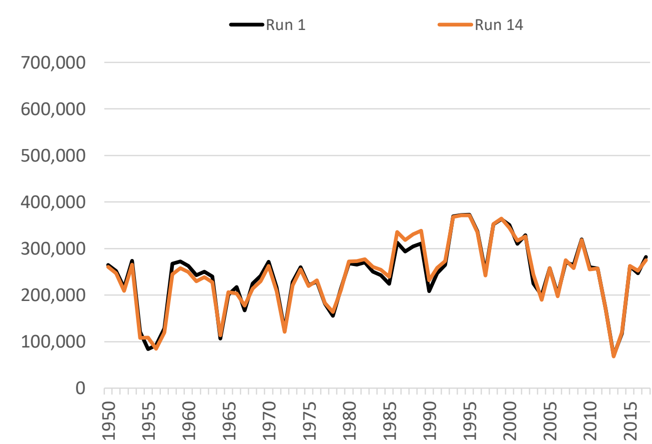


Note:
Computed as Total Charges/Caballo Release.

Annual Delivery Charges - EBID

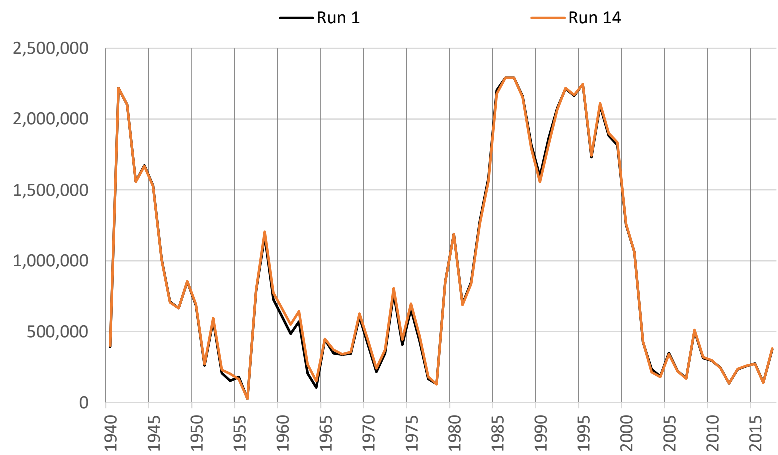


Annual Delivery Charges - EPCWID

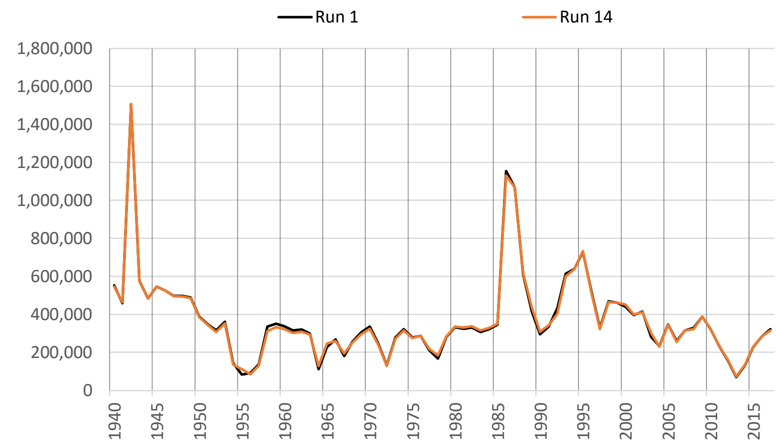


Run 14 - All Hueco Pumping Off
Annual Summary of Project Storage and Rio Grande Flows
Run 14 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

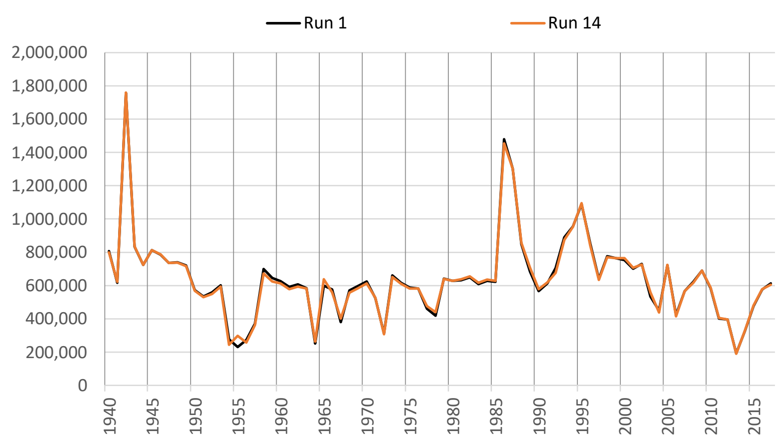
Total Year-End Project Reservoir Storage



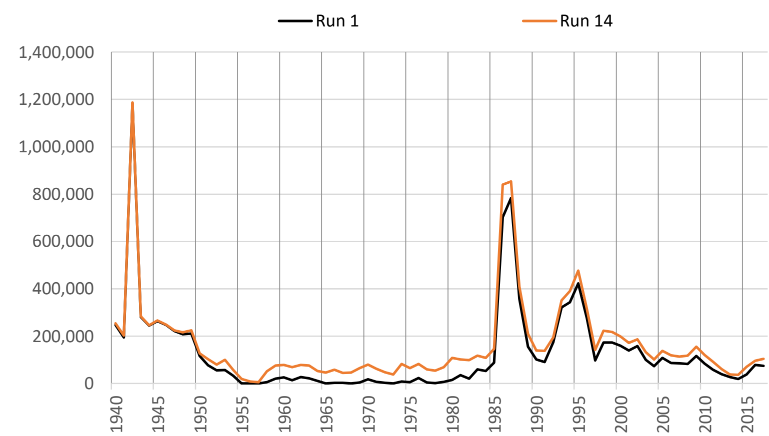
Rio Grande at El Paso



Rio Grande Below Caballo



Rio Grande at Fort Quitman



***Note different scales.**

Run 14 - All Hueco Pumping Off

Irrigation Season Summary of Irrigation Operations

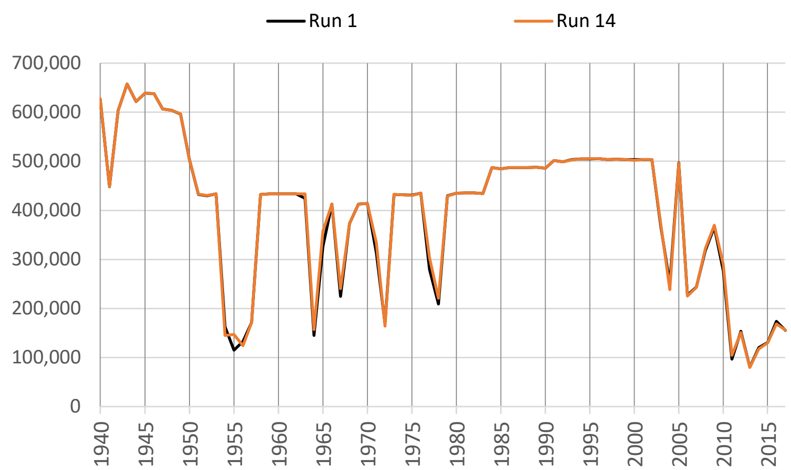
Run 14 v. Run 1

ILRG Model

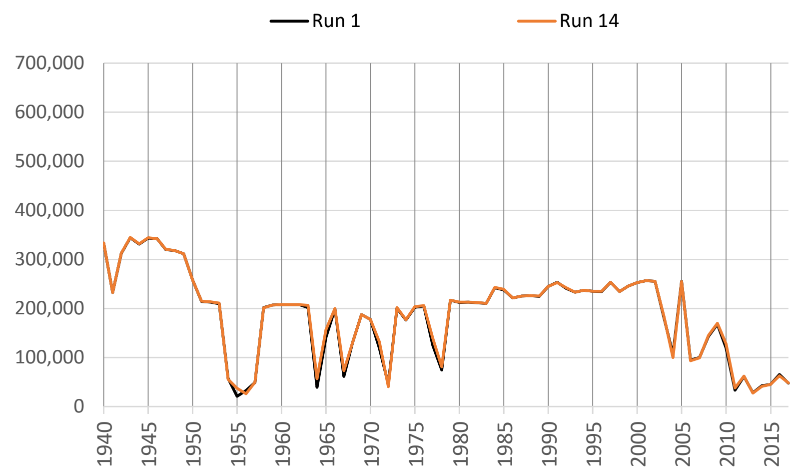
1940 - 2017 (acre-feet)

EBID Total

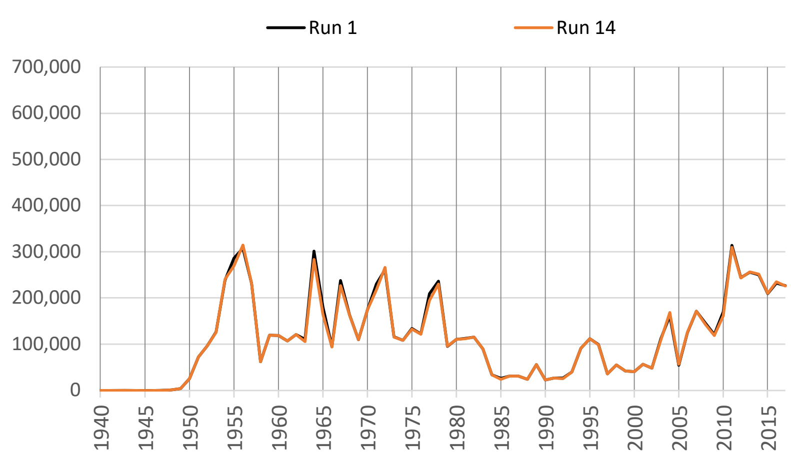
Net River Headgate Diversions



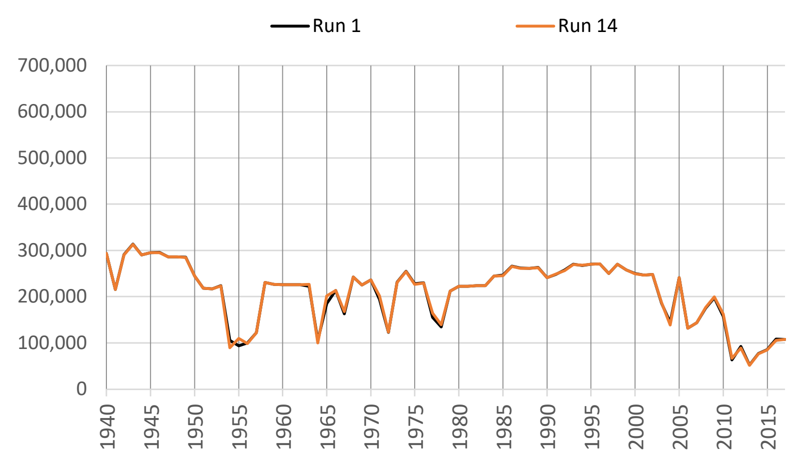
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries

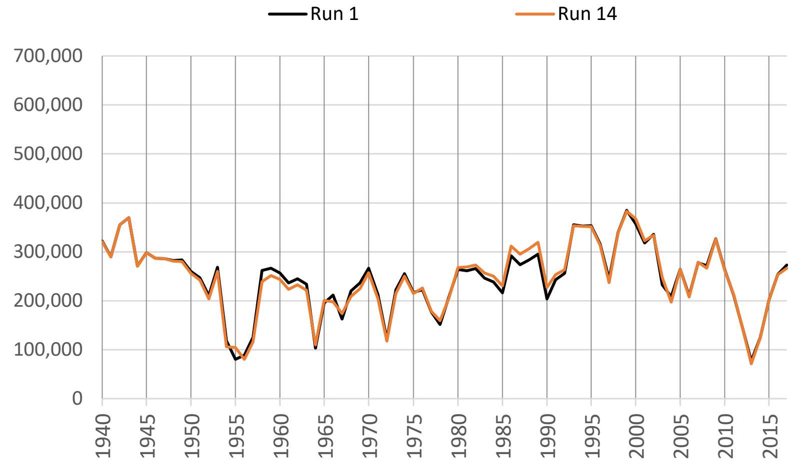


Notes: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).
Pumping includes Supplemental and Primary groundwater pumping.

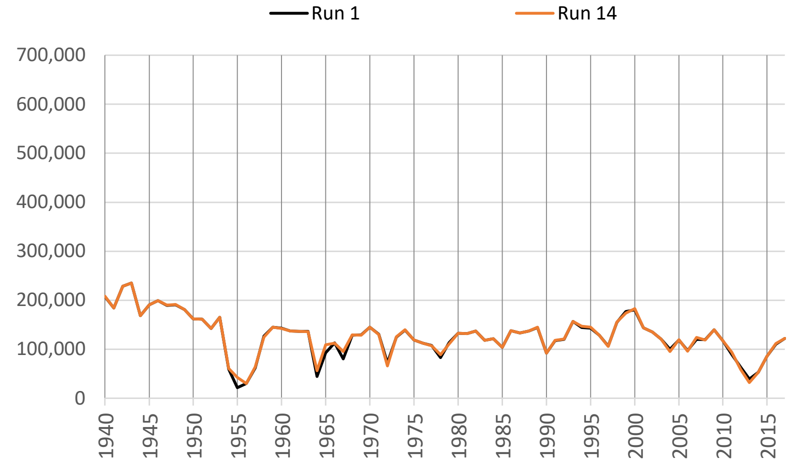
Run 14 - All Hueco Pumping Off
Irrigation Season Summary of Irrigation Operations
Run 14 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

EPCWID Total

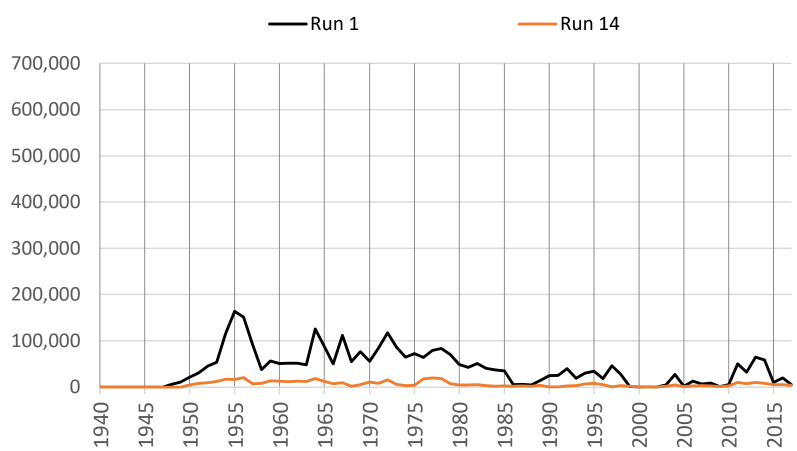
Net River Headgate Diversions



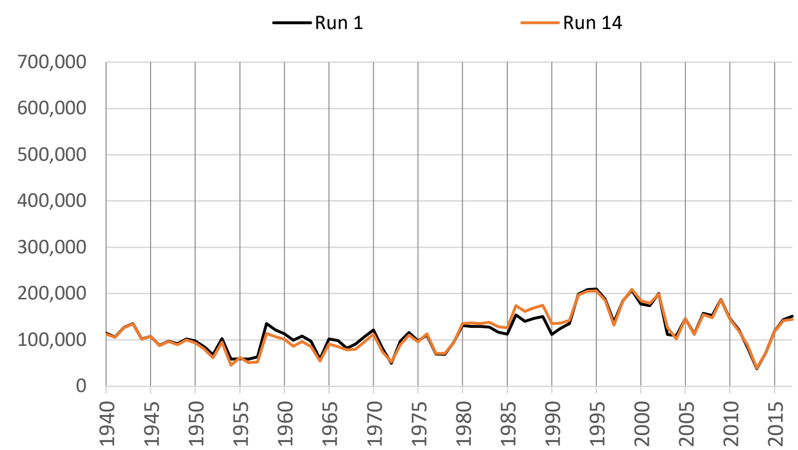
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries

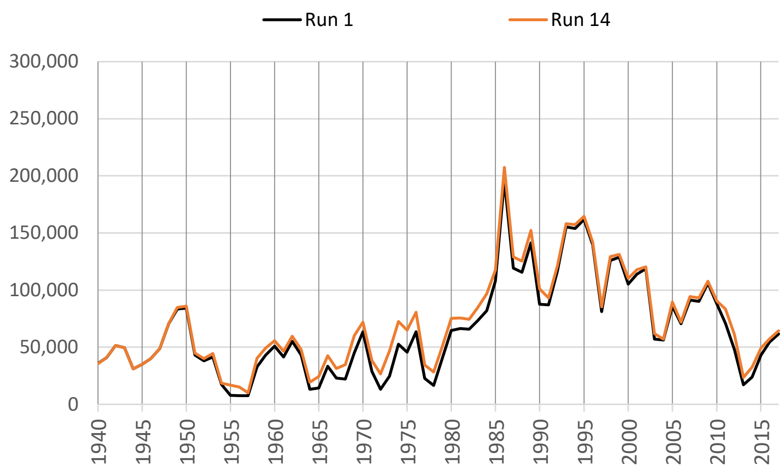


Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

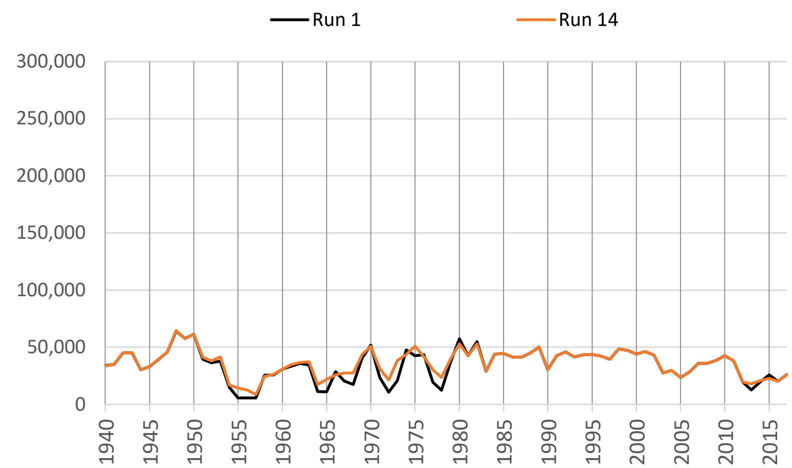
Run 14 - All Hueco Pumping Off
Irrigation Season Summary of Irrigation Operations
Run 14 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

HCCRD Total

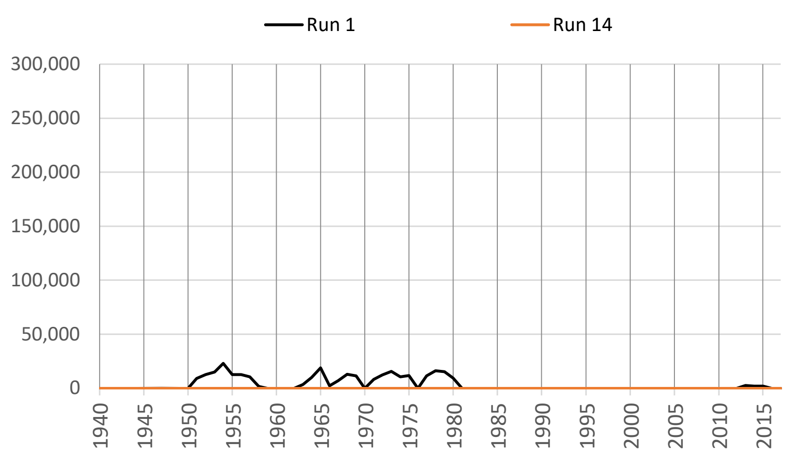
Net River Headgate Diversions



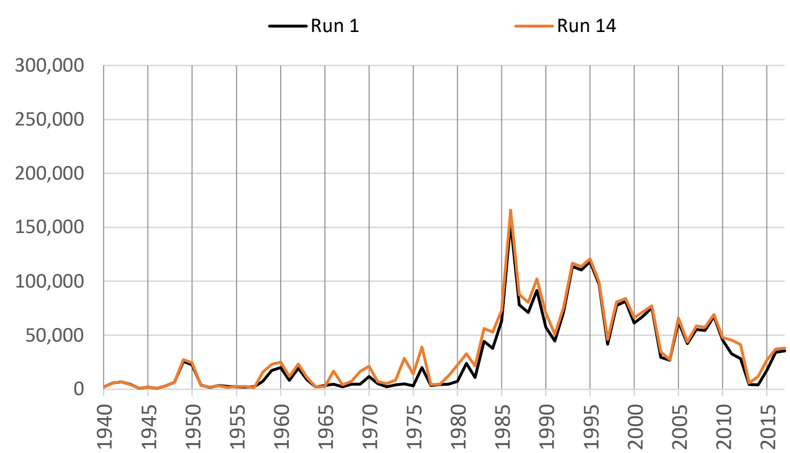
Farm Headgate Deliveries



Pumping



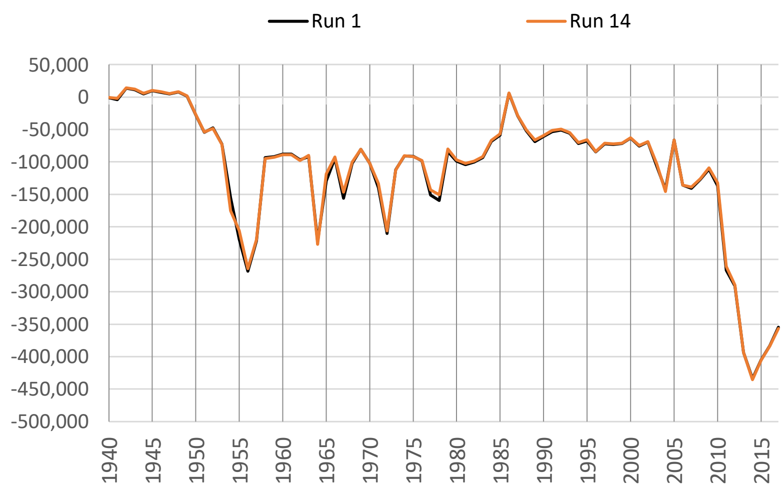
RHG Diversions - FHG Deliveries



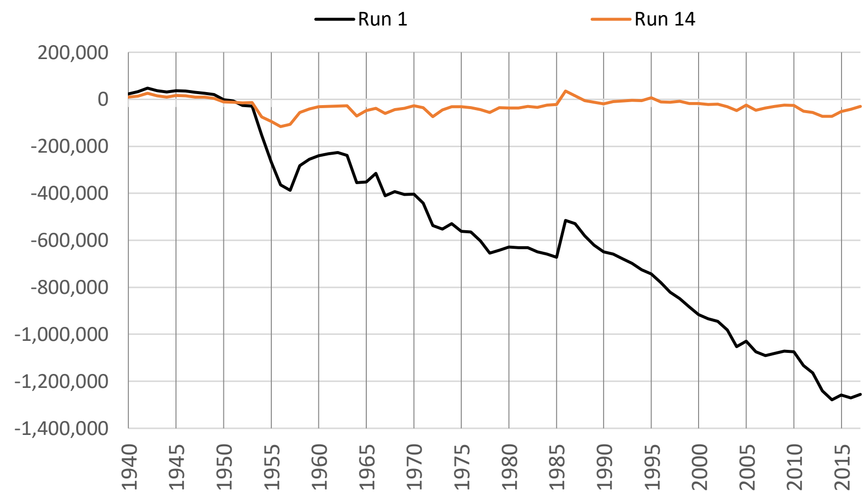
Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

Run 14 - All Hueco Pumping Off
Cumulative Change in Ground Water Storage
Run 14 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

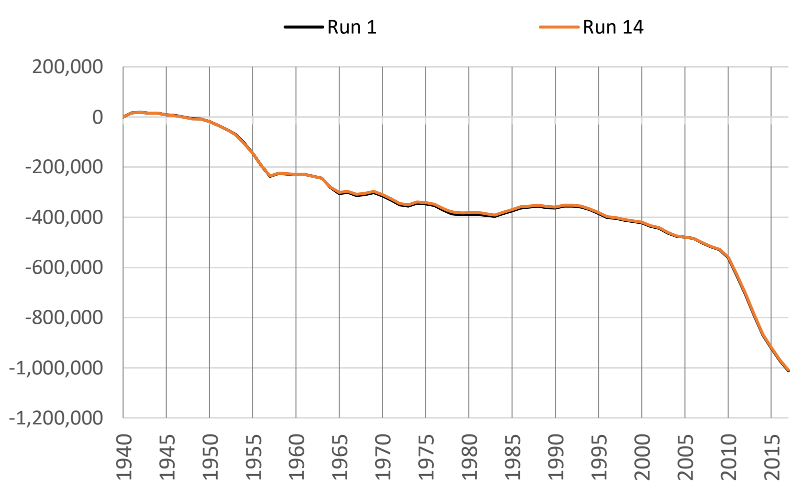
Rincon-Mesilla Alluvial Aquifer



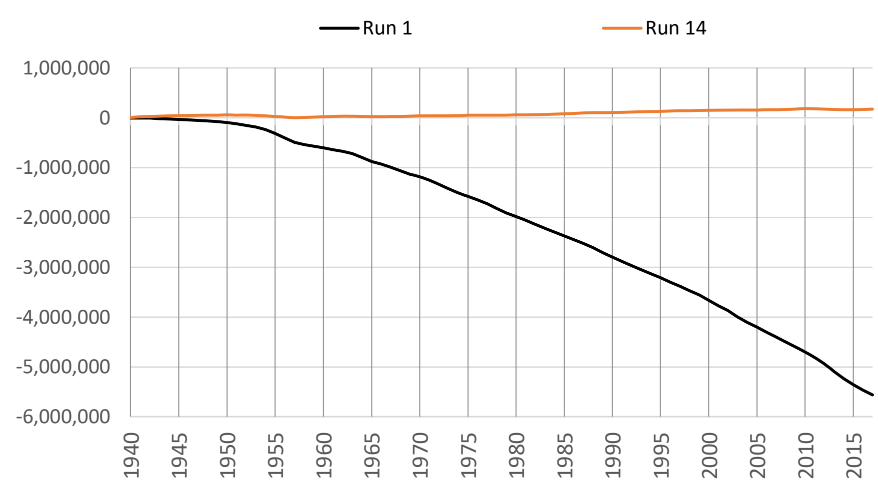
Hueco Alluvial Aquifer



Rincon-Mesilla Non-Alluvial Aquifer

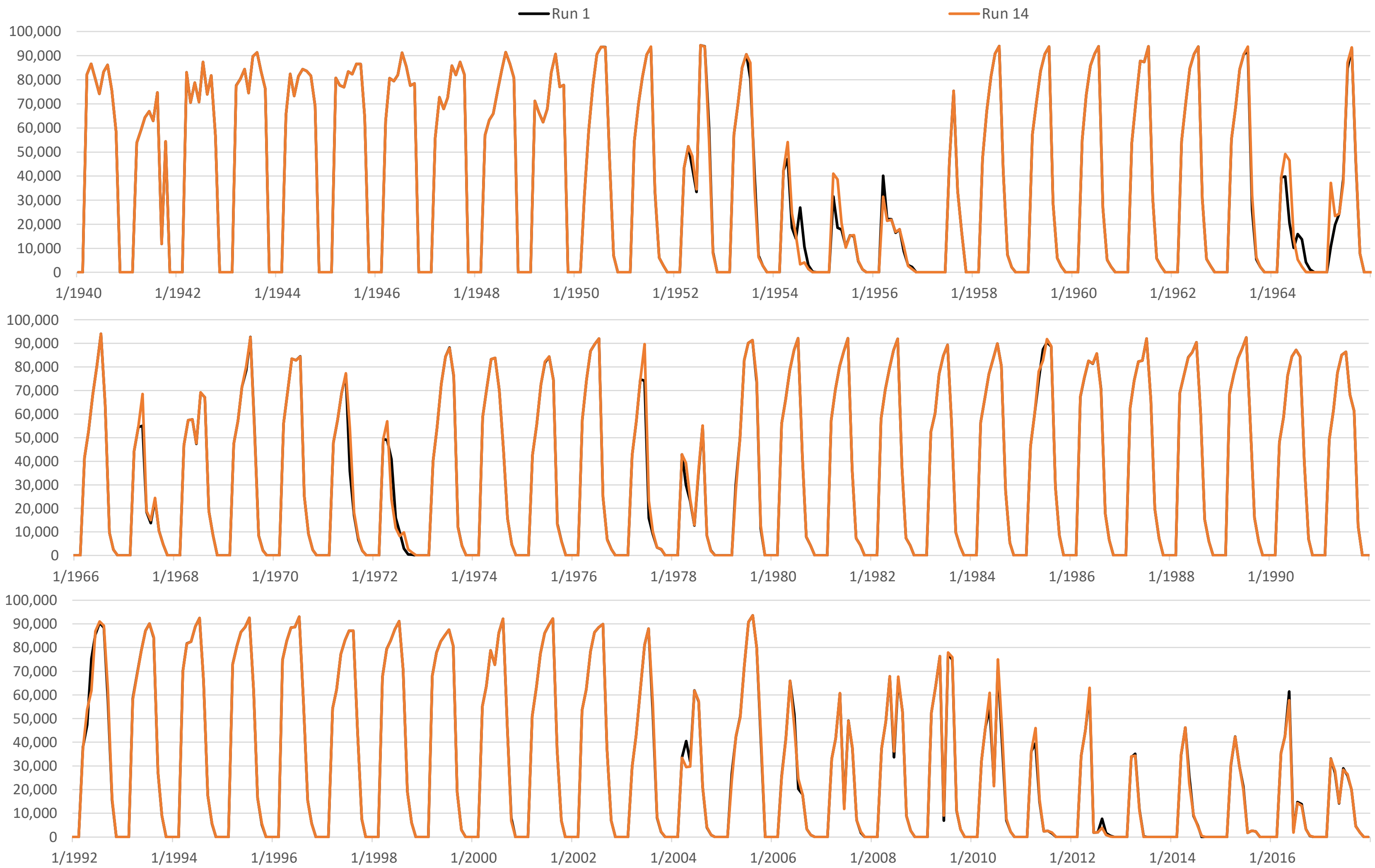


Hueco Non-Alluvial Aquifer



***Note different scales.**

Run 14 - All Hueco Pumping Off
Monthly Net RHG Diversions
Run 14 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
EBID Total



Note: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

Run 14 - All Hueco Pumping Off

Monthly Net RHG Diversions

Run 14 v. Run 1

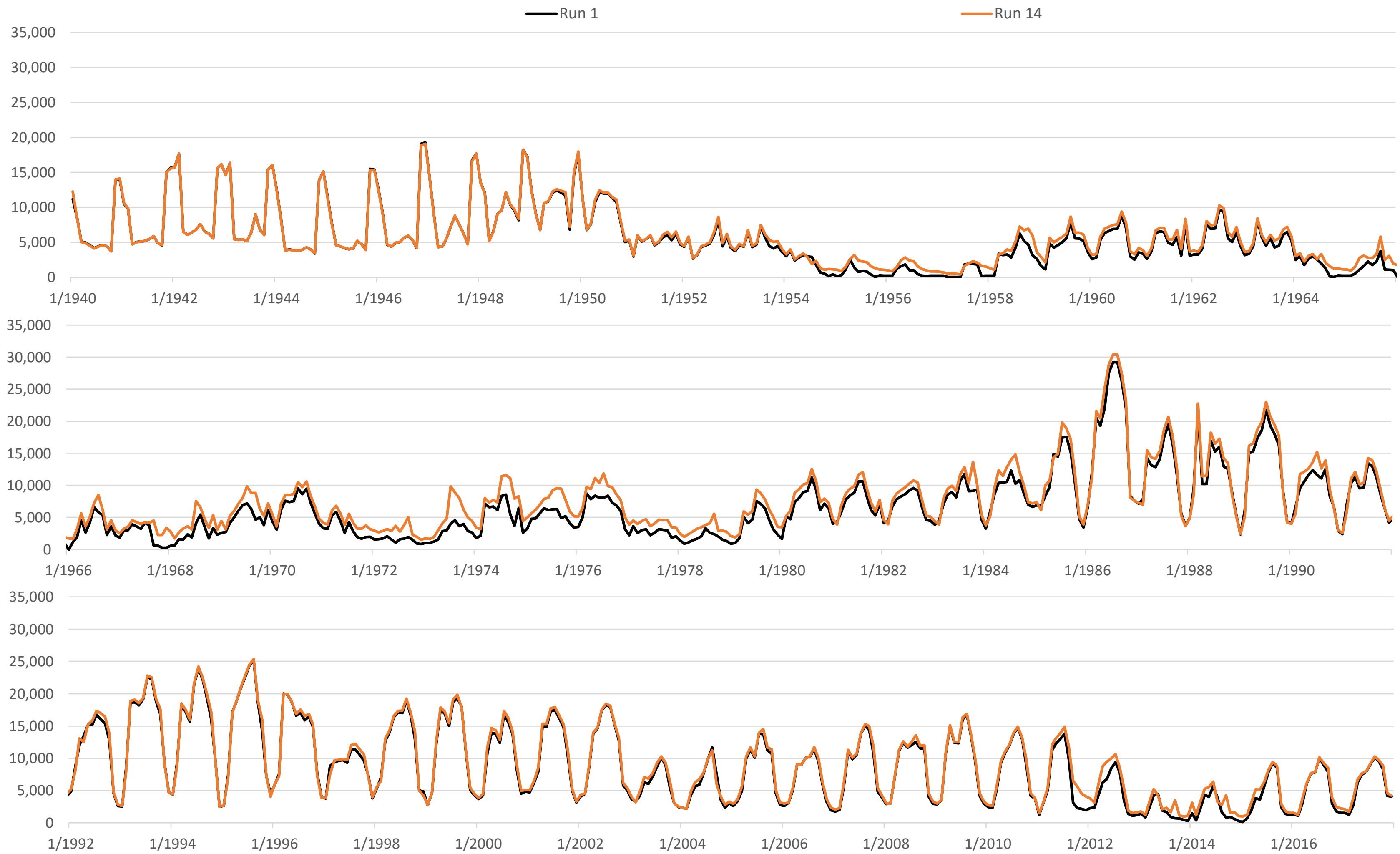
ILRG Model

1940 - 2017 (acre-feet)

EPCWID Total

Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

Run 14 - All Hueco Pumping Off
Monthly Net RHG Diversions
Run 14 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
HCCRD Total



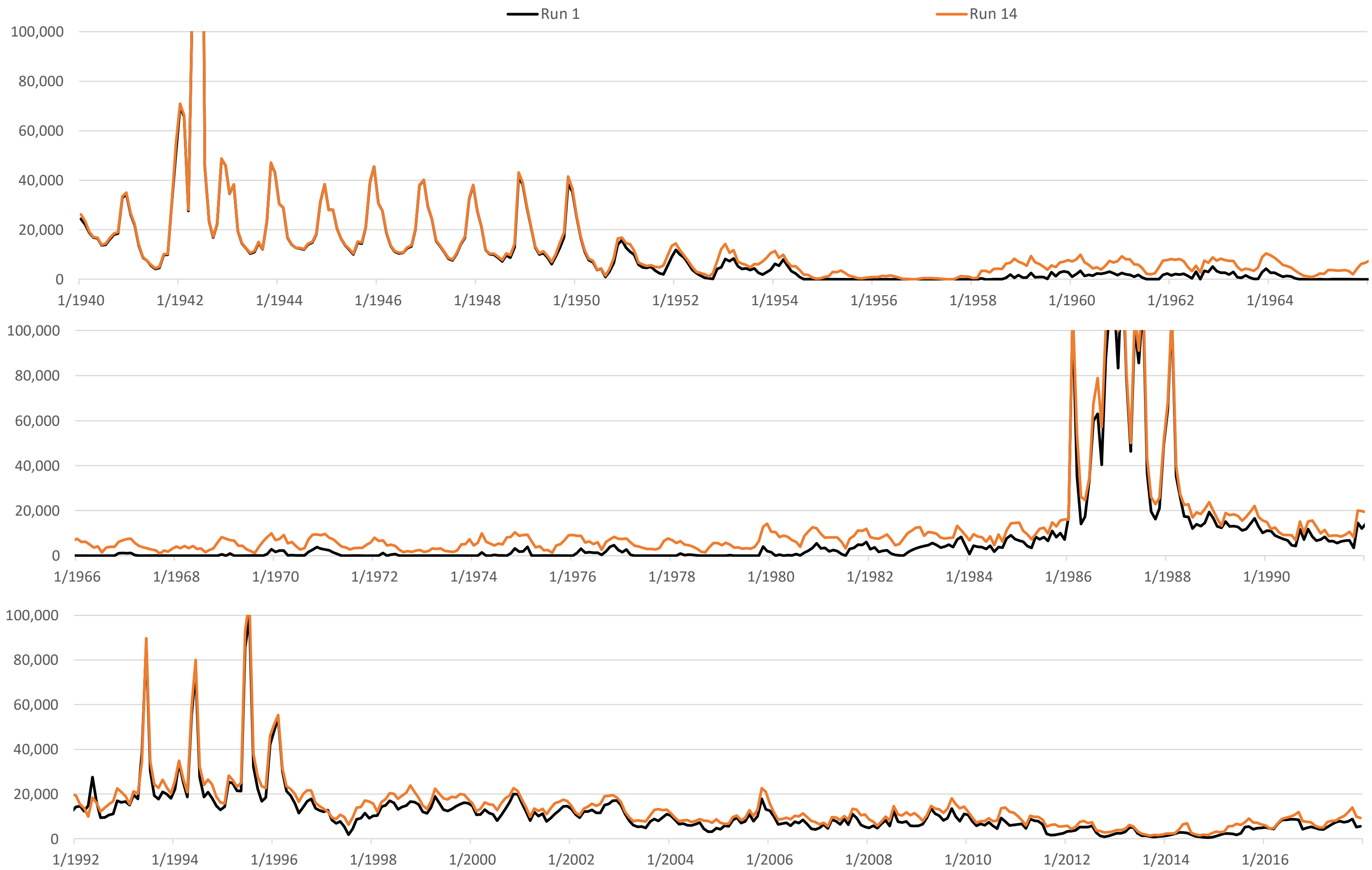
Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

Run 14 - All Hueco Pumping Off
End of Month Reservoir Storage (Elephant Butte + Caballo)
Run 14 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

Run 14 - All Hueco Pumping Off
Monthly Caballo Releases
Run 14 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

Run 14 - All Hueco Pumping Off
Monthly Rio Grande at El Paso Flow
Run 14 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

Run 14 - All Hueco Pumping Off
Monthly Rio Grande at Fort Quitman Flow
Run 14 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)



Appendix 30O

Comparison of ILRG Model Runs
Run 14a v. Run 1

Model Run Specifications

Model Version: LRG_v116

Name: **Run 14a - TX Hueco Pumping Off**

Run ID: LRG_v116_Operational_Run14a
Date: 8/28/2020

Name: **Run 1 - Historical Base Run (All Pumping On)**

Run ID: LRG_v116_Operational_Run1
Date: 8/23/2020

Selected Model Inputs

Pumping and Returns	Run 14a	Run 1
Irrigation Pumping	TX Hueco Off	On
Irrigated Area	Hist	Hist
Non-Irrigation Pumping	TX Hueco Off	On
Non-Irrigation Pumping Returns	TX Hueco Off	On
Las Cruces Jornada Pumping Returns	On	On

Project Allocation Rules		
1950-2005	D1/D2	D1/D2
2006-2007	D3	D3
2008-2017	D3 + CO	D3 + CO

EPCWID Operations		
Charge EPCWID for Use of WWTP Returns	Off	Off
ACE and Haskell Credits for EPCWID	On	On
Increased EPCWID Use of Fabens Drain Flows	Off	Off
Charge EPCWID for Fabens Drain Flow Use	Off	Off

Run 14a - TX Hueco Pumping Off
Comparison of ILRG Model Runs
Run 14a v. Run 1
1951 - 2017 Annual Average
(1,000 acre-feet)

Run No.	1	14a	14a - 1		
Simulated Input or Output	**Run 1**	**Run 14a**	**Run 14a minus Run 1**		
Pumping Stress					
Irrigation Pumping	44.3	0.0	-44.3		
Non-Irrigation Pumping	181.0	118.3	-62.6		
WWTP Flows	58.0	46.7	-11.4		
Urban Deep Percolation	13.1	7.8	-5.3		
Total Stress	154.2	63.9	-90.3		
	Stress is Pumping minus WWTP and Urban Deep Perc				
Effects of Pumping Stress				***% Chg***	
FHG Deliveries (Mar - Oct)				***Stress***	***% Diff.***
EBID	167.6	166.7	-1.0	*1%*	*-1%*
EPCWID (incl. EPW)	139.9	139.2	-0.7	*1%*	*0%*
HCCRD	32.8	34.4	1.6	*-2%*	*5%*
Total	340.3	340.3	0.0	*0%*	*0%*
FHG Deliveries (Nov - Feb)					
EBID	0.0	0.0	0.0	*0%*	*3%*
EPCWID (incl. EPW)	0.2	0.1	-0.1	*0%*	*-43%*
HCCRD	2.4	2.4	0.0	*0%*	*-1%*
Total	2.6	2.5	-0.1	*0%*	*-4%*
Irrigation Pumping					
EBID	140.4	141.4	0.9	*-1%*	*1%*
EPCWID (Mesilla Valley)	7.4	7.4	0.0	*0%*	*1%*
EPCWID (El Paso Valley)	40.1	0.0	-40.1		
HCCRD	4.2	0.0	-4.2		
Total	147.8	148.8	1.0	*-1%*	*1%*
	Pumping turned off.	*Other values are simulated responses and are totaled.*			
Other Inflows/Outflows					
Net Reservoir Evaporation	125.3	124.3	-1.1	*1%*	*-1%*
Riparian ET	70.9	75.6	4.7	*-5%*	*7%*
River Evaporation + Incidental Canal Loss	30.3	29.8	-0.6	*1%*	*-2%*
Total	226.6	229.7	3.1	*-3%*	*1%*
Rio Grande at Fort Quitman					
Reservoir Spills	33.3	31.2	-2.1	*2%*	*-6%*
Nov-Feb Flows	21.4	25.3	3.9	*-4%*	*18%*
Mar - Oct Flows	41.1	51.2	10.2	*-11%*	*25%*
Underflow (GW Model)	0.2	0.3	0.0	*0%*	*22%*
Total	96.0	108.0	12.0	*-13%*	*13%*

Run 14a - TX Hueco Pumping Off
Comparison of ILRG Model Runs
Run 14a v. Run 1
1951 - 2017 Annual Average
(1,000 acre-feet)

Run No.	1	14a	14a - 1		
Simulated Input or Output	**Run 1**	**Run 14a**	**Run 14a minus Run 1**		
Effects of Pumping Stress (continued)				*% Chg*	
Change in Storage				***Stress***	***% Diff.***
Reservoir Storage	-4.7	-4.6	0.1	*0%*	*-2%*
Alluvial GW Storage (RW Model)	-23.6	-17.4	6.2	*-7%*	*-26%*
Non-alluvial GW Storage (GW Models)	-96.4	-51.4	45.0	*-50%*	*-47%*
Soil Moisture Storage	0.6	0.6	0.0	*0%*	*5%*
Total	-124.0	-72.7	51.3	*-57%*	*-41%*
Summary of Effects					
FHG Deliveries (Mar-Oct)	340.3	340.3	0.0	*0%*	*0%*
FHG Deliveries (Nov-Feb)	2.6	2.5	-0.1	*0%*	*-4%*
Irrigation Pumping	147.8	148.8	1.0	*-1%*	*1%*
Riparian ET + Evaporation	226.6	229.7	3.1	*-3%*	*1%*
Fort Quitman Flow	96.0	108.0	12.0	*-13%*	*13%*
Change in Storage	-124.0	-72.7	51.3	*-57%*	*-41%*
Total	689.2	756.5	67.2	*-74%*	*10%*
Other Effects of Pumping Stress				*% Chg*	
Rio Grande at El Paso				***Stress***	***% Diff.***
Reservoir Spills	49.4	44.0	-5.4	*6%*	*-11%*
Nov-Feb Flows	22.8	23.2	0.4	*0%*	*2%*
Mar - Oct Flows	263.8	270.5	6.8	*-8%*	*3%*
Total	336.0	337.8	1.8	*-2%*	*1%*
Rio Grande below Caballo					
Reservoir Spills	65.9	57.6	-8.2	*9%*	*-13%*
Nov-Feb Flows	0.5	0.3	-0.2	*0%*	*-40%*
Mar - Oct Flows	541.3	550.7	9.5	*-10%*	*2%*
Total	607.6	608.6	1.0	*-1%*	*0%*
Surface Water Diversions (Mar - Oct)					
EBID	366.5	364.2	-2.3	*3%*	*-1%*
EPCWID (incl. EPW)	236.8	238.7	1.9	*-2%*	*1%*
HCCRD	67.5	72.1	4.5	*-5%*	*7%*
Total	670.8	674.9	4.1	*-5%*	*1%*
Surface Water Diversions (Nov - Feb)					
EBID	0.0	0.0	0.0	*0%*	*0%*
EPCWID (incl. EPW)	14.3	12.3	-2.0	*2%*	*-14%*
HCCRD	14.2	14.7	0.5	*-1%*	*4%*
Total	28.5	27.0	-1.5	*2%*	*-5%*

Run 14a - TX Hueco Pumping Off

Annual Differences in ILRG Model Outputs

Run 14a minus Run 1

1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1940	19	19	-619	69	-150	554	-12	-12	377	377	-96	-96	-3,476	-3,370	6,846
1941	47	47	-111	-1,251	218	51	3	4	-2	-200	200	111	3,180	2,886	3,425
1942	-27	-27	-46	-2,051	-175	-176	9	9	465	-155	-197	-220	1,879	1,870	-273
1943	-23	-23	-156	-1,660	-157	-296	24	24	437	192	-101	-403	4,312	4,210	2,309
1944	-24	-24	-480	-1,862	135	-166	-1	0	-234	-446	83	-149	1,829	1,798	2,079
1945	-22	-22	-255	-2,172	218	-416	8	9	-297	-697	193	216	3,058	2,899	2,467
1946	-11	-11	52	-2,535	318	-537	12	12	-48	-862	256	178	3,080	3,024	2,565
1947	-14	-14	476	-1,559	172	-477	4	4	646	54	119	150	2,030	2,011	2,735
1948	2	2	-973	-2,409	568	281	-9	-9	309	1	439	216	-628	-575	4,441
1949	17	17	-2,379	-4,232	1,613	1,557	-2	-3	-378	-403	-149	-300	-571	-606	6,930
1950	8	8	-3,573	-4,509	1,761	1,906	-17	-17	-319	-320	-34	-61	-1,347	-1,337	5,938
1951	-4,399	-4,399	-4,345	-4,807	1,617	2,211	-2,556	-2,557	-324	-326	1,705	1,236	-3,724	-1,800	15,966
1952	-53	-53	-6,283	-6,771	1,700	2,515	37	37	-699	-700	1,528	815	-2,568	-3,106	16,365
1953	13	13	-7,414	-7,903	3,098	4,461	23	23	-298	-299	3,475	3,906	-5,945	-5,478	27,904
1954	3,639	3,639	2,124	267	4,544	6,290	2,144	2,144	4,478	4,478	4,628	6,422	9,508	6,495	18,799
1955	-2,299	-2,299	-1,483	-4,234	8,415	11,136	-1,739	-1,739	1,487	1,468	7,414	9,988	2,979	1,161	11,757
1956	-3,769	-3,769	-5,909	-8,745	6,832	8,807	-2,121	-2,121	1,838	1,468	6,344	7,798	-5,727	-1,690	5,919
1957	54	54	-7,953	-10,992	556	3,539	6	6	1,750	1,462	1,368	2,925	-5,000	-4,484	4,289
1958	1	1	-20,720	-22,492	6,060	10,851	-85	-85	-1,963	-1,933	-1,581	-271	-18,188	-17,795	30,017
1959	5	5	-12,845	-13,769	4,918	7,668	-44	-44	-888	-888	403	682	-10,427	-10,699	34,197
1960	3	3	-10,878	-12,032	3,649	5,007	-28	-28	-1,417	-1,417	0	0	-5,142	-5,563	28,201
1961	2	2	-10,075	-11,187	3,952	5,174	-19	-19	-41	-41	1,465	-545	-2,998	-3,253	30,477
1962	6	6	-9,071	-10,240	3,512	4,742	-2	-2	-838	-838	756	1,152	-2,201	-2,295	28,653
1963	8,875	8,875	-8,043	-9,123	3,610	4,559	4,821	4,821	-1,025	-1,024	2,230	2,071	7,111	3,309	30,373
1964	12,453	12,453	9,210	6,209	5,805	7,277	6,593	6,593	6,651	6,485	5,199	6,565	26,434	16,573	21,351
1965	-4,655	-4,655	-16,350	-18,842	5,165	8,666	-1,577	-1,577	-98	-397	5,949	8,423	-14,991	-6,890	16,949
1966	-8	-8	-10,221	-11,335	6,521	9,497	14	14	-210	-210	-3,939	-6,472	-3,925	-2,191	28,891
1967	7,856	7,856	5,287	3,033	7,605	11,931	4,964	4,964	7,803	7,285	6,523	9,888	12,256	8,025	16,466
1968	-1,210	-1,210	-5,982	-7,548	9,850	14,407	-752	-752	577	177	8,539	8,609	-1,606	1,682	18,616
1969	-8	-8	-6,334	-7,460	12,172	15,084	17	17	-92	-92	3,047	-1,388	-1,505	-845	31,704
1970	-2	-2	-3,951	-5,243	5,132	6,482	18	18	-231	-231	-1,274	-2,725	783	1,051	27,033
1971	696	696	-3,883	-6,224	6,269	7,884	462	462	-775	-775	5,620	7,140	2,506	2,146	20,573
1972	-718	-718	-735	-3,467	8,660	9,962	-566	-566	-1,246	-1,279	7,223	7,285	3,217	3,174	17,992
1973	-4	-4	-2,124	-4,335	17,167	20,154	115	115	157	38	16,715	15,050	2,725	2,761	11,060
1974	-3	-3	-15	-1,330	15,605	19,467	38	38	543	544	-2,741	-4,365	5,865	5,573	40,330
1975	16	16	2,400	1,125	15,104	18,781	-217	-217	-83	-83	10,360	7,050	6,573	6,531	20,479
1976	-9	-9	6,434	5,138	12,322	16,318	170	170	-78	-78	-1,658	-5,692	11,014	10,712	30,609
1977	-16,520	-16,520	4,463	2,189	8,103	10,991	-10,539	-10,539	-840	-841	7,927	8,758	4,876	9,876	15,253
1978	-17,735	-17,735	-13,347	-18,006	5,522	7,523	-8,096	-8,096	-12,428	-12,430	5,638	6,584	-19,421	-8,786	12,153

Run 14a - TX Hueco Pumping Off
Annual Differences in ILRG Model Outputs
Run 14a minus Run 1
1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1979	-172	-172	1,609	-1,724	4,557	6,984	-893	-893	-3,309	-3,311	4,586	6,442	16,787	8,542	18,419
1980	32	32	8,675	7,073	6,699	7,677	-94	-94	-12	-14	-1,274	-3,285	16,863	14,242	44,827
1981	10	10	11,950	10,657	5,314	4,545	-165	-165	-14	-15	-56	-223	19,243	17,936	30,951
1982	-6	-6	11,006	9,592	4,986	4,118	16	16	-15	-15	-1,259	-2,736	19,678	19,104	40,847
1983	-8	-8	13,657	12,110	8,229	7,460	37	37	1	1	0	0	20,879	20,259	30,644
1984	44	44	15,052	13,595	10,641	9,392	-199	-198	-12	-12	0	0	17,898	17,642	21,414
1985	1,541	1,541	23,813	23,160	-8,361	-9,945	8,036	8,036	4,863	4,777	0	0	-10,454	-12,057	640
1986	-240	-240	22,259	22,065	7,145	4,626	-515	-522	-419	-425	0	0	-70,987	-68,061	24,683
1987	-92	-92	25,163	24,979	7,559	4,879	-76	-76	19	19	0	0	141	1,265	4,404
1988	-13	-13	26,729	26,545	8,044	5,028	87	87	5	5	0	0	23,859	20,908	3,604
1989	-19	-19	28,377	27,910	9,135	6,425	145	145	353	-26	0	0	40,668	38,459	17,628
1990	-11	-11	25,481	24,326	9,651	6,961	122	122	313	-202	0	0	20,841	21,808	8,571
1991	-152	-152	12,463	11,771	4,117	2,443	-687	-686	34	-762	0	0	16,595	16,374	14,136
1992	-280	-280	8,712	8,270	2,028	1,102	1,544	1,546	4	-340	0	0	-16,091	-16,312	-8,850
1993	-43	-43	-458	-657	966	-678	6	6	-787	-790	0	0	-52,277	-50,568	-48,159
1994	39	39	-213	-409	1,686	172	-64	-65	821	819	0	0	-7,107	-7,243	-5,299
1995	181	181	-732	-972	1,085	-804	11	10	1,488	1,428	0	0	-932	-996	-1,375
1996	18	18	351	176	1,338	-315	-221	-221	-22	-22	0	0	6,868	5,848	1,050
1997	134	134	-4,051	-6,756	3,344	865	-199	-198	-1,709	-2,732	0	0	7,214	6,432	10,770
1998	7	7	3,807	3,072	2,536	412	25	25	540	541	0	0	12,137	11,613	16,405
1999	-1,233	-1,233	-4,439	-7,456	1,169	856	8,464	8,469	5,961	5,972	0	0	0	-7,739	-17,225
2000	-164	-164	4,110	607	1,160	1,054	529	530	-4,883	-4,877	0	0	3,019	9,329	-3,433
2001	-53	-53	8,387	4,389	1,512	1,104	57	57	-101	-100	0	0	8,007	8,521	-6,480
2002	-7	-7	2,234	-417	-756	-1,200	54	54	167	167	0	0	200	1,020	-10,683
2003	-19,382	-19,382	17,140	14,716	2,449	1,332	-11,491	-11,491	-1,656	-1,661	0	0	14,195	19,198	521
2004	-21,145	-21,145	-18,246	-21,590	-3,265	-4,200	-11,462	-11,462	-15,646	-15,653	0	0	-21,496	-12,906	-4,397
2005	-1,488	-1,488	1,143	-2,518	-964	-1,534	-919	-906	-3,166	-3,165	0	0	9,422	-113	-5,572
2006	-7,339	-7,339	-11,517	-14,375	-3,046	-3,486	-4,588	-4,588	-11,417	-11,418	0	0	-23,410	-16,738	-8,296
2007	-2,794	-2,794	2,766	-677	-680	-1,142	-1,468	-1,468	835	833	0	0	1,928	-128	-4,001
2008	-275	-275	1,095	-2,106	-328	-1,149	-249	-249	-613	-614	0	0	1,141	51	-4,034
2009	283	283	3,945	68	-504	-1,172	-28	-28	-319	-320	0	0	4,880	3,918	-2,003
2010	-8,451	-8,451	3,769	-946	598	344	-5,467	-5,467	-321	-323	0	0	2,522	3,953	-1,287
2011	-8,497	-8,497	-519	-4,590	4,024	5,669	-5,043	-5,043	-864	-866	0	0	-6,584	-952	4,630
2012	5,518	5,518	8,250	4,538	5,967	5,945	2,696	2,696	-1,960	-1,960	0	0	18,230	12,479	8,849
2013	-34,776	-34,776	-5,695	-8,826	2,428	2,624	-16,973	-16,973	-11,396	-11,397	2,917	3,172	-33,420	2,513	2,853
2014	-25,093	-25,093	21,899	18,146	9,347	10,537	-11,985	-11,985	8,459	8,458	3,510	3,955	15,091	29,173	12,847
2015	7,474	7,474	-6,019	-9,613	1,212	1,492	4,669	4,669	-9,510	-9,512	-4,130	-3,398	4,130	-3,574	14,063
2016	-11,431	-11,431	-672	-4,699	-1,018	-1,365	-5,243	-5,243	-3,137	-3,139	0	0	-3,894	766	-6,180
2017	-7,953	-7,953	2,928	-486	587	470	-3,769	-3,769	-473	-474	0	0	1,569	3,125	-2,588
Averages															
1951-2017	-2,293	-2,293	1,883	-137	4,538	5,058	-959	-958	-689	-770	1,599	1,564	1,042	1,810	12,019
1951-1978	-635	-635	-4,930	-6,719	6,909	9,335	-319	-319	61	-17	3,674	3,603	-269	150	21,871
1979-2005	-1,574	-1,574	9,036	7,501	3,408	2,176	-291	-290	-636	-755	74	7	3,525	3,056	6,594
2006-2017	-7,778	-7,778	1,686	-1,964	1,549	1,564	-3,954	-3,954	-2,560	-2,561	191	311	-1,485	2,882	1,238
1985-2017	-4,113	-4,113	6,129	3,868	2,126	1,132	-1,636	-1,636	-1,350	-1,447	70	113	-1,030	587	176
1985-2005	-2,019	-2,019	8,668	7,201	2,456	885	-312	-311	-658	-811	0	0	-770	-725	-431

Notes:

EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

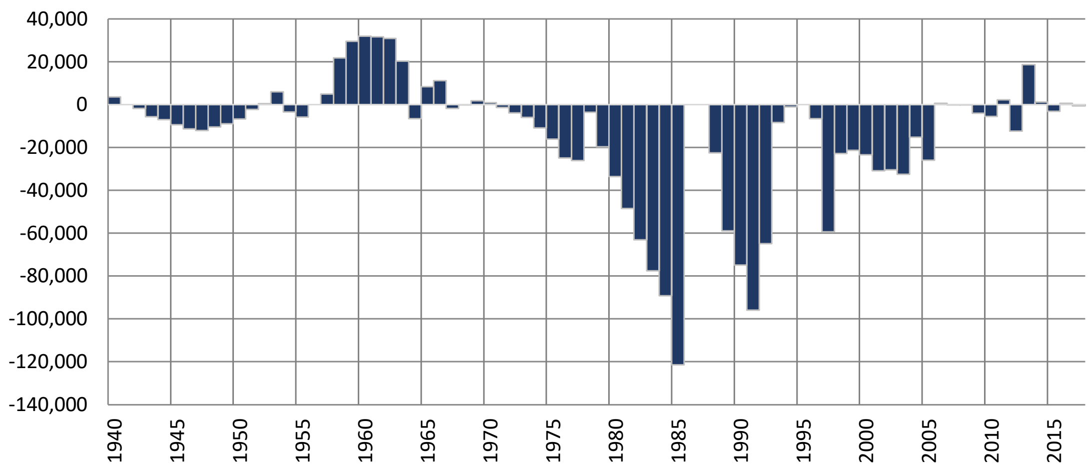
Run 14a - TX Hueco Pumping Off

Simulated Differences in ILRG Model Outputs

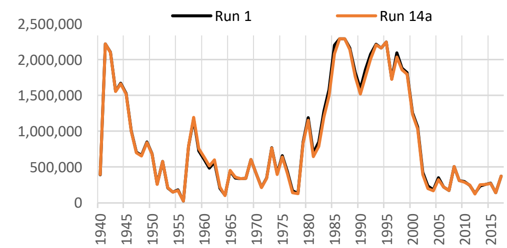
Run 14a minus Run 1

1940 - 2017 (acre-feet)

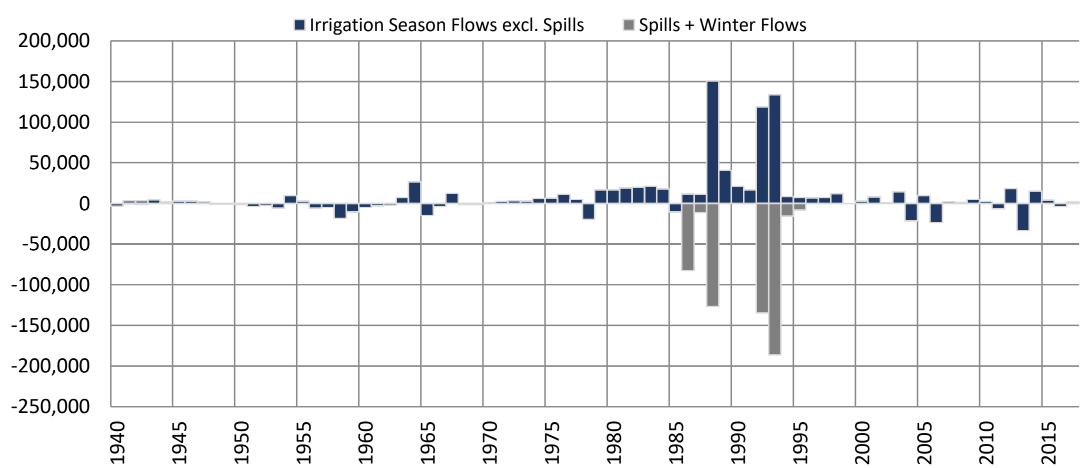
Total Project Storage (Year End)



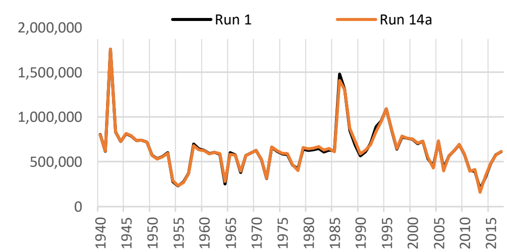
Period	Average Difference
1951-2017	92
1951-1978	112
1979-2005	-828
2006-2017	2,111
1985-2017	2,687
1985-2005	3,017



Caballo Reservoir Outflows (Annual)



	Average Difference		
Period	Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	9,470	-8,428	1,042
1951-1978	-269	0	-269
1979-2005	24,438	-20,914	3,525
2006-2017	-1,485	0	-1,485
1985-2017	16,081	-17,111	-1,030
1985-2005	26,119	-26,889	-770



Notes:

Reservoir storage does not include storage attributed to SJC, CO, or NM credit waters.

Average differences calculated as (Final Storage - Initial Storage)/(no. years).

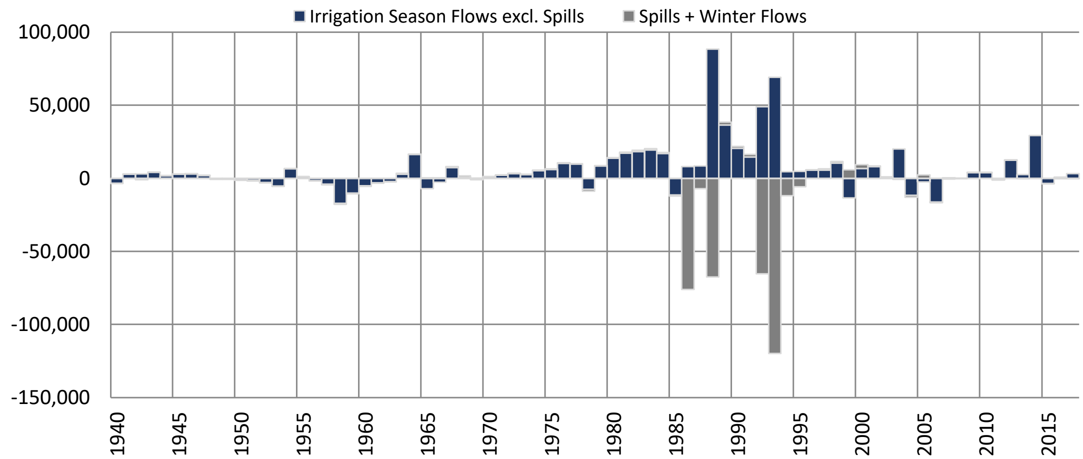
Run 14a - TX Hueco Pumping Off

Simulated Differences in ILRG Model Outputs

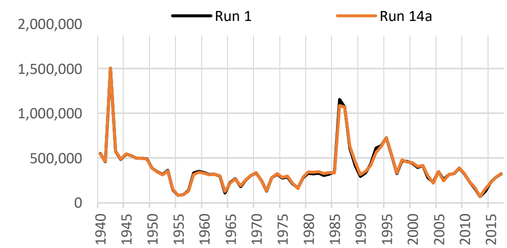
Run 14a minus Run 1

1940 - 2017 (acre-feet)

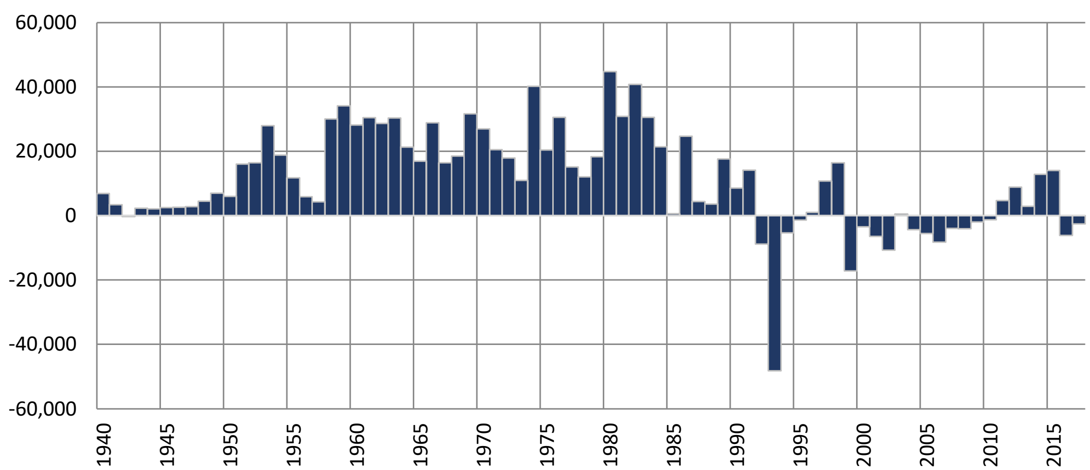
Rio Grande at El Paso (Annual)



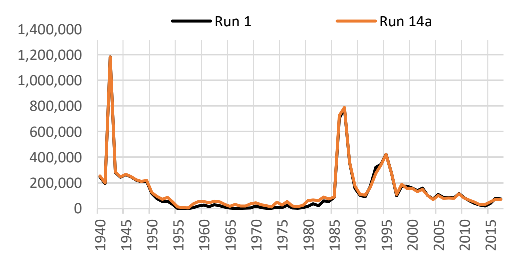
	Average Difference		
Period	Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	6,781	-4,971	1,810
1951-1978	126	24	150
1979-2005	15,374	-12,318	3,056
2006-2017	2,978	-96	2,882
1985-2017	10,818	-10,232	587
1985-2005	15,299	-16,023	-725



Rio Grande at Fort Quitman (Annual)



Period	Average Difference
1951-2017	11,971
1951-1978	21,802
1979-2005	6,551
2006-2017	1,228
1985-2017	154
1985-2005	-460



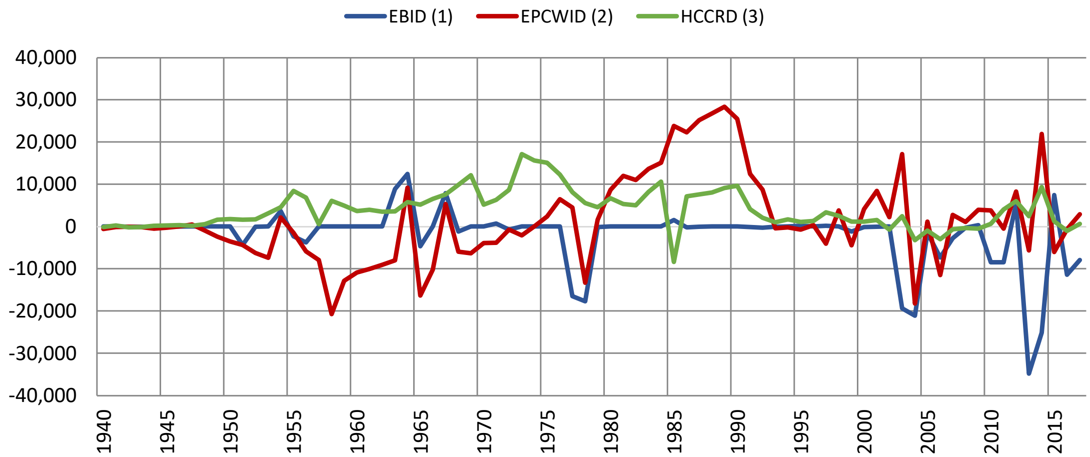
Run 14a - TX Hueco Pumping Off

Simulated Differences in ILRG Model Outputs

Run 14a minus Run 1

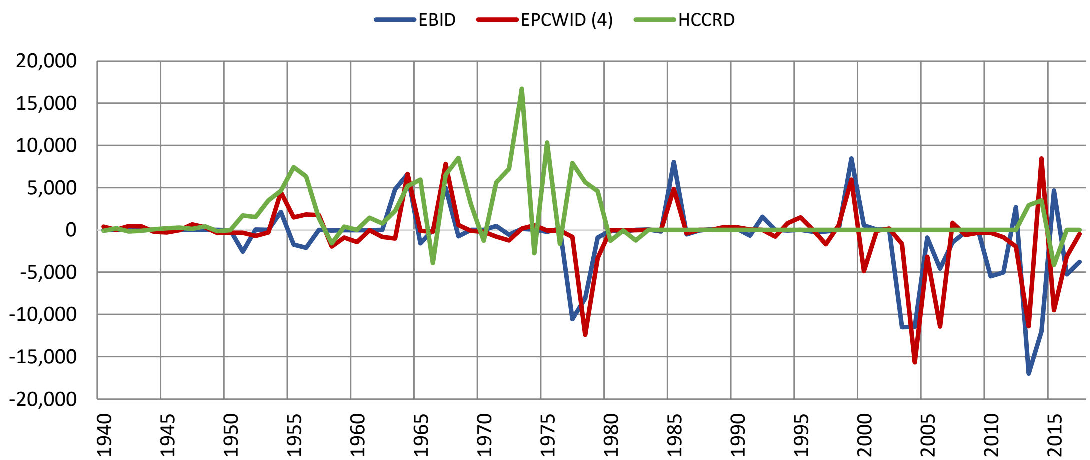
1940 - 2017 (acre-feet)

River Headgate (RHG) Diversions (Irrigation Season)



	Average Difference		
Period	EBID	EPCWID	HCCRD
1951-2017	-2,293	1,883	4,538
1951-1978	-635	-4,930	6,909
1979-2005	-1,574	9,036	3,408
2006-2017	-7,778	1,686	1,549
1985-2017	-4,113	6,129	2,126
1985-2005	-2,019	8,668	2,456

Farm Headgate (FHG) Deliveries (Irrigation Season)



	Average Difference		
Period	EBID	EPCWID	HCCRD
1951-2017	-959	-689	1,599
1951-1978	-319	61	3,674
1979-2005	-291	-636	74
2006-2017	-3,954	-2,560	191
1985-2017	-1,636	-1,350	70
1985-2005	-312	-658	0

Notes:

(1) EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

(2) EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

(3) HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

(4) EPCWID FHG values include deliveries to Rogers WTP and R/U WTP.

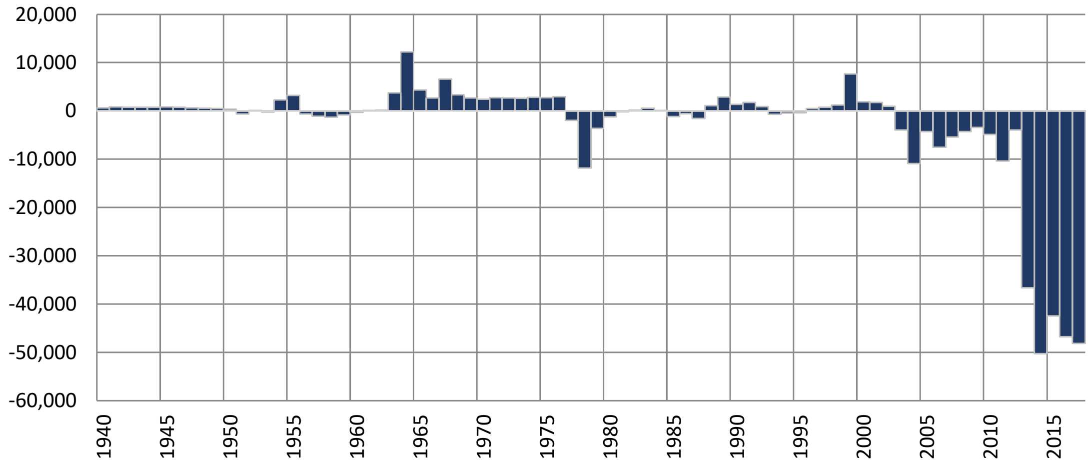
Run 14a - TX Hueco Pumping Off

Simulated Differences in ILRG Model Outputs

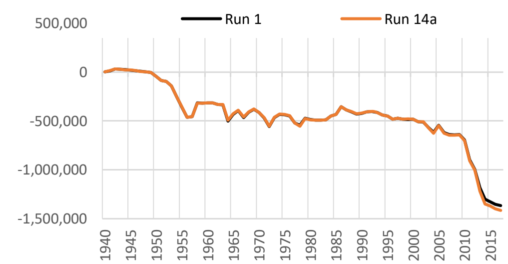
Run 14a minus Run 1

1940 - 2017 (acre-feet)

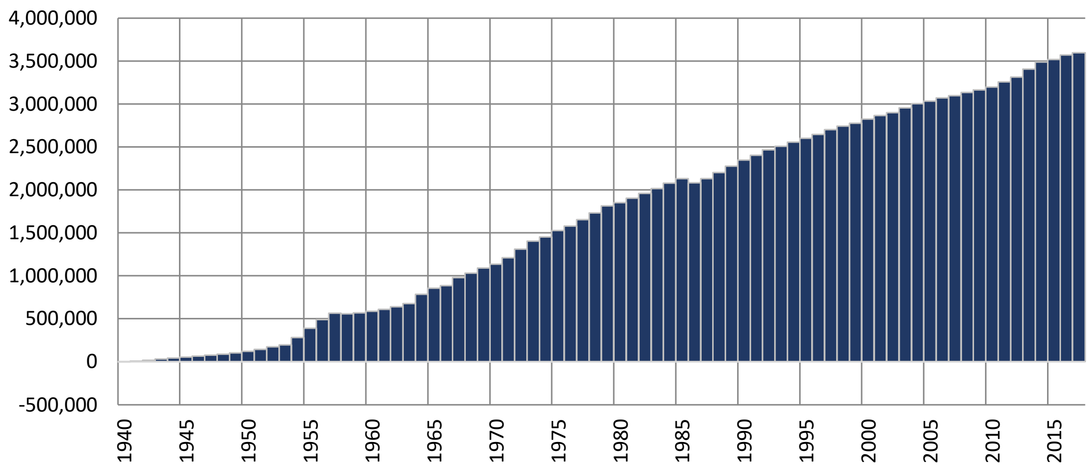
Cumulative Annual Rincon-Mesilla Groundwater Storage



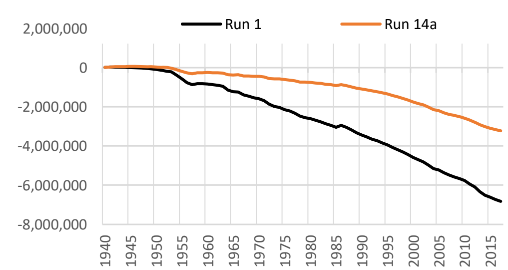
Period	Average Difference
1951-2017	-724
1951-1978	-435
1979-2005	280
2006-2017	-3,654
1985-2017	-1,460
1985-2005	-206



Cumulative Annual Hueco Groundwater Storage



Period	Average Difference
1951-2017	51,892
1951-1978	57,550
1979-2005	48,233
2006-2017	46,924
1985-2017	46,047
1985-2005	45,546



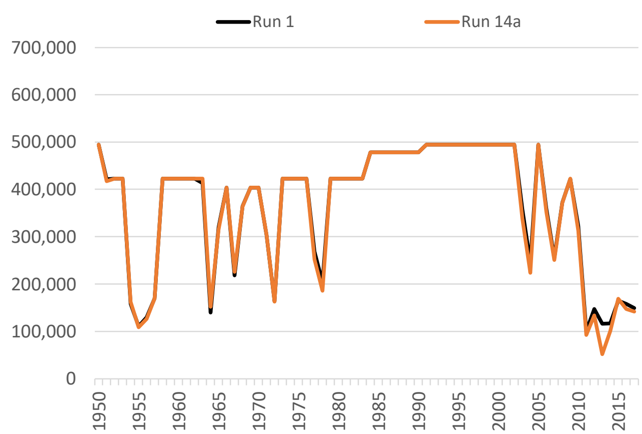
Notes:

Cumulative storage change in alluvial and non-alluvial aquifers.

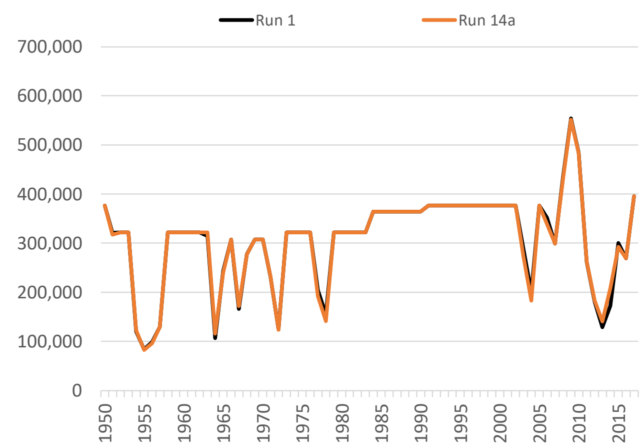
Average differences calculated as (Final Storage - Initial Storage)/(no. years).

Run 14a - TX Hueco Pumping Off
Annual Allocation and Charges
Run 14a v. Run 1
ILRG Model
1950 - 2017 (acre-feet)

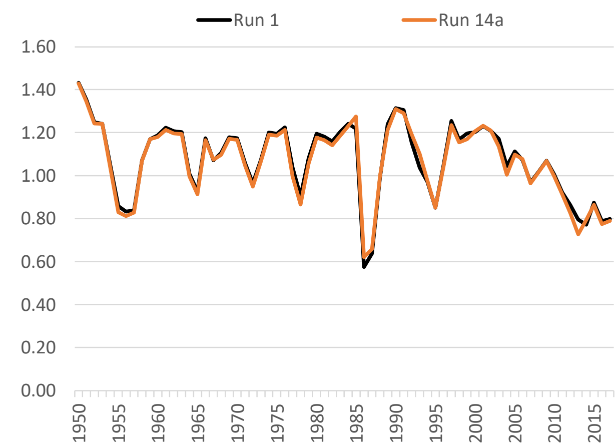
Total Allocation - EBID



Total Allocation - EPCWID

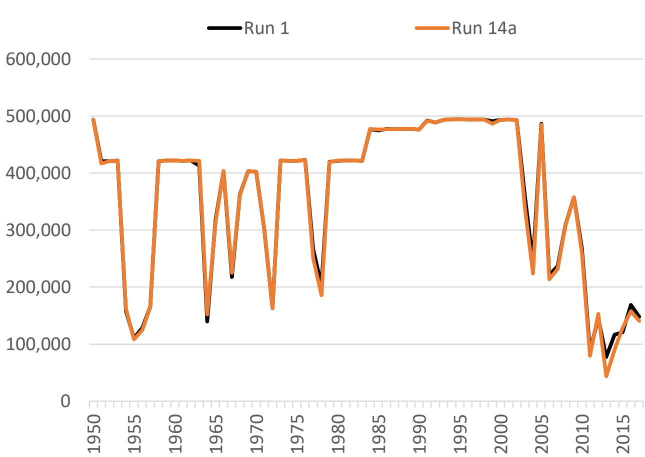


Diversion Ratio

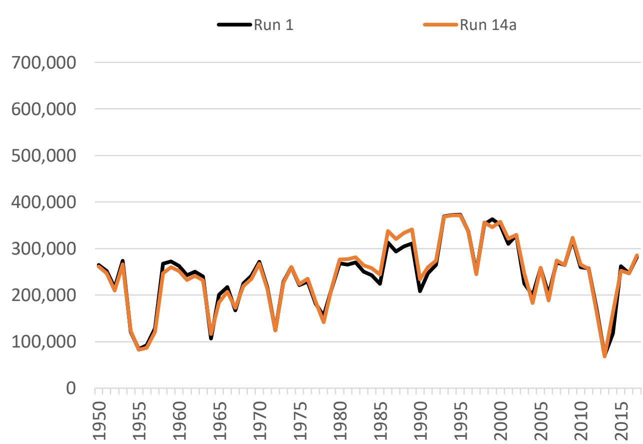


Note:
Computed as Total Charges/Caballo Release.

Annual Delivery Charges - EBID



Annual Delivery Charges - EPCWID



Run 14a - TX Hueco Pumping Off

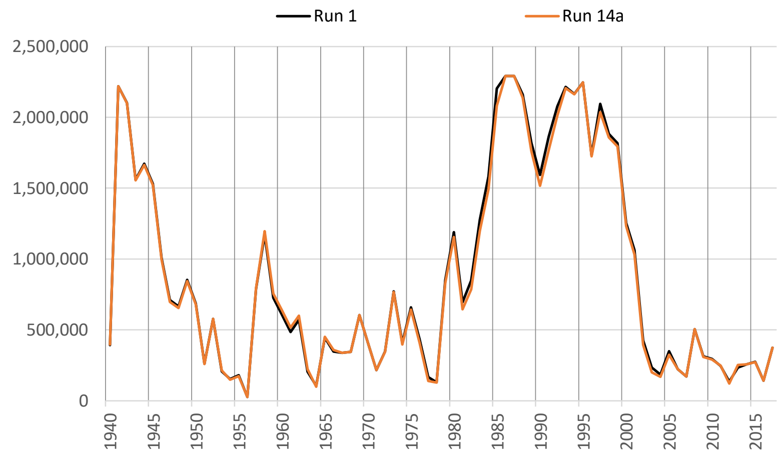
Annual Summary of Project Storage and Rio Grande Flows

Run 14a v. Run 1

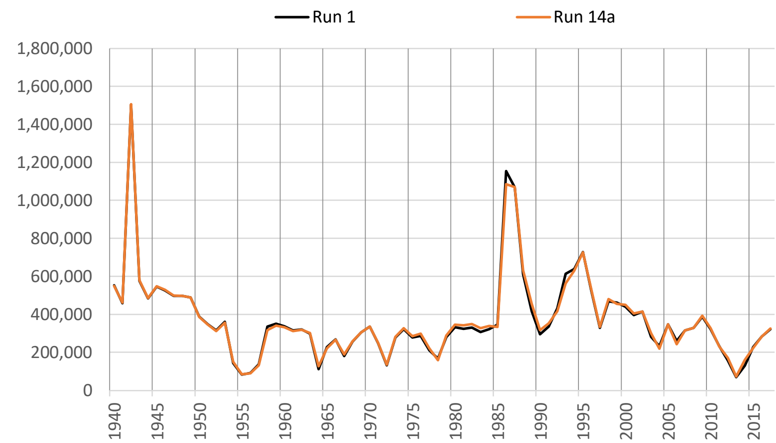
ILRG Model

1940 - 2017 (acre-feet)

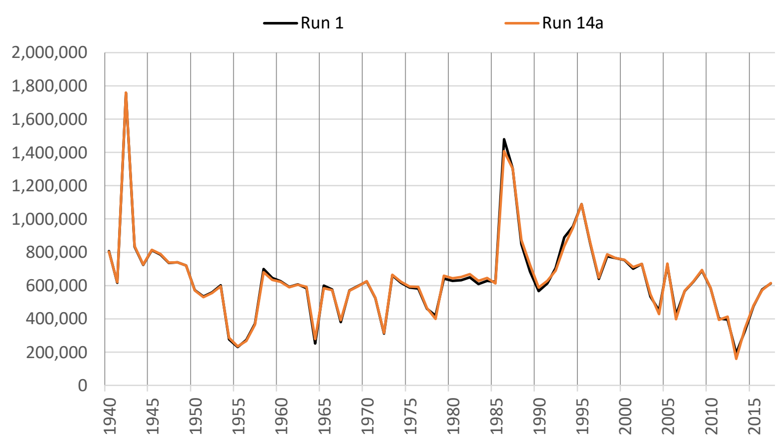
Total Year-End Project Reservoir Storage



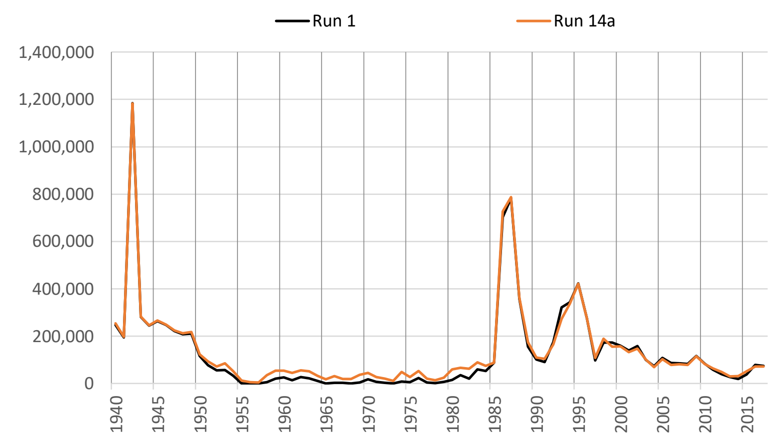
Rio Grande at El Paso



Rio Grande Below Caballo



Rio Grande at Fort Quitman



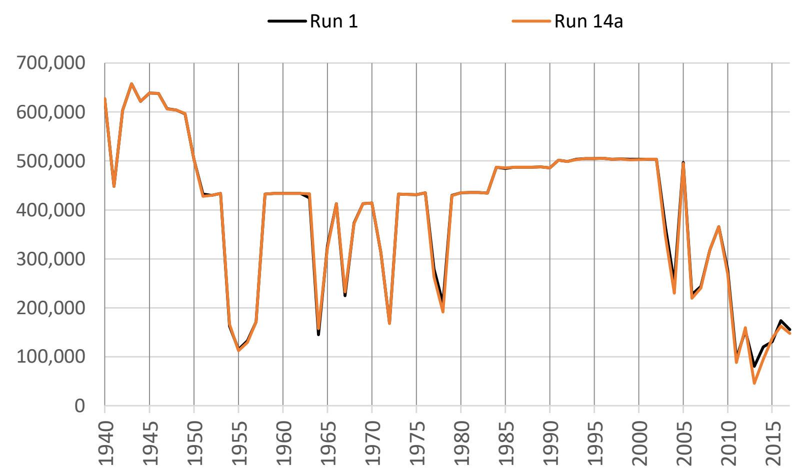
***Note different scales.**

US_MSJ_00003285

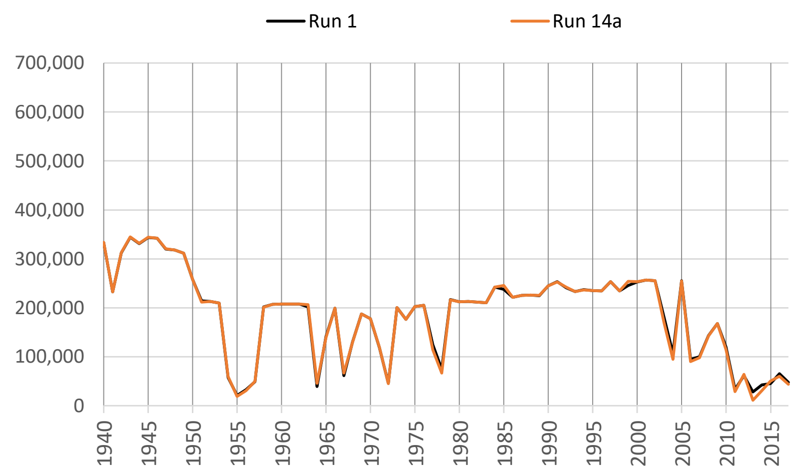
Run 14a - TX Hueco Pumping Off
Irrigation Season Summary of Irrigation Operations
Run 14a v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

EBID Total

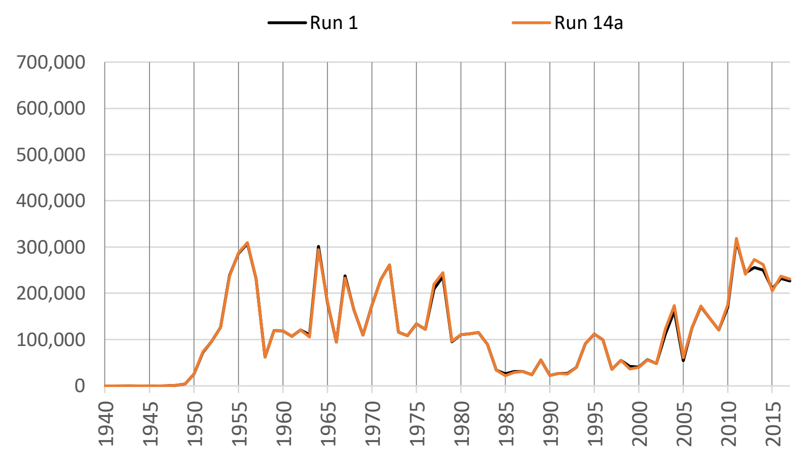
Net River Headgate Diversions



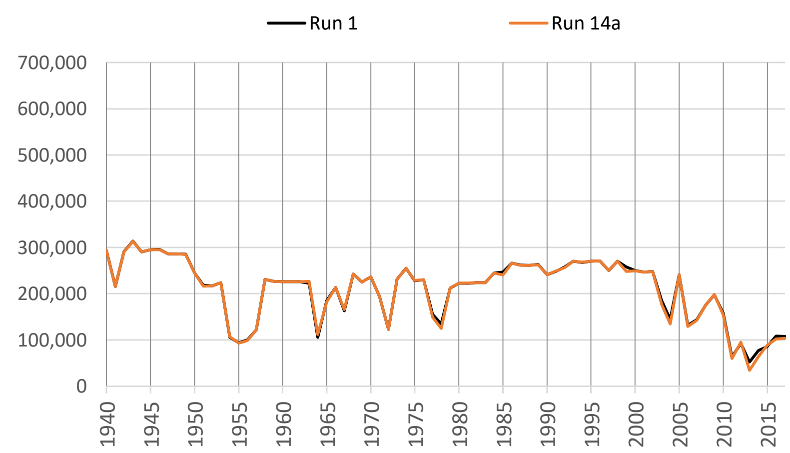
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries

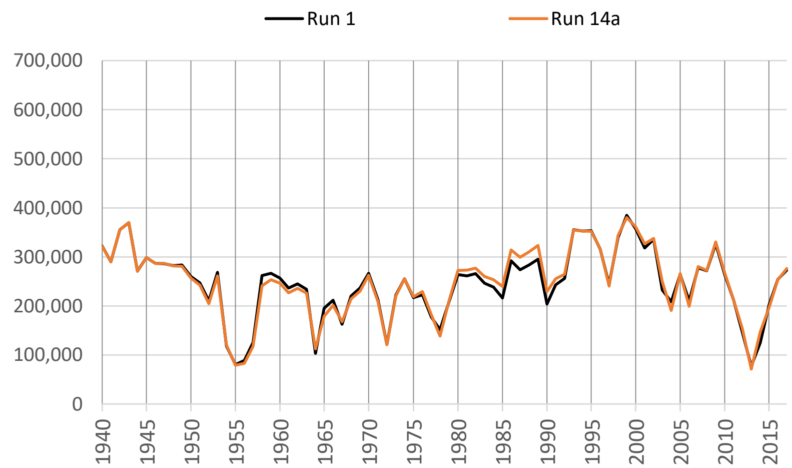


Notes: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).
Pumping includes Supplemental and Primary groundwater pumping.

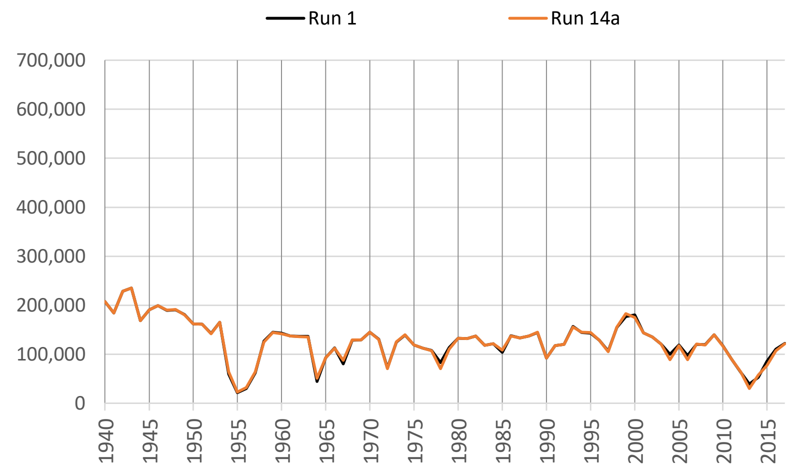
Run 14a - TX Hueco Pumping Off
Irrigation Season Summary of Irrigation Operations
Run 14a v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

EPCWID Total

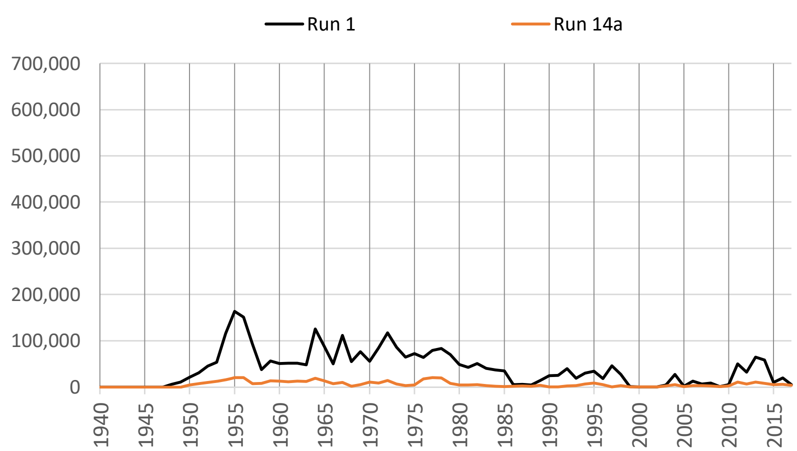
Net River Headgate Diversions



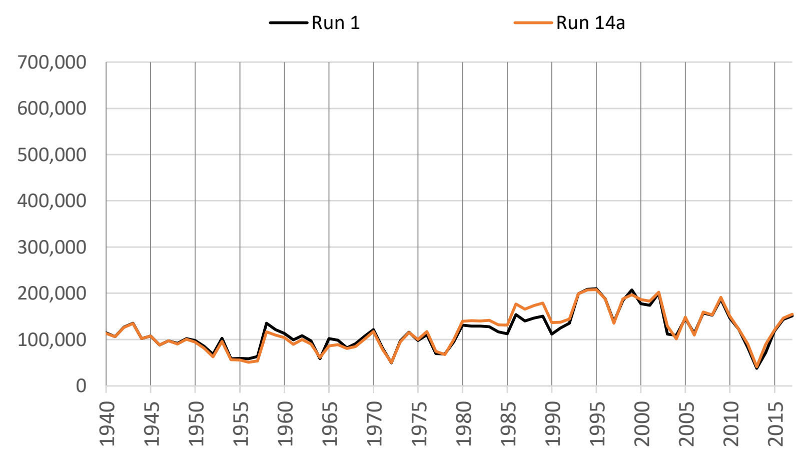
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries

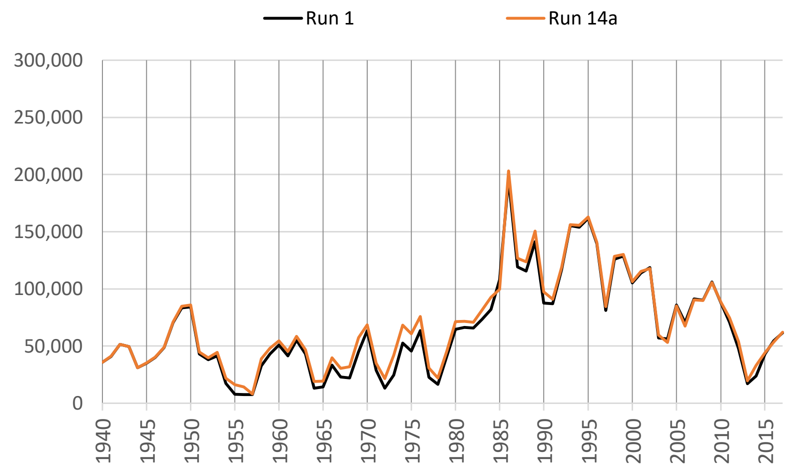


Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

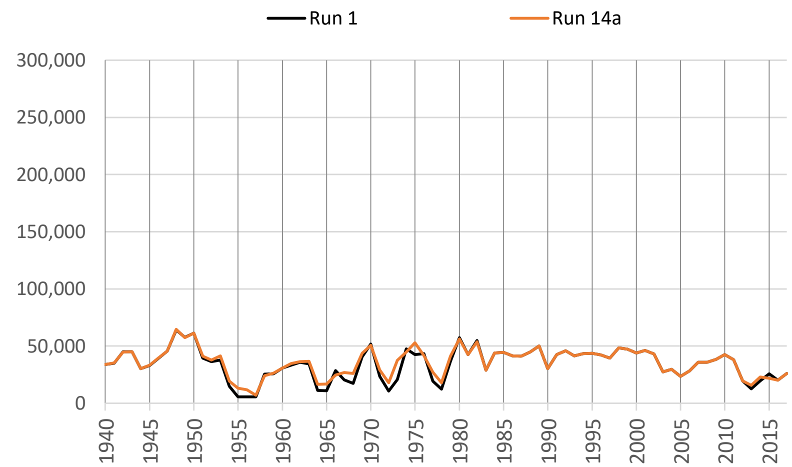
Run 14a - TX Hueco Pumping Off
Irrigation Season Summary of Irrigation Operations
Run 14a v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

HCCRD Total

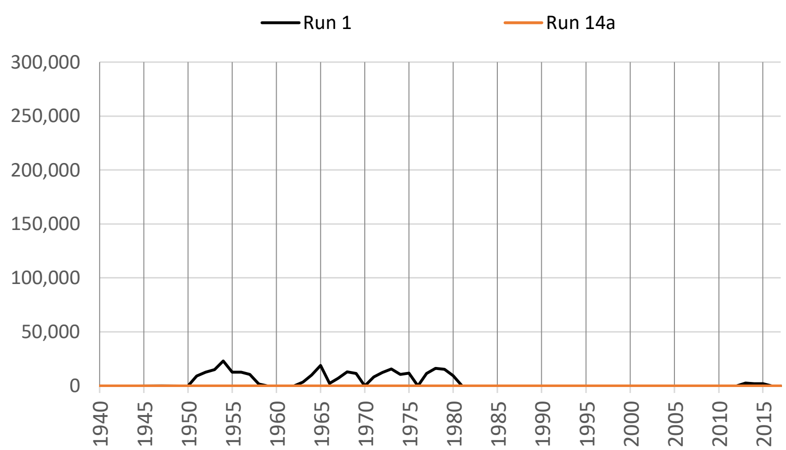
Net River Headgate Diversions



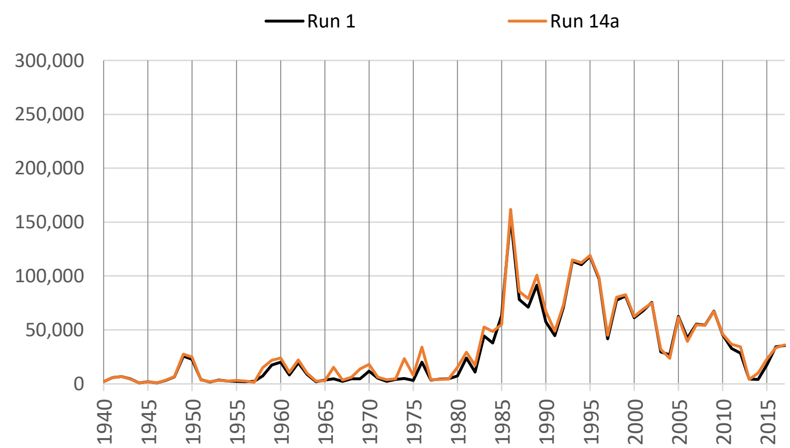
Farm Headgate Deliveries



Pumping



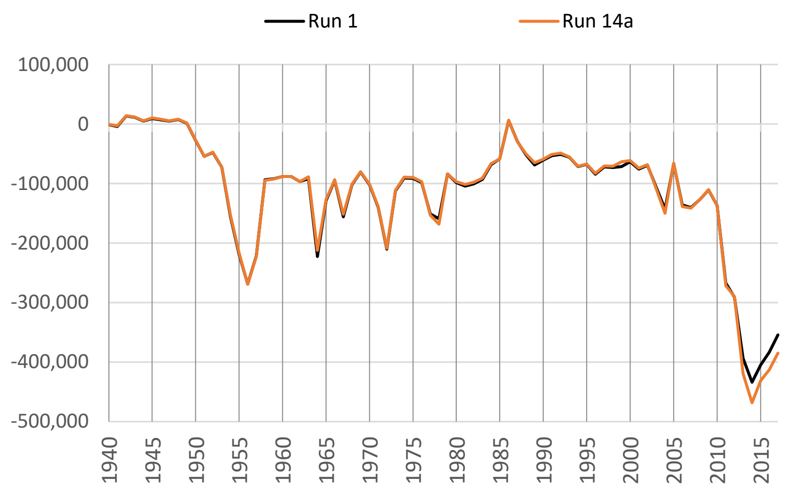
RHG Diversions - FHG Deliveries



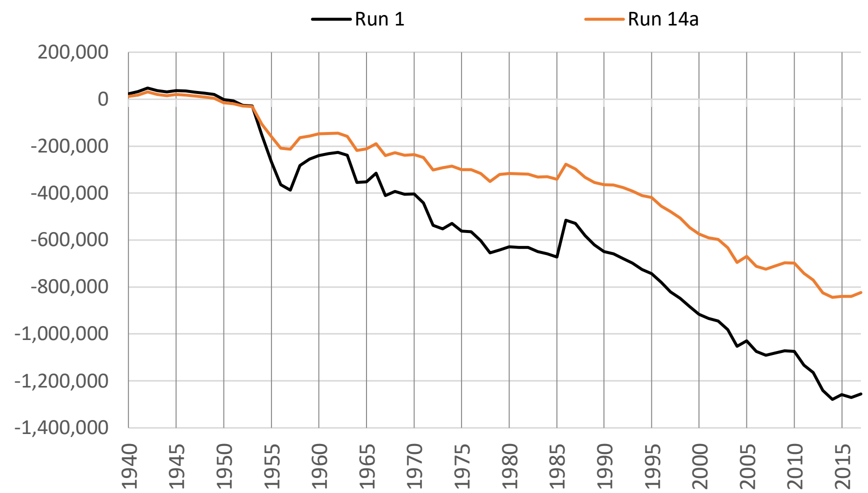
Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

Run 14a - TX Hueco Pumping Off
Cumulative Change in Ground Water Storage
Run 14a v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

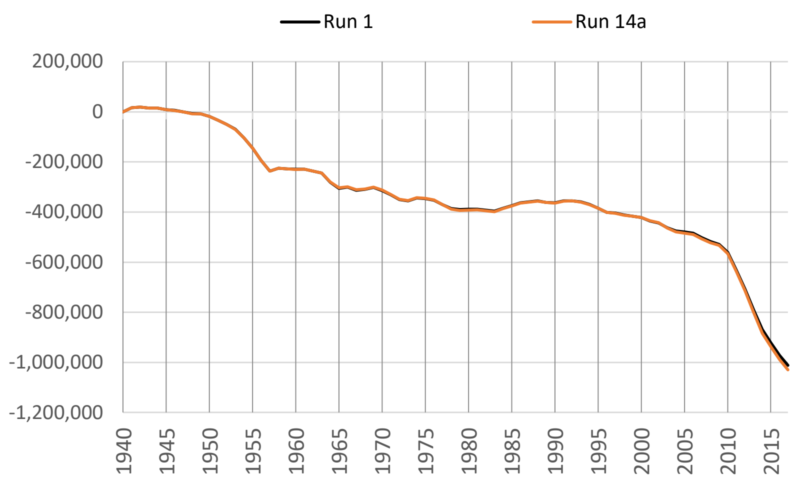
Rincon-Mesilla Alluvial Aquifer



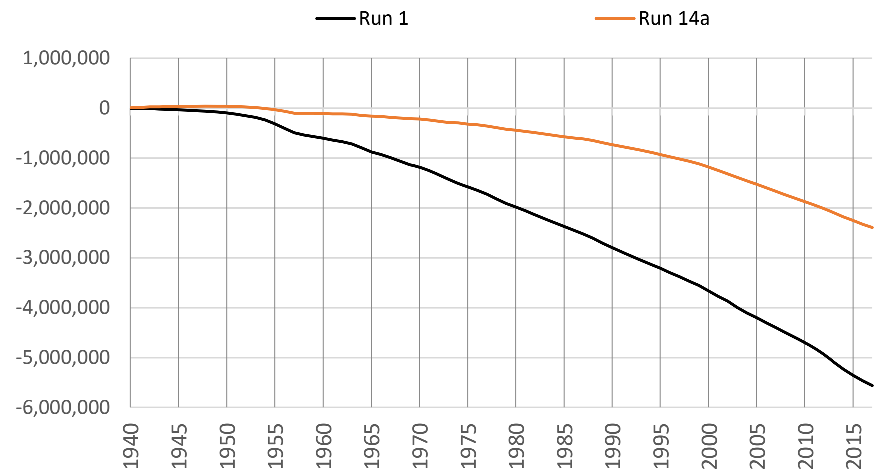
Hueco Alluvial Aquifer



Rincon-Mesilla Non-Alluvial Aquifer

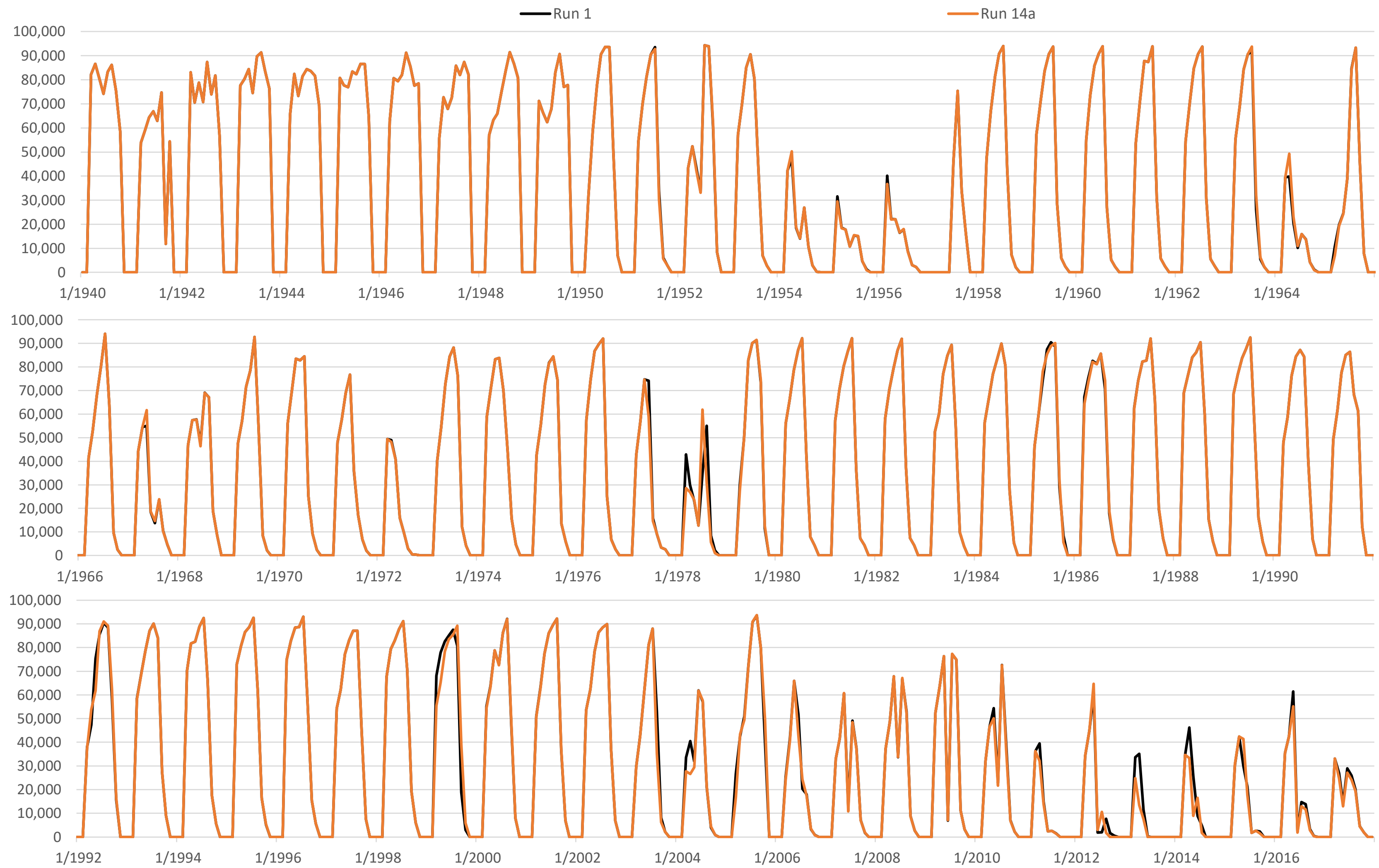


Hueco Non-Alluvial Aquifer



***Note different scales.**

Run 14a - TX Hueco Pumping Off
Monthly Net RHG Diversions
Run 14a v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
EBID Total

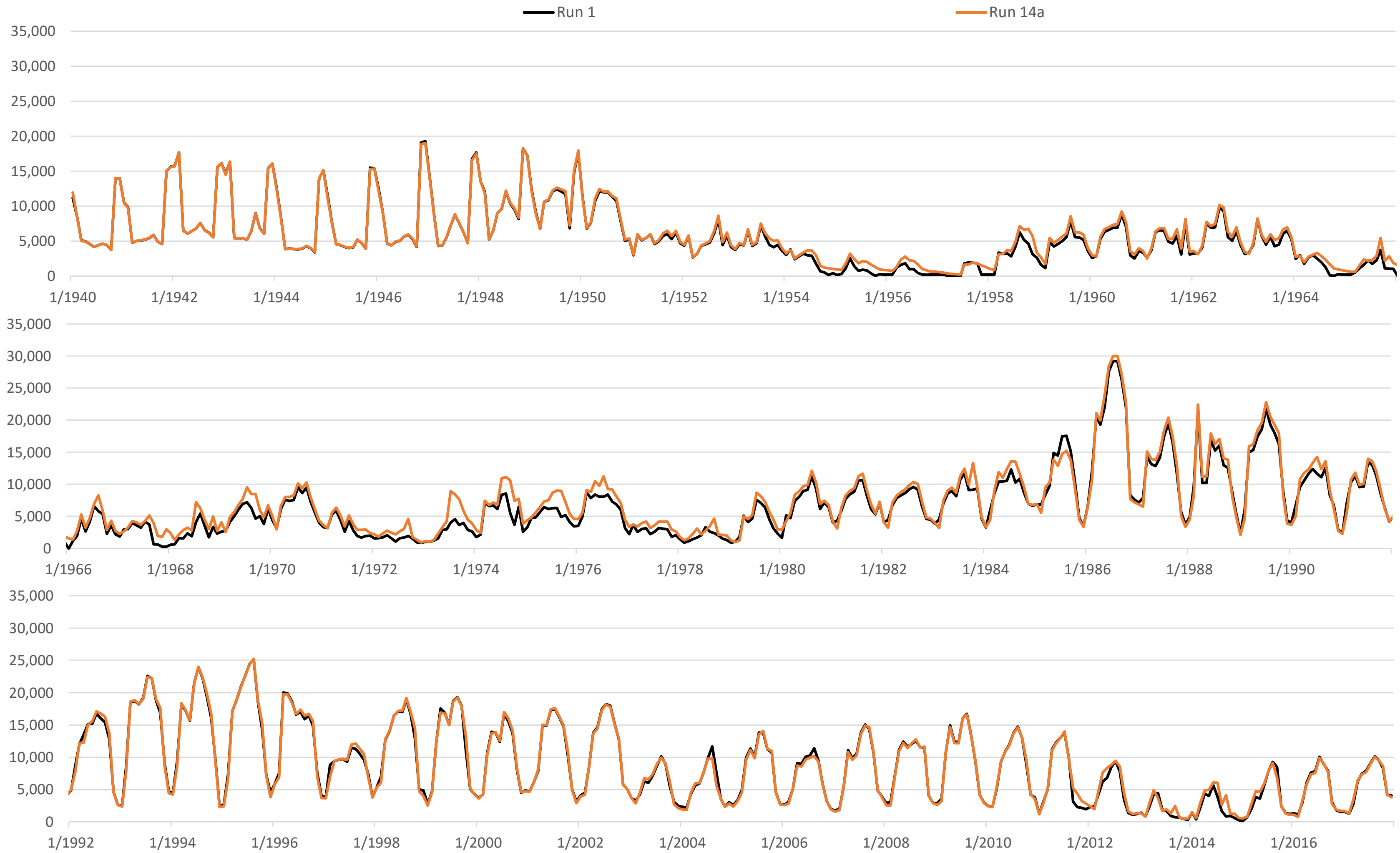


Note: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

Run 14a - TX Hueco Pumping Off
Monthly Net RHG Diversions
Run 14a v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
EPCWID Total

Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

Run 14a - TX Hueco Pumping Off
Monthly Net RHG Diversions
Run 14a v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
HCCRD Total



Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

Run 14a - TX Hueco Pumping Off
End of Month Reservoir Storage (Elephant Butte + Caballo)
Run 14a v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

Run 14a - TX Hueco Pumping Off

Monthly Caballo Releases

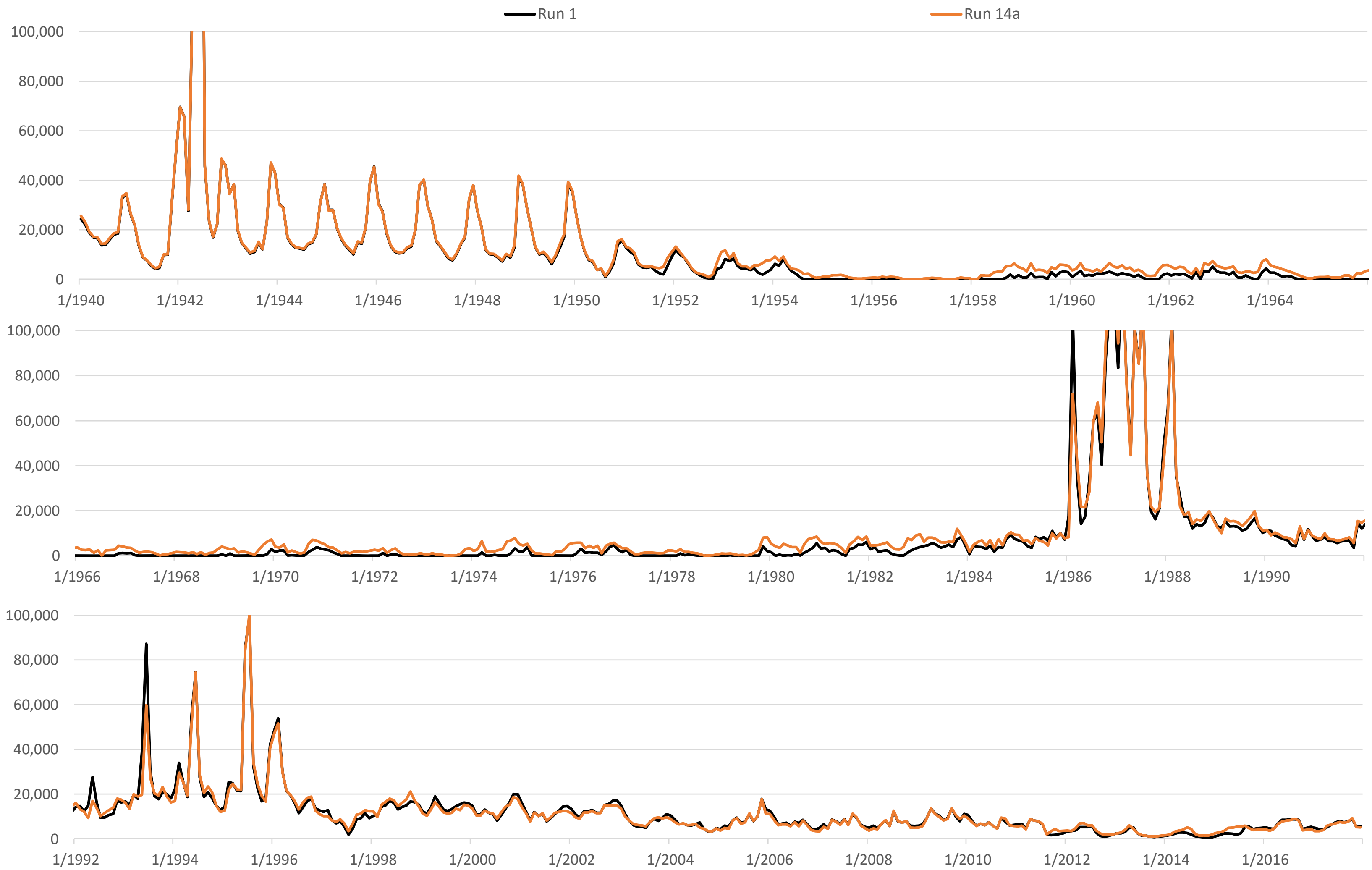
Run 14a v. Run 1

ILRG Model

1940 - 2017 (acre-feet)

Run 14a - TX Hueco Pumping Off
Monthly Rio Grande at El Paso Flow
Run 14a v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

Run 14a - TX Hueco Pumping Off
Monthly Rio Grande at Fort Quitman Flow
Run 14a v. Run 1
ILRG Model
1940 - 2017 (acre-feet)



Appendix 30P

Comparison of ILRG Model Runs
Run 14b v. Run 1

Model Run Specifications

Model Version: LRG_v116

Name: **Run 14b - MX Hueco Pumping Off**

Run ID: LRG_v116_Operational_Run14b
Date: 8/24/2020

Name: **Run 1 - Historical Base Run (All Pumping On)**

Run ID: LRG_v116_Operational_Run1
Date: 8/23/2020

Selected Model Inputs

Pumping and Returns	Run 14b	Run 1
Irrigation Pumping	MX Hueco Off	On
Irrigated Area	Hist	Hist
Non-Irrigation Pumping	MX Hueco Off	On
Non-Irrigation Pumping Returns	MX Hueco Off	On
Las Cruces Jornada Pumping Returns	On	On

Project Allocation Rules		
1950-2005	D1/D2	D1/D2
2006-2007	D3	D3
2008-2017	D3 + CO	D3 + CO

EPCWID Operations		
Charge EPCWID for Use of WWTP Returns	Off	Off
ACE and Haskell Credits for EPCWID	On	On
Increased EPCWID Use of Fabens Drain Flows	Off	Off
Charge EPCWID for Fabens Drain Flow Use	Off	Off

Run 14b - MX Hueco Pumping Off
Comparison of ILRG Model Runs
Run 14b v. Run 1
1951 - 2017 Annual Average
(1,000 acre-feet)

Run No.	1	14b	14b - 1		
Simulated Input or Output	**Run 1**	**Run 14b**	**Run 14b minus Run 1**		
Pumping Stress					
Irrigation Pumping	62.8	0.0	-62.8		
Non-Irrigation Pumping	181.0	112.0	-68.9		
WWTP Flows	58.0	35.3	-22.7		
Urban Deep Percolation	13.1	13.1	0.0		
Total Stress	172.7	63.6	-109.0		
	Stress is Pumping minus WWTP and Urban Deep Perc				
Effects of Pumping Stress				***% Chg***	
FHG Deliveries (Mar - Oct)				***Stress***	***% Diff.***
EBID	167.6	169.3	1.7	*-2%*	*1%*
EPCWID (incl. EPW)	139.9	141.4	1.5	*-1%*	*1%*
HCCRD	32.8	33.6	0.7	*-1%*	*2%*
Total	340.3	344.3	4.0	*-4%*	*1%*
FHG Deliveries (Nov - Feb)					
EBID	0.0	0.0	0.0	*0%*	*-2%*
EPCWID (incl. EPW)	0.2	0.2	0.0	*0%*	*-7%*
HCCRD	2.4	2.3	-0.1	*0%*	*-3%*
Total	2.6	2.5	-0.1	*0%*	*-4%*
Irrigation Pumping					
EBID	140.4	138.8	-1.6	*2%*	*-1%*
EPCWID (Mesilla Valley)	7.4	7.3	-0.1	*0%*	*-1%*
EPCWID (El Paso Valley)	40.1	38.8	-1.3	*1%*	*-3%*
HCCRD	4.2	2.9	-1.3	*1%*	*-31%*
Total	192.1	187.8	-4.3	*4%*	*-2%*
	Pumping turned off.	*Other values are simulated responses and are totaled.*			
Other Inflows/Outflows					
Net Reservoir Evaporation	125.3	126.4	1.1	*-1%*	*1%*
Riparian ET	70.9	77.1	6.2	*-6%*	*9%*
River Evaporation + Incidental Canal Loss	30.3	30.1	-0.2	*0%*	*-1%*
Total	226.6	233.6	7.1	*-7%*	*3%*
Rio Grande at Fort Quitman					
Reservoir Spills	33.3	36.3	3.0	*-3%*	*9%*
Nov-Feb Flows	21.4	30.5	9.1	*-8%*	*43%*
Mar - Oct Flows	41.1	54.4	13.3	*-12%*	*32%*
Underflow (GW Model)	0.2	0.2	0.0	*0%*	*16%*
Total	96.0	121.5	25.5	*-23%*	*27%*

Run 14b - MX Hueco Pumping Off
Comparison of ILRG Model Runs
Run 14b v. Run 1
1951 - 2017 Annual Average
(1,000 acre-feet)

Run No.	1	14b	14b - 1		
Simulated Input or Output	**Run 1**	**Run 14b**	**Run 14b minus Run 1**		
Effects of Pumping Stress (continued)				*% Chg*	
Change in Storage				*Stress*	*% Diff.*
Reservoir Storage	-4.7	-4.8	-0.1	*0%*	*3%*
Alluvial GW Storage (RW Model)	-23.6	-6.1	17.5	*-16%*	*-74%*
Non-alluvial GW Storage (GW Models)	-96.4	-53.9	42.5	*-39%*	*-44%*
Soil Moisture Storage	0.6	0.5	-0.1	*0%*	*-21%*
Total	-124.0	-64.2	59.8	*-55%*	*-48%*
Summary of Effects					
FHG Deliveries (Mar-Oct)	340.3	344.3	4.0	*-4%*	*1%*
FHG Deliveries (Nov-Feb)	2.6	2.5	-0.1	*0%*	*-4%*
Irrigation Pumping	192.1	187.8	-4.3	*4%*	*-2%*
Riparian ET + Evaporation	226.6	233.6	7.1	*-7%*	*3%*
Fort Quitman Flow	96.0	121.5	25.5	*-23%*	*27%*
Change in Storage	-124.0	-64.2	59.8	*-55%*	*-48%*
Total	733.6	825.5	91.9	*-84%*	*13%*
Other Effects of Pumping Stress				*% Chg*	
Rio Grande at El Paso				*Stress*	*% Diff.*
Reservoir Spills	49.4	48.3	-1.1	*1%*	*-2%*
Nov-Feb Flows	22.8	23.0	0.2	*0%*	*1%*
Mar - Oct Flows	263.8	263.5	-0.3	*0%*	*0%*
Total	336.0	334.8	-1.2	*1%*	*0%*
Rio Grande below Caballo					
Reservoir Spills	65.9	63.5	-2.4	*2%*	*-4%*
Nov-Feb Flows	0.5	0.6	0.1	*0%*	*21%*
Mar - Oct Flows	541.3	542.6	1.3	*-1%*	*0%*
Total	607.6	606.7	-0.9	*1%*	*0%*
Surface Water Diversions (Mar - Oct)					
EBID	366.5	368.9	2.5	*-2%*	*1%*
EPCWID (incl. EPW)	236.8	236.4	-0.3	*0%*	*0%*
HCCRD	67.5	71.5	3.9	*-4%*	*6%*
Total	670.8	676.9	6.0	*-6%*	*1%*
Surface Water Diversions (Nov - Feb)					
EBID	0.0	0.0	0.0	*0%*	*0%*
EPCWID (incl. EPW)	14.3	14.4	0.1	*0%*	*0%*
HCCRD	14.2	16.2	2.0	*-2%*	*14%*
Total	28.5	30.6	2.1	*-2%*	*7%*

Run 14b - MX Hueco Pumping Off
Annual Differences in ILRG Model Outputs
Run 14b minus Run 1
1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1940	-42	-42	-151	468	-246	80	-14	-14	466	514	-223	-223	-4,070	-3,847	147
1941	-243	-243	-694	67	-264	30	-3	-3	-34	100	-230	-165	3,530	2,292	4,585
1942	-39	-39	-315	477	107	101	2	2	-278	116	70	87	-669	505	4,053
1943	-54	-54	-321	265	47	163	-24	-24	-262	-152	81	239	-1,966	-1,893	282
1944	-64	-64	-322	68	-200	-106	-12	-12	165	254	-160	-51	-2,153	-2,082	103
1945	-55	-55	-264	256	-269	-39	-9	-9	140	268	-244	-89	-2,209	-2,160	54
1946	-25	-25	-370	343	-171	42	-16	-17	100	447	-167	-212	-2,312	-2,269	176
1947	-41	-41	-687	-59	-212	-199	-13	-14	-135	308	-179	-191	-2,688	-2,639	-5
1948	-35	-35	-610	53	-204	-7	-10	-10	29	323	-77	-49	-2,789	-2,740	3,670
1949	-60	-60	-424	268	-165	135	-5	-5	253	406	12	25	-2,727	-2,686	6,545
1950	14	14	-492	-294	-75	142	102	102	111	110	8	14	-2,434	-2,423	4,153
1951	1,028	1,028	-385	-417	18	149	563	563	255	256	40	108	-1,559	-1,830	8,886
1952	203	203	-506	-528	188	338	276	275	231	229	198	151	-6,475	-4,714	7,173
1953	186	186	-769	-782	106	319	1,161	1,161	203	201	142	85	-1,657	-2,777	12,726
1954	3,311	3,311	2,631	2,615	890	1,033	5,654	5,654	5,731	5,730	1,056	1,254	1,800	6,046	9,406
1955	9,054	9,054	6,488	6,339	-644	-887	4,793	4,793	4,865	4,681	-534	-709	19,188	9,465	338
1956	-2,978	-2,978	-1,942	-1,942	-383	-500	-1,746	-1,746	-1,610	-2,108	-665	-1,011	-4,870	-2,335	-88
1957	8	8	-7	-548	-12	-394	25	24	12	-236	-148	-571	104	-636	-83
1958	23	23	-3,032	-2,955	1,035	3,089	124	124	30	-68	-406	-702	-5,082	-3,076	3,175
1959	13	13	-1,764	-1,795	3,042	4,884	46	45	238	238	6	23	-4,565	-3,875	7,073
1960	13	13	-1,691	-1,593	2,367	3,681	13	13	257	257	0	0	-6,862	-6,373	7,016
1961	21	21	-2,636	-2,409	2,769	4,372	11	11	1,688	1,688	1,289	-856	-9,015	-8,407	15,061
1962	10	10	-2,671	-2,442	2,527	4,034	-20	-20	360	360	425	500	-8,887	-8,474	18,964
1963	8,893	8,893	-3,399	-3,170	2,231	3,701	4,829	4,829	443	444	950	977	-2,551	-5,860	19,841
1964	16,176	16,176	11,686	12,036	4,095	5,201	8,489	8,489	8,122	7,792	3,589	3,821	20,664	11,902	17,143
1965	2,770	2,770	-1,001	-1,037	2,418	4,569	1,377	1,377	905	586	2,289	4,556	-3,982	-292	930
1966	-19	-19	-2,622	-2,309	5,986	8,625	187	186	-24	-22	-3,338	-4,158	-7,879	-4,056	14,037
1967	9,349	9,349	7,328	8,064	4,925	7,019	5,526	5,526	6,761	6,398	4,093	4,601	11,190	7,059	11,991
1968	1,035	1,035	-4,172	-3,451	5,892	7,826	931	931	204	-196	6,262	5,748	-5,134	-2,376	5,000
1969	7	7	-4,612	-4,548	7,022	10,452	187	187	-104	-104	4,641	2,058	-7,734	-5,976	20,721
1970	2	2	-4,544	-4,536	5,295	8,056	34	34	37	37	-1,274	-2,459	-8,899	-7,940	26,242
1971	12,895	12,895	-3,482	-3,050	4,914	7,875	7,727	7,727	284	285	3,953	5,643	891	-4,247	13,309
1972	-1,336	-1,336	-744	-569	4,560	6,732	4,734	4,734	335	255	4,358	4,992	-6,232	352	9,984
1973	-174	-174	-3,740	-3,770	2,377	4,492	50	50	387	321	2,347	2,856	-1,776	-4,553	3,881
1974	3	3	-3,802	-3,861	5,212	10,399	48	48	464	465	1,153	987	-6,475	-6,069	18,460
1975	-203	-203	-3,499	-3,488	8,277	13,817	978	978	138	138	7,507	8,989	-8,109	-6,188	19,561
1976	8	8	-2,550	-2,560	7,515	13,874	371	371	53	53	-924	-3,067	-5,382	-5,369	31,160
1977	21,817	21,817	-2,909	-1,918	7,513	12,671	13,272	13,272	239	240	7,002	8,202	7,192	-1,124	14,078
1978	15,026	15,026	10,723	12,162	5,774	11,467	7,975	7,975	12,580	12,583	5,935	6,941	25,188	16,929	16,108

Run 14b - MX Hueco Pumping Off
Annual Differences in ILRG Model Outputs
Run 14b minus Run 1
1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1979	-397	-397	-5,651	-5,282	7,819	12,954	359	359	-1,163	-1,158	3,112	731	-9,645	-3,395	27,070
1980	-67	-67	-3,451	-3,248	6,428	10,767	136	136	41	44	-3,917	-7,984	-7,586	-4,231	51,979
1981	-34	-34	-2,995	-3,007	4,766	7,505	193	193	8	9	-56	-339	-4,932	-3,704	39,817
1982	-23	-23	-3,028	-3,035	4,187	6,761	71	71	8	57	-1,040	-2,366	-4,393	-3,565	48,731
1983	-28	-28	-2,394	-2,435	4,369	6,820	42	42	-32	-32	0	0	-3,252	-2,666	36,214
1984	-51	-51	-2,065	-2,036	6,280	8,563	-1	-1	-8	83	0	0	-962	-806	30,942
1985	-84	-84	-1,902	-1,856	4,756	6,957	-2	-2	-172	-9	0	0	-2,396	-1,927	33,926
1986	-45	-45	-1,974	-2,005	4,120	6,342	257	260	11	14	0	0	20,407	20,077	170,489
1987	-31	-31	-1,932	-1,982	2,712	4,719	8	9	2	3	0	0	-26	-32	70,107
1988	-16	-16	-1,819	-1,874	2,238	4,061	98	98	10	10	0	0	-3,761	-2,877	44,628
1989	-16	-16	-1,906	-1,860	2,226	3,892	8	8	-176	19	0	0	-2,671	-2,359	34,255
1990	-67	-67	-618	-490	4,534	5,949	145	145	-122	160	0	0	550	805	23,748
1991	-117	-117	-436	-445	2,392	3,666	33	33	-106	-17	0	0	-881	-606	34,501
1992	1,198	1,198	72,337	72,255	28,846	31,058	-8,094	-8,101	32,197	32,213	0	0	44,828	47,514	65,451
1993	502	502	-6,312	-6,416	256	1,911	658	654	-2,976	-2,982	0	0	-39,112	-39,201	4,209
1994	65	65	-108	-208	1,662	2,843	-128	-128	868	866	0	0	508	-1,048	31,228
1995	99	99	-307	-275	1,686	2,860	-23	-23	541	750	0	0	2,404	1,669	38,681
1996	-46	-46	-1,263	-1,363	1,526	2,759	334	334	39	39	0	0	-5,230	-3,679	36,716
1997	-34	-34	-1,927	-1,810	1,770	2,621	-48	-48	-97	245	0	0	-2,313	-2,378	27,386
1998	-27	-27	-2,292	-2,391	1,485	2,539	87	87	-150	-29	0	0	-5,375	-4,970	36,580
1999	114	114	-249	-310	2,440	3,693	4	4	1,805	1,884	0	0	0	-531	38,229
2000	-34	-34	-6,389	-6,455	1,777	3,234	-19	-19	-1,818	-1,818	0	0	-6,349	-5,981	36,222
2001	-71	-71	-2,714	-2,794	2,770	4,334	-42	-41	6	6	0	0	-2,243	-2,271	35,313
2002	-44	-44	-2,818	-2,896	2,748	4,283	-18	-18	6	6	0	0	-2,367	-2,311	34,651
2003	14,438	14,438	-1,658	-1,698	2,514	4,166	9,325	9,325	1,022	1,026	0	0	6,651	1,179	26,718
2004	2,384	2,384	1,737	1,772	3,482	5,242	1,713	1,713	2,838	2,842	0	0	2,187	3,227	27,632
2005	-37	-37	-3,895	-3,953	3,862	5,734	44	44	74	75	0	0	-5,310	-3,084	30,933
2006	4,494	4,494	6,388	6,337	4,316	6,207	3,080	3,080	5,583	5,585	0	0	4,849	3,225	33,206
2007	3,085	3,085	2,170	2,206	4,310	6,361	1,547	1,547	5,170	5,172	0	0	5,615	3,889	26,373
2008	6,501	6,501	-6,212	-6,248	3,757	5,672	4,363	4,363	-1,117	-1,114	0	0	-6,635	-5,764	33,820
2009	6,294	6,294	-4,294	-4,391	2,369	3,858	2,949	2,949	51	53	0	0	-3,467	-3,927	36,575
2010	18,287	18,287	-4,022	-4,081	2,172	3,595	11,440	11,440	252	256	0	0	519	-3,581	33,863
2011	12,564	12,564	1,441	1,368	8,260	9,748	6,864	6,864	3,854	3,856	0	0	9,352	2,578	24,339
2012	-509	-509	96	-19	9,587	11,881	792	792	2,853	2,854	0	0	-1,778	32	12,761
2013	-3,483	-3,483	-1,252	-1,365	3,180	4,763	-1,623	-1,623	704	704	1,609	2,143	-4,809	-1,301	5,453
2014	170	170	-1,204	-1,317	5,124	7,209	1,208	1,208	1,816	1,816	2,488	4,125	-153	-880	403
2015	-1,769	-1,769	-7,259	-7,381	3,962	6,188	-1,262	-1,262	-6	-6	-2,409	-1,159	-11,146	-7,436	12,407
2016	-1,663	-1,663	4,788	4,644	4,024	6,261	758	758	8,964	8,965	0	0	12,821	6,613	16,466
2017	7,006	7,006	-10,346	-10,486	2,334	4,288	8,529	8,529	-315	-314	0	0	-10,331	-11,243	24,418
Averages															
1951-2017	2,472	2,472	-349	-288	3,925	5,958	1,663	1,663	1,545	1,532	742	658	-945	-1,190	25,500
1951-1978	3,469	3,469	-629	-445	3,425	5,603	2,415	2,415	1,539	1,447	1,784	1,749	-961	-1,600	11,860
1979-2005	649	649	517	515	4,209	6,157	190	190	1,209	1,271	-70	-369	-1,158	-635	41,347
2006-2017	4,248	4,248	-1,642	-1,728	4,450	6,336	3,220	3,220	2,317	2,319	141	426	-430	-1,483	21,674
1985-2017	2,094	2,094	420	370	4,036	5,724	1,303	1,302	1,867	1,913	51	155	-172	-502	34,597
1985-2005	863	863	1,598	1,569	3,800	5,374	207	206	1,610	1,681	0	0	-24	58	41,981

Notes:

EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

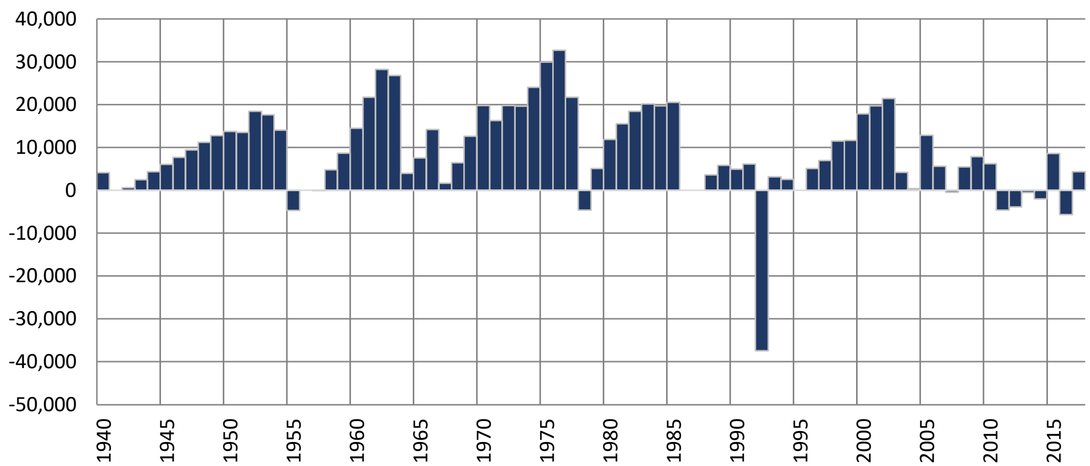
Run 14b - MX Hueco Pumping Off

Simulated Differences in ILRG Model Outputs

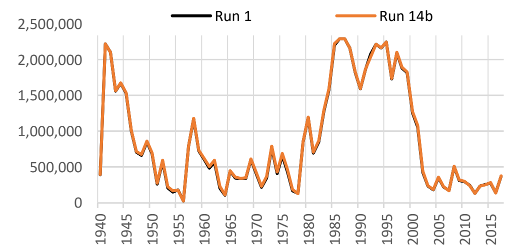
Run 14b minus Run 1

1940 - 2017 (acre-feet)

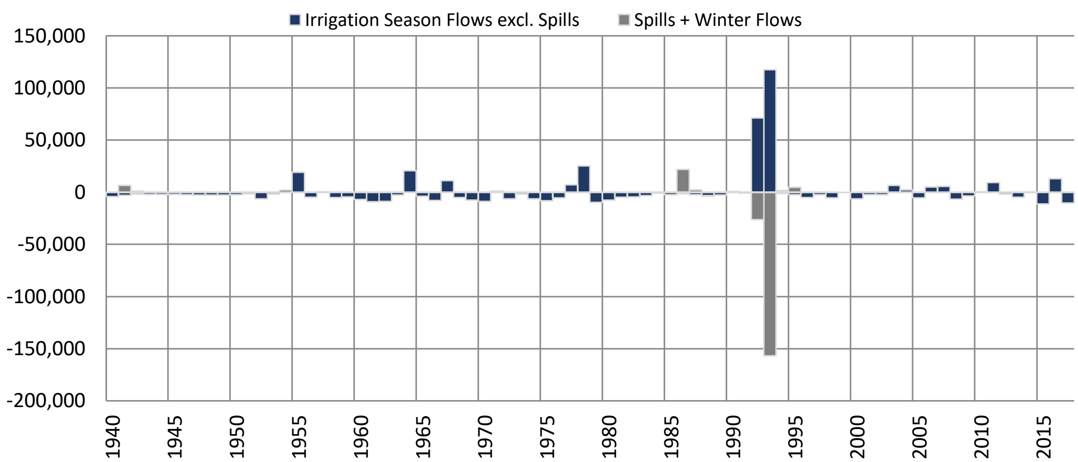
Total Project Storage (Year End)



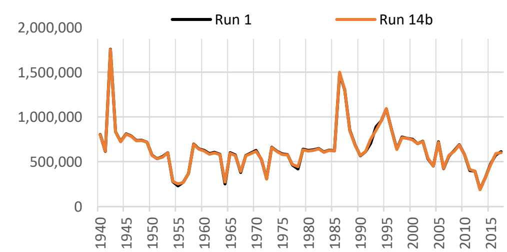
Period	Average Difference
1951-2017	-141
1951-1978	-657
1979-2005	647
2006-2017	-709
1985-2017	-467
1985-2005	-329



Caballo Reservoir Outflows (Annual)



Period	Average Difference: Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	1,341	-2,286	-945
1951-1978	-961	0	-961
1979-2005	4,515	-5,673	-1,158
2006-2017	-430	0	-430
1985-2017	4,470	-4,641	-172
1985-2005	7,270	-7,294	-24



Notes:

Reservoir storage does not include storage attributed to SJC, CO, or NM credit waters.

Average differences calculated as (Final Storage - Initial Storage)/(no. years).

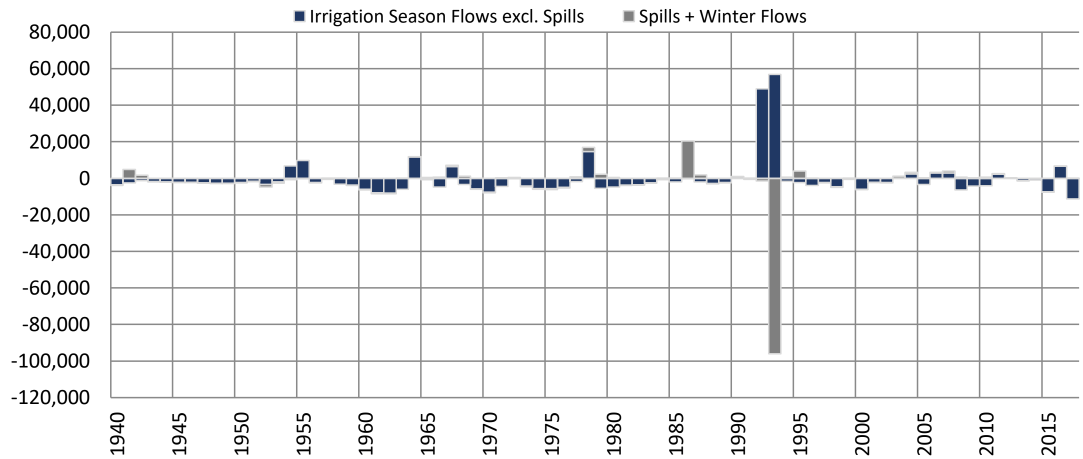
Run 14b - MX Hueco Pumping Off

Simulated Differences in ILRG Model Outputs

Run 14b minus Run 1

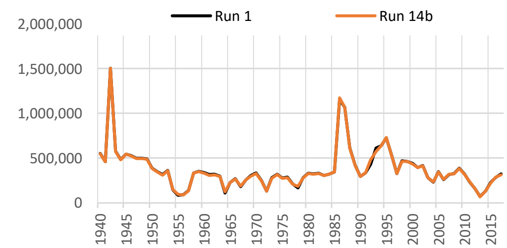
1940 - 2017 (acre-feet)

Rio Grande at El Paso (Annual)

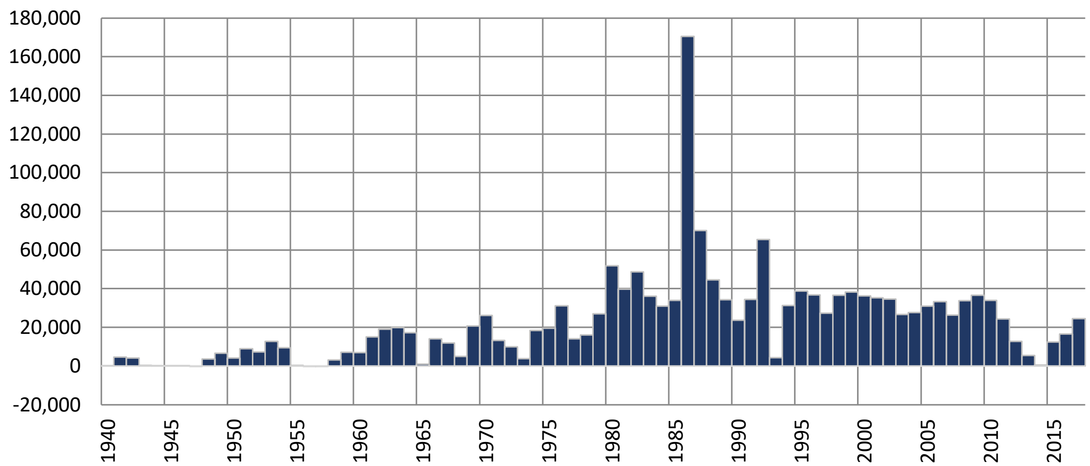


Average Difference

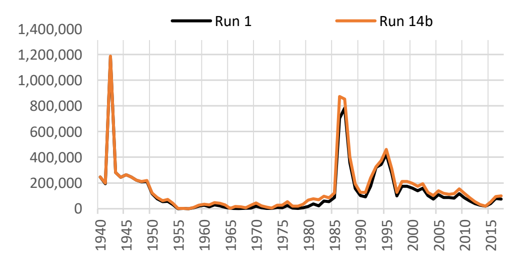
Period	Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	-254	-936	-1,190
1951-1978	-1,598	-1	-1,600
1979-2005	1,806	-2,441	-635
2006-2017	-1,754	271	-1,483
1985-2017	1,474	-1,976	-502
1985-2005	3,319	-3,261	58



Rio Grande at Fort Quitman (Annual)



Period	Average Difference
1951-2017	25,466
1951-1978	11,817
1979-2005	41,310
2006-2017	21,665
1985-2017	34,578
1985-2005	41,957



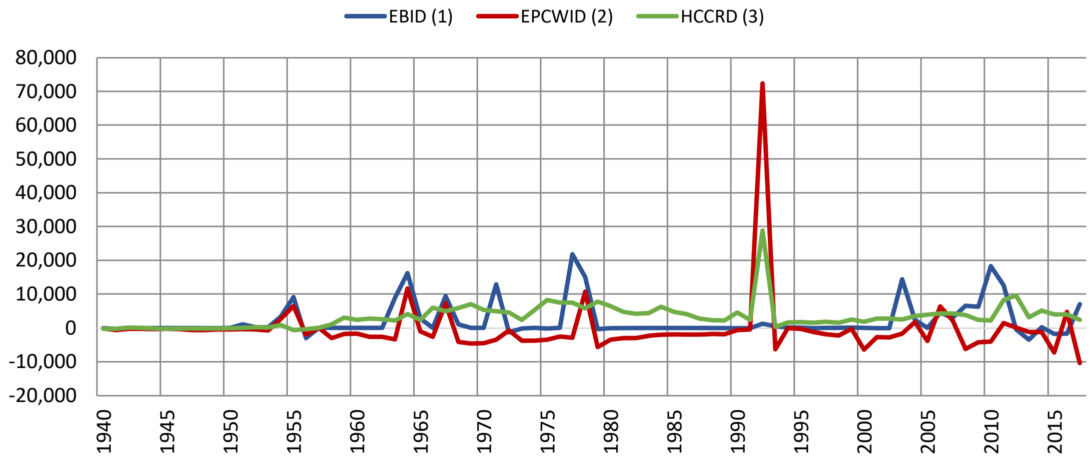
Run 14b - MX Hueco Pumping Off

Simulated Differences in ILRG Model Outputs

Run 14b minus Run 1

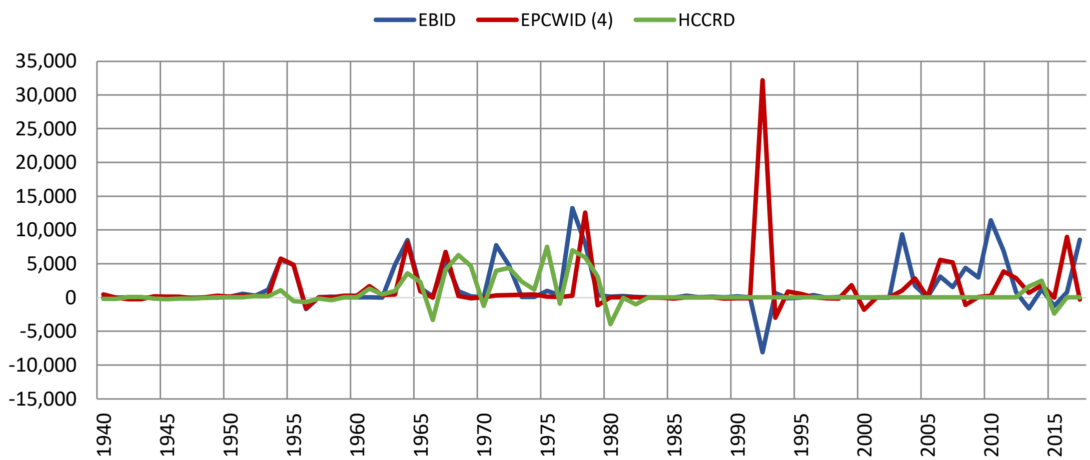
1940 - 2017 (acre-feet)

River Headgate (RHG) Diversions (Irrigation Season)



	Average Difference		
Period	EBID	EPCWID	HCCRD
1951-2017	2,472	-349	3,925
1951-1978	3,469	-629	3,425
1979-2005	649	517	4,209
2006-2017	4,248	-1,642	4,450
1985-2017	2,094	420	4,036
1985-2005	863	1,598	3,800

Farm Headgate (FHG) Deliveries (Irrigation Season)



	Average Difference		
Period	EBID	EPCWID	HCCRD
1951-2017	1,663	1,545	742
1951-1978	2,415	1,539	1,784
1979-2005	190	1,209	-70
2006-2017	3,220	2,317	141
1985-2017	1,303	1,867	51
1985-2005	207	1,610	0

Notes:

(1) EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

(2) EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

(3) HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

(4) EPCWID FHG values include deliveries to Rogers WTP and R/U WTP.

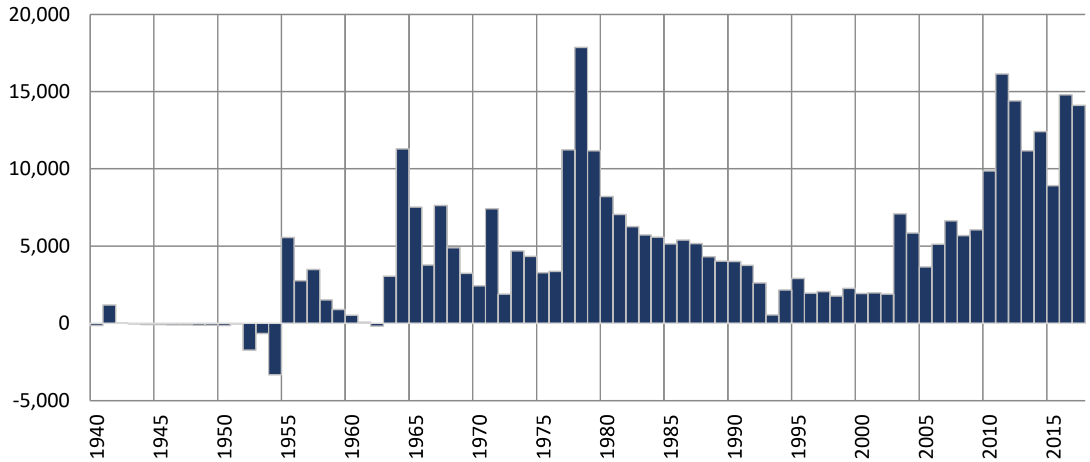
Run 14b - MX Hueco Pumping Off

Simulated Differences in ILRG Model Outputs

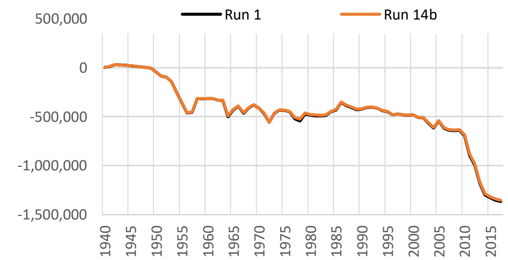
Run 14b minus Run 1

1940 - 2017 (acre-feet)

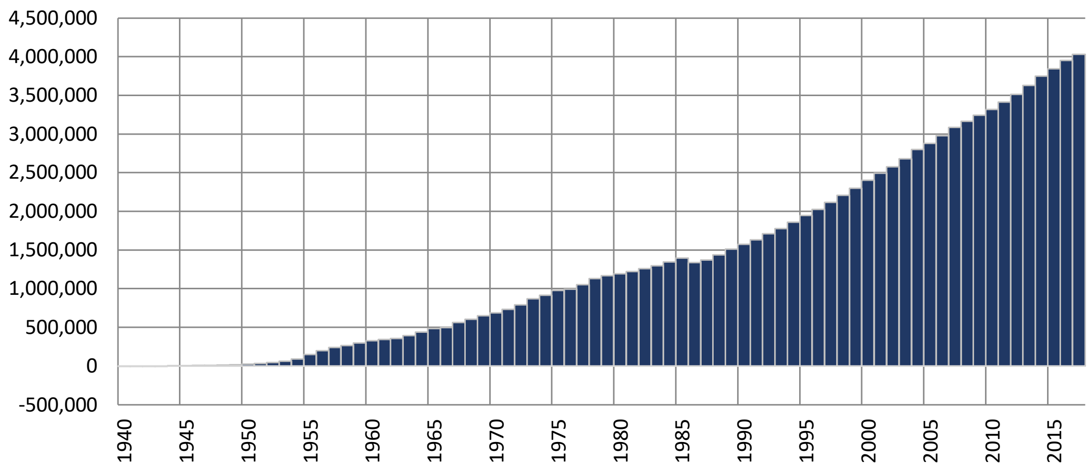
Cumulative Annual Rincon-Mesilla Groundwater Storage



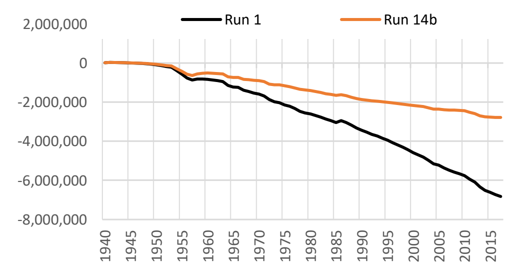
Period	Average Difference
1951-2017	213
1951-1978	643
1979-2005	-526
2006-2017	872
1985-2017	259
1985-2005	-91



Cumulative Annual Hueco Groundwater Storage



Period	Average Difference
1951-2017	59,813
1951-1978	39,526
1979-2005	64,723
2006-2017	96,107
1985-2017	81,328
1985-2005	72,883



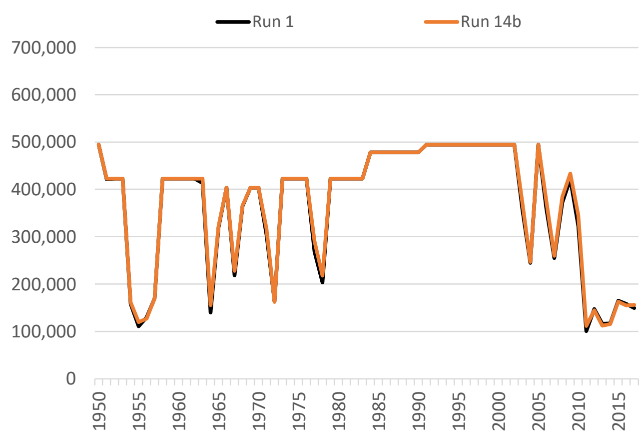
Notes:

Cumulative storage change in alluvial and non-alluvial aquifers.

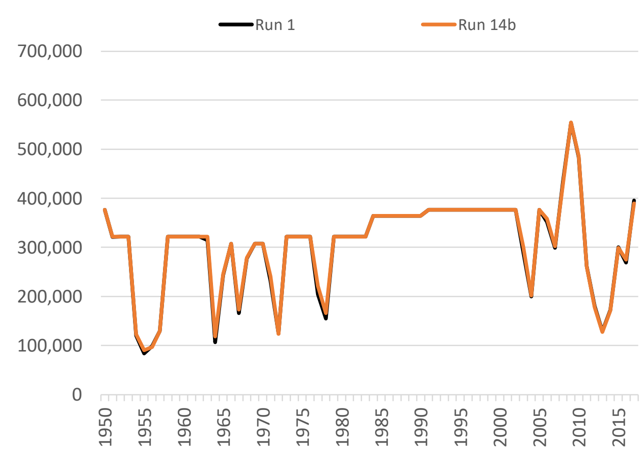
Average differences calculated as (Final Storage - Initial Storage)/(no. years).

Run 14b - MX Hueco Pumping Off
Annual Allocation and Charges
Run 14b v. Run 1
ILRG Model
1950 - 2017 (acre-feet)

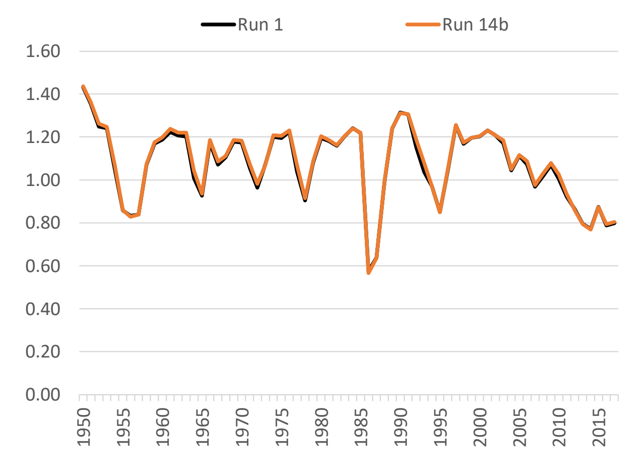
Total Allocation - EBID



Total Allocation - EPCWID

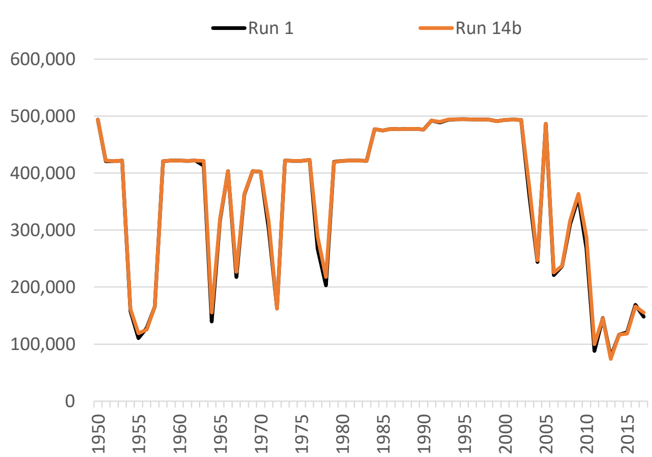


Diversion Ratio

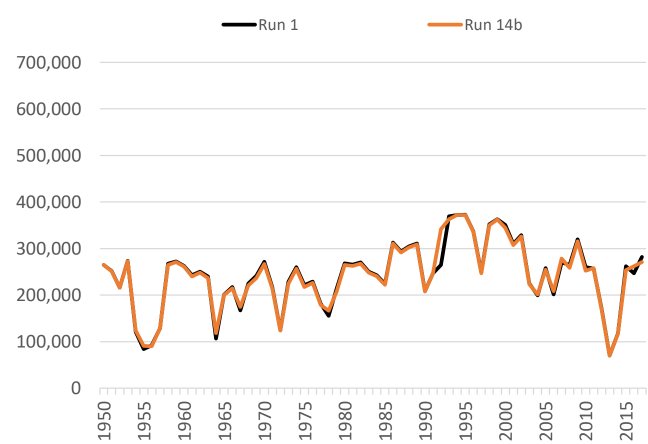


Note:
Computed as Total Charges/Caballo Release.

Annual Delivery Charges - EBID



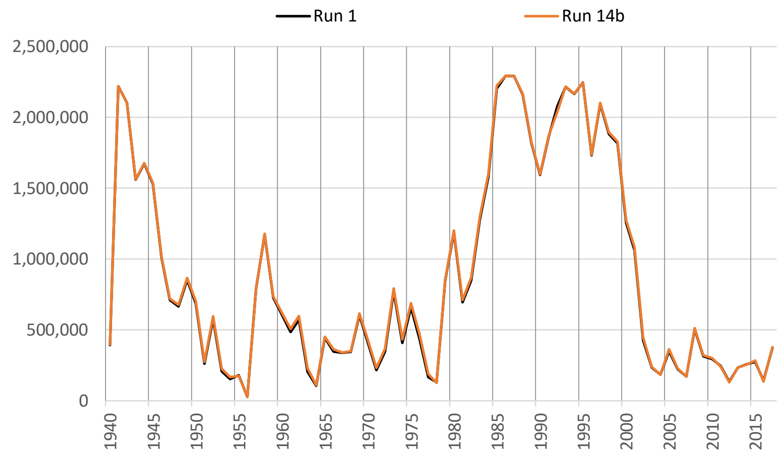
Annual Delivery Charges - EPCWID



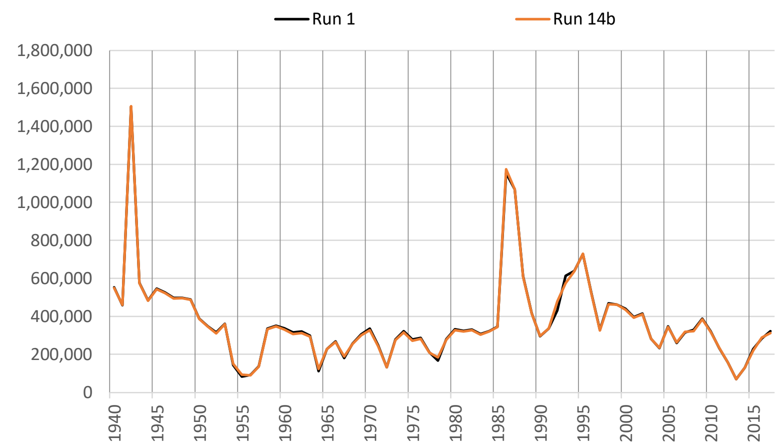
US_MSJ_00003306

Run 14b - MX Hueco Pumping Off
Annual Summary of Project Storage and Rio Grande Flows
Run 14b v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

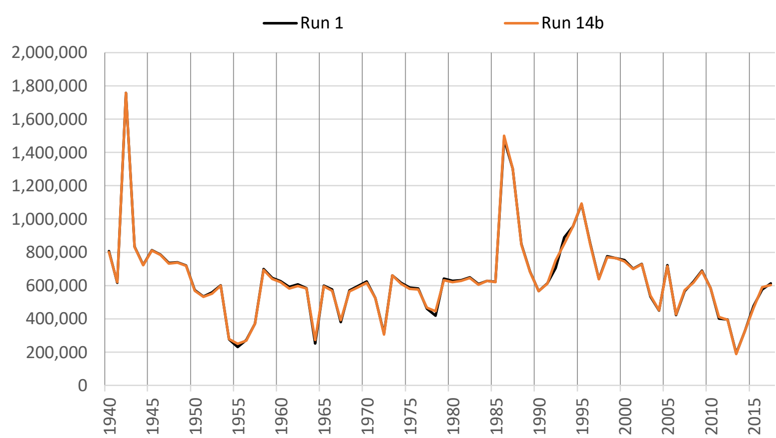
Total Year-End Project Reservoir Storage



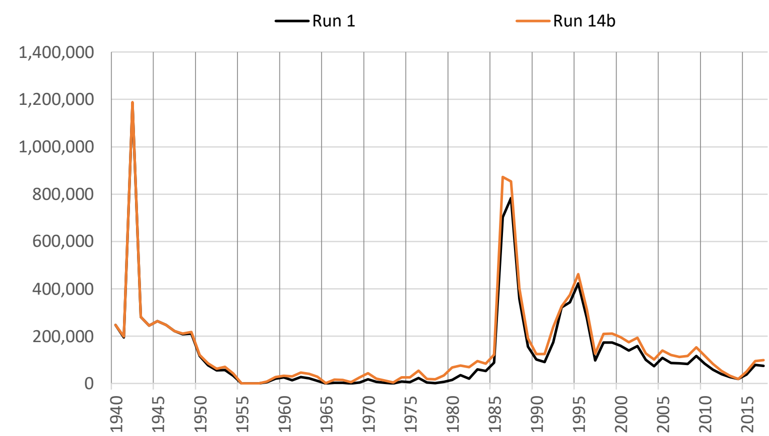
Rio Grande at El Paso



Rio Grande Below Caballo



Rio Grande at Fort Quitman

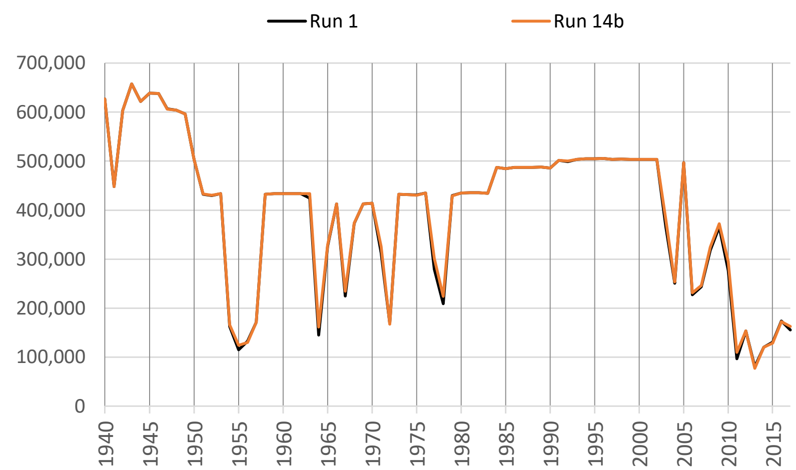


***Note different scales.**

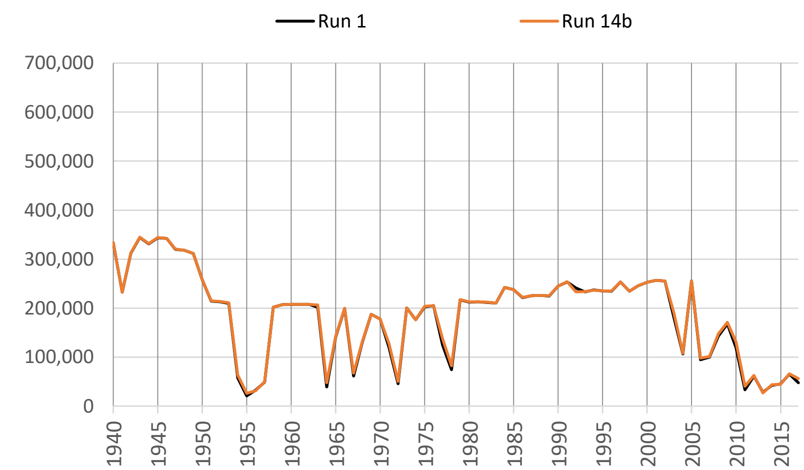
Run 14b - MX Hueco Pumping Off
Irrigation Season Summary of Irrigation Operations
Run 14b v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

EBID Total

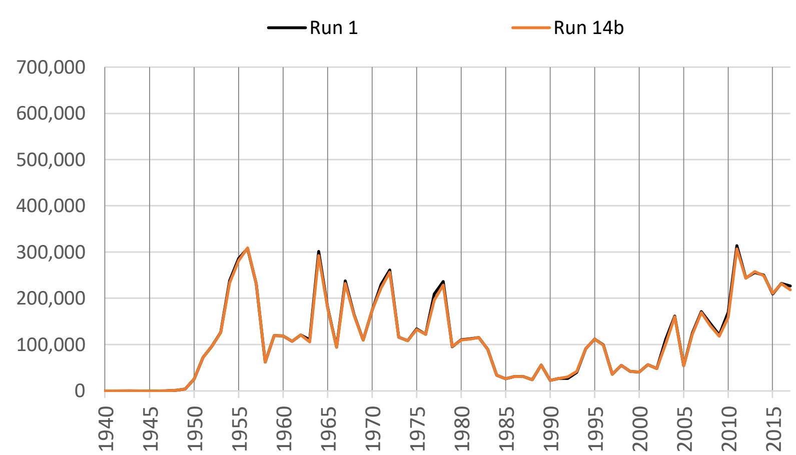
Net River Headgate Diversions



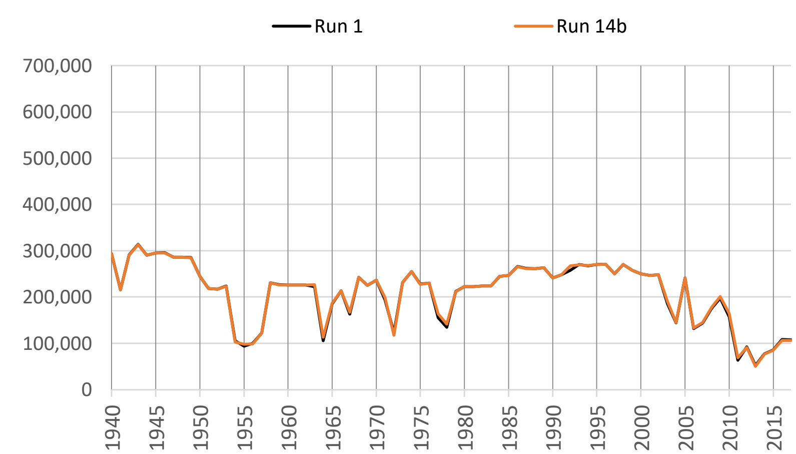
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries

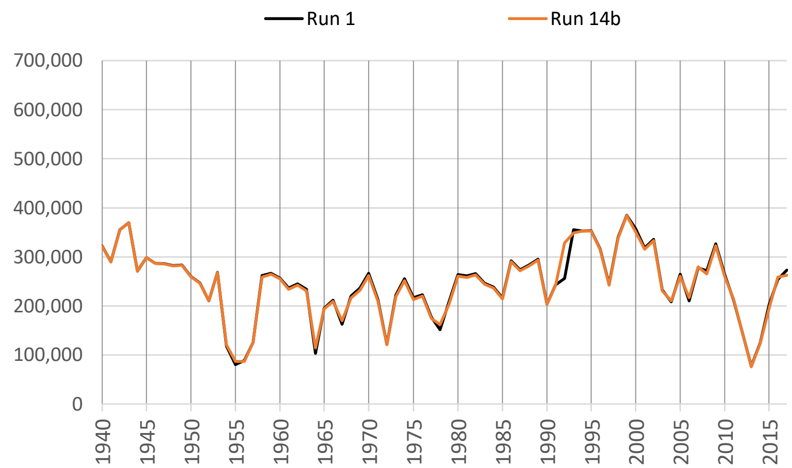


Notes: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).
Pumping includes Supplemental and Primary groundwater pumping.

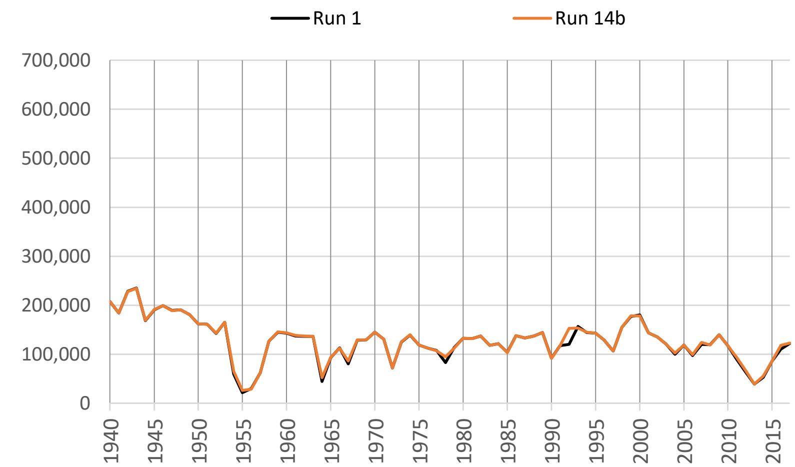
Run 14b - MX Hueco Pumping Off
Irrigation Season Summary of Irrigation Operations
Run 14b v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

EPCWID Total

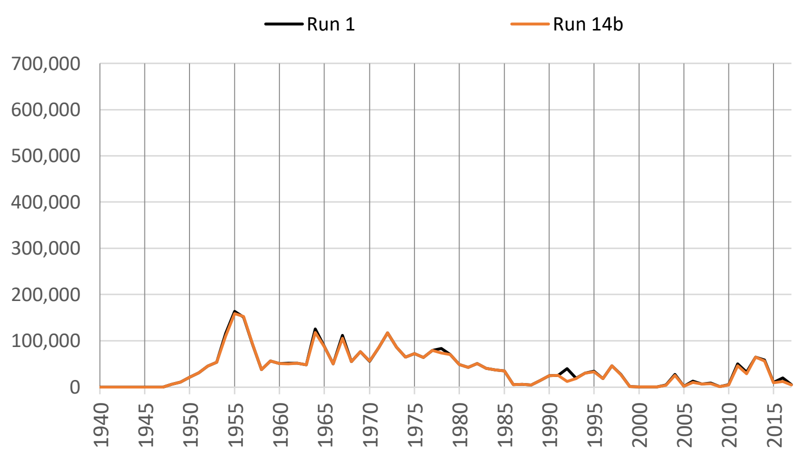
Net River Headgate Diversions



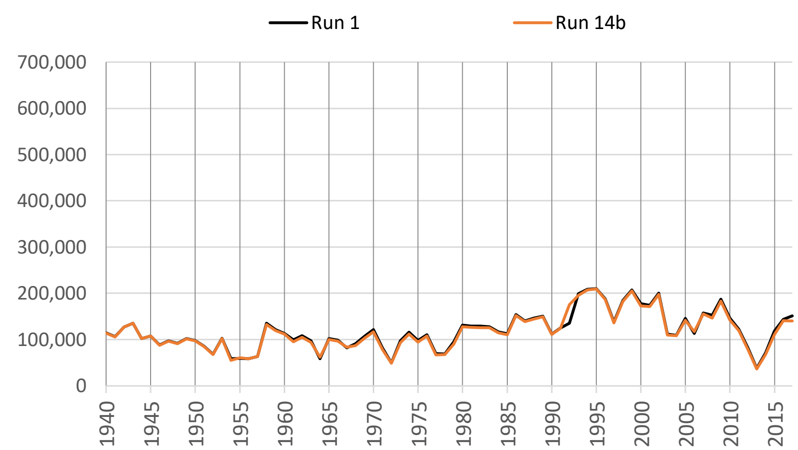
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries

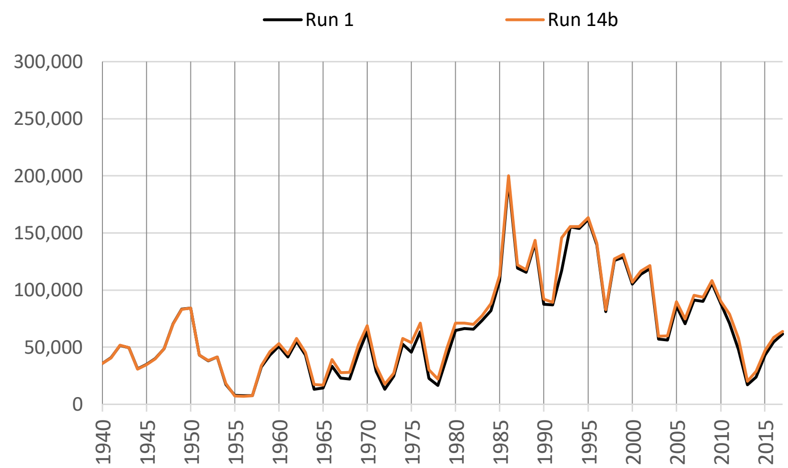


Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

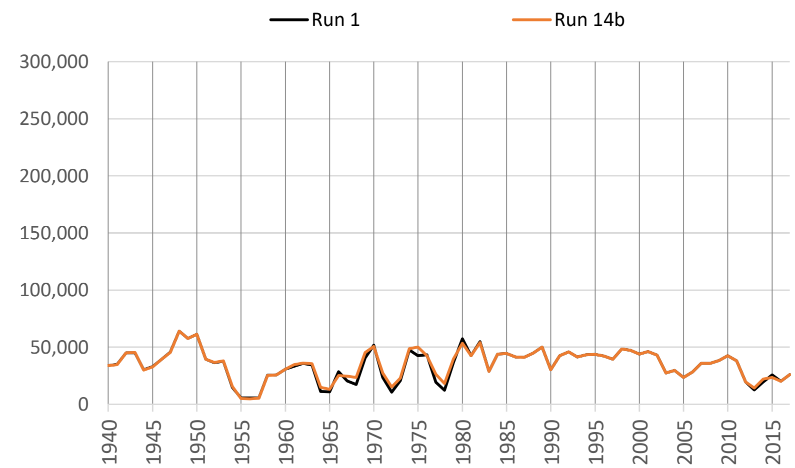
Run 14b - MX Hueco Pumping Off
Irrigation Season Summary of Irrigation Operations
Run 14b v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

HCCRD Total

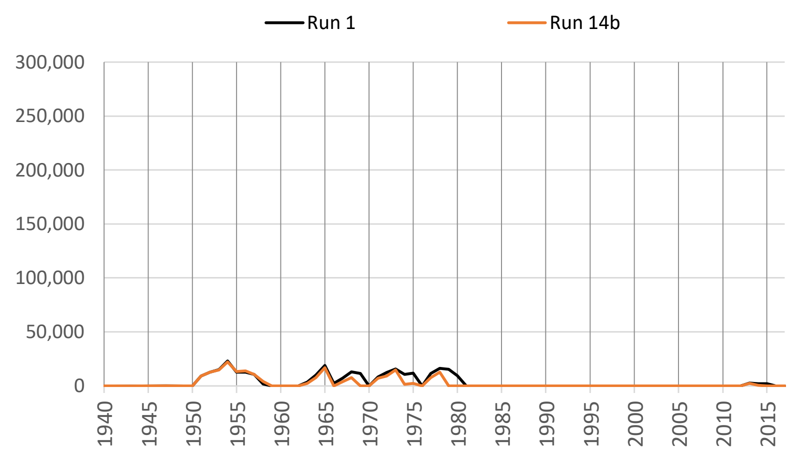
Net River Headgate Diversions



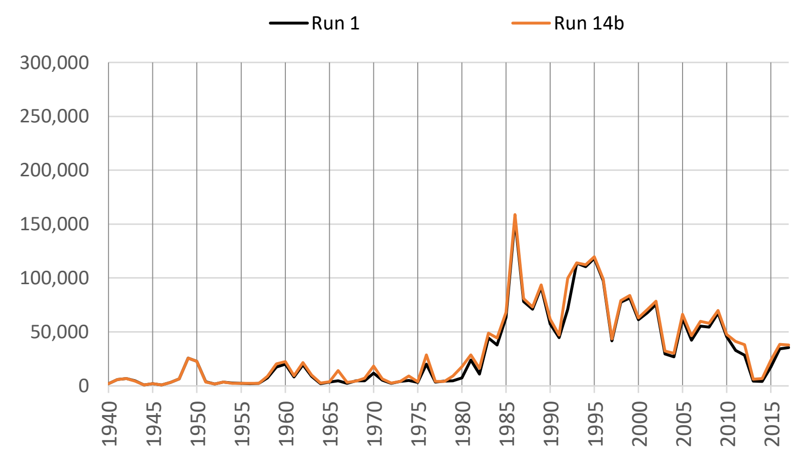
Farm Headgate Deliveries



Pumping



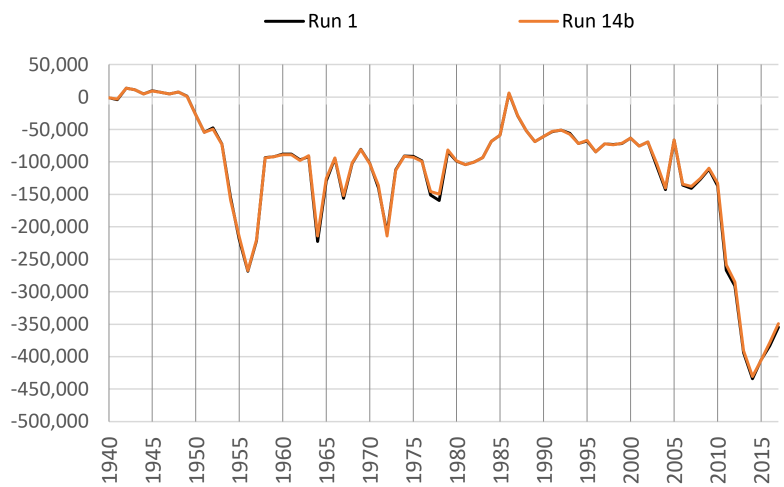
RHG Diversions - FHG Deliveries



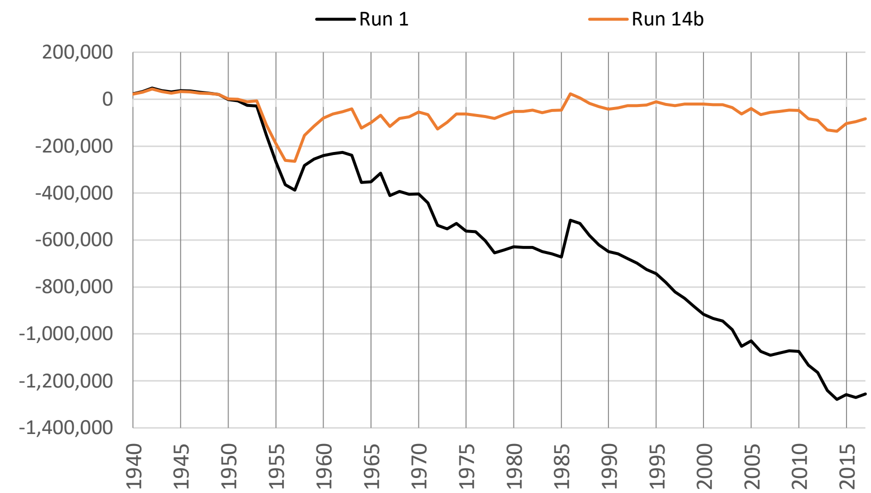
Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

Run 14b - MX Hueco Pumping Off
Cumulative Change in Ground Water Storage
Run 14b v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

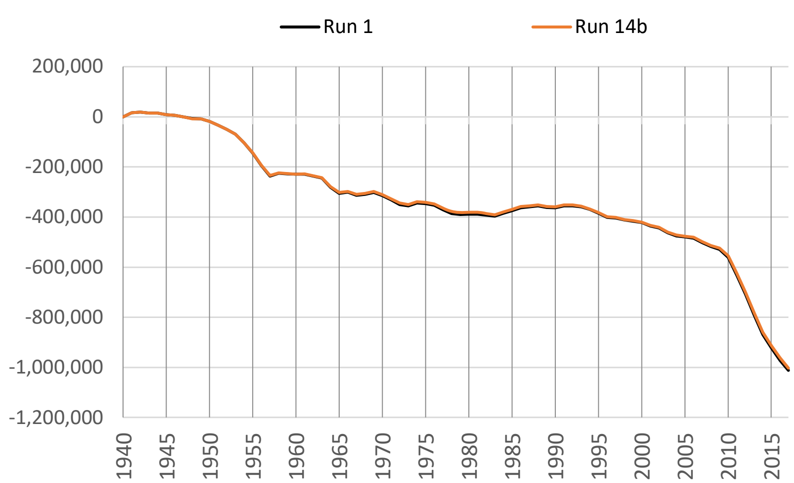
Rincon-Mesilla Alluvial Aquifer



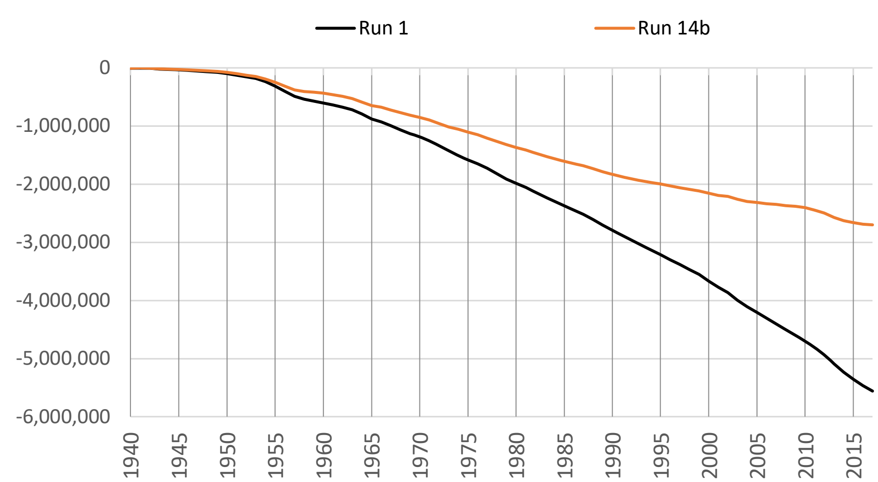
Hueco Alluvial Aquifer



Rincon-Mesilla Non-Alluvial Aquifer

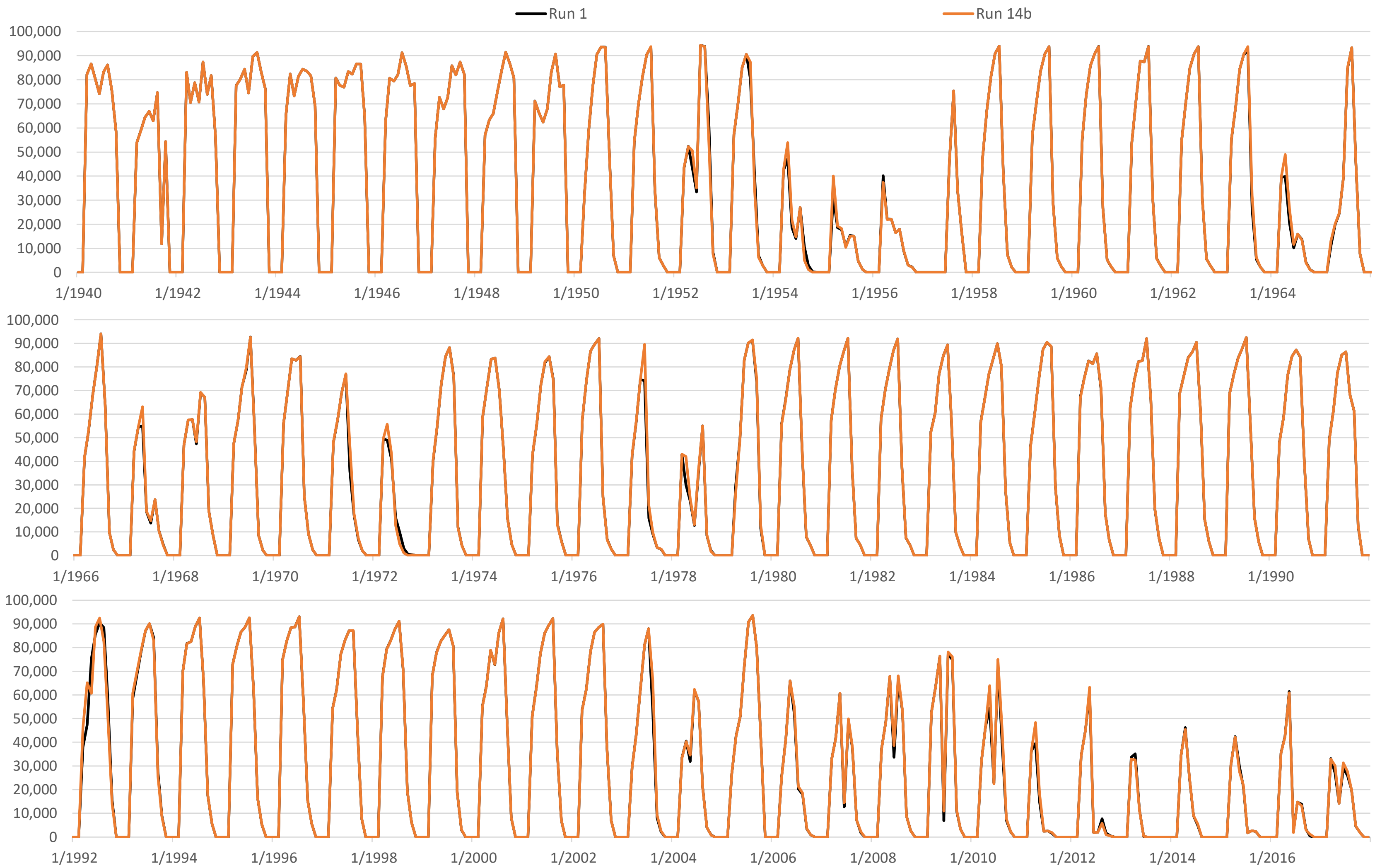


Hueco Non-Alluvial Aquifer



***Note different scales.**

Run 14b - MX Hueco Pumping Off
Monthly Net RHG Diversions
Run 14b v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
EBID Total



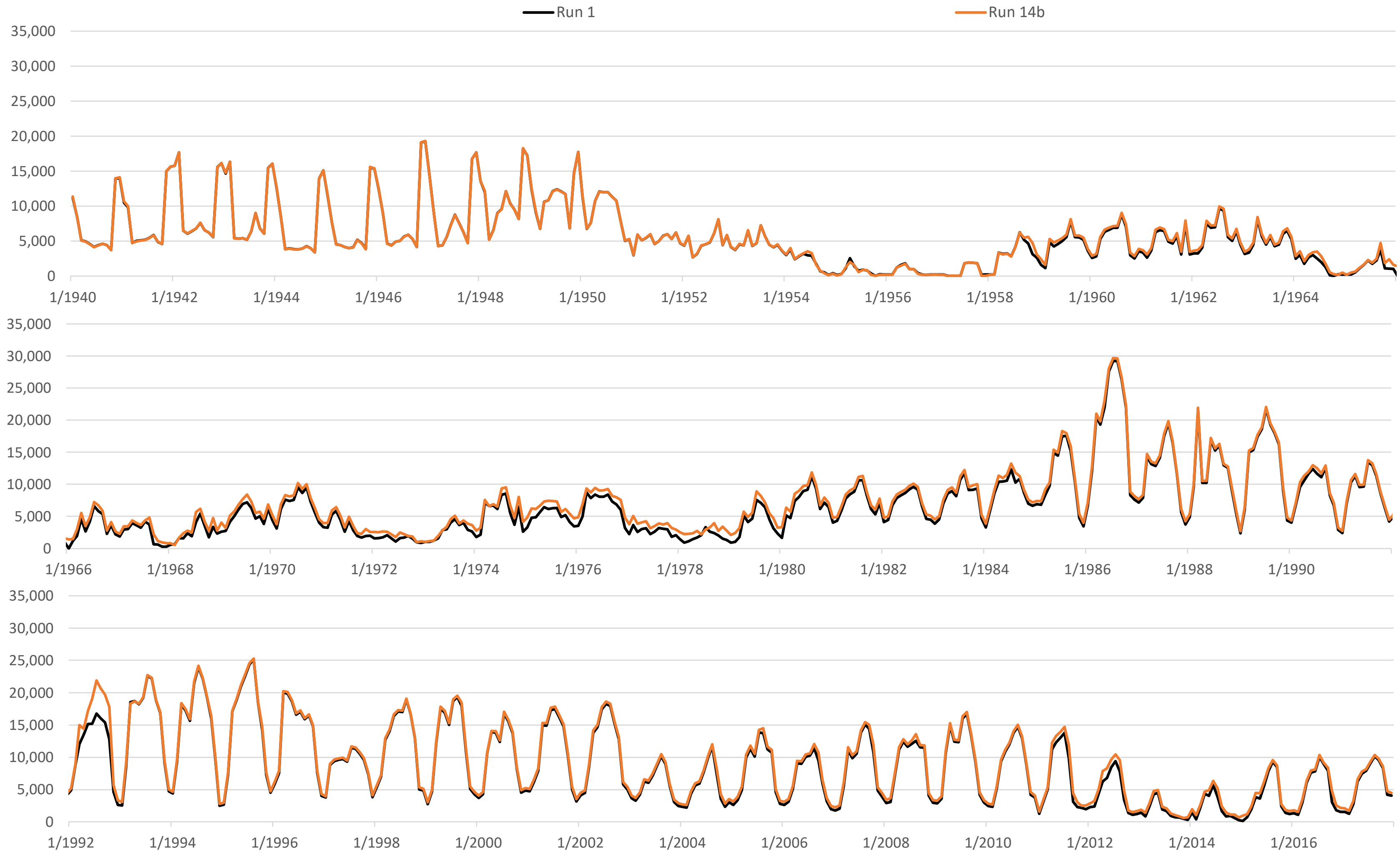
Note: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

Run 14b - MX Hueco Pumping Off
Monthly Net RHG Diversions
Run 14b v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

EPCWID Total

Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

Run 14b - MX Hueco Pumping Off
Monthly Net RHG Diversions
Run 14b v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
HCCRD Total



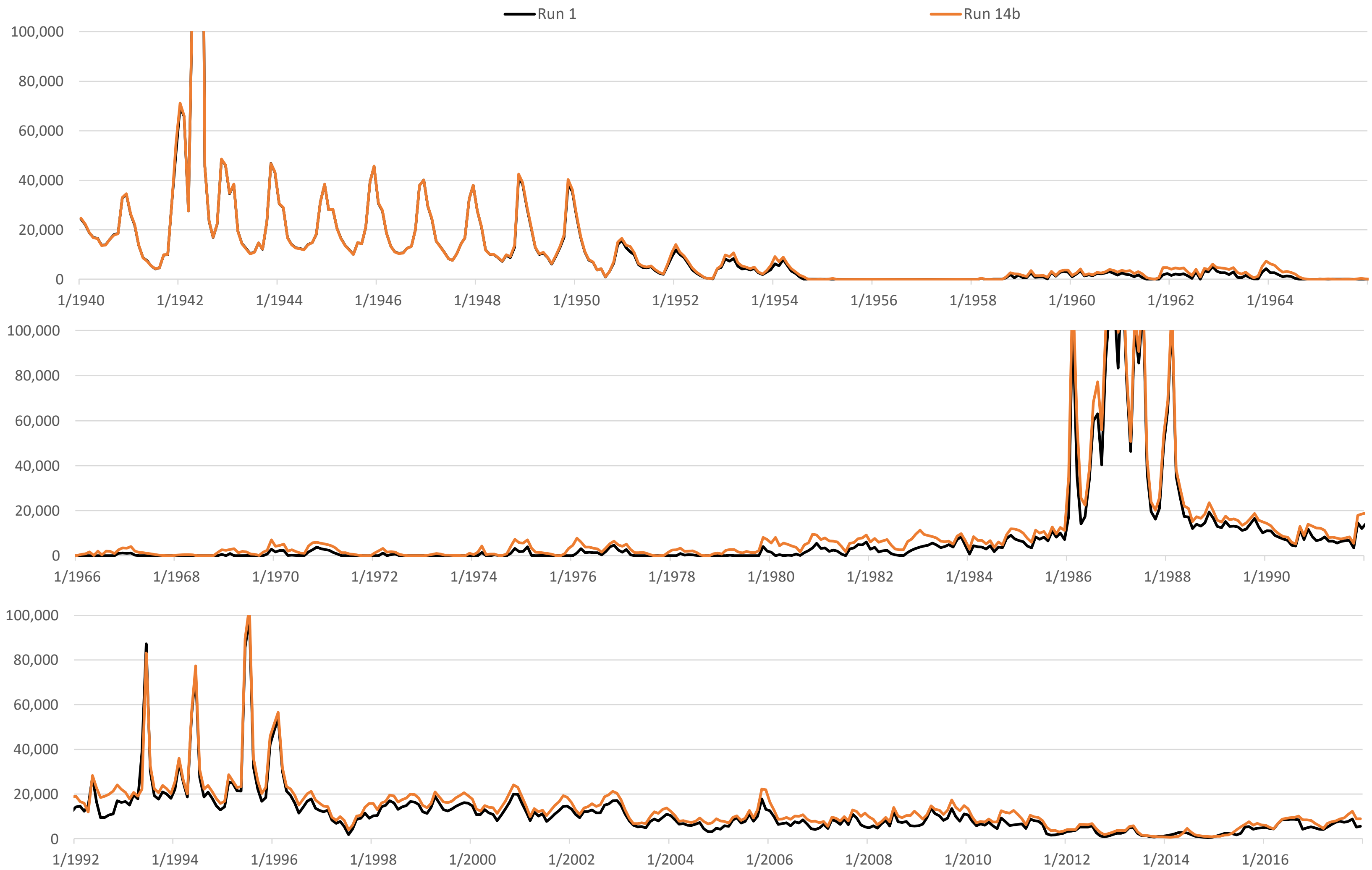
Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

Run 14b - MX Hueco Pumping Off
End of Month Reservoir Storage (Elephant Butte + Caballo)
Run 14b v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

Run 14b - MX Hueco Pumping Off
Monthly Caballo Releases
Run 14b v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

Run 14b - MX Hueco Pumping Off
Monthly Rio Grande at El Paso Flow
Run 14b v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

Run 14b - MX Hueco Pumping Off
Monthly Rio Grande at Fort Quitman Flow
Run 14b v. Run 1
ILRG Model
1940 - 2017 (acre-feet)



Appendix 30Q

Comparison of ILRG Model Runs
Run 14c v. Run 1

Model Run Specifications

Model Version: LRG_v116

Name: **Run 14c - TX WWTP Discharges Off**

Run ID: LRG_v116_Operational_Run14c
Date: 8/25/2020

Name: **Run 1 - Historical Base Run (All Pumping On)**

Run ID: LRG_v116_Operational_Run1
Date: 8/23/2020

Selected Model Inputs

Pumping and Returns	**Run 14c**	**Run 1**
Irrigation Pumping	On	On
Irrigated Area	Hist	Hist
Non-Irrigation Pumping	On	On
Non-Irrigation Pumping Returns	TX Off	On
Las Cruces Jornada Pumping Returns	On	On

Project Allocation Rules		
1950-2005	D1/D2	D1/D2
2006-2007	D3	D3
2008-2017	D3 + CO	D3 + CO

EPCWID Operations		
Charge EPCWID for Use of WWTP Returns	Off	Off
ACE and Haskell Credits for EPCWID	On	On
Increased EPCWID Use of Fabens Drain Flows	Off	Off
Charge EPCWID for Fabens Drain Flow Use	Off	Off

Run 14c - TX WWTP Discharges Off
Comparison of ILRG Model Runs
Run 14c v. Run 1
1951 - 2017 Annual Average
(1,000 acre-feet)

Run No.	1	14c	14c - 1		
Simulated Input or Output	**Run 1**	**Run 14c**	**Run 14c minus Run 1**		
Pumping Stress					
WWTP Flows	58.0	29.5	-28.5		
Total Stress	-58.0	-29.5	28.5		
	Stress is Pumping minus WWTP and Urban Deep Perc				
Effects of Pumping Stress				***% Chg***	
FHG Deliveries (Mar - Oct)				***Stress***	***% Diff.***
EBID	167.6	161.0	-6.6	*-23%*	*-4%*
EPCWID (incl. EPW)	139.9	130.4	-9.5	*-33%*	*-7%*
HCCRD	32.8	32.4	-0.5	*-2%*	*-1%*
Total	340.3	323.8	-16.5	*-58%*	*-5%*
FHG Deliveries (Nov - Feb)					
EBID	0.0	0.0	0.0	*0%*	*5%*
EPCWID (incl. EPW)	0.2	0.1	-0.1	*0%*	*-48%*
HCCRD	2.4	1.9	-0.5	*-2%*	*-22%*
Total	2.6	2.0	-0.6	*-2%*	*-24%*
Irrigation Pumping					
EBID	140.4	146.7	6.3	*22%*	*4%*
EPCWID (Mesilla Valley)	7.4	7.9	0.5	*2%*	*7%*
EPCWID (El Paso Valley)	40.1	47.3	7.2	*25%*	*18%*
HCCRD	4.2	4.9	0.7	*2%*	*16%*
Total	192.1	206.7	14.6	*51%*	*8%*
	Pumping turned off.	*Other values are simulated responses and are totaled.*			
Other Inflows/Outflows					
Net Reservoir Evaporation	125.3	118.5	-6.8	*-24%*	*-5%*
Riparian ET	70.9	68.2	-2.7	*-9%*	*-4%*
River Evaporation + Incidental Canal Loss	30.3	29.2	-1.1	*-4%*	*-4%*
Total	226.6	216.0	-10.5	*-37%*	*-5%*
Rio Grande at Fort Quitman					
Reservoir Spills	33.3	21.8	-11.5	*-40%*	*-35%*
Nov-Feb Flows	21.4	14.1	-7.3	*-26%*	*-34%*
Mar - Oct Flows	41.1	35.4	-5.7	*-20%*	*-14%*
Underflow (GW Model)	0.2	0.2	0.0	*0%*	*-10%*
Total	96.0	71.4	-24.5	*-86%*	*-26%*

Run 14c - TX WWTP Discharges Off
Comparison of ILRG Model Runs
Run 14c v. Run 1
1951 - 2017 Annual Average
(1,000 acre-feet)

Run No.	1	14c	14c - 1		
Simulated Input or Output	**Run 1**	**Run 14c**	**Run 14c minus Run 1**		
Effects of Pumping Stress (continued)				*% Chg*	
Change in Storage				***Stress***	***% Diff.***
Reservoir Storage	-4.7	-4.6	0.1	*0%*	*-1%*
Alluvial GW Storage (RW Model)	-23.6	-26.1	-2.5	*-9%*	*11%*
Non-alluvial GW Storage (GW Models)	-96.4	-100.6	-4.3	*-15%*	*4%*
Soil Moisture Storage	0.6	0.5	-0.1	*0%*	*-17%*
Total	-124.0	-130.8	-6.8	*-24%*	*6%*
Summary of Effects					
FHG Deliveries (Mar-Oct)	340.3	323.8	-16.5	*-58%*	*-5%*
FHG Deliveries (Nov-Feb)	2.6	2.0	-0.6	*-2%*	*-24%*
Irrigation Pumping	192.1	206.7	14.6	*51%*	*8%*
Riparian ET + Evaporation	226.6	216.0	-10.5	*-37%*	*-5%*
Fort Quitman Flow	96.0	71.4	-24.5	*-86%*	*-26%*
Change in Storage	-124.0	-130.8	-6.8	*-24%*	*6%*
Total	733.6	689.1	-44.5	*-156%*	*-6%*
Other Effects of Pumping Stress				*% Chg*	
Rio Grande at El Paso				***Stress***	***% Diff.***
Reservoir Spills	49.4	36.1	-13.3	*-46%*	*-27%*
Nov-Feb Flows	22.8	23.2	0.4	*2%*	*2%*
Mar - Oct Flows	263.8	285.4	21.7	*76%*	*8%*
Total	336.0	344.8	8.8	*31%*	*3%*
Rio Grande below Caballo					
Reservoir Spills	65.9	46.8	-19.1	*-67%*	*-29%*
Nov-Feb Flows	0.5	0.9	0.4	*1%*	*84%*
Mar - Oct Flows	541.3	566.4	25.2	*88%*	*5%*
Total	607.6	614.1	6.5	*23%*	*1%*
Surface Water Diversions (Mar - Oct)					
EBID	366.5	351.9	-14.6	*-51%*	*-4%*
EPCWID (incl. EPW)	236.8	239.4	2.6	*9%*	*1%*
HCCRD	67.5	64.2	-3.4	*-12%*	*-5%*
Total	670.8	655.5	-15.4	*-54%*	*-2%*
Surface Water Diversions (Nov - Feb)					
EBID	0.0	0.0	0.0	*0%*	*0%*
EPCWID (incl. EPW)	14.3	11.2	-3.2	*-11%*	*-22%*
HCCRD	14.2	10.8	-3.4	*-12%*	*-24%*
Total	28.5	22.0	-6.6	*-23%*	*-23%*

Run 14c - TX WWTP Discharges Off
Annual Differences in ILRG Model Outputs
Run 14c minus Run 1
1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1940	-50	-50	194	-829	406	-216	20	20	-808	-808	370	370	6,635	6,248	-505
1941	21	21	867	-791	253	-418	-2	-6	-4	-251	192	78	-24,426	-16,414	-17,465
1942	3	3	612	-865	-347	-417	-9	-11	514	-201	-345	-374	22,247	14,366	-3,098
1943	-35	-35	562	-1,191	-270	-676	-30	-30	434	191	-80	-532	8,940	8,503	-1,619
1944	20	20	776	-344	708	251	115	116	-906	-1,118	596	301	10,757	10,368	-912
1945	-97	-97	798	-832	764	126	41	41	-1,171	-1,572	696	595	10,773	10,525	-684
1946	-45	-45	1,217	-2,037	801	-170	60	61	-735	-2,113	726	642	10,262	10,125	46
1947	-72	-72	2,109	-546	775	-202	-4	-3	69	-744	658	719	11,010	10,795	455
1948	-9	-9	1,441	-64	936	366	78	78	-596	-1,072	421	199	10,114	9,962	310
1949	-100	-100	641	-1,704	695	-335	25	26	-1,262	-1,286	-63	-150	9,742	9,621	-591
1950	-11	-11	909	65	755	194	47	48	-961	-961	-47	-83	8,553	8,408	-1,988
1951	-37,046	-37,046	-650	-647	371	286	-21,655	-21,657	-2,050	-2,057	284	216	-9,990	4,928	-2,044
1952	-728	-728	-25	-997	-193	-782	-362	-357	-965	-963	-175	-272	23,174	13,772	-1,646
1953	-34,188	-34,188	-910	-905	220	138	-22,028	-22,028	-2,282	-2,285	122	78	-8,111	6,593	1,536
1954	-26,125	-26,125	-19,375	-22,941	-3,136	-4,237	-15,499	-15,499	-15,650	-15,656	-3,030	-3,965	-26,235	-18,163	-4,626
1955	-8,276	-8,276	-6,482	-11,427	-822	-1,299	-4,970	-4,970	-6,509	-6,737	-1,224	-1,646	4,238	-1,641	-1
1956	-10,015	-10,015	-12,551	-16,894	-720	-1,600	-5,197	-5,197	-7,895	-8,700	-615	-1,426	-15,535	-6,830	-100
1957	-38	-38	-1,036	-5,875	58	-626	-81	-81	-1,420	-1,866	630	-5	6,050	4,076	-1
1958	18	18	7,263	5,086	1,858	74	-171	-171	408	308	-857	-1,264	30,615	21,242	1,949
1959	5	5	2,273	1,139	-1,544	-3,247	-45	-45	-1,288	-1,289	328	533	18,600	15,664	-3,753
1960	0	0	1,613	257	-360	-1,762	-3	-3	-1,863	-1,863	0	0	21,678	20,060	-2,397
1961	3	3	1,465	-57	-8	-2,082	3	3	-2,319	-2,319	82	-198	18,204	17,190	-2,613
1962	-1,538	-1,538	-35,465	-36,870	-10,934	-12,577	10,396	10,397	-15,676	-15,668	1,783	2,546	-8,679	-19,502	-15,894
1963	-40,855	-40,855	3,500	2,009	-86	-1,625	-23,174	-23,174	-926	-926	248	420	-1,199	19,427	-1,572
1964	-32,204	-32,204	-24,316	-30,140	-1,927	-3,782	-18,705	-18,705	-20,189	-20,565	-1,738	-1,808	-24,525	-14,570	-5,467
1965	-16,682	-16,682	-9,676	-16,358	-5	-2,008	-4,833	-4,833	-4,680	-5,121	1,418	33	1,242	5,159	-34
1966	73	73	3,300	-539	-3,945	-5,678	-565	-565	-168	-172	-3,987	-3,508	31,887	20,565	-2,403
1967	-34,915	-34,915	-25,959	-31,062	-5,545	-8,501	-13,324	-13,324	-20,556	-20,885	-6,072	-5,578	-35,878	-16,077	-2,238
1968	-6,353	-6,353	12,308	8,431	-2,629	-4,873	-5,080	-5,080	-2,204	-2,405	-1,844	-3,014	43,397	26,236	-664
1969	-155	-155	9,236	7,711	169	-3,336	-3,210	-3,209	179	180	107	-1,348	34,330	25,665	-2,126
1970	-57	-57	9,009	6,934	1,007	-2,614	146	146	-1,118	-1,116	-680	-952	25,644	25,614	-1,620
1971	-61,509	-61,509	-30,235	-38,826	-2,177	-8,003	-36,463	-36,463	-29,564	-29,279	-727	-3,502	-69,997	-26,948	-2,844
1972	-4,623	-4,623	-3,693	-12,812	-5,313	-10,200	-4,116	-4,116	-12,382	-12,286	-5,047	-8,722	16,600	1,217	-1,751
1973	103	103	20,136	15,964	1,296	-5,365	-509	-509	-1,398	-1,560	2,012	-3,946	53,960	39,514	117
1974	35	35	17,691	15,832	5,082	1,669	-140	-140	-755	-757	3,258	-101	46,029	40,051	1,346
1975	-1,388	-1,388	16,203	14,384	2,265	163	-8,520	-8,516	204	211	2,140	2,070	47,680	34,566	-1,706
1976	-67	-67	18,080	16,950	4,213	940	147	148	-453	-453	-42	-138	32,646	38,665	1,768
1977	-112,651	-112,651	-55,845	-63,016	-5,621	-10,873	-54,465	-54,465	-44,989	-44,998	-3,974	-6,636	-150,337	-56,825	-1,651
1978	3,766	3,766	-16,186	-27,310	-4,608	-9,528	2,046	2,046	-23,175	-22,954	-2,456	-5,221	29,237	-8,976	-1,657

Run 14c - TX WWTP Discharges Off
Annual Differences in ILRG Model Outputs
Run 14c minus Run 1
1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1979	-1,656	-1,656	10,543	5,216	-3,061	-5,523	-2,549	-2,547	-10,467	-10,475	-1,324	-2,866	59,724	35,460	-3,621
1980	28	28	23,797	21,567	1,389	-5,196	-297	-297	8	1	1,286	-2,339	62,012	52,711	-4,096
1981	25	25	23,696	21,982	-322	-8,169	-260	-260	-34	-36	0	0	57,536	52,481	-8,777
1982	-1	-1	23,084	21,211	-819	-7,184	-27	-27	-201	-202	96	298	56,364	53,032	-7,822
1983	-14	-14	23,187	21,210	-163	-6,257	36	36	-38	-39	0	0	56,515	53,818	-7,140
1984	44	44	24,806	22,888	2,831	-2,876	-164	-164	-14	-15	71	71	52,752	50,532	-5,929
1985	1,558	1,558	31,725	30,665	-18,091	-22,530	7,406	7,406	4,811	4,726	0	0	20,156	16,944	-26,390
1986	-89	-89	25,787	25,183	-8,859	-17,339	-1,125	-1,141	-404	-426	0	0	-273,089	-264,279	-235,939
1987	-45	-45	28,585	28,514	5,567	1,618	-143	-145	-4	-7	0	0	258	-1,494	-184,789
1988	-18	-18	29,631	29,561	6,354	2,335	97	97	3	2	0	0	48,393	41,238	-52,483
1989	-36	-36	32,704	32,333	7,505	4,080	230	231	353	-26	0	0	75,980	71,335	6,320
1990	-33	-33	30,874	29,234	6,084	2,121	279	279	317	-199	0	0	51,177	51,158	-7,490
1991	-114	-114	19,035	17,978	1,069	-1,947	-803	-802	17	-779	0	0	52,095	49,961	-15,589
1992	2,874	2,874	24,795	24,489	-16,414	-19,156	13,519	13,518	5,599	5,258	0	0	-20,156	-23,804	-76,604
1993	-4,360	-4,360	-76,454	-76,459	-42,179	-46,094	10,345	10,357	-41,644	-41,627	0	0	-118,319	-123,399	-167,945
1994	-1,384	-1,384	7,204	7,199	-1,107	-5,179	277	278	-3,747	-3,745	0	0	-26,045	-15,137	-77,581
1995	-790	-790	6,044	5,968	-1,333	-5,595	235	235	-2,269	-2,331	0	0	-4,698	-3,494	-72,264
1996	41	41	15,703	15,653	2,774	-77	-170	-170	-25	-26	0	0	58,274	51,084	-18,491
1997	119	119	30,499	27,186	3,231	-501	-783	-783	-690	-1,710	0	0	72,538	69,078	-5,976
1998	74	74	20,306	19,073	-24,759	-28,857	12,310	12,309	-4,269	-4,271	0	0	-12,032	-9,352	-60,817
1999	-15,445	-15,445	-11,202	-14,404	784	-1,516	8,954	8,957	-18,794	-18,806	0	0	0	-319	-43,854
2000	-20,572	-20,572	13,598	9,230	4,401	2,661	-3,583	-3,580	-13,992	-14,028	0	0	11,450	24,072	-32,501
2001	-774	-774	42,509	37,273	8,572	7,240	-52	-52	9,326	9,308	0	0	61,817	54,189	-16,180
2002	-1,214	-1,214	19,102	15,590	3,642	2,431	-201	-201	3,702	3,699	0	0	34,086	32,821	-29,897
2003	-188,305	-188,305	-92,535	-97,137	-16,577	-21,405	-107,496	-107,496	-74,909	-74,941	0	0	-195,008	-99,545	-48,119
2004	35,509	35,509	14,477	9,466	-3,230	-8,540	22,730	22,730	-7,171	-7,197	0	0	99,456	37,140	-42,229
2005	-56,707	-56,707	-17,429	-22,118	-18,579	-22,594	-28,839	-28,832	-32,076	-32,085	274	295	-684	1,121	-40,762
2006	-40,533	-40,533	-57,389	-62,537	-22,304	-27,418	-20,833	-20,833	-49,976	-49,993	-4	0	-80,528	-54,224	-47,743
2007	-28,056	-28,056	-13,151	-18,147	-15,772	-22,655	-12,140	-12,140	-28,253	-28,272	0	0	-5,704	-1,090	-42,495
2008	-27,517	-27,517	35,834	31,037	1,849	-845	-16,684	-16,684	-1,100	-1,117	0	0	63,164	51,090	-20,406
2009	-36,291	-36,291	23,087	17,872	3,996	2,628	-21,708	-21,708	-5,673	-5,688	0	0	37,550	38,016	-17,383
2010	-59,204	-59,204	19,316	13,810	3,597	2,740	-34,332	-34,332	-8,657	-8,676	0	0	19,625	30,061	-8,251
2011	-20,678	-20,678	-61,119	-65,450	-21,981	-26,808	-8,994	-8,994	-50,191	-50,201	-8,545	-8,710	-89,479	-56,010	-22,502
2012	-10,100	-10,100	4,267	-424	-13,495	-20,492	-4,638	-4,638	-11,406	-11,411	3,069	2,838	16,931	21,187	-27,109
2013	-8,550	-8,550	-12,048	-15,649	-7,001	-10,012	-3,844	-3,844	-18,854	-18,856	-4,781	-5,327	-4,692	2,126	-19,954
2014	-23,652	-23,652	7,212	3,034	-3,927	-6,633	-7,053	-7,053	-7,666	-7,668	-3,477	-5,068	3,476	21,276	-8,681
2015	-4,967	-4,967	-4,916	-8,898	-7,688	-11,130	3,415	3,415	-22,942	-22,945	121	8	3,043	10,550	-21,522
2016	-26,773	-26,773	-6,276	-10,585	-9,527	-14,946	-9,660	-9,660	-22,982	-22,988	724	746	-6,980	9,339	-46,820
2017	-14,154	-14,154	35,005	31,512	1,672	-1,801	-4,228	-4,228	-1,425	-1,429	635	58	61,116	51,973	-21,988
Averages															
1951-2017	-14,585	-14,585	2,590	-565	-3,357	-6,758	-6,584	-6,584	-9,484	-9,573	-476	-1,005	6,460	8,840	-24,536
1951-1978	-15,193	-15,193	-4,297	-7,928	-1,180	-3,619	-8,228	-8,227	-7,846	-7,935	-716	-1,691	4,812	7,524	-1,860
1979-2005	-9,307	-9,307	12,003	9,946	-3,751	-7,928	-2,595	-2,595	-6,912	-7,036	15	-168	10,391	9,531	-47,665
2006-2017	-25,040	-25,040	-2,515	-7,035	-7,548	-11,448	-11,725	-11,725	-19,094	-19,104	-1,021	-1,288	1,460	10,358	-25,404
1985-2017	-16,672	-16,672	4,993	2,123	-5,810	-9,582	-6,288	-6,288	-12,272	-12,378	-363	-459	-1,419	2,534	-47,104
1985-2005	-11,891	-11,891	9,284	7,356	-4,816	-8,516	-3,182	-3,181	-8,375	-8,534	13	14	-3,064	-1,937	-59,504

Notes:

EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

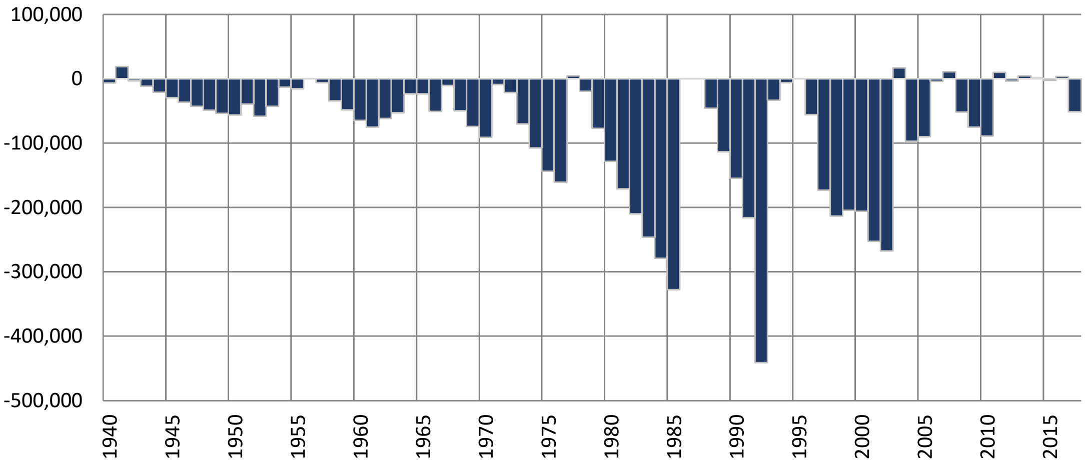
Run 14c - TX WWTP Discharges Off

Simulated Differences in ILRG Model Outputs

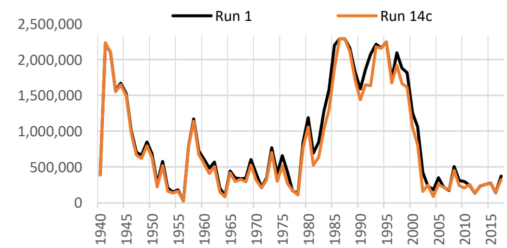
Run 14c minus Run 1

1940 - 2017 (acre-feet)

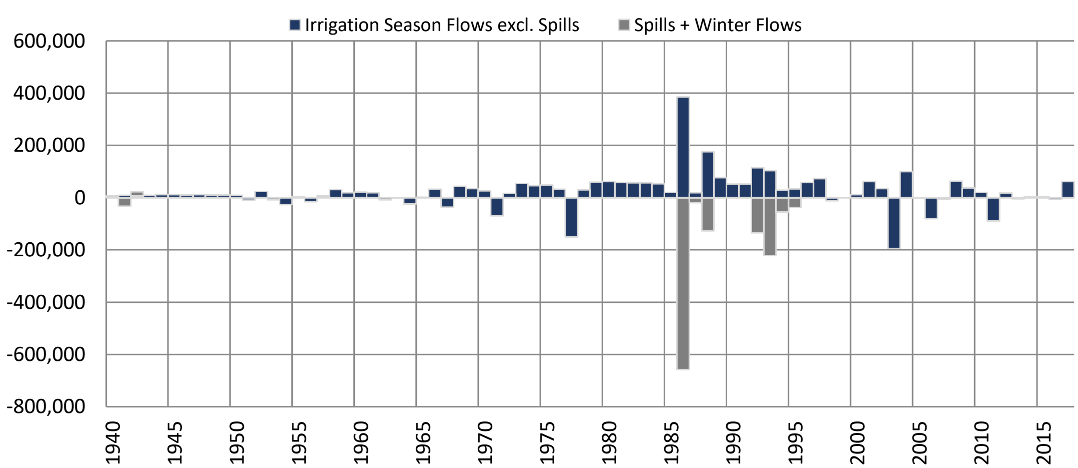
Total Project Storage (Year End)



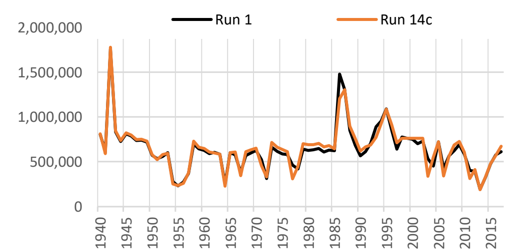
Period	Average Difference
1951-2017	69
1951-1978	1,312
1979-2005	-2,609
2006-2017	3,195
1985-2017	6,888
1985-2005	8,998



Caballo Reservoir Outflows (Annual)



	Average Difference		
Period	Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	25,155	-18,695	6,460
1951-1978	4,812	0	4,812
1979-2005	56,782	-46,391	10,391
2006-2017	1,460	0	1,460
1985-2017	36,538	-37,957	-1,419
1985-2005	56,582	-59,646	-3,064



Notes:

Reservoir storage does not include storage attributed to SJC, CO, or NM credit waters.

Average differences calculated as (Final Storage - Initial Storage)/(no. years).

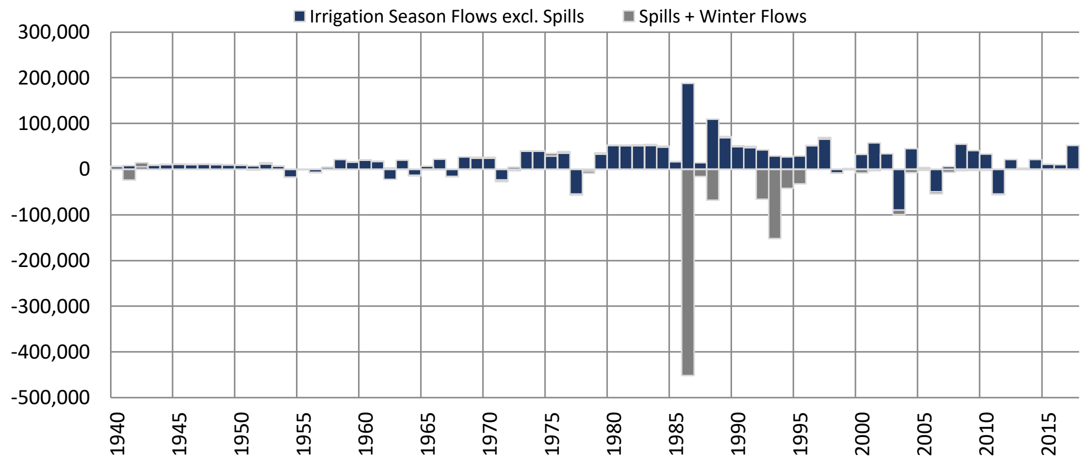
Run 14c - TX WWTP Discharges Off

Simulated Differences in ILRG Model Outputs

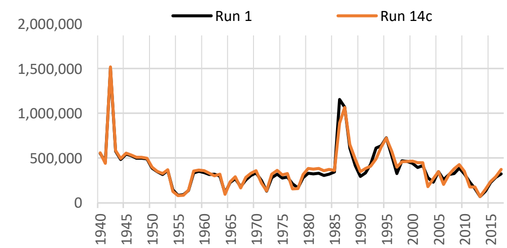
Run 14c minus Run 1

1940 - 2017 (acre-feet)

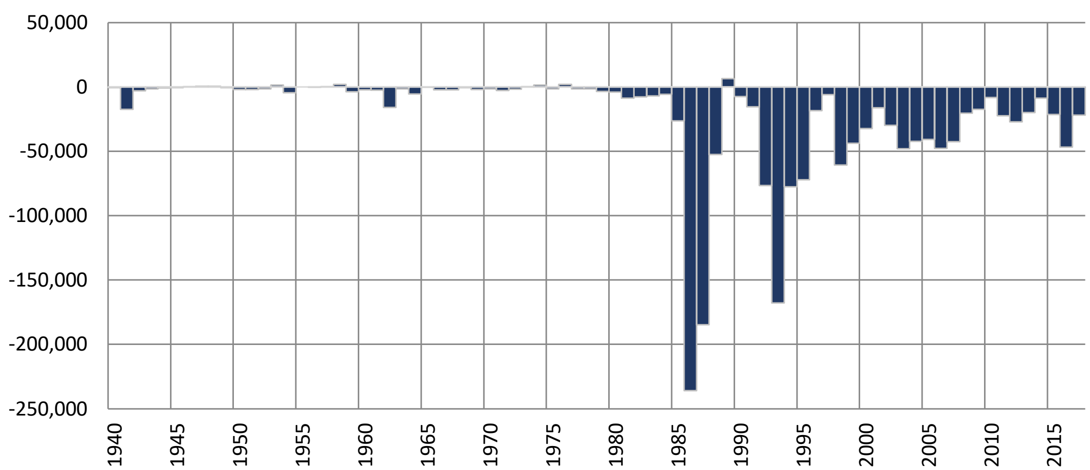
Rio Grande at El Paso (Annual)



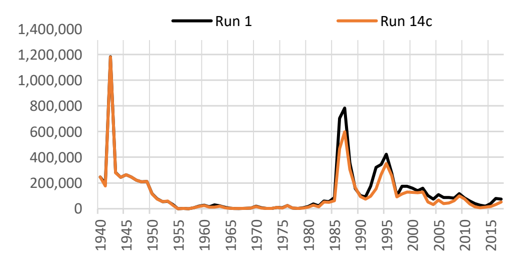
	Average Difference		
Period	Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	21,653	-12,812	8,840
1951-1978	7,574	-50	7,524
1979-2005	40,433	-30,902	9,531
2006-2017	12,247	-1,889	10,358
1985-2017	28,828	-26,295	2,534
1985-2005	38,304	-40,241	-1,937



Rio Grande at Fort Quitman (Annual)



Period	Average Difference
1951-2017	-24,515
1951-1978	-1,845
1979-2005	-47,638
2006-2017	-25,387
1985-2017	-47,085
1985-2005	-59,484



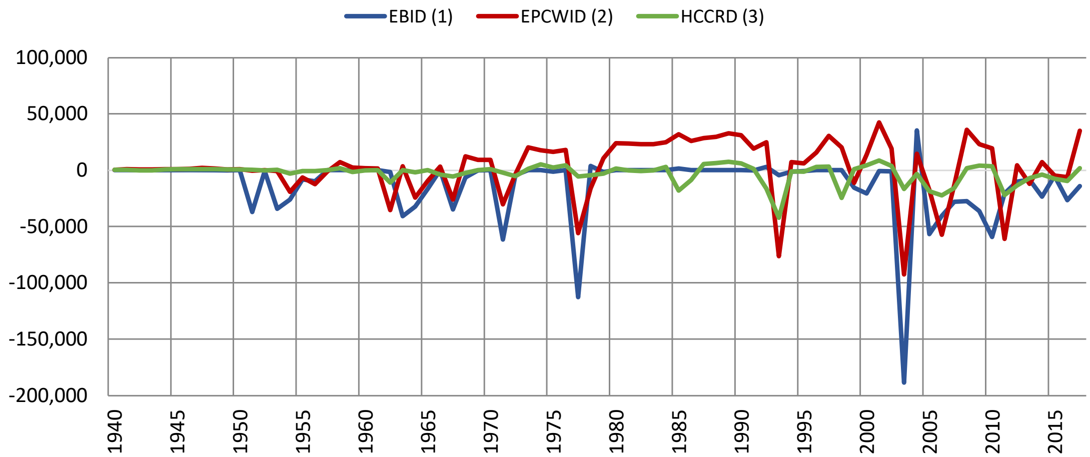
Run 14c - TX WWTP Discharges Off

Simulated Differences in ILRG Model Outputs

Run 14c minus Run 1

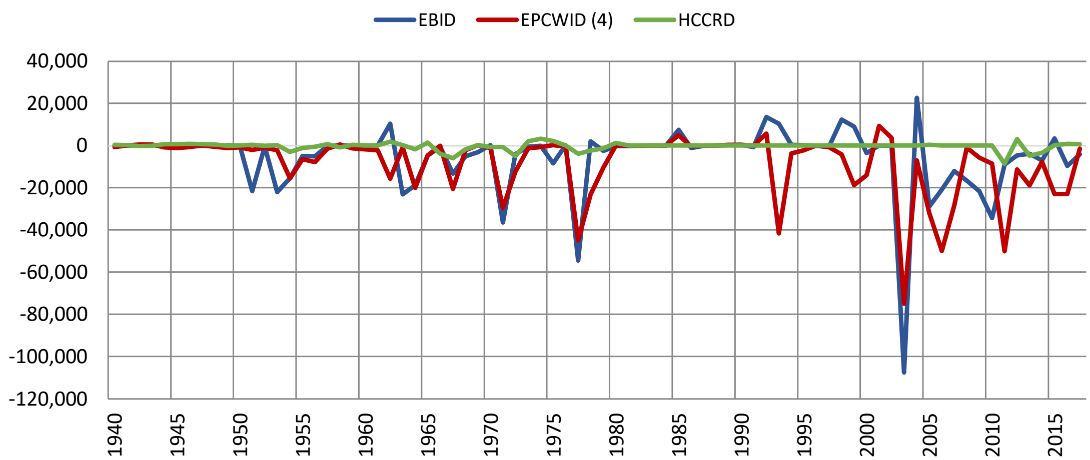
1940 - 2017 (acre-feet)

River Headgate (RHG) Diversions (Irrigation Season)



	Average Difference		
Period	EBID	EPCWID	HCCRD
1951-2017	-14,585	2,590	-3,357
1951-1978	-15,193	-4,297	-1,180
1979-2005	-9,307	12,003	-3,751
2006-2017	-25,040	-2,515	-7,548
1985-2017	-16,672	4,993	-5,810
1985-2005	-11,891	9,284	-4,816

Farm Headgate (FHG) Deliveries (Irrigation Season)



	Average Difference		
Period	EBID	EPCWID	HCCRD
1951-2017	-6,584	-9,484	-476
1951-1978	-8,228	-7,846	-716
1979-2005	-2,595	-6,912	15
2006-2017	-11,725	-19,094	-1,021
1985-2017	-6,288	-12,272	-363
1985-2005	-3,182	-8,375	13

Notes:

(1) EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

(2) EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

(3) HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

(4) EPCWID FHG values include deliveries to Rogers WTP and R/U WTP.

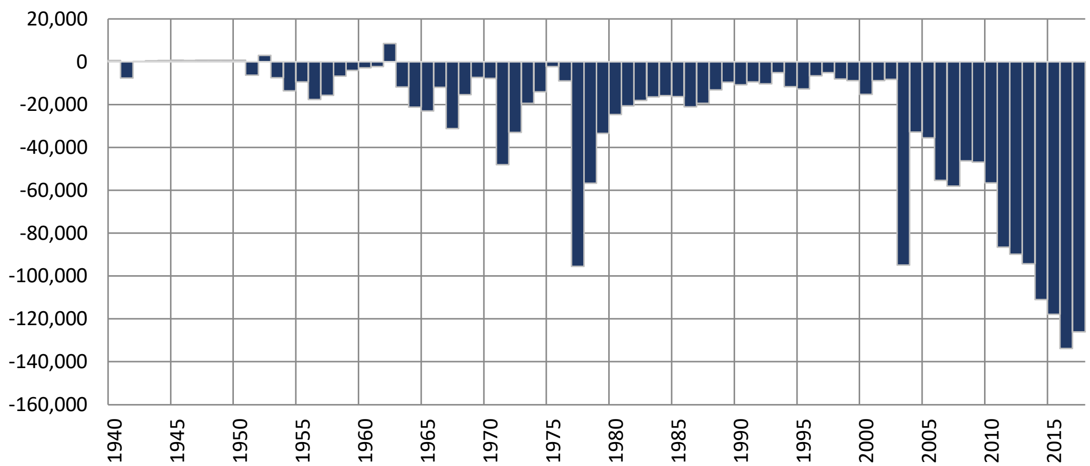
Run 14c - TX WWTP Discharges Off

Simulated Differences in ILRG Model Outputs

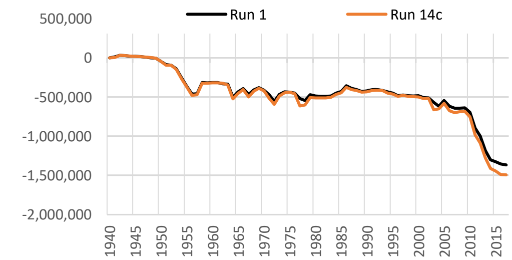
Run 14c minus Run 1

1940 - 2017 (acre-feet)

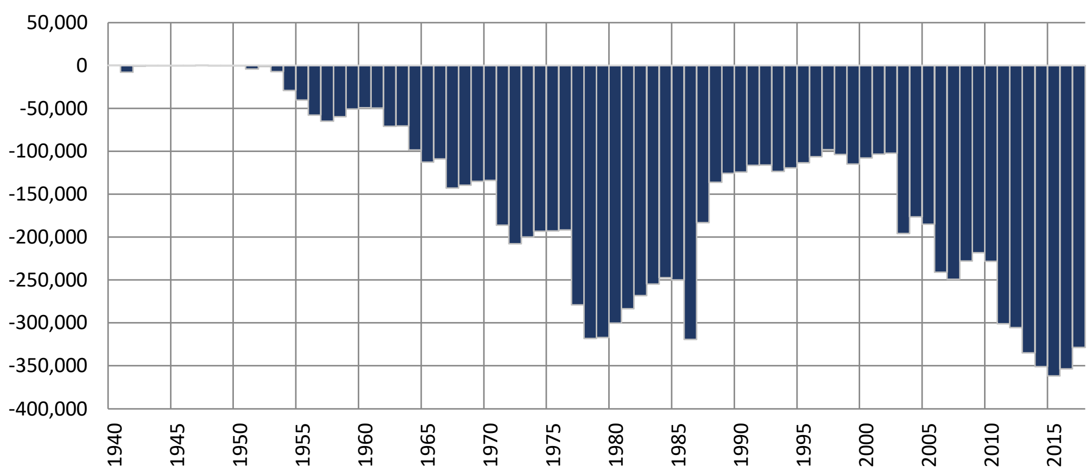
Cumulative Annual Rincon-Mesilla Groundwater Storage



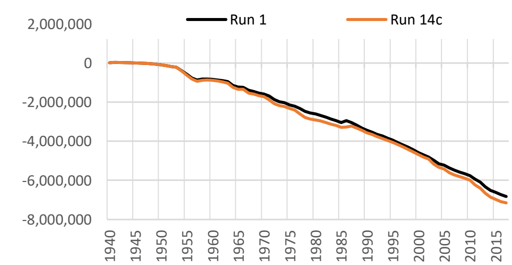
Period	Average Difference
1951-2017	-1,891
1951-1978	-2,049
1979-2005	782
2006-2017	-7,537
1985-2017	-3,336
1985-2005	-936



Cumulative Annual Hueco Groundwater Storage



Period	Average Difference
1951-2017	-4,896
1951-1978	-11,352
1979-2005	4,937
2006-2017	-11,956
1985-2017	-2,458
1985-2005	2,970



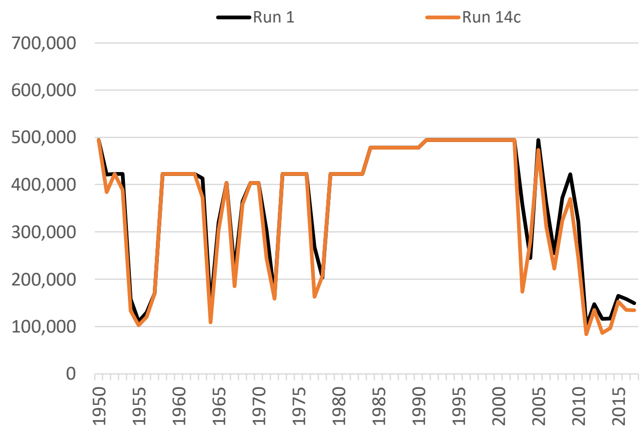
Notes:

Cumulative storage change in alluvial and non-alluvial aquifers.

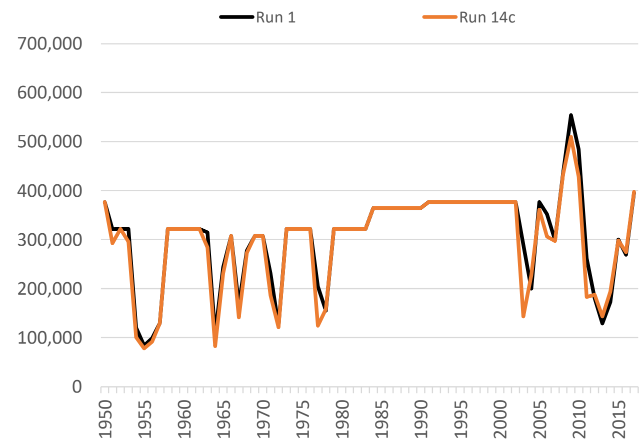
Average differences calculated as (Final Storage - Initial Storage)/(no. years).

Run 14c - TX WWTP Discharges Off
Annual Allocation and Charges
Run 14c v. Run 1
ILRG Model
1950 - 2017 (acre-feet)

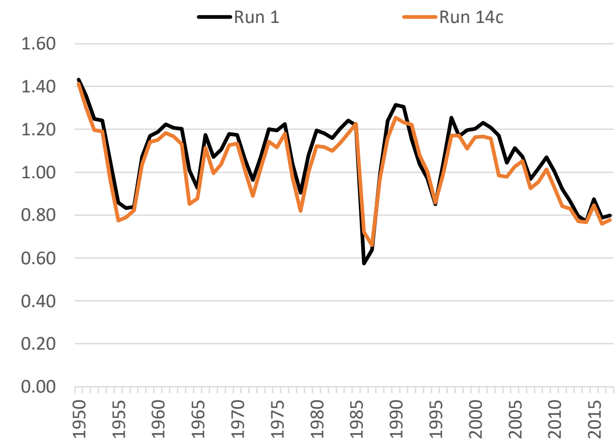
Total Allocation - EBID



Total Allocation - EPCWID

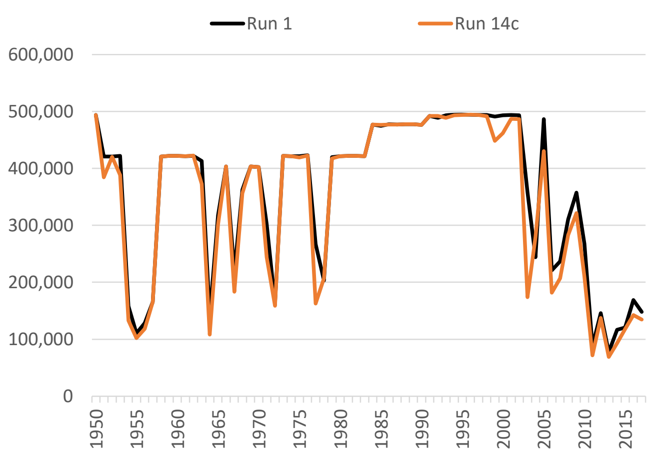


Diversion Ratio

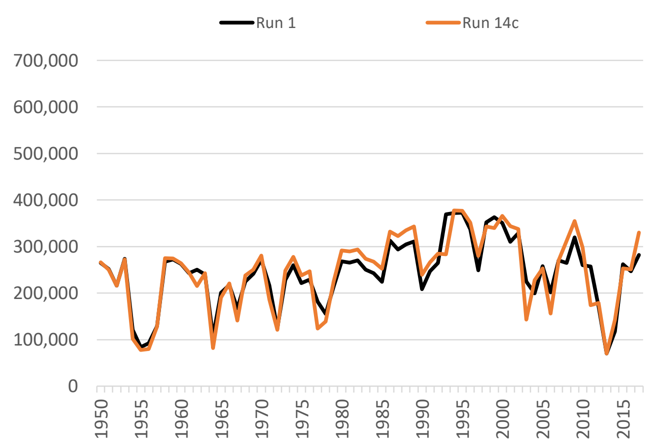


Note:
Computed as Total Charges/Caballo Release.

Annual Delivery Charges - EBID

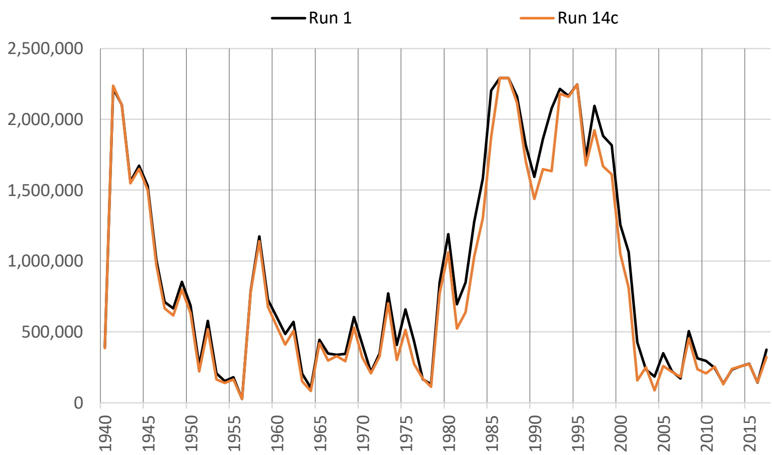


Annual Delivery Charges - EPCWID

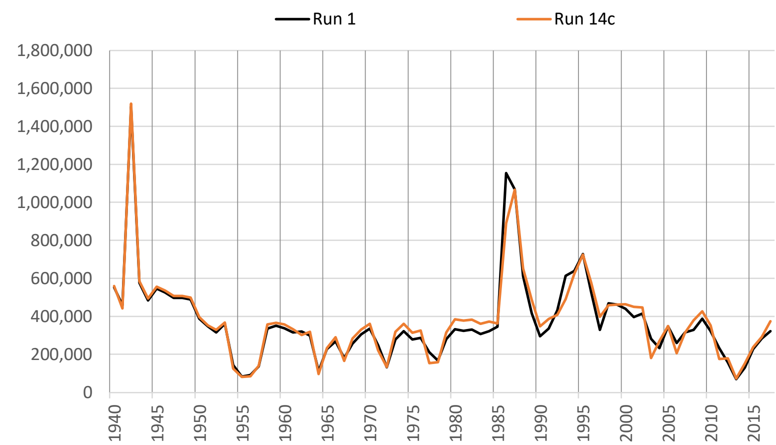


Run 14c - TX WWTP Discharges Off
Annual Summary of Project Storage and Rio Grande Flows
Run 14c v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

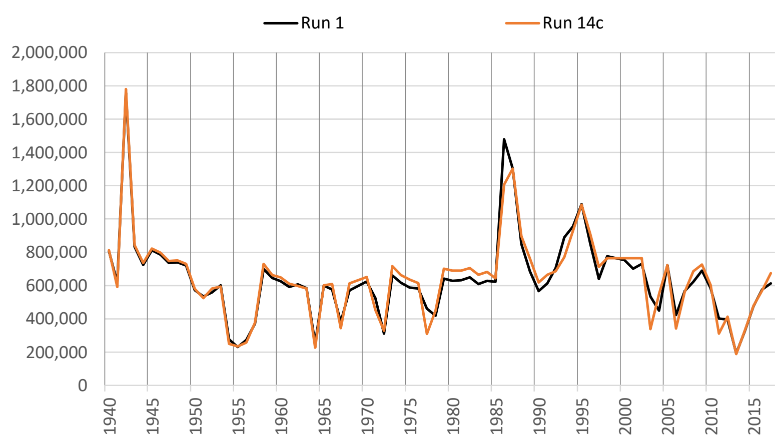
Total Year-End Project Reservoir Storage



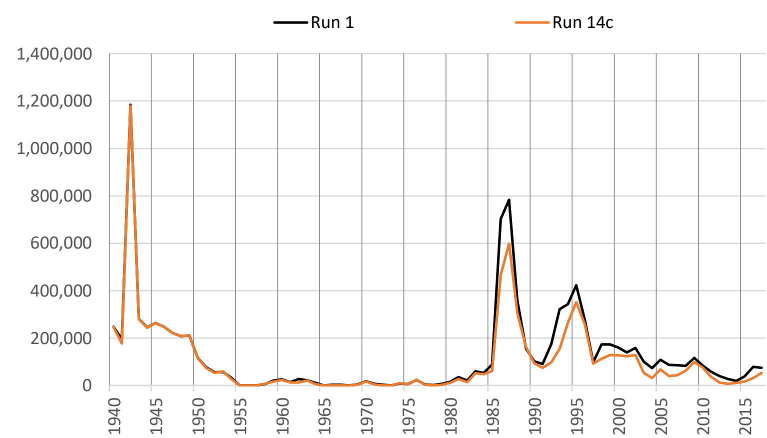
Rio Grande at El Paso



Rio Grande Below Caballo



Rio Grande at Fort Quitman

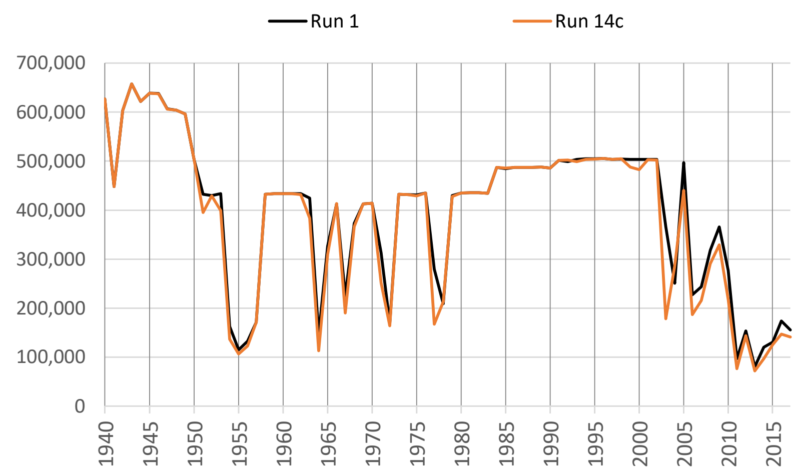


***Note different scales.**

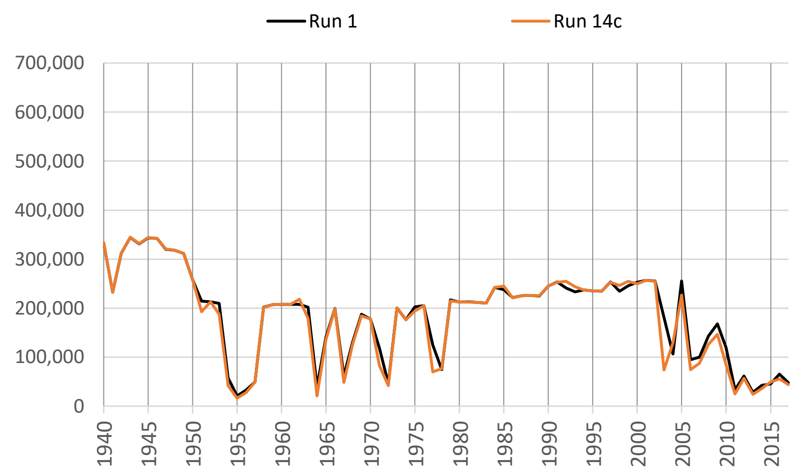
Run 14c - TX WWTP Discharges Off
Irrigation Season Summary of Irrigation Operations
Run 14c v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

EBID Total

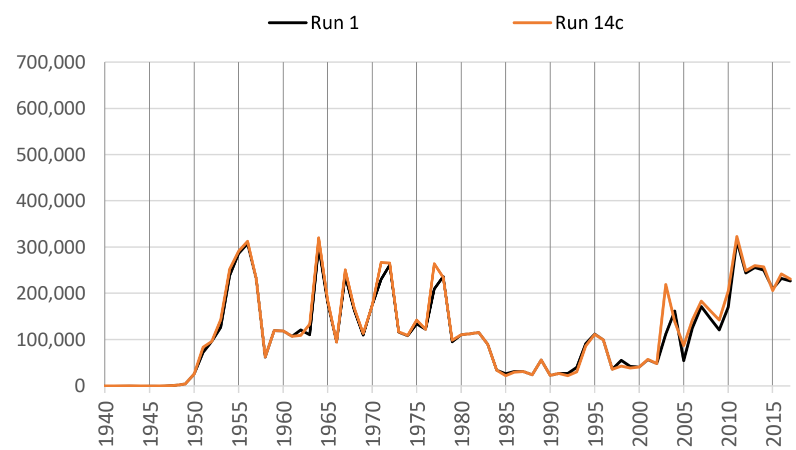
Net River Headgate Diversions



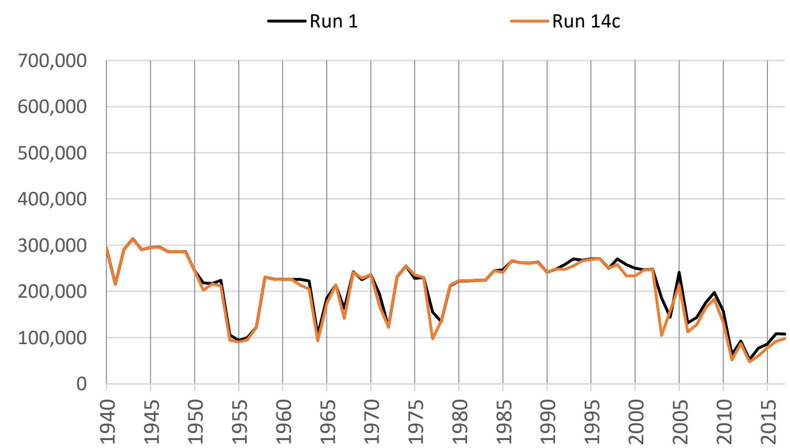
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries

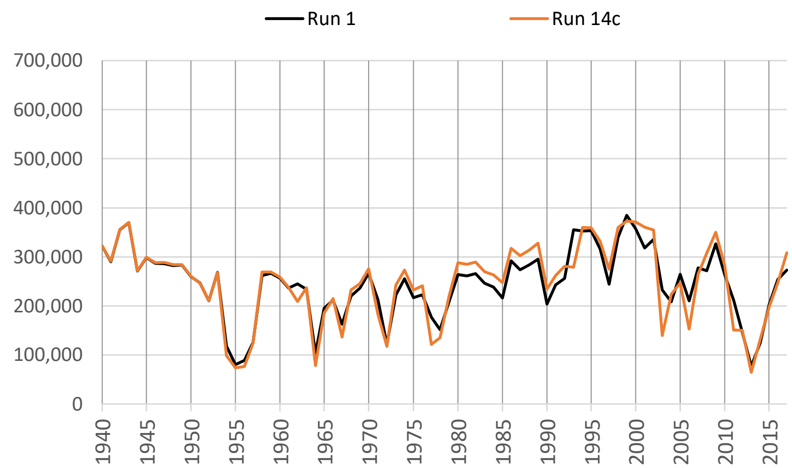


Notes: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).
Pumping includes Supplemental and Primary groundwater pumping.

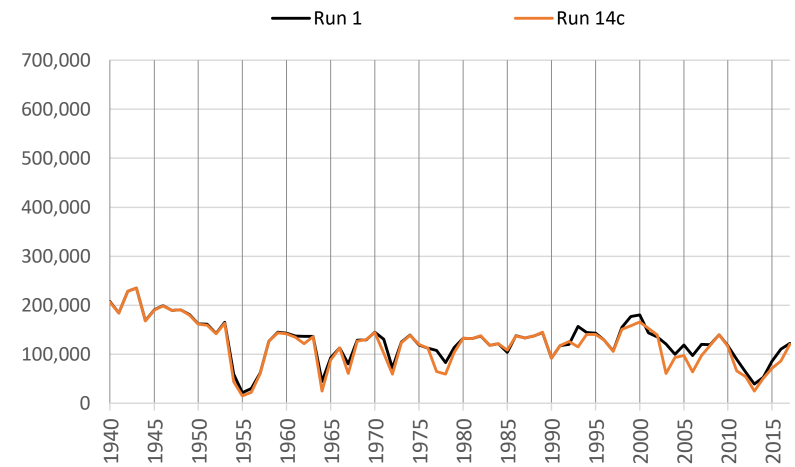
Run 14c - TX WWTP Discharges Off
Irrigation Season Summary of Irrigation Operations
Run 14c v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

EPCWID Total

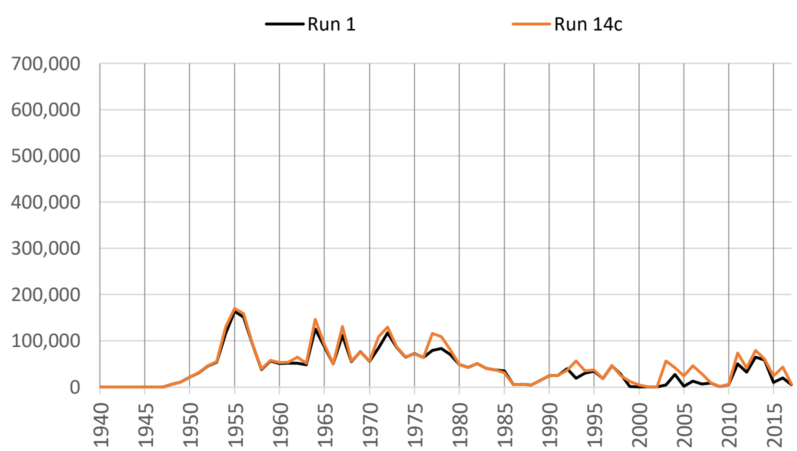
Net River Headgate Diversions



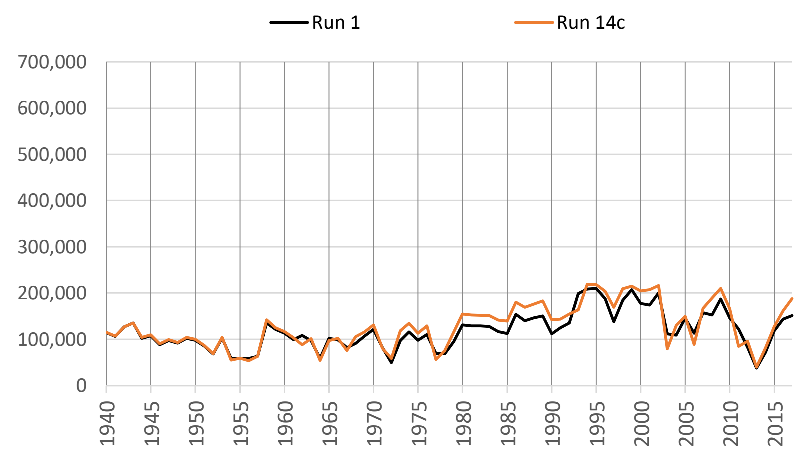
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries

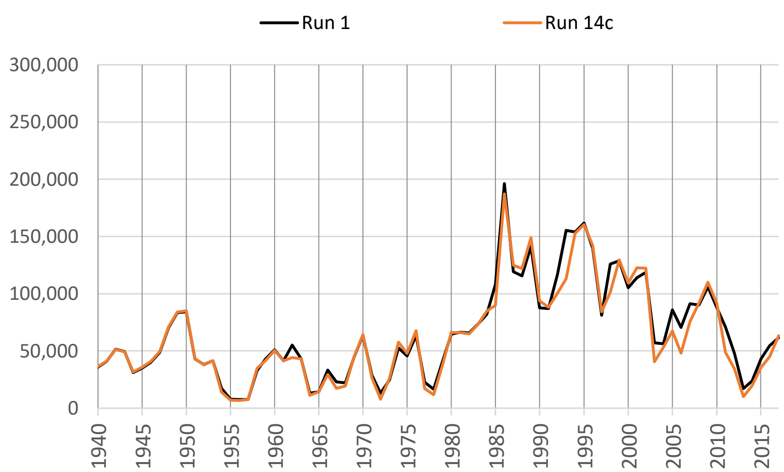


Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

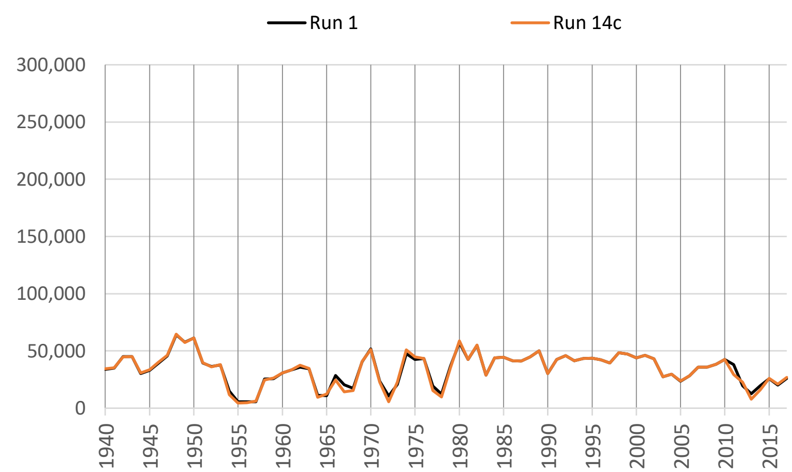
Run 14c - TX WWTP Discharges Off
Irrigation Season Summary of Irrigation Operations
Run 14c v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

HCCRD Total

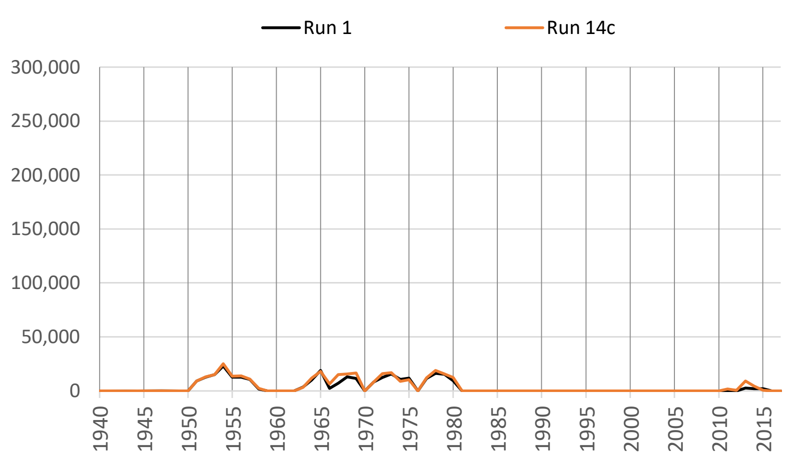
Net River Headgate Diversions



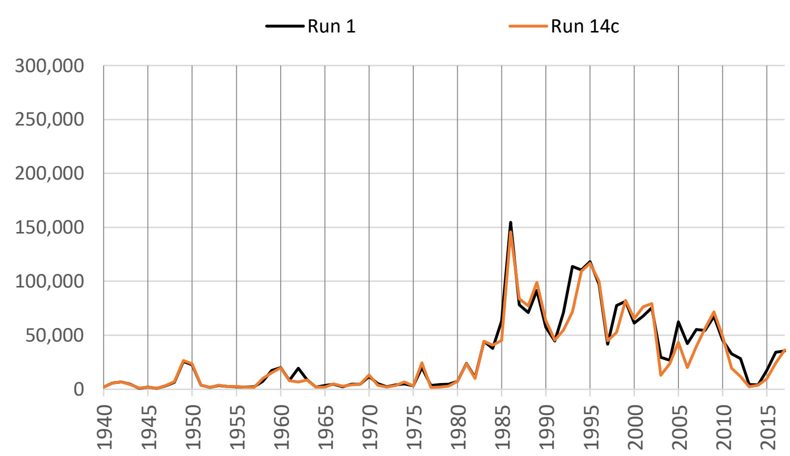
Farm Headgate Deliveries



Pumping



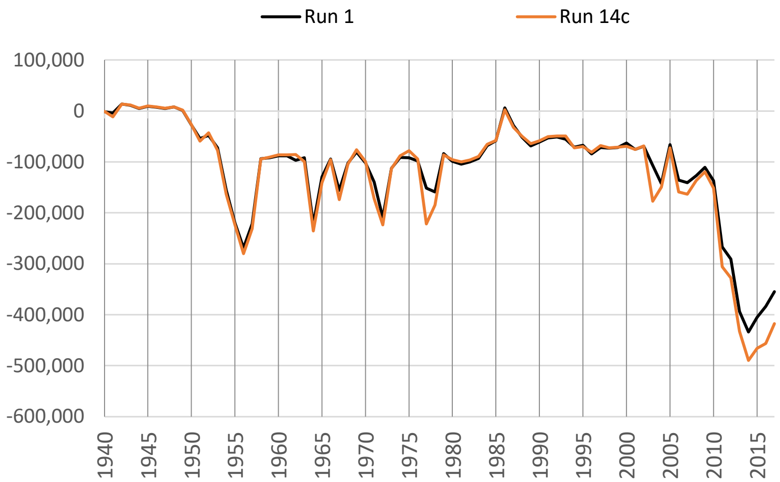
RHG Diversions - FHG Deliveries



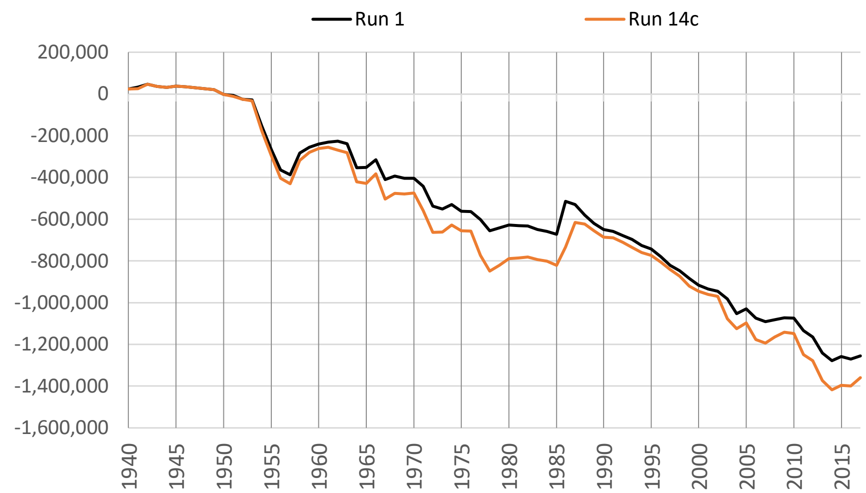
Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

Run 14c - TX WWTP Discharges Off
Cumulative Change in Ground Water Storage
Run 14c v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

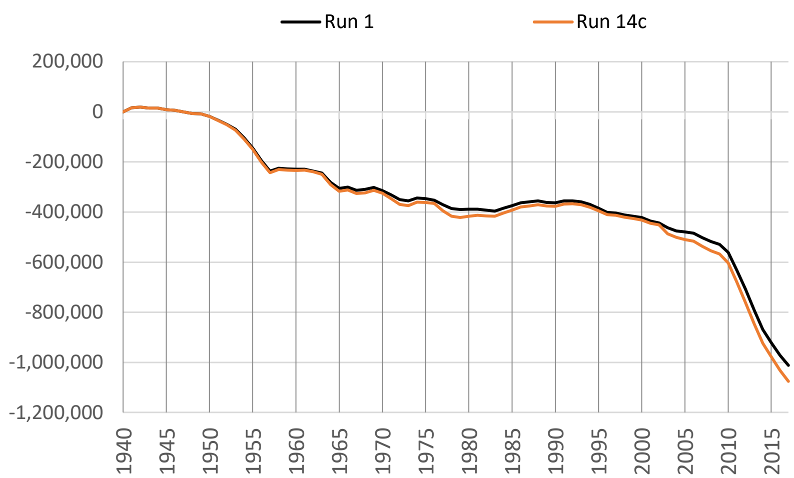
Rincon-Mesilla Alluvial Aquifer



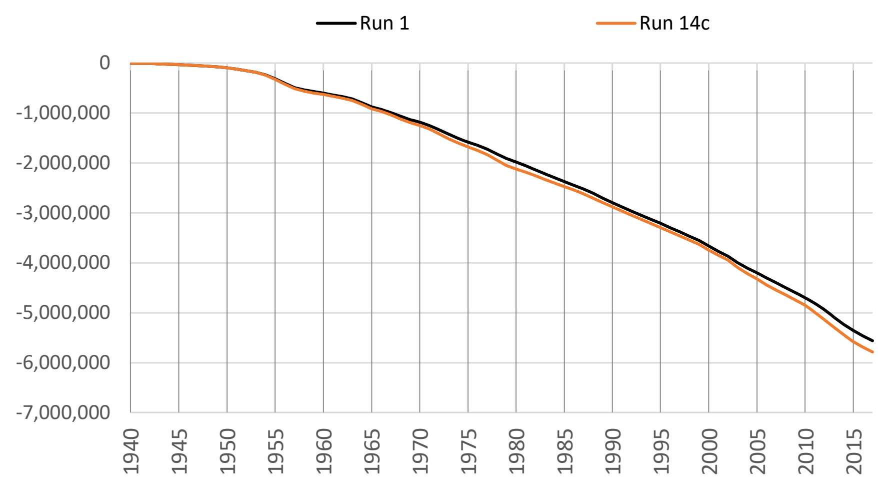
Hueco Alluvial Aquifer



Rincon-Mesilla Non-Alluvial Aquifer

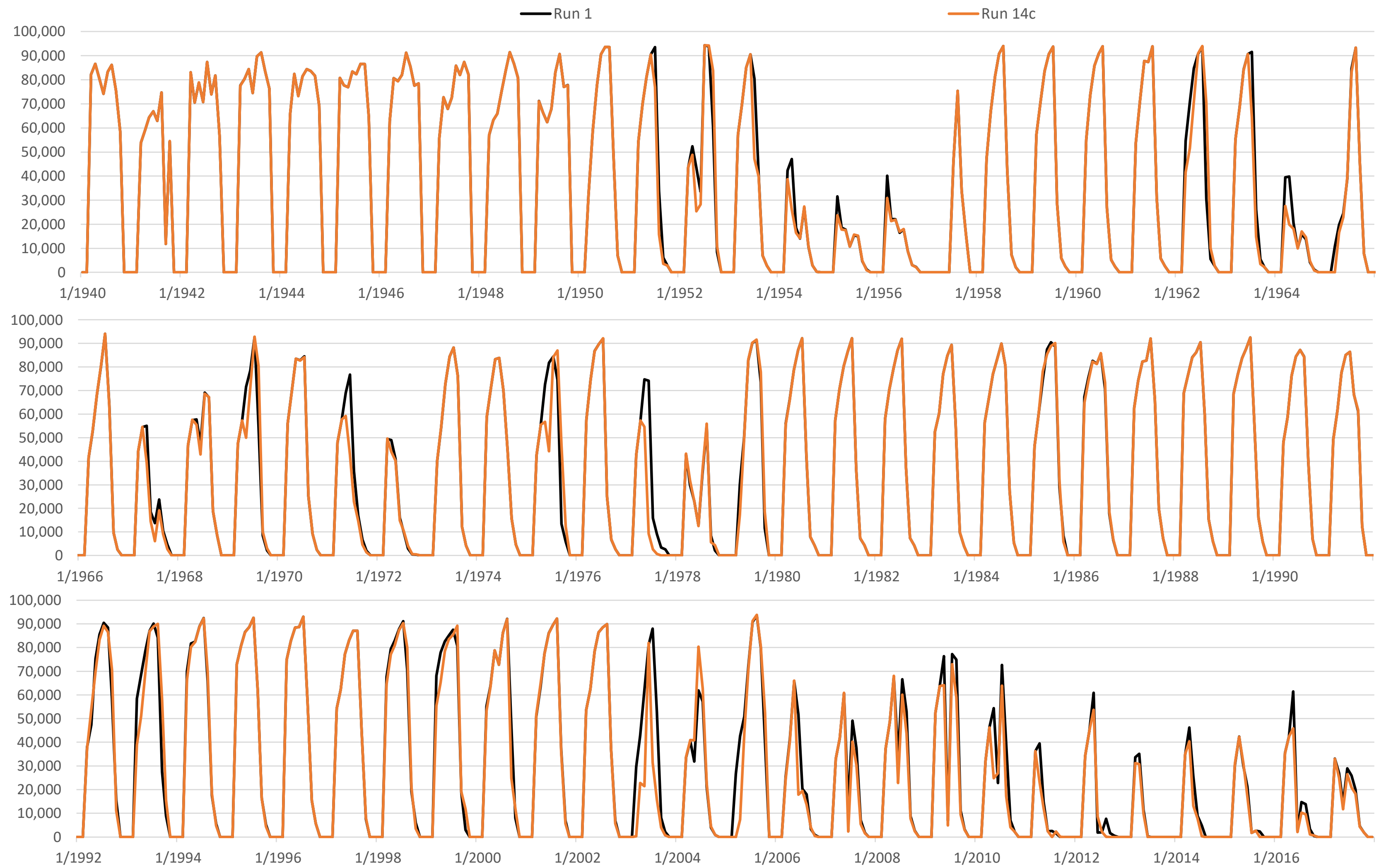


Hueco Non-Alluvial Aquifer



***Note different scales.**

Run 14c - TX WWTP Discharges Off
Monthly Net RHG Diversions
Run 14c v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
EBID Total



Note: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

Run 14c - TX WWTP Discharges Off

Monthly Net RHG Diversions

Run 14c v. Run 1

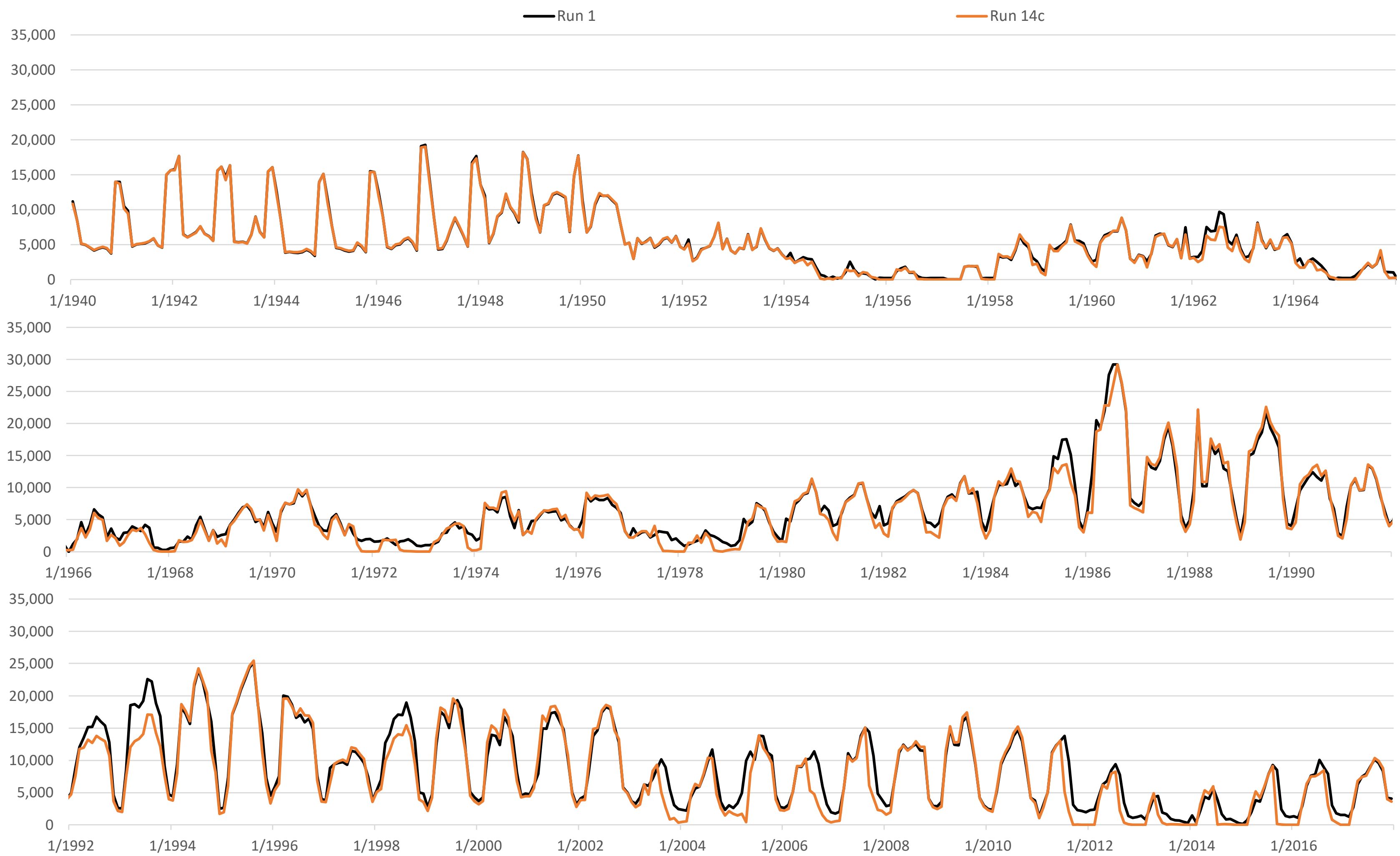
ILRG Model

1940 - 2017 (acre-feet)

EPCWID Total

Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

Run 14c - TX WWTP Discharges Off
Monthly Net RHG Diversions
Run 14c v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
HCCRD Total



Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

Run 14c - TX WWTP Discharges Off

End of Month Reservoir Storage (Elephant Butte + Caballo)

Run 14c v. Run 1

ILRG Model

1940 - 2017 (acre-feet)

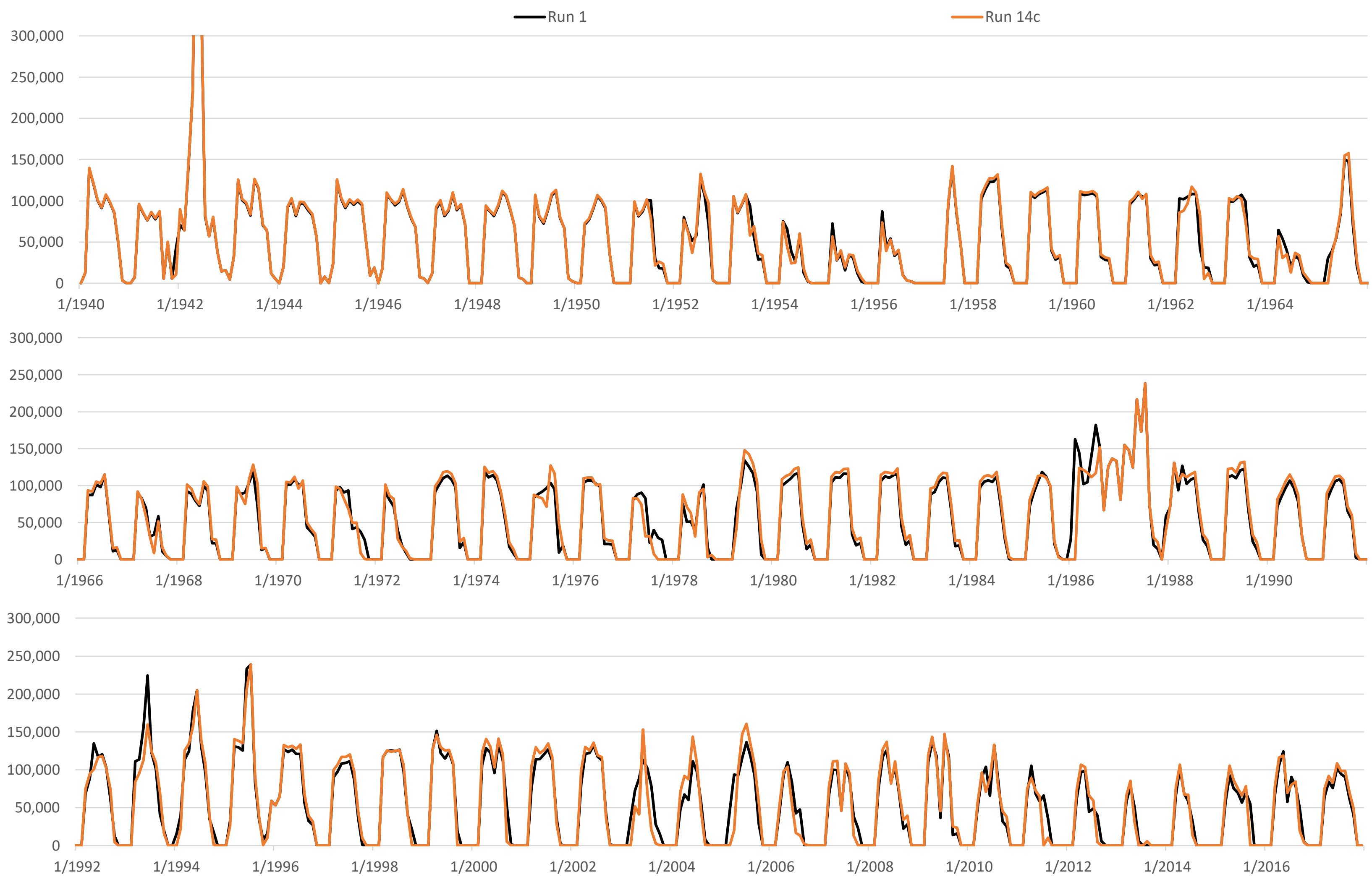
Run 14c - TX WWTP Discharges Off

Monthly Caballo Releases

Run 14c v. Run 1

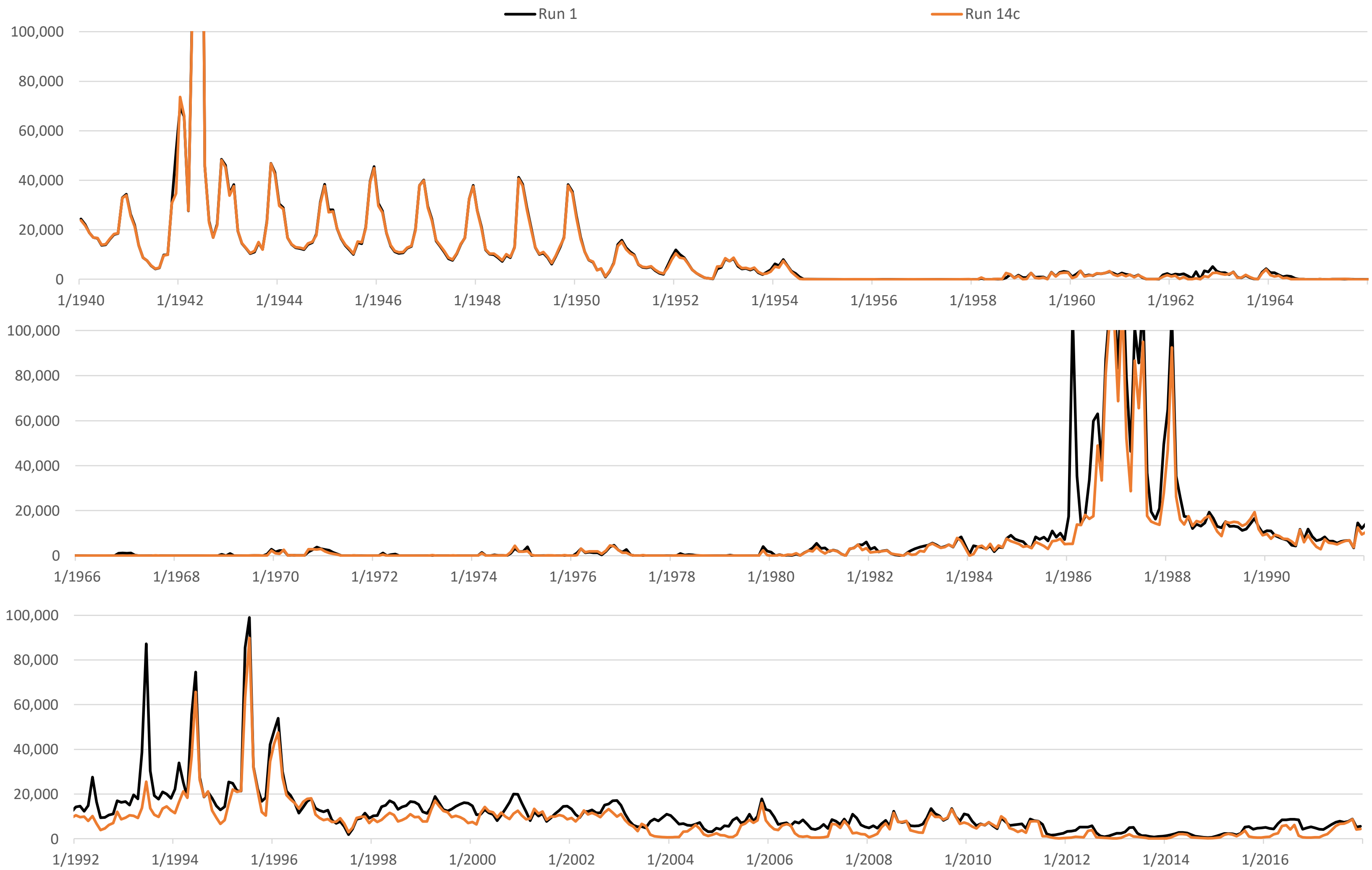
ILRG Model

1940 - 2017 (acre-feet)



Run 14c - TX WWTP Discharges Off
Monthly Rio Grande at El Paso Flow
Run 14c v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

Run 14c - TX WWTP Discharges Off
Monthly Rio Grande at Fort Quitman Flow
Run 14c v. Run 1
ILRG Model
1940 - 2017 (acre-feet)



Appendix 30R

Comparison of ILRG Model Runs
Run 14d v. Run 1

Model Run Specifications

Model Version: LRG_v116

Name: **Run 14d - TX Hueco Pumping Off (Returns Left On)**

Run ID: LRG_v116_Operational_Run14d
Date: 8/27/2020

Name: **Run 1 - Historical Base Run (All Pumping On)**

Run ID: LRG_v116_Operational_Run1
Date: 8/23/2020

Selected Model Inputs

Pumping and Returns	Run 14d	Run 1
Irrigation Pumping	TX Hueco Off	On
Irrigated Area	Hist	Hist
Non-Irrigation Pumping	TX Hueco Off	On
Non-Irrigation Pumping Returns	On	On
Las Cruces Jornada Pumping Returns	On	On

Project Allocation Rules		
1950-2005	D1/D2	D1/D2
2006-2007	D3	D3
2008-2017	D3 + CO	D3 + CO

EPCWID Operations		
Charge EPCWID for Use of WWTP Returns	Off	Off
ACE and Haskell Credits for EPCWID	On	On
Increased EPCWID Use of Fabens Drain Flows	Off	Off
Charge EPCWID for Fabens Drain Flow Use	Off	Off

Run 14d - TX Hueco Pumping Off (Returns Left On)

Comparison of ILRG Model Runs

Run 14d v. Run 1

1951 - 2017 Annual Average

(1,000 acre-feet)

Run No.	1	14d	14d - 1		
Simulated Input or Output	**Run 1**	**Run 14d**	**Run 14d minus Run 1**		
Pumping Stress					
Irrigation Pumping	44.3	0.0	-44.3		
Non-Irrigation Pumping	181.0	118.4	-62.6		
WWTP Flows	58.0	58.0	0.0		
Urban Deep Percolation	13.1	13.1	0.0		
Total Stress	154.2	47.3	-106.9		
	Stress is Pumping minus WWTP and Urban Deep Perc				
Effects of Pumping Stress				***% Chg***	
FHG Deliveries (Mar - Oct)				***Stress***	***% Diff.***
EBID	167.6	170.2	2.5	*-2%*	*2%*
EPCWID (incl. EPW)	139.9	142.7	2.9	*-3%*	*2%*
HCCRD	32.8	34.6	1.7	*-2%*	*5%*
Total	340.3	347.5	7.1	*-7%*	*2%*
FHG Deliveries (Nov - Feb)					
EBID	0.0	0.0	0.0	*0%*	*-3%*
EPCWID (incl. EPW)	0.2	0.2	0.0	*0%*	*5%*
HCCRD	2.4	2.3	-0.1	*0%*	*-3%*
Total	2.6	2.5	-0.1	*0%*	*-2%*
Irrigation Pumping					
EBID	140.4	138.0	-2.5	*2%*	*-2%*
EPCWID (Mesilla Valley)	7.4	7.1	-0.2	*0%*	*-3%*
EPCWID (El Paso Valley)	40.1	0.0			
HCCRD	4.2	0.0			
Total	147.8	145.1	-2.7	*3%*	*-2%*
	Pumping turned off.	*Other values are simulated responses and are totaled.*			
Other Inflows/Outflows					
Net Reservoir Evaporation	125.3	128.1	2.8	*-3%*	*2%*
Riparian ET	70.9	76.4	5.6	*-5%*	*8%*
River Evaporation + Incidental Canal Loss	30.3	30.3	-0.1	*0%*	*0%*
Total	226.6	234.8	8.3	*-8%*	*4%*
Rio Grande at Fort Quitman					
Reservoir Spills	33.3	36.4	3.1	*-3%*	*9%*
Nov-Feb Flows	21.4	31.6	10.2	*-10%*	*48%*
Mar - Oct Flows	41.1	54.6	13.6	*-13%*	*33%*
Underflow (GW Model)	0.2	0.3	0.1	*0%*	*24%*
Total	96.0	122.9	26.9	*-25%*	*28%*

Run 14d - TX Hueco Pumping Off (Returns Left On)

Comparison of ILRG Model Runs

Run 14d v. Run 1

1951 - 2017 Annual Average

(1,000 acre-feet)

Run No.	1	14d	14d - 1		
Simulated Input or Output	**Run 1**	**Run 14d**	**Run 14d minus Run 1**		
Effects of Pumping Stress (continued)				*% Chg*	
Change in Storage				*Stress*	*% Diff.*
Reservoir Storage	-4.7	-5.1	-0.5	*0%*	*10%*
Alluvial GW Storage (RW Model)	-23.6	-16.1	7.5	*-7%*	*-32%*
Non-alluvial GW Storage (GW Models)	-96.4	-47.6	48.8	*-46%*	*-51%*
Soil Moisture Storage	0.6	0.6	0.0	*0%*	*5%*
Total	-124.0	-68.2	55.8	*-52%*	*-45%*
Summary of Effects					
FHG Deliveries (Mar-Oct)	340.3	347.5	7.1	*-7%*	*2%*
FHG Deliveries (Nov-Feb)	2.6	2.5	-0.1	*0%*	*-2%*
Irrigation Pumping	147.8	145.1	-2.7	*3%*	*-2%*
Riparian ET + Evaporation	226.6	234.8	8.3	*-8%*	*4%*
Fort Quitman Flow	96.0	122.9	26.9	*-25%*	*28%*
Change in Storage	-124.0	-68.2	55.8	*-52%*	*-45%*
Total	689.2	784.7	95.5	*-89%*	*14%*
Other Effects of Pumping Stress				*% Chg*	
Rio Grande at El Paso				*Stress*	*% Diff.*
Reservoir Spills	49.4	49.3	-0.1	*0%*	*0%*
Nov-Feb Flows	22.8	22.8	0.0	*0%*	*0%*
Mar - Oct Flows	263.8	261.3	-2.4	*2%*	*-1%*
Total	336.0	333.5	-2.5	*2%*	*-1%*
Rio Grande below Caballo					
Reservoir Spills	65.9	64.8	-1.1	*1%*	*-2%*
Nov-Feb Flows	0.5	0.5	0.0	*0%*	*-4%*
Mar - Oct Flows	541.3	540.1	-1.1	*1%*	*0%*
Total	607.6	605.4	-2.2	*2%*	*0%*
Surface Water Diversions (Mar - Oct)					
EBID	366.5	370.9	4.4	*-4%*	*1%*
EPCWID (incl. EPW)	236.8	233.7	-3.1	*3%*	*-1%*
HCCRD	67.5	72.4	4.9	*-5%*	*7%*
Total	670.8	677.0	6.2	*-6%*	*1%*
Surface Water Diversions (Nov - Feb)					
EBID	0.0	0.0	0.0	*0%*	*0%*
EPCWID (incl. EPW)	14.3	14.4	0.1	*0%*	*0%*
HCCRD	14.2	16.5	2.3	*-2%*	*16%*
Total	28.5	30.9	2.4	*-2%*	*8%*

Run 14d - TX Hueco Pumping Off (Returns Left On)
Annual Differences in ILRG Model Outputs
Run 14d minus Run 1
1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1940	-52	-52	-996	1,239	-595	790	-37	-38	1,198	1,432	-496	-496	-10,994	-10,492	7,603
1941	-194	-194	-1,744	-531	-357	180	1	3	-170	241	-314	-223	9,572	6,548	13,619
1942	-19	-19	-1,416	-585	259	186	8	9	-706	134	134	157	-1,564	1,203	12,130
1943	9	9	-1,390	-654	82	352	-26	-26	-469	-225	147	478	-4,537	-4,387	4,071
1944	26	26	-1,218	-1,057	-295	-159	-16	-16	252	475	-235	-12	-4,811	-4,659	4,180
1945	19	19	-1,274	-816	-370	-186	-19	-19	195	583	-339	-169	-4,706	-4,626	3,671
1946	11	11	-1,537	-869	-285	-212	-28	-29	32	730	-266	-303	-4,936	-4,842	3,266
1947	22	22	-1,963	-1,369	-362	-517	-21	-21	-280	514	-308	-327	-5,356	-5,262	3,059
1948	30	30	-2,601	-1,961	161	442	-25	-26	-31	527	282	105	-6,591	-6,421	5,103
1949	35	35	-2,996	-2,419	1,191	2,191	-16	-16	236	520	-115	-232	-6,253	-6,184	8,410
1950	2	2	-4,409	-4,465	1,377	2,071	-56	-56	14	72	-13	-22	-6,381	-6,221	8,690
1951	1,020	1,020	-4,745	-5,292	1,368	1,968	609	609	373	383	1,524	1,120	-6,357	-6,285	17,938
1952	402	402	-6,032	-6,597	1,744	2,586	1,507	1,504	47	42	1,567	905	-17,218	-13,142	16,824
1953	346	346	-8,284	-8,871	2,815	4,200	2,536	2,535	153	149	3,247	3,674	-7,518	-9,703	27,063
1954	-341	-341	302	251	2,764	4,949	5,454	5,454	6,790	6,788	3,317	5,153	-5,343	3,261	20,679
1955	29,567	29,567	21,954	22,140	8,299	11,291	15,081	15,081	22,401	22,444	7,826	10,480	52,340	23,908	18,235
1956	-2,641	-2,641	-128	193	7,219	9,550	-4,267	-4,267	3,956	3,789	6,669	8,335	-7,036	-2,574	8,336
1957	31	31	-8,792	-8,299	1,138	4,581	54	54	1,774	1,620	1,806	3,451	-10,680	-8,418	5,320
1958	-17	-17	-22,237	-21,901	6,040	11,098	-20	-20	-1,449	-1,546	-1,522	-91	-32,538	-25,883	34,009
1959	0	0	-13,508	-13,730	4,881	8,131	-15	-15	-313	-312	403	682	-19,553	-17,850	36,981
1960	3	3	-11,581	-11,852	3,406	5,419	-28	-28	-447	-447	0	0	-16,337	-15,722	31,073
1961	7	7	-10,743	-11,003	3,658	5,528	-31	-31	1,116	1,116	1,402	-703	-15,416	-14,842	34,125
1962	9	9	-9,576	-9,833	3,364	5,257	-17	-17	201	201	702	1,047	-14,581	-13,765	31,050
1963	8,879	8,879	-9,037	-9,306	3,217	4,799	4,814	4,815	118	120	1,971	1,878	-1,358	-5,109	31,773
1964	17,399	17,399	10,909	11,251	4,304	6,467	20,705	20,705	14,065	13,883	4,983	6,333	12,652	17,413	25,063
1965	35,664	35,664	10,617	10,428	7,888	11,200	18,071	18,071	19,889	19,648	8,417	10,758	34,892	15,957	28,458
1966	-82	-82	-11,352	-10,748	7,446	10,827	263	263	-118	40	-3,930	-6,341	-20,791	-11,119	37,547
1967	21,861	21,861	16,002	17,987	7,233	13,201	13,530	13,530	20,154	19,640	6,184	9,836	29,869	18,367	23,458
1968	-515	-515	-15,877	-14,426	10,276	16,206	-95	-95	520	122	8,693	8,690	-23,955	-12,719	25,817
1969	-4	-4	-14,775	-14,945	11,854	15,627	480	480	-270	-269	3,104	-1,268	-21,320	-17,523	36,217
1970	4	4	-12,455	-12,791	4,434	6,794	-9	-8	66	66	-1,274	-2,725	-17,327	-15,964	30,809
1971	33,445	33,445	-13,201	-12,596	5,715	9,219	20,592	20,592	76	79	5,200	7,909	878	-11,491	24,578
1972	7,404	7,404	5,199	5,841	11,387	15,478	-119	-119	5,812	5,658	7,841	7,583	16,792	6,838	27,677
1973	-323	-323	-17,178	-17,308	16,618	21,287	1,208	1,208	525	458	16,982	16,158	-33,152	-19,657	17,323
1974	-74	-74	-15,080	-15,225	14,449	19,815	407	407	558	560	-2,592	-4,322	-20,493	-17,771	44,849
1975	-253	-253	-12,738	-12,931	14,341	19,582	1,132	1,132	32	33	11,534	8,792	-17,398	-14,334	25,116
1976	-17	-17	-11,070	-11,307	10,954	16,918	708	708	16	16	-1,658	-5,532	-14,503	-13,903	34,717
1977	58,620	58,620	26,108	27,514	15,614	20,894	26,127	26,127	16,201	16,203	13,994	13,612	50,277	35,165	35,968
1978	19,319	19,319	8,312	10,652	5,628	11,868	10,376	10,376	16,431	16,435	7,399	7,593	25,996	16,106	29,436

Run 14d - TX Hueco Pumping Off (Returns Left On)
Annual Differences in ILRG Model Outputs
Run 14d minus Run 1
1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1979	-220	-220	-12,479	-12,048	6,190	11,315	899	900	801	821	4,319	1,934	-22,046	-10,642	38,530
1980	-82	-82	-12,549	-12,367	3,936	7,636	151	151	-7	151	-3,214	-6,867	-18,326	-13,877	54,196
1981	-43	-43	-10,791	-10,960	2,235	4,098	501	501	33	34	-56	-251	-13,841	-11,965	34,685
1982	-14	-14	-11,840	-11,891	1,936	3,711	59	59	-4	165	-403	-1,356	-14,588	-12,998	43,912
1983	-13	-13	-9,489	-9,621	4,401	6,238	42	42	-164	-72	0	0	-11,053	-10,246	33,839
1984	-13	-13	-9,546	-9,593	8,207	9,916	19	19	-5	229	0	0	-8,351	-8,075	29,315
1985	-60	-60	-8,472	-8,506	3,659	5,256	28	28	-207	56	0	0	-10,531	-9,622	27,085
1986	-32	-32	-4,005	-4,153	1,907	3,166	216	225	-37	-25	0	0	70,333	68,942	199,296
1987	-34	-34	-3,319	-3,471	426	1,218	13	14	-6	-4	0	0	-28	494	42,214
1988	-9	-9	-2,697	-2,850	477	1,213	54	54	0	1	0	0	-3,498	-2,377	18,065
1989	-8	-8	-4,043	-4,144	544	1,292	17	17	-74	9	0	0	-5,474	-4,831	14,034
1990	-42	-42	-5,429	-5,338	4,830	5,645	143	143	-70	305	0	0	-4,710	-4,092	17,383
1991	-24	-24	-7,080	-7,134	1,771	2,875	26	26	-248	-25	0	0	-6,944	-6,353	31,361
1992	2,639	2,639	69,785	69,633	34,315	36,215	-10,090	-10,102	33,107	33,182	0	0	33,627	39,824	53,137
1993	567	567	-10,585	-10,788	-551	945	775	770	-2,956	-2,963	0	0	-21,522	-24,620	9,905
1994	301	301	-1,135	-1,321	2,107	3,464	-172	-172	3,474	3,474	0	0	9,963	6,905	30,601
1995	490	490	-1,985	-2,001	1,413	2,988	13	12	2,385	2,667	0	0	-3,330	-2,359	24,745
1996	-50	-50	-5,656	-5,813	161	1,190	207	207	19	20	0	0	-7,859	-7,032	18,271
1997	-10	-10	-9,543	-9,549	2,997	4,024	-48	-48	-1,032	-744	0	0	-8,150	-7,905	24,360
1998	-8	-8	-6,852	-7,045	373	1,477	-1	-1	-180	-138	0	0	-9,032	-8,554	25,667
1999	111	111	-229	-347	604	1,084	9	9	1,642	1,645	0	0	0	-614	14,145
2000	-14	-14	-4,336	-4,404	-200	69	-1	-1	-1,541	-1,541	0	0	-4,486	-4,170	8,916
2001	-26	-26	-1,789	-1,868	252	494	-8	-8	2	2	0	0	-1,601	-1,532	8,842
2002	-17	-17	-1,770	-1,849	215	430	-4	-4	2	2	0	0	-1,528	-1,450	9,271
2003	18,515	18,515	-211	-233	430	798	11,529	11,529	1,315	1,320	0	0	10,713	3,607	9,387
2004	3,721	3,721	2,777	2,849	1,519	2,825	2,485	2,485	3,168	3,173	0	0	3,141	4,817	15,142
2005	115	115	-2,873	-2,927	1,325	2,100	234	233	163	164	0	0	-5,108	-2,233	14,707
2006	5,677	5,677	8,580	8,550	2,094	3,113	3,711	3,711	6,076	6,078	0	0	8,524	6,223	12,150
2007	3,364	3,364	2,181	2,216	2,156	3,130	1,652	1,652	3,928	3,930	0	0	5,047	3,878	13,377
2008	6,470	6,470	-4,337	-4,352	1,486	1,990	4,122	4,122	-782	-780	0	0	-4,376	-3,761	12,355
2009	6,009	6,009	-2,448	-2,518	213	509	2,681	2,681	-155	-153	0	0	-1,473	-1,888	10,515
2010	11,405	11,405	-2,033	-2,102	531	902	6,580	6,580	139	142	0	0	292	-1,648	10,015
2011	7,012	7,012	441	377	8,434	12,611	3,699	3,699	2,247	2,249	0	0	4,285	1,052	20,278
2012	-211	-211	51	-31	9,576	13,616	348	348	2,784	2,785	0	0	-947	-30	23,295
2013	-2,109	-2,109	-664	-735	6,210	8,863	-1,137	-1,137	2,090	2,090	5,149	6,831	-2,229	-618	17,427
2014	453	453	-699	-773	8,308	13,123	316	316	3,158	3,159	902	2,228	-1,185	-1,524	25,084
2015	-537	-537	-5,607	-5,674	3,078	5,306	-171	-171	54	54	-4,255	-3,626	-7,969	-5,706	30,366
2016	-574	-574	4,165	4,078	1,777	2,955	-25	-25	5,384	5,385	0	0	9,570	5,409	11,314
2017	3,816	3,816	-4,668	-4,770	518	1,189	1,914	1,914	-408	-407	0	0	-4,097	-4,883	7,654
Averages															
1951-2017	4,421	4,421	-3,137	-3,077	4,894	7,220	2,535	2,535	2,877	2,886	1,735	1,670	-2,208	-2,466	26,944
1951-1978	8,204	8,204	-4,607	-4,382	7,073	10,526	4,966	4,966	4,596	4,533	4,064	4,036	-3,542	-4,670	27,159
1979-2005	953	953	-2,820	-2,879	3,166	4,507	263	263	1,466	1,552	24	-242	-2,008	-1,147	31,519
2006-2017	3,398	3,398	-420	-478	3,698	5,609	1,974	1,974	2,043	2,044	150	453	454	-291	16,152
1985-2017	2,027	2,027	-439	-515	3,120	4,427	882	882	1,922	1,973	54	165	1,195	1,011	24,556
1985-2005	1,244	1,244	-450	-536	2,789	3,751	258	258	1,854	1,932	0	0	1,618	1,755	29,359

Notes:

EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

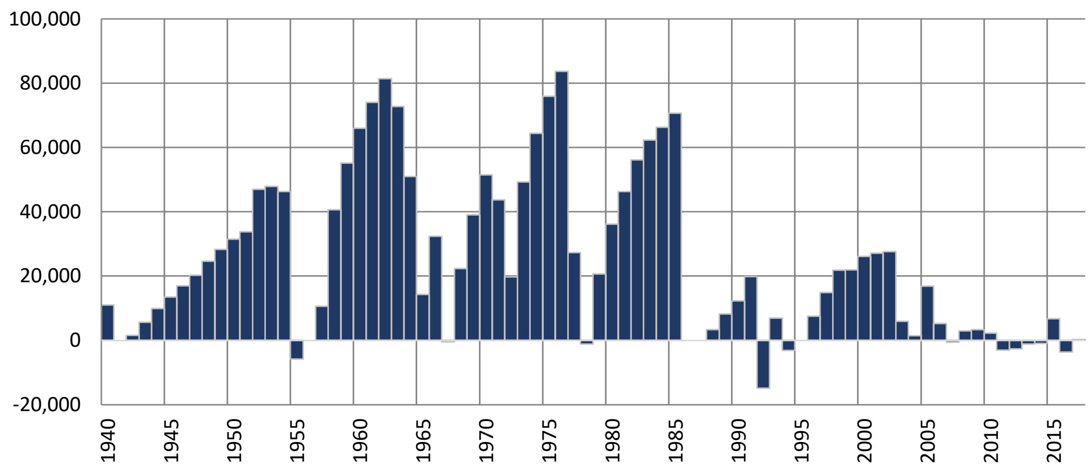
Run 14d - TX Hueco Pumping Off (Returns Left On)

Simulated Differences in ILRG Model Outputs

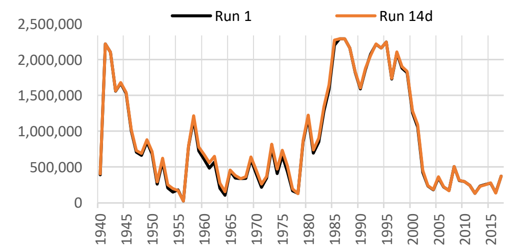
Run 14d minus Run 1

1940 - 2017 (acre-feet)

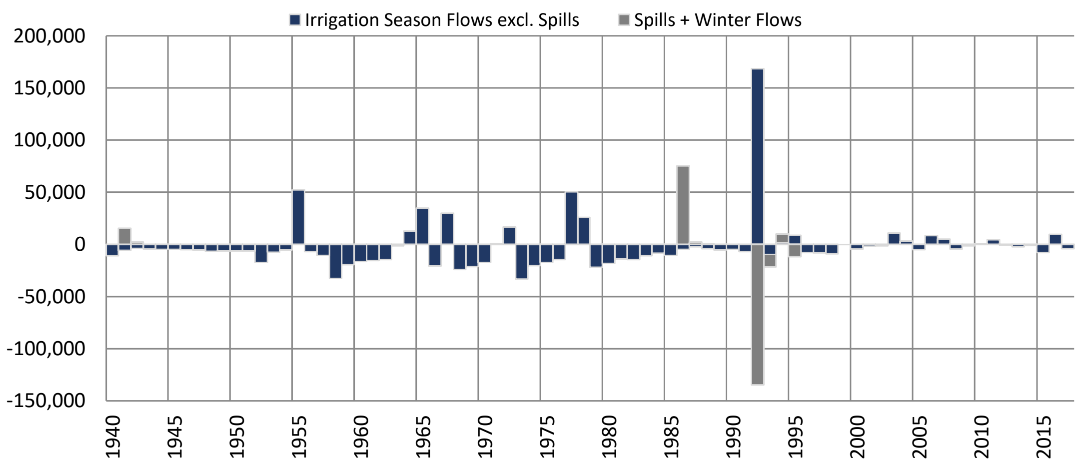
Total Project Storage (Year End)



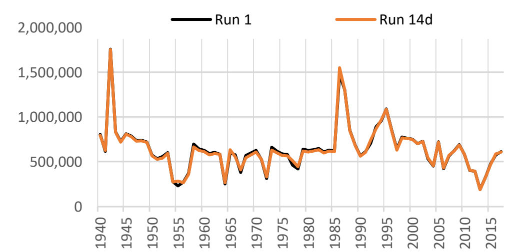
Period	Average Difference
1951-2017	-466
1951-1978	-1,167
1979-2005	668
2006-2017	-1,382
1985-2017	-1,999
1985-2005	-2,352



Caballo Reservoir Outflows (Annual)



	Average Difference		
Period	Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	-1,131	-1,077	-2,208
1951-1978	-3,542	0	-3,542
1979-2005	665	-2,673	-2,008
2006-2017	454	0	454
1985-2017	3,381	-2,187	1,195
1985-2005	5,055	-3,437	1,618



Notes:

Reservoir storage does not include storage attributed to SJC, CO, or NM credit waters.

Average differences calculated as (Final Storage - Initial Storage)/(no. years).

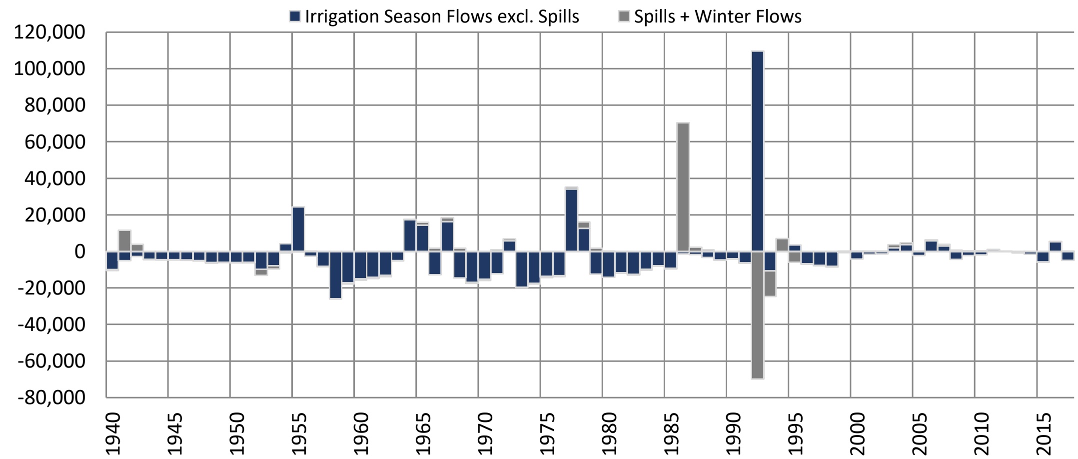
Run 14d - TX Hueco Pumping Off (Returns Left On)

Simulated Differences in ILRG Model Outputs

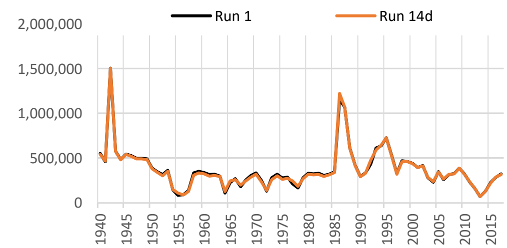
Run 14d minus Run 1

1940 - 2017 (acre-feet)

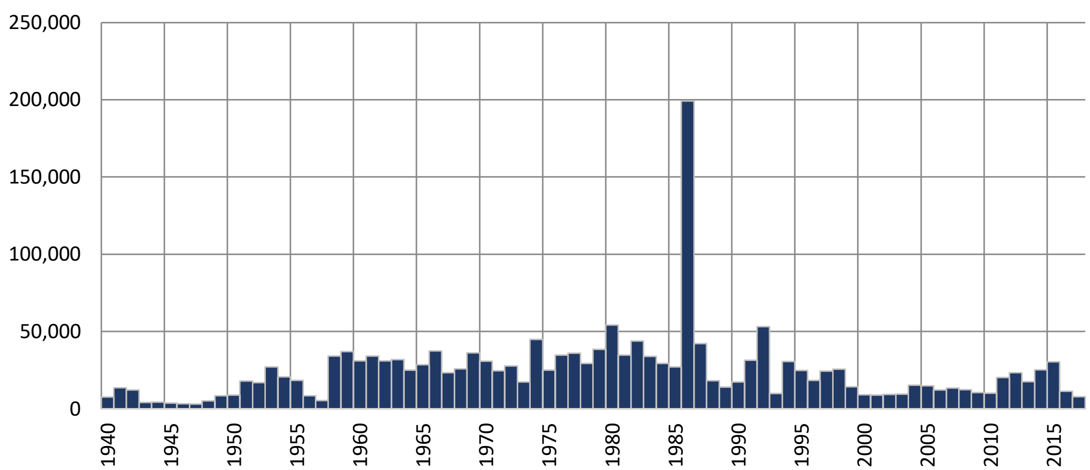
Rio Grande at El Paso (Annual)



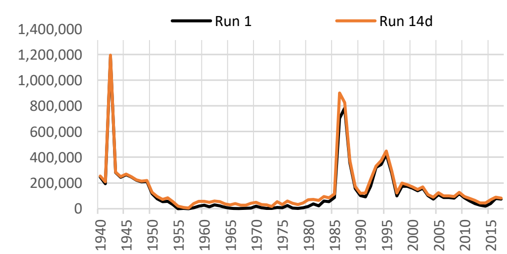
	Average Difference		
Period	Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	-2,432	-34	-2,466
1951-1978	-4,715	46	-4,670
1979-2005	-897	-250	-1,147
2006-2017	-560	268	-291
1985-2017	1,137	-127	1,011
1985-2005	2,107	-352	1,755



Rio Grande at Fort Quitman (Annual)



Period	Average Difference
1951-2017	26,892
1951-1978	27,084
1979-2005	31,472
2006-2017	16,140
1985-2017	24,532
1985-2005	29,328



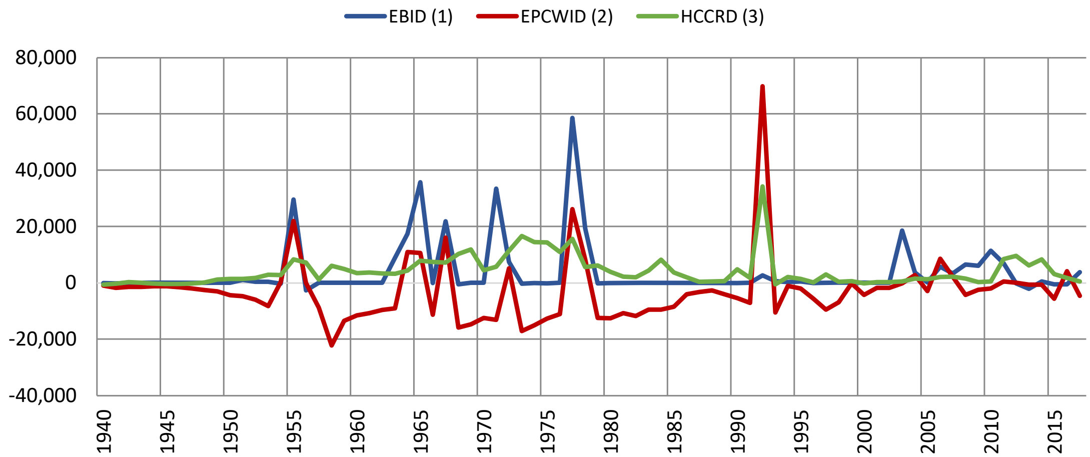
Run 14d - TX Hueco Pumping Off (Returns Left On)

Simulated Differences in ILRG Model Outputs

Run 14d minus Run 1

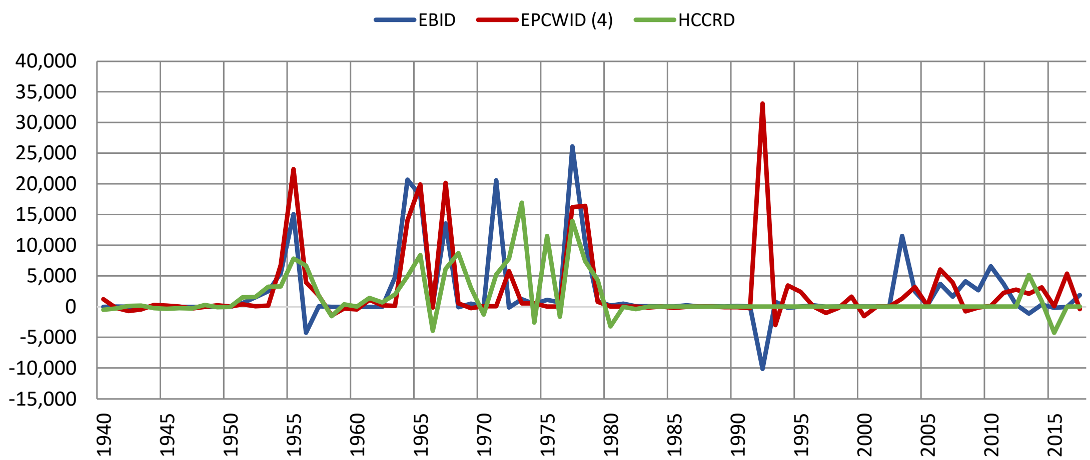
1940 - 2017 (acre-feet)

River Headgate (RHG) Diversions (Irrigation Season)



Average Difference			
Period	EBID	EPCWID	HCCRD
1951-2017	4,421	-3,137	4,894
1951-1978	8,204	-4,607	7,073
1979-2005	953	-2,820	3,166
2006-2017	3,398	-420	3,698
1985-2017	2,027	-439	3,120
1985-2005	1,244	-450	2,789

Farm Headgate (FHG) Deliveries (Irrigation Season)



Average Difference			
Period	EBID	EPCWID	HCCRD
1951-2017	2,535	2,877	1,735
1951-1978	4,966	4,596	4,064
1979-2005	263	1,466	24
2006-2017	1,974	2,043	150
1985-2017	882	1,922	54
1985-2005	258	1,854	0

Notes:

(1) EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

(2) EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

(3) HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

(4) EPCWID FHG values include deliveries to Rogers WTP and R/U WTP.

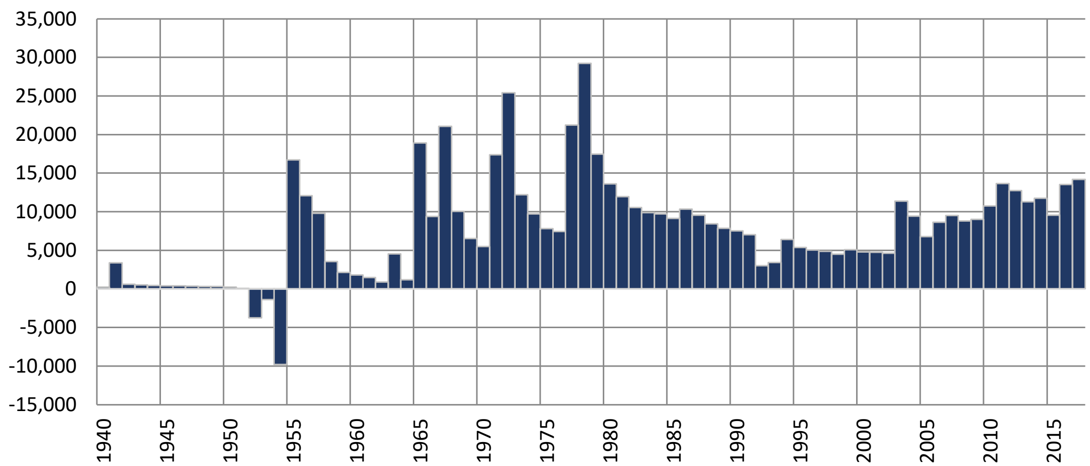
Run 14d - TX Hueco Pumping Off (Returns Left On)

Simulated Differences in ILRG Model Outputs

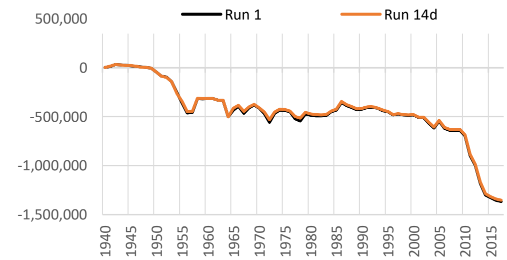
Run 14d minus Run 1

1940 - 2017 (acre-feet)

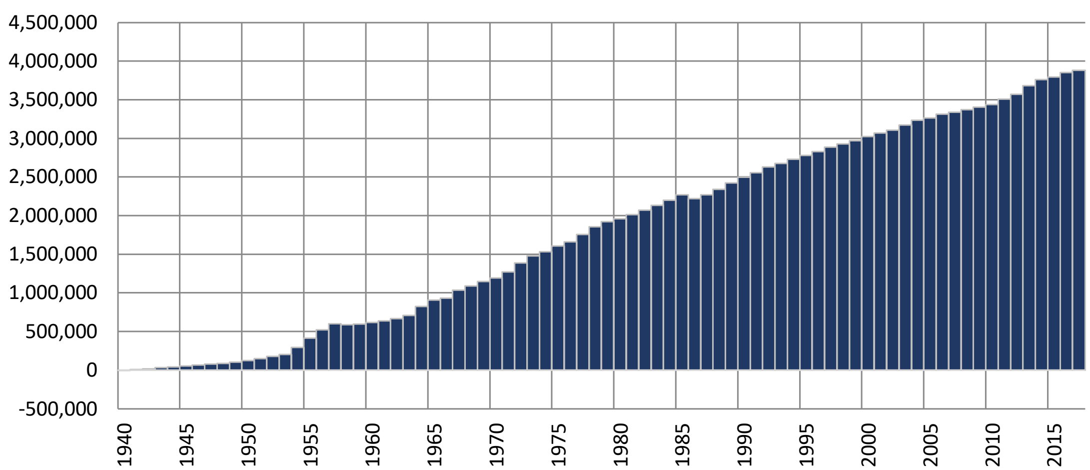
Cumulative Annual Rincon-Mesilla Groundwater Storage



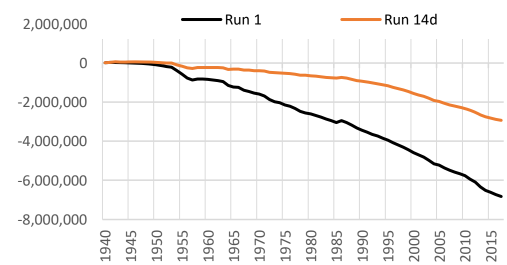
Period	Average Difference
1951-2017	208
1951-1978	1,035
1979-2005	-831
2006-2017	617
1985-2017	136
1985-2005	-139



Cumulative Annual Hueco Groundwater Storage



Period	Average Difference
1951-2017	56,075
1951-1978	61,814
1979-2005	52,185
2006-2017	51,440
1985-2017	50,989
1985-2005	50,731



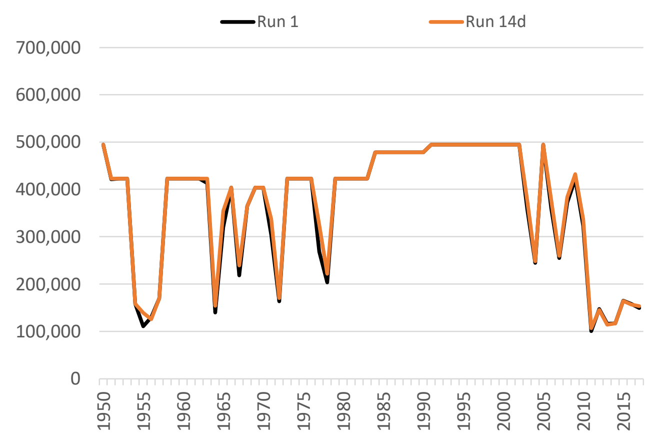
Notes:

Cumulative storage change in alluvial and non-alluvial aquifers.

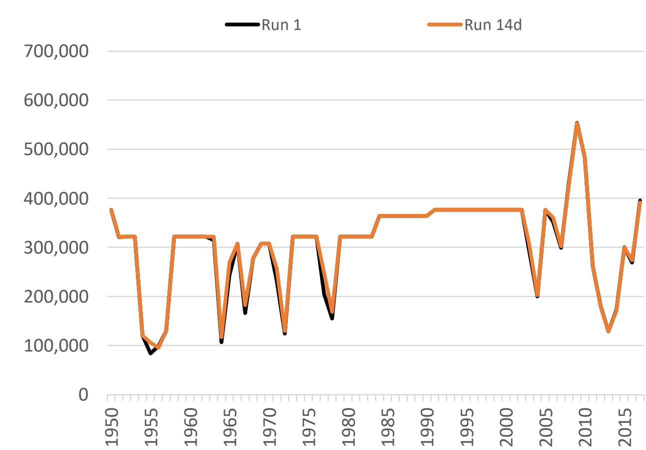
Average differences calculated as (Final Storage - Initial Storage)/(no. years).

Run 14d - TX Hueco Pumping Off (Returns Left On)
Annual Allocation and Charges
Run 14d v. Run 1
ILRG Model
1950 - 2017 (acre-feet)

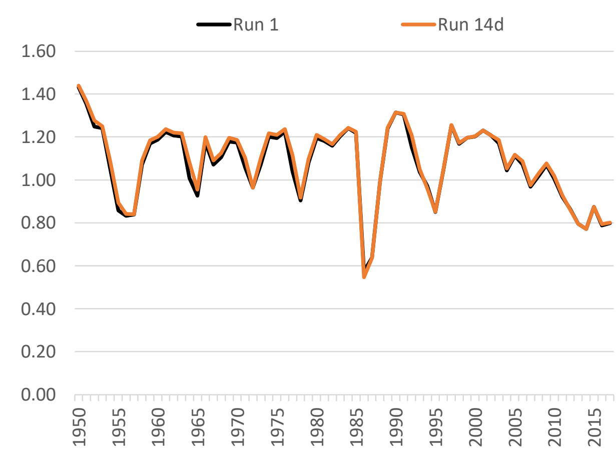
Total Allocation - EBID



Total Allocation - EPCWID

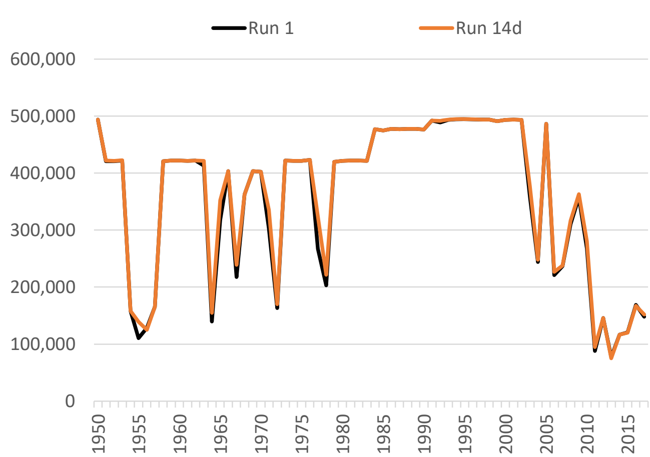


Diversion Ratio

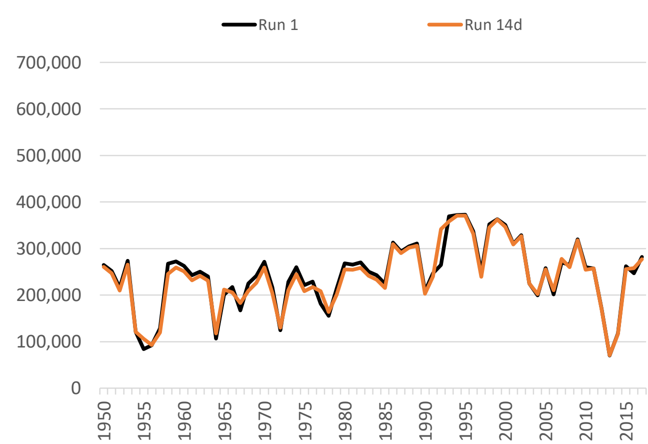


Note:
Computed as Total Charges/Caballo Release.

Annual Delivery Charges - EBID



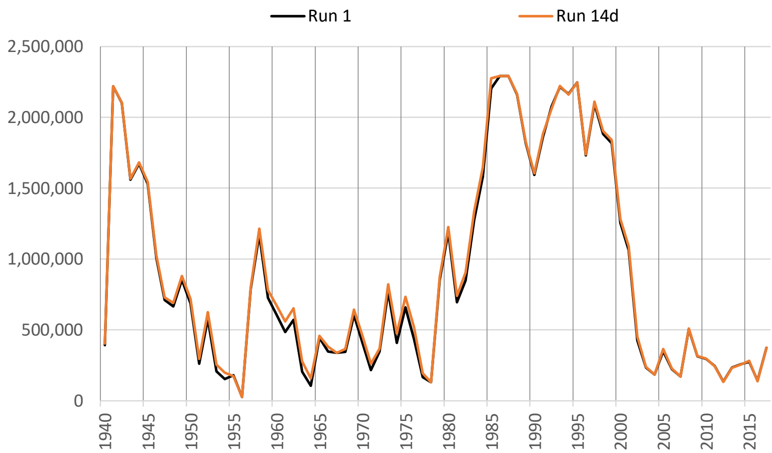
Annual Delivery Charges - EPCWID



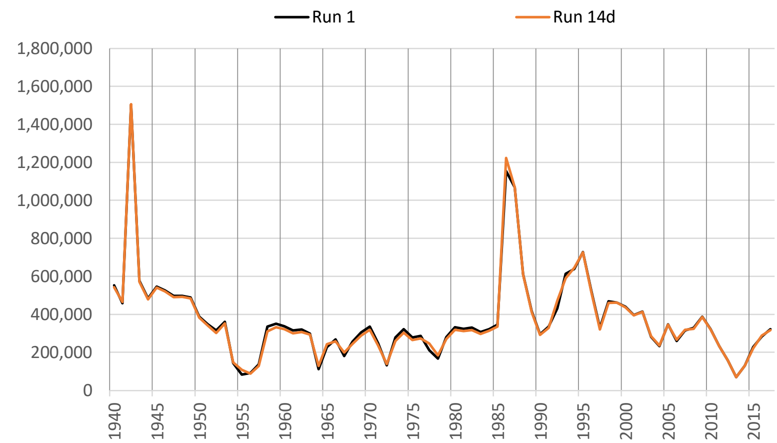
US_MSJ_00003350

Run 14d - TX Hueco Pumping Off (Returns Left On)
Annual Summary of Project Storage and Rio Grande Flows
Run 14d v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

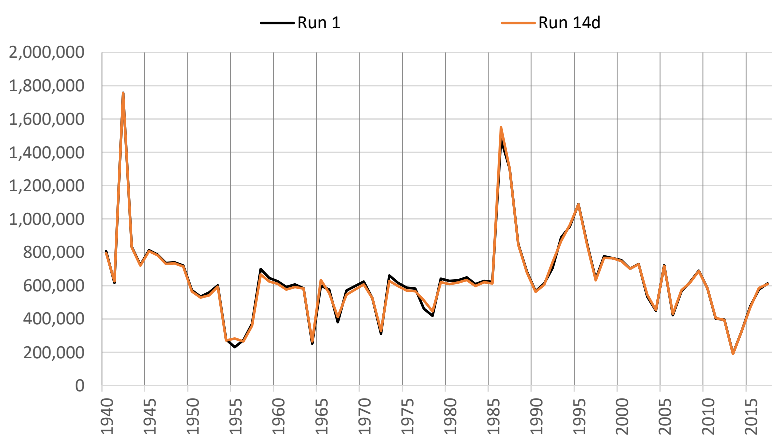
Total Year-End Project Reservoir Storage



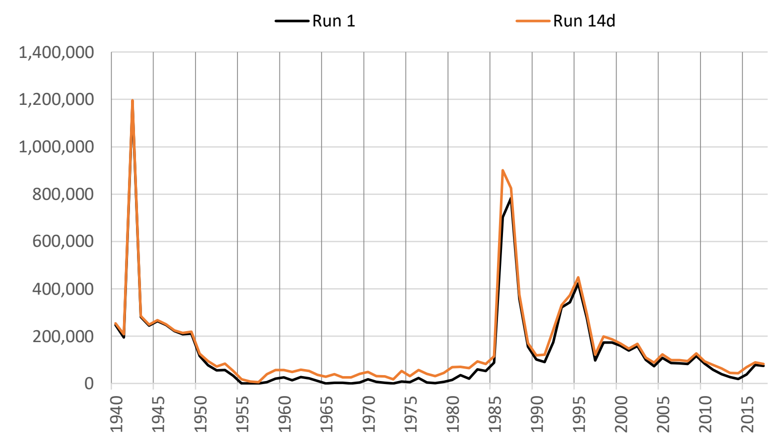
Rio Grande at El Paso



Rio Grande Below Caballo



Rio Grande at Fort Quitman

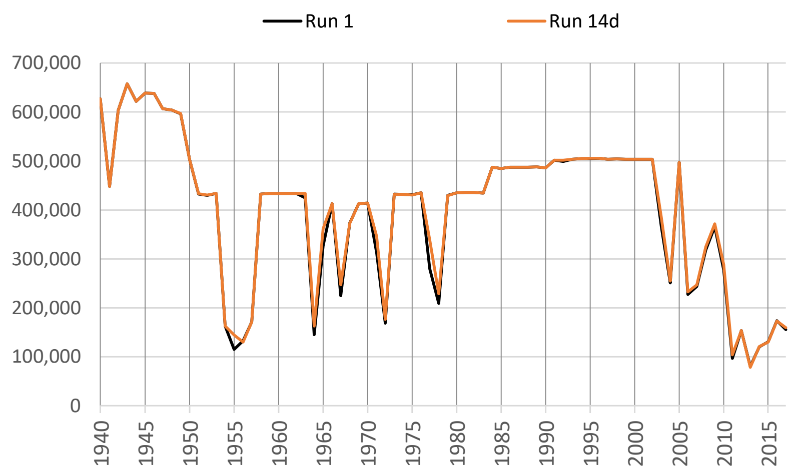


***Note different scales.**

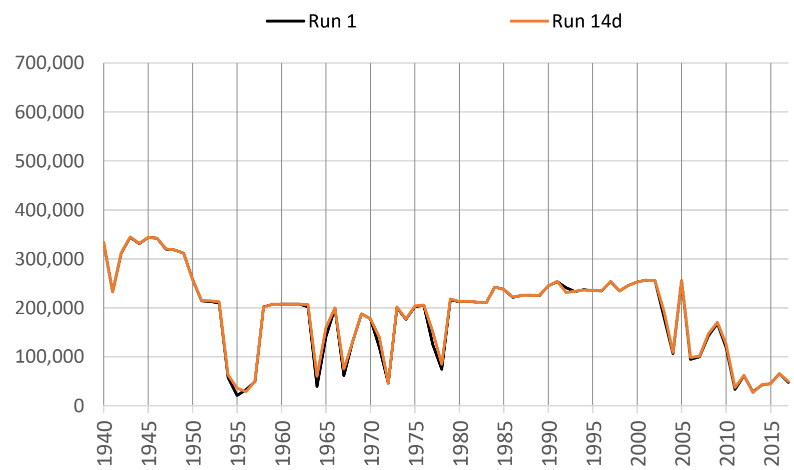
Run 14d - TX Hueco Pumping Off (Returns Left On)
Irrigation Season Summary of Irrigation Operations
Run 14d v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

EBID Total

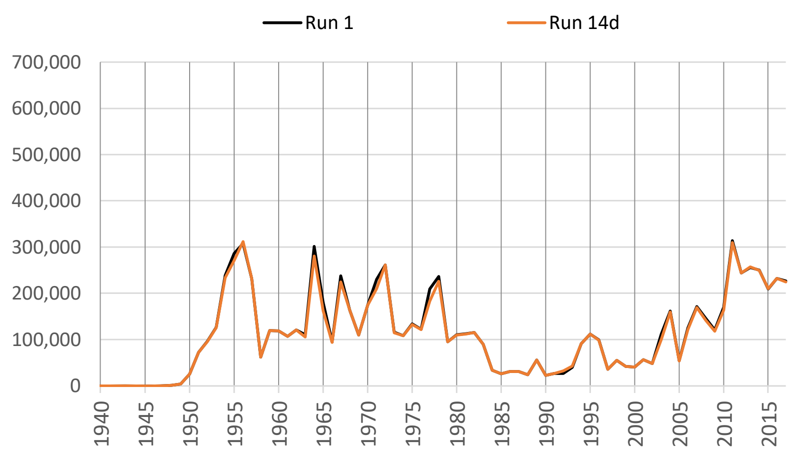
Net River Headgate Diversions



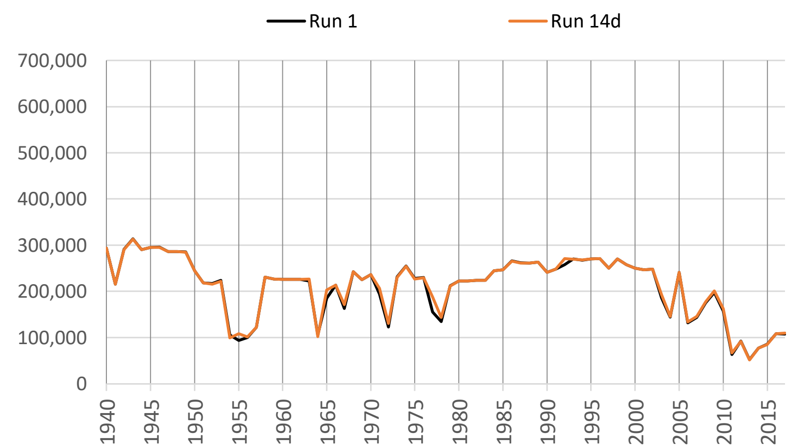
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries



Notes: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).
Pumping includes Supplemental and Primary groundwater pumping.

Run 14d - TX Hueco Pumping Off (Returns Left On)

Irrigation Season Summary of Irrigation Operations

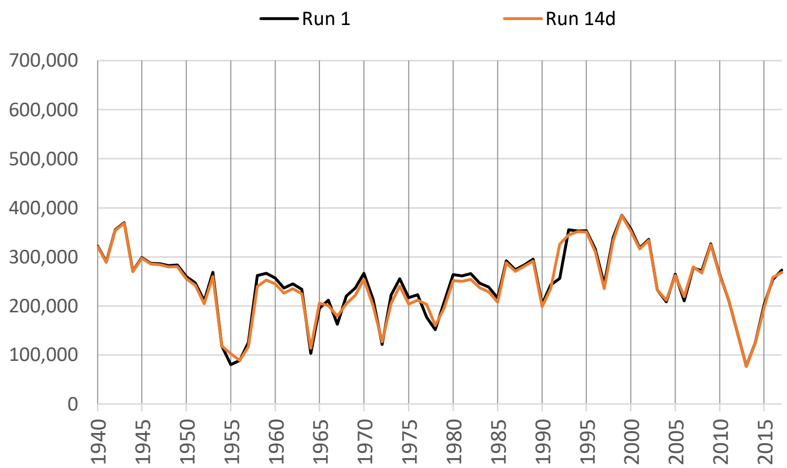
Run 14d v. Run 1

ILRG Model

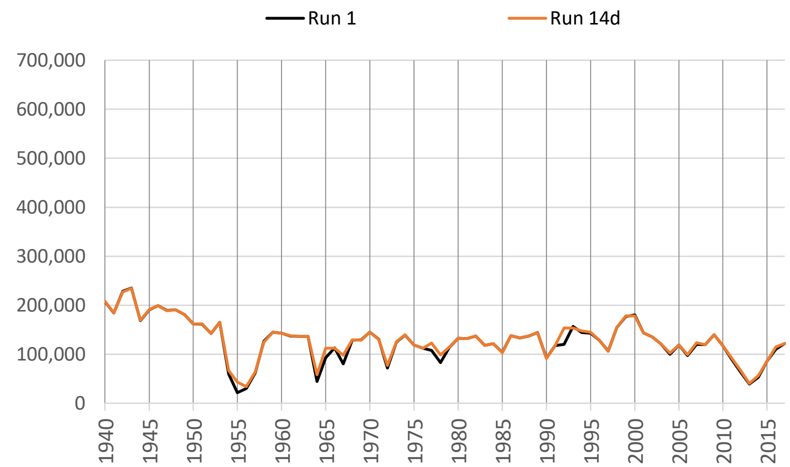
1940 - 2017 (acre-feet)

EPCWID Total

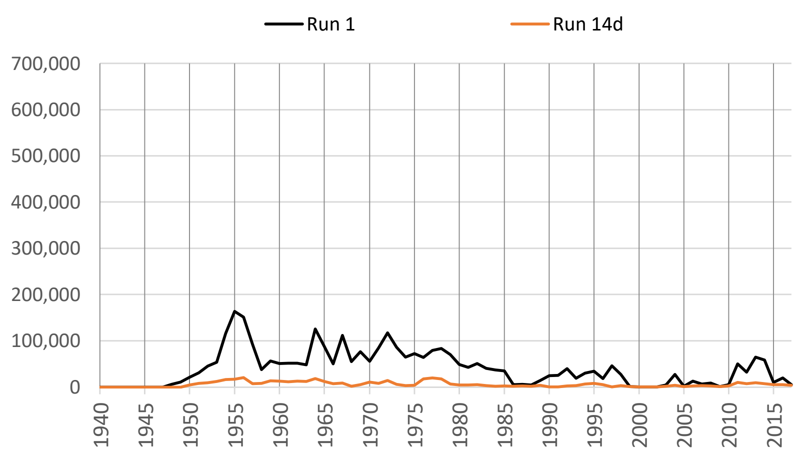
Net River Headgate Diversions



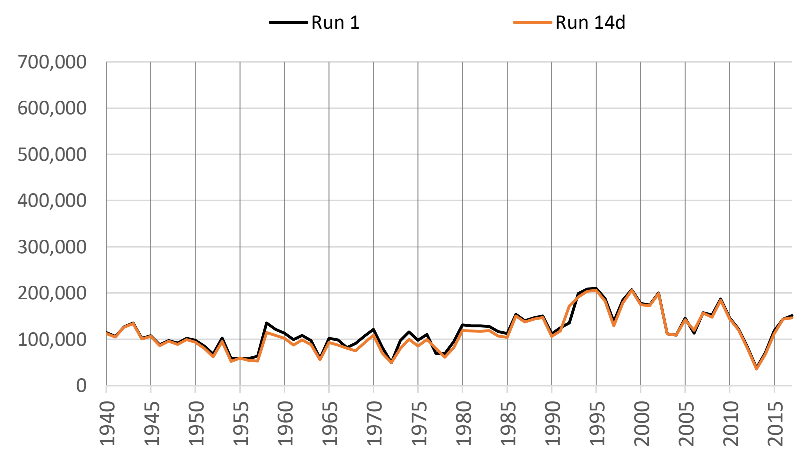
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries

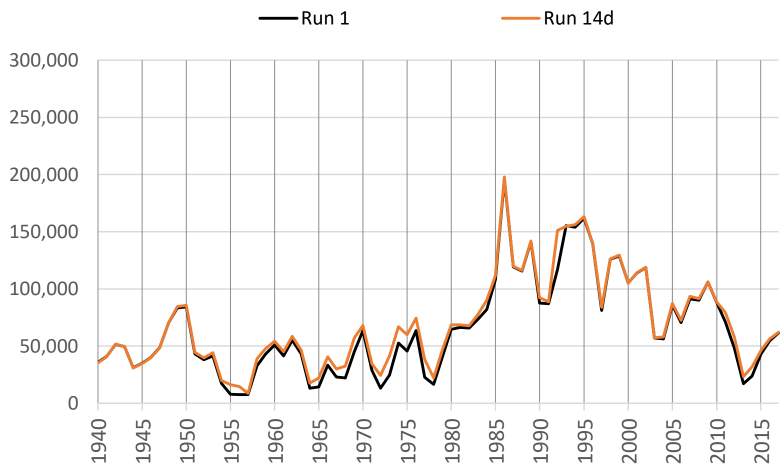


Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

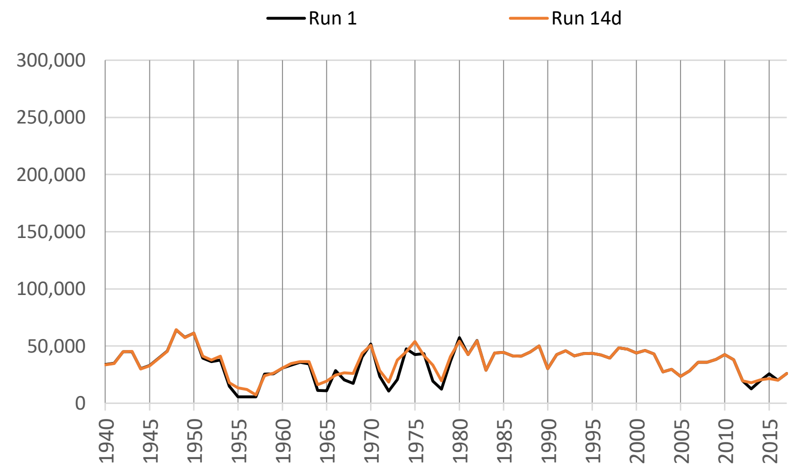
Run 14d - TX Hueco Pumping Off (Returns Left On)
Irrigation Season Summary of Irrigation Operations
Run 14d v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

HCCRD Total

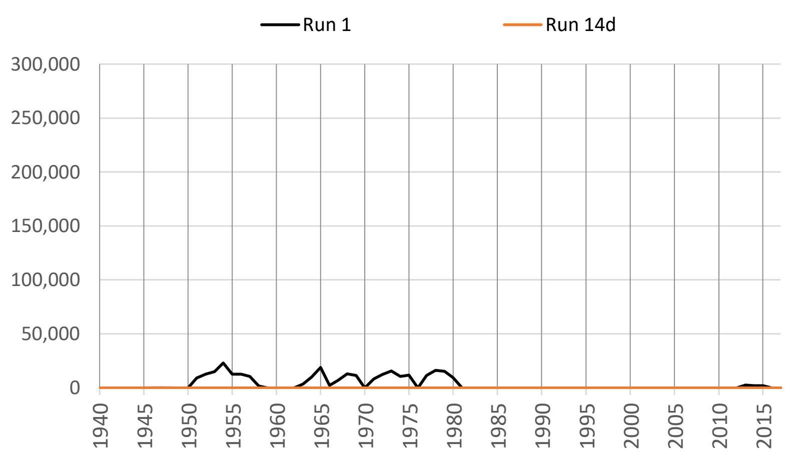
Net River Headgate Diversions



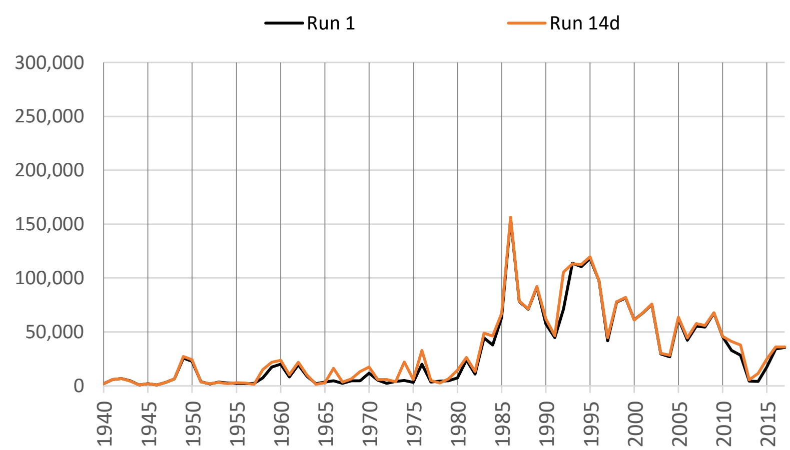
Farm Headgate Deliveries



Pumping



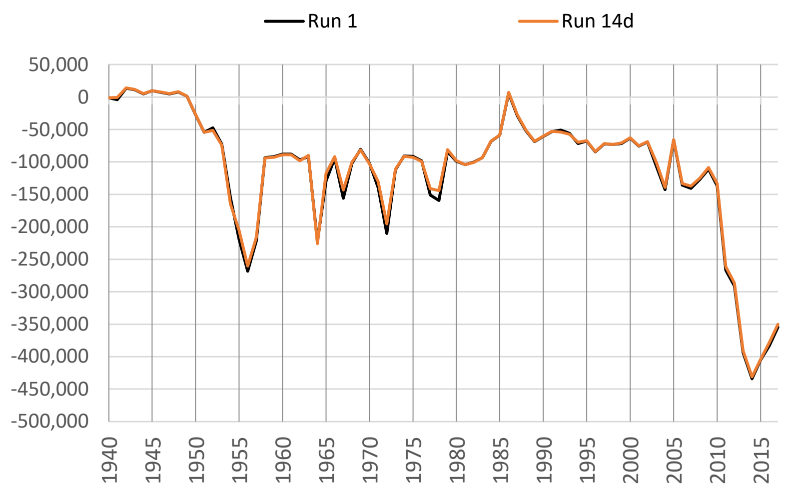
RHG Diversions - FHG Deliveries



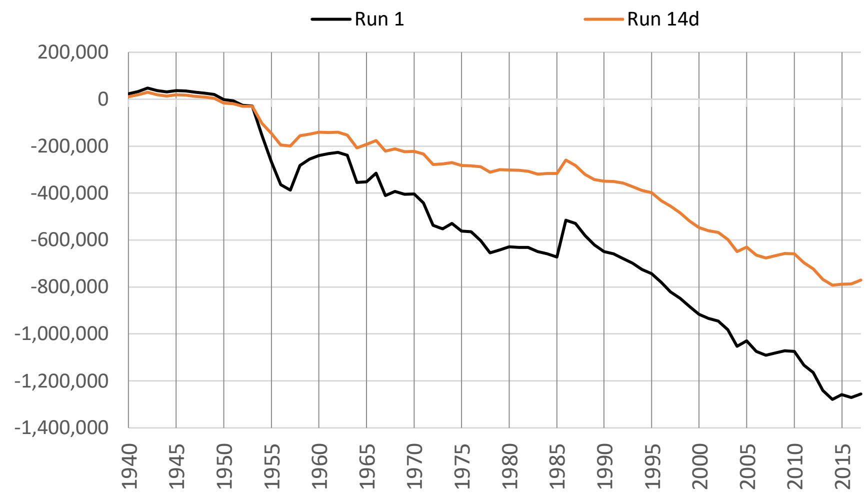
Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

Run 14d - TX Hueco Pumping Off (Returns Left On)
Cumulative Change in Ground Water Storage
Run 14d v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

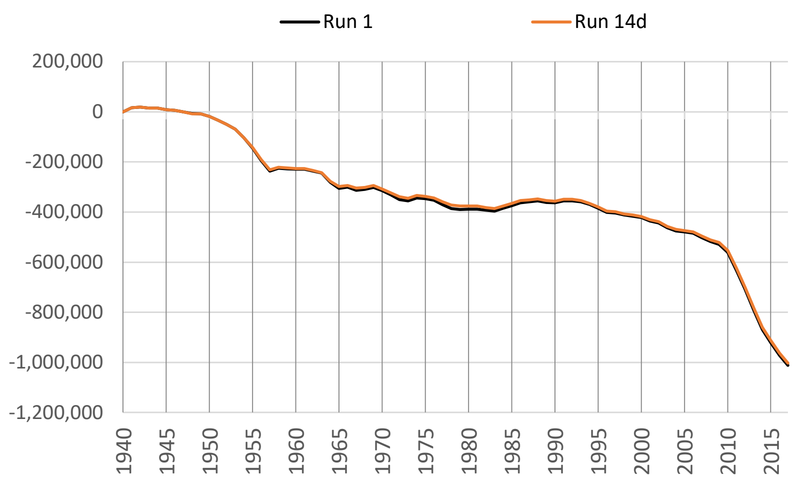
Rincon-Mesilla Alluvial Aquifer



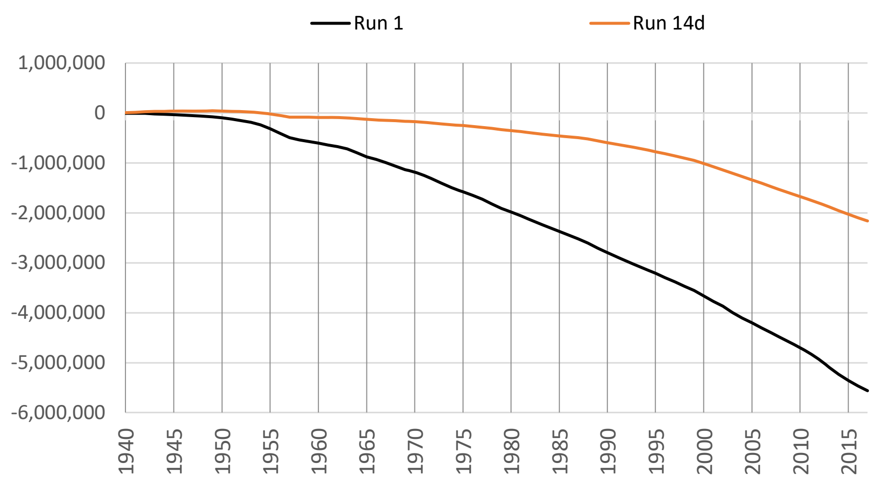
Hueco Alluvial Aquifer



Rincon-Mesilla Non-Alluvial Aquifer

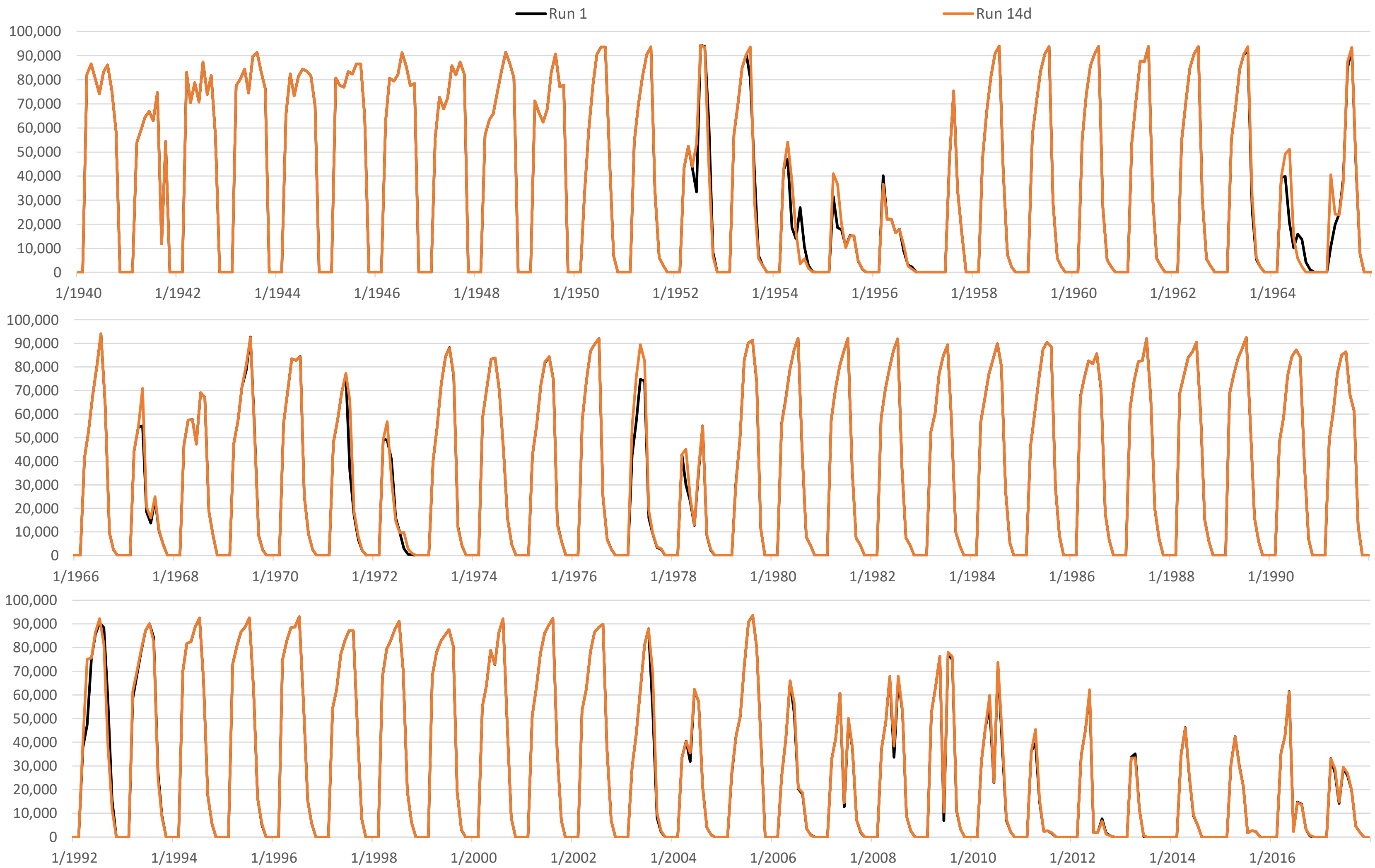


Hueco Non-Alluvial Aquifer



***Note different scales.**

Run 14d - TX Hueco Pumping Off (Returns Left On)
Monthly Net RHG Diversions
Run 14d v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
EBID Total



Note: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

Run 14d - TX Hueco Pumping Off (Returns Left On)
Monthly Net RHG Diversions
Run 14d v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
EPCWID Total

Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

Run 14d - TX Hueco Pumping Off (Returns Left On)

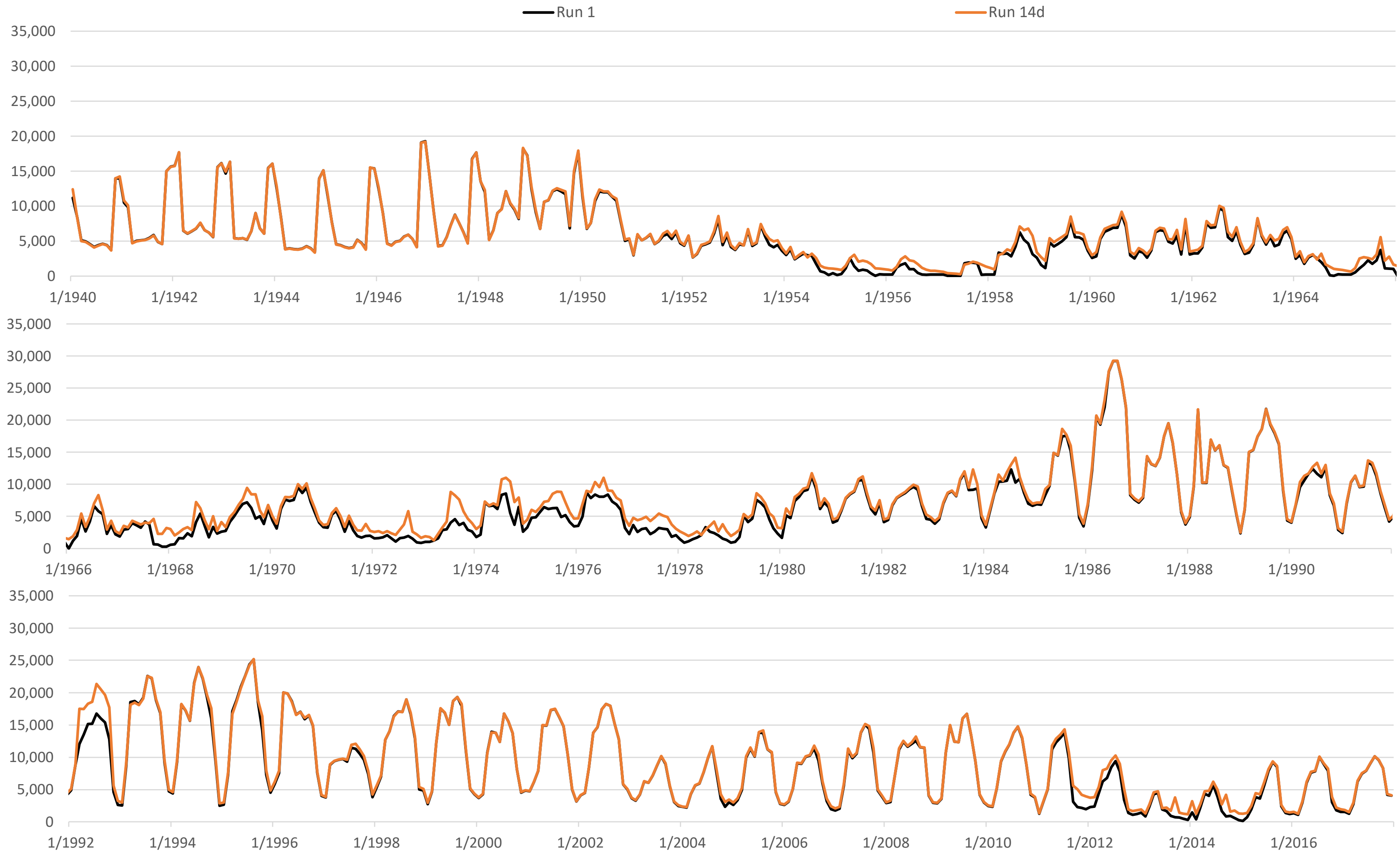
Monthly Net RHG Diversions

Run 14d v. Run 1

ILRG Model

1940 - 2017 (acre-feet)

HCCRD Total



Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

Run 14d - TX Hueco Pumping Off (Returns Left On)

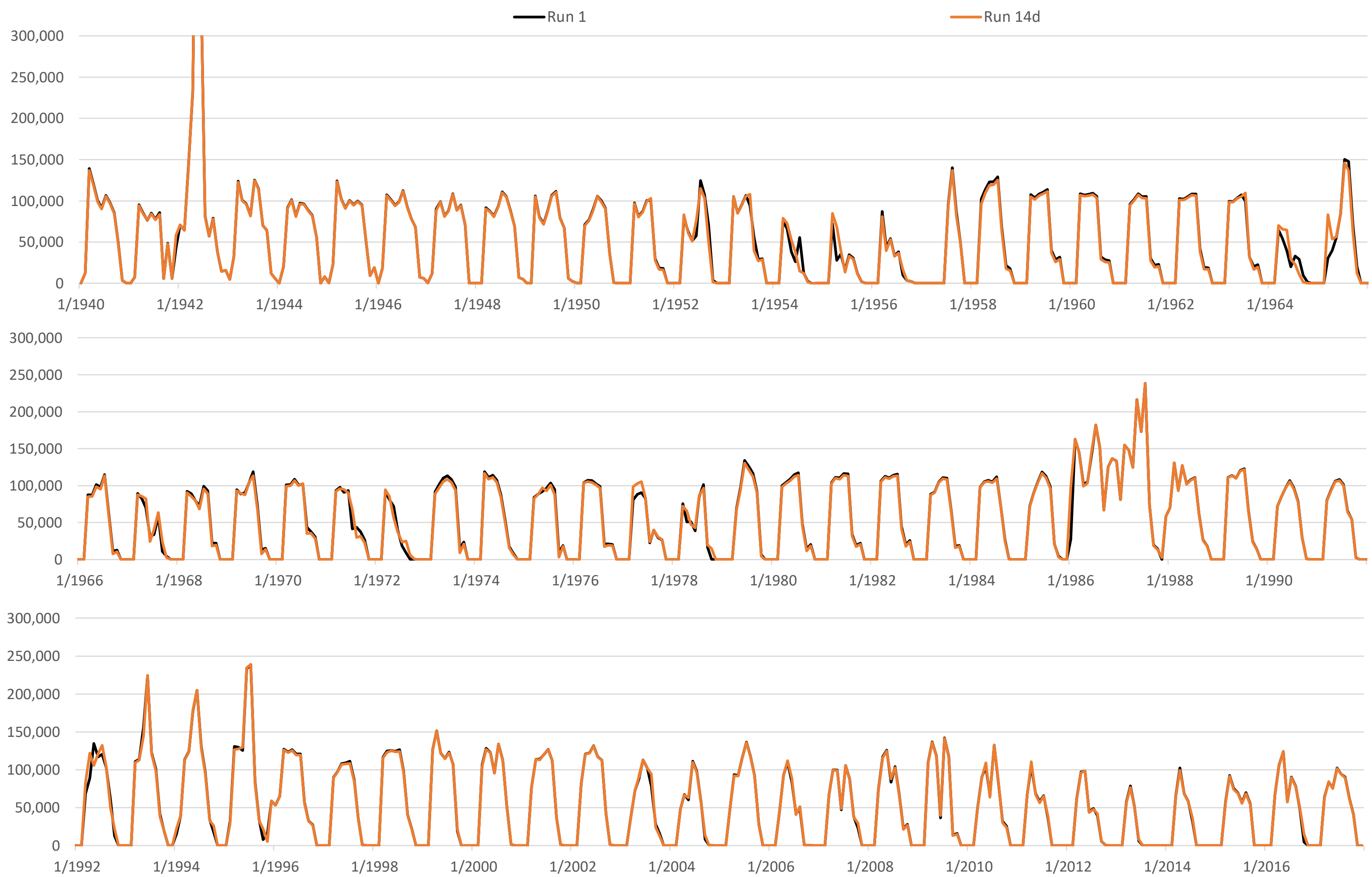
End of Month Reservoir Storage (Elephant Butte + Caballo)

Run 14d v. Run 1

ILRG Model

1940 - 2017 (acre-feet)

Run 14d - TX Hueco Pumping Off (Returns Left On)
Monthly Caballo Releases
Run 14d v. Run 1
ILRG Model
1940 - 2017 (acre-feet)



Run 14d - TX Hueco Pumping Off (Returns Left On)
Monthly Rio Grande at El Paso Flow
Run 14d v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

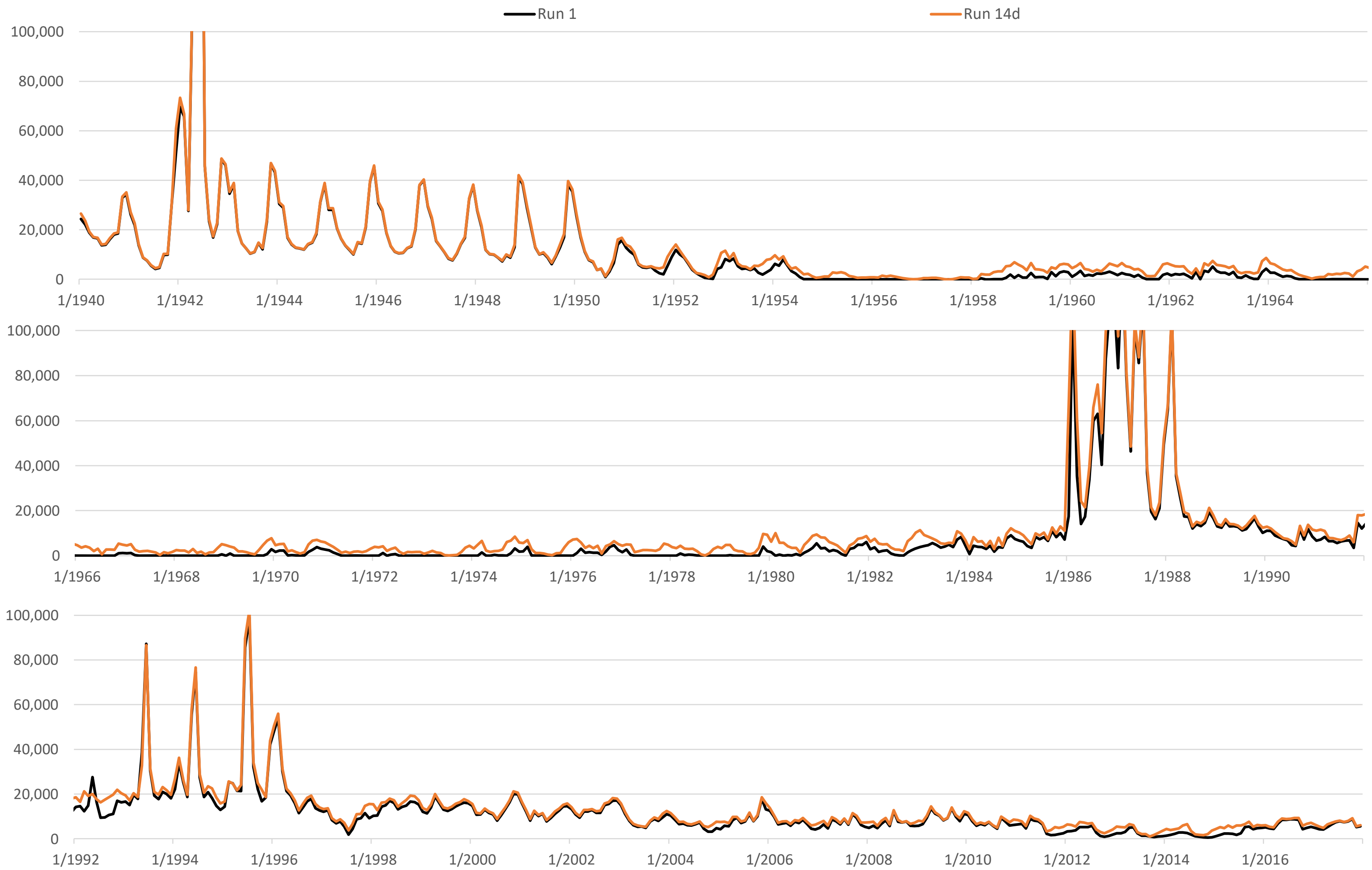
Run 14d - TX Hueco Pumping Off (Returns Left On)

Monthly Rio Grande at Fort Quitman Flow

Run 14d v. Run 1

ILRG Model

1940 - 2017 (acre-feet)



Appendix 30S

Comparison of ILRG Model Runs
Run 15 v. Run 1

Model Run Specifications

Model Version: LRG_v116

Name: **Run 15 - Early EPCWID Ops (WWTP & Fabens Drain)**

Run ID: LRG_v116_Operational_Run15
Date: 8/27/2020

Name: **Run 1 - Historical Base Run (All Pumping On)**

Run ID: LRG_v116_Operational_Run1
Date: 8/23/2020

Selected Model Inputs

Pumping and Returns	Run 15	Run 1
Irrigation Pumping	On	On
Irrigated Area	Hist	Hist
Non-Irrigation Pumping	On	On
Non-Irrigation Pumping Returns	On	On
Las Cruces Jornada Pumping Returns	On	On

Project Allocation Rules		
1950-2005	D1/D2	D1/D2
2006-2007	D3	D3
2008-2017	D3 + CO	D3 + CO

EPCWID Operations		
Charge EPCWID for Use of WWTP Returns	On	Off
ACE and Haskell Credits for EPCWID	Off	On
(1) Increased EPCWID Use of Fabens Drain Flows	On	Off
Charge EPCWID for Fabens Drain Flow Use	On	Off

Notes:
(1) Starting in July 1945, use 70% of simulated Fabens drain flow up to 6,000 af/month.

Run 15 - Early EPCWID Ops (WWTP & Fabens Drain)

Comparison of ILRG Model Runs

Run 15 v. Run 1

1951 - 2017 Annual Average

(1,000 acre-feet)

Run No.	1	15	15 - 1	
Simulated Input or Output	**Run 1**	**Run 15**	**Run 15 minus Run 1**	
Effects of Alternate Scenario				
FHG Deliveries (Mar - Oct)				***% Diff.***
EBID	167.6	177.9	10.3	*6%*
EPCWID (incl. EPW)	139.9	141.2	1.4	*1%*
HCCRD	32.8	32.4	-0.5	*-1%*
Total	340.3	351.5	11.2	*3%*
FHG Deliveries (Nov - Feb)				
EBID	0.0	0.0	0.0	*-3%*
EPCWID (incl. EPW)	0.2	1.9	1.7	*894%*
HCCRD	2.4	2.7	0.3	*14%*
Total	2.6	4.6	2.0	*78%*
Irrigation Pumping				
EBID	140.4	130.4	-10.0	*-7%*
EPCWID (Mesilla Valley)	7.4	7.0	-0.4	*-5%*
EPCWID (El Paso Valley)	40.1	37.5	-2.6	*-6%*
HCCRD	4.2	4.7	0.5	*11%*
Total	192.1	179.6	-12.5	*-7%*
Other Inflows/Outflows				
Net Reservoir Evaporation	125.3	129.6	4.3	*3%*
Riparian ET	70.9	70.5	-0.4	*-1%*
River Evaporation + Incidental Canal Loss	30.3	30.7	0.3	*1%*
Total	226.6	230.8	4.3	*2%*
Rio Grande at Fort Quitman				
Reservoir Spills	33.3	38.6	5.3	*16%*
Nov-Feb Flows	21.4	18.2	-3.2	*-15%*
Mar - Oct Flows	41.1	32.4	-8.6	*-21%*
Underflow (GW Model)	0.2	0.2	0.0	*-5%*
Total	96.0	89.4	-6.6	*-7%*

Run 15 - Early EPCWID Ops (WWTP & Fabens Drain)

Comparison of ILRG Model Runs

Run 15 v. Run 1

1951 - 2017 Annual Average

(1,000 acre-feet)

Run No.	1	15	15 - 1	
Simulated Input or Output	**Run 1**	**Run 15**	**Run 15 minus Run 1**	
Effects of Alternate Scenario (continued)				
Change in Storage				***% Diff.***
Reservoir Storage	-4.7	-6.0	-1.4	*29%*
Alluvial GW Storage (RW Model)	-23.6	-21.9	1.7	*-7%*
Non-alluvial GW Storage (GW Models)	-96.4	-94.6	1.8	*-2%*
Soil Moisture Storage	0.6	0.6	0.0	*-2%*
Total	-124.0	-121.9	2.1	*-2%*
Summary of Effects				
FHG Deliveries (Mar-Oct)	340.3	351.5	11.2	*3%*
FHG Deliveries (Nov-Feb)	2.6	4.6	2.0	*78%*
Irrigation Pumping	192.1	179.6	-12.5	*-7%*
Riparian ET + Evaporation	226.6	230.8	4.3	*2%*
Fort Quitman Flow	96.0	89.4	-6.6	*-7%*
Change in Storage	-124.0	-121.9	2.1	*-2%*
Total	733.6	734.0	0.5	*0%*
Other Effects of Alternate Scenario				
Rio Grande at El Paso				***% Diff.***
Reservoir Spills	49.4	59.4	10.0	*20%*
Nov-Feb Flows	22.8	22.7	-0.1	*0%*
Mar - Oct Flows	263.8	247.4	-16.3	*-6%*
Total	336.0	329.5	-6.4	*-2%*
Rio Grande below Caballo				
Reservoir Spills	65.9	79.3	13.5	*20%*
Nov-Feb Flows	0.5	0.3	-0.2	*-39%*
Mar - Oct Flows	541.3	525.0	-16.3	*-3%*
Total	607.6	604.6	-3.0	*0%*
Surface Water Diversions (Mar - Oct)				
EBID	366.5	384.8	18.4	*5%*
EPCWID (incl. EPW)	236.8	221.7	-15.1	*-6%*
HCCRD	67.5	64.4	-3.1	*-5%*
Total	670.8	671.0	0.2	*0%*
Surface Water Diversions (Nov - Feb)				
EBID	0.0	0.0	0.0	*0%*
EPCWID (incl. EPW)	14.3	15.7	1.4	*10%*
HCCRD	14.2	14.3	0.1	*1%*
Total	28.5	30.0	1.5	*5%*

Run 15 - Early EPCWID Ops (WWTP & Fabens Drain)
Annual Differences in ILRG Model Outputs
Run 15 minus Run 1
1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1940	-53	-53	3	-5	1	-4	-2	-2	1	1	1	1	-52	-27	-51
1941	-165	-165	-6	-10	-2	-4	-4	-4	-1	0	-2	-4	44	71	10
1942	-33	-33	-1	-6	-1	-1	0	0	2	7	0	-1	28	9	-45
1943	-64	-64	-4	-7	2	3	-14	-14	-12	-12	2	-1	-22	-11	-113
1944	-82	-82	-144	-137	-73	-71	-5	-5	16	-2	-62	-63	-164	-156	-59
1945	2	2	-17,007	-5,527	1,397	918	-53	-53	-308	6,373	1,081	988	-10,929	-10,412	-16,329
1946	36	36	-10,388	-11,149	-392	-7,349	-110	-111	-717	3,359	-75	-239	-18,238	-17,652	-18,288
1947	56	56	-12,881	-6,763	699	-5,757	-15	-15	3,974	11,138	923	1,019	-10,314	-10,390	-19,242
1948	10	10	-10,680	-6,705	136	-4,668	-15	-16	-1,976	4,581	410	237	-8,508	-8,535	-10,866
1949	46	46	-20,056	-15,361	1,553	3,235	-52	-53	622	6,491	-293	-545	-18,657	-18,082	-19,561
1950	29	29	-22,080	-18,138	-9,742	-11,071	-10	-11	-2,678	2,556	238	420	-20,459	-20,089	-17,835
1951	1,031	1,031	-11,245	-5,716	-641	-2,838	547	546	-3,508	1,706	-204	-2,191	-8,349	-8,207	-12,040
1952	990	990	-10,230	-6,917	-852	-2,128	3,848	3,843	-3,031	-53	-2,244	545	-24,631	-18,186	-11,150
1953	374	374	-15,022	-11,707	-843	-1,988	2,382	2,381	-2,558	344	-1,247	625	-5,823	-11,206	-16,020
1954	19,737	19,737	5,461	6,461	-608	369	15,858	15,858	16,864	17,821	-80	877	15,476	12,025	-11,775
1955	32,948	32,948	21,327	21,393	1,978	3,108	17,384	17,384	21,132	21,075	1,916	2,969	52,052	26,213	387
1956	521	521	1,018	1,024	621	593	-2,354	-2,354	416	307	444	300	-1,818	812	-25
1957	10	10	-584	-750	511	466	70	70	546	503	680	590	-1,763	-567	-3
1958	-2	-2	-3,303	-3,501	725	1,763	283	283	-180	-162	75	57	-13,440	-3,251	1,334
1959	5	5	-10,170	-9,846	537	1,432	96	96	-543	-340	6	23	-14,382	-10,295	1,117
1960	8	8	-10,551	-10,102	-549	-807	50	50	-1,427	-893	0	0	-13,090	-11,464	-1,317
1961	15	15	232	1,210	665	823	54	54	1,142	2,162	647	-428	713	-73	1,652
1962	10	10	-13,595	-12,220	-2,153	-2,313	-12	-12	-1,499	-320	19	-303	-17,703	-15,417	-1,863
1963	8,891	8,891	-5,579	-3,709	-1,278	-1,594	4,851	4,851	-911	785	-512	-514	1,784	-2,062	-1,637
1964	23,205	23,205	8,235	9,173	123	793	11,908	11,908	18,888	19,529	1,038	969	23,726	12,129	-4,022
1965	7,409	7,409	258	252	1,736	1,733	3,904	3,904	3,401	3,377	594	585	-2,303	1,783	191
1966	-32	-32	-10,691	-10,007	-3,129	-3,345	248	248	-216	146	-3,069	-1,086	-14,380	-8,987	-1,154
1967	15,337	15,337	3,524	4,296	1,284	1,703	8,631	8,631	3,819	3,587	582	1,688	10,590	5,925	-648
1968	7,801	7,801	4,888	5,719	1,768	1,255	6,287	6,287	1,298	1,009	1,704	1,366	7,992	7,786	173
1969	-16	-16	-15,894	-15,390	-9,696	-9,407	240	240	71	402	-9,314	-7,737	-21,223	-16,229	-1,587
1970	3	3	-21,538	-20,836	-7,851	-7,431	41	41	-1,263	-577	-322	4,348	-25,952	-23,128	-10,297
1971	28,846	28,846	-7,523	-6,074	-1,589	-3,323	17,598	17,598	-682	249	-297	-1,642	8,379	-4,291	-1,433
1972	-1,898	-1,898	-8,574	-7,858	-1,434	-1,584	-3,800	-3,800	-6,355	-6,343	-1,651	-1,789	-12,245	-6,506	-1,224
1973	-88	-88	2,895	2,897	673	833	715	715	607	423	585	838	514	2,778	6
1974	-5	-5	-9,063	-8,751	-4,117	-4,195	246	246	398	672	-3,588	-2,517	-9,589	-9,128	-1,922
1975	-235	-235	-17,873	-17,244	-12,941	-12,503	1,178	1,178	-323	220	-12,707	-12,582	-22,060	-17,960	384
1976	7	7	-18,342	-17,514	-17,236	-17,463	722	722	-858	-139	-2,753	3,540	-21,564	-20,125	-19,603
1977	51,142	51,142	23,618	25,238	9,140	9,553	21,699	21,699	14,206	16,535	8,479	9,420	44,578	32,383	1,611
1978	15,205	15,205	-1,303	444	-3,121	-3,420	7,924	7,924	9,342	10,771	-2,852	-3,213	9,167	4,134	-1,212

Run 15 - Early EPCWID Ops (WWTP & Fabens Drain)
Annual Differences in ILRG Model Outputs
Run 15 minus Run 1
1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1979	253	253	-10,377	-8,624	-3,606	-2,620	1,079	1,079	3,320	4,818	-3,489	-2,644	-16,702	-8,342	-228
1980	11	11	-22,674	-20,834	-4,707	-4,195	159	159	-394	1,444	-1,795	-843	-27,114	-24,352	-5,028
1981	-53	-53	-26,925	-24,375	-6,320	-7,234	657	657	-1,235	1,748	964	1,298	-31,299	-29,363	-8,489
1982	-8	-8	-28,591	-25,816	-4,306	-4,952	-11	-11	-1,802	1,698	-1,222	840	-32,831	-31,337	-7,001
1983	-13	-13	-28,620	-26,278	-11,457	-11,853	-57	-57	-2,488	511	0	0	-32,938	-31,875	-12,753
1984	-46	-46	-26,481	-24,447	-17,022	-17,717	-1	-1	-1,502	1,776	377	377	-23,244	-23,579	-18,354
1985	-225	-225	-27,784	-25,505	-12,900	-12,637	458	460	-1,858	1,014	0	0	38,669	33,590	19,304
1986	-80	-80	-40,660	-39,311	-7,856	-6,639	345	356	-1,790	-32	0	0	87,164	89,553	69,341
1987	-194	-194	-52,069	-49,311	-7,544	-6,810	1,311	1,315	-879	3,230	0	0	-233	-729	-67,914
1988	-15	-15	-50,023	-46,674	-7,294	-6,895	128	128	-4,800	-97	0	0	-50,042	-43,698	-36,915
1989	9	9	-43,364	-38,789	-12,650	-13,149	-187	-188	-5,889	363	0	0	-52,018	-50,077	-36,657
1990	1,051	1,051	14,165	18,028	-2,570	-2,863	-7,635	-7,639	18,214	24,085	0	0	-20,240	-11,618	-19,924
1991	888	888	-39,567	-35,475	-15,468	-15,815	954	950	-7,965	-1,571	0	0	-38,656	-41,873	-31,558
1992	3,403	3,403	36,137	38,980	28,845	29,495	-10,156	-10,170	30,536	35,119	0	0	105,864	109,404	80,995
1993	591	591	-51,458	-47,315	-8,621	-8,841	729	723	-8,830	-2,284	0	0	-9,220	-13,448	-2,718
1994	419	419	-36,180	-32,959	-3,095	-3,119	-178	-175	27	5,072	0	0	17,113	13,291	9,011
1995	917	917	-31,911	-28,023	-722	-946	9	9	1,845	8,155	0	0	11,381	9,918	2,318
1996	-66	-66	-45,779	-43,137	-5,767	-5,071	120	120	-5,771	-1,639	0	0	-59,657	-54,301	-40,418
1997	-19	-19	-32,326	-29,971	-10,300	-11,792	-233	-233	-7,293	-2,217	0	0	-31,274	-32,198	-24,924
1998	-18	-18	-31,214	-29,092	-565	-1,507	41	42	-2,062	1,399	0	0	-19,924	-19,658	-24,533
1999	-299	-299	-46,311	-45,372	-735	-1,358	-296	-296	-8,090	-6,644	0	0	-39,106	-38,286	-29,025
2000	-410	-410	-22,677	-22,758	4,190	3,943	-8,914	-8,914	-5,757	-5,772	0	0	-24,407	-15,524	-11,196
2001	289	289	-21,542	-21,834	-4,646	-4,357	-362	-362	5,178	5,169	0	0	-18,646	-24,813	-25,825
2002	-9	-9	-28,214	-28,290	-2,044	-1,232	-266	-266	-40	-42	0	0	-28,180	-29,060	-30,520
2003	104,684	104,684	15,689	15,830	10,491	11,530	55,835	55,836	18,137	18,156	0	0	77,099	43,035	8,017
2004	36,680	36,680	-24,635	-23,896	-1,167	670	25,385	25,385	208	225	0	0	-20,644	-13,065	-10,748
2005	3,019	3,019	-13,484	-13,243	-6,336	-5,539	5,480	5,467	6,321	6,323	0	0	-30,347	-13,905	-15,419
2006	89,189	89,189	20,732	21,024	12,472	13,842	49,031	49,031	17,090	17,102	0	0	68,427	39,326	10,730
2007	70,547	70,547	-14,508	-14,011	-8,157	-6,780	43,568	43,568	5,963	5,985	0	0	-1,322	-8,275	-8,183
2008	121,041	121,041	-24,237	-23,578	-13,652	-12,353	76,791	76,793	-1,257	-1,216	0	0	21,645	-12,698	-11,250
2009	154,564	154,564	-30,342	-29,368	-3,004	-2,074	97,071	97,084	-3,739	-3,681	0	0	24,467	-973	-274
2010	129,946	129,946	-24,930	-23,113	-10,388	-9,848	86,115	86,116	-2,230	-2,181	0	0	-9,689	-10,302	-1,227
2011	78,768	78,768	-20,548	-19,675	-14,764	-14,519	40,483	40,483	-1,460	-1,431	0	0	4,052	-16,945	-14,042
2012	21,367	21,367	-3,236	-3,128	-6,274	-6,726	6,198	6,198	9,014	9,731	0	0	-1,904	-3,497	-3,784
2013	12,578	12,578	-11,693	-11,687	959	1,256	6,914	6,914	-2,803	-2,716	1,378	1,086	-9,724	-11,507	-2,944
2014	41,026	41,026	-26,778	-26,773	-4,886	-5,067	25,060	25,060	-13,253	-13,251	-4,631	-4,647	-1,140	-27,625	-6,221
2015	47,320	47,320	1,387	1,455	2,566	2,746	22,428	22,428	3,760	5,143	966	862	40,907	-692	-9,453
2016	486	486	-28,778	-28,693	-1,681	-1,848	-6,379	-6,379	-5,703	-4,800	0	0	-52,839	-32,180	-18,081
2017	101,668	101,668	-12,047	-11,741	1,194	747	56,084	56,084	3,097	3,791	0	0	39,662	-12,233	-14,095
Averages															
1951-2017	18,365	18,365	-15,097	-13,699	-3,105	-3,016	10,274	10,274	1,382	3,064	-471	-133	-3,018	-6,433	-6,598
1951-1978	7,544	7,544	-4,272	-3,215	-1,724	-1,783	4,307	4,307	2,456	3,314	-860	-188	-1,977	-2,897	-3,288
1979-2005	5,584	5,584	-26,551	-24,389	-4,229	-4,130	2,385	2,384	568	3,704	-191	-36	-9,979	-9,345	-10,043
2006-2017	72,375	72,375	-14,581	-14,107	-3,801	-3,385	41,947	41,948	707	1,040	-191	-225	10,212	-8,133	-6,569
1985-2017	30,882	30,882	-22,672	-21,134	-3,405	-3,138	17,149	17,149	846	3,045	-69	-82	522	-6,093	-9,034
1985-2005	7,172	7,172	-27,296	-25,148	-3,179	-2,997	2,979	2,978	926	4,191	0	0	-5,014	-4,927	-10,443

Notes:

EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

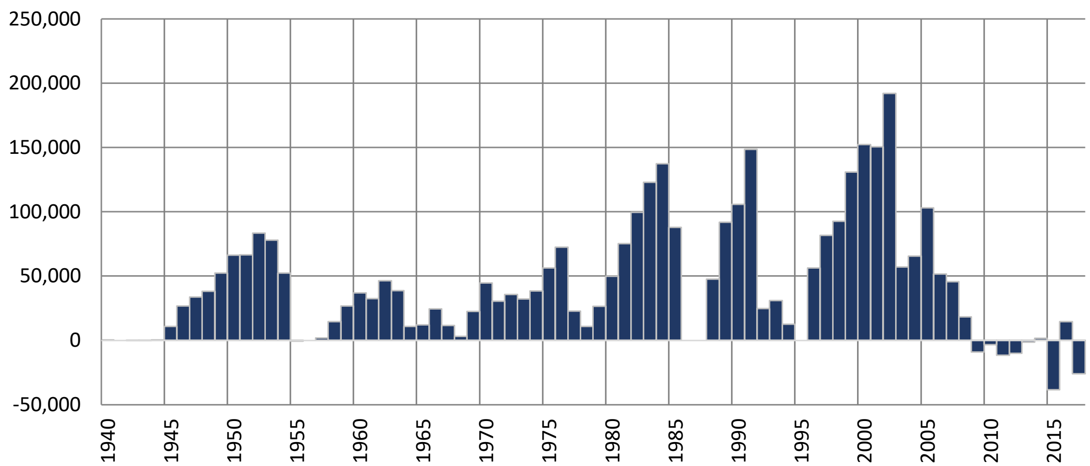
Run 15 - Early EPCWID Ops (WWTP & Fabens Drain)

Simulated Differences in ILRG Model Outputs

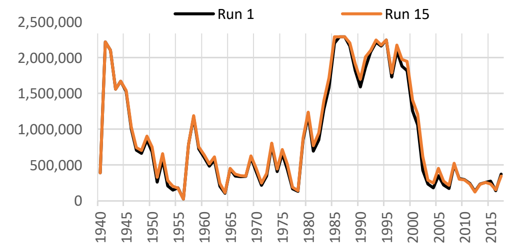
Run 15 minus Run 1

1940 - 2017 (acre-feet)

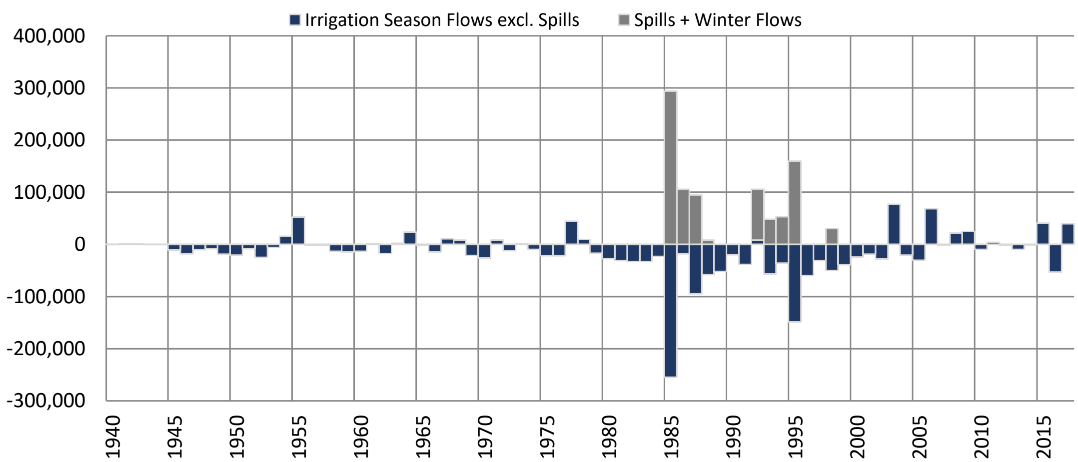
Total Project Storage (Year End)



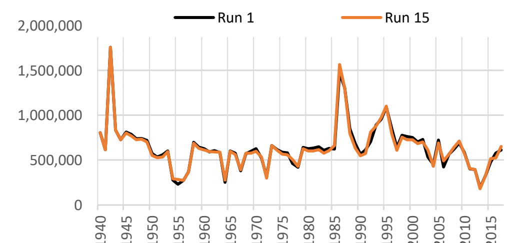
Period	Average Difference
1951-2017	-1,374
1951-1978	-1,980
1979-2005	3,418
2006-2017	-10,743
1985-2017	-4,944
1985-2005	-1,631



Caballo Reservoir Outflows (Annual)



Period	Average Difference Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	-16,303	13,285	-3,018
1951-1978	-1,977	0	-1,977
1979-2005	-42,945	32,966	-9,979
2006-2017	10,212	0	10,212
1985-2017	-26,450	26,972	522
1985-2005	-47,399	42,385	-5,014



Notes:

Reservoir storage does not include storage attributed to SJC, CO, or NM credit waters.

Average differences calculated as (Final Storage - Initial Storage)/(no. years).

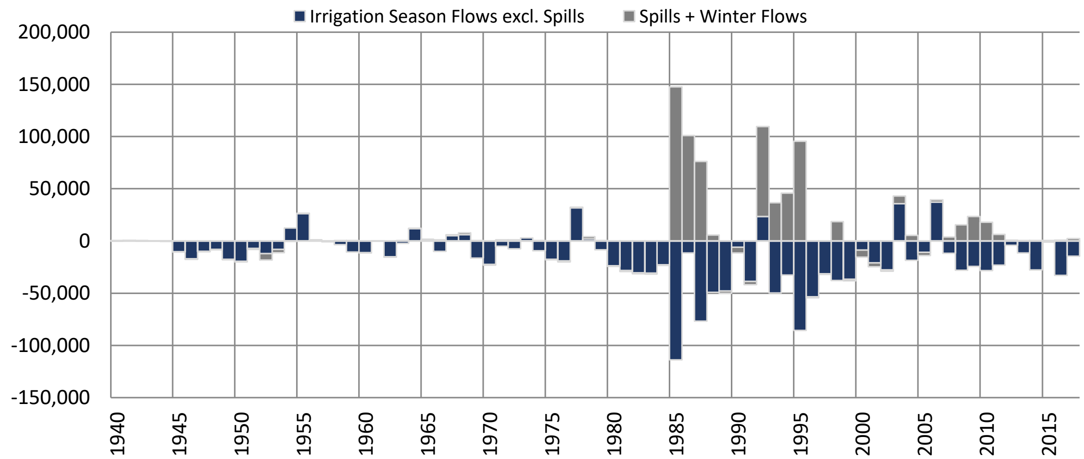
Run 15 - Early EPCWID Ops (WWTP & Fabens Drain)

Simulated Differences in ILRG Model Outputs

Run 15 minus Run 1

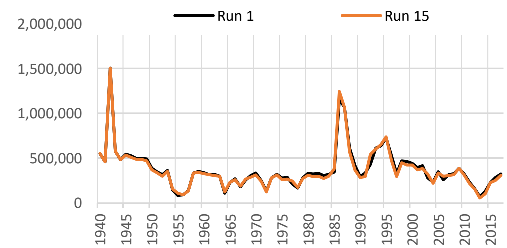
1940 - 2017 (acre-feet)

Rio Grande at El Paso (Annual)

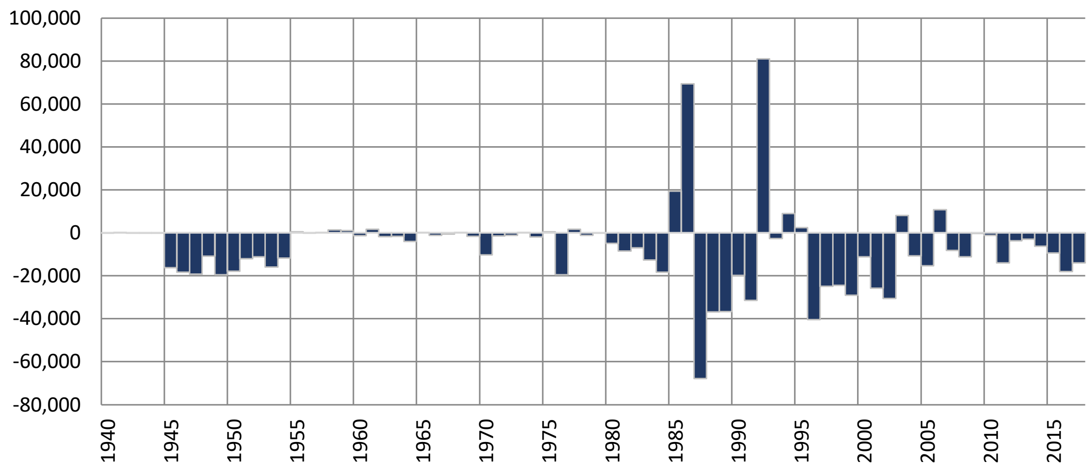


Average Difference

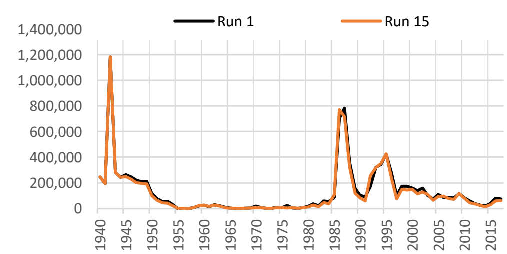
Period	Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	-16,337	9,904	-6,433
1951-1978	-2,825	-72	-2,897
1979-2005	-31,287	21,942	-9,345
2006-2017	-14,229	6,096	-8,133
1985-2017	-26,393	20,300	-6,093
1985-2005	-33,344	28,417	-4,927



Rio Grande at Fort Quitman (Annual)



Period	Average Difference
1951-2017	-6,586
1951-1978	-3,280
1979-2005	-10,025
2006-2017	-6,564
1985-2017	-9,024
1985-2005	-10,430



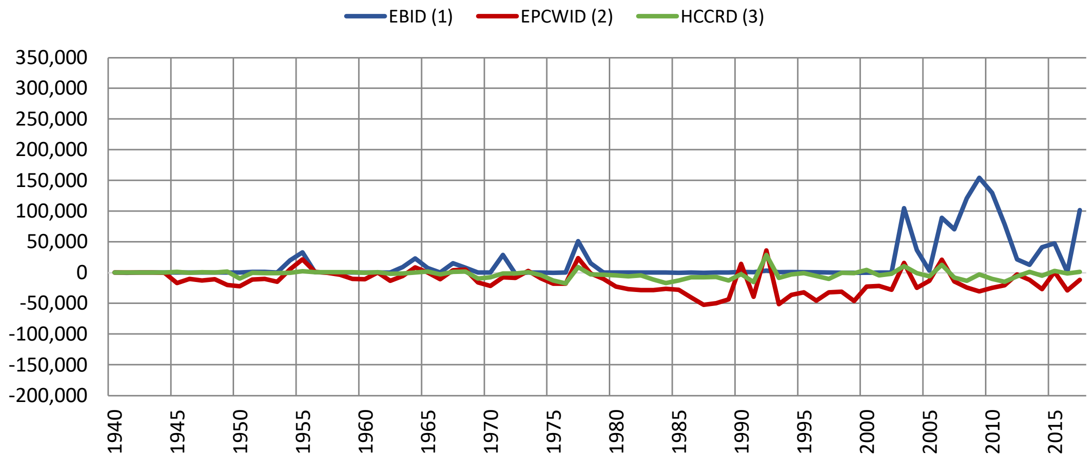
Run 15 - Early EPCWID Ops (WWTP & Fabens Drain)

Simulated Differences in ILRG Model Outputs

Run 15 minus Run 1

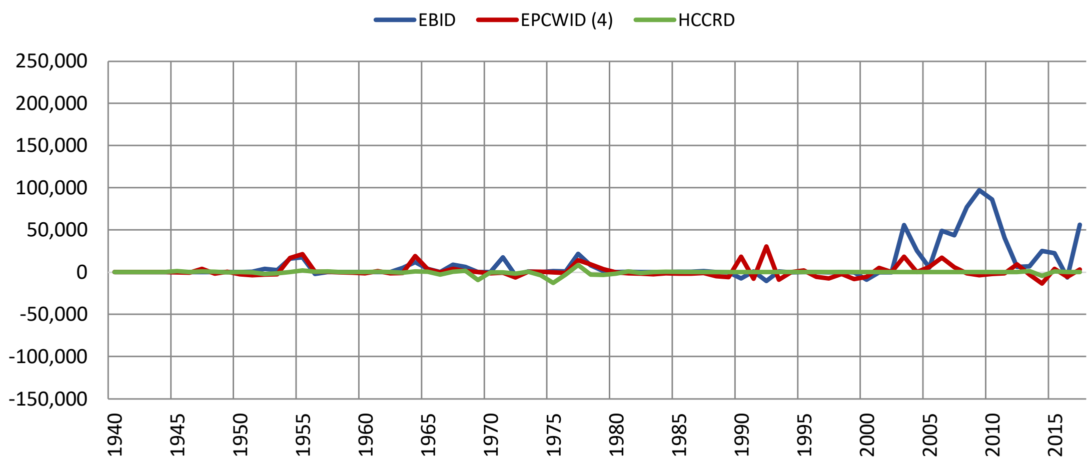
1940 - 2017 (acre-feet)

River Headgate (RHG) Diversions (Irrigation Season)



	Average Difference		
Period	EBID	EPCWID	HCCRD
1951-2017	18,365	-15,097	-3,105
1951-1978	7,544	-4,272	-1,724
1979-2005	5,584	-26,551	-4,229
2006-2017	72,375	-14,581	-3,801
1985-2017	30,882	-22,672	-3,405
1985-2005	7,172	-27,296	-3,179

Farm Headgate (FHG) Deliveries (Irrigation Season)



	Average Difference		
Period	EBID	EPCWID	HCCRD
1951-2017	10,274	1,382	-471
1951-1978	4,307	2,456	-860
1979-2005	2,385	568	-191
2006-2017	41,947	707	-191
1985-2017	17,149	846	-69
1985-2005	2,979	926	0

Notes:

(1) EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

(2) EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

(3) HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

(4) EPCWID FHG values include deliveries to Rogers WTP and R/U WTP.

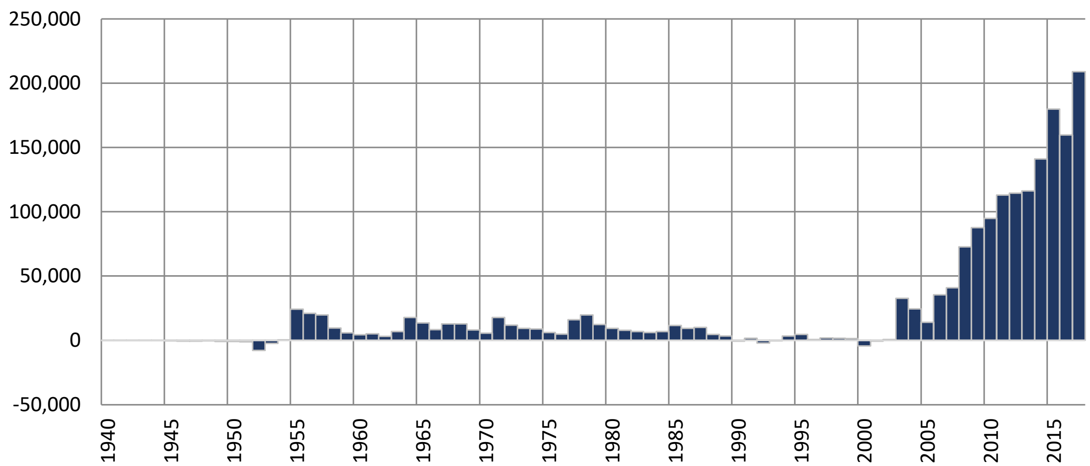
Run 15 - Early EPCWID Ops (WWTP & Fabens Drain)

Simulated Differences in ILRG Model Outputs

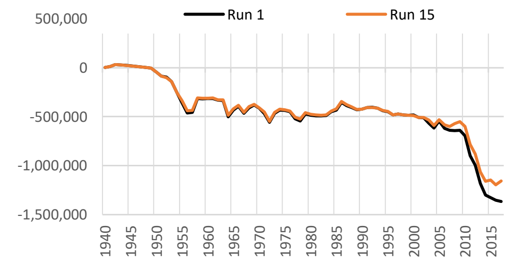
Run 15 minus Run 1

1940 - 2017 (acre-feet)

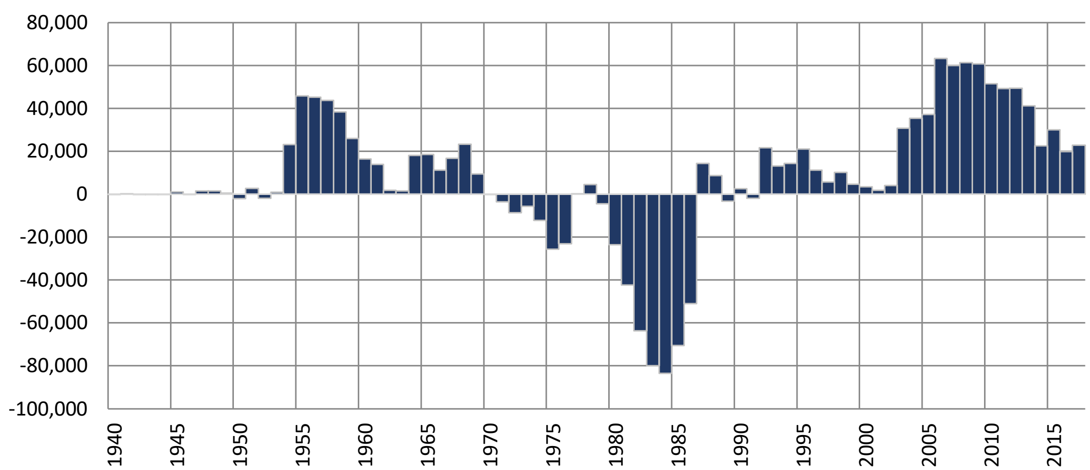
Cumulative Annual Rincon-Mesilla Groundwater Storage



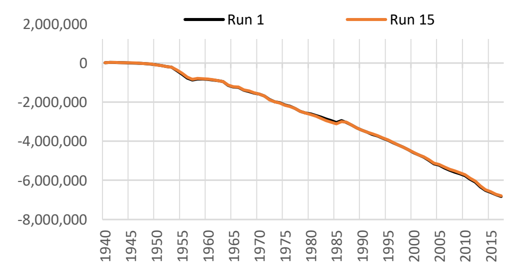
Period	Average Difference
1951-2017	3,131
1951-1978	733
1979-2005	-206
2006-2017	16,235
1985-2017	6,126
1985-2005	349



Cumulative Annual Hueco Groundwater Storage



Period	Average Difference
1951-2017	371
1951-1978	236
1979-2005	1,208
2006-2017	-1,196
1985-2017	3,221
1985-2005	5,744



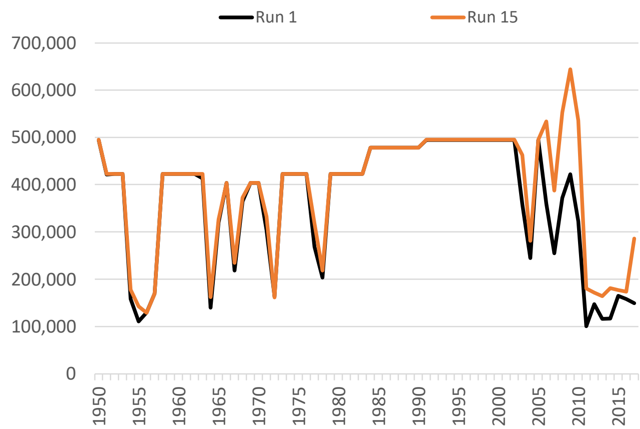
Notes:

Cumulative storage change in alluvial and non-alluvial aquifers.

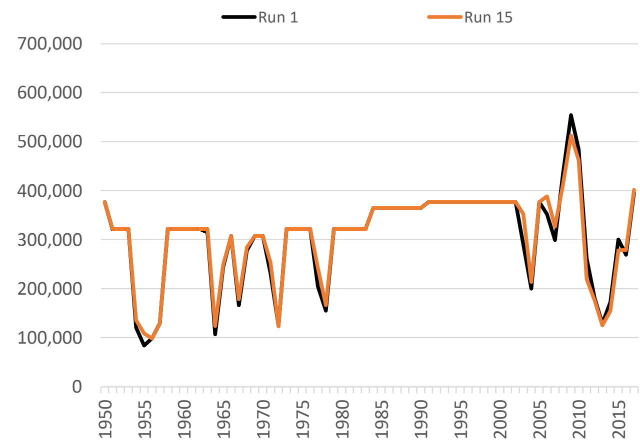
Average differences calculated as (Final Storage - Initial Storage)/(no. years).

Run 15 - Early EPCWID Ops (WWTP & Fabens Drain)
Annual Allocation and Charges
Run 15 v. Run 1
ILRG Model
1950 - 2017 (acre-feet)

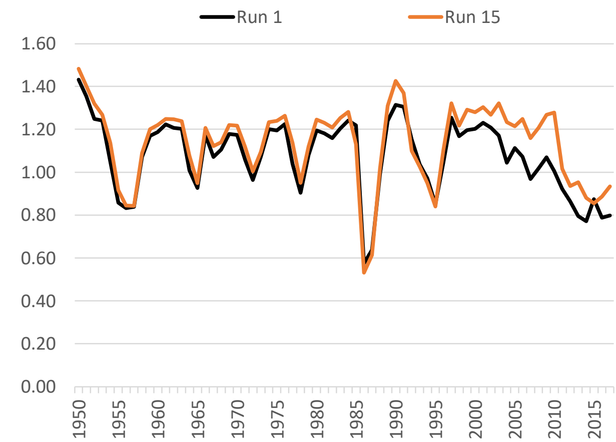
Total Allocation - EBID



Total Allocation - EPCWID

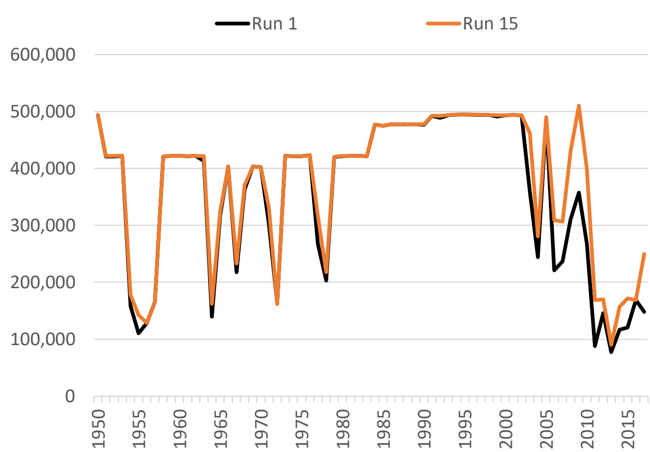


Diversion Ratio

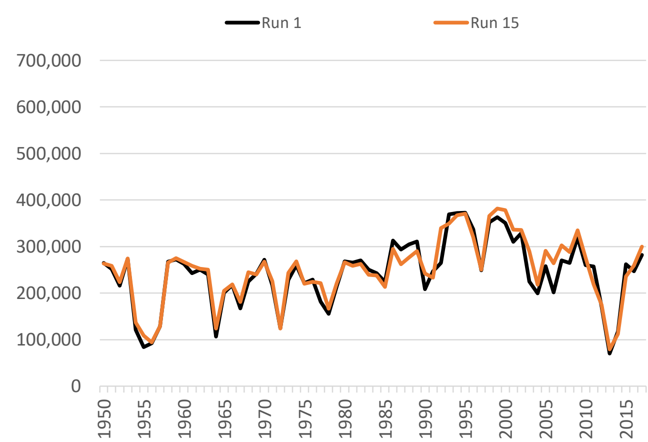


Note:
Computed as Total Charges/Caballo Release.

Annual Delivery Charges - EBID

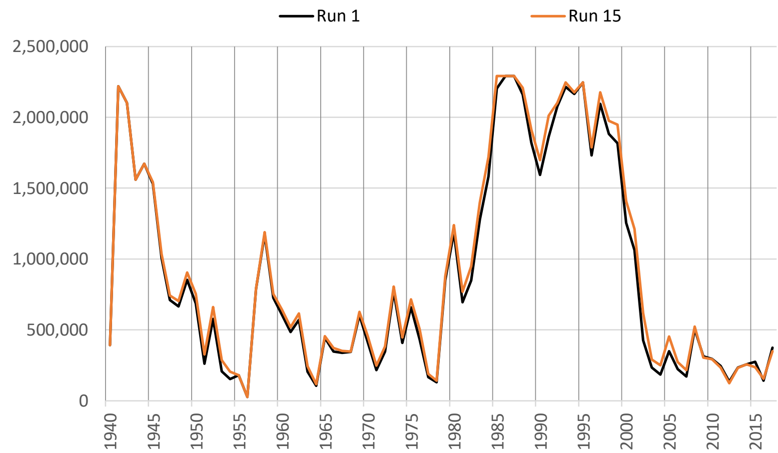


Annual Delivery Charges - EPCWID

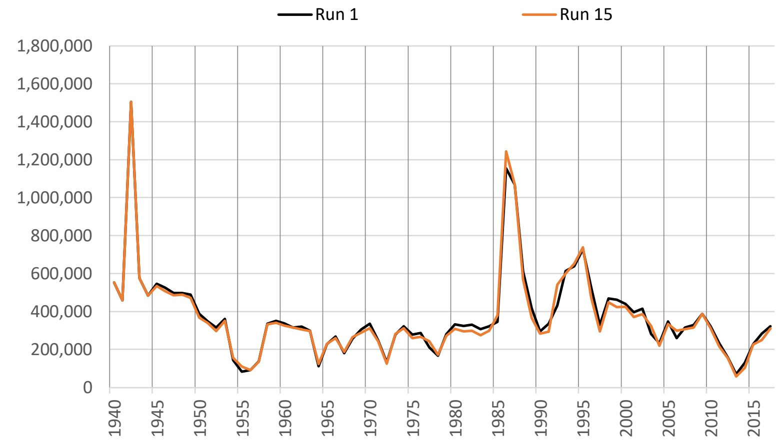


Run 15 - Early EPCWID Ops (WWTP & Fabens Drain)
Annual Summary of Project Storage and Rio Grande Flows
Run 15 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

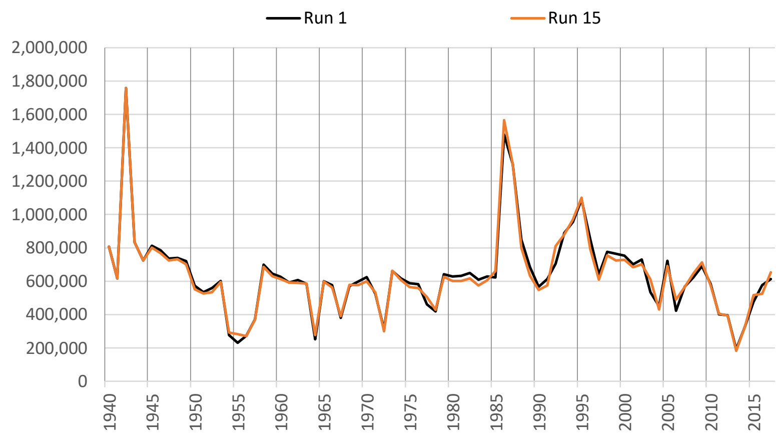
Total Year-End Project Reservoir Storage



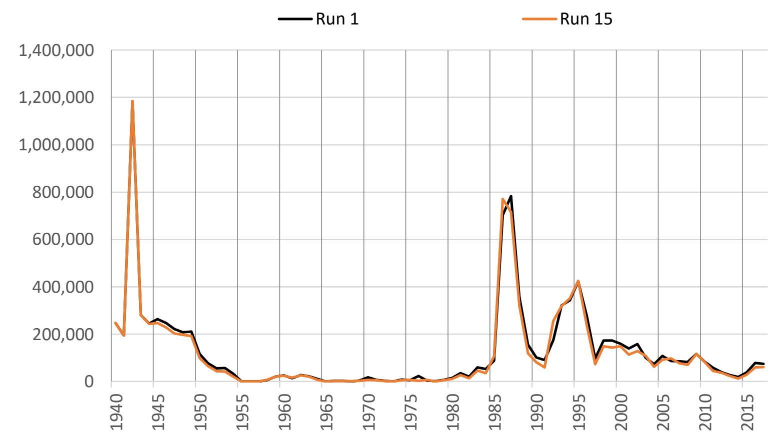
Rio Grande at El Paso



Rio Grande Below Caballo



Rio Grande at Fort Quitman

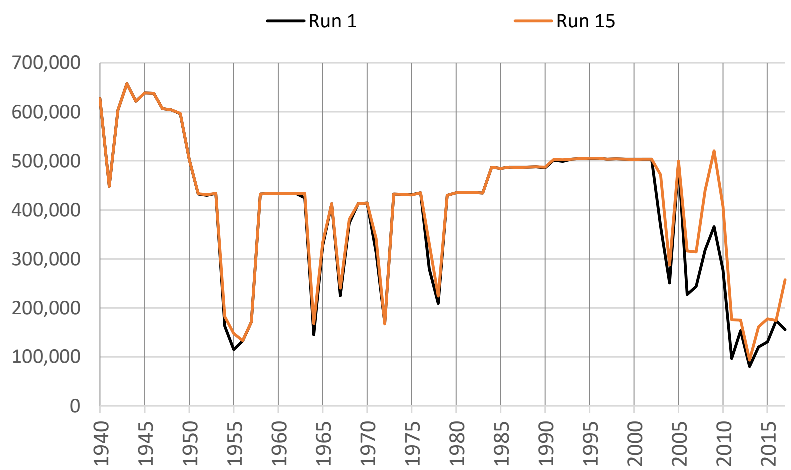


***Note different scales.**

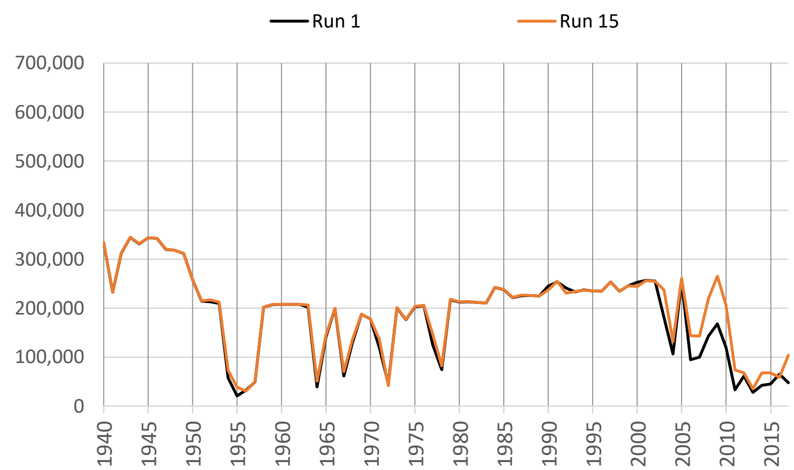
Run 15 - Early EPCWID Ops (WWTP & Fabens Drain)
Irrigation Season Summary of Irrigation Operations
Run 15 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

EBID Total

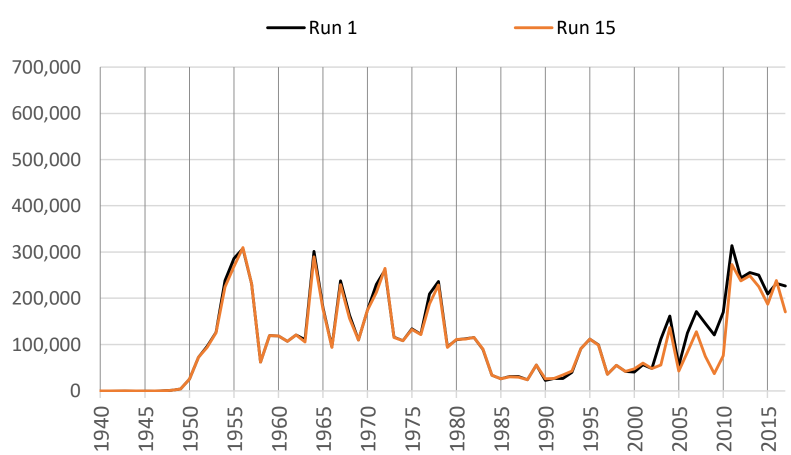
Net River Headgate Diversions



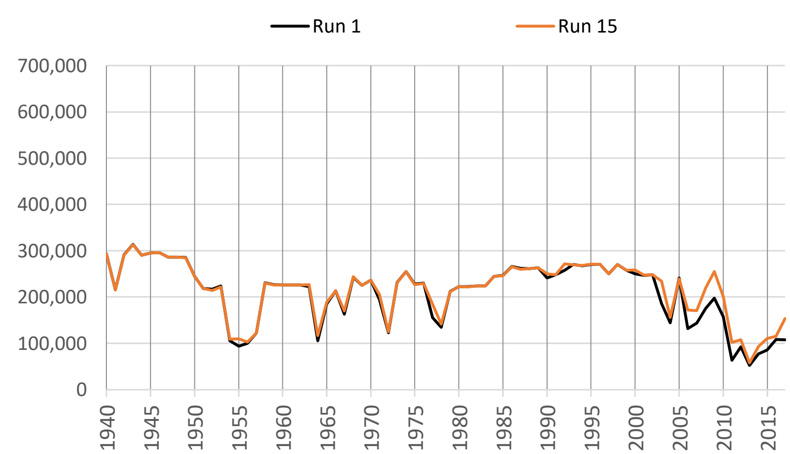
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries



Notes: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).
Pumping includes Supplemental and Primary groundwater pumping.

Run 15 - Early EPCWID Ops (WWTP & Fabens Drain)

Irrigation Season Summary of Irrigation Operations

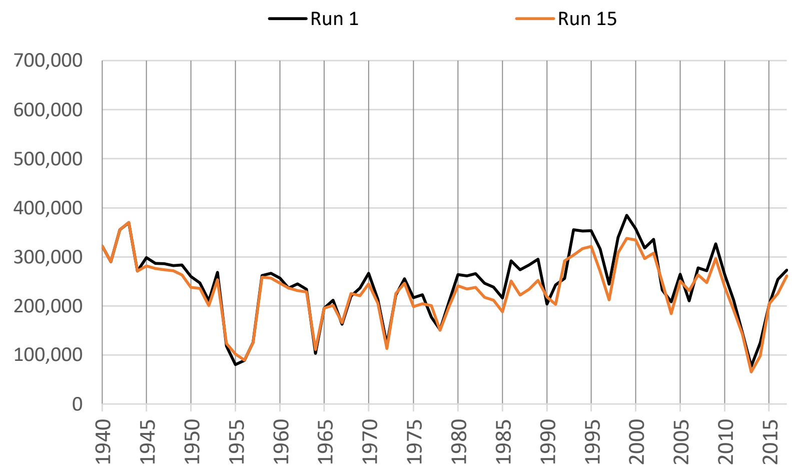
Run 15 v. Run 1

ILRG Model

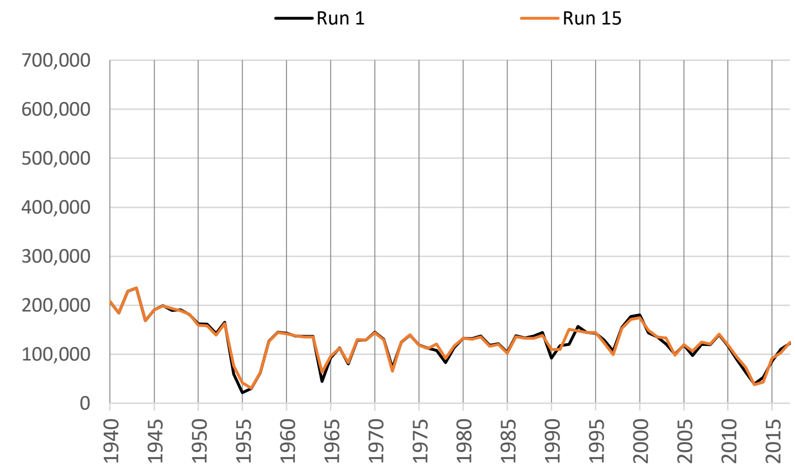
1940 - 2017 (acre-feet)

EPCWID Total

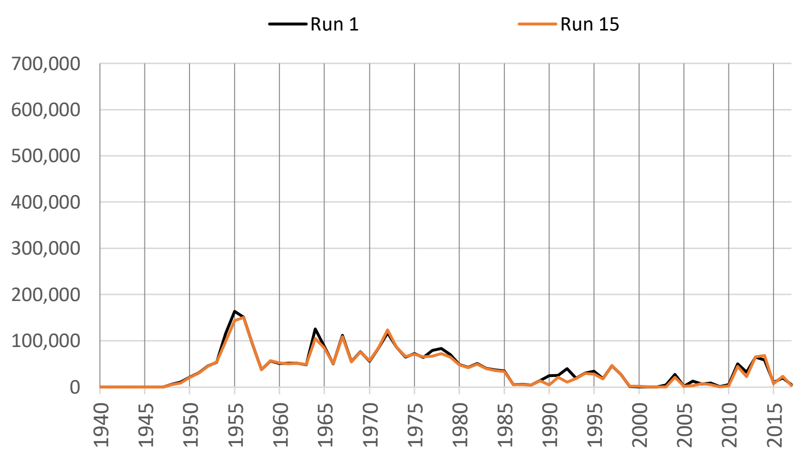
Net River Headgate Diversions



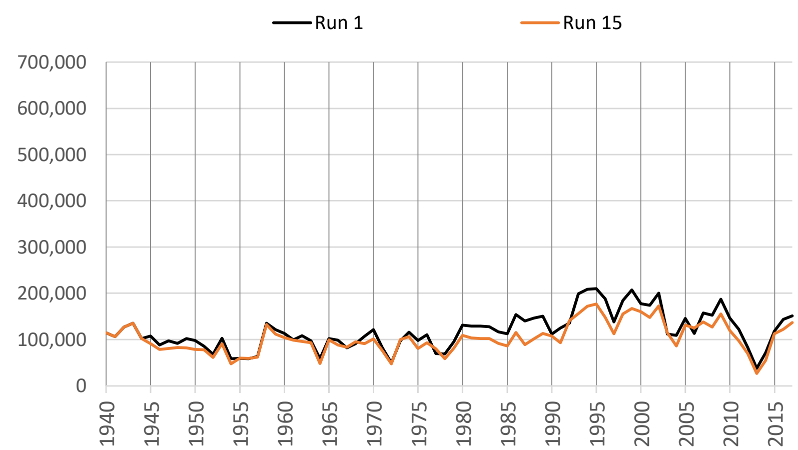
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries

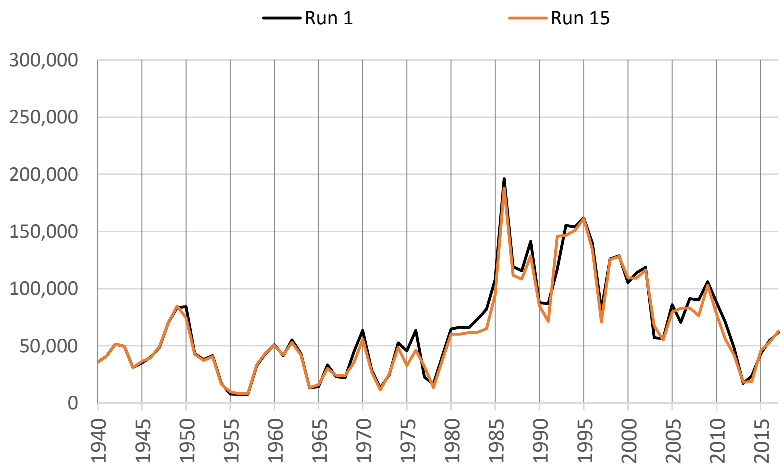


Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

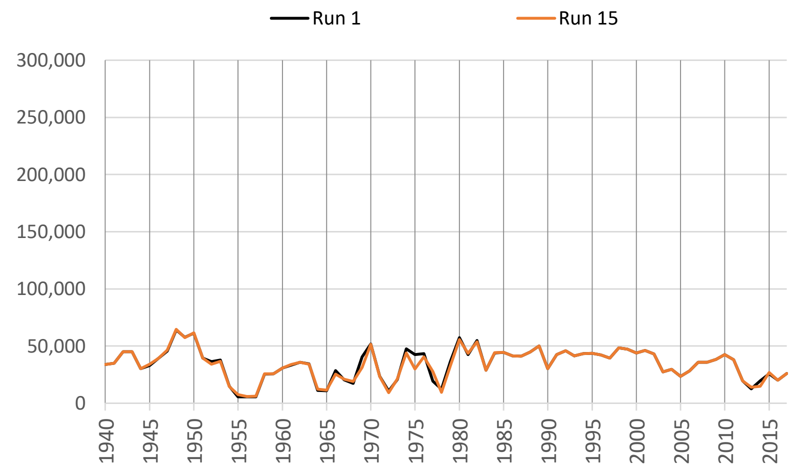
Run 15 - Early EPCWID Ops (WWTP & Fabens Drain)
Irrigation Season Summary of Irrigation Operations
Run 15 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

HCCRD Total

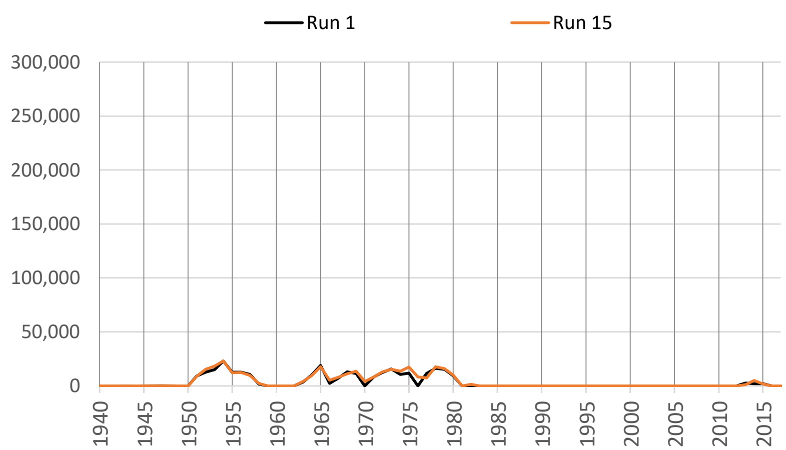
Net River Headgate Diversions



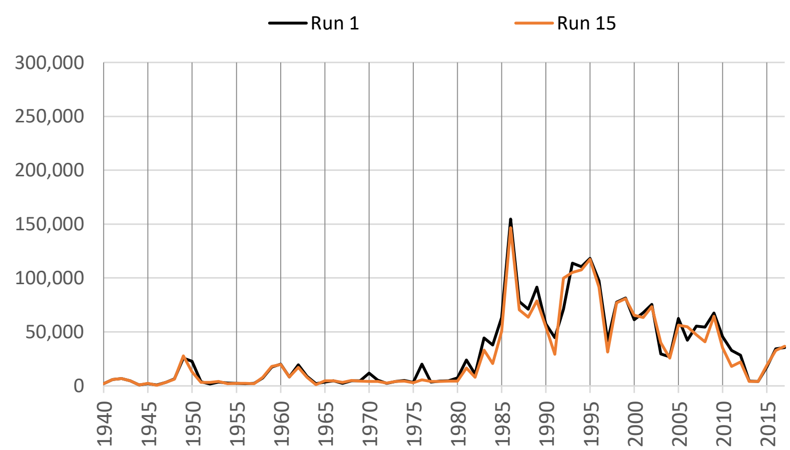
Farm Headgate Deliveries



Pumping



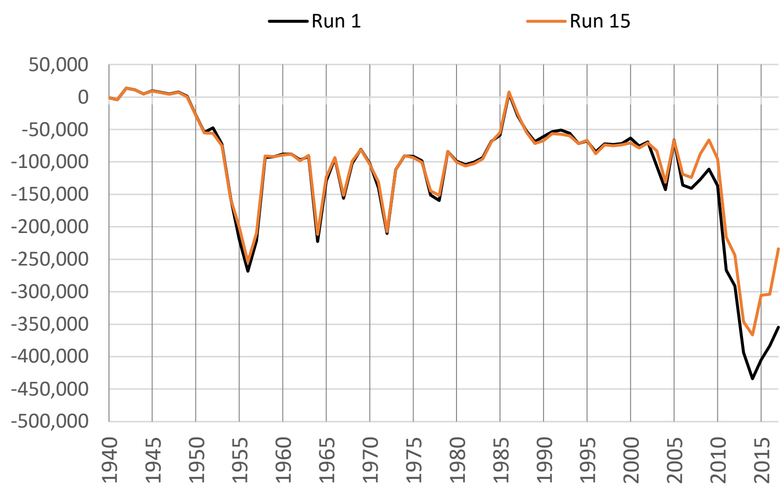
RHG Diversions - FHG Deliveries



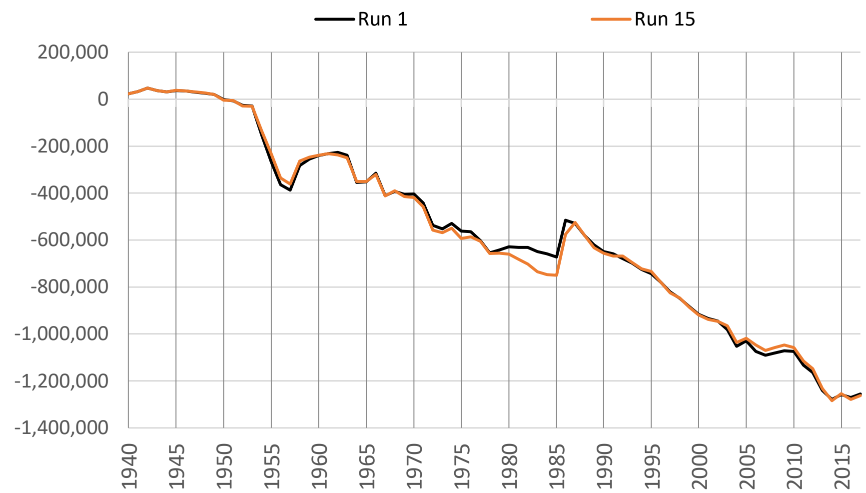
Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

Run 15 - Early EPCWID Ops (WWTP & Fabens Drain)
Cumulative Change in Ground Water Storage
Run 15 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

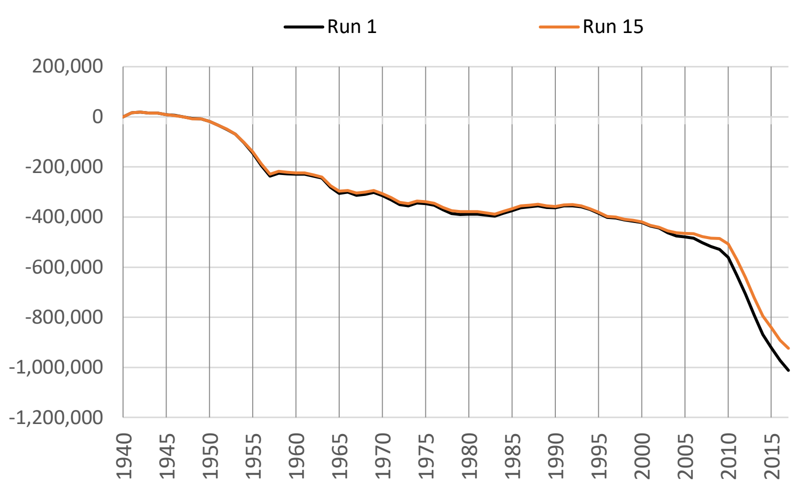
Rincon-Mesilla Alluvial Aquifer



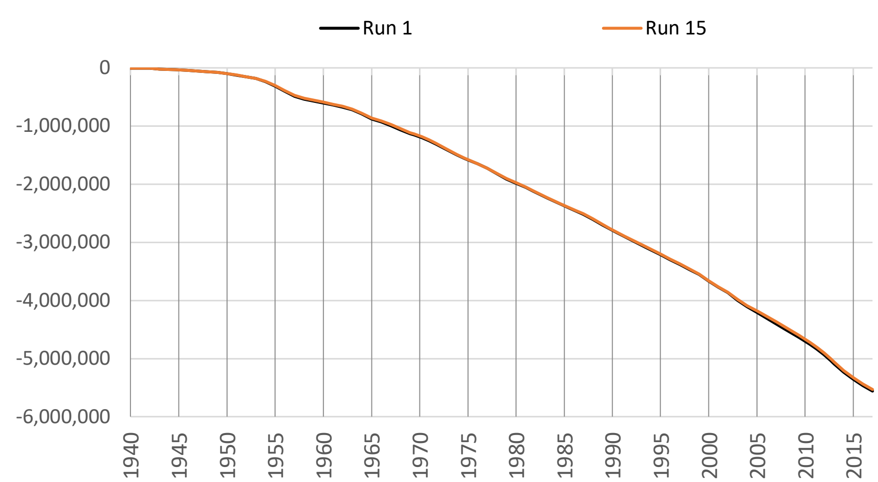
Hueco Alluvial Aquifer



Rincon-Mesilla Non-Alluvial Aquifer

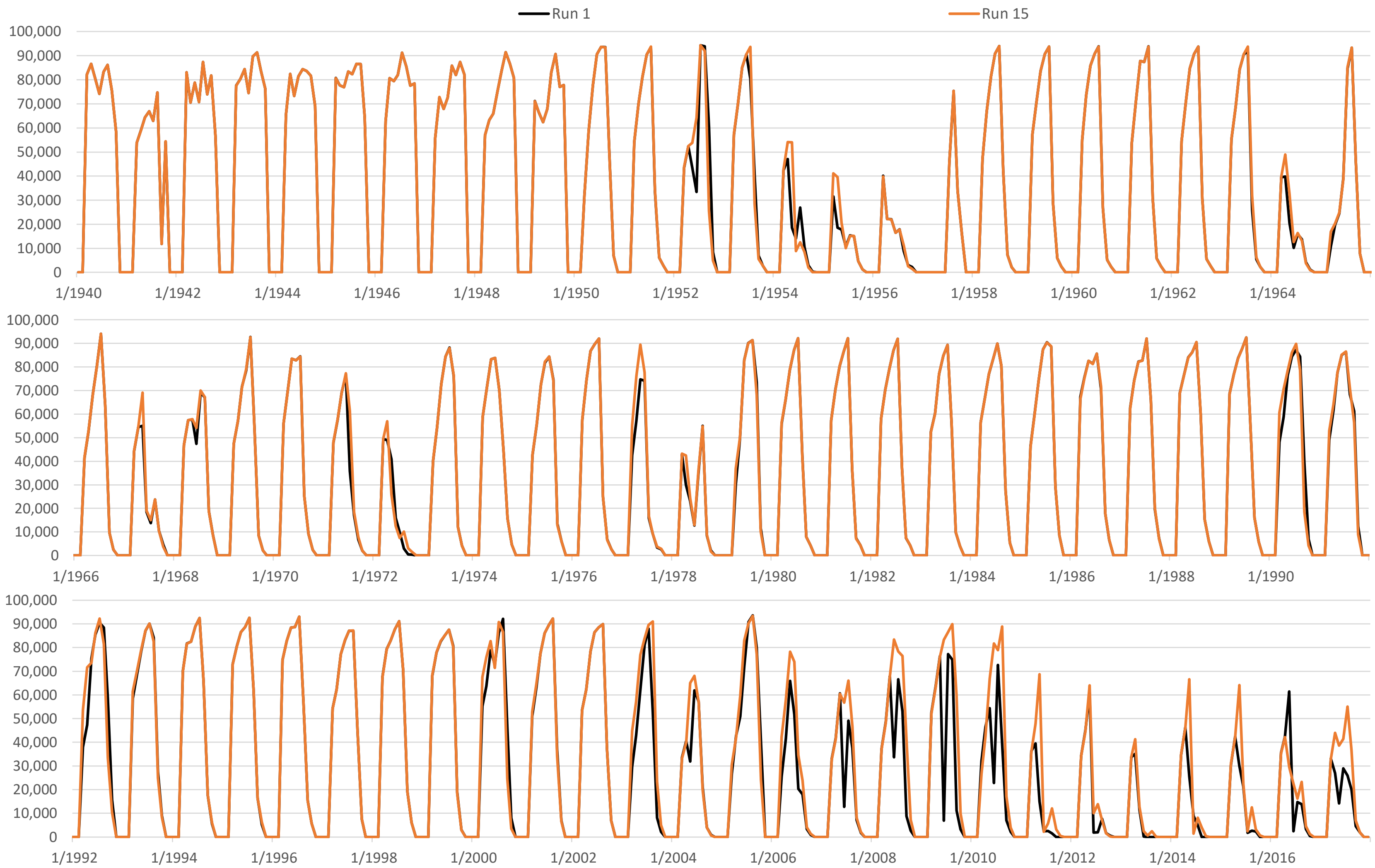


Hueco Non-Alluvial Aquifer



***Note different scales.**

Run 15 - Early EPCWID Ops (WWTP & Fabens Drain)
Monthly Net RHG Diversions
Run 15 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
EBID Total

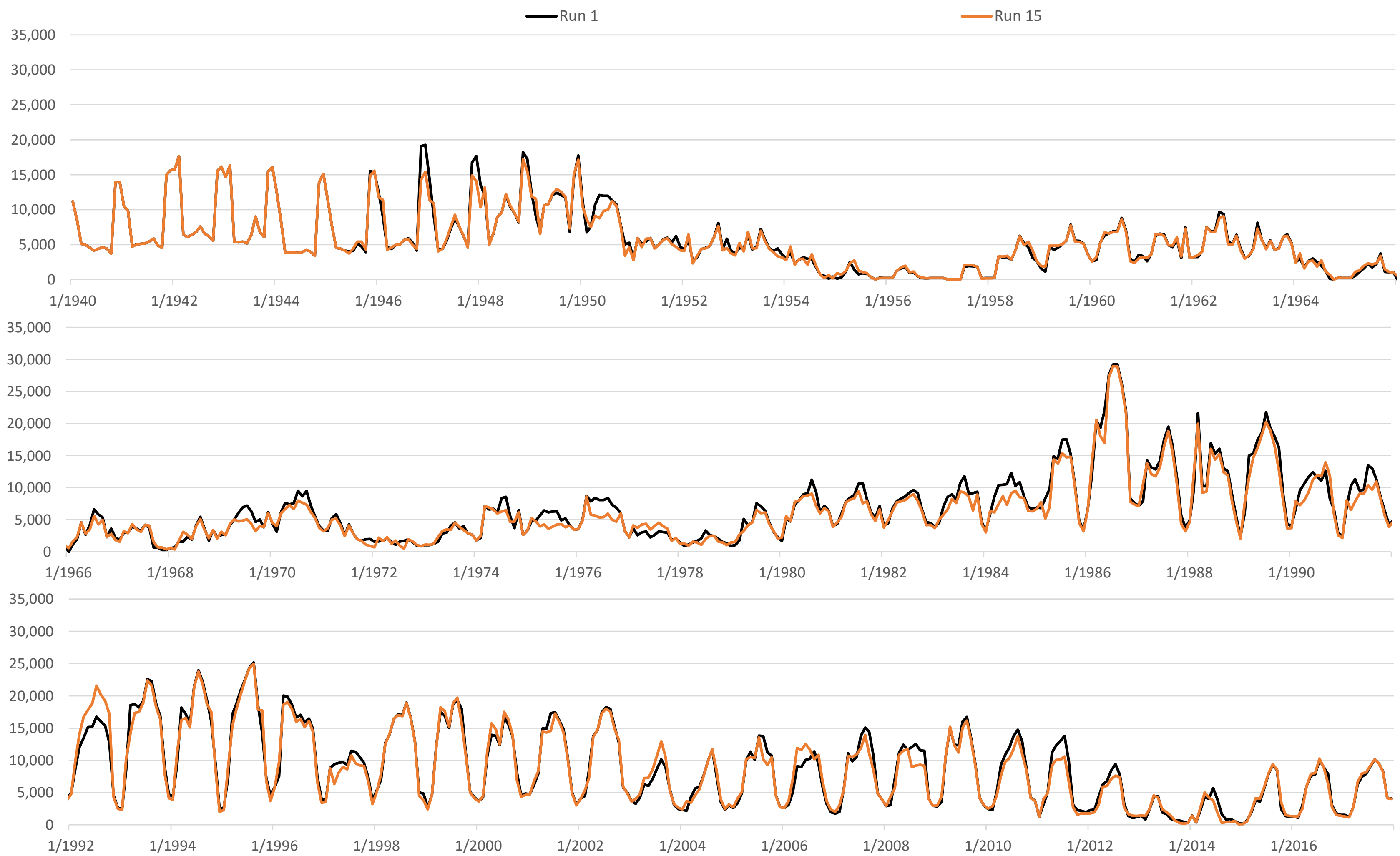


Note: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

Run 15 - Early EPCWID Ops (WWTP & Fabens Drain)
Monthly Net RHG Diversions
Run 15 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
EPCWID Total

Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

Run 15 - Early EPCWID Ops (WWTP & Fabens Drain)
Monthly Net RHG Diversions
Run 15 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
HCCRD Total



Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

Run 15 - Early EPCWID Ops (WWTP & Fabens Drain)

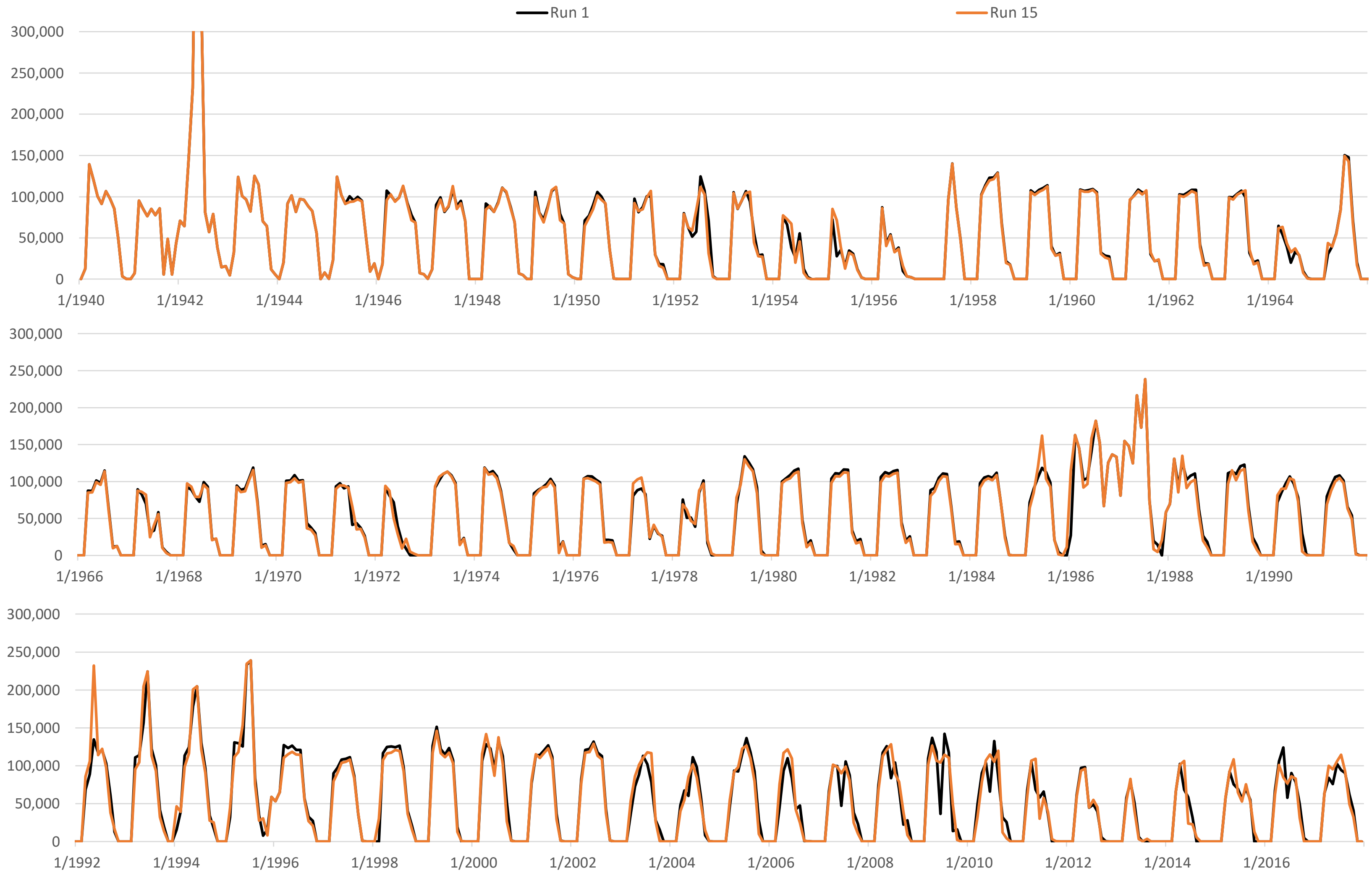
End of Month Reservoir Storage (Elephant Butte + Caballo)

Run 15 v. Run 1

ILRG Model

1940 - 2017 (acre-feet)

Run 15 - Early EPCWID Ops (WWTP & Fabens Drain)
Monthly Caballo Releases
Run 15 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)



Run 15 - Early EPCWID Ops (WWTP & Fabens Drain)

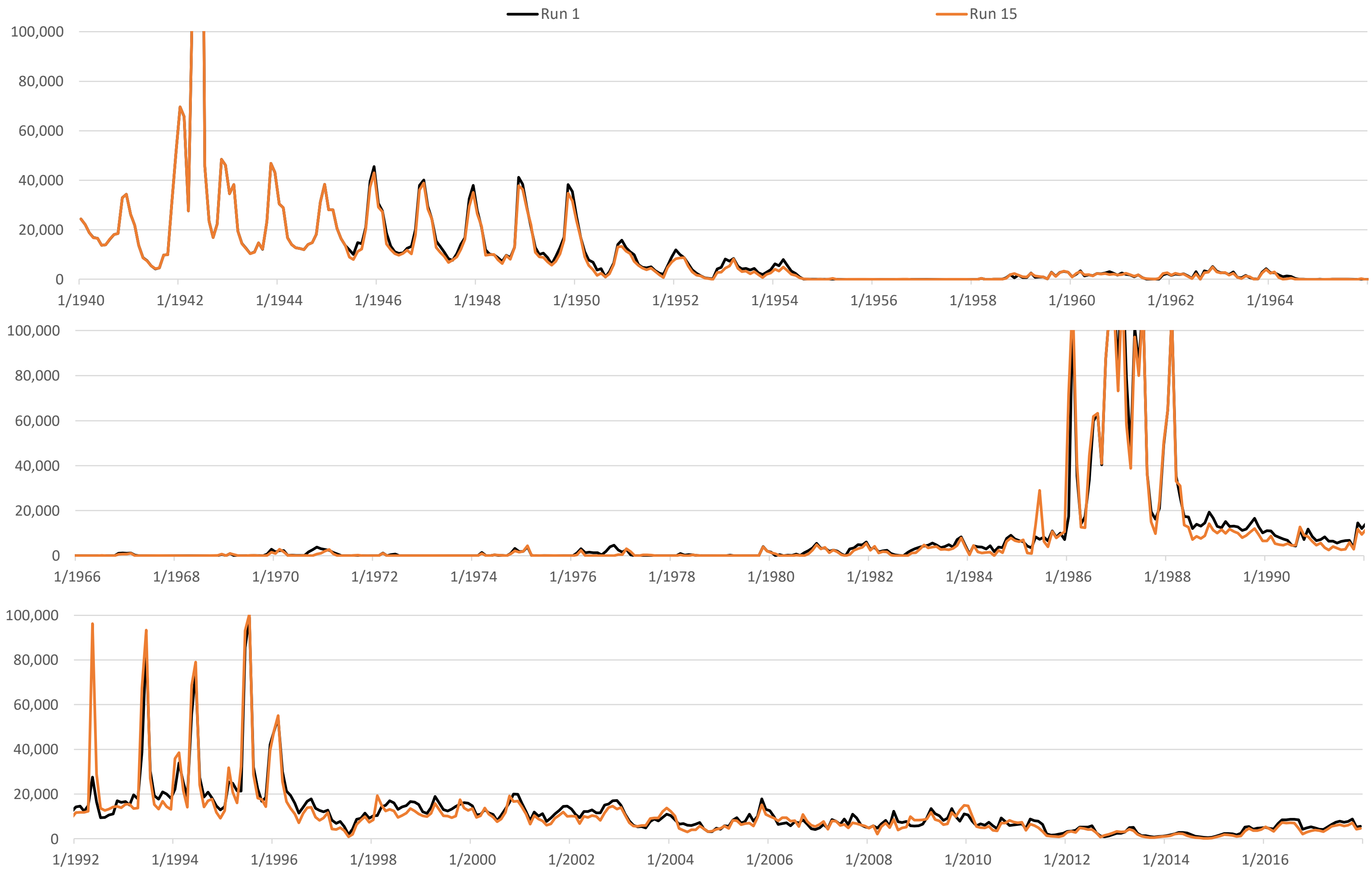
Monthly Rio Grande at El Paso Flow

Run 15 v. Run 1

ILRG Model

1940 - 2017 (acre-feet)

Run 15 - Early EPCWID Ops (WWTP & Fabens Drain)
Monthly Rio Grande at Fort Quitman Flow
Run 15 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)



Appendix 30T

Comparison of ILRG Model Runs
Run 15a v. Run 1

Model Run Specifications

Model Version: LRG_v116

Name: **Run 15a - Early EPCWID Ops (WWTP)**

Run ID: LRG_v116_Operational_Run15a
Date: 8/28/2020

Name: **Run 1 - Historical Base Run (All Pumping On)**

Run ID: LRG_v116_Operational_Run1
Date: 8/23/2020

Selected Model Inputs

Pumping and Returns	Run 15a	Run 1
Irrigation Pumping	On	On
Irrigated Area	Hist	Hist
Non-Irrigation Pumping	On	On
Non-Irrigation Pumping Returns	On	On
Las Cruces Jornada Pumping Returns	On	On

Project Allocation Rules		
1950-2005	D1/D2	D1/D2
2006-2007	D3	D3
2008-2017	D3 + CO	D3 + CO

EPCWID Operations		
Charge EPCWID for Use of WWTP Returns	On	Off
ACE and Haskell Credits for EPCWID	Off	On
Increased EPCWID Use of Fabens Drain Flows	Off	Off
Charge EPCWID for Fabens Drain Flow Use	Off	Off

Run 15a - Early EPCWID Ops (WWTP)
Comparison of ILRG Model Runs
Run 15a v. Run 1
1951 - 2017 Annual Average
(1,000 acre-feet)

Run No.	1	15a	15a - 1	
Simulated Input or Output	**Run 1**	**Run 15a**	**Run 15a minus Run 1**	
Effects of Alternate Scenario				
FHG Deliveries (Mar - Oct)				***% Diff.***
EBID	167.6	172.6	5.0	*3%*
EPCWID (incl. EPW)	139.9	138.0	-1.9	*-1%*
HCCRD	32.8	32.8	-0.1	*0%*
Total	340.3	343.4	3.0	*1%*
FHG Deliveries (Nov - Feb)				
EBID	0.0	0.0	0.0	*-4%*
EPCWID (incl. EPW)	0.2	0.2	0.0	*1%*
HCCRD	2.4	2.4	0.0	*1%*
Total	2.6	2.6	0.0	*1%*
Irrigation Pumping				
EBID	140.4	135.5	-4.9	*-4%*
EPCWID (Mesilla Valley)	7.4	7.3	0.0	*-1%*
EPCWID (El Paso Valley)	40.1	41.2	1.1	*3%*
HCCRD	4.2	4.3	0.1	*2%*
Total	192.1	188.3	-3.8	*-2%*
Other Inflows/Outflows				
Net Reservoir Evaporation	125.3	125.2	-0.1	*0%*
Riparian ET	70.9	70.8	-0.1	*0%*
River Evaporation + Incidental Canal Loss	30.3	30.4	0.1	*0%*
Total	226.6	226.4	-0.1	*0%*
Rio Grande at Fort Quitman				
Reservoir Spills	33.3	34.1	0.8	*2%*
Nov-Feb Flows	21.4	20.5	-0.9	*-4%*
Mar - Oct Flows	41.1	40.8	-0.2	*-1%*
Underflow (GW Model)	0.2	0.2	0.0	*0%*
Total	96.0	95.6	-0.4	*0%*

Run 15a - Early EPCWID Ops (WWTP)
Comparison of ILRG Model Runs
Run 15a v. Run 1
1951 - 2017 Annual Average
(1,000 acre-feet)

Run No.	1	15a	15a - 1	
Simulated Input or Output	**Run 1**	**Run 15a**	**Run 15a minus Run 1**	
Effects of Alternate Scenario (continued)				
Change in Storage				***% Diff.***
Reservoir Storage	-4.7	-5.2	-0.6	*12%*
Alluvial GW Storage (RW Model)	-23.6	-22.6	1.0	*-4%*
Non-alluvial GW Storage (GW Models)	-96.4	-96.3	0.0	*0%*
Soil Moisture Storage	0.6	0.6	0.0	*-6%*
Total	-124.0	-123.6	0.5	*0%*
Summary of Effects				
FHG Deliveries (Mar-Oct)	340.3	343.4	3.0	*1%*
FHG Deliveries (Nov-Feb)	2.6	2.6	0.0	*1%*
Irrigation Pumping	192.1	188.3	-3.8	*-2%*
Riparian ET + Evaporation	226.6	226.4	-0.1	*0%*
Fort Quitman Flow	96.0	95.6	-0.4	*0%*
Change in Storage	-124.0	-123.6	0.5	*0%*
Total	733.6	732.7	-0.8	*0%*
Other Effects of Alternate Scenario				
Rio Grande at El Paso				***% Diff.***
Reservoir Spills	49.4	50.3	0.9	*2%*
Nov-Feb Flows	22.8	22.4	-0.4	*-2%*
Mar - Oct Flows	263.8	261.7	-2.1	*-1%*
Total	336.0	334.4	-1.5	*0%*
Rio Grande below Caballo				
Reservoir Spills	65.9	66.8	0.9	*1%*
Nov-Feb Flows	0.5	0.0	-0.5	*-100%*
Mar - Oct Flows	541.3	541.4	0.1	*0%*
Total	607.6	608.2	0.6	*0%*
Surface Water Diversions (Mar - Oct)				
EBID	366.5	374.6	8.1	*2%*
EPCWID (incl. EPW)	236.8	233.9	-2.9	*-1%*
HCCRD	67.5	66.9	-0.7	*-1%*
Total	670.8	675.4	4.6	*1%*
Surface Water Diversions (Nov - Feb)				
EBID	0.0	0.0	0.0	*0%*
EPCWID (incl. EPW)	14.3	14.4	0.0	*0%*
HCCRD	14.2	14.0	-0.2	*-2%*
Total	28.5	28.4	-0.2	*-1%*

Run 15a - Early EPCWID Ops (WWTP)
Annual Differences in ILRG Model Outputs
Run 15a minus Run 1
1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1940	-12	-12	2	0	1	0	0	0	2	1	0	0	-9	-4	-28
1941	-56	-56	0	0	0	0	-1	-1	0	1	0	-1	8	25	-27
1942	-1	-1	-1	0	0	1	1	1	-2	-4	0	0	13	-1	-70
1943	-15	-15	1	6	0	2	-3	-3	2	-12	-1	-1	-2	0	-70
1944	-15	-15	-134	-128	-69	-68	-1	-1	11	-1	-59	-59	-144	-140	-61
1945	-15	-15	11	19	2	6	-1	-1	9	1	2	2	10	10	-1
1946	-6	-6	6	6	1	1	-1	-1	4	3	1	1	8	7	-5
1947	-13	-13	5	8	-34	-20	-1	-1	3	-20	-34	-34	4	3	5
1948	-11	-11	12	11	4	7	-1	-1	14	8	1	1	12	13	22
1949	-15	-15	1	1	-1	0	0	0	2	1	0	0	1	1	60
1950	-3	-3	-3	-3	0	0	-11	-11	-2	-2	0	0	-3	-6	-21
1951	33	33	4	4	1	1	-25	-25	2	2	0	1	5	4	-41
1952	0	0	13	14	5	7	-17	-17	0	0	5	6	-6	9	-77
1953	4	4	1	1	2	2	16	16	1	1	2	-2	-2	-2	-44
1954	26	26	133	139	123	63	57	57	12	12	305	234	56	25	10
1955	-7	-7	-19	-14	-60	-89	-56	-56	-125	-125	-90	-132	-87	-39	0
1956	28	28	5	5	-1	-2	129	129	69	69	8	7	50	5	0
1957	-1	-1	-1	-2	0	-1	-2	-2	1	1	34	32	-3	-1	0
1958	4	4	-45	-44	-5	-14	0	0	3	-4	14	19	-20	-47	-55
1959	3	3	-15	-16	-21	-43	10	10	3	3	0	2	-26	-25	2
1960	2	2	-6	-7	0	0	5	5	2	2	0	0	-10	-13	16
1961	5	5	-2	-3	-1	-1	4	4	0	0	-2	2	-14	-9	-6
1962	-6	-6	-33	-33	-2	-2	-41	-41	-22	-22	0	1	24	-10	-175
1963	23	23	-7	-6	1	1	10	10	-6	-6	0	0	1	5	2
1964	12	12	19	20	1	0	23	23	9	10	2	1	-16	17	-57
1965	29	29	-26	-26	10	-90	-2	-2	533	533	109	9	-16	-50	15
1966	-6	-6	-12	-12	-124	-197	-10	-10	6	6	-150	127	-71	-26	-122
1967	357	357	-1,668	-1,690	-117	-142	675	675	-1,143	-1,094	-378	-274	-1,856	-2,269	-46
1968	1,322	1,322	447	956	9	-50	808	808	-35	104	17	47	991	1,224	4
1969	-1	-1	23	41	-23	-16	14	14	-4	-4	-23	-22	-200	74	4
1970	1	1	14	15	-4	-8	6	6	3	3	5	7	-4	8	-16
1971	521	521	-168	-168	-13	-33	377	377	4	4	16	1	28	-127	-11
1972	-5,700	-5,700	-6,757	-6,761	-1,025	-1,049	553	553	-2,870	-2,864	-778	-760	-13,370	-3,997	0
1973	10	10	770	760	-632	-619	-262	-262	-31	-27	-585	-432	5,421	473	-1
1974	15	15	153	101	80	38	-71	-71	-7	-8	25	-71	1,036	-33	176
1975	-4	-4	55	35	-113	-130	91	91	-3	-4	-194	-208	265	-50	-17
1976	8	8	44	29	-50	-81	-18	-18	0	0	0	0	309	-10	-73
1977	2,640	2,640	40	122	1	7	1,392	1,392	73	73	10	22	1,535	372	-16
1978	1,306	1,306	-7,081	-7,099	-842	-688	615	615	-3,996	-3,997	-889	-645	-6,798	-5,484	66

Run 15a - Early EPCWID Ops (WWTP)
Annual Differences in ILRG Model Outputs
Run 15a minus Run 1
1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1979	364	364	1,521	1,509	-869	-1,079	235	234	2,800	2,799	-910	-1,125	2,144	2,823	-450
1980	61	61	-27	-128	-299	-529	72	71	-64	-65	-289	-511	975	-311	-5
1981	-3	-3	14	-5	-74	-109	-5	-5	-5	-5	0	0	273	-37	-141
1982	-7	-7	8	5	-30	-49	5	5	-3	-3	8	25	75	4	-120
1983	-8	-8	4	4	-25	-38	3	3	-4	-4	0	0	62	14	-43
1984	-10	-10	6	7	-34	-44	4	4	1	1	0	0	56	26	-45
1985	-21	-21	-9	-7	-6	-13	-7	-7	-11	-12	0	0	80	60	-3
1986	-11	-11	6	7	15	17	56	57	7	7	0	0	2,367	2,288	781
1987	-20	-20	-19	-19	-9	-15	-18	-18	-12	-12	0	0	1	26	-890
1988	-5	-5	0	0	-7	-11	18	18	-2	-1	0	0	84	67	40
1989	-7	-7	0	2	-6	-9	5	5	0	-1	0	0	177	44	4
1990	-11	-11	3	5	-3	-6	6	6	2	2	0	0	19	74	-6
1991	-49	-49	-16	-15	-13	-12	-64	-64	-13	-12	0	0	53	79	-38
1992	-117	-117	-139	-130	-71	-80	432	431	18	16	0	0	527	242	220
1993	-359	-359	-6,125	-6,114	-1,320	-1,498	188	187	-3,924	-3,927	0	0	-11,179	-9,138	-4,819
1994	-687	-687	-4,228	-4,212	-624	-1,273	20	21	-2,150	-2,153	0	0	-6,604	-4,214	-2,576
1995	-583	-583	-3,831	-3,855	-1,477	-1,974	171	172	-1,488	-1,548	0	0	16,579	13,840	9,630
1996	13	13	330	334	77	-7	-2	-2	0	-1	0	0	618	444	-617
1997	-10	-10	69	69	17	16	-5	-5	7	2	0	0	145	94	-5
1998	-10	-10	29	27	12	7	27	27	2	2	0	0	97	49	18
1999	-671	-671	-27,414	-27,420	-4,198	-4,841	1,799	1,799	-14,025	-14,030	0	0	-13,161	-11,327	1,514
2000	-2,511	-2,511	-3,169	-3,208	-401	-905	-503	-503	-589	-594	0	0	11,450	12,359	8,876
2001	57	57	11,315	11,271	2,003	1,909	-175	-175	7,475	7,473	0	0	12,428	10,633	3,071
2002	-13	-13	38	34	37	51	-27	-27	0	-1	0	0	145	54	304
2003	-8,312	-8,312	-2,145	-2,220	-248	-271	-5,029	-5,029	-1,659	-1,661	0	0	-6,963	-3,777	-311
2004	-1,367	-1,367	-36,958	-37,115	-6,192	-7,360	557	557	-22,083	-22,088	0	0	-36,577	-30,318	-9,046
2005	3,101	3,101	6,052	5,972	-865	-1,775	4,296	4,281	3,315	3,308	0	0	812	1,523	-9,210
2006	48,251	48,251	-2,028	-2,073	3,731	3,423	23,446	23,446	-9,543	-9,544	0	0	26,355	11,546	10,664
2007	29,118	29,118	-22,247	-22,335	-4,528	-6,009	17,081	17,081	-12,916	-12,912	0	0	-16,640	-16,343	-6,893
2008	60,581	60,581	-1,251	-1,014	-1,275	-2,038	40,851	40,851	-2,076	-2,066	0	0	20,134	1,442	-3,576
2009	99,699	99,699	-8,633	-8,289	-1,737	-1,640	61,522	61,522	-6,369	-6,345	0	0	21,213	-714	3,510
2010	99,846	99,846	-7,237	-6,094	-1,078	-786	65,702	65,702	-5,657	-5,629	0	0	10,979	629	6,281
2011	60,012	60,012	-40,451	-39,976	-11,869	-14,677	36,801	36,801	-26,251	-26,235	-685	-224	-41,716	-43,081	-6,283
2012	18,009	18,009	2,683	2,690	-1,291	-3,261	8,856	8,856	1,992	1,996	992	1,824	13,290	4,218	-7,950
2013	19,749	19,749	-12,601	-12,599	-2,322	-2,603	10,753	10,753	-8,968	-8,967	-788	-1,080	-1,763	-11,756	-2,659
2014	25,941	25,941	-13,193	-13,191	-2,503	-2,684	17,390	17,390	-8,111	-8,111	-2,091	-2,149	2,607	-12,783	-3,298
2015	47,924	47,924	3,465	3,539	-343	-336	23,114	23,114	1,367	1,371	-61	-154	44,811	1,610	-2,486
2016	-21,628	-21,628	-16,833	-16,782	-2,528	-3,334	-15,408	-15,408	-10,108	-10,105	0	0	-53,411	-19,428	-4,966
2017	66,268	66,268	4,891	5,079	-521	-1,005	35,888	35,888	2,486	2,490	0	0	49,546	5,360	-3,442
Averages															
1951-2017	8,107	8,107	-2,869	-2,834	-652	-865	4,960	4,960	-1,852	-1,849	-95	-81	557	-1,547	-379
1951-1978	22	22	-504	-487	-100	-112	153	153	-269	-262	-91	-72	-456	-356	-16
1979-2005	-415	-415	-2,396	-2,415	-541	-737	76	76	-1,200	-1,204	-44	-60	-938	-532	-143
2006-2017	46,147	46,147	-9,453	-9,254	-2,189	-2,912	27,166	27,166	-7,013	-7,005	-219	-149	6,284	-6,608	-1,758
1985-2017	16,430	16,430	-5,444	-5,383	-1,198	-1,606	9,932	9,931	-3,615	-3,615	-80	-54	1,409	-2,915	-732
1985-2005	-552	-552	-3,153	-3,171	-632	-859	83	83	-1,673	-1,678	0	0	-1,376	-805	-146

Notes:

EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

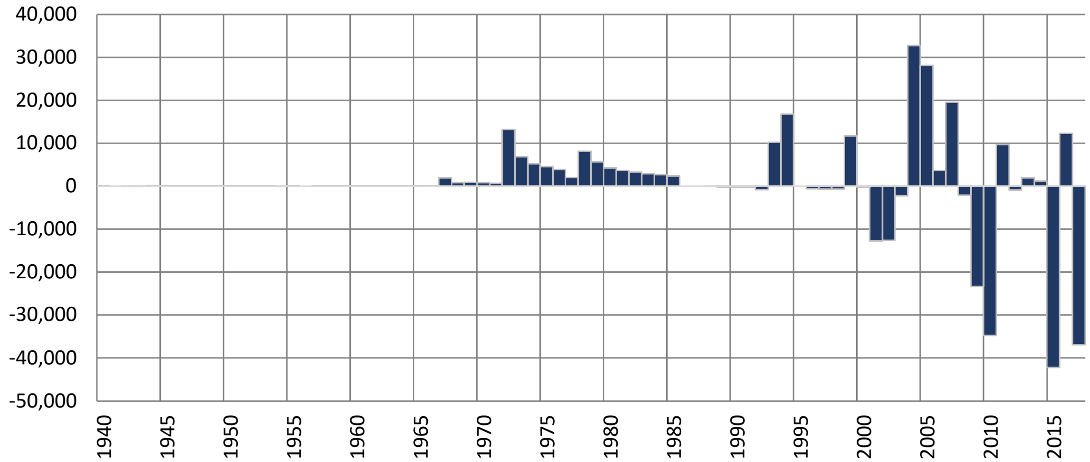
Run 15a - Early EPCWID Ops (WWTP)

Simulated Differences in ILRG Model Outputs

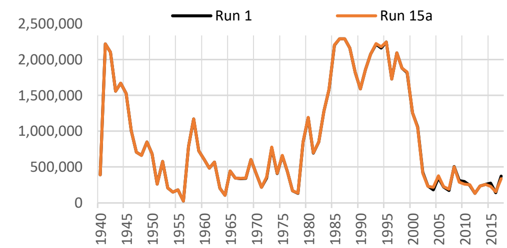
Run 15a minus Run 1

1940 - 2017 (acre-feet)

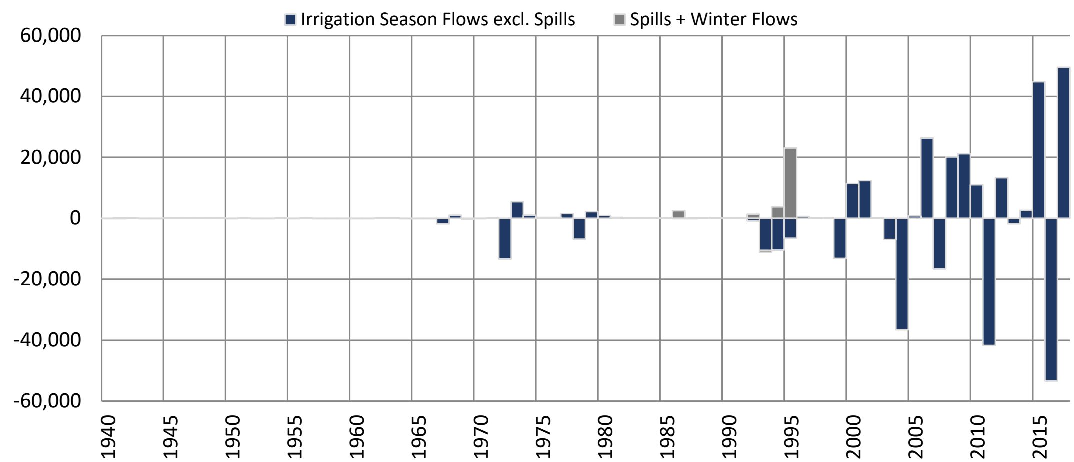
Total Project Storage (Year End)



Period	Average Difference
1951-2017	-551
1951-1978	289
1979-2005	738
2006-2017	-5,415
1985-2017	-1,199
1985-2005	1,210

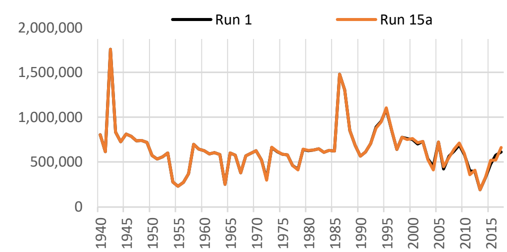


Caballo Reservoir Outflows (Annual)



Average Difference

Period	Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	108	449	557
1951-1978	-456	0	-456
1979-2005	-2,051	1,113	-938
2006-2017	6,284	0	6,284
1985-2017	498	911	1,409
1985-2005	-2,808	1,431	-1,376



Notes:

Reservoir storage does not include storage attributed to SJC, CO, or NM credit waters.

Average differences calculated as (Final Storage - Initial Storage)/(no. years).

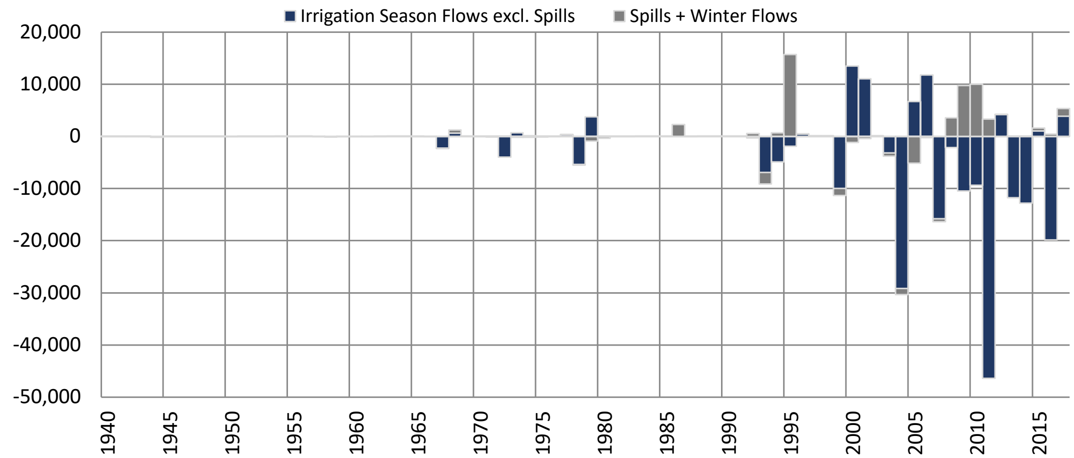
Run 15a - Early EPCWID Ops (WWTP)

Simulated Differences in ILRG Model Outputs

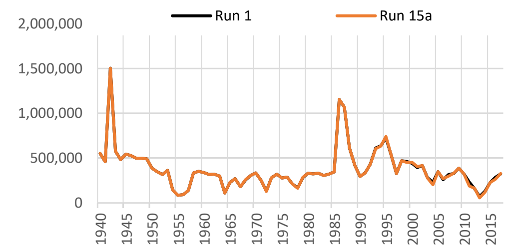
Run 15a minus Run 1

1940 - 2017 (acre-feet)

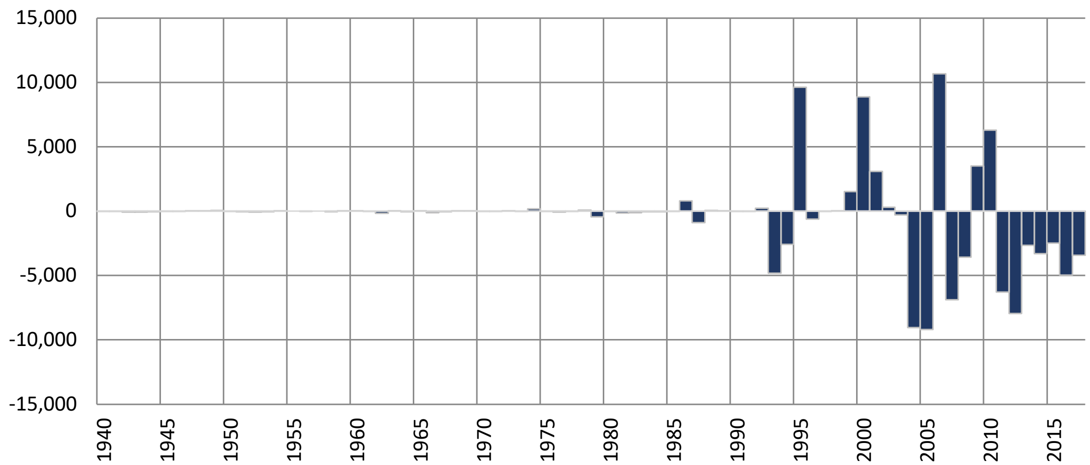
Rio Grande at El Paso (Annual)



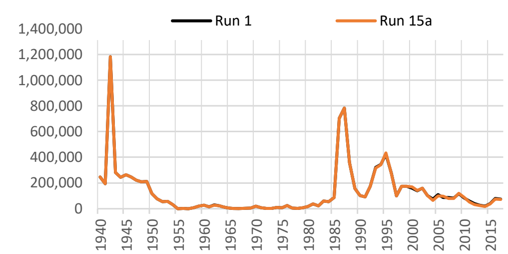
	Average Difference		
Period	Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	-2,065	518	-1,547
1951-1978	-357	1	-356
1979-2005	-766	234	-532
2006-2017	-8,971	2,363	-6,608
1985-2017	-4,005	1,090	-2,915
1985-2005	-1,168	363	-805



Rio Grande at Fort Quitman (Annual)



Period	Average Difference
1951-2017	-379
1951-1978	-16
1979-2005	-142
2006-2017	-1,757
1985-2017	-731
1985-2005	-145



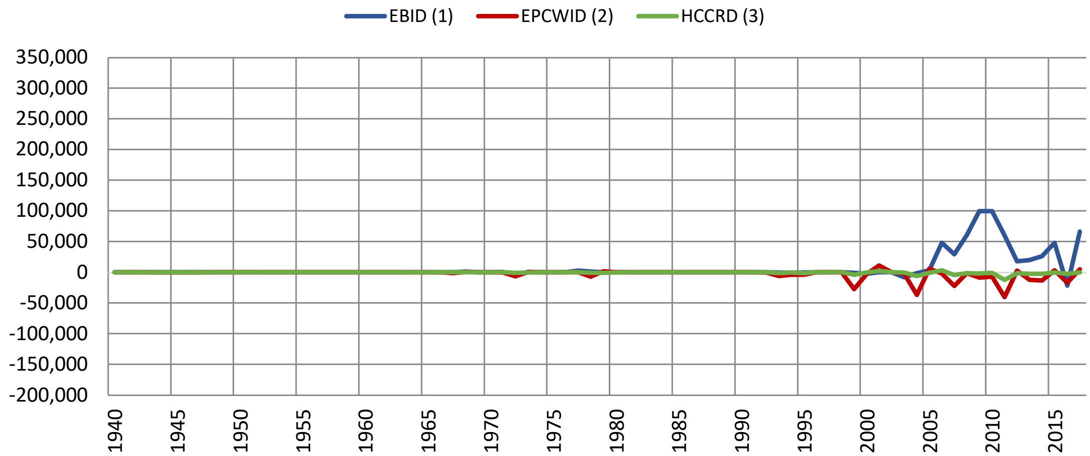
Run 15a - Early EPCWID Ops (WWTP)

Simulated Differences in ILRG Model Outputs

Run 15a minus Run 1

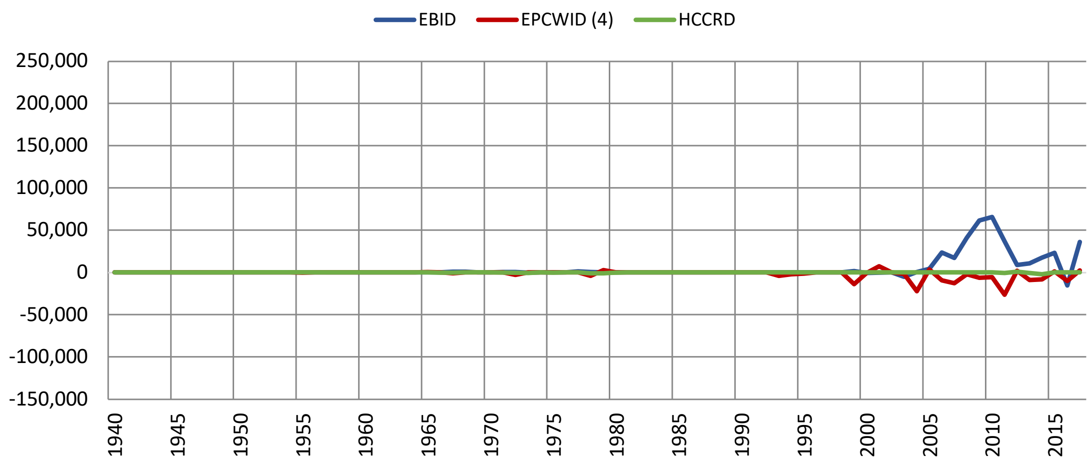
1940 - 2017 (acre-feet)

River Headgate (RHG) Diversions (Irrigation Season)



Period	Average Difference EBID	EPCWID	HCCRD
1951-2017	8,107	-2,869	-652
1951-1978	22	-504	-100
1979-2005	-415	-2,396	-541
2006-2017	46,147	-9,453	-2,189
1985-2017	16,430	-5,444	-1,198
1985-2005	-552	-3,153	-632

Farm Headgate (FHG) Deliveries (Irrigation Season)



Period	Average Difference EBID	EPCWID	HCCRD
1951-2017	4,960	-1,852	-95
1951-1978	153	-269	-91
1979-2005	76	-1,200	-44
2006-2017	27,166	-7,013	-219
1985-2017	9,932	-3,615	-80
1985-2005	83	-1,673	0

Notes:

(1) EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

(2) EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

(3) HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

(4) EPCWID FHG values include deliveries to Rogers WTP and R/U WTP.

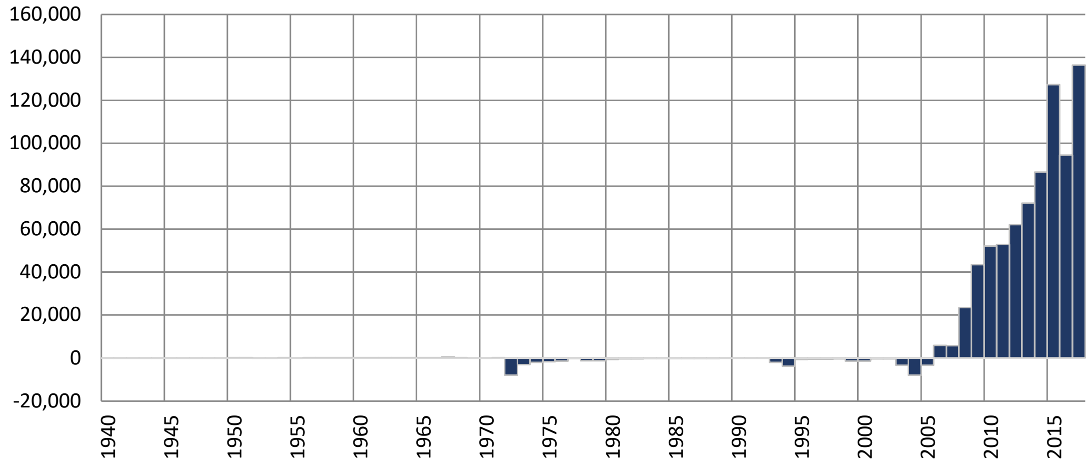
Run 15a - Early EPCWID Ops (WWTP)

Simulated Differences in ILRG Model Outputs

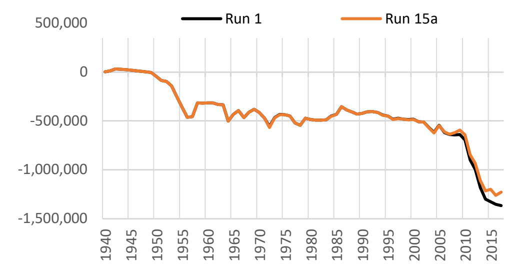
Run 15a minus Run 1

1940 - 2017 (acre-feet)

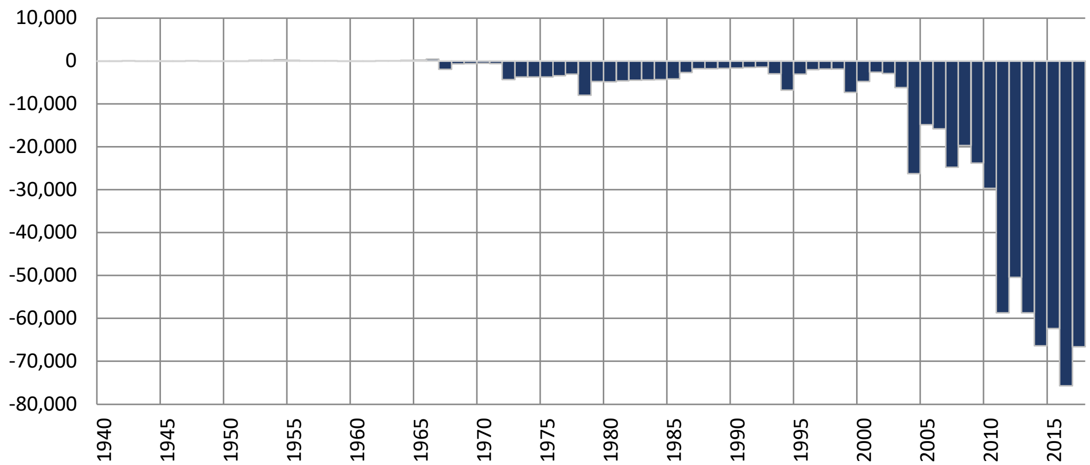
Cumulative Annual Rincon-Mesilla Groundwater Storage



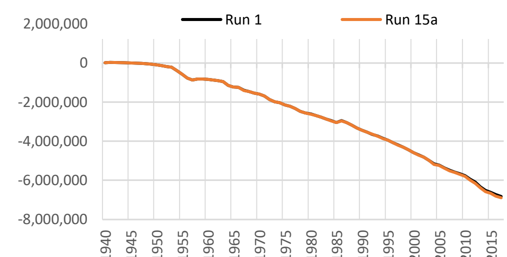
Period	Average Difference
1951-2017	2,036
1951-1978	-47
1979-2005	-77
2006-2017	11,650
1985-2017	4,143
1985-2005	-147



Cumulative Annual Hueco Groundwater Storage



Period	Average Difference
1951-2017	-994
1951-1978	-285
1979-2005	-252
2006-2017	-4,315
1985-2017	-1,888
1985-2005	-501



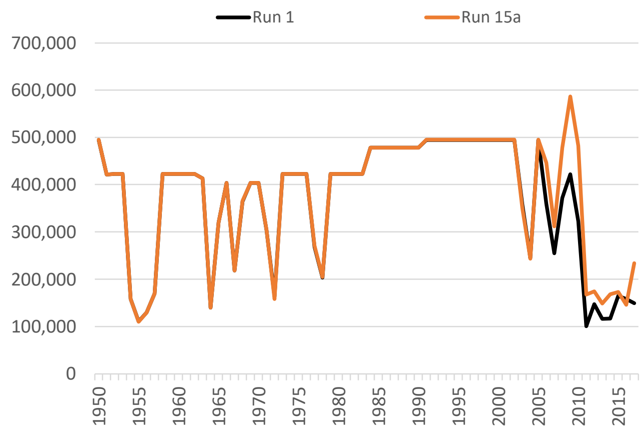
Notes:

Cumulative storage change in alluvial and non-alluvial aquifers.

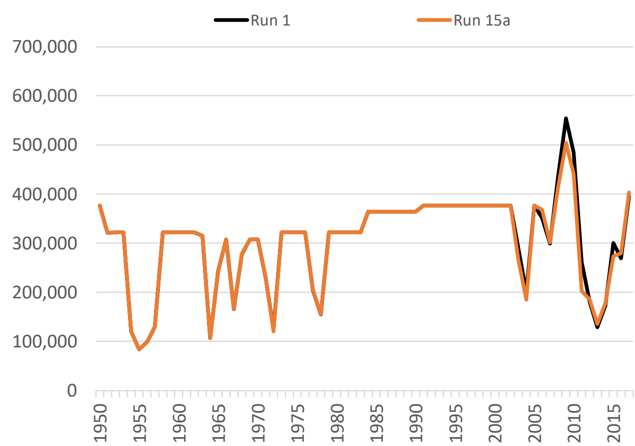
Average differences calculated as (Final Storage - Initial Storage)/(no. years).

Run 15a - Early EPCWID Ops (WWTP)
Annual Allocation and Charges
Run 15a v. Run 1
ILRG Model
1950 - 2017 (acre-feet)

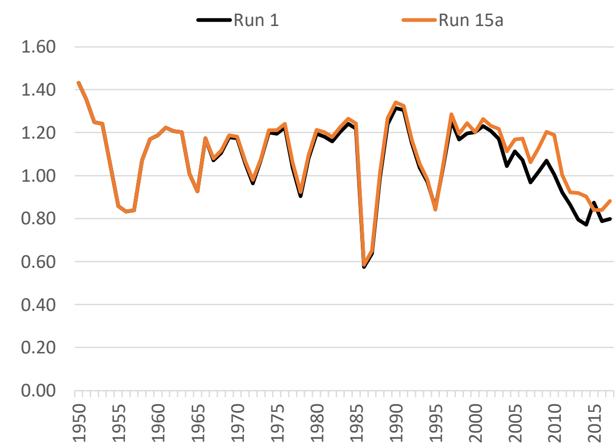
Total Allocation - EBID



Total Allocation - EPCWID

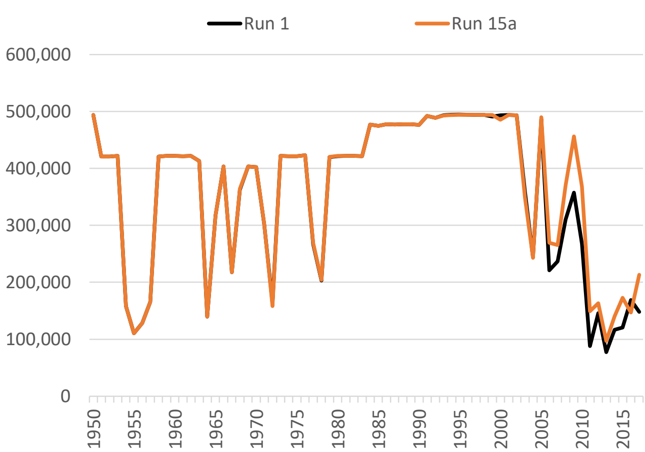


Diversion Ratio

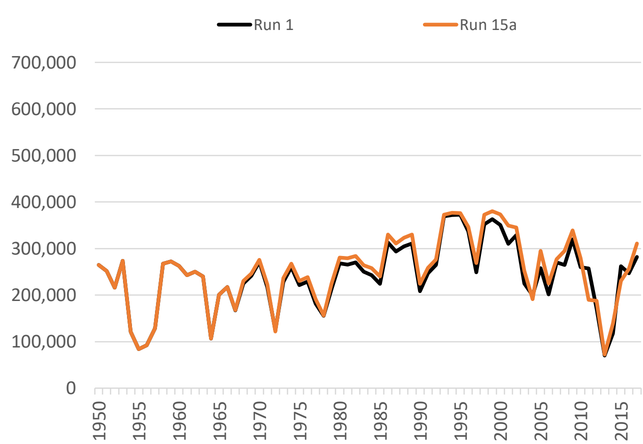


Note:
Computed as Total Charges/Caballo Release.

Annual Delivery Charges - EBID

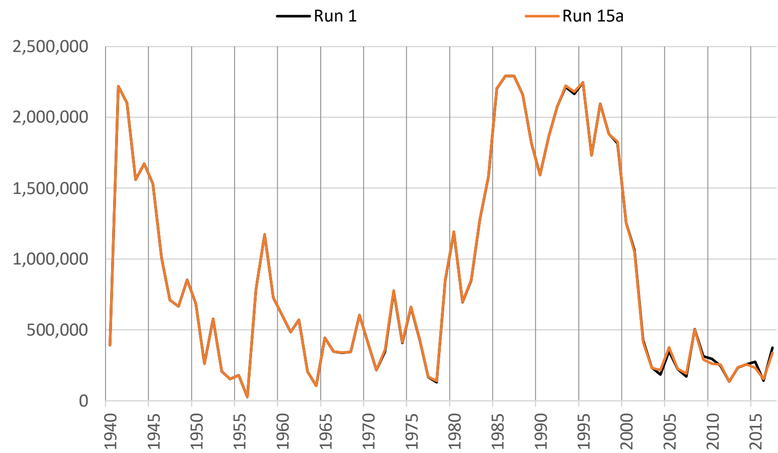


Annual Delivery Charges - EPCWID

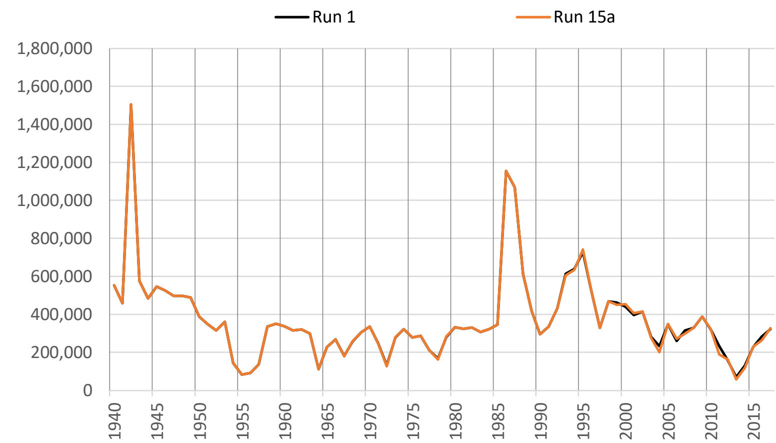


Run 15a - Early EPCWID Ops (WWTP)
Annual Summary of Project Storage and Rio Grande Flows
Run 15a v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

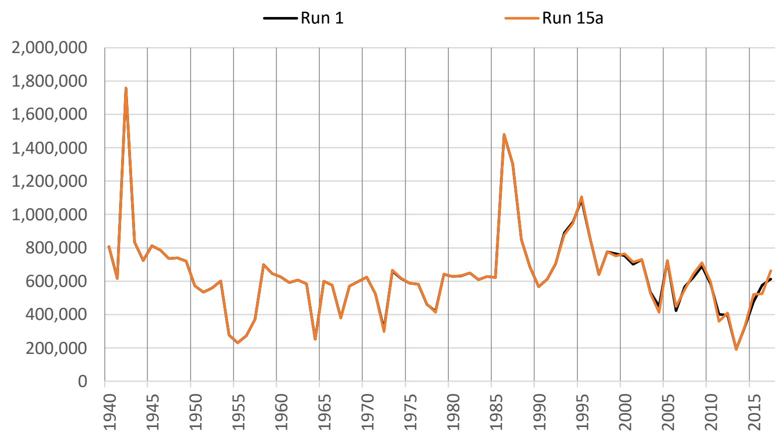
Total Year-End Project Reservoir Storage



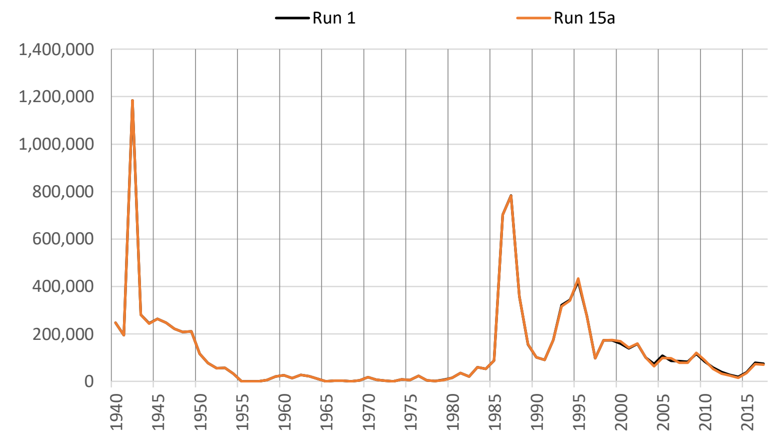
Rio Grande at El Paso



Rio Grande Below Caballo



Rio Grande at Fort Quitman

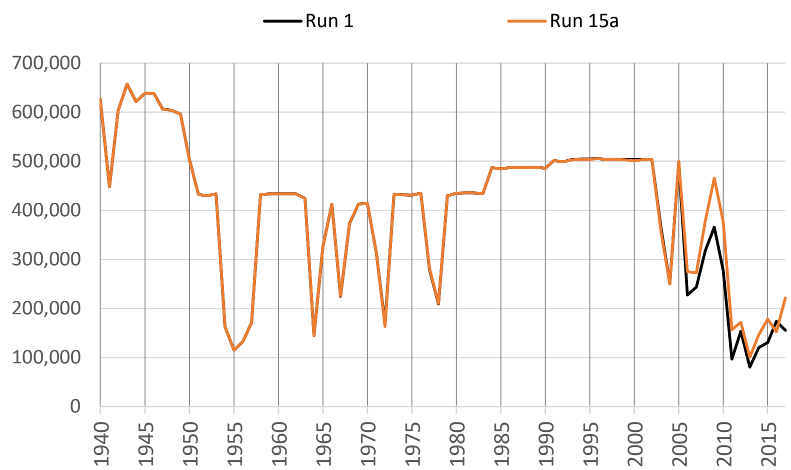


***Note different scales.**

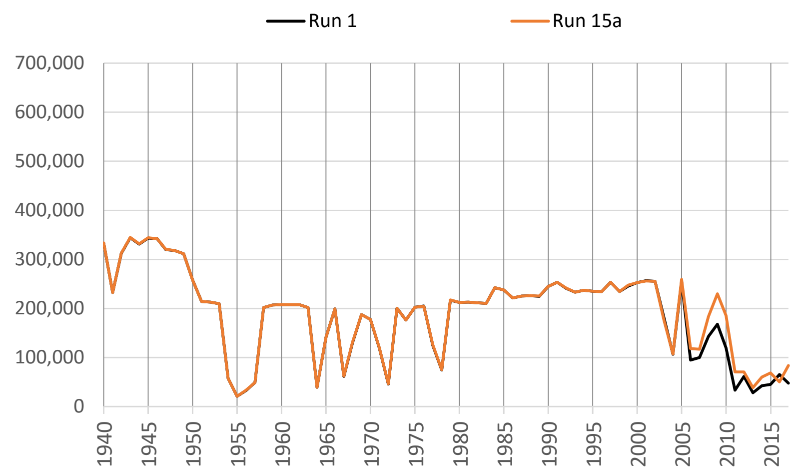
Run 15a - Early EPCWID Ops (WWTP)
Irrigation Season Summary of Irrigation Operations
Run 15a v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

EBID Total

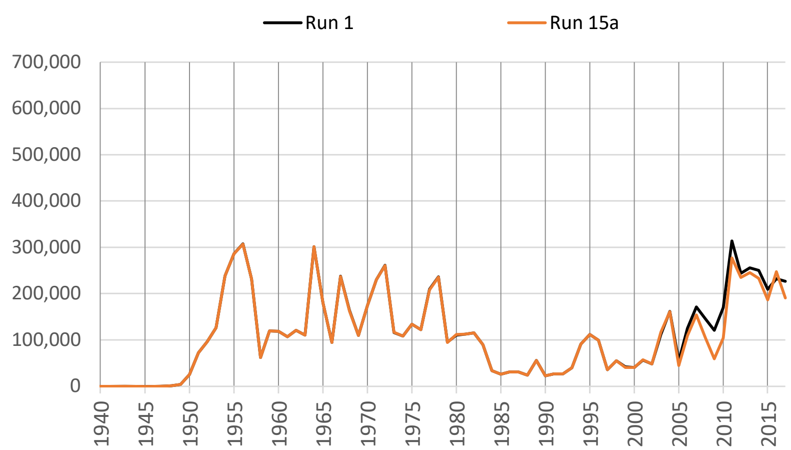
Net River Headgate Diversions



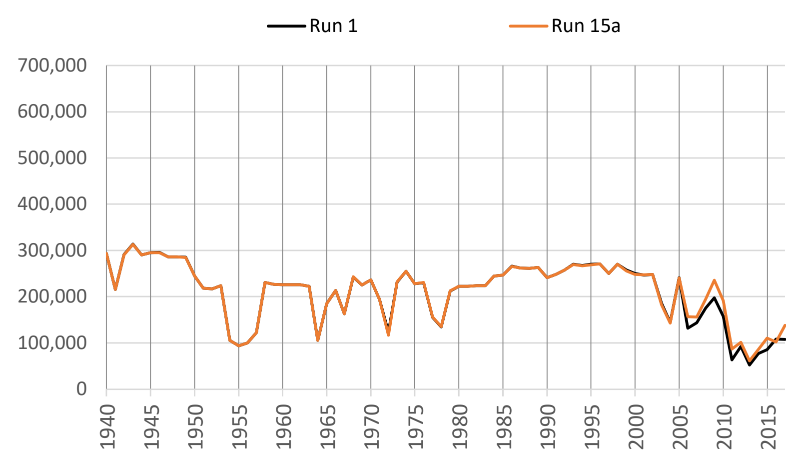
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries



Notes: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).
Pumping includes Supplemental and Primary groundwater pumping.

Run 15a - Early EPCWID Ops (WWTP)

Irrigation Season Summary of Irrigation Operations

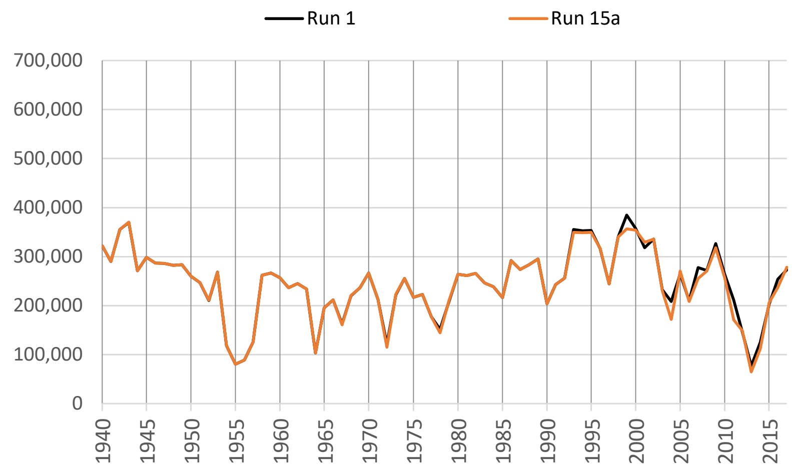
Run 15a v. Run 1

ILRG Model

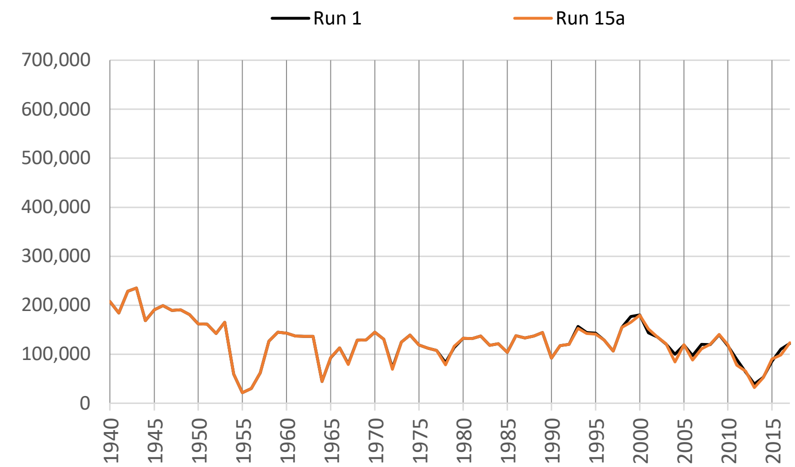
1940 - 2017 (acre-feet)

EPCWID Total

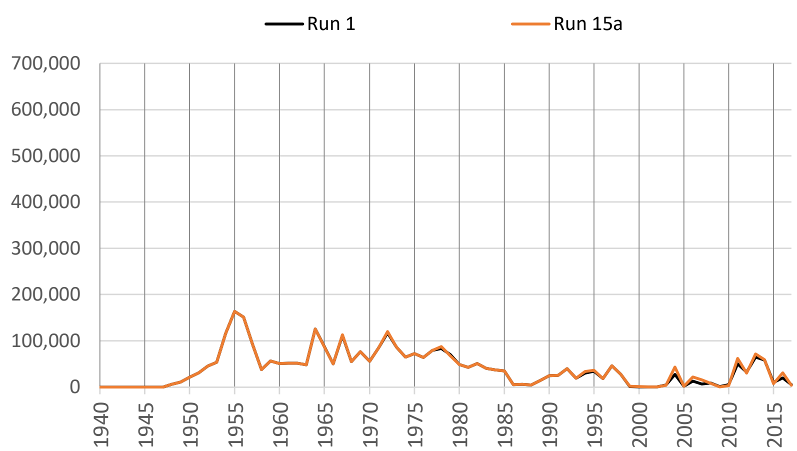
Net River Headgate Diversions



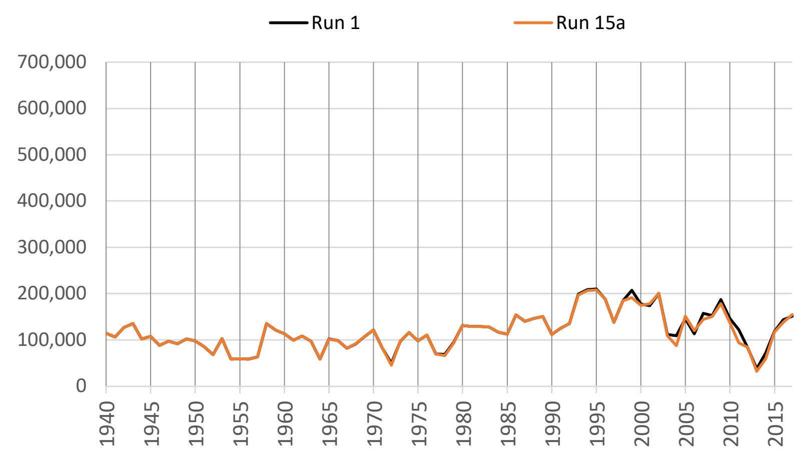
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries

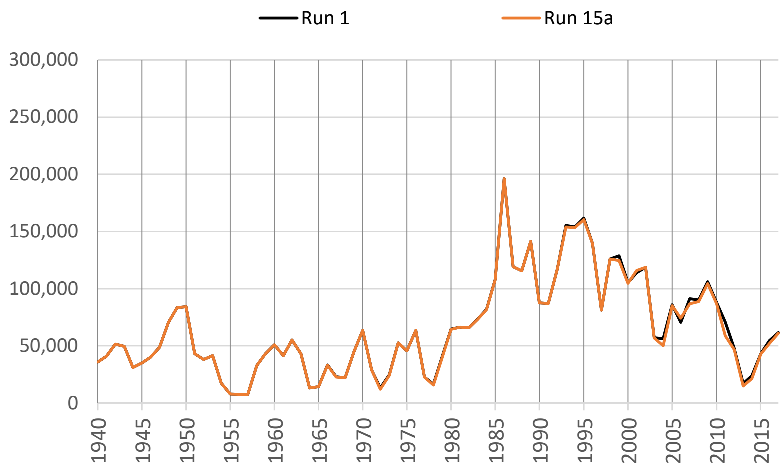


Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

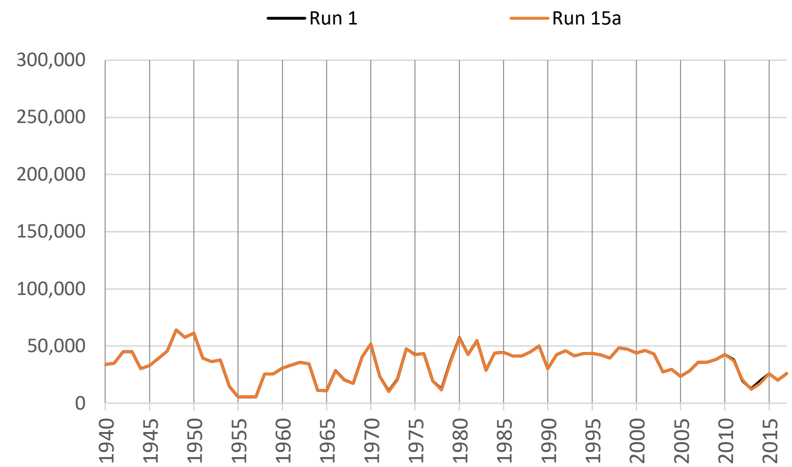
Run 15a - Early EPCWID Ops (WWTP)
Irrigation Season Summary of Irrigation Operations
Run 15a v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

HCCRD Total

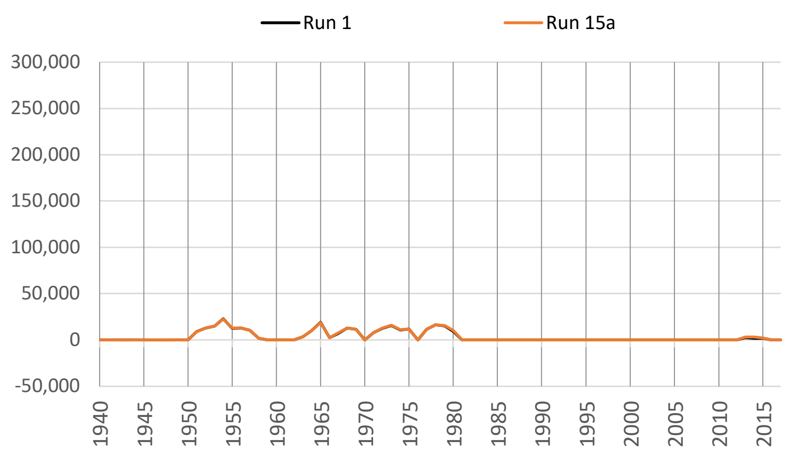
Net River Headgate Diversions



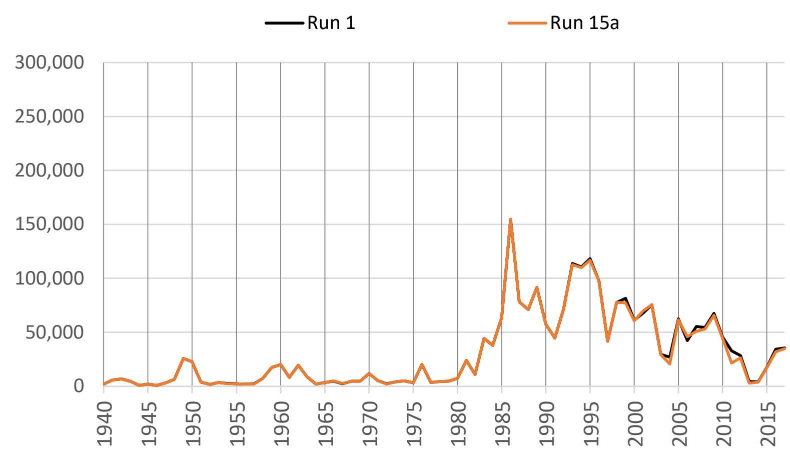
Farm Headgate Deliveries



Pumping

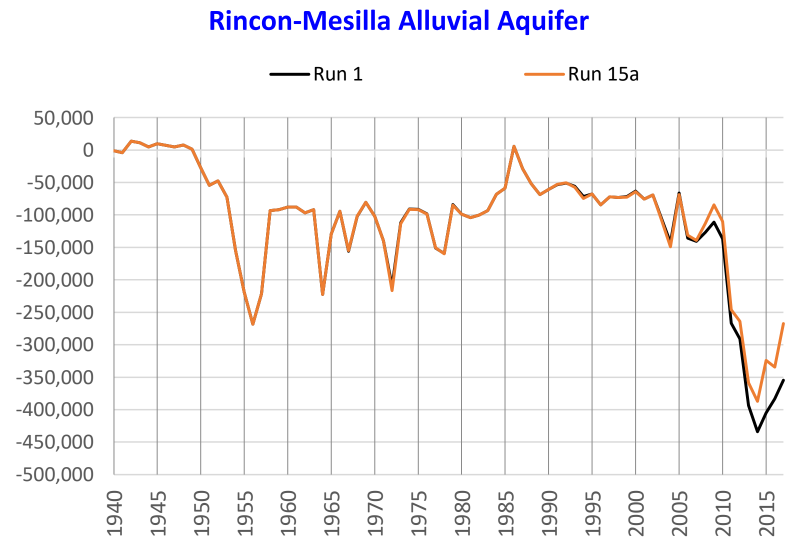


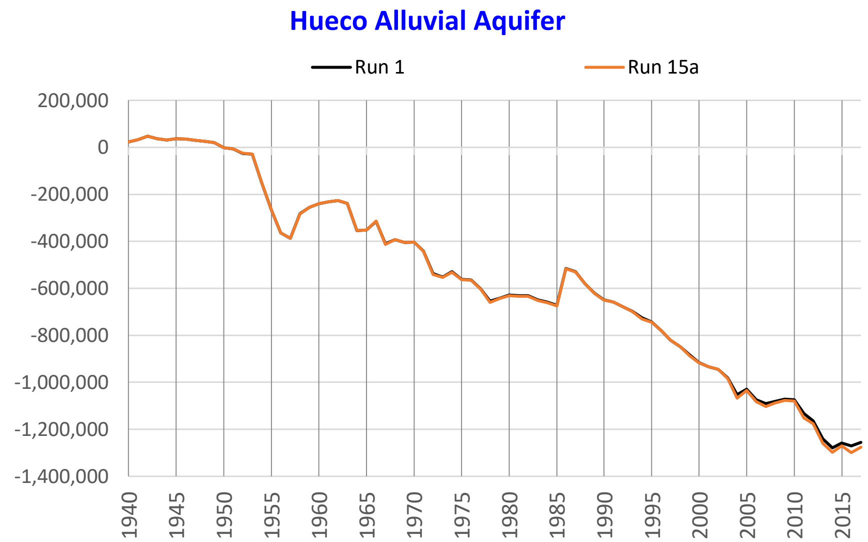
RHG Diversions - FHG Deliveries

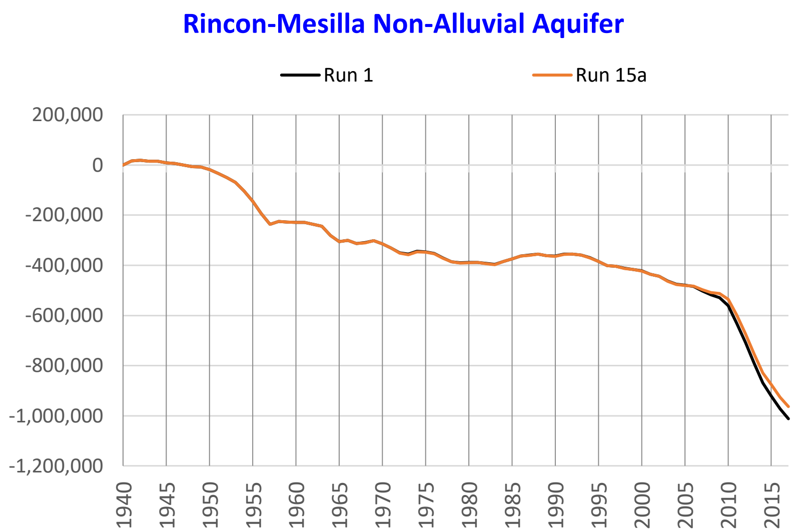


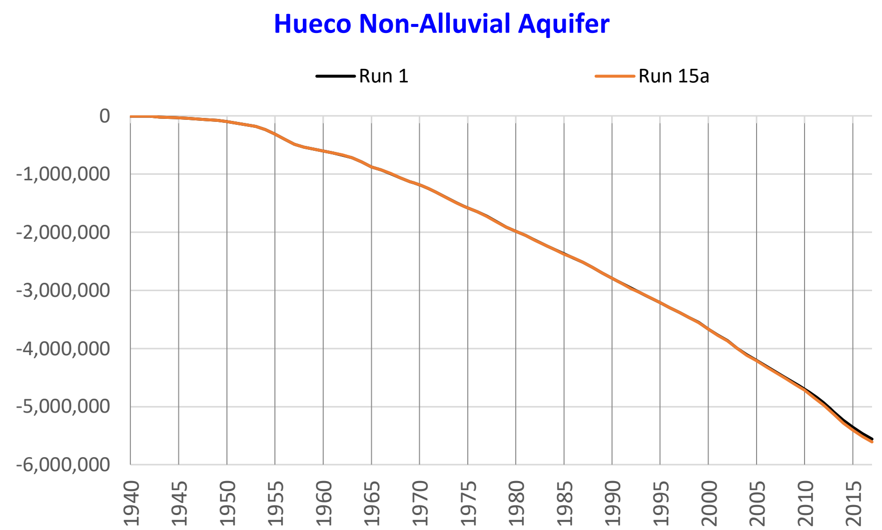
Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

Run 15a - Early EPCWID Ops (WWTP)
Cumulative Change in Ground Water Storage
Run 15a v. Run 1
ILRG Model
1940 - 2017 (acre-feet)



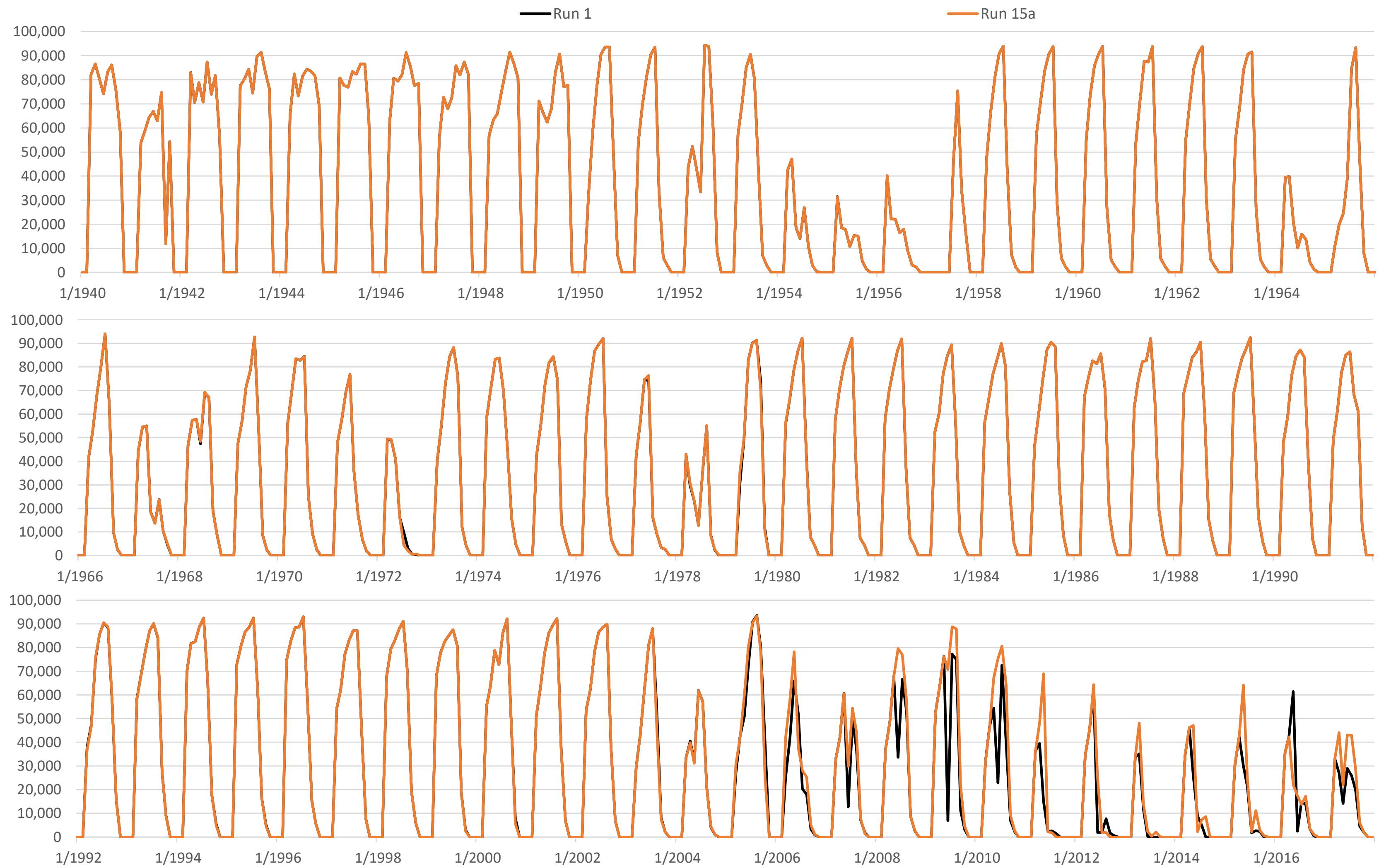






***Note different scales.**

Run 15a - Early EPCWID Ops (WWTP)
Monthly Net RHG Diversions
Run 15a v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
EBID Total

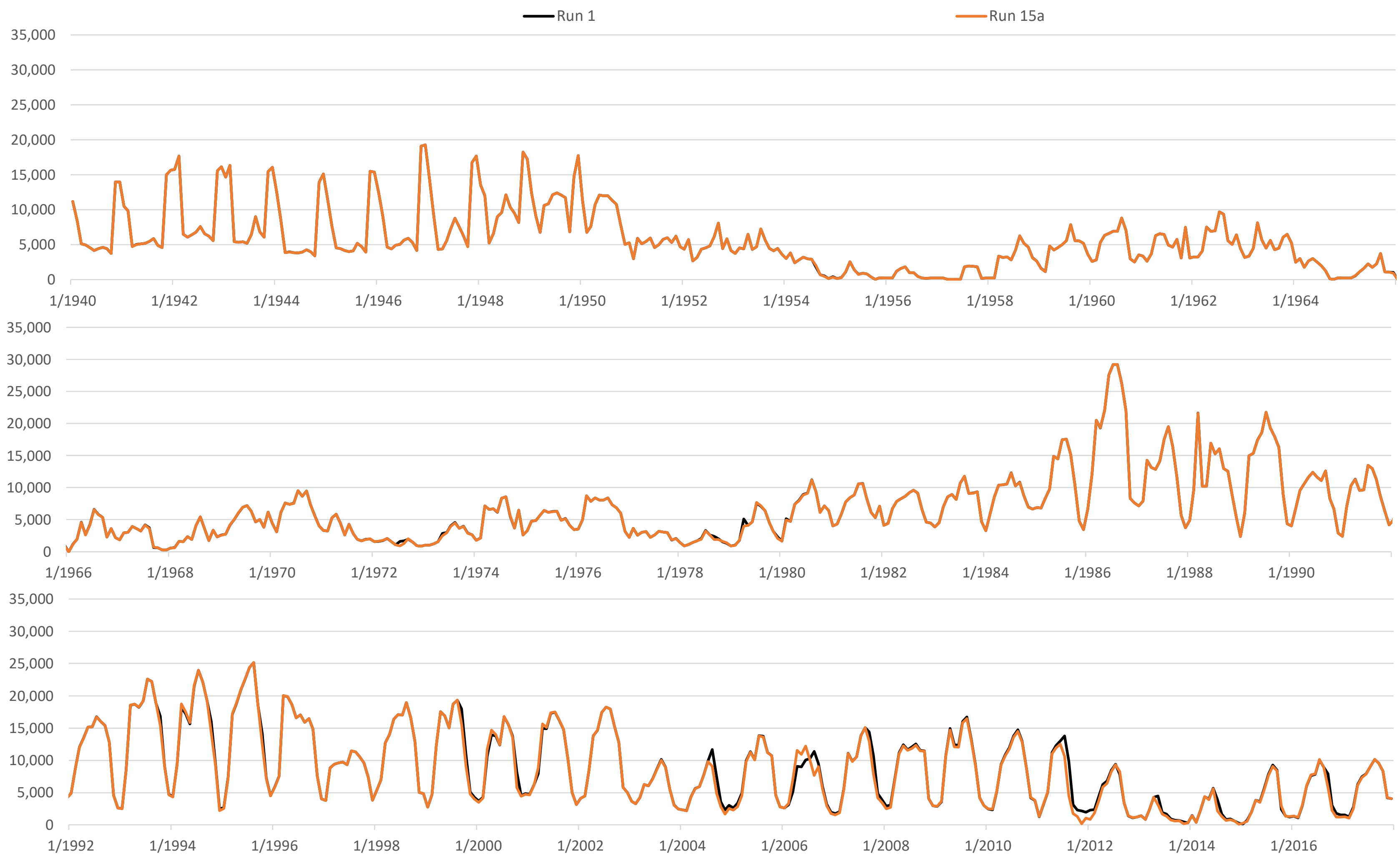


Note: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

Run 15a - Early EPCWID Ops (WWTP)
Monthly Net RHG Diversions
Run 15a v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
EPCWID Total

Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

Run 15a - Early EPCWID Ops (WWTP)
Monthly Net RHG Diversions
Run 15a v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
HCCRD Total



Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

Run 15a - Early EPCWID Ops (WWTP)
End of Month Reservoir Storage (Elephant Butte + Caballo)
Run 15a v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

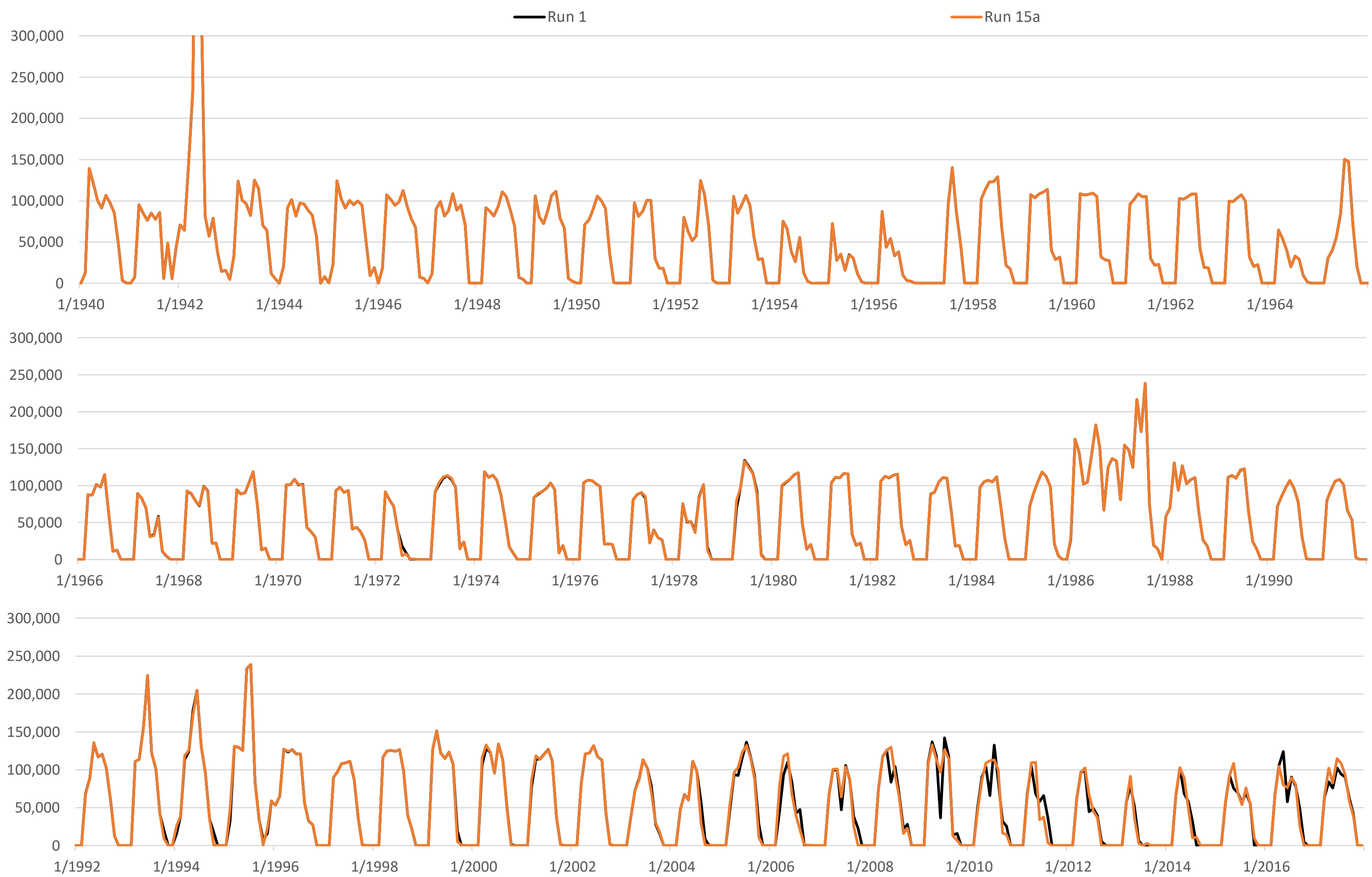
Run 15a - Early EPCWID Ops (WWTP)

Monthly Caballo Releases

Run 15a v. Run 1

ILRG Model

1940 - 2017 (acre-feet)



Run 15a - Early EPCWID Ops (WWTP)

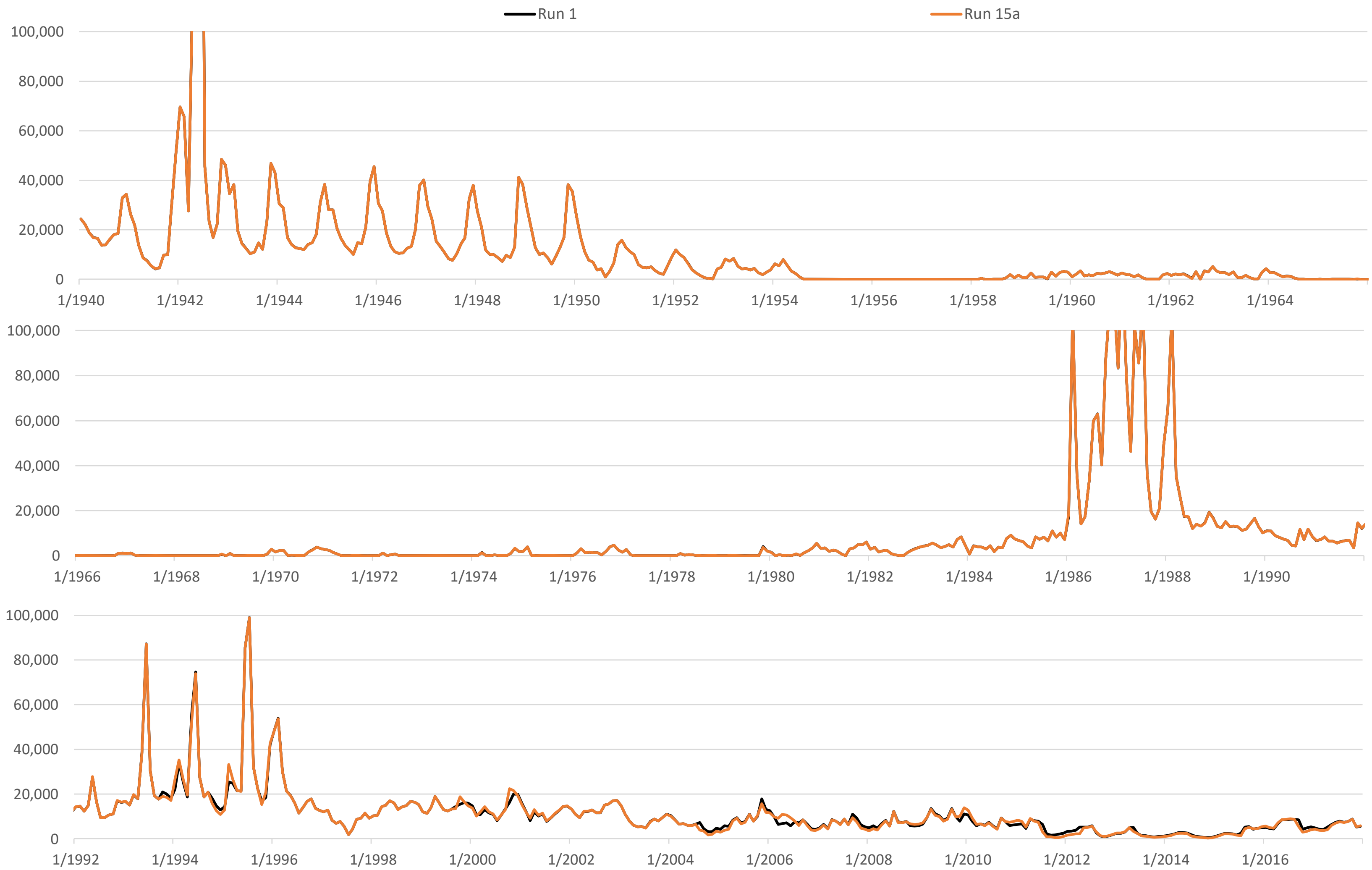
Monthly Rio Grande at El Paso Flow

Run 15a v. Run 1

ILRG Model

1940 - 2017 (acre-feet)

Run 15a - Early EPCWID Ops (WWTP)
Monthly Rio Grande at Fort Quitman Flow
Run 15a v. Run 1
ILRG Model
1940 - 2017 (acre-feet)



Appendix 30U

Comparison of ILRG Model Runs
Run 15b v. Run 1

Model Run Specifications

Model Version: LRG_v116

Name: **Run 15b - Early EPCWID Ops (Fabens Drain)**

Run ID: LRG_v116_Operational_Run15b
Date: 8/28/2020

Name: **Run 1 - Historical Base Run (All Pumping On)**

Run ID: LRG_v116_Operational_Run1
Date: 8/23/2020

Selected Model Inputs

Pumping and Returns	**Run 15b**	**Run 1**
Irrigation Pumping	On	On
Irrigated Area	Hist	Hist
Non-Irrigation Pumping	On	On
Non-Irrigation Pumping Returns	On	On
Las Cruces Jornada Pumping Returns	On	On
Project Allocation Rules		
1950-2005	D1/D2	D1/D2
2006-2007	D3	D3
2008-2017	D3 + CO	D3 + CO
EPCWID Operations		
Charge EPCWID for Use of WWTP Returns	Off	Off
ACE and Haskell Credits for EPCWID	On	On
(1) Increased EPCWID Use of Fabens Drain Flows	On	Off
Charge EPCWID for Fabens Drain Flow Use	On	Off

Notes:
(1) Starting in July 1945, use 70% of simulated Fabens drain flow up to 6,000 af/month.

Run 15b - Early EPCWID Ops (Fabens Drain)
Comparison of ILRG Model Runs
Run 15b v. Run 1
1951 - 2017 Annual Average
(1,000 acre-feet)

Run No.	1	15b	15b - 1	
Simulated Input or Output	**Run 1**	**Run 15b**	**Run 15b minus Run 1**	
Effects of Alternate Scenario				
FHG Deliveries (Mar - Oct)				***% Diff.***
EBID	167.6	174.4	6.7	*4%*
EPCWID (incl. EPW)	139.9	143.0	3.1	*2%*
HCCRD	32.8	32.4	-0.4	*-1%*
Total	340.3	349.8	9.4	*3%*
FHG Deliveries (Nov - Feb)				
EBID	0.0	0.0	0.0	*-6%*
EPCWID (incl. EPW)	0.2	1.9	1.7	*912%*
HCCRD	2.4	2.8	0.4	*15%*
Total	2.6	4.7	2.1	*80%*
Irrigation Pumping				
EBID	140.4	133.9	-6.6	*-5%*
EPCWID (Mesilla Valley)	7.4	7.0	-0.3	*-4%*
EPCWID (El Paso Valley)	40.1	36.2	-3.9	*-10%*
HCCRD	4.2	4.6	0.3	*8%*
Total	192.1	181.7	-10.4	*-5%*
Other Inflows/Outflows				
Net Reservoir Evaporation	125.3	130.0	4.7	*4%*
Riparian ET	70.9	70.6	-0.2	*0%*
River Evaporation + Incidental Canal Loss	30.3	30.6	0.2	*1%*
Total	226.6	231.2	4.6	*2%*
Rio Grande at Fort Quitman				
Reservoir Spills	33.3	38.5	5.3	*16%*
Nov-Feb Flows	21.4	18.2	-3.2	*-15%*
Mar - Oct Flows	41.1	32.7	-8.4	*-20%*
Underflow (GW Model)	0.2	0.2	0.0	*-5%*
Total	96.0	89.7	-6.3	*-7%*

Run 15b - Early EPCWID Ops (Fabens Drain)
Comparison of ILRG Model Runs
Run 15b v. Run 1
1951 - 2017 Annual Average
(1,000 acre-feet)

Run No.	1	15b	15b - 1	
Simulated Input or Output	**Run 1**	**Run 15b**	**Run 15b minus Run 1**	
Effects of Alternate Scenario (continued)				
Change in Storage				***% Diff.***
Reservoir Storage	-4.7	-5.7	-1.0	*22%*
Alluvial GW Storage (RW Model)	-23.6	-22.6	1.0	*-4%*
Non-alluvial GW Storage (GW Models)	-96.4	-94.8	1.6	*-2%*
Soil Moisture Storage	0.6	0.6	0.0	*2%*
Total	-124.0	-122.5	1.5	*-1%*
Summary of Effects				
FHG Deliveries (Mar-Oct)	340.3	349.8	9.4	*3%*
FHG Deliveries (Nov-Feb)	2.6	4.7	2.1	*80%*
Irrigation Pumping	192.1	181.7	-10.4	*-5%*
Riparian ET + Evaporation	226.6	231.2	4.6	*2%*
Fort Quitman Flow	96.0	89.7	-6.3	*-7%*
Change in Storage	-124.0	-122.5	1.5	*-1%*
Total	733.6	734.5	0.9	*0%*
Other Effects of Alternate Scenario				
Rio Grande at El Paso				***% Diff.***
Reservoir Spills	49.4	59.4	10.0	*20%*
Nov-Feb Flows	22.8	22.3	-0.5	*-2%*
Mar - Oct Flows	263.8	249.1	-14.7	*-6%*
Total	336.0	330.7	-5.2	*-2%*
Rio Grande below Caballo				
Reservoir Spills	65.9	79.3	13.5	*20%*
Nov-Feb Flows	0.5	0.3	-0.2	*-40%*
Mar - Oct Flows	541.3	524.4	-16.9	*-3%*
Total	607.6	604.0	-3.6	*-1%*
Surface Water Diversions (Mar - Oct)				
EBID	366.5	378.6	12.2	*3%*
EPCWID (incl. EPW)	236.8	223.9	-12.9	*-5%*
HCCRD	67.5	65.0	-2.6	*-4%*
Total	670.8	667.6	-3.2	*0%*
Surface Water Diversions (Nov - Feb)				
EBID	0.0	0.0	0.0	*0%*
EPCWID (incl. EPW)	14.3	15.7	1.4	*10%*
HCCRD	14.2	14.4	0.2	*2%*
Total	28.5	30.2	1.6	*6%*

Run 15b - Early EPCWID Ops (Fabens Drain)
Annual Differences in ILRG Model Outputs
Run 15b minus Run 1
1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1940	-53	-53	6	-1	1	-3	-2	-2	3	2	1	1	-47	-23	-48
1941	-165	-165	-5	-9	-2	-4	-4	-4	-1	0	-2	-4	40	68	12
1942	-33	-33	1	-4	-1	0	0	0	2	8	0	-1	28	8	-57
1943	-64	-64	-8	-11	1	1	-14	-14	-13	-13	1	-1	-27	-15	-88
1944	-81	-81	-144	-137	-110	-92	-5	-5	16	-2	-99	-100	-162	-155	-65
1945	2	2	-17,006	-5,526	1,400	925	-53	-53	-308	6,374	1,084	991	-10,928	-10,411	-16,322
1946	36	36	-10,389	-11,150	-392	-7,349	-110	-111	-717	3,359	-75	-239	-18,240	-17,653	-18,285
1947	56	56	-12,881	-6,763	699	-5,757	-15	-15	3,974	11,138	922	1,018	-10,314	-10,390	-19,236
1948	10	10	-10,680	-6,705	136	-4,668	-15	-16	-1,977	4,581	410	237	-8,507	-8,534	-10,885
1949	46	46	-20,056	-15,361	1,554	3,235	-52	-53	622	6,491	-293	-545	-18,657	-18,081	-19,553
1950	29	29	-22,082	-18,140	-9,742	-11,072	-10	-11	-2,678	2,555	239	421	-20,460	-20,089	-17,853
1951	1,031	1,031	-11,245	-5,716	-641	-2,838	547	546	-3,508	1,705	-204	-2,191	-8,348	-8,206	-12,029
1952	990	990	-10,233	-6,921	-853	-2,129	3,848	3,843	-3,031	-55	-2,244	544	-24,633	-18,189	-11,119
1953	374	374	-15,020	-11,706	-841	-1,984	2,382	2,381	-2,557	343	-1,245	629	-5,820	-11,203	-15,941
1954	19,737	19,737	5,461	6,461	-606	373	15,855	15,855	16,862	17,818	-77	881	15,476	12,024	-11,847
1955	33,004	33,004	21,928	21,994	2,038	3,168	17,426	17,426	20,346	20,290	1,944	2,995	52,752	26,837	313
1956	177	177	800	807	628	600	-2,670	-2,670	199	89	451	307	-2,375	566	-25
1957	10	10	-584	-751	511	465	70	70	546	503	680	589	-1,748	-569	-3
1958	-2	-2	-3,302	-3,501	802	1,820	283	283	-180	-162	75	57	-13,274	-3,257	1,392
1959	5	5	-10,246	-9,922	512	1,404	96	96	-549	-344	6	23	-14,442	-10,381	1,094
1960	8	8	-10,577	-10,131	-542	-805	50	50	-1,436	-903	0	0	-13,113	-11,494	-1,323
1961	15	15	250	1,225	663	817	54	55	1,147	2,163	647	-428	736	-54	1,643
1962	10	10	-13,589	-12,215	-2,154	-2,315	-12	-12	-1,497	-319	18	-304	-17,696	-15,410	-1,866
1963	8,891	8,891	-5,576	-3,706	-1,279	-1,595	4,851	4,851	-911	785	-512	-514	1,780	-2,066	-1,639
1964	23,165	23,165	8,207	9,146	118	788	11,871	11,871	18,866	19,507	1,095	1,026	23,673	12,098	-4,022
1965	7,402	7,402	262	256	1,736	1,733	3,897	3,897	3,395	3,371	595	586	-2,288	1,785	191
1966	-32	-32	-10,691	-10,008	-3,130	-3,346	247	247	-216	145	-3,073	-1,092	-14,379	-8,990	-1,154
1967	15,337	15,337	4,232	5,011	1,431	1,871	8,637	8,637	4,100	3,867	667	1,796	11,091	6,360	-644
1968	7,453	7,453	4,725	5,559	1,742	1,220	6,057	6,057	1,296	1,008	1,683	1,333	7,623	7,603	172
1969	-12	-12	-15,911	-15,412	-9,708	-9,419	233	233	65	395	-9,331	-7,757	-21,188	-16,251	-1,584
1970	3	3	-21,538	-20,837	-7,856	-7,436	41	41	-1,262	-576	-327	4,344	-25,942	-23,129	-10,298
1971	28,767	28,767	-7,447	-6,004	-1,586	-3,319	17,499	17,499	-680	235	-301	-1,643	8,456	-4,217	-1,434
1972	-1,857	-1,857	-7,035	-6,333	-1,458	-1,599	-3,722	-3,722	-5,203	-5,206	-1,691	-1,821	-11,164	-6,091	-1,223
1973	-106	-106	2,690	2,690	723	889	697	697	591	408	638	868	-43	2,562	6
1974	-9	-9	-9,109	-8,794	-4,113	-4,187	244	244	392	667	-3,584	-2,510	-9,687	-9,173	-1,930
1975	-236	-236	-17,895	-17,262	-12,930	-12,490	1,182	1,181	-323	223	-12,682	-12,557	-22,108	-17,970	386
1976	7	7	-18,353	-17,524	-17,238	-17,462	722	722	-858	-140	-2,751	3,542	-21,595	-20,135	-19,603
1977	50,960	50,960	23,636	25,251	9,141	9,599	21,791	21,791	14,213	16,550	8,478	9,465	44,512	32,365	1,612
1978	15,214	15,214	102	1,940	-2,800	-3,054	7,991	7,991	10,136	11,559	-2,527	-2,843	11,462	5,197	-1,212

Run 15b - Early EPCWID Ops (Fabens Drain)
Annual Differences in ILRG Model Outputs
Run 15b minus Run 1
1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1979	185	185	-10,680	-8,919	-3,506	-2,444	1,084	1,084	3,320	4,864	-3,383	-2,450	-17,429	-8,540	-97
1980	-13	-13	-22,726	-20,842	-4,667	-4,114	138	138	-380	1,474	-1,755	-804	-27,458	-24,318	-4,974
1981	-54	-54	-26,970	-24,410	-6,312	-7,212	663	663	-1,241	1,750	963	1,296	-31,441	-29,390	-8,462
1982	-8	-8	-28,615	-25,840	-4,301	-4,944	-11	-11	-1,805	1,697	-1,220	841	-32,875	-31,360	-6,989
1983	-14	-14	-28,634	-26,291	-11,452	-11,845	-58	-58	-2,490	512	0	0	-32,959	-31,890	-12,740
1984	-46	-46	-26,493	-24,457	-17,016	-17,708	-1	-1	-1,503	1,777	376	376	-23,256	-23,590	-18,342
1985	-225	-225	-27,784	-25,506	-12,908	-12,645	453	455	-1,858	1,015	0	0	38,073	33,029	18,957
1986	-79	-79	-40,662	-39,314	-7,858	-6,640	345	356	-1,790	-32	0	0	87,164	89,533	69,288
1987	-195	-195	-52,072	-49,313	-7,542	-6,808	1,311	1,315	-879	3,230	0	0	-233	-735	-67,975
1988	-15	-15	-50,025	-46,675	-7,293	-6,893	128	128	-4,800	-96	0	0	-50,044	-43,702	-36,924
1989	9	9	-43,358	-38,785	-12,654	-13,134	-188	-188	-5,882	362	0	0	-52,011	-50,073	-36,571
1990	1,051	1,051	14,163	18,026	-2,570	-2,864	-7,635	-7,639	18,214	24,084	0	0	-20,241	-11,620	-19,956
1991	888	888	-39,570	-35,478	-15,470	-15,817	953	950	-7,966	-1,571	0	0	-38,659	-41,877	-31,554
1992	3,403	3,403	36,136	38,978	28,839	29,486	-10,156	-10,171	30,536	35,119	0	0	105,863	109,402	80,986
1993	585	585	-51,453	-47,309	-8,630	-8,855	730	724	-8,828	-2,282	0	0	-9,222	-13,449	-2,780
1994	420	420	-36,169	-32,951	-3,099	-3,125	-178	-175	35	5,072	0	0	17,120	13,296	9,074
1995	917	917	-31,910	-28,020	-727	-952	9	10	1,846	8,156	0	0	11,377	9,913	2,352
1996	-66	-66	-45,785	-43,144	-5,776	-5,084	120	120	-5,770	-1,638	0	0	-59,664	-54,310	-40,523
1997	-19	-19	-32,329	-29,974	-10,310	-11,807	-233	-233	-7,293	-2,217	0	0	-31,276	-32,201	-24,859
1998	-18	-18	-31,213	-29,092	-573	-1,519	42	43	-2,061	1,399	0	0	-19,917	-19,652	-24,520
1999	1,199	1,199	-21,612	-20,670	3,380	2,952	-2	-3	7,076	8,524	0	0	-29,641	-30,541	-33,411
2000	1,300	1,300	-25,409	-25,435	2,416	2,582	-8,884	-8,884	-9,559	-9,569	0	0	-43,856	-33,996	-25,280
2001	227	227	-29,773	-30,051	-6,946	-6,600	-335	-335	-96	-102	0	0	-27,438	-33,000	-27,844
2002	-11	-11	-28,245	-28,323	-2,131	-1,350	-271	-271	-40	-42	0	0	-28,066	-29,050	-31,125
2003	114,024	114,024	18,968	19,113	10,933	12,002	61,044	61,044	20,565	20,588	0	0	90,501	51,468	11,711
2004	38,938	38,938	11,291	12,629	4,342	7,771	25,575	25,575	24,790	24,815	0	0	23,590	21,608	1,238
2005	2,125	2,125	-30,980	-30,551	-9,345	-7,352	3,888	3,879	-3,501	-3,492	0	0	-54,018	-27,695	-9,400
2006	66,685	66,685	30,353	30,678	14,518	16,284	33,977	33,977	24,922	24,934	0	0	68,901	46,128	14,913
2007	40,156	40,156	-10,767	-10,273	-6,159	-4,344	23,697	23,697	9,727	9,746	0	0	-3,245	-5,761	-4,016
2008	60,837	60,837	-24,037	-23,565	-12,698	-11,296	40,672	40,672	86	105	0	0	-12,262	-20,643	-14,626
2009	69,879	69,879	-23,416	-23,031	-1,996	-1,461	42,037	42,037	1,154	1,177	0	0	-12,719	-19,688	-18,434
2010	99,018	99,018	-19,805	-18,946	-9,630	-9,621	64,821	64,821	973	998	0	0	-398	-15,102	-11,780
2011	63,693	63,693	10,686	11,165	-7,729	-5,619	36,839	36,839	22,091	22,608	0	0	40,762	13,474	-8,084
2012	5,094	5,094	14,763	14,861	-1,142	393	2,685	2,685	22,821	24,178	0	0	18,915	15,458	5,391
2013	-13,590	-13,590	-15,843	-15,757	814	1,493	-6,606	-6,606	-4,275	-3,743	1,696	1,404	-41,249	-17,160	348
2014	-7,039	-7,039	10,200	10,200	6,467	6,917	-2,911	-2,911	11,401	11,401	3,243	3,565	9,472	12,042	-1,702
2015	1,156	1,156	-10,596	-10,603	2,445	3,382	746	746	1,006	2,300	-4,184	-3,453	-12,971	-11,417	1,241
2016	11,964	11,964	-6,885	-6,852	1,580	2,126	3,067	3,067	9,002	10,079	0	0	3,667	-7,048	-11,963
2017	43,010	43,010	-18,317	-18,112	1,307	1,464	22,704	22,704	1,461	2,780	0	0	6,333	-19,372	-11,379
Averages															
1951-2017	12,174	12,174	-12,860	-11,481	-2,554	-2,305	6,723	6,722	3,119	4,834	-416	-58	-3,628	-5,242	-6,312
1951-1978	7,511	7,511	-4,145	-3,086	-1,703	-1,758	4,292	4,292	2,498	3,355	-842	-167	-1,867	-2,835	-3,289
1979-2005	6,093	6,093	-25,256	-23,059	-4,118	-3,886	2,538	2,538	1,431	4,570	-186	-27	-9,482	-8,990	-10,027
2006-2017	36,739	36,739	-5,305	-5,019	-1,019	-24	21,811	21,811	8,364	8,880	63	126	5,434	-2,424	-5,008
1985-2017	18,343	18,343	-18,226	-16,730	-2,307	-1,725	9,953	9,952	4,337	6,603	23	46	-770	-3,719	-8,461
1985-2005	7,831	7,831	-25,609	-23,421	-3,044	-2,698	3,177	3,176	2,035	5,301	0	0	-4,314	-4,460	-10,434

Notes:

EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

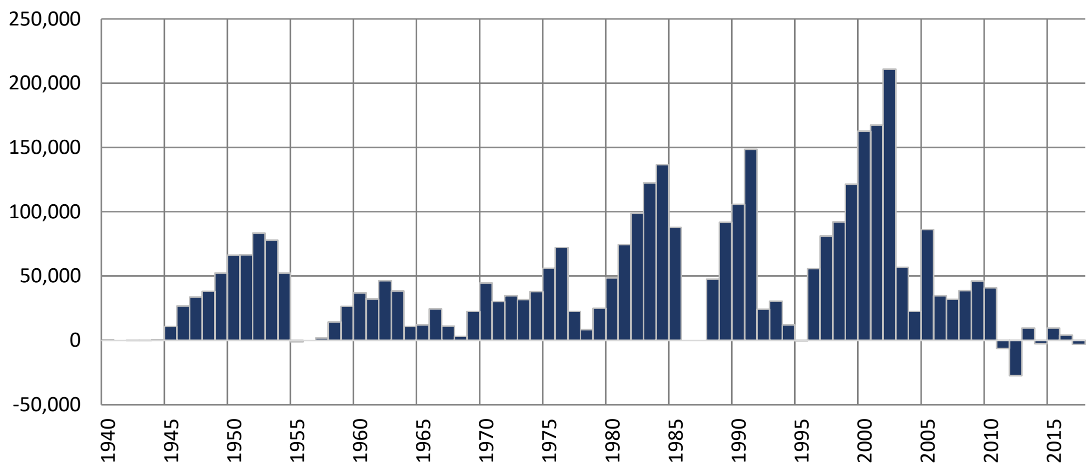
Run 15b - Early EPCWID Ops (Fabens Drain)

Simulated Differences in ILRG Model Outputs

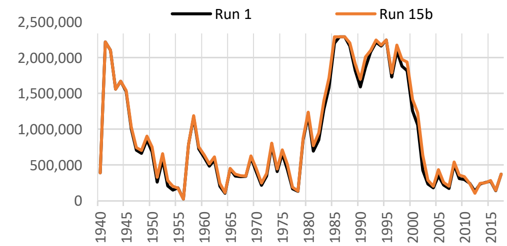
Run 15b minus Run 1

1940 - 2017 (acre-feet)

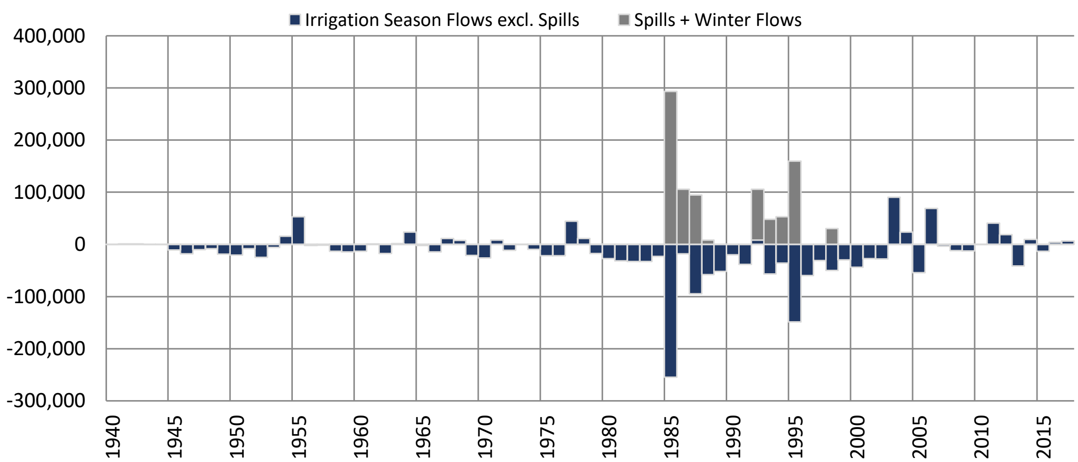
Total Project Storage (Year End)



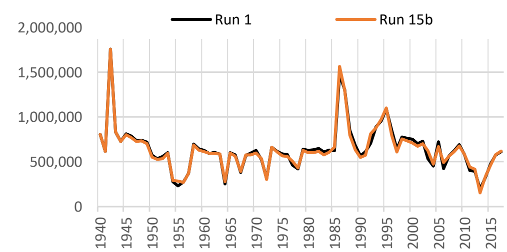
Period	Average Difference
1951-2017	-1,032
1951-1978	-2,067
1979-2005	2,881
2006-2017	-7,421
1985-2017	-4,231
1985-2005	-2,408



Caballo Reservoir Outflows (Annual)



Period	Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
	Average Difference		
1951-2017	-16,904	13,275	-3,628
1951-1978	-1,867	0	-1,867
1979-2005	-42,425	32,943	-9,482
2006-2017	5,434	0	5,434
1985-2017	-27,723	26,953	-770
1985-2005	-46,669	42,355	-4,314



Notes:

Reservoir storage does not include storage attributed to SJC, CO, or NM credit waters.

Average differences calculated as (Final Storage - Initial Storage)/(no. years).

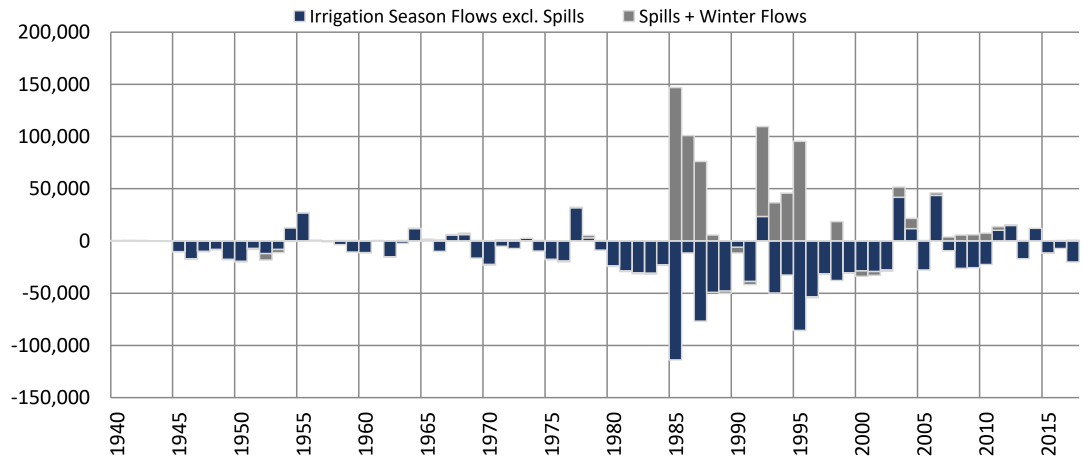
Run 15b - Early EPCWID Ops (Fabens Drain)

Simulated Differences in ILRG Model Outputs

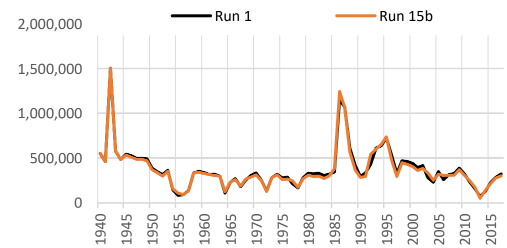
Run 15b minus Run 1

1940 - 2017 (acre-feet)

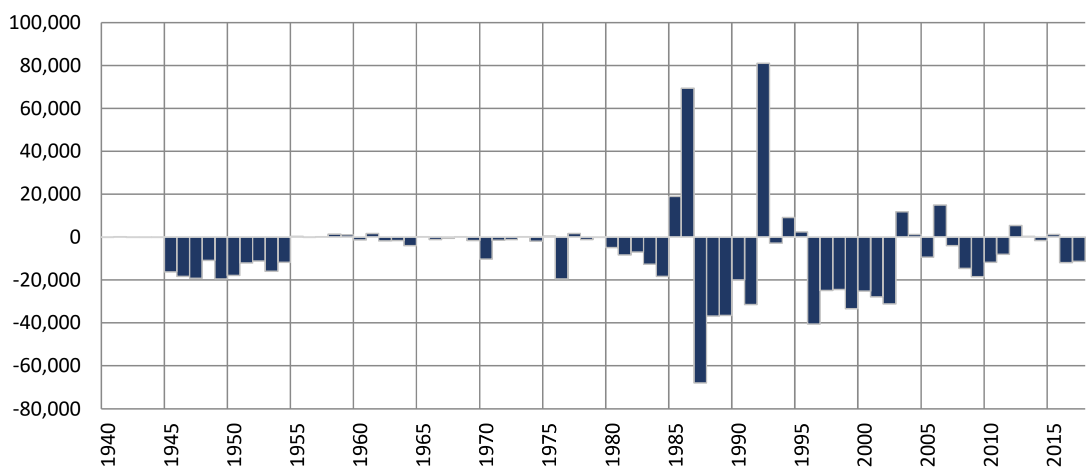
Rio Grande at El Paso (Annual)



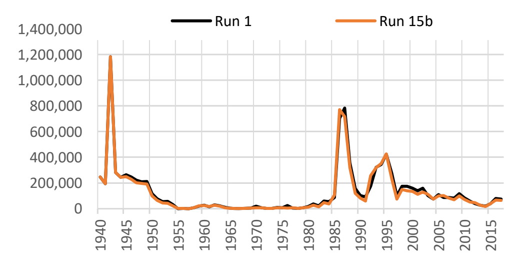
	Average Difference		
Period	Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	-14,685	9,443	-5,242
1951-1978	-2,761	-74	-2,835
1979-2005	-31,383	22,393	-8,990
2006-2017	-4,933	2,509	-2,424
1985-2017	-23,076	19,357	-3,719
1985-2005	-33,443	28,984	-4,460



Rio Grande at Fort Quitman (Annual)



Period	Average Difference
1951-2017	-6,301
1951-1978	-3,281
1979-2005	-10,009
2006-2017	-5,005
1985-2017	-8,452
1985-2005	-10,421



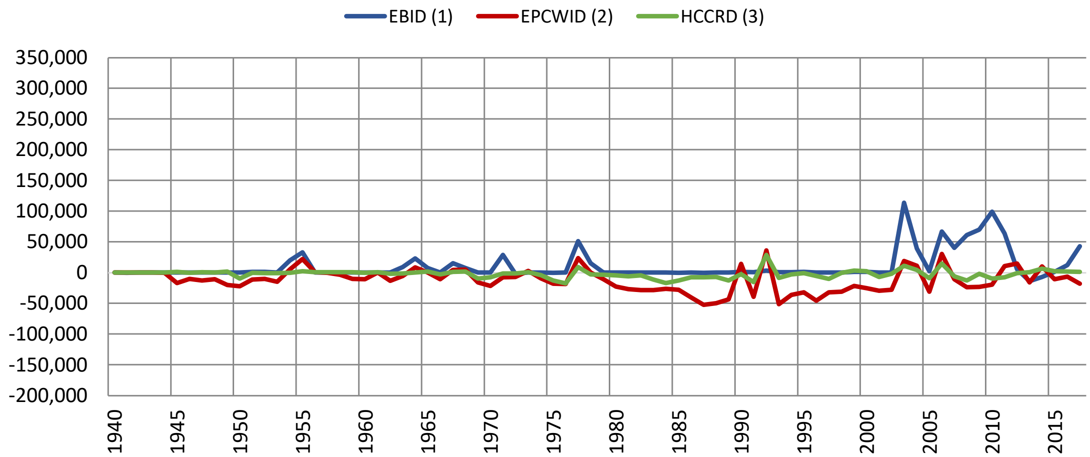
Run 15b - Early EPCWID Ops (Fabens Drain)

Simulated Differences in ILRG Model Outputs

Run 15b minus Run 1

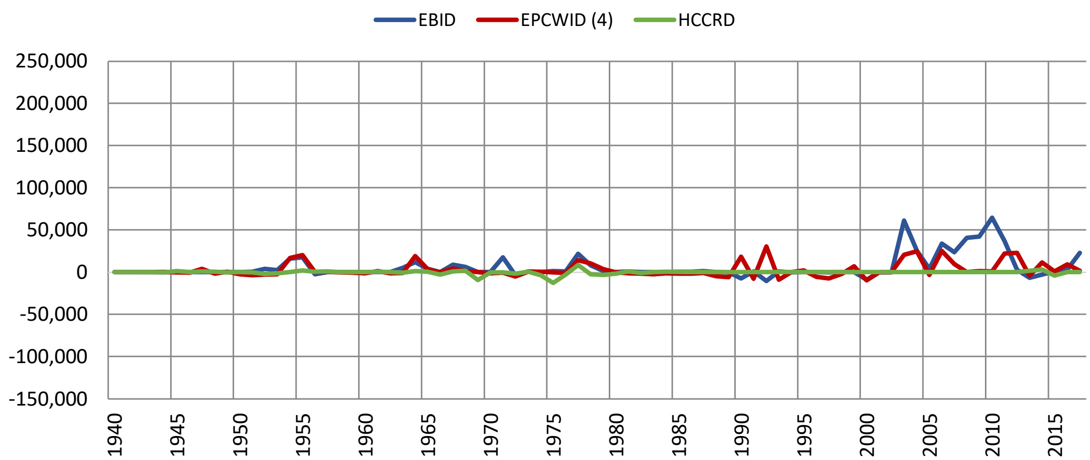
1940 - 2017 (acre-feet)

River Headgate (RHG) Diversions (Irrigation Season)



	Average Difference		
Period	EBID	EPCWID	HCCRD
1951-2017	12,174	-12,860	-2,554
1951-1978	7,511	-4,145	-1,703
1979-2005	6,093	-25,256	-4,118
2006-2017	36,739	-5,305	-1,019
1985-2017	18,343	-18,226	-2,307
1985-2005	7,831	-25,609	-3,044

Farm Headgate (FHG) Deliveries (Irrigation Season)



	Average Difference		
Period	EBID	EPCWID	HCCRD
1951-2017	6,723	3,119	-416
1951-1978	4,292	2,498	-842
1979-2005	2,538	1,431	-186
2006-2017	21,811	8,364	63
1985-2017	9,953	4,337	23
1985-2005	3,177	2,035	0

Notes:

(1) EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

(2) EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

(3) HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

(4) EPCWID FHG values include deliveries to Rogers WTP and R/U WTP.

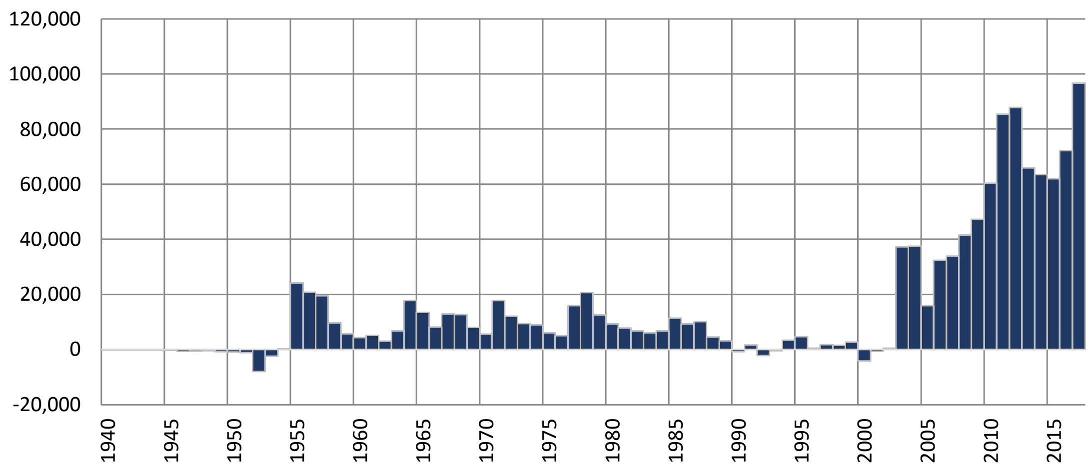
Run 15b - Early EPCWID Ops (Fabens Drain)

Simulated Differences in ILRG Model Outputs

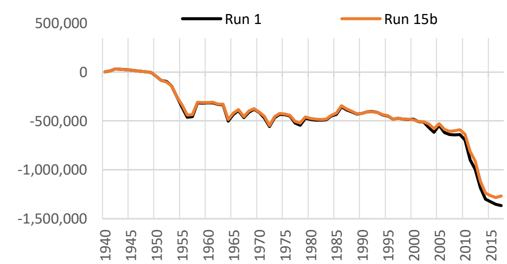
Run 15b minus Run 1

1940 - 2017 (acre-feet)

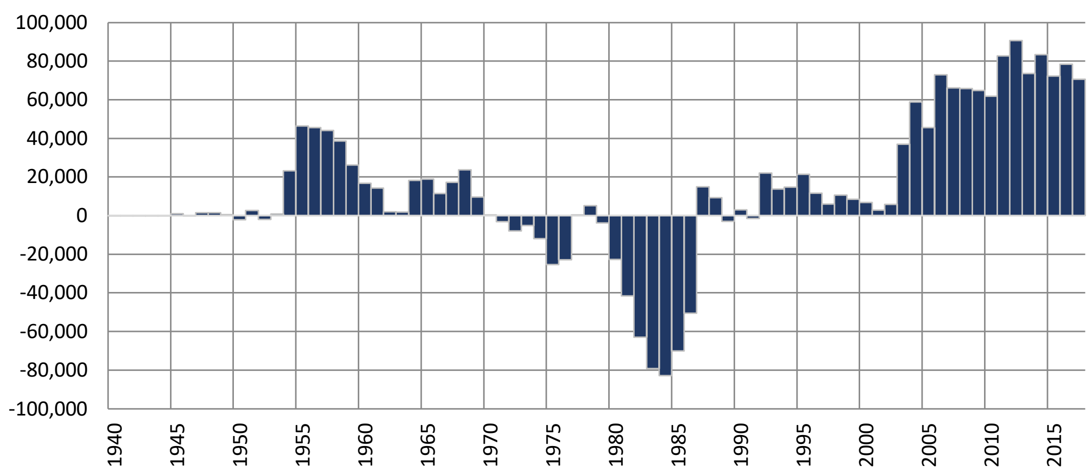
Cumulative Annual Rincon-Mesilla Groundwater Storage



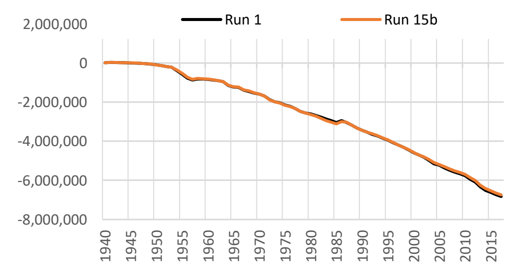
Period	Average Difference
1951-2017	1,456
1951-1978	770
1979-2005	-178
2006-2017	6,732
1985-2017	2,725
1985-2005	436



Cumulative Annual Hueco Groundwater Storage



Period	Average Difference
1951-2017	1,085
1951-1978	259
1979-2005	1,496
2006-2017	2,087
1985-2017	4,651
1985-2005	6,116

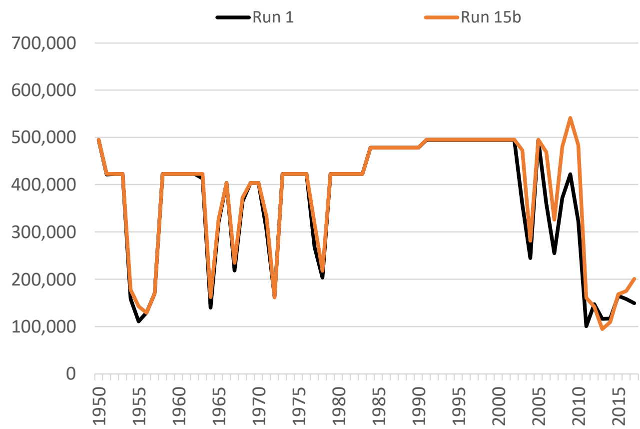


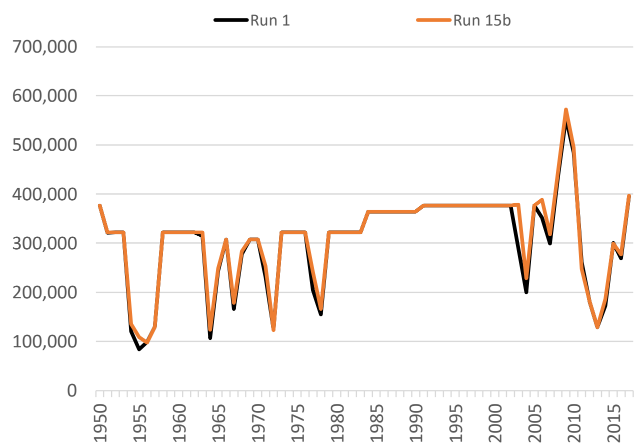
Notes:

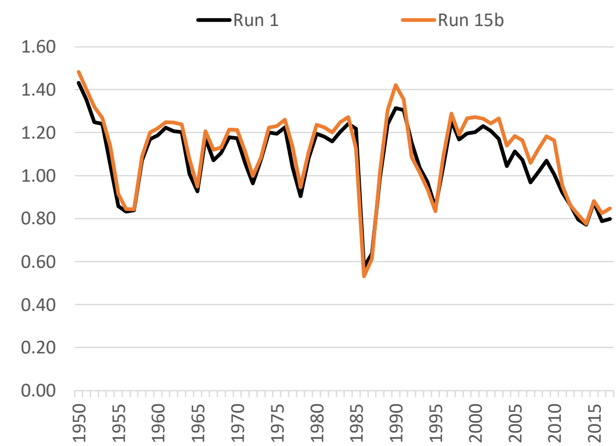
Cumulative storage change in alluvial and non-alluvial aquifers.

Average differences calculated as (Final Storage - Initial Storage)/(no. years).

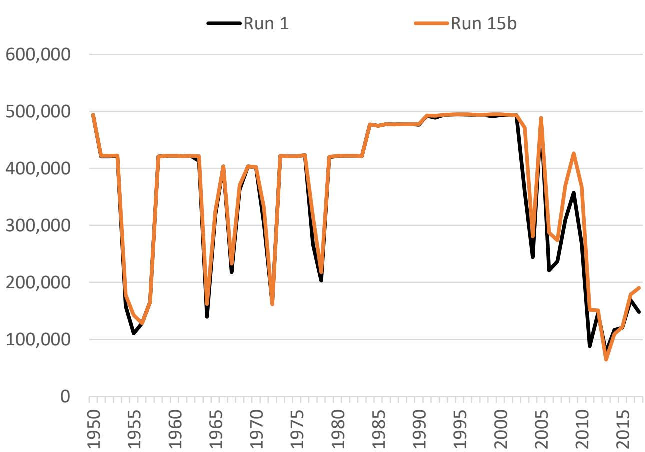
Run 15b - Early EPCWID Ops (Fabens Drain)
Annual Allocation and Charges
Run 15b v. Run 1
ILRG Model
1950 - 2017 (acre-feet)

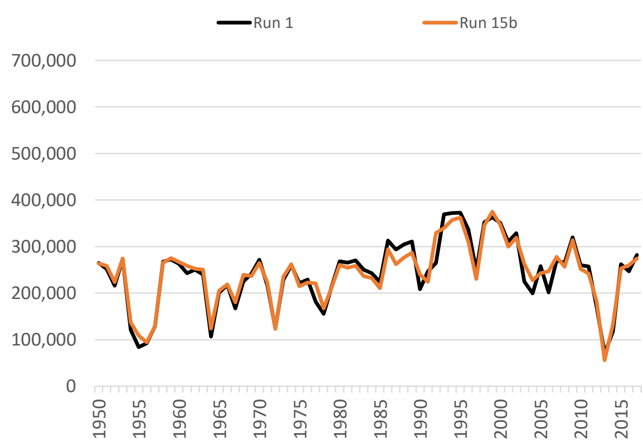
Total Allocation - EBID


Total Allocation - EPCWID


Diversion Ratio


Note:
Computed as Total Charges/Caballo Release.

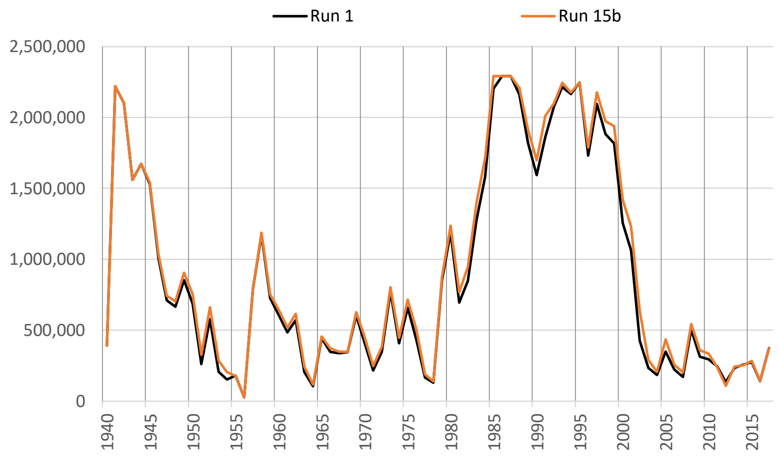
Annual Delivery Charges - EBID


Annual Delivery Charges - EPCWID


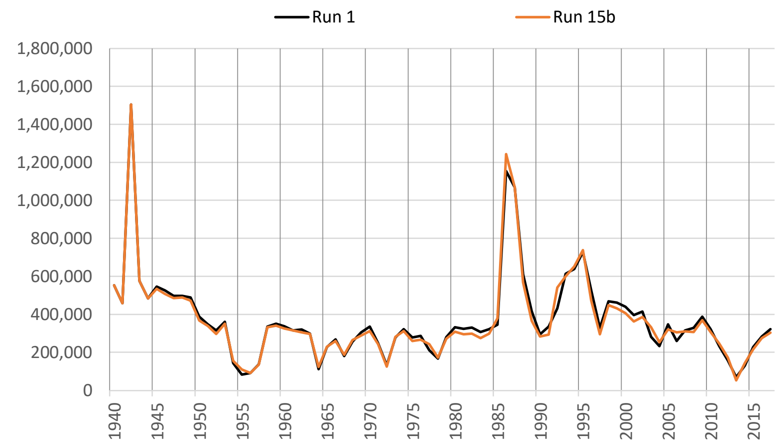
US_MSJ_00003416

Run 15b - Early EPCWID Ops (Fabens Drain)
Annual Summary of Project Storage and Rio Grande Flows
Run 15b v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

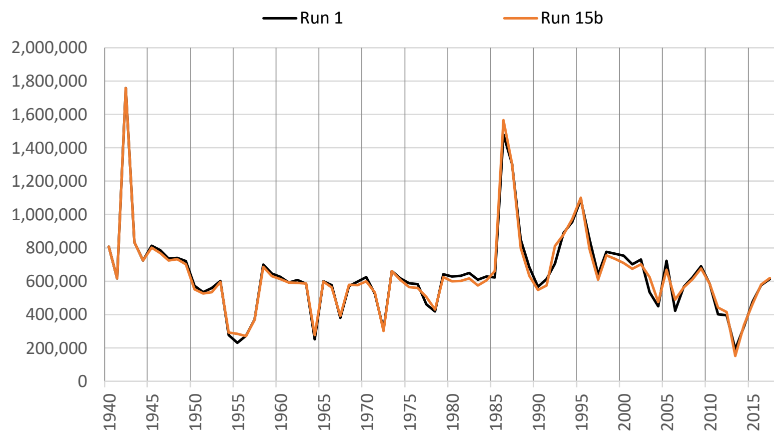
Total Year-End Project Reservoir Storage



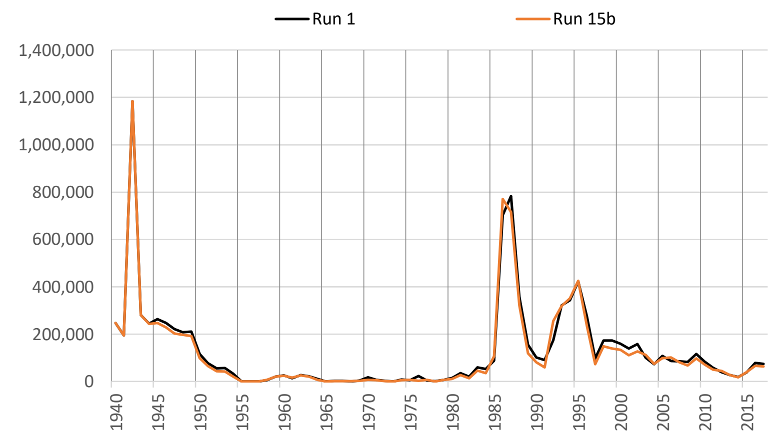
Rio Grande at El Paso



Rio Grande Below Caballo



Rio Grande at Fort Quitman

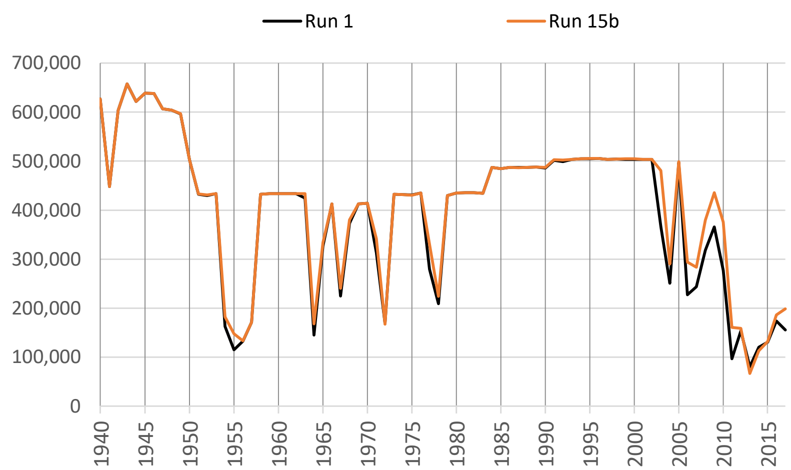


***Note different scales.**

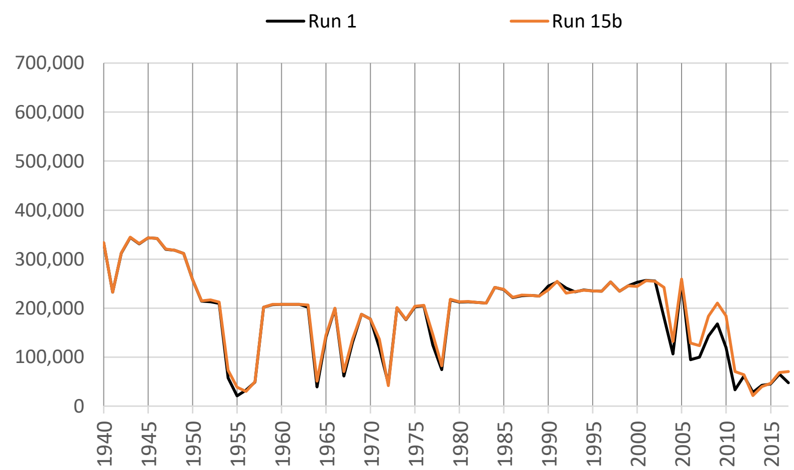
Run 15b - Early EPCWID Ops (Fabens Drain)
Irrigation Season Summary of Irrigation Operations
Run 15b v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

EBID Total

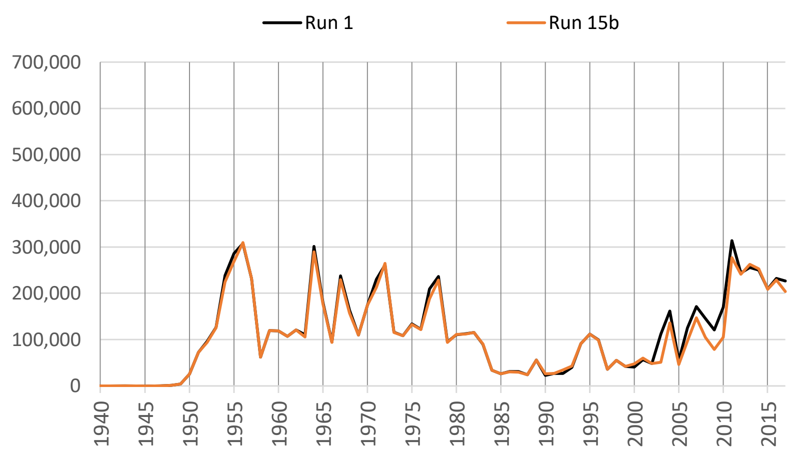
Net River Headgate Diversions



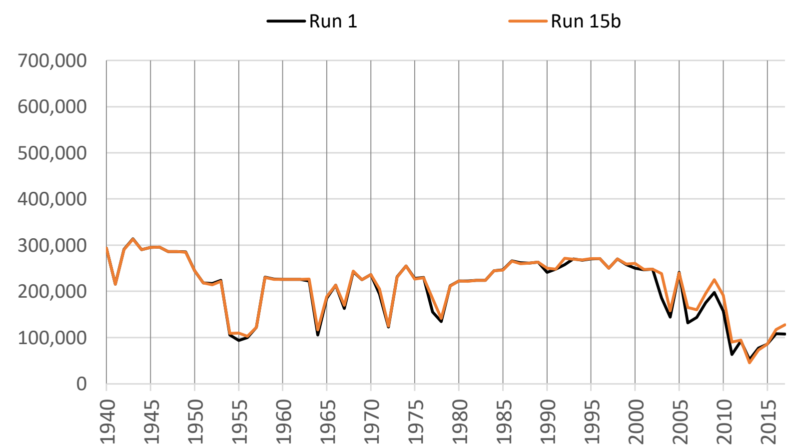
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries

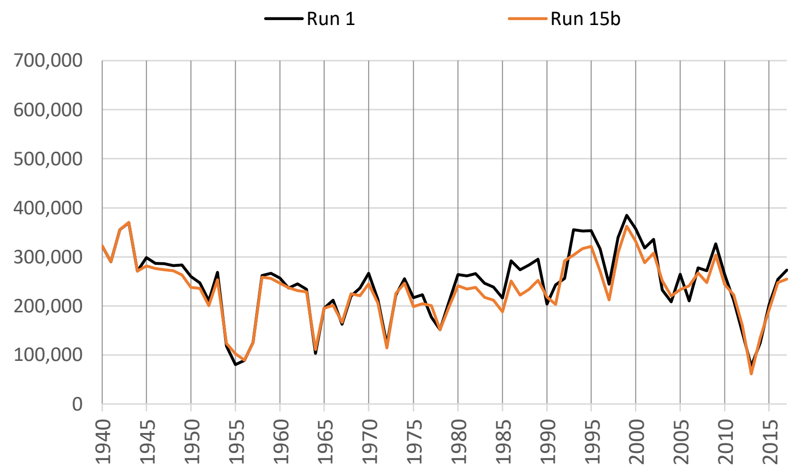


Notes: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).
Pumping includes Supplemental and Primary groundwater pumping.

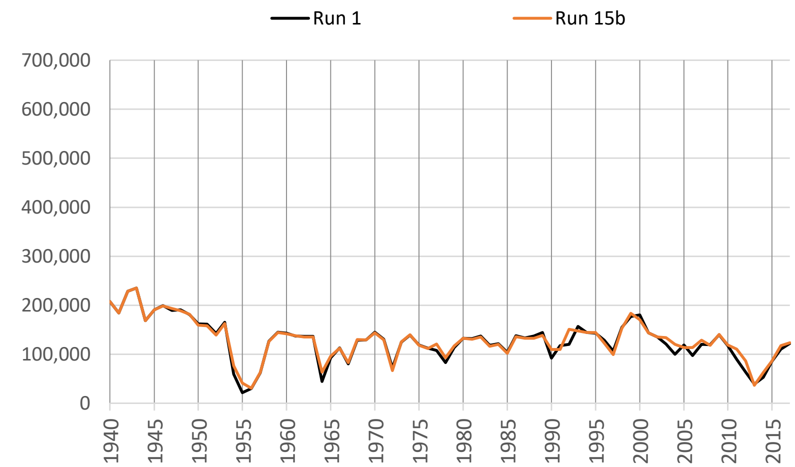
Run 15b - Early EPCWID Ops (Fabens Drain)
Irrigation Season Summary of Irrigation Operations
Run 15b v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

EPCWID Total

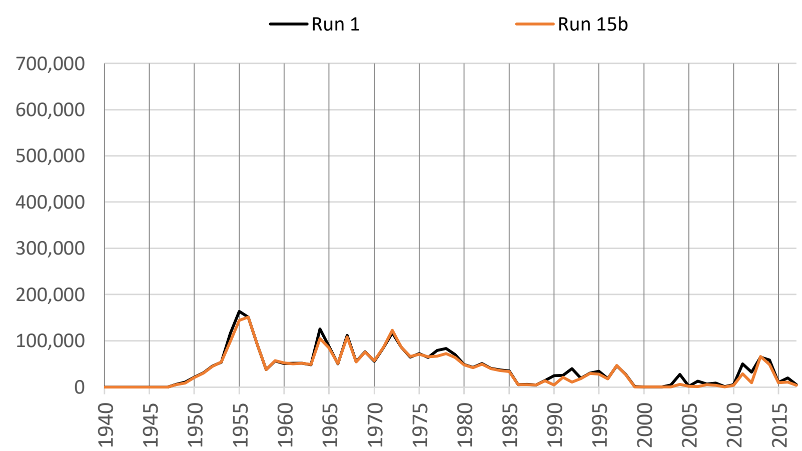
Net River Headgate Diversions



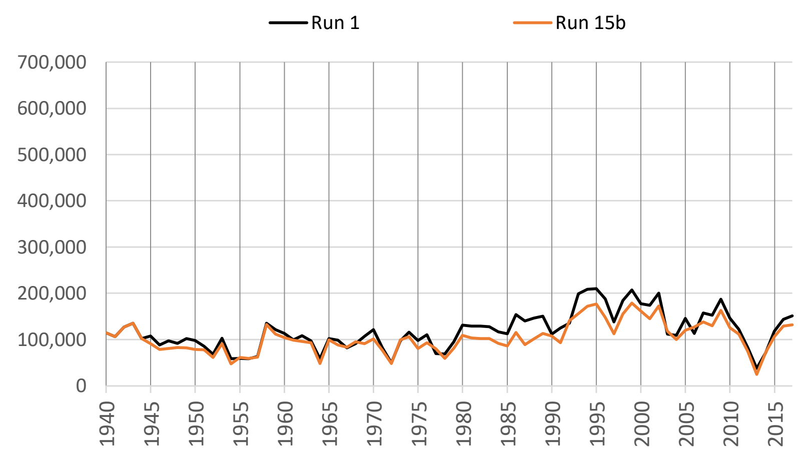
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries

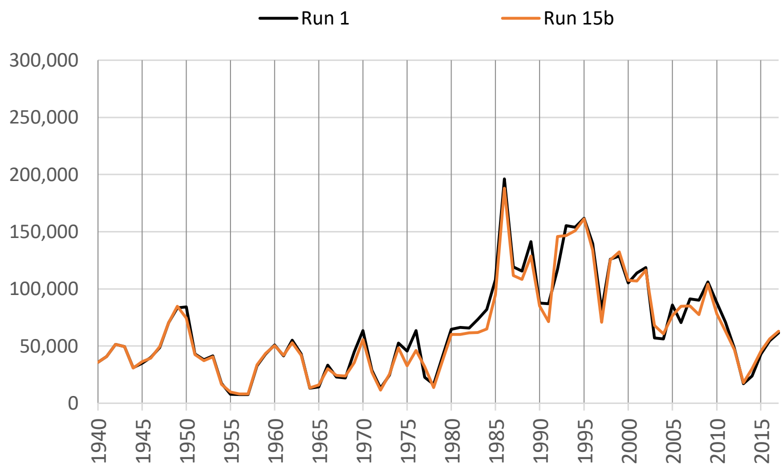


Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

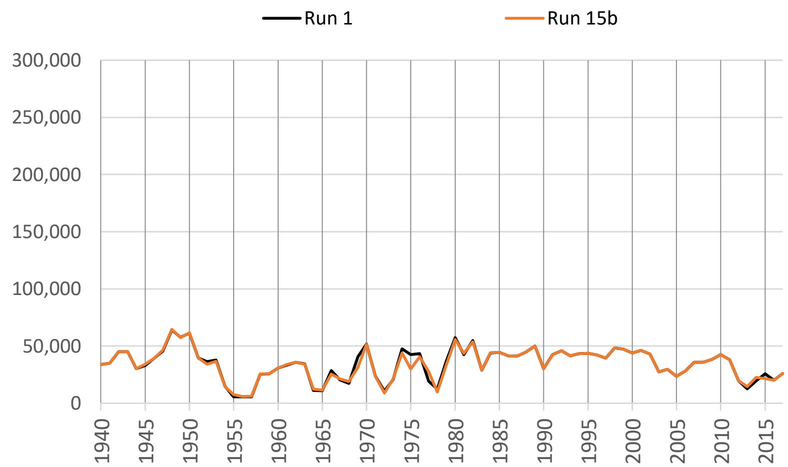
Run 15b - Early EPCWID Ops (Fabens Drain)
Irrigation Season Summary of Irrigation Operations
Run 15b v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

HCCRD Total

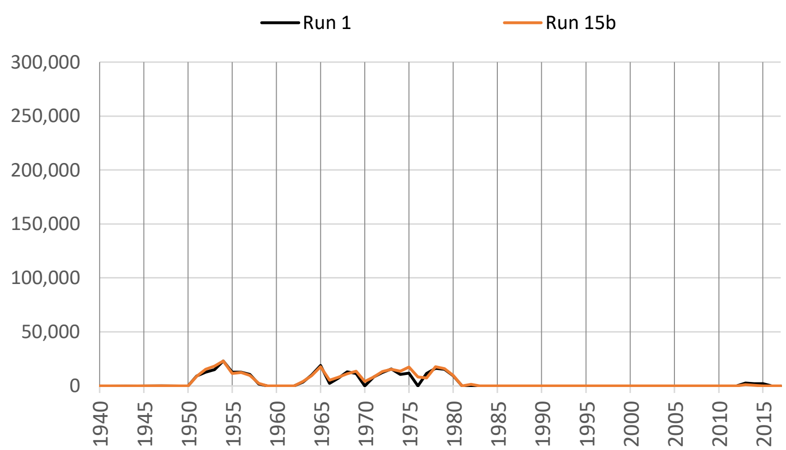
Net River Headgate Diversions



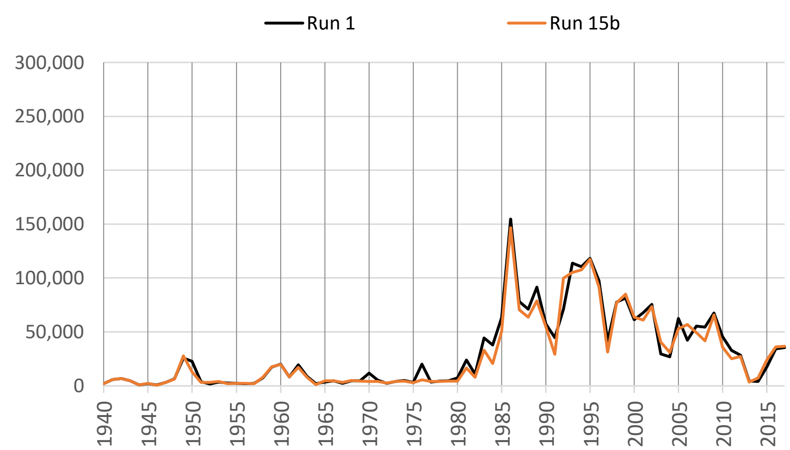
Farm Headgate Deliveries



Pumping



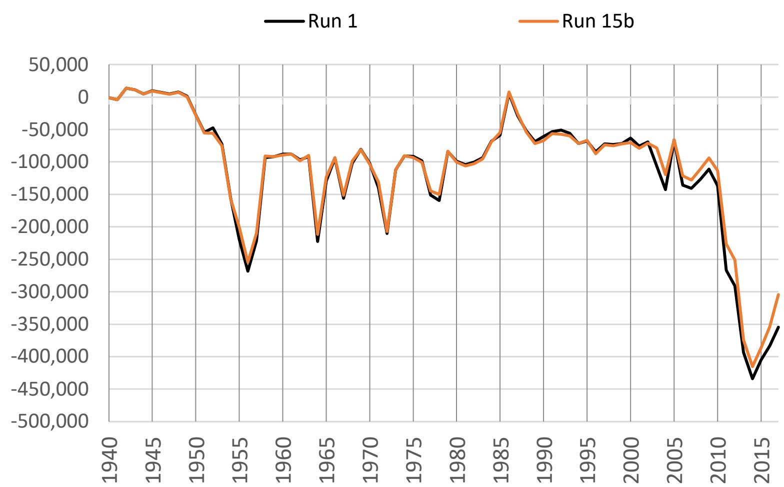
RHG Diversions - FHG Deliveries



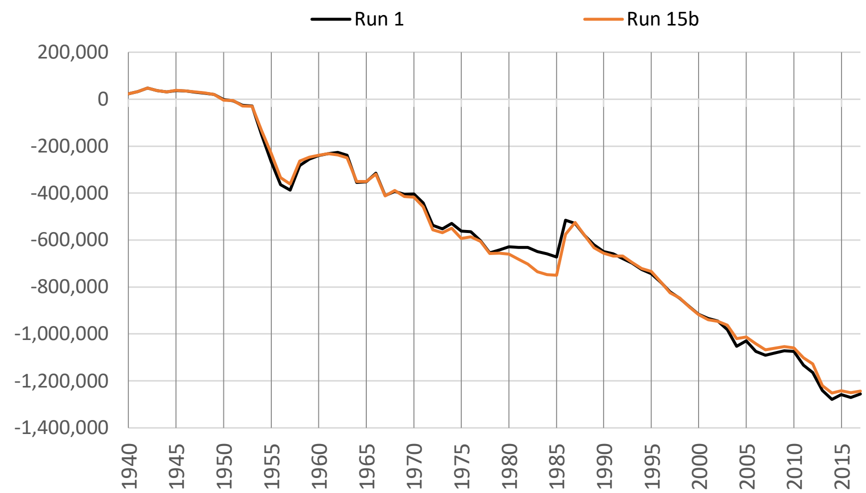
Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

Run 15b - Early EPCWID Ops (Fabens Drain)
Cumulative Change in Ground Water Storage
Run 15b v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

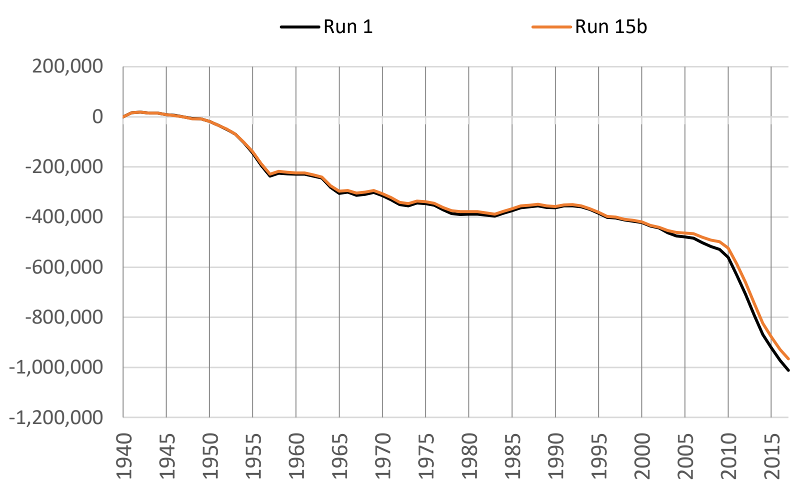
Rincon-Mesilla Alluvial Aquifer



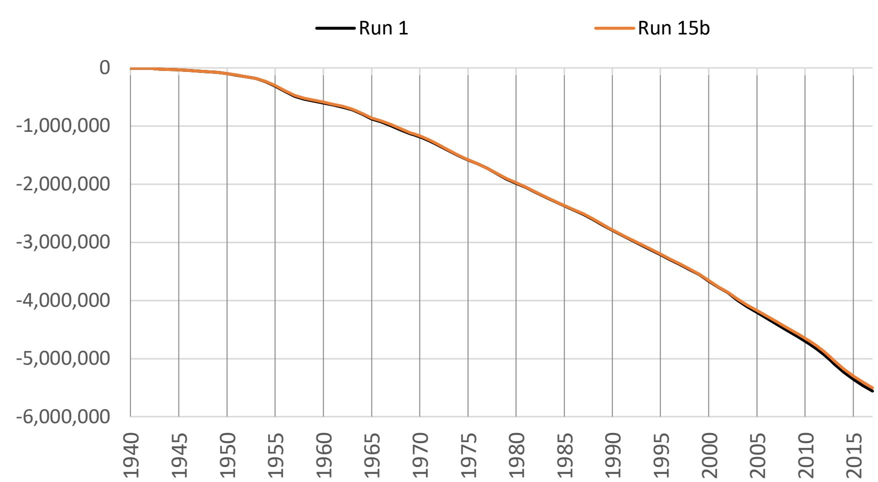
Hueco Alluvial Aquifer



Rincon-Mesilla Non-Alluvial Aquifer



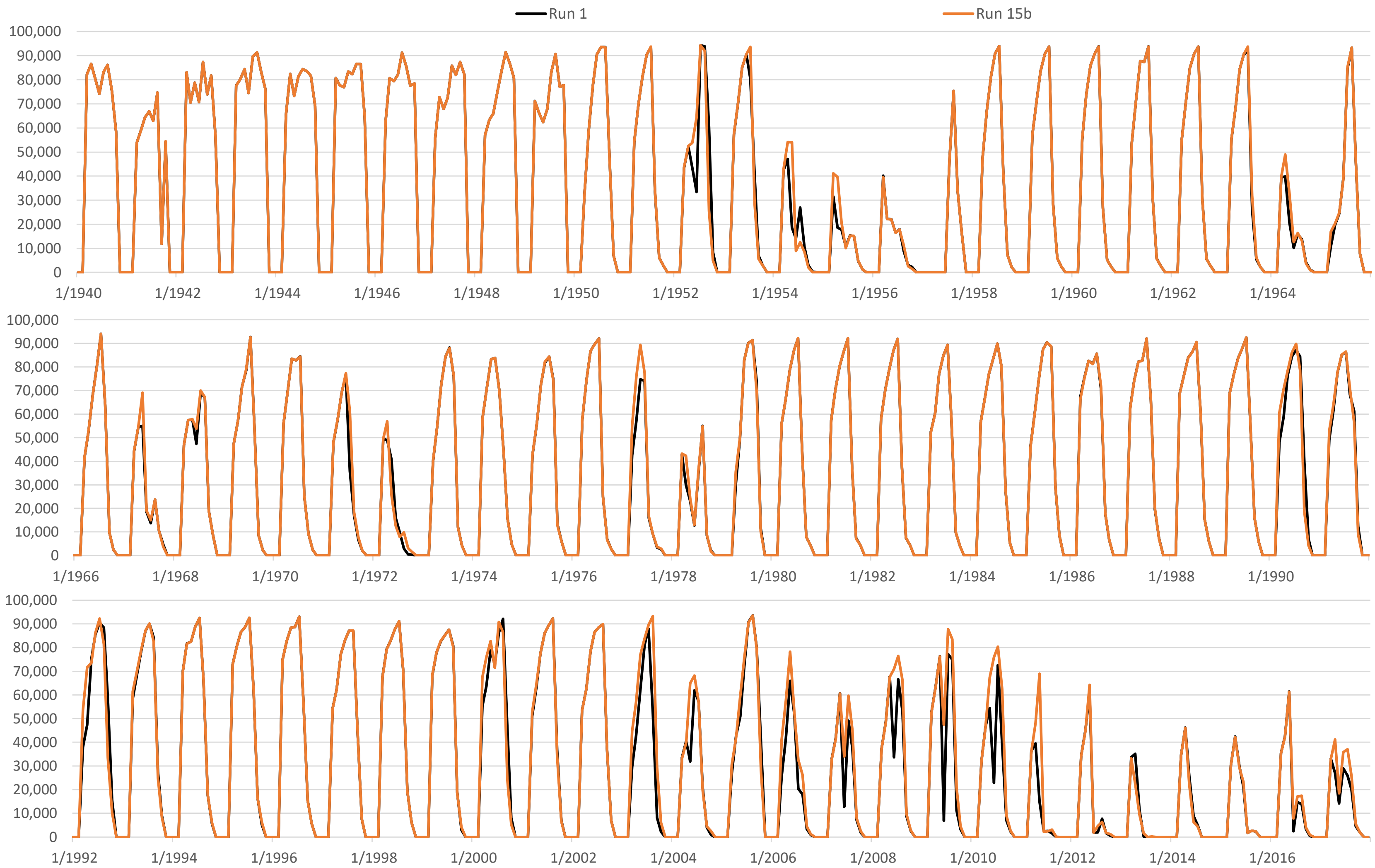
Hueco Non-Alluvial Aquifer



***Note different scales.**

Run 15b - Early EPCWID Ops (Fabens Drain)
Monthly Net RHG Diversions
Run 15b v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

EBID Total

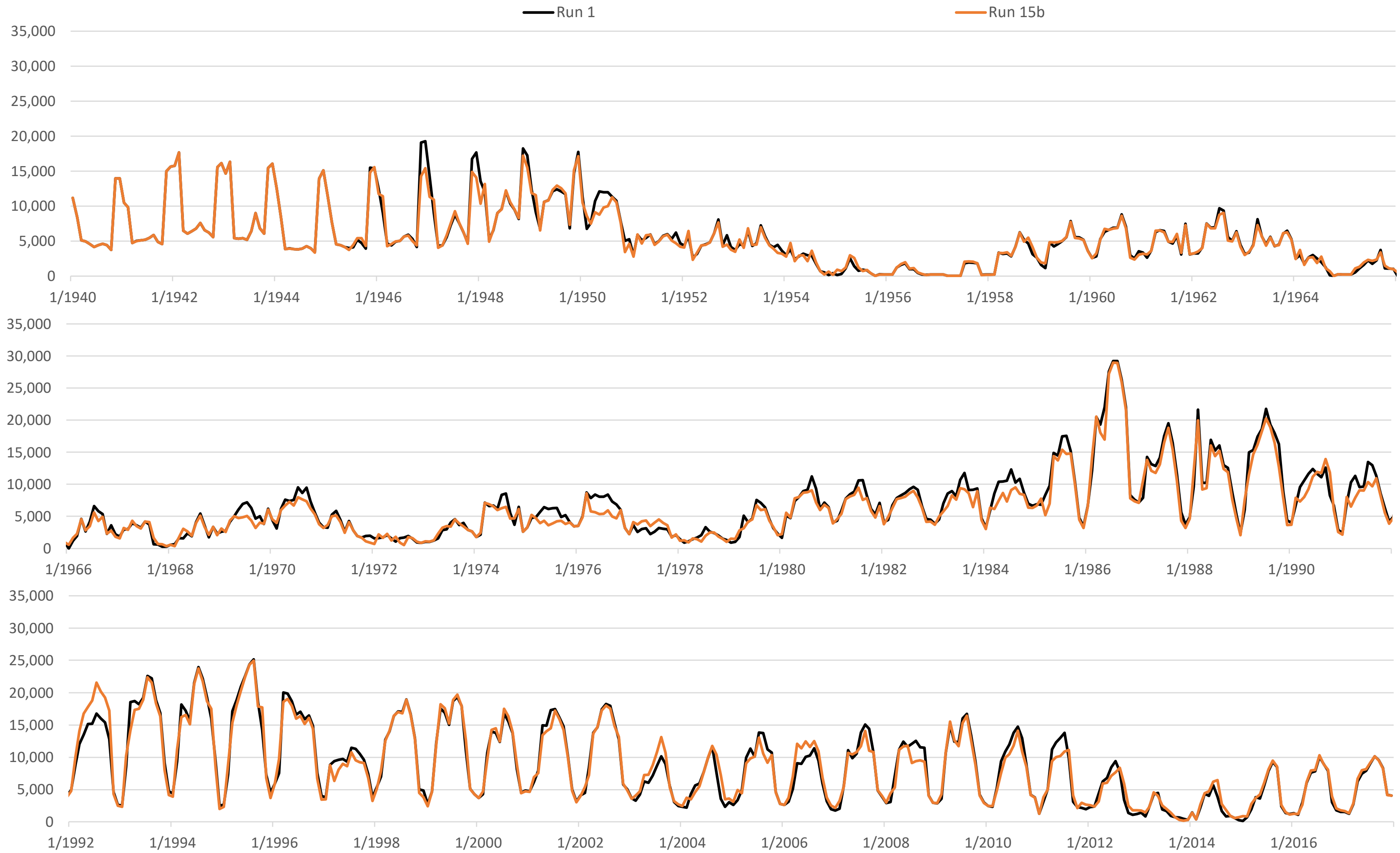


Note: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

Run 15b - Early EPCWID Ops (Fabens Drain)
Monthly Net RHG Diversions
Run 15b v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
EPCWID Total

Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

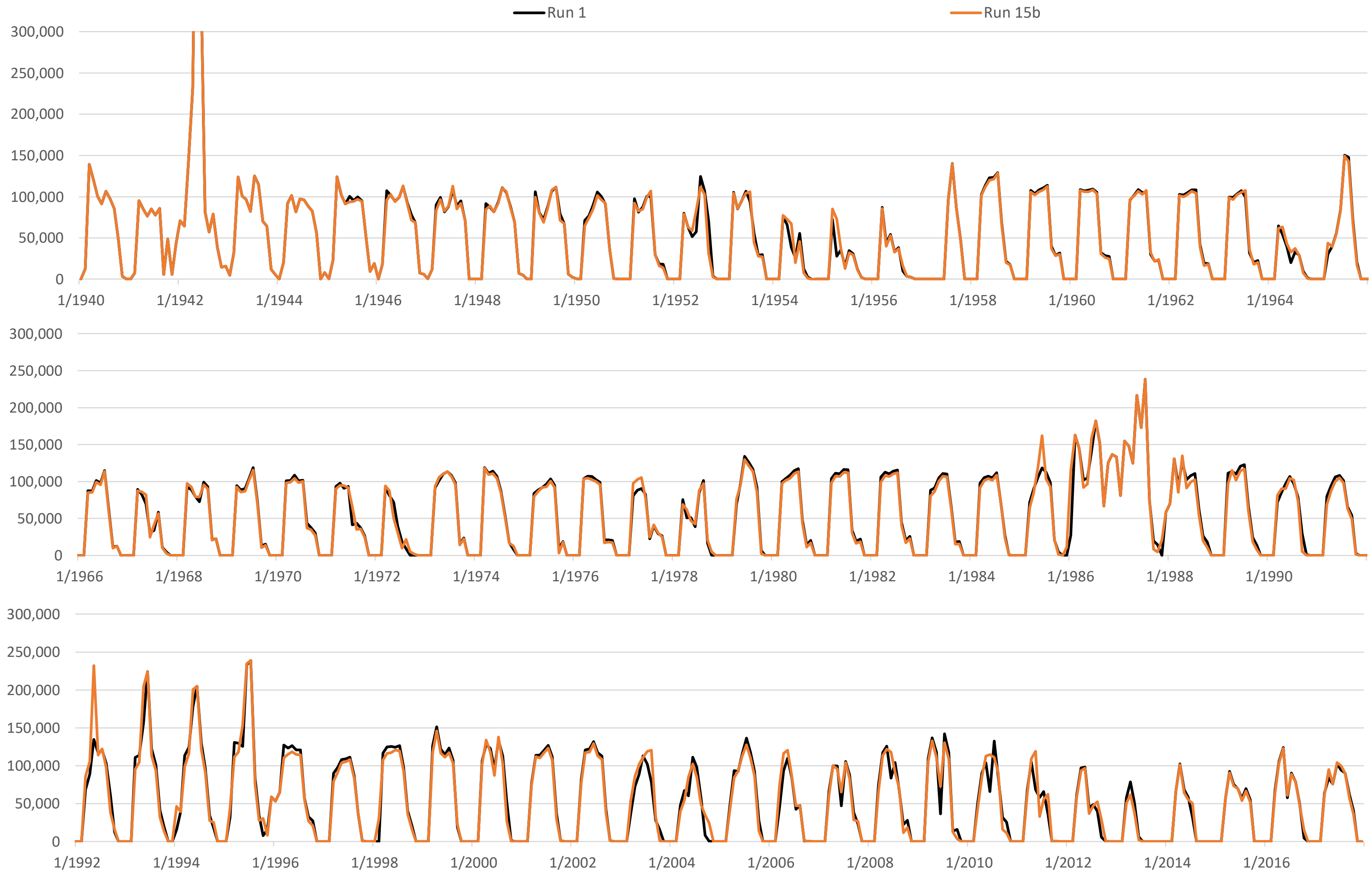
Run 15b - Early EPCWID Ops (Fabens Drain)
Monthly Net RHG Diversions
Run 15b v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
HCCRD Total



Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

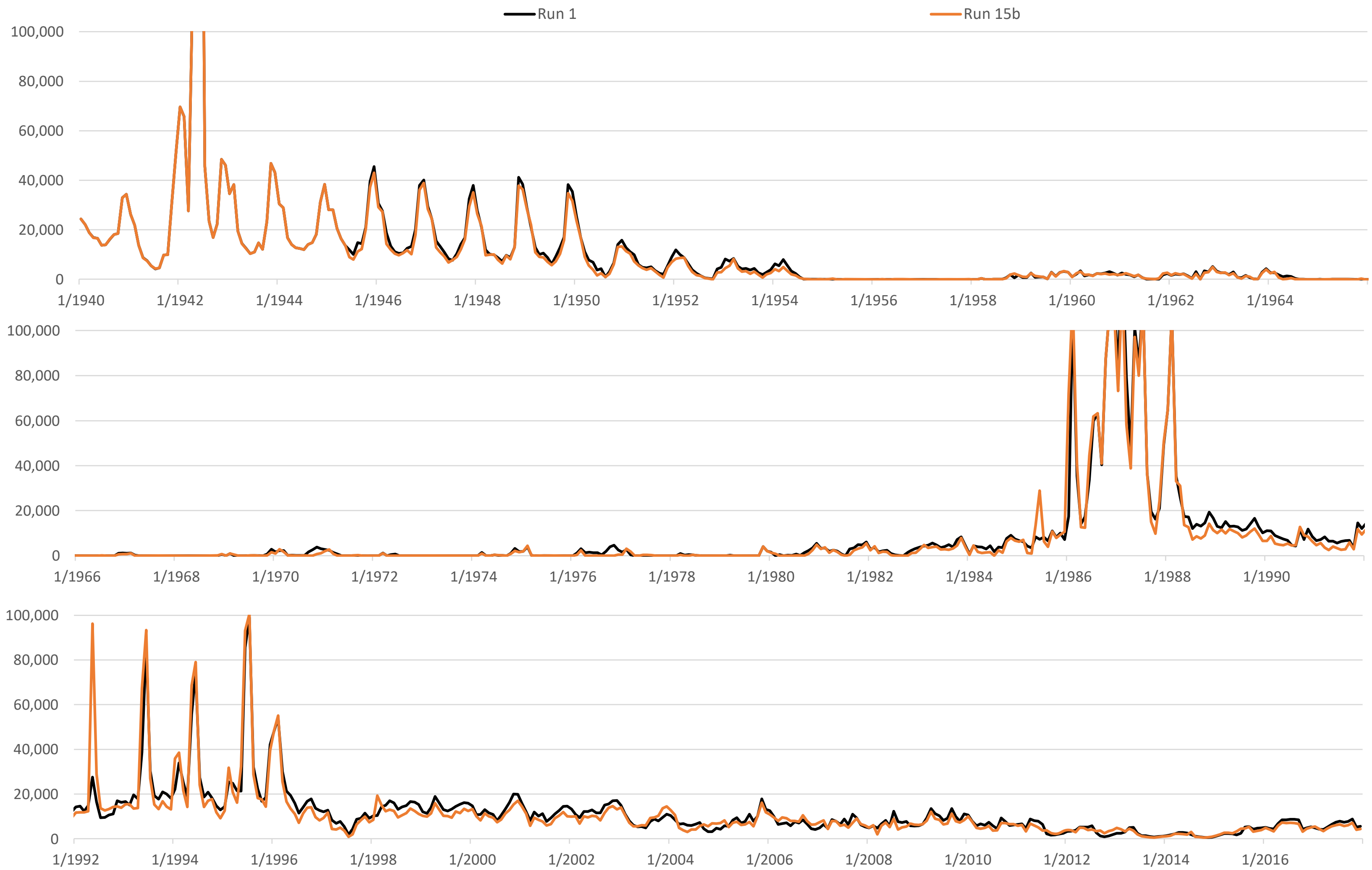
Run 15b - Early EPCWID Ops (Fabens Drain)
End of Month Reservoir Storage (Elephant Butte + Caballo)
Run 15b v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

Run 15b - Early EPCWID Ops (Fabens Drain)
Monthly Caballo Releases
Run 15b v. Run 1
ILRG Model
1940 - 2017 (acre-feet)



Run 15b - Early EPCWID Ops (Fabens Drain)
Monthly Rio Grande at El Paso Flow
Run 15b v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

Run 15b - Early EPCWID Ops (Fabens Drain)
Monthly Rio Grande at Fort Quitman Flow
Run 15b v. Run 1
ILRG Model
1940 - 2017 (acre-feet)



Appendix 30V

Comparison of ILRG Model Runs
Run 15c v. Run 15

Model Run Specifications

Model Version: LRG_v116

Name: **Run 15c - Early EPCWID Ops (TX Hueco Pumping Off)**

Run ID: LRG_v116_Operational_Run15c
Date: 8/28/2020

Name: **Run 15 - Early EPCWID Ops (WWTP & Fabens Drains)**

Run ID: LRG_v116_Operational_Run15
Date: 8/27/2020

Selected Model Inputs

Pumping and Returns	**Run 15c**	**Run 15**
Irrigation Pumping	TX Hueco Off	On
Irrigated Area	Hist	Hist
Non-Irrigation Pumping	TX Hueco Off	On
Non-Irrigation Pumping Returns	TX Hueco Off	On
Las Cruces Jornada Pumping Returns	On	On

Project Allocation Rules		
1950-2005	D1/D2	D1/D2
2006-2007	D3	D3
2008-2017	D3 + CO	D3 + CO

EPCWID Operations		
Charge EPCWID for Use of WWTP Returns	On	On
ACE and Haskell Credits for EPCWID	Off	Off
(1) Increased EPCWID Use of Fabens Drain Flows	On	On
Charge EPCWID for Fabens Drain Flow Use	On	On

Notes:
(1) Starting in July 1945, use 70% of simulated Fabens drain flow up to 6,000 af/month.

Run 15c - Early EPCWID Ops (TX Hueco Pumping Off)

Comparison of ILRG Model Runs

Run 15c v. Run 15
1951 - 2017 Annual Average
(1,000 acre-feet)

Run No.	15	15c	15c - 15		
Simulated Input or Output	**Run 15**	**Run 15c**	**Run 15c minus Run 15**		
Pumping Stress					
Irrigation Pumping	42.2	0.0	-42.2		
Non-Irrigation Pumping	180.9	118.3	-62.6		
WWTP Flows	58.0	46.7	-11.4		
Urban Deep Percolation	13.1	7.8	-5.3		
Total Stress	152.0	63.9	-88.2		
	Stress is Pumping minus WWTP and Urban Deep Perc				
Effects of Pumping Stress				***% Chg***	
FHG Deliveries (Mar - Oct)				***Stress***	***% Diff.***
EBID	177.9	177.6	-0.3	*0%*	*0%*
EPCWID (incl. EPW)	141.2	142.4	1.2	*-1%*	*1%*
HCCRD	32.4	34.7	2.3	*-3%*	*7%*
Total	351.5	354.7	3.2	*-4%*	*1%*
FHG Deliveries (Nov - Feb)					
EBID	0.0	0.0	0.0	*0%*	*1%*
EPCWID (incl. EPW)	1.9	1.4	-0.5	*1%*	*-26%*
HCCRD	2.7	2.6	-0.1	*0%*	*-5%*
Total	4.6	4.0	-0.6	*1%*	*-13%*
Irrigation Pumping					
EBID	130.4	130.7	0.2	*0%*	*0%*
EPCWID (Mesilla Valley)	7.0	6.9	0.0	*0%*	*-1%*
EPCWID (El Paso Valley)	37.5	0.0	-37.5		
HCCRD	4.7	0.0	-4.7		
Total	137.4	137.6	0.2	*0%*	*0%*
	Pumping turned off.	*Other values are simulated responses and are totaled.*			
Other Inflows/Outflows					
Net Reservoir Evaporation	129.6	130.3	0.7	*-1%*	*1%*
Riparian ET	70.5	75.0	4.5	*-5%*	*6%*
River Evaporation + Incidental Canal Loss	30.7	30.2	-0.5	*1%*	*-2%*
Total	230.8	235.5	4.7	*-5%*	*2%*
Rio Grande at Fort Quitman					
Reservoir Spills	38.6	37.3	-1.2	*1%*	*-3%*
Nov-Feb Flows	18.2	20.9	2.7	*-3%*	*15%*
Mar - Oct Flows	32.4	38.5	6.0	*-7%*	*19%*
Underflow (GW Model)	0.2	0.3	0.1	*0%*	*25%*
Total	89.4	97.0	7.6	*-9%*	*8%*

Run 15c - Early EPCWID Ops (TX Hueco Pumping Off)
Comparison of ILRG Model Runs
Run 15c v. Run 15
1951 - 2017 Annual Average
(1,000 acre-feet)

Run No.	15	15c	15c - 15		
Simulated Input or Output	**Run 15**	**Run 15c**	**Run 15c minus Run 15**		
Effects of Pumping Stress (continued)				*% Chg*	
Change in Storage				*Stress*	*% Diff.*
Reservoir Storage	-6.0	-5.9	0.1	*0%*	*-2%*
Alluvial GW Storage (RW Model)	-21.9	-15.6	6.3	*-7%*	*-29%*
Non-alluvial GW Storage (GW Models)	-94.6	-49.7	44.9	*-51%*	*-47%*
Soil Moisture Storage	0.6	0.6	0.0	*0%*	*3%*
Total	-121.9	-70.6	51.3	*-58%*	*-42%*
Summary of Effects					
FHG Deliveries (Mar-Oct)	351.5	354.7	3.2	*-4%*	*1%*
FHG Deliveries (Nov-Feb)	4.6	4.0	-0.6	*1%*	*-13%*
Irrigation Pumping	137.4	137.6	0.2	*0%*	*0%*
Riparian ET + Evaporation	230.8	235.5	4.7	*-5%*	*2%*
Fort Quitman Flow	89.4	97.0	7.6	*-9%*	*8%*
Change in Storage	-121.9	-70.6	51.3	*-58%*	*-42%*
Total	691.9	758.2	66.3	*-75%*	*10%*
Other Effects of Pumping Stress				*% Chg*	
Rio Grande at El Paso				*Stress*	*% Diff.*
Reservoir Spills	59.4	53.8	-5.6	*6%*	*-9%*
Nov-Feb Flows	22.7	23.3	0.6	*-1%*	*3%*
Mar - Oct Flows	247.4	252.5	5.0	*-6%*	*2%*
Total	329.5	329.5	0.0	*0%*	*0%*
Rio Grande below Caballo					
Reservoir Spills	79.3	71.2	-8.1	*9%*	*-10%*
Nov-Feb Flows	0.3	0.7	0.4	*0%*	*144%*
Mar - Oct Flows	525.0	532.0	7.0	*-8%*	*1%*
Total	604.6	603.9	-0.7	*1%*	*0%*
Surface Water Diversions (Mar - Oct)					
EBID	384.8	384.7	-0.2	*0%*	*0%*
EPCWID (incl. EPW)	221.7	220.5	-1.2	*1%*	*-1%*
HCCRD	64.4	69.8	5.4	*-6%*	*8%*
Total	671.0	675.0	4.0	*-5%*	*1%*
Surface Water Diversions (Nov - Feb)					
EBID	0.0	0.0	0.0	*0%*	*0%*
EPCWID (incl. EPW)	15.7	13.6	-2.2	*2%*	*-14%*
HCCRD	14.3	15.0	0.7	*-1%*	*5%*
Total	30.0	28.6	-1.4	*2%*	*-5%*

Run 15c - Early EPCWID Ops (TX Hueco Pumping Off)
Annual Differences in ILRG Model Outputs
Run 15c minus Run 15
1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1940	19	19	-623	65	-150	555	-12	-12	376	376	-95	-95	-3,480	-3,374	6,877
1941	56	56	-111	-1,255	217	51	4	4	-2	-206	199	110	3,185	2,887	3,535
1942	-28	-28	-41	-2,038	-174	-173	8	8	467	-168	-196	-219	1,879	1,874	-231
1943	-22	-22	-137	-1,639	-155	-294	24	24	455	211	-106	-410	4,335	4,233	2,445
1944	-21	-21	-341	-1,730	188	-109	0	0	-232	-427	127	-104	1,976	1,940	2,124
1945	-15	-15	-927	-3,594	401	140	6	6	-323	-1,233	288	220	2,486	2,355	2,359
1946	-12	-12	-3	-1,753	571	565	9	9	664	-531	391	354	3,653	3,554	2,727
1947	-2	-2	-290	-2,231	331	176	3	2	950	116	261	293	1,573	1,597	2,084
1948	10	10	-2,036	-3,997	704	679	-10	-10	520	-499	276	226	-1,233	-1,158	4,036
1949	19	19	-3,073	-5,084	966	981	-1	-2	348	-330	-28	-57	-583	-620	5,250
1950	11	11	-4,462	-5,863	2,048	2,611	-28	-28	435	-304	-8	-14	-1,317	-1,314	6,147
1951	9	9	-6,191	-7,000	1,918	2,708	-5	-5	-157	-294	1,907	2,451	-4,118	-3,615	12,605
1952	-151	-151	-9,859	-9,501	2,174	2,924	-29	-30	-456	722	3,536	1,439	-7,506	-6,899	10,930
1953	15	15	-13,402	-12,656	2,738	4,102	-39	-39	-461	1,249	3,777	3,662	-12,853	-12,040	20,942
1954	11,625	11,625	5,507	5,115	5,194	7,284	3,773	3,773	12,592	13,905	4,941	6,958	31,617	15,397	15,771
1955	-9,862	-9,862	-9,031	-11,042	8,504	10,852	-5,676	-5,676	5,403	6,041	8,424	11,020	-19,433	-7,082	10,611
1956	2,524	2,524	-4,266	-7,059	8,666	11,399	582	582	9,079	9,676	8,632	11,410	3,377	-40	4,081
1957	29	29	-12,242	-14,706	3,238	6,473	31	31	1,158	1,942	2,962	4,997	-10,781	-8,546	2,111
1958	-2	-2	-43,445	-43,916	4,654	8,069	-97	-97	-2,468	-1,521	-1,204	265	-46,709	-42,098	13,687
1959	9	9	-26,926	-27,002	3,179	5,704	-80	-80	-1,958	-673	397	659	-26,236	-26,378	15,194
1960	8	8	-24,456	-24,143	2,706	4,088	-69	-69	-2,461	-945	0	0	-20,704	-20,633	13,154
1961	6	6	-21,105	-21,143	2,442	3,517	-53	-53	-2,070	-764	751	-199	-15,309	-15,593	14,241
1962	13	13	-17,941	-18,880	4,054	4,717	6	6	-1,649	-650	729	1,438	-12,228	-11,790	14,581
1963	0	0	-16,894	-17,159	3,412	4,560	3	2	-1,560	-710	2,288	2,252	-2,234	-2,900	13,871
1964	27,567	27,567	17,751	14,770	6,077	8,269	13,746	13,746	17,554	18,079	5,104	7,404	56,211	31,711	11,357
1965	15,717	15,717	-17,286	-18,840	6,746	9,894	7,992	7,992	12,743	13,912	8,597	11,685	-11,400	-3,419	10,165
1966	1,363	1,363	8,910	9,469	15,876	18,129	-10,253	-10,253	13,341	15,233	-339	-4,399	4,313	20,285	31,375
1967	19,143	19,143	9,302	8,155	6,770	10,587	8,799	8,799	18,379	19,594	6,113	8,067	31,717	13,276	11,347
1968	-4,775	-4,775	-23,805	-24,073	7,139	11,179	-3,439	-3,439	-971	257	6,810	8,125	-28,603	-16,501	12,942
1969	-157	-157	-20,725	-20,487	13,415	15,708	486	486	-1,051	164	13,235	10,193	-19,762	-17,262	15,648
1970	-1	-1	-16,668	-17,417	9,575	10,112	-28	-28	-1,752	165	-593	-5,967	-13,415	-13,364	21,250
1971	32,313	32,313	21,429	20,157	16,152	18,575	6,924	6,924	16,137	19,062	11,817	13,617	42,412	36,475	16,848
1972	1,094	1,094	-1,885	-3,889	9,080	10,763	356	356	5,963	7,762	8,186	8,686	3,980	1,421	7,543
1973	-172	-172	-21,489	-23,209	11,339	13,386	288	288	-336	1,024	11,379	9,438	-23,548	-18,271	3,136
1974	-151	-151	-17,864	-18,065	11,590	15,260	644	644	-2,155	-724	1,498	-1,180	-14,919	-13,304	20,957
1975	-8	-8	-9,672	-9,844	16,621	20,425	31	31	-979	512	16,219	14,377	-5,889	-5,561	7,235
1976	-36	-36	-6,383	-7,041	12,191	15,700	905	905	-939	12	1,208	-8,666	-4,459	-3,614	26,569
1977	24,846	24,846	-1,487	-2,965	6,516	9,435	14,316	14,316	279	715	5,518	4,335	20,260	8,926	9,539
1978	10,796	10,796	2,905	2,028	7,330	10,261	6,502	6,502	5,545	6,587	8,117	8,837	20,520	16,107	4,581

Run 15c - Early EPCWID Ops (TX Hueco Pumping Off)

Annual Differences in ILRG Model Outputs

Run 15c minus Run 15

1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1979	-225	-225	-4,902	-6,473	7,852	9,524	211	213	-1,707	-1,296	8,107	9,864	-3,593	2,587	5,390
1980	-84	-84	-4,504	-5,980	6,214	6,882	141	141	-40	27	1,698	-586	-2,155	949	22,029
1981	-20	-20	2,879	258	5,715	5,889	301	301	359	-1,225	-970	-1,315	7,985	8,523	12,284
1982	-14	-14	4,133	1,228	4,896	5,062	101	101	1,110	-819	1,034	-1,658	11,778	12,237	9,134
1983	-13	-13	8,430	5,642	9,962	10,141	99	99	1,434	-250	0	0	15,259	15,224	16,839
1984	-10	-10	8,084	5,431	10,223	10,154	115	115	789	-1,038	-377	-377	10,878	11,558	10,919
1985	140	140	10,892	8,491	7,137	6,403	-432	-433	800	-1,241	0	0	-36,860	-33,233	-18,202
1986	19	19	20,992	19,581	7,954	6,310	54	53	1,564	-27	0	0	266	-1,881	85,213
1987	104	104	24,643	22,876	8,035	6,419	-760	-761	1,092	-1,300	0	0	100	366	69,510
1988	5	5	28,668	25,879	6,806	5,122	-75	-75	2,837	-840	0	0	23,412	20,920	3,869
1989	-19	-19	31,575	27,856	15,984	14,772	159	159	4,597	-356	0	0	37,628	36,060	15,800
1990	-1,112	-1,112	-22,358	-27,000	-8,546	-10,115	7,751	7,755	-18,963	-24,374	0	0	12,933	4,861	-3,943
1991	-1,036	-1,036	18,946	15,139	7,325	6,823	-914	-911	7,193	1,387	0	0	20,376	24,943	12,751
1992	-393	-393	14,488	12,089	4,739	4,595	-789	-787	1,920	-1,706	0	0	-63,014	-58,856	-57,500
1993	-5	-5	6,228	2,793	4,825	4,890	52	53	4,947	-299	0	0	-9,275	-8,198	-15,913
1994	4	4	-730	-2,893	2,796	2,608	29	29	3,800	560	0	0	-8,119	-6,987	-5,780
1995	3	3	-3,057	-6,489	842	757	23	24	3,398	-1,949	0	0	5,295	4,482	5,614
1996	-4	-4	2,439	-153	1,910	1,269	50	50	3,614	-185	0	0	8,869	8,957	-715
1997	-42	-42	-5,839	-10,695	8,726	7,111	235	235	1,601	-3,943	0	0	4,837	5,786	9,250
1998	2	2	1,129	-1,207	2,252	2,184	5	5	3,029	-383	0	0	-697	-769	7,658
1999	-174	-174	3,682	55	912	730	2,405	2,405	-70	-959	0	0	3,337	4,425	-1,306
2000	-14	-14	7,031	3,242	2,181	1,690	590	590	-2,104	-2,108	0	0	8,846	9,674	-6,019
2001	18	18	15,058	11,013	3,910	2,903	13	13	3,946	3,944	0	0	14,979	14,164	-5,271
2002	2	2	2,567	-128	162	-1,150	12	12	165	165	0	0	-47	402	-10,836
2003	-16,886	-16,886	19,514	17,183	4,659	3,086	-9,267	-9,267	-1,614	-1,620	0	0	3,752	11,623	-6,442
2004	-16,869	-16,869	-4,513	-8,111	112	-1,563	-11,175	-11,175	-8,908	-8,915	0	0	-5,573	-2,270	-4,625
2005	141	141	2,892	-895	340	-657	-183	-184	-1,212	-1,217	0	0	5,506	80	-6,477
2006	-4,541	-4,541	-8,028	-10,895	-2,956	-3,725	-3,664	-3,664	-8,369	-8,371	0	0	-12,890	-11,236	-10,060
2007	-8,209	-8,209	-7,504	-11,167	-884	-2,427	-5,211	-5,211	-5,440	-5,444	0	0	-16,710	-12,166	-7,143
2008	-9,400	-9,400	2,688	-670	1,416	-700	-5,963	-5,965	603	595	0	0	-807	-205	-6,241
2009	-6,202	-6,202	2,804	-1,203	342	-949	-3,722	-3,724	-516	-523	0	0	11	-575	-6,133
2010	1,148	1,148	2,649	-2,109	1,455	958	576	575	-381	-384	0	0	7,009	2,360	-2,529
2011	439	439	-2,648	-6,503	1,488	4,012	240	240	-2,497	-2,366	0	0	-4,495	-3,116	3,105
2012	-15,369	-15,369	6,582	2,882	2,559	3,170	-3,240	-3,240	-4,922	-5,370	0	0	869	10,788	4,505
2013	-12,556	-12,556	1,709	-1,428	3,161	4,182	-6,505	-6,505	-7,539	-7,624	1,940	3,194	774	9,536	-75
2014	-28,140	-28,140	14,088	10,334	11,279	13,354	-17,980	-17,980	3,746	3,770	7,328	8,996	-1,649	18,629	9,142
2015	-26,665	-26,665	-5,431	-8,737	2,943	3,741	-10,864	-10,864	-3,423	-4,635	-4,116	-2,894	-26,178	-1,079	14,344
2016	19,400	19,400	43	-3,561	682	830	12,256	12,256	-3,864	-4,535	0	0	23,702	3,075	-4,183
2017	-15,419	-15,419	2,868	-645	1,000	1,237	-8,985	-8,985	-234	-865	0	0	2,017	2,644	-2,423
Averages															
1951-2017	-153	-153	-1,180	-3,363	5,369	6,113	-279	-279	1,157	666	2,308	2,181	-707	-15	7,579
1951-1978	4,706	4,706	-9,901	-10,727	7,475	9,789	1,629	1,629	3,455	4,655	5,000	4,675	-3,061	-3,761	13,295
1979-2005	-1,351	-1,351	6,977	4,027	4,738	4,142	-417	-416	503	-1,851	352	220	2,471	3,171	5,305
2006-2017	-8,793	-8,793	818	-2,809	1,874	1,973	-4,422	-4,422	-2,736	-2,979	429	775	-2,362	1,554	-641
1985-2017	-4,292	-4,292	5,578	2,270	3,198	2,663	-1,978	-1,978	-643	-2,458	156	282	-54	1,612	1,786
1985-2005	-1,720	-1,720	8,297	5,173	3,955	3,056	-582	-581	554	-2,160	0	0	1,264	1,645	3,173

Notes:

EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

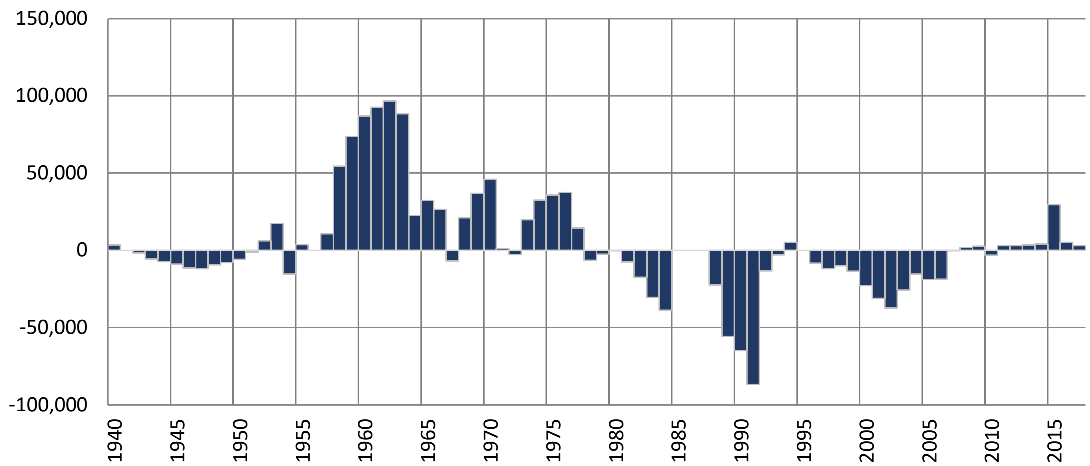
Run 15c - Early EPCWID Ops (TX Hueco Pumping Off)

Simulated Differences in ILRG Model Outputs

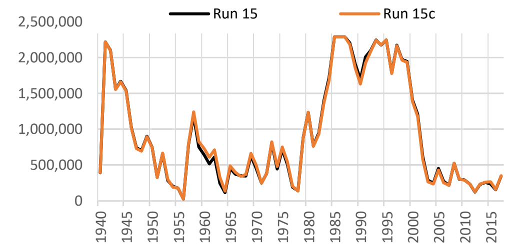
Run 15c minus Run 15

1940 - 2017 (acre-feet)

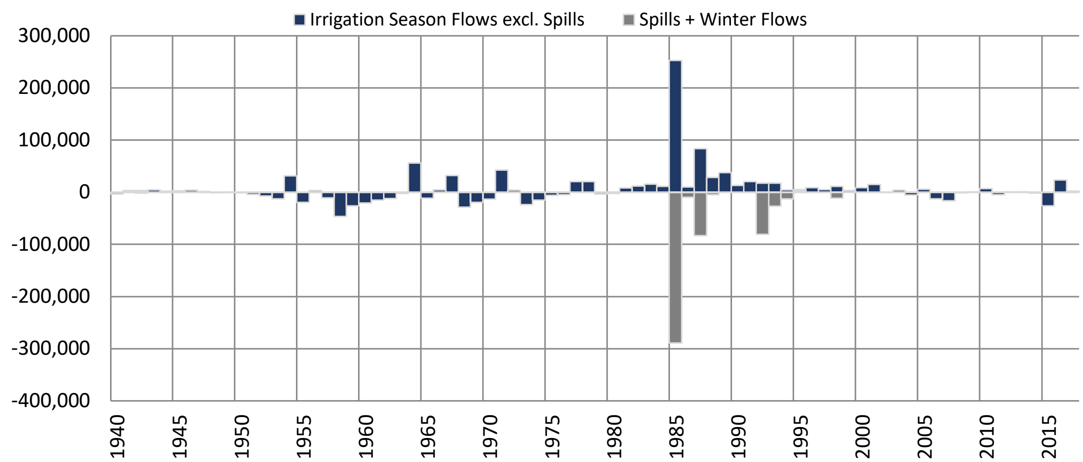
Total Project Storage (Year End)



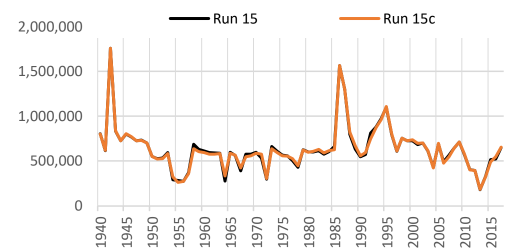
Period	Average Difference
1951-2017	133
1951-1978	-27
1979-2005	-460
2006-2017	1,839
1985-2017	1,271
1985-2005	946



Caballo Reservoir Outflows (Annual)



	Average Difference		
Period	Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	6,992	-7,698	-707
1951-1978	-3,061	0	-3,061
1979-2005	21,574	-19,103	2,471
2006-2017	-2,362	0	-2,362
1985-2017	15,576	-15,630	-54
1985-2005	25,826	-24,561	1,264



Notes:

Reservoir storage does not include storage attributed to SJC, CO, or NM credit waters.

Average differences calculated as (Final Storage - Initial Storage)/(no. years).

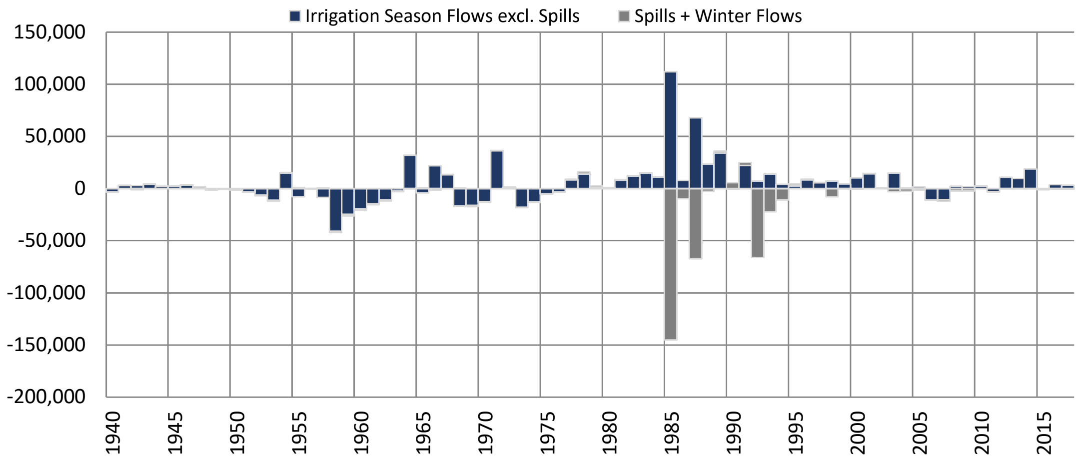
Run 15c - Early EPCWID Ops (TX Hueco Pumping Off)

Simulated Differences in ILRG Model Outputs

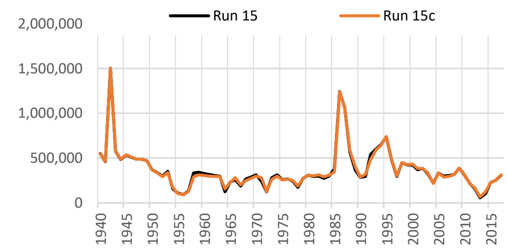
Run 15c minus Run 15

1940 - 2017 (acre-feet)

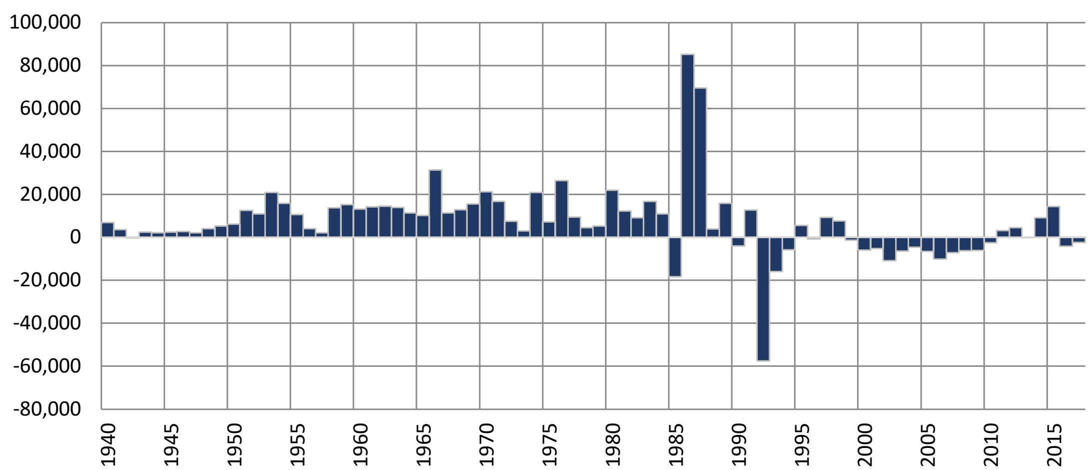
Rio Grande at El Paso (Annual)



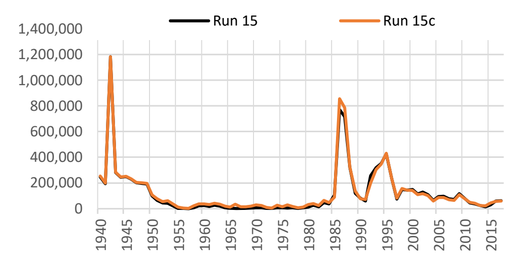
Period	Average Difference: Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	5,031	-5,046	-15
1951-1978	-3,525	-236	-3,761
1979-2005	15,136	-11,965	3,171
2006-2017	2,257	-702	1,554
1985-2017	11,774	-10,162	1,612
1985-2005	17,213	-15,568	1,645



Rio Grande at Fort Quitman (Annual)



Period	Average Difference
1951-2017	7,529
1951-1978	13,231
1979-2005	5,252
2006-2017	-652
1985-2017	1,759
1985-2005	3,137



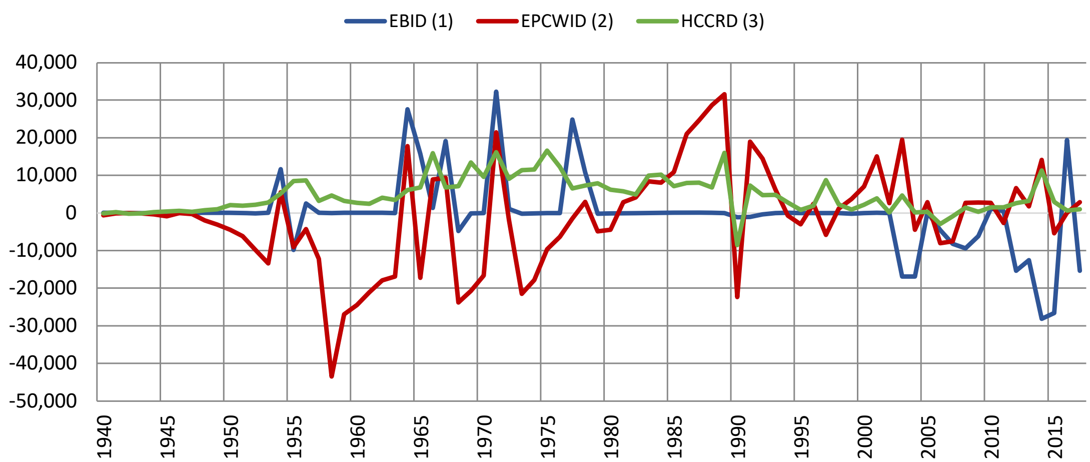
Run 15c - Early EPCWID Ops (TX Hueco Pumping Off)

Simulated Differences in ILRG Model Outputs

Run 15c minus Run 15

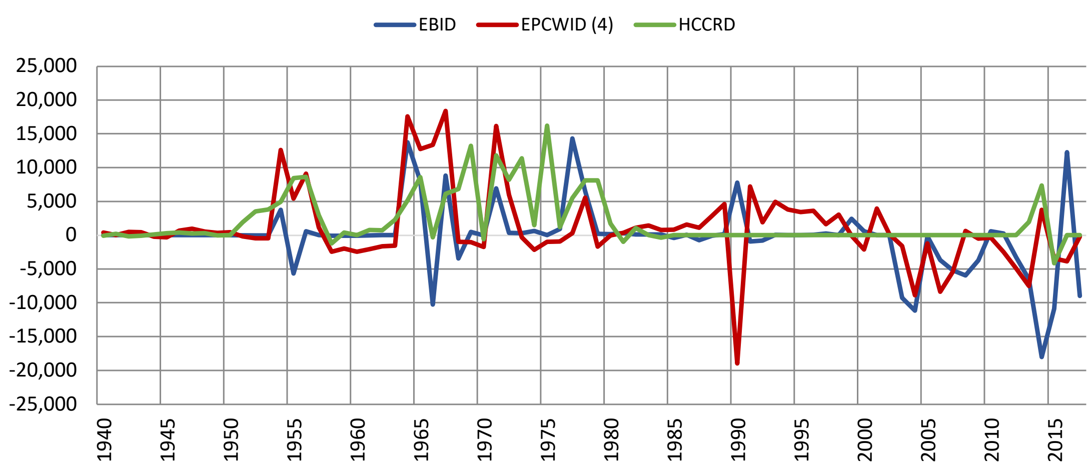
1940 - 2017 (acre-feet)

River Headgate (RHG) Diversions (Irrigation Season)



	Average Difference		
Period	EBID	EPCWID	HCCRD
1951-2017	-153	-1,180	5,369
1951-1978	4,706	-9,901	7,475
1979-2005	-1,351	6,977	4,738
2006-2017	-8,793	818	1,874
1985-2017	-4,292	5,578	3,198
1985-2005	-1,720	8,297	3,955

Farm Headgate (FHG) Deliveries (Irrigation Season)



	Average Difference		
Period	EBID	EPCWID	HCCRD
1951-2017	-279	1,157	2,308
1951-1978	1,629	3,455	5,000
1979-2005	-417	503	352
2006-2017	-4,422	-2,736	429
1985-2017	-1,978	-643	156
1985-2005	-582	554	0

Notes:

(1) EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

(2) EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

(3) HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

(4) EPCWID FHG values include deliveries to Rogers WTP and R/U WTP.

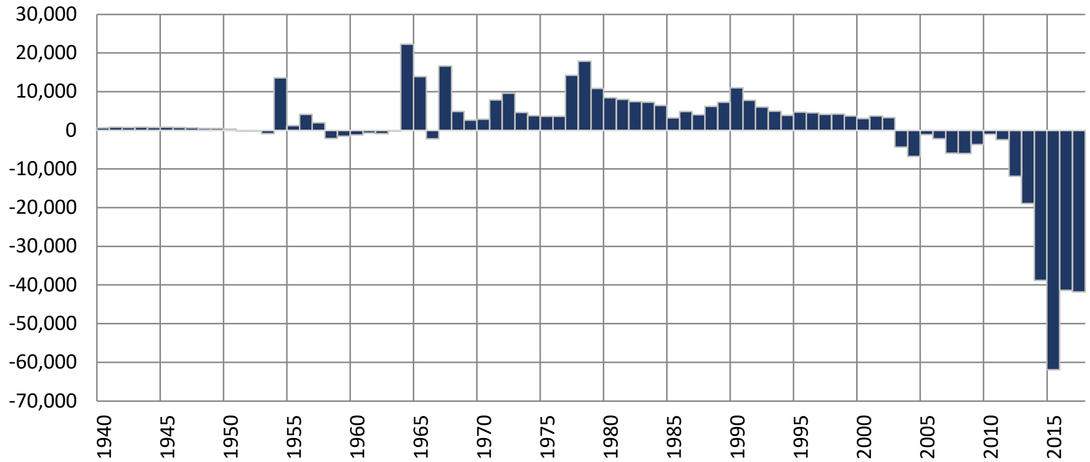
Run 15c - Early EPCWID Ops (TX Hueco Pumping Off)

Simulated Differences in ILRG Model Outputs

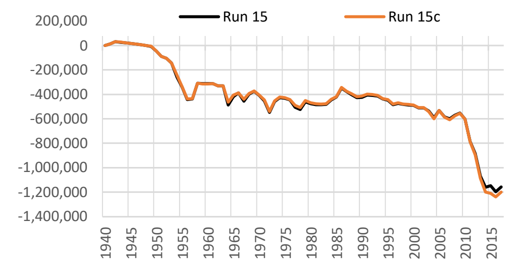
Run 15c minus Run 15

1940 - 2017 (acre-feet)

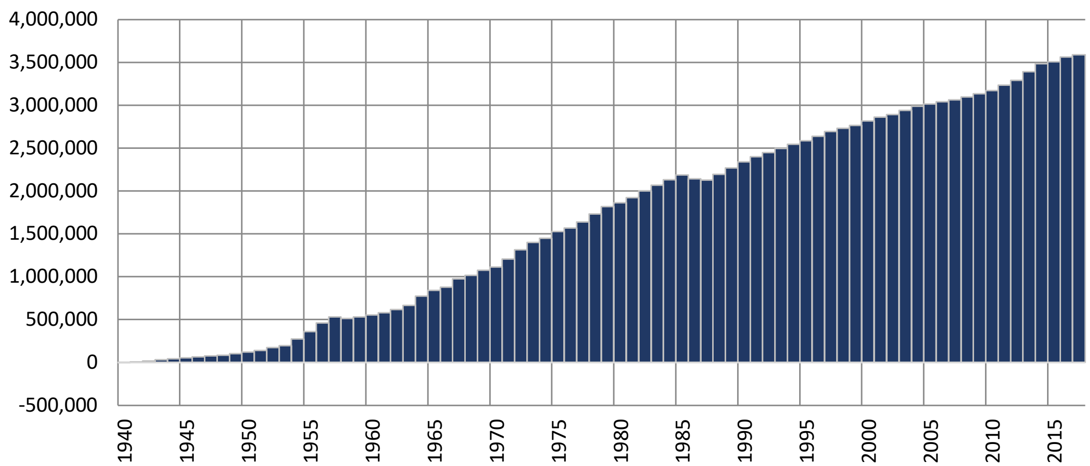
Cumulative Annual Rincon-Mesilla Groundwater Storage



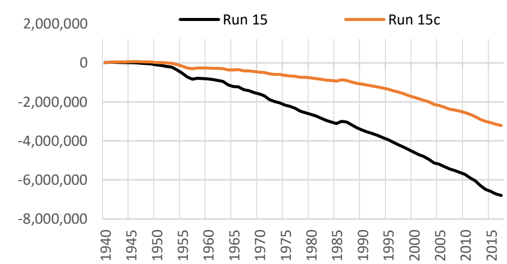
Period	Average Difference
1951-2017	-629
1951-1978	627
1979-2005	-703
2006-2017	-3,393
1985-2017	-1,464
1985-2005	-361



Cumulative Annual Hueco Groundwater Storage



Period	Average Difference
1951-2017	51,785
1951-1978	57,536
1979-2005	47,467
2006-2017	48,081
1985-2017	44,179
1985-2005	41,950



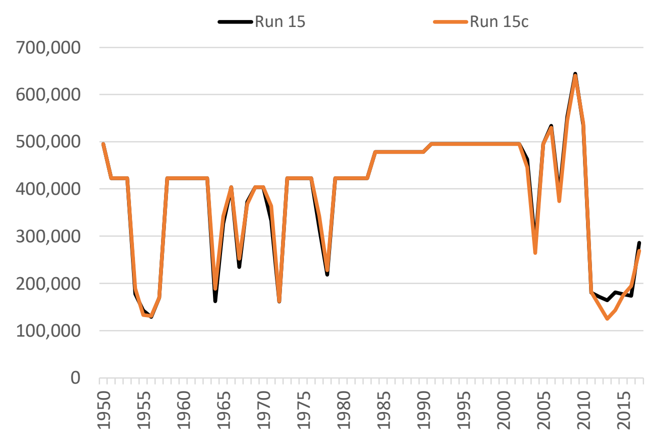
Notes:

Cumulative storage change in alluvial and non-alluvial aquifers.

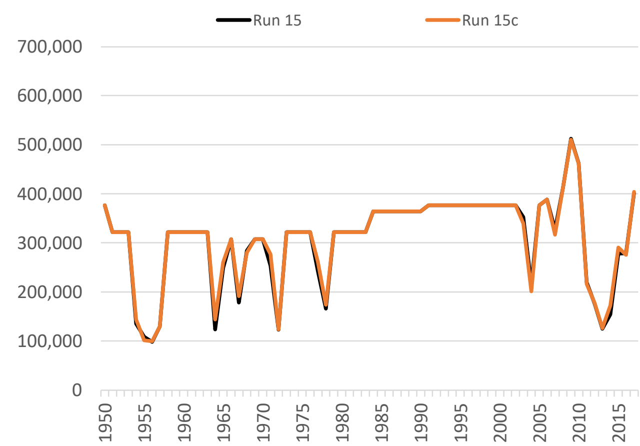
Average differences calculated as (Final Storage - Initial Storage)/(no. years).

Run 15c - Early EPCWID Ops (TX Hueco Pumping Off)
Annual Allocation and Charges
Run 15c v. Run 15
ILRG Model
1950 - 2017 (acre-feet)

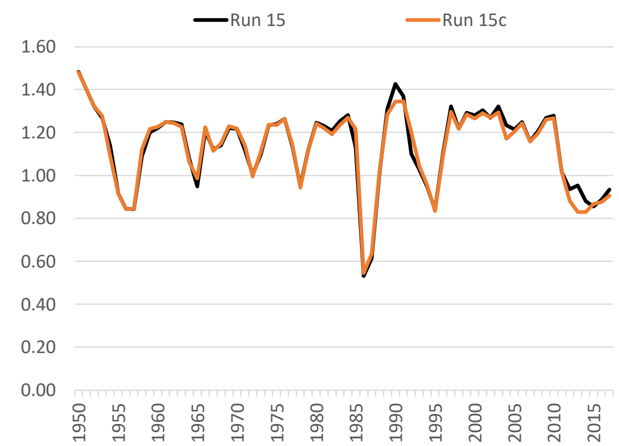
Total Allocation - EBID



Total Allocation - EPCWID

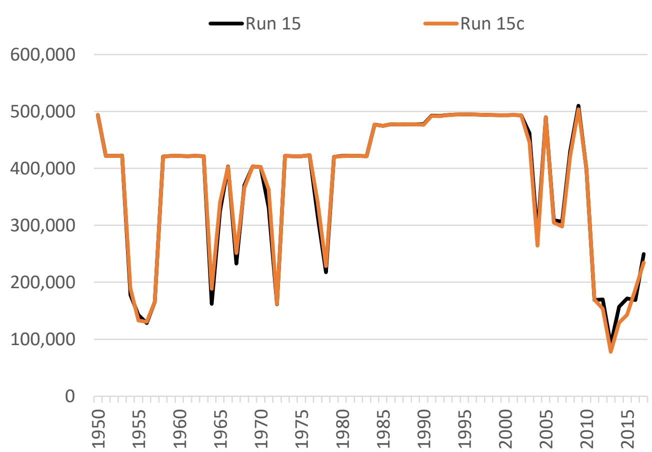


Diversion Ratio

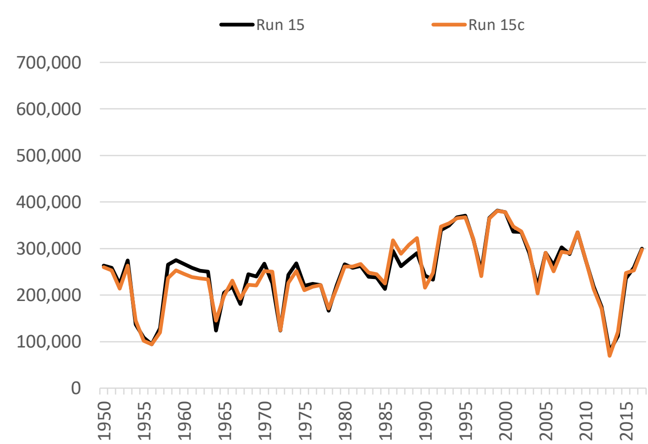


Note:
Computed as Total Charges/Caballo Release.

Annual Delivery Charges - EBID



Annual Delivery Charges - EPCWID



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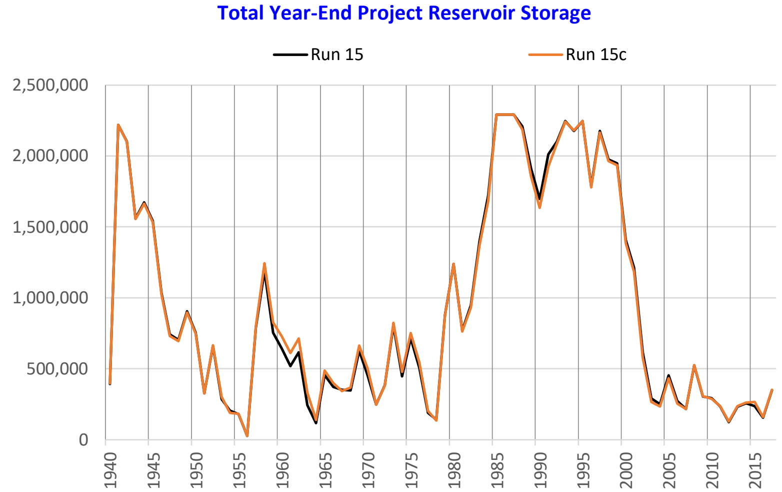
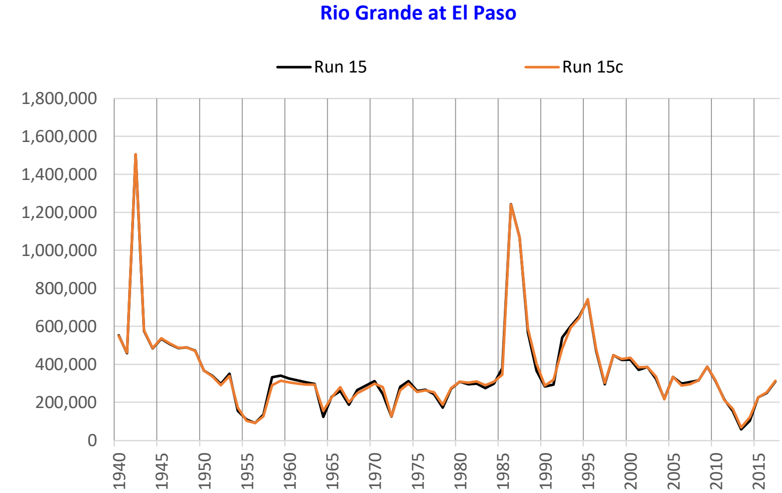
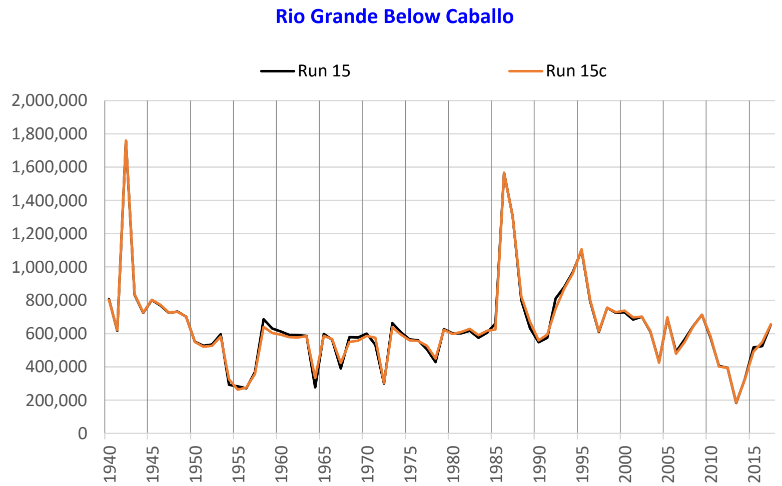
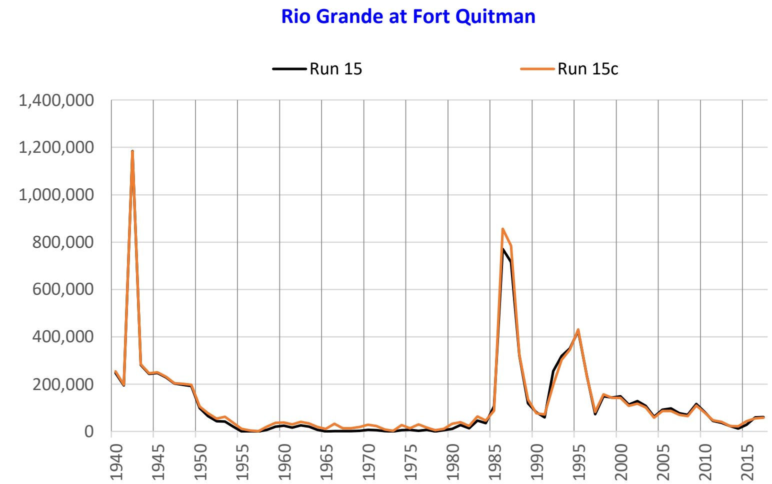
Run 15c - Early EPCWID Ops (TX Hueco Pumping Off)
Annual Summary of Project Storage and Rio Grande Flows
Run 15c v. Run 15
ILRG Model
1940 - 2017 (acre-feet)







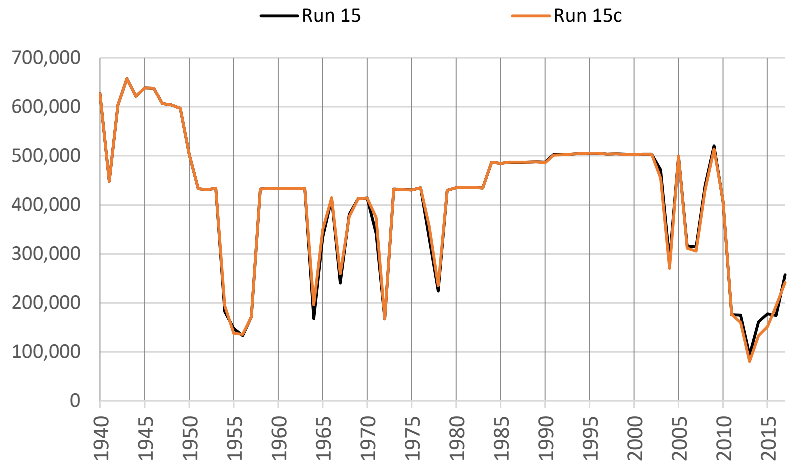


***Note different scales.**

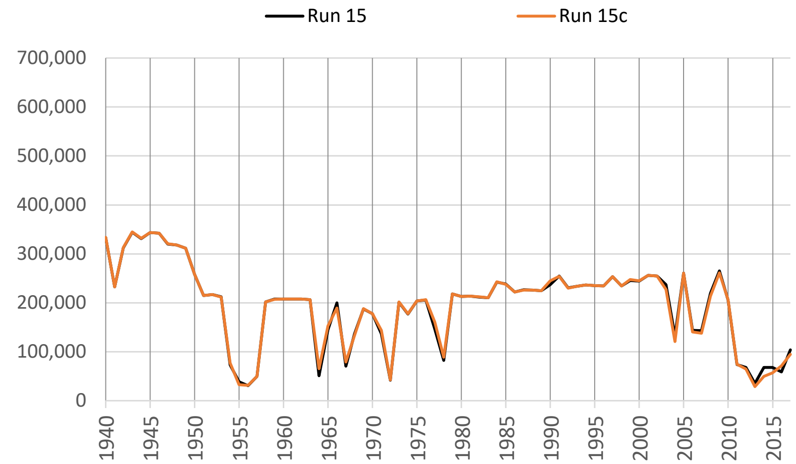
Run 15c - Early EPCWID Ops (TX Hueco Pumping Off)
Irrigation Season Summary of Irrigation Operations
Run 15c v. Run 15
ILRG Model
1940 - 2017 (acre-feet)

EBID Total

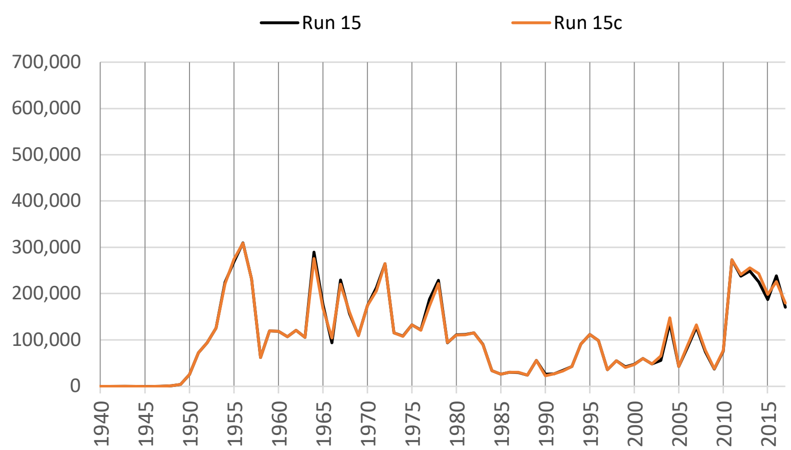
Net River Headgate Diversions



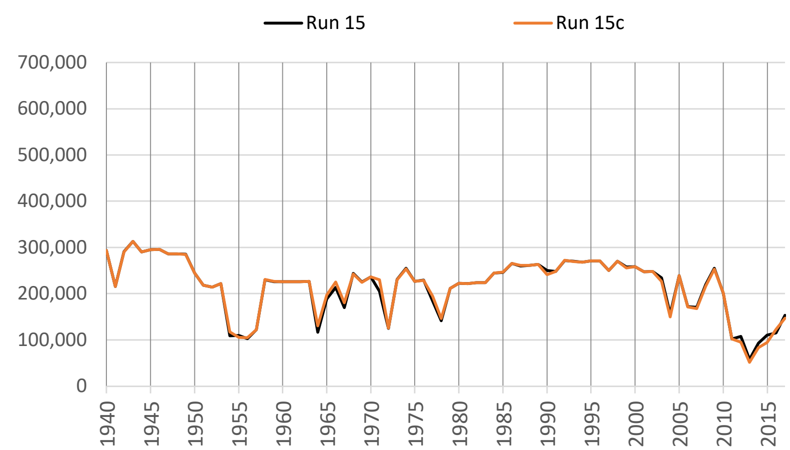
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries



Notes: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).
Pumping includes Supplemental and Primary groundwater pumping.

Run 15c - Early EPCWID Ops (TX Hueco Pumping Off)

Irrigation Season Summary of Irrigation Operations

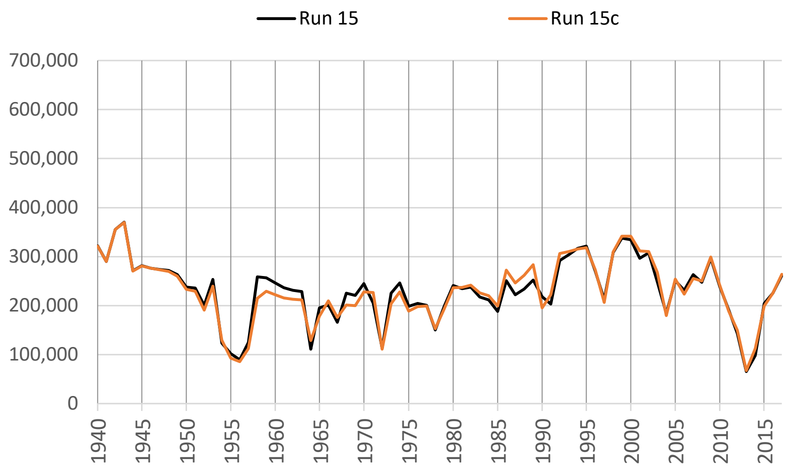
Run 15c v. Run 15

ILRG Model

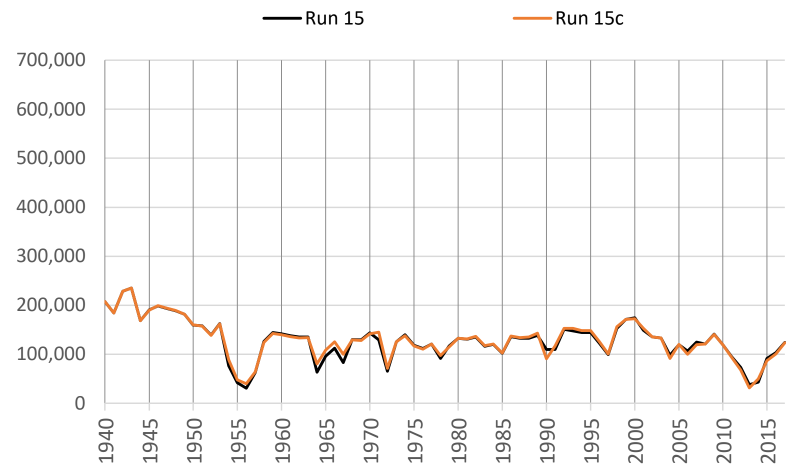
1940 - 2017 (acre-feet)

EPCWID Total

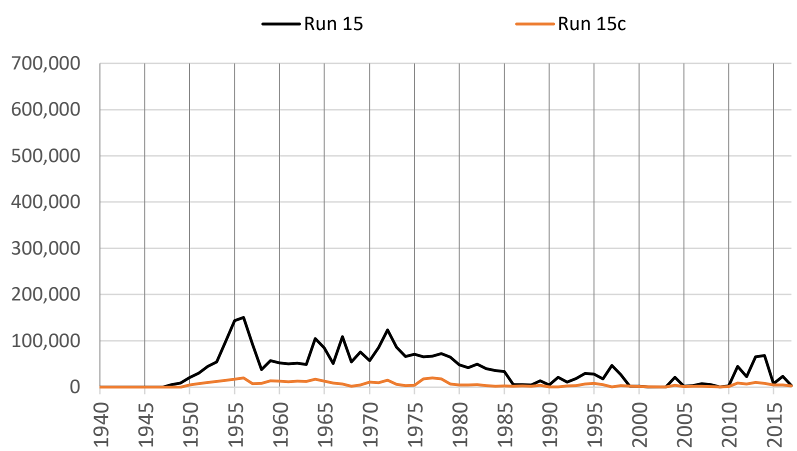
Net River Headgate Diversions



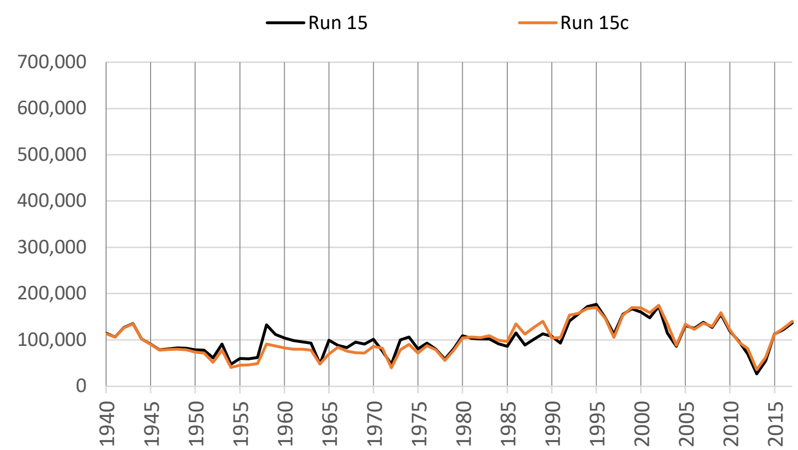
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries

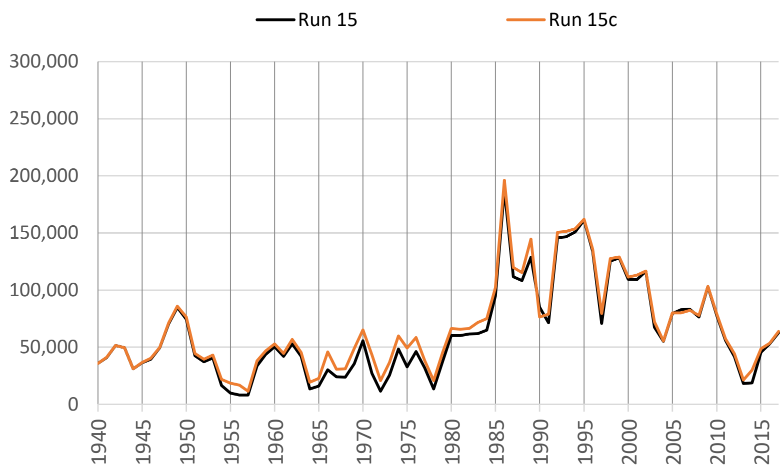


Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

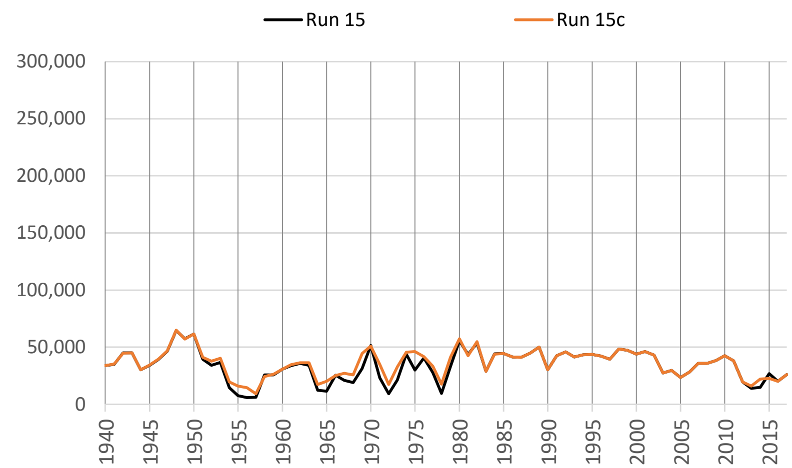
Run 15c - Early EPCWID Ops (TX Hueco Pumping Off)
Irrigation Season Summary of Irrigation Operations
Run 15c v. Run 15
ILRG Model
1940 - 2017 (acre-feet)

HCCRD Total

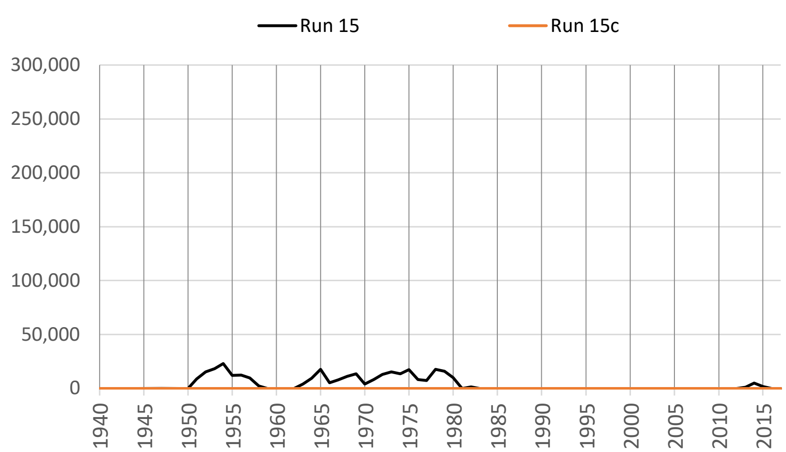
Net River Headgate Diversions



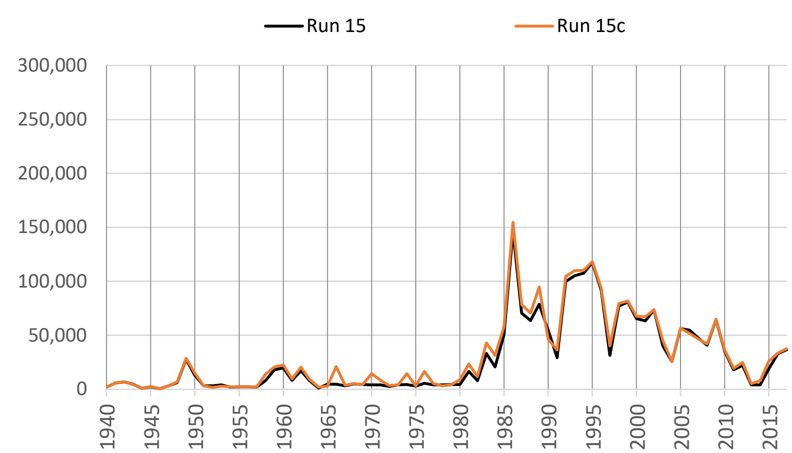
Farm Headgate Deliveries



Pumping



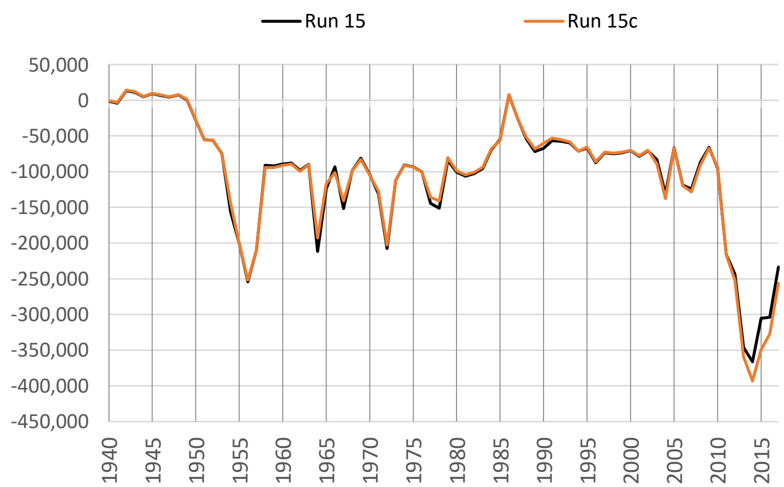
RHG Diversions - FHG Deliveries



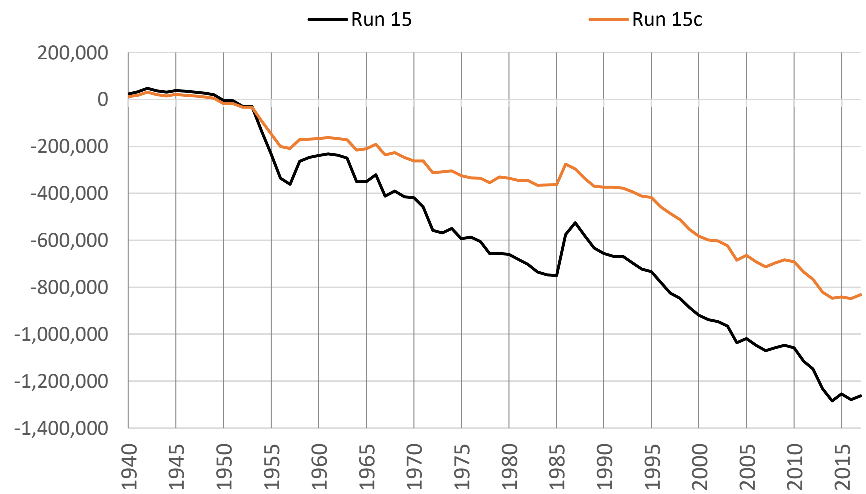
Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

Run 15c - Early EPCWID Ops (TX Hueco Pumping Off)
Cumulative Change in Ground Water Storage
Run 15c v. Run 15
ILRG Model
1940 - 2017 (acre-feet)

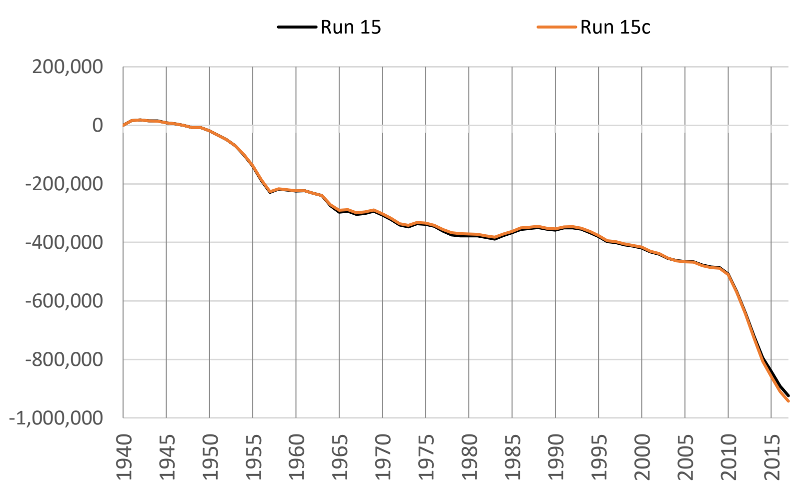
Rincon-Mesilla Alluvial Aquifer



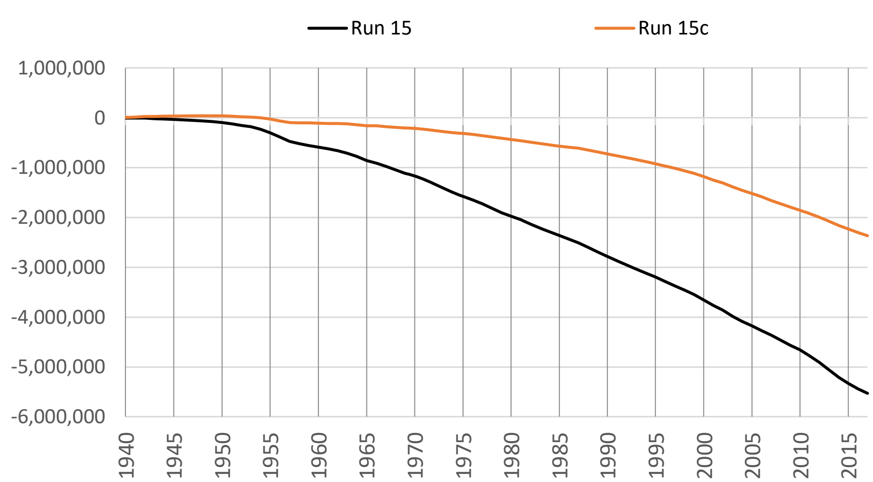
Hueco Alluvial Aquifer



Rincon-Mesilla Non-Alluvial Aquifer

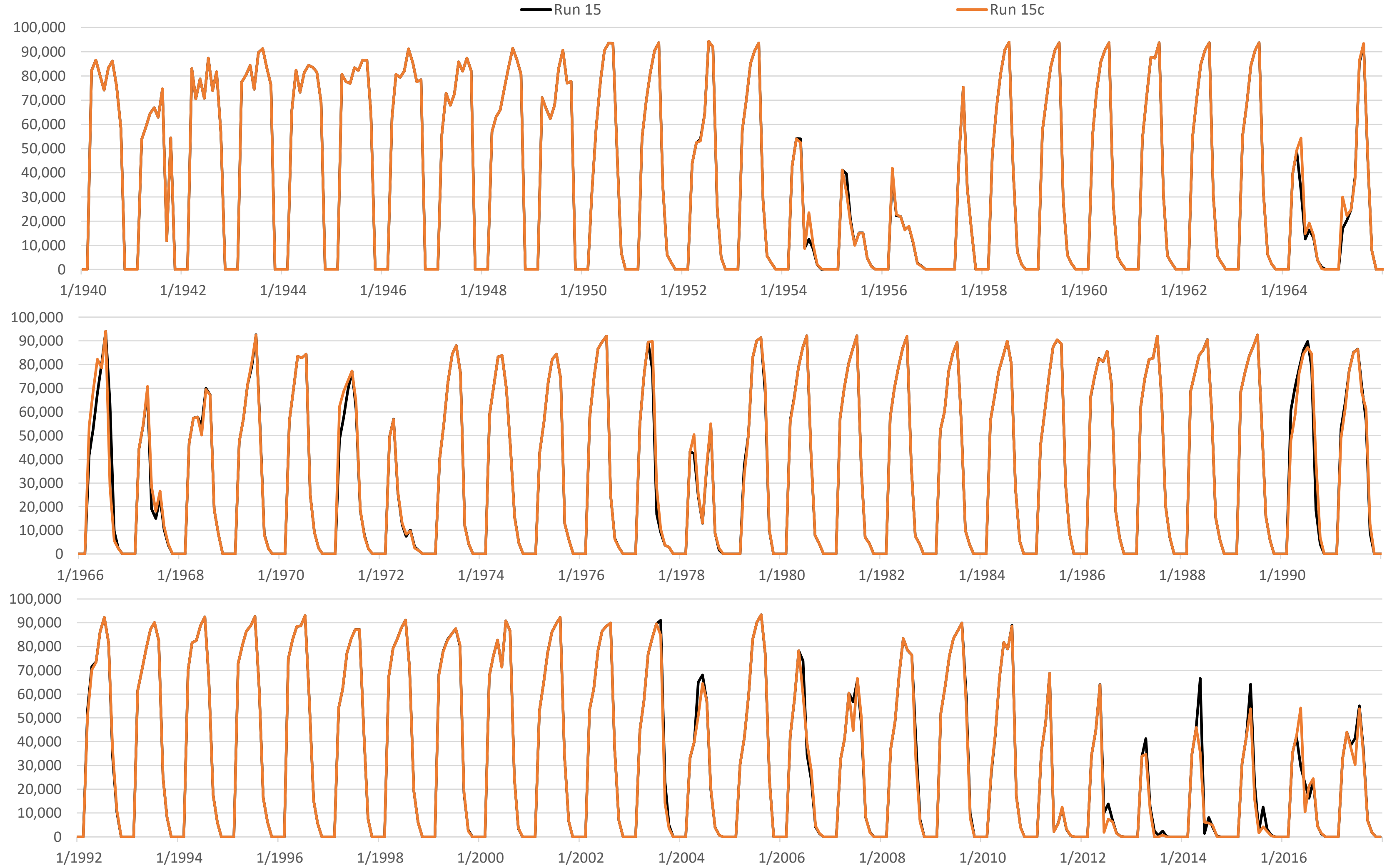


Hueco Non-Alluvial Aquifer



***Note different scales.**

Run 15c - Early EPCWID Ops (TX Hueco Pumping Off)
Monthly Net RHG Diversions
Run 15c v. Run 15
ILRG Model
1940 - 2017 (acre-feet)
EBID Total

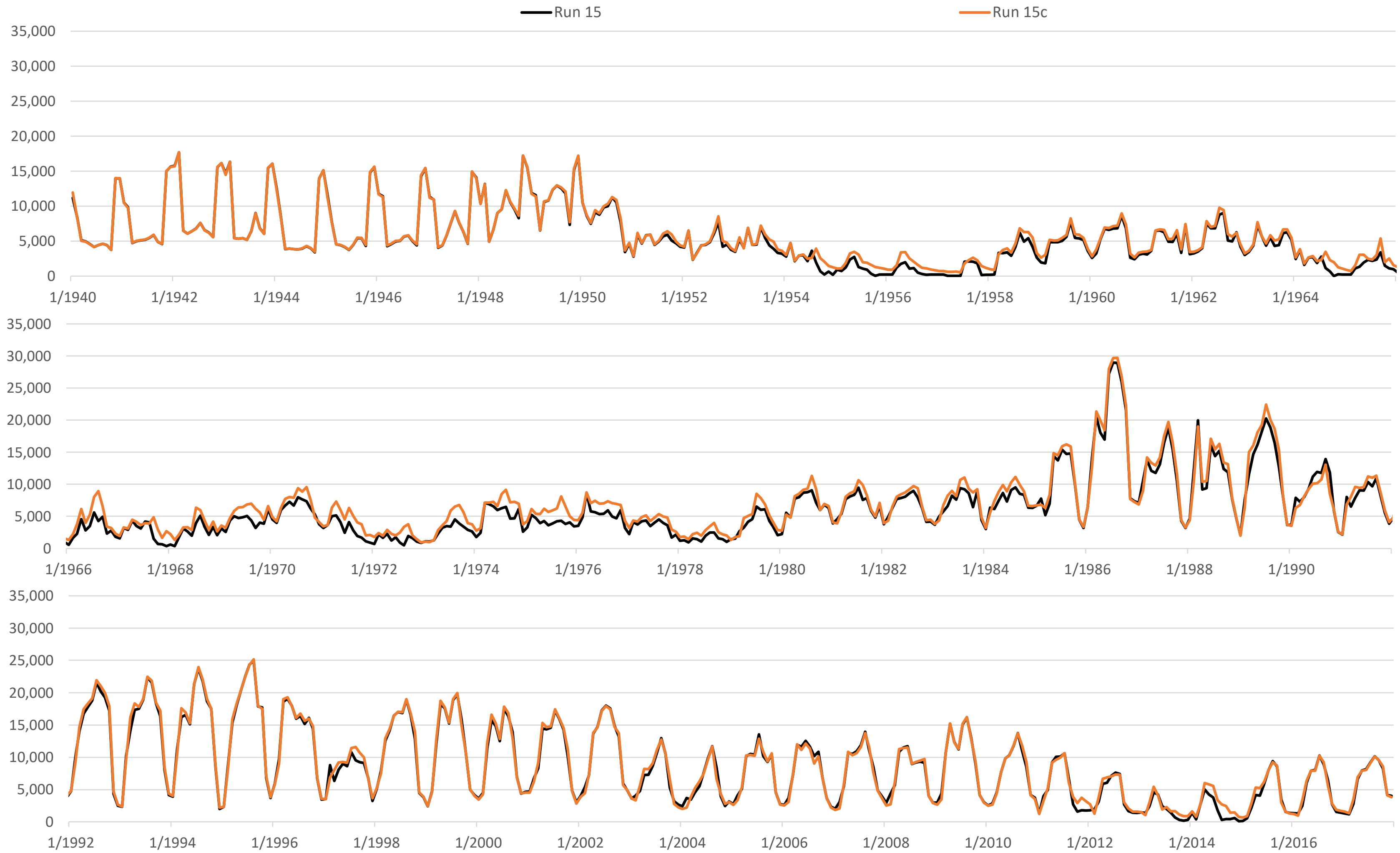


Note: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

Run 15c - Early EPCWID Ops (TX Hueco Pumping Off)
Monthly Net RHG Diversions
Run 15c v. Run 15
ILRG Model
1940 - 2017 (acre-feet)
EPCWID Total

Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

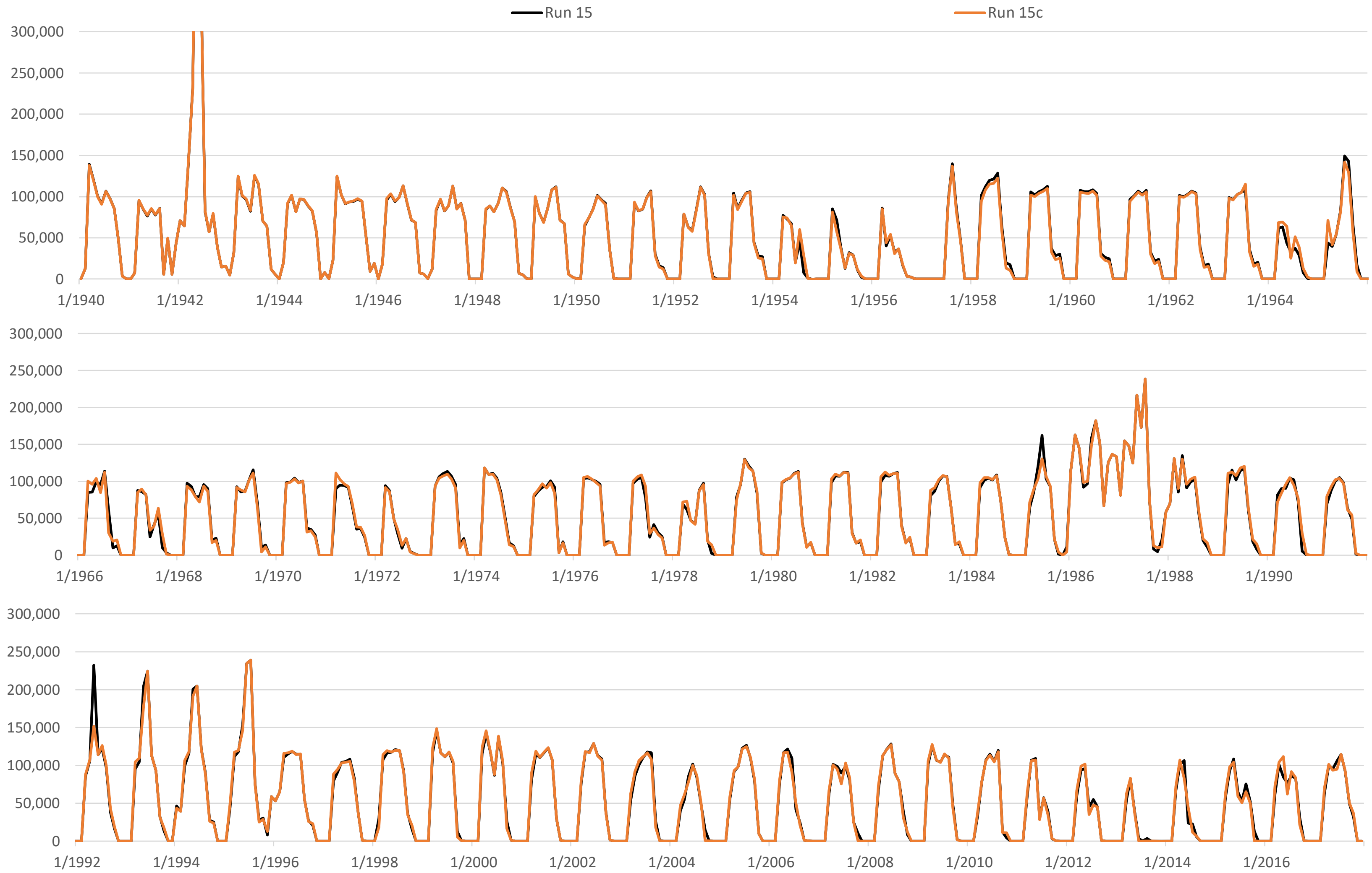
Run 15c - Early EPCWID Ops (TX Hueco Pumping Off)
Monthly Net RHG Diversions
Run 15c v. Run 15
ILRG Model
1940 - 2017 (acre-feet)
HCCRD Total



Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

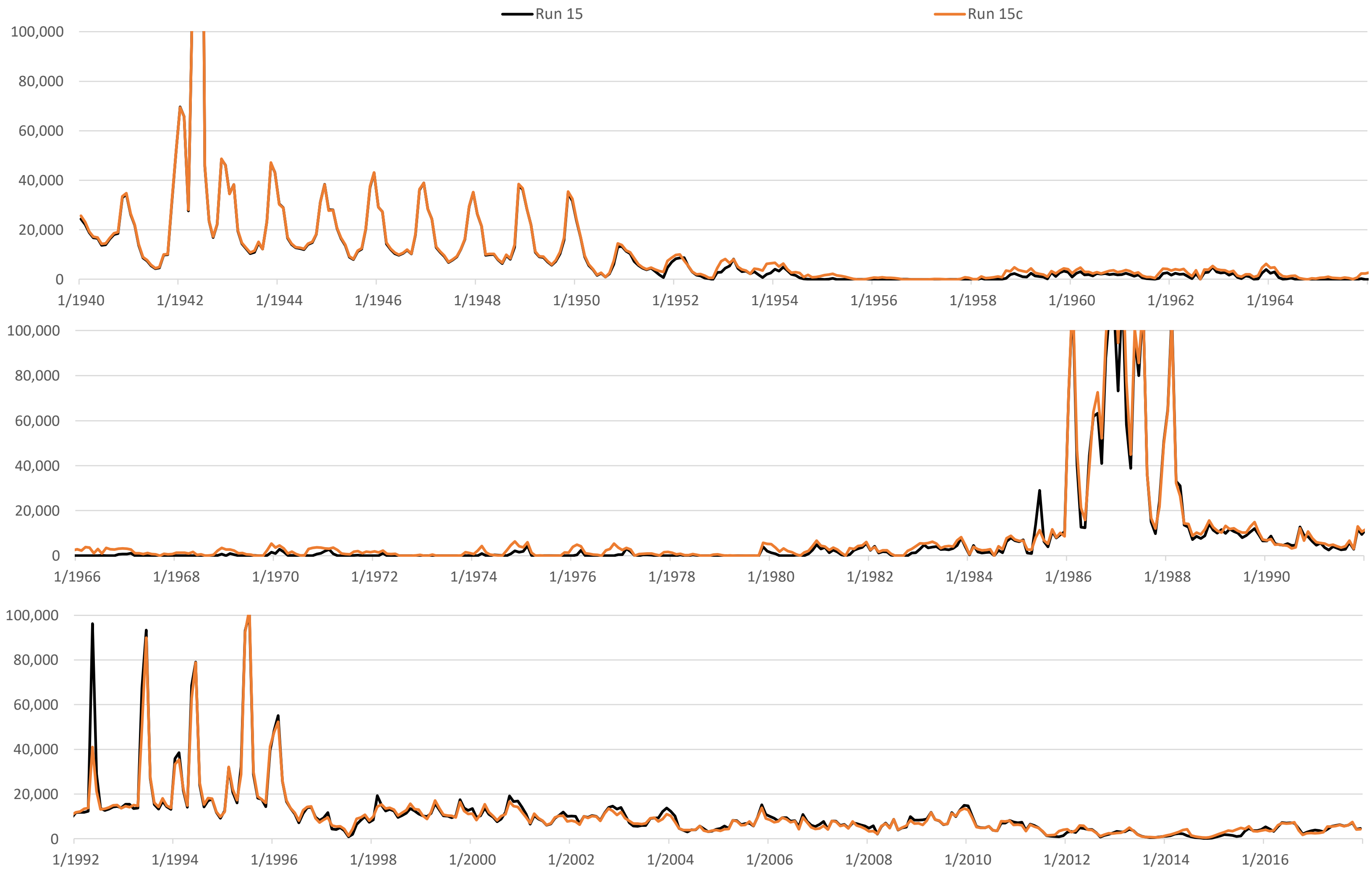
Run 15c - Early EPCWID Ops (TX Hueco Pumping Off)
End of Month Reservoir Storage (Elephant Butte + Caballo)
Run 15c v. Run 15
ILRG Model
1940 - 2017 (acre-feet)

Run 15c - Early EPCWID Ops (TX Hueco Pumping Off)
Monthly Caballo Releases
Run 15c v. Run 15
ILRG Model
1940 - 2017 (acre-feet)



Run 15c - Early EPCWID Ops (TX Hueco Pumping Off)
Monthly Rio Grande at El Paso Flow
Run 15c v. Run 15
ILRG Model
1940 - 2017 (acre-feet)

Run 15c - Early EPCWID Ops (TX Hueco Pumping Off)
Monthly Rio Grande at Fort Quitman Flow
Run 15c v. Run 15
ILRG Model
1940 - 2017 (acre-feet)



Appendix 30W

Comparison of ILRG Model Runs
Run 16 v. Run 1

Model Run Specifications

Model Version: LRG_v116

Name: **Run 16 - Conj Use 1: Hist All Acres D1/D2 (Hist M&I)**

Run ID: LRG_v116_Operational_Run16
Date: 8/27/2020

Name: **Run 1 - Historical Base Run (All Pumping On)**

Run ID: LRG_v116_Operational_Run1
Date: 8/23/2020

Selected Model Inputs

	Pumping and Returns	Run 16	Run 1
(1)	Irrigation Pumping	1978 Limit	On
	Irrigated Area	Hist	Hist
	Non-Irrigation Pumping	On	On
	Non-Irrigation Pumping Returns	On	On
	Las Cruces Jornada Pumping Returns	Off	On
	Project Allocation Rules		
	1950-2005	D1/D2	D1/D2
	2006-2007	D1/D2	D3
	2008-2017	D1/D2	D3 + CO
	EPCWID Operations		
	Charge EPCWID for Use of WWTP Returns	On	Off
	ACE and Haskell Credits for EPCWID	Off	On
(2)	Increased EPCWID Use of Fabens Drain Flows	On	Off
	Charge EPCWID for Fabens Drain Flow Use	On	Off

Notes:

(1) Ten-year average irrigation pumping limited to 1951-1978 average:
EBID = 166,866 AF, EPCWID=70,783 AF, HCCRD = 11,188 AF.

(2) Starting in July 1945, use 70% of simulated Fabens drain flow up to 6,000 AF/month.

Run 16 - Conj Use 1: Hist All Acres D1/D2 (Hist M&I)
Comparison of ILRG Model Runs
Run 16 v. Run 1
1951 - 2017 Annual Average
(1,000 acre-feet)

Run No.	1	16	16 - 1	
Simulated Input or Output	**Run 1**	**Run 16**	**Run 16 minus Run 1**	
Effects of Alternate Scenario				
FHG Deliveries (Mar - Oct)				***% Diff.***
EBID	167.6	182.8	15.1	*9%*
EPCWID (incl. EPW)	139.9	138.5	-1.4	*-1%*
HCCRD	32.8	32.3	-0.6	*-2%*
Total	340.3	353.5	13.2	*4%*
FHG Deliveries (Nov - Feb)				
EBID	0.0	0.0	0.0	*14%*
EPCWID (incl. EPW)	0.2	1.9	1.7	*899%*
HCCRD	2.4	2.8	0.4	*15%*
Total	2.6	4.6	2.0	*79%*
Irrigation Pumping				
EBID	140.4	125.3	-15.1	*-11%*
EPCWID (Mesilla Valley)	7.4	6.8	-0.5	*-7%*
EPCWID (El Paso Valley)	40.1	38.4	-1.7	*-4%*
HCCRD	4.2	4.5	0.3	*6%*
Total	192.1	175.0	-17.1	*-9%*
Other Inflows/Outflows				
Net Reservoir Evaporation	125.3	130.5	5.2	*4%*
Riparian ET	70.9	70.3	-0.6	*-1%*
River Evaporation + Incidental Canal Loss	30.3	30.9	0.5	*2%*
Total	226.6	231.7	5.1	*2%*
Rio Grande at Fort Quitman				
Reservoir Spills	33.3	39.2	6.0	*18%*
Nov-Feb Flows	21.4	18.7	-2.7	*-12%*
Mar - Oct Flows	41.1	31.5	-9.6	*-23%*
Underflow (GW Model)	0.2	0.2	0.0	*-5%*
Total	96.0	89.7	-6.3	*-7%*

Run 16 - Conj Use 1: Hist All Acres D1/D2 (Hist M&I)
Comparison of ILRG Model Runs
Run 16 v. Run 1
1951 - 2017 Annual Average
(1,000 acre-feet)

Run No.	1	16	16 - 1	
Simulated Input or Output	**Run 1**	**Run 16**	**Run 16 minus Run 1**	
Effects of Alternate Scenario (continued)				
Change in Storage				***% Diff.***
Reservoir Storage	-4.7	-7.2	-2.5	*54%*
Alluvial GW Storage (RW Model)	-23.6	-20.8	2.7	*-12%*
Non-alluvial GW Storage (GW Models)	-96.4	-95.1	1.2	*-1%*
Soil Moisture Storage	0.6	0.7	0.1	*23%*
Total	-124.0	-122.4	1.6	*-1%*
Summary of Effects				
FHG Deliveries (Mar-Oct)	340.3	353.5	13.2	*4%*
FHG Deliveries (Nov-Feb)	2.6	4.6	2.0	*79%*
Irrigation Pumping	192.1	175.0	-17.1	*-9%*
Riparian ET + Evaporation	226.6	231.7	5.1	*2%*
Fort Quitman Flow	96.0	89.7	-6.3	*-7%*
Change in Storage	-124.0	-122.4	1.6	*-1%*
Total	733.6	732.1	-1.5	*0%*
Other Effects of Alternate Scenario				
Rio Grande at El Paso				***% Diff.***
Reservoir Spills	49.4	59.8	10.4	*21%*
Nov-Feb Flows	22.8	23.9	1.1	*5%*
Mar - Oct Flows	263.8	243.2	-20.5	*-8%*
Total	336.0	326.9	-9.0	*-3%*
Rio Grande below Caballo				
Reservoir Spills	65.9	79.8	13.9	*21%*
Nov-Feb Flows	0.5	0.3	-0.2	*-38%*
Mar - Oct Flows	541.3	524.8	-16.5	*-3%*
Total	607.6	604.8	-2.8	*0%*
Surface Water Diversions (Mar - Oct)				
EBID	366.5	393.2	26.7	*7%*
EPCWID (incl. EPW)	236.8	217.9	-18.9	*-8%*
HCCRD	67.5	63.5	-4.1	*-6%*
Total	670.8	674.6	3.8	*1%*
Surface Water Diversions (Nov - Feb)				
EBID	0.0	0.0	0.0	*0%*
EPCWID (incl. EPW)	14.3	15.9	1.5	*11%*
HCCRD	14.2	14.2	0.0	*0%*
Total	28.5	30.1	1.5	*5%*

Run 16 - Conj Use 1: Hist All Acres D1/D2 (Hist M&I)

Annual Differences in ILRG Model Outputs

Run 16 minus Run 1

1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1940	-53	-53	7	-1	2	-2	-2	-2	3	2	2	2	-47	-23	-58
1941	-163	-163	-6	-10	-3	-4	-4	-4	-1	0	-2	-4	39	69	13
1942	-32	-32	-1	-5	-1	-1	0	0	2	8	0	-1	29	10	-21
1943	-64	-64	-6	-9	2	2	-14	-14	-12	-13	2	-1	-24	-12	-49
1944	-81	-81	-145	-138	-112	-94	-5	-5	15	-3	-101	-102	-165	-157	-64
1945	2	2	-17,006	-5,526	1,400	926	-53	-53	-307	6,375	1,084	991	-10,929	-10,411	-16,323
1946	36	36	-10,388	-11,149	-392	-7,349	-110	-111	-718	3,359	-75	-239	-18,238	-17,652	-18,290
1947	56	56	-12,881	-6,763	699	-5,757	-15	-15	3,974	11,138	923	1,019	-10,314	-10,389	-19,231
1948	10	10	-10,680	-6,705	136	-4,668	-15	-16	-1,977	4,581	410	237	-8,507	-8,534	-10,864
1949	46	46	-20,056	-15,361	1,551	3,232	-52	-53	622	6,491	-292	-545	-18,658	-18,083	-19,524
1950	29	29	-22,082	-18,141	-9,743	-11,073	-11	-11	-2,678	2,554	239	421	-20,461	-20,090	-17,874
1951	1,031	1,031	-11,245	-5,715	-641	-2,838	547	546	-3,507	1,706	-204	-2,191	-8,348	-8,206	-12,045
1952	990	990	-10,233	-6,920	-853	-2,130	3,849	3,844	-3,031	-54	-2,245	544	-24,634	-18,190	-11,165
1953	374	374	-15,022	-11,706	-841	-1,985	2,382	2,381	-2,558	345	-1,245	629	-5,822	-11,205	-15,927
1954	19,739	19,739	5,460	6,461	-605	375	15,852	15,852	16,864	17,821	-76	883	15,482	12,026	-11,818
1955	32,943	32,943	21,327	21,393	1,984	3,109	17,392	17,392	21,131	21,074	1,922	2,971	52,041	26,214	387
1956	524	524	1,023	1,029	612	584	-2,350	-2,350	423	313	434	289	-1,809	815	-25
1957	10	10	-584	-750	511	465	70	70	546	503	679	589	-1,763	-567	-3
1958	-2	-2	-3,307	-3,505	725	1,767	284	284	-180	-162	74	57	-13,442	-3,255	1,339
1959	5	5	-10,171	-9,847	543	1,441	97	97	-543	-340	6	23	-14,382	-10,296	1,124
1960	8	8	-10,550	-10,104	-548	-806	50	50	-1,426	-893	0	0	-13,089	-11,463	-1,315
1961	15	15	232	1,210	666	825	55	55	1,142	2,161	648	-429	712	-74	1,657
1962	10	10	-13,593	-12,220	-2,152	-2,311	-12	-12	-1,497	-320	19	-302	-17,701	-15,415	-1,860
1963	8,891	8,891	-5,579	-3,708	-1,277	-1,593	4,851	4,851	-911	784	-512	-513	1,785	-2,062	-1,636
1964	23,204	23,204	8,235	9,175	124	794	11,907	11,907	18,886	19,528	1,039	970	23,728	12,129	-4,022
1965	7,408	7,408	257	251	1,741	1,728	3,891	3,891	3,488	3,464	591	573	-2,291	1,783	194
1966	-32	-32	-10,709	-10,021	-3,155	-3,397	247	247	-217	146	-3,085	-1,129	-14,406	-9,008	-1,155
1967	15,342	15,342	3,533	4,310	1,295	1,713	8,684	8,684	3,854	3,623	600	1,698	10,602	5,938	-647
1968	7,800	7,800	4,821	5,652	1,735	1,219	6,280	6,280	1,307	1,018	1,675	1,346	7,887	7,718	160
1969	-15	-15	-15,897	-15,394	-9,717	-9,437	246	246	72	403	-9,337	-7,757	-21,227	-16,233	-1,605
1970	3	3	-21,539	-20,839	-7,857	-7,439	40	40	-1,263	-577	-328	4,345	-25,952	-23,131	-10,302
1971	28,900	28,900	-7,514	-6,083	-1,590	-3,324	17,588	17,588	-682	203	-300	-1,644	8,431	-4,271	-1,438
1972	-1,887	-1,887	-8,572	-7,843	-1,433	-1,577	-3,840	-3,840	-6,353	-6,329	-1,650	-1,781	-12,198	-6,476	-1,223
1973	-89	-89	2,889	2,892	672	834	723	723	607	423	585	833	536	2,773	6
1974	-6	-6	-9,065	-8,753	-4,117	-4,195	249	249	399	672	-3,588	-2,517	-9,594	-9,130	-1,923
1975	-235	-235	-17,876	-17,250	-12,940	-12,503	1,176	1,176	-324	218	-12,707	-12,582	-22,064	-17,962	384
1976	7	7	-18,345	-17,517	-17,237	-17,463	722	722	-858	-140	-2,753	3,540	-21,570	-20,128	-19,603
1977	51,126	51,126	23,621	25,241	9,141	9,553	21,680	21,680	14,205	16,535	8,478	9,419	44,573	32,386	1,612
1978	15,194	15,194	-1,311	450	-3,123	-3,421	7,923	7,923	9,338	10,801	-2,853	-3,213	9,144	4,123	-1,212

Run 16 - Conj Use 1: Hist All Acres D1/D2 (Hist M&I)
Annual Differences in ILRG Model Outputs
Run 16 minus Run 1
1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1979	55	55	-23,558	-20,095	-418	1,613	3,306	3,314	3,206	6,623	-548	1,441	-42,606	-11,941	5,272
1980	-75	-75	-31,743	-27,690	-5,346	-3,243	785	787	-1,279	2,177	-2,194	-2,062	-44,948	-31,160	-1,870
1981	-64	-64	-28,886	-26,043	-6,441	-7,207	867	867	-1,537	1,795	954	1,274	-34,879	-31,260	-8,339
1982	-11	-11	-29,287	-26,416	-4,337	-4,944	49	49	-1,897	1,722	-1,227	834	-34,147	-31,994	-6,927
1983	-15	-15	-28,951	-26,564	-11,438	-11,796	-21	-21	-2,538	515	0	0	-33,670	-32,176	-12,638
1984	-47	-47	-26,668	-24,607	-16,942	-17,587	31	31	-1,520	1,787	372	372	-23,624	-23,651	-18,212
1985	-248	-248	-28,222	-25,903	-12,287	-11,976	643	644	-1,860	1,072	0	0	70,857	64,458	41,662
1986	-89	-89	-41,044	-39,694	-7,558	-6,281	347	359	-1,832	-70	0	0	87,161	90,831	71,157
1987	-200	-200	-52,191	-49,430	-7,533	-6,773	1,313	1,317	-880	3,239	0	0	-233	-419	-42,294
1988	-16	-16	-50,098	-46,746	-7,257	-6,837	145	145	-4,805	-96	0	0	-50,221	-43,677	-36,523
1989	8	8	-43,409	-38,834	-12,628	-13,096	-176	-177	-5,883	362	0	0	-51,942	-49,965	-36,397
1990	1,051	1,051	14,131	17,993	-2,542	-2,825	-7,632	-7,635	18,211	24,082	0	0	-20,261	-11,653	-19,810
1991	887	887	-39,600	-35,505	-15,447	-15,784	961	958	-7,969	-1,568	0	0	-38,644	-41,903	-31,328
1992	3,401	3,401	36,106	38,951	28,853	29,509	-10,153	-10,167	30,532	35,119	0	0	105,968	109,428	81,676
1993	590	590	-51,481	-47,337	-8,622	-8,836	734	728	-8,833	-2,283	0	0	-9,067	-13,734	-2,865
1994	419	419	-36,186	-32,963	-3,094	-3,116	-176	-173	24	5,074	0	0	17,344	12,591	8,534
1995	917	917	-31,915	-28,019	-718	-947	8	9	1,843	8,160	0	0	11,046	8,868	1,579
1996	-66	-66	-45,781	-43,139	-5,766	-5,089	116	116	-5,781	-1,648	0	0	-58,665	-54,744	-40,926
1997	-26	-26	-32,316	-30,010	-10,312	-11,862	-235	-235	-7,286	-2,208	0	0	-30,534	-32,530	-25,051
1998	-18	-18	-31,189	-29,066	-582	-1,530	35	36	-2,064	1,397	0	0	-20,217	-21,158	-25,867
1999	-297	-297	-46,304	-45,381	-745	-1,374	-304	-304	-8,094	-6,652	0	0	-38,374	-38,603	-29,307
2000	-404	-404	-22,658	-22,758	4,185	3,931	-8,909	-8,909	-5,753	-5,768	0	0	-23,605	-15,846	-11,423
2001	285	285	-21,517	-21,830	-4,653	-4,370	-357	-357	5,189	5,179	0	0	-17,801	-25,166	-26,091
2002	-12	-12	-28,193	-28,292	-2,053	-1,249	-264	-264	-34	-36	0	0	-27,123	-29,531	-30,875
2003	102,398	102,398	15,467	15,573	10,450	11,471	54,538	54,538	17,954	17,973	0	0	75,821	41,098	6,834
2004	35,426	35,426	-25,446	-24,822	-1,350	424	24,473	24,473	-376	-360	0	0	-20,534	-15,032	-11,734
2005	3,026	3,026	-13,535	-13,333	-6,456	-5,695	5,434	5,421	6,188	6,189	0	0	-28,293	-14,530	-16,193
2006	63,122	63,122	-16,791	-16,657	992	2,386	41,741	41,741	-42	-30	0	0	19,682	-5,562	-7,784
2007	143,680	143,680	-25,351	-24,535	-8,598	-7,960	92,049	92,049	-1,878	-1,844	0	0	26,375	-11,345	-10,929
2008	178,820	178,820	-23,308	-22,378	-14,419	-13,386	112,948	112,972	-2,500	-2,424	0	0	58,279	995	-793
2009	136,024	136,024	-47,532	-45,965	-6,047	-4,941	87,280	87,293	-15,343	-15,273	0	0	-12,821	-8,211	3,668
2010	199,257	199,257	-33,667	-31,792	-12,799	-12,103	128,677	128,687	-9,609	-9,528	0	0	35,239	-1,676	8,971
2011	74,340	74,340	-99,204	-97,549	-39,000	-41,459	30,984	30,985	-59,217	-59,172	-13,971	-13,820	-107,333	-95,638	-13,363
2012	84,194	84,194	10,187	10,367	-6,717	-10,354	38,377	38,377	12,731	12,747	3,844	4,290	60,312	10,557	-16,246
2013	-47,106	-47,106	-48,733	-48,650	-9,924	-9,369	-23,114	-23,114	-34,322	-34,316	-5,871	-6,149	-118,077	-52,297	-9,606
2014	86,986	86,986	16,328	16,320	2,570	2,347	38,069	38,069	13,131	13,135	1,721	1,789	114,567	16,783	-6,580
2015	117,686	117,686	-40,078	-39,860	-4,207	-5,421	55,308	55,308	-22,178	-22,167	1,156	991	17,162	-48,732	-15,377
2016	102,147	102,147	-72,554	-72,163	-12,452	-14,454	50,495	50,495	-44,358	-44,341	0	0	-54,665	-79,836	-37,474
2017	293,517	293,517	-21,107	-19,441	-2,935	-3,480	175,420	175,443	-10,640	-10,575	776	799	112,753	-5,300	-6,392
Averages															
1951-2017	26,728	26,728	-18,896	-17,379	-4,073	-4,085	15,140	15,141	-1,379	312	-584	-233	-2,763	-9,027	-6,297
1951-1978	7,545	7,545	-4,276	-3,218	-1,726	-1,786	4,306	4,306	2,461	3,319	-862	-191	-1,978	-2,899	-3,288
1979-2005	5,440	5,440	-27,573	-25,258	-4,113	-3,906	2,428	2,428	479	3,769	-98	69	-10,415	-9,015	-8,072
2006-2017	119,389	119,389	-33,484	-32,692	-9,461	-9,850	69,020	69,025	-14,519	-14,482	-1,029	-1,008	12,623	-23,355	-9,325
1985-2017	47,870	47,870	-29,612	-27,965	-5,444	-5,470	26,933	26,934	-4,719	-2,625	-374	-367	2,550	-10,954	-8,701
1985-2005	7,001	7,001	-27,399	-25,264	-3,148	-2,967	2,883	2,882	881	4,150	0	0	-3,206	-3,868	-8,345

Notes:

EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

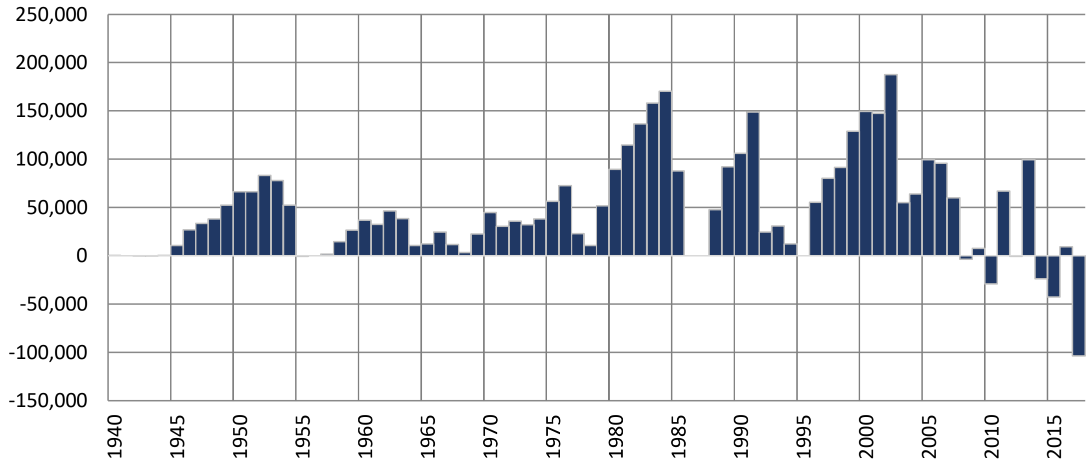
Run 16 - Conj Use 1: Hist All Acres D1/D2 (Hist M&I)

Simulated Differences in ILRG Model Outputs

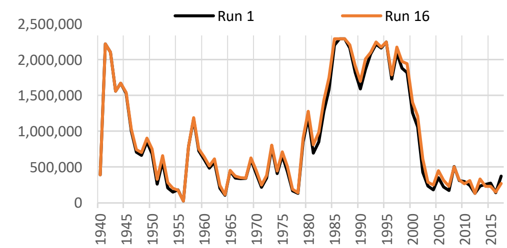
Run 16 minus Run 1

1940 - 2017 (acre-feet)

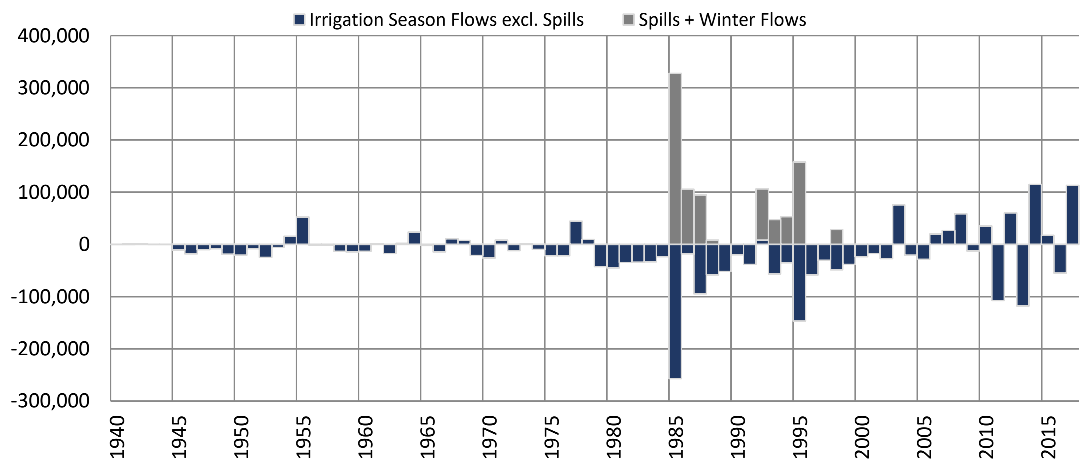
Total Project Storage (Year End)



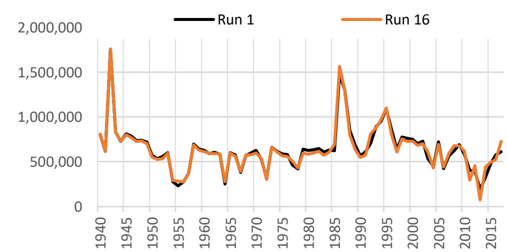
Period	Average Difference
1951-2017	-2,534
1951-1978	-1,979
1979-2005	3,291
2006-2017	-16,936
1985-2017	-8,303
1985-2005	-3,370



Caballo Reservoir Outflows (Annual)



Period	Average Difference Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	-16,502	13,740	-2,763
1951-1978	-1,978	0	-1,978
1979-2005	-44,510	34,095	-10,415
2006-2017	12,623	0	12,623
1985-2017	-25,346	27,896	2,550
1985-2005	-47,042	43,836	-3,206



Notes:

Reservoir storage does not include storage attributed to SJC, CO, or NM credit waters.

Average differences calculated as (Final Storage - Initial Storage)/(no. years).

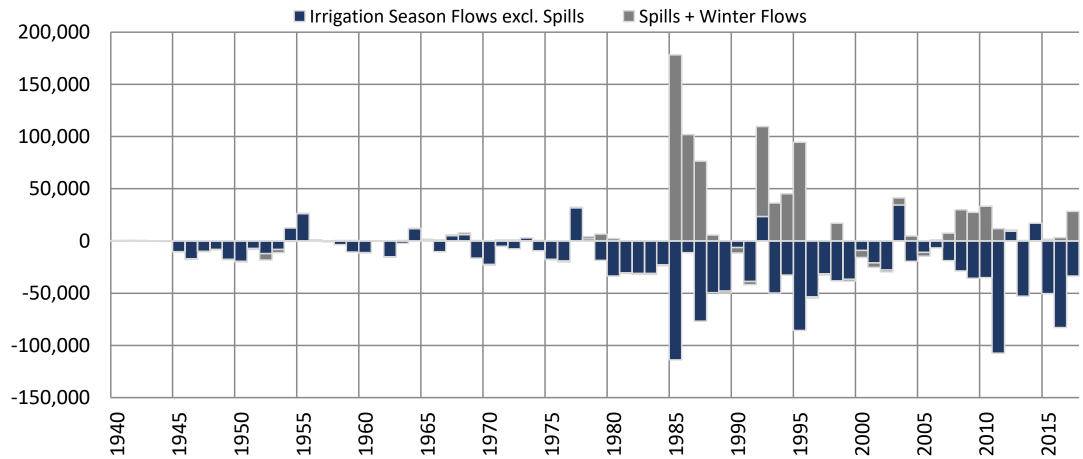
Run 16 - Conj Use 1: Hist All Acres D1/D2 (Hist M&I)

Simulated Differences in ILRG Model Outputs

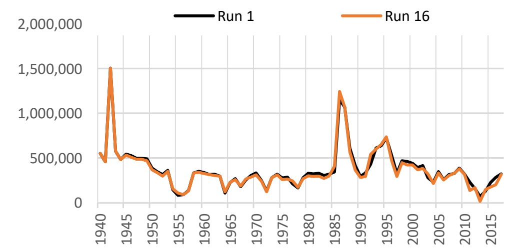
Run 16 minus Run 1

1940 - 2017 (acre-feet)

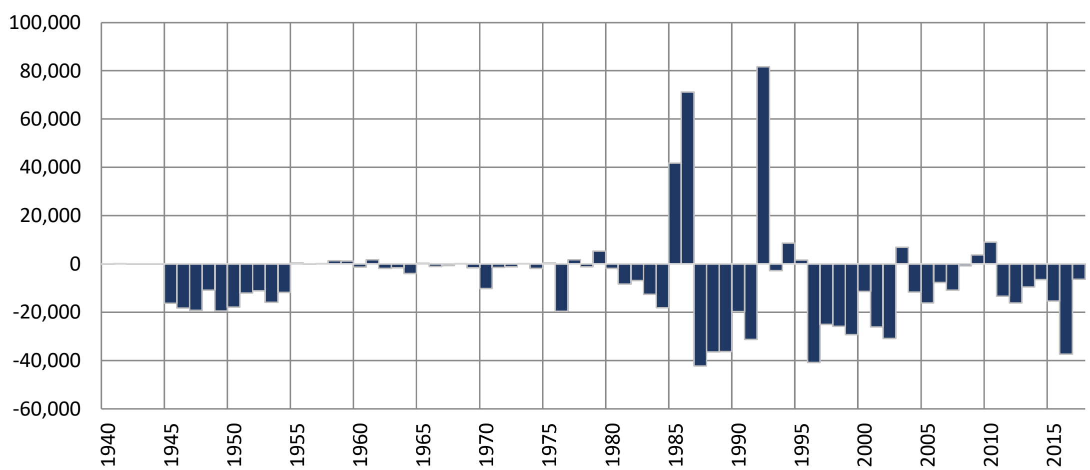
Rio Grande at El Paso (Annual)



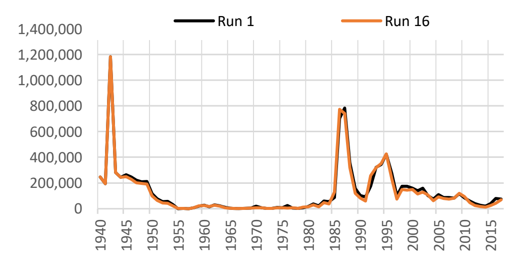
	Average Difference		
Period	Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	-20,531	11,504	-9,027
1951-1978	-2,827	-72	-2,899
1979-2005	-32,234	23,219	-9,015
2006-2017	-35,509	12,153	-23,355
1985-2017	-34,200	23,246	-10,954
1985-2005	-33,452	29,584	-3,868



Rio Grande at Fort Quitman (Annual)



Period	Average Difference
1951-2017	-6,287
1951-1978	-3,280
1979-2005	-8,058
2006-2017	-9,318
1985-2017	-8,692
1985-2005	-8,334



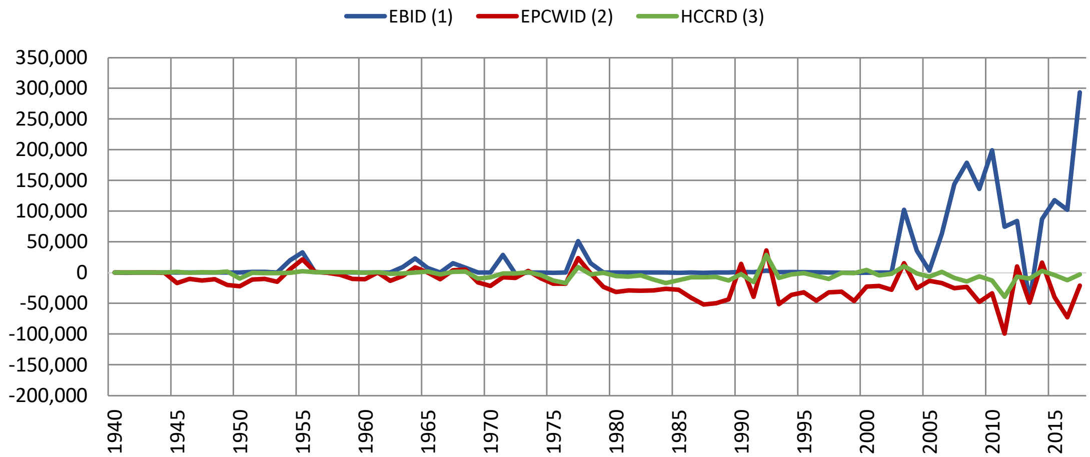
Run 16 - Conj Use 1: Hist All Acres D1/D2 (Hist M&I)

Simulated Differences in ILRG Model Outputs

Run 16 minus Run 1

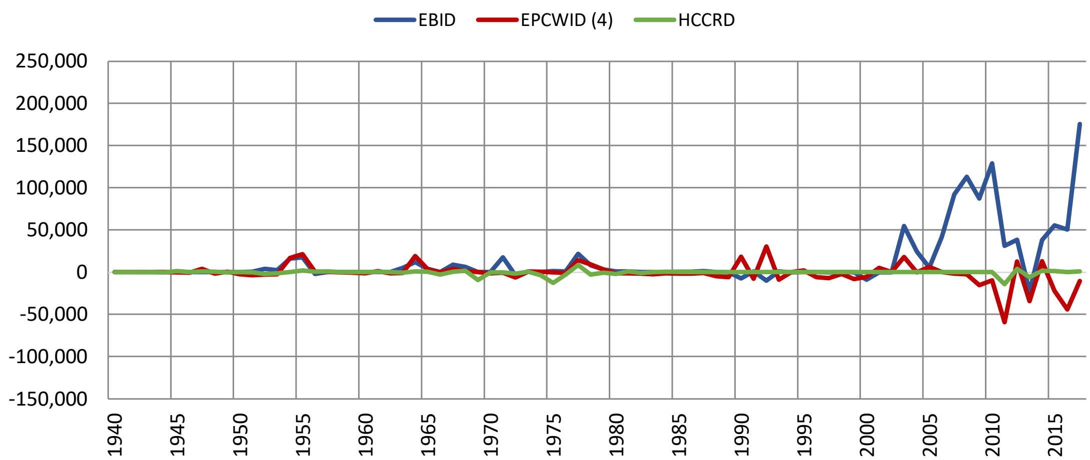
1940 - 2017 (acre-feet)

River Headgate (RHG) Diversions (Irrigation Season)



	Average Difference		
Period	EBID	EPCWID	HCCRD
1951-2017	26,728	-18,896	-4,073
1951-1978	7,545	-4,276	-1,726
1979-2005	5,440	-27,573	-4,113
2006-2017	119,389	-33,484	-9,461
1985-2017	47,870	-29,612	-5,444
1985-2005	7,001	-27,399	-3,148

Farm Headgate (FHG) Deliveries (Irrigation Season)



	Average Difference		
Period	EBID	EPCWID	HCCRD
1951-2017	15,140	-1,379	-584
1951-1978	4,306	2,461	-862
1979-2005	2,428	479	-98
2006-2017	69,020	-14,519	-1,029
1985-2017	26,933	-4,719	-374
1985-2005	2,883	881	0

Notes:

(1) EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

(2) EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

(3) HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

(4) EPCWID FHG values include deliveries to Rogers WTP and R/U WTP.

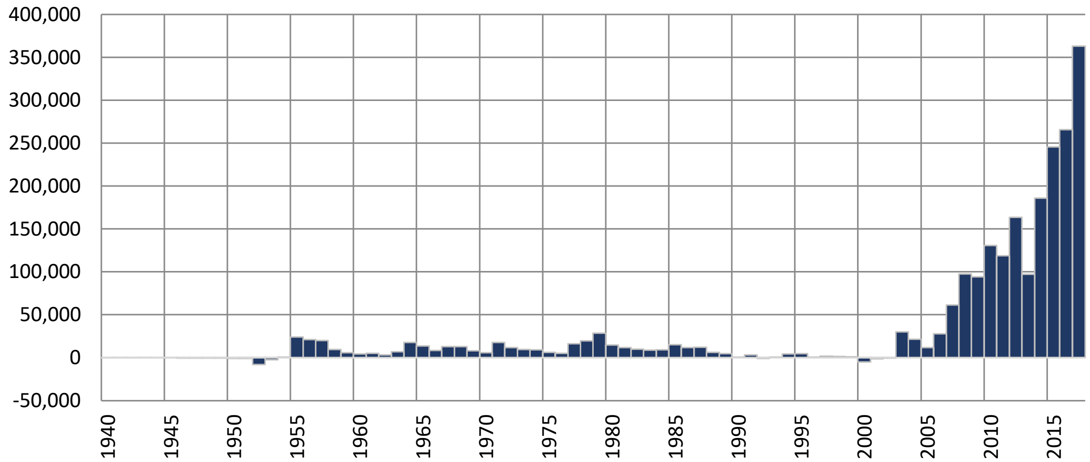
Run 16 - Conj Use 1: Hist All Acres D1/D2 (Hist M&I)

Simulated Differences in ILRG Model Outputs

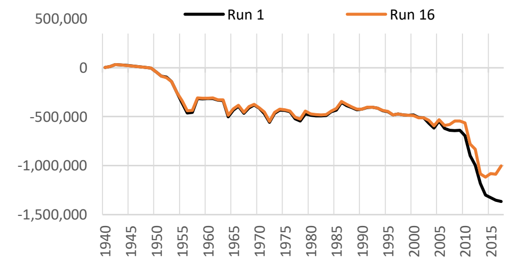
Run 16 minus Run 1

1940 - 2017 (acre-feet)

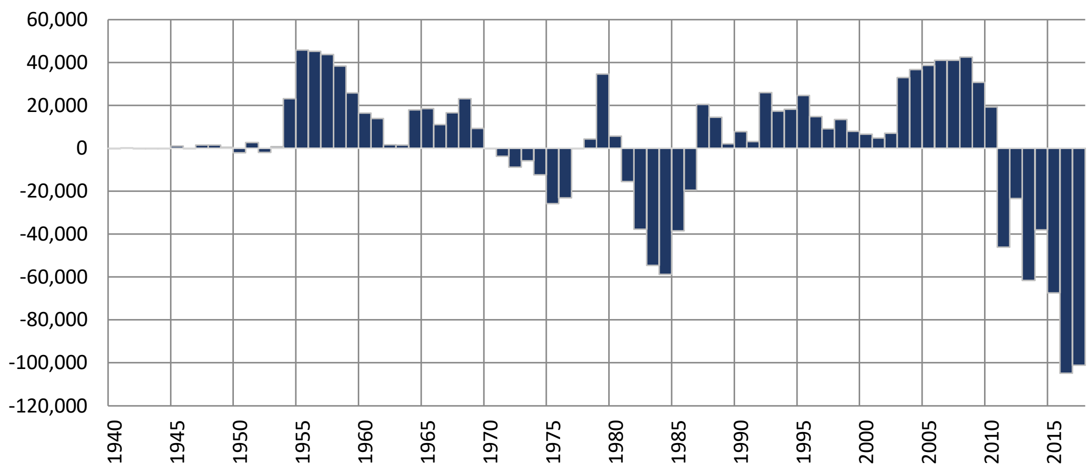
Cumulative Annual Rincon-Mesilla Groundwater Storage



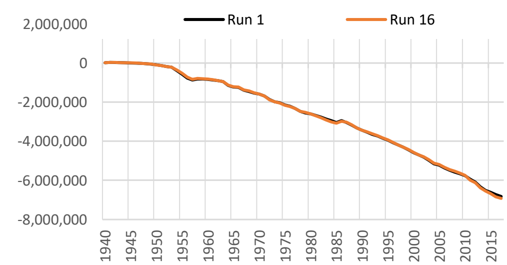
Period	Average Difference
1951-2017	5,433
1951-1978	734
1979-2005	-300
2006-2017	29,295
1985-2017	10,725
1985-2005	114



Cumulative Annual Hueco Groundwater Storage



Period	Average Difference
1951-2017	-1,478
1951-1978	231
1979-2005	1,269
2006-2017	-11,651
1985-2017	-1,287
1985-2005	4,635



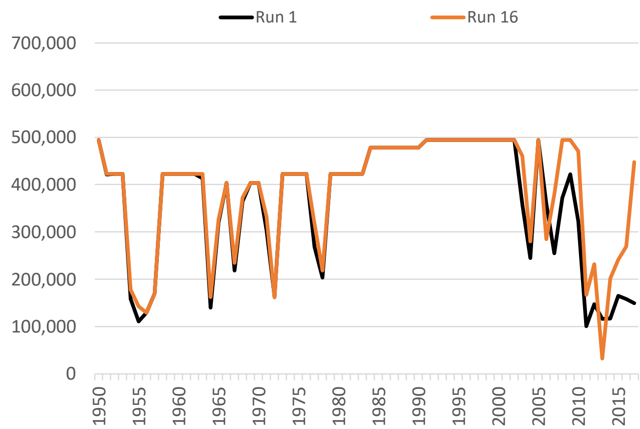
Notes:

Cumulative storage change in alluvial and non-alluvial aquifers.

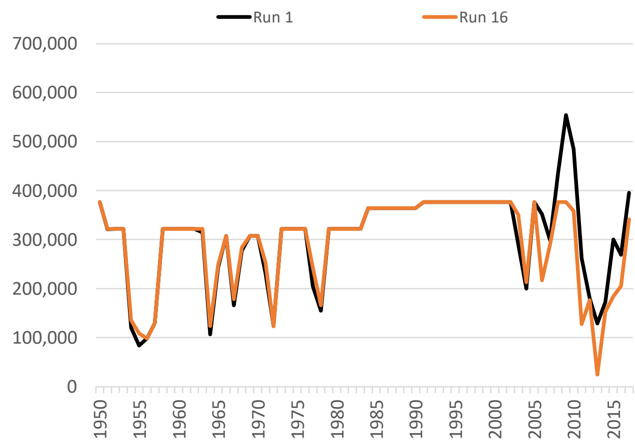
Average differences calculated as (Final Storage - Initial Storage)/(no. years).

Run 16 - Conj Use 1: Hist All Acres D1/D2 (Hist M&I)
Annual Allocation and Charges
Run 16 v. Run 1
ILRG Model
1950 - 2017 (acre-feet)

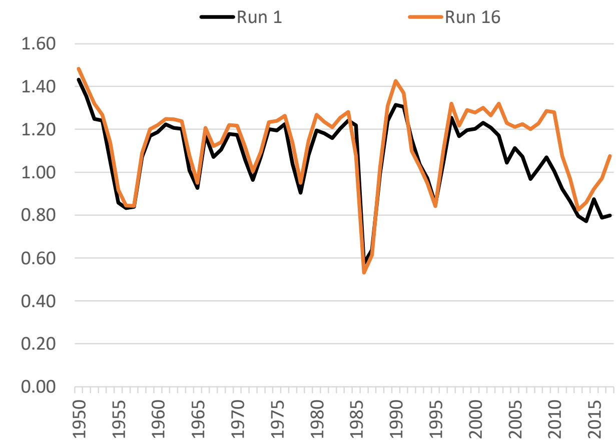
Total Allocation - EBID



Total Allocation - EPCWID

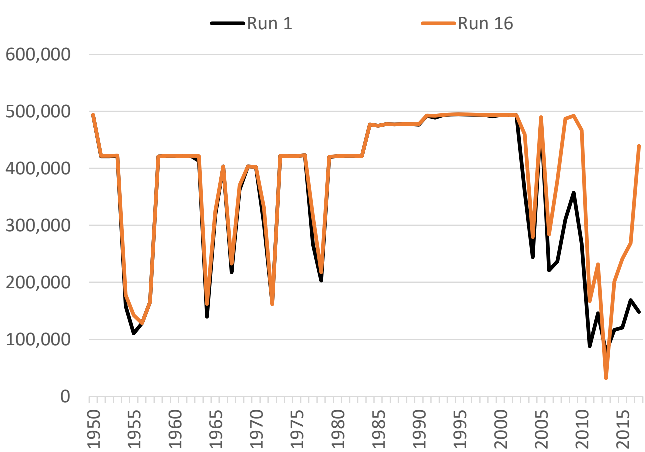


Diversion Ratio

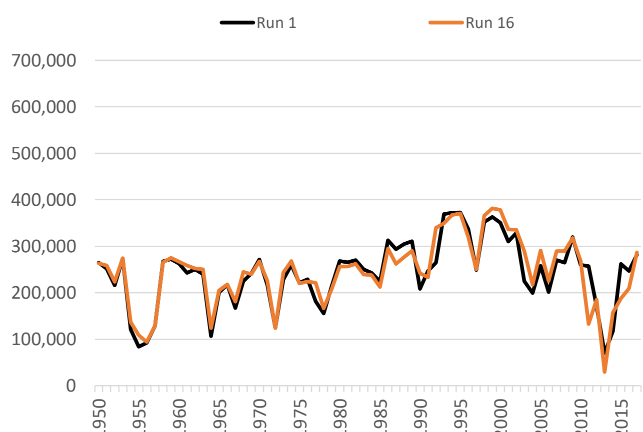


Note:
Computed as Total Charges/Caballo Release.

Annual Delivery Charges - EBID



Annual Delivery Charges - EPCWID



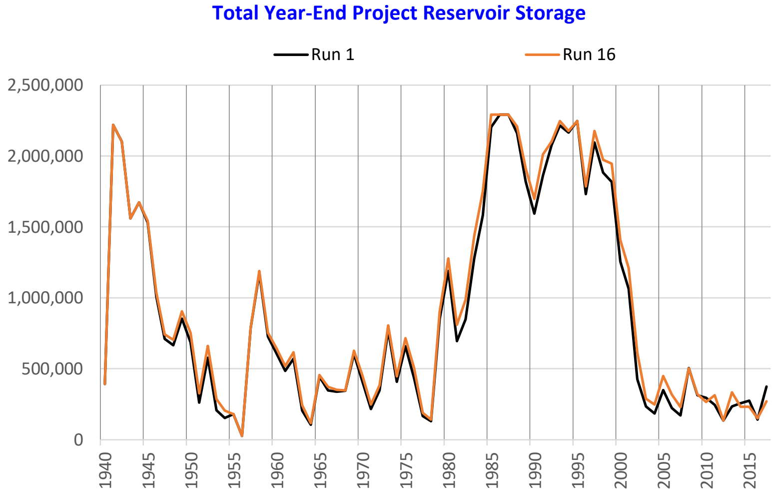
Run 16 - Conj Use 1: Hist All Acres D1/D2 (Hist M&I)

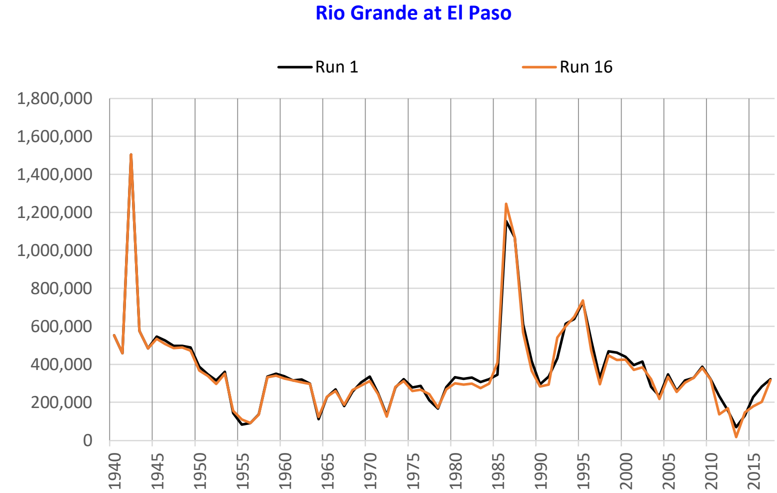
Annual Summary of Project Storage and Rio Grande Flows

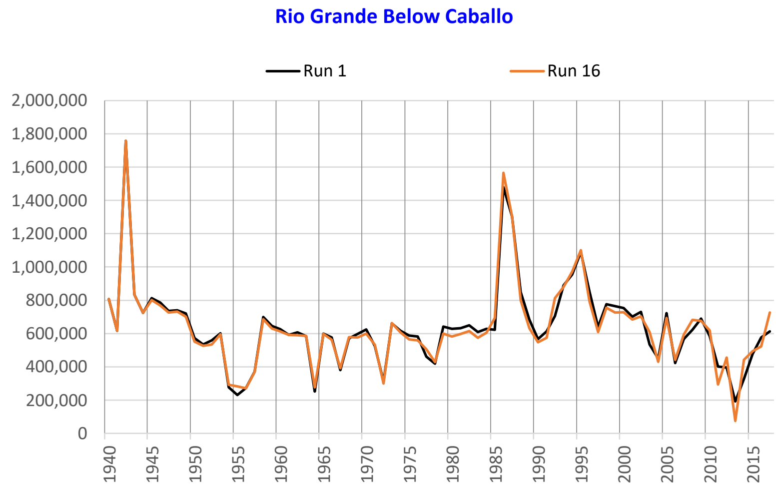
Run 16 v. Run 1

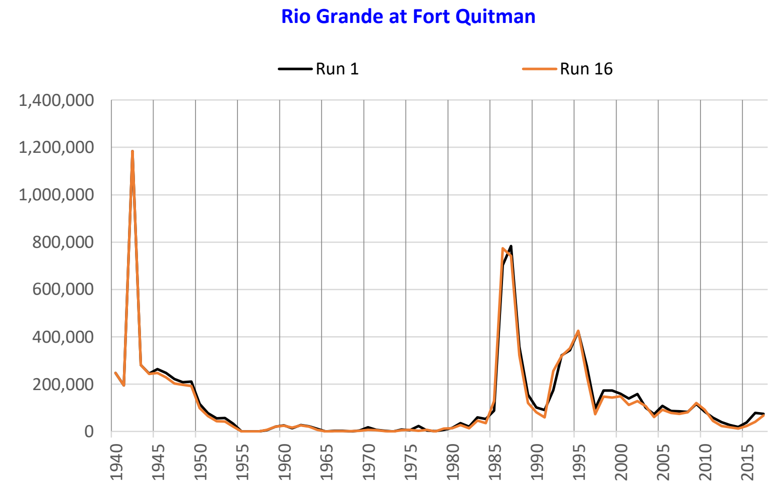
ILRG Model

1940 - 2017 (acre-feet)









***Note different scales.**

Run 16 - Conj Use 1: Hist All Acres D1/D2 (Hist M&I)

Irrigation Season Summary of Irrigation Operations

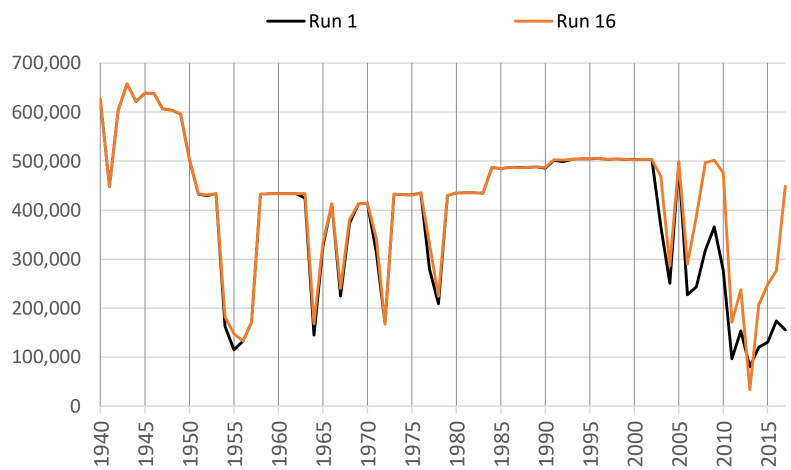
Run 16 v. Run 1

ILRG Model

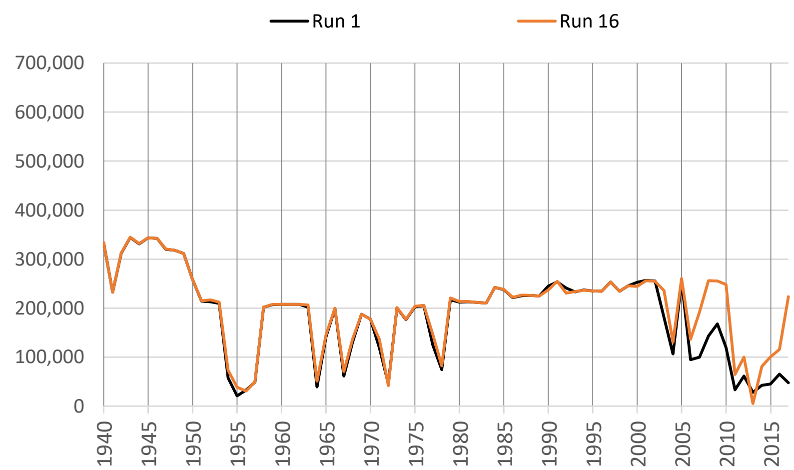
1940 - 2017 (acre-feet)

EBID Total

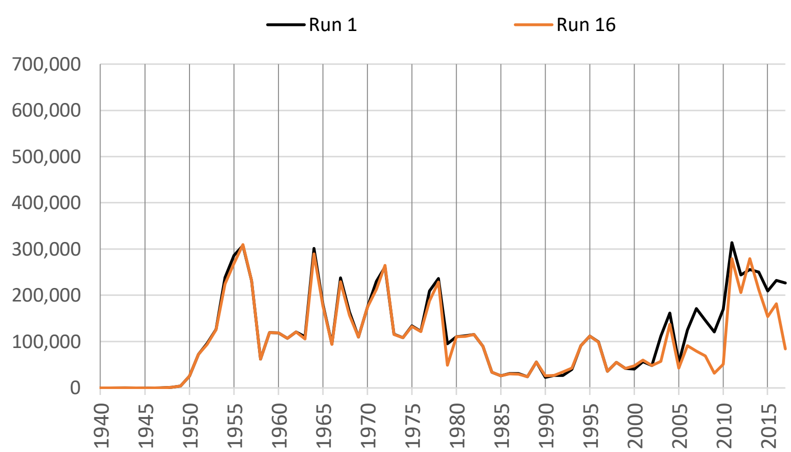
Net River Headgate Diversions



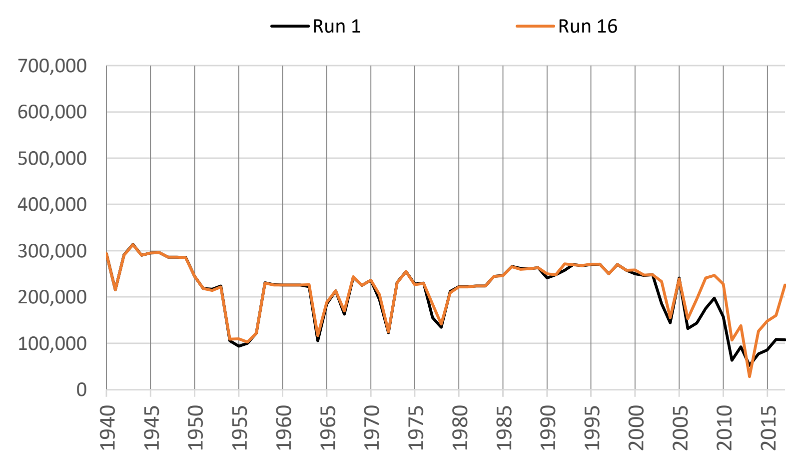
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries

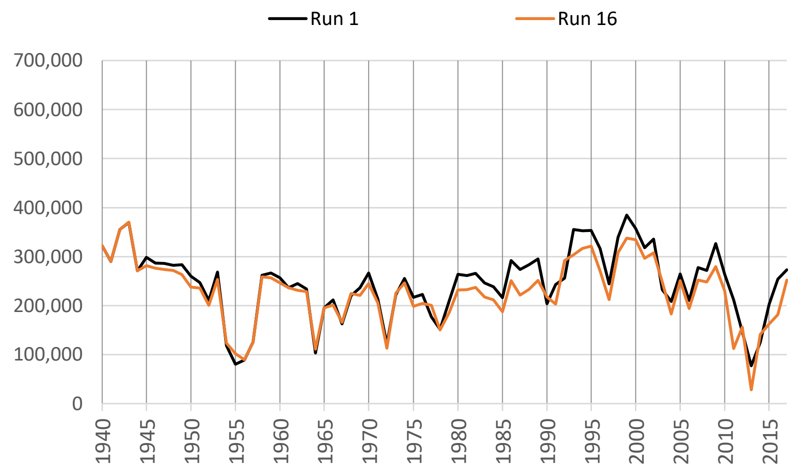


Notes: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).
Pumping includes Supplemental and Primary groundwater pumping.

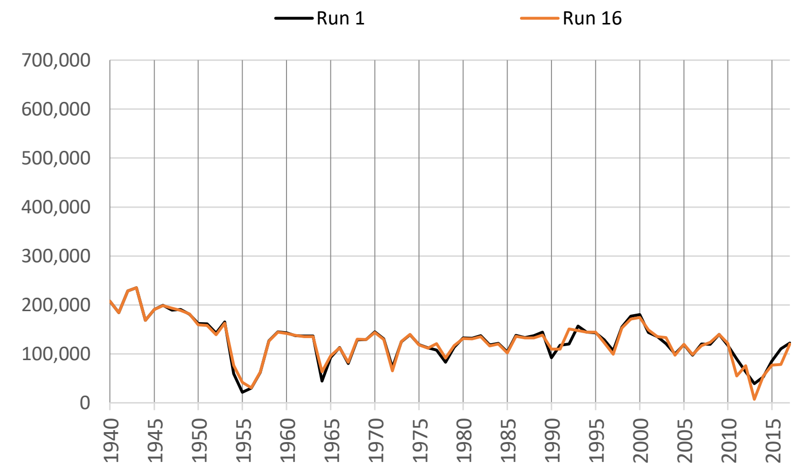
Run 16 - Conj Use 1: Hist All Acres D1/D2 (Hist M&I)
Irrigation Season Summary of Irrigation Operations
Run 16 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

EPCWID Total

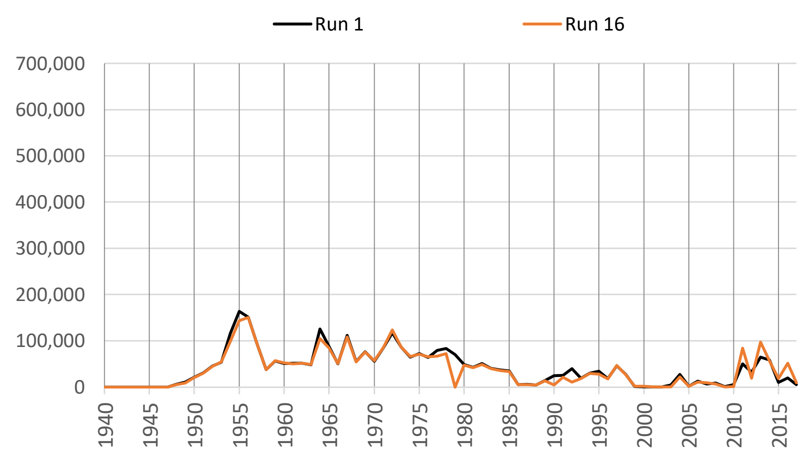
Net River Headgate Diversions



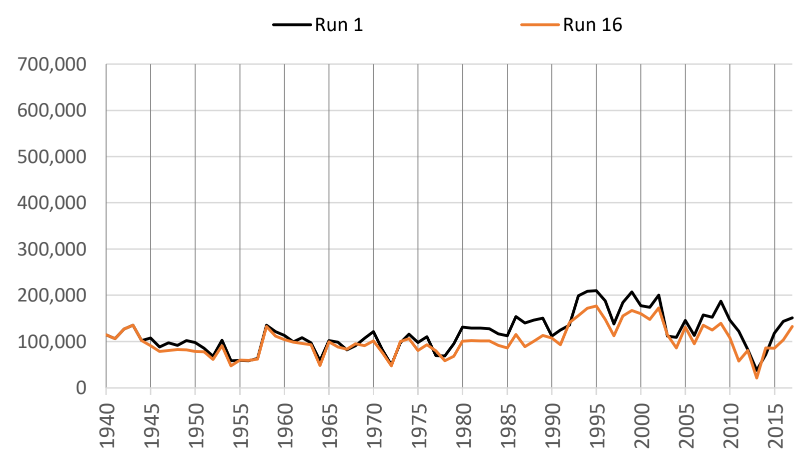
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries

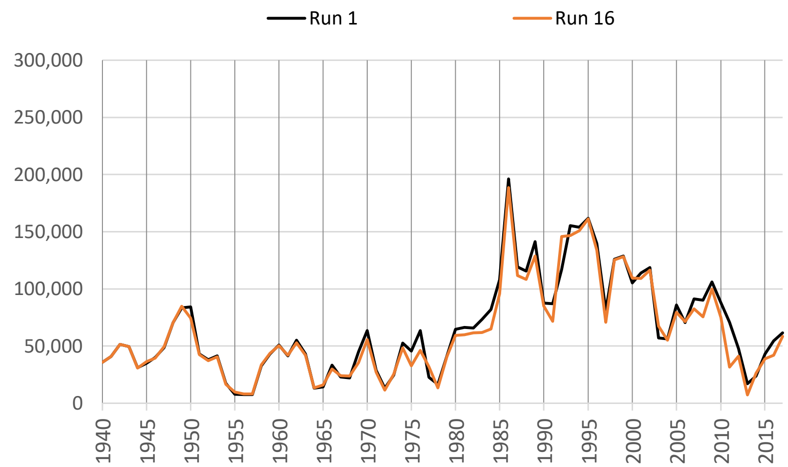


Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

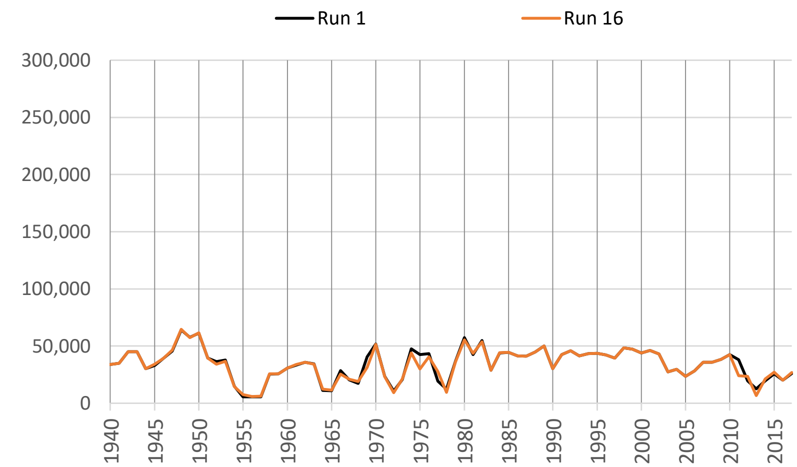
Run 16 - Conj Use 1: Hist All Acres D1/D2 (Hist M&I)
Irrigation Season Summary of Irrigation Operations
Run 16 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

HCCRD Total

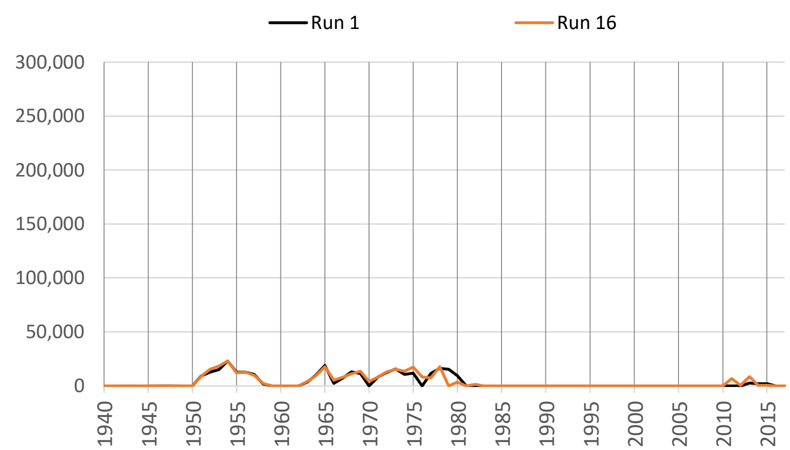
Net River Headgate Diversions



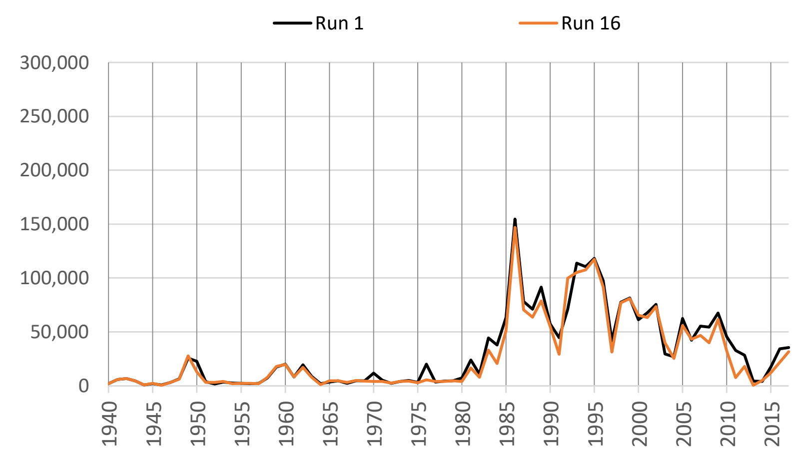
Farm Headgate Deliveries



Pumping



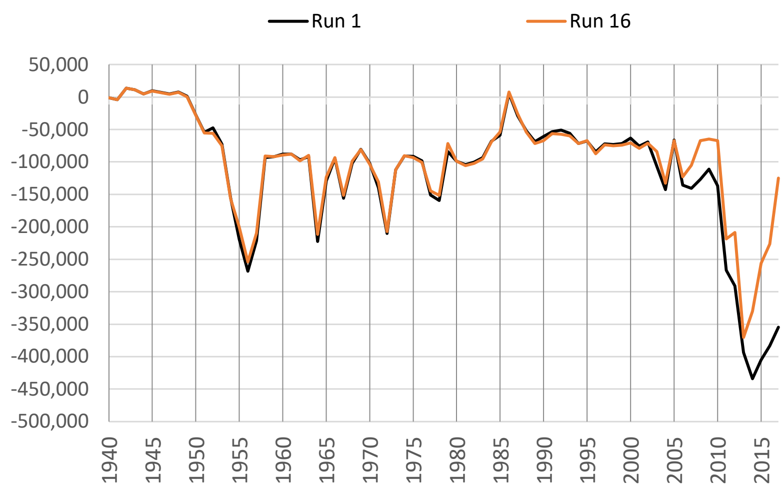
RHG Diversions - FHG Deliveries



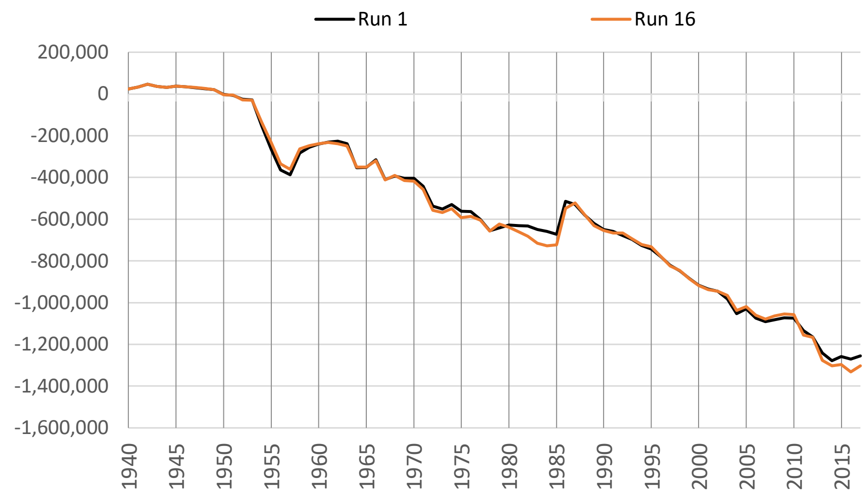
Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

Run 16 - Conj Use 1: Hist All Acres D1/D2 (Hist M&I)
Cumulative Change in Ground Water Storage
Run 16 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

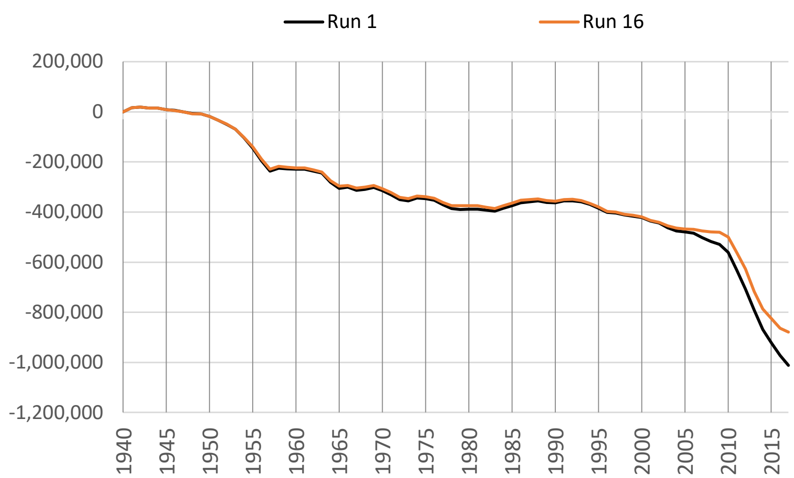
Rincon-Mesilla Alluvial Aquifer



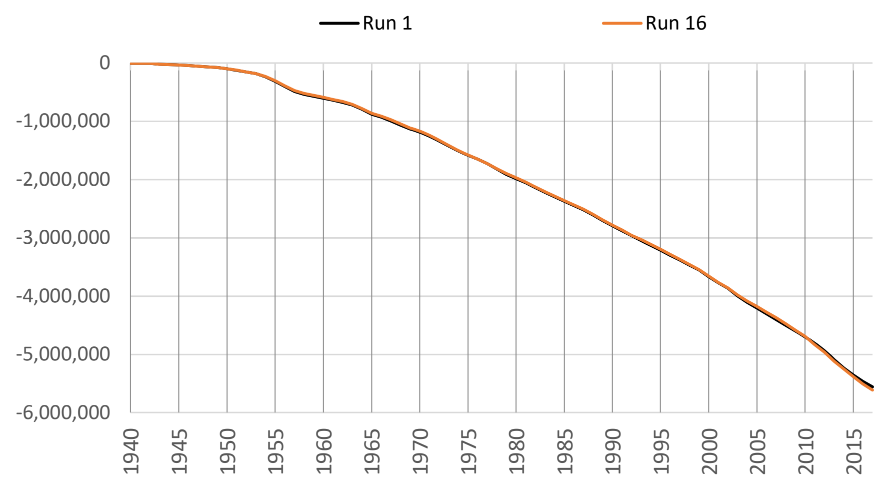
Hueco Alluvial Aquifer



Rincon-Mesilla Non-Alluvial Aquifer



Hueco Non-Alluvial Aquifer



***Note different scales.**

Run 16 - Conj Use 1: Hist All Acres D1/D2 (Hist M&I)

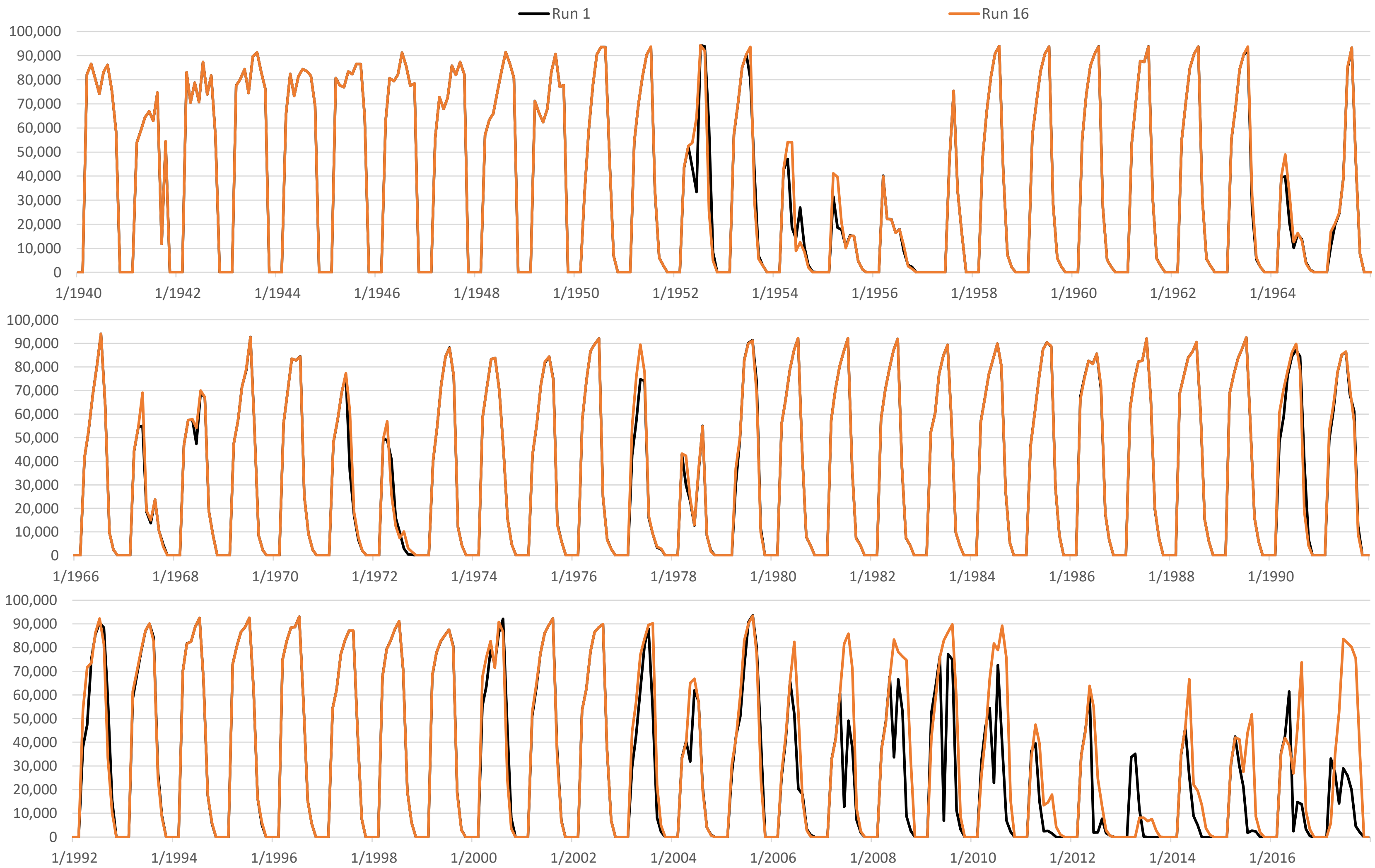
Monthly Net RHG Diversions

Run 16 v. Run 1

ILRG Model

1940 - 2017 (acre-feet)

EBID Total



Note: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

Run 16 - Conj Use 1: Hist All Acres D1/D2 (Hist M&I)

Monthly Net RHG Diversions

Run 16 v. Run 1

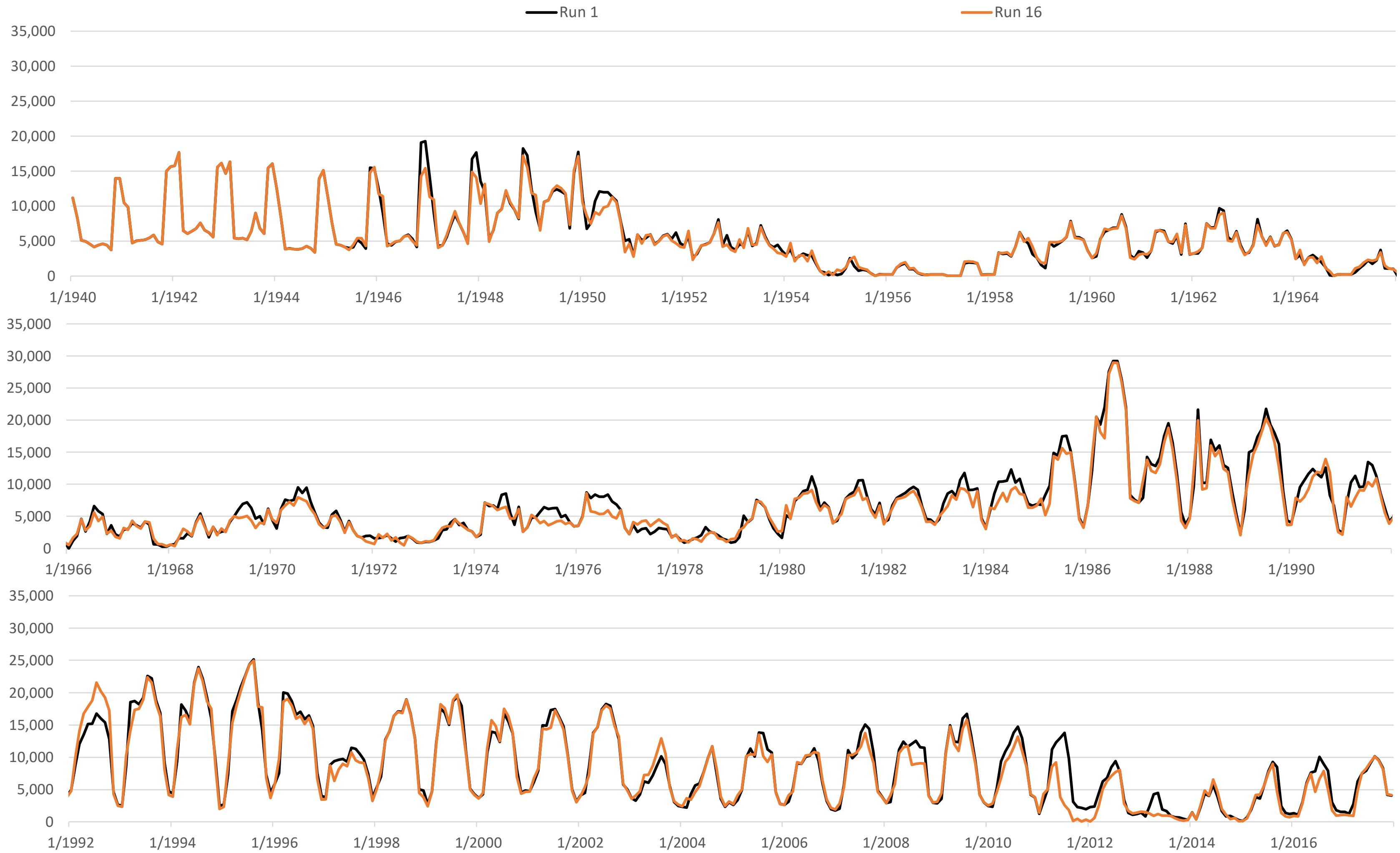
ILRG Model

1940 - 2017 (acre-feet)

EPCWID Total

Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

Run 16 - Conj Use 1: Hist All Acres D1/D2 (Hist M&I)
Monthly Net RHG Diversions
Run 16 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
HCCRD Total



Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

Run 16 - Conj Use 1: Hist All Acres D1/D2 (Hist M&I)

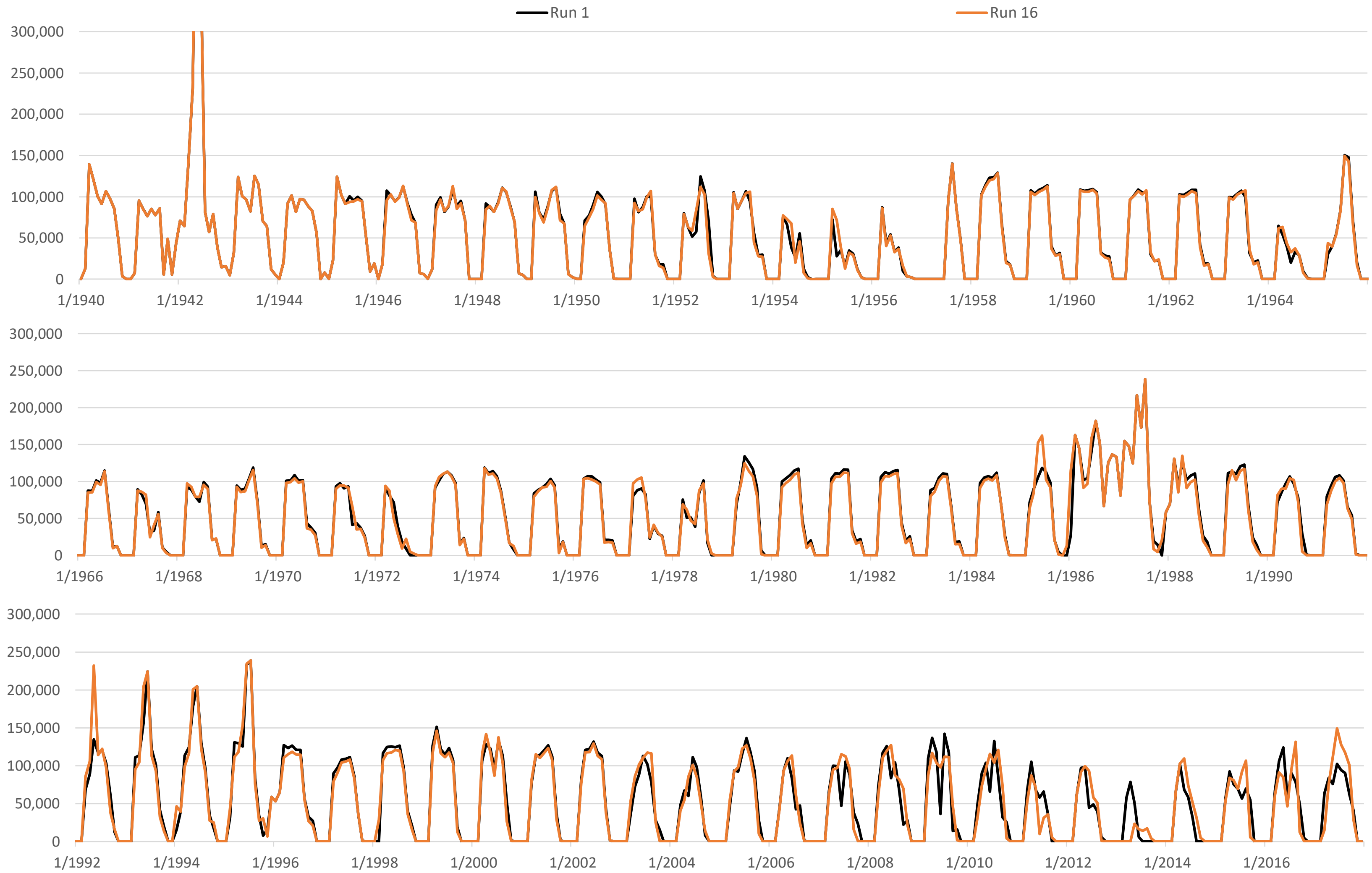
End of Month Reservoir Storage (Elephant Butte + Caballo)

Run 16 v. Run 1

ILRG Model

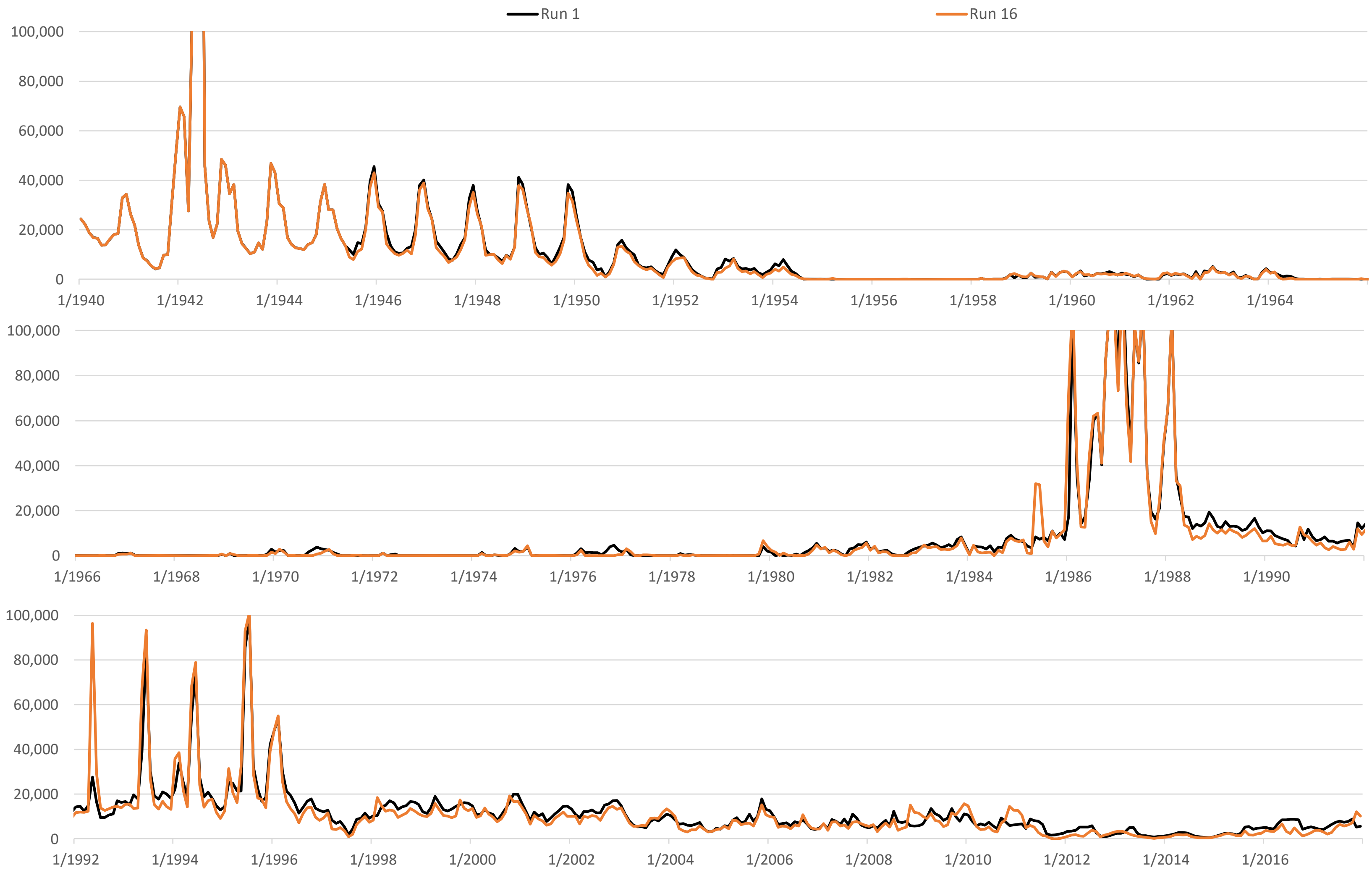
1940 - 2017 (acre-feet)

Run 16 - Conj Use 1: Hist All Acres D1/D2 (Hist M&I)
Monthly Caballo Releases
Run 16 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)



Run 16 - Conj Use 1: Hist All Acres D1/D2 (Hist M&I)
Monthly Rio Grande at El Paso Flow
Run 16 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

Run 16 - Conj Use 1: Hist All Acres D1/D2 (Hist M&I)
Monthly Rio Grande at Fort Quitman Flow
Run 16 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)



Appendix 30X

Comparison of ILRG Model Runs
Run 16a v. Run 1

Model Run Specifications

Model Version: LRG_v116

Name: **Run 16a - Conj Use 1a: Hist All Acres D1/D2 (1978 M&**

Run ID: LRG_v116_Operational_Run16a
Date: 8/28/2020

Name: **Run 1 - Historical Base Run (All Pumping On)**

Run ID: LRG_v116_Operational_Run1
Date: 8/23/2020

Selected Model Inputs

	Pumping and Returns	**Run 16a**	**Run 1**
(1)	Irrigation Pumping	1978 Limit	On
	Irrigated Area	Hist	Hist
(2)	Non-Irrigation Pumping	1978 Limit	On
	Non-Irrigation Pumping Returns	Reduced	On
	Las Cruces Jornada Pumping Returns	Off	On
	Project Allocation Rules		
	1950-2005	D1/D2	D1/D2
	2006-2007	D1/D2	D3
	2008-2017	D1/D2	D3 + CO
	EPCWID Operations		
	Charge EPCWID for Use of WWTP Returns	On	Off
	ACE and Haskell Credits for EPCWID	Off	On
(3)	Increased EPCWID Use of Fabens Drain Flows	On	Off
	Charge EPCWID for Fabens Drain Flow Use	On	Off

Notes:

(1) Ten-year average irrigation pumping limited to 1951-1978 average:
EBID = 166,866 AF, EPCWID=70,783 AF, HCCRD = 11,188 AF.

(2) Annual non-Irrigation pumping limited to 1951-1978 maximum: NM = 20,993 AF,
TX (Hueco) = 89,979 AF, TX (Mesilla) = 30,264 AF. Returns reduced based on pumping change.

(3) Starting in July 1945, use 70% of simulated Fabens drain flow up to 6,000 AF/month.

Run 16a - Conj Use 1a: Hist All Acres D1/D2 (1978 M&I)
Comparison of ILRG Model Runs
Run 16a v. Run 1
1951 - 2017 Annual Average
(1,000 acre-feet)

Run No.	1	16a	16a - 1	
Simulated Input or Output	**Run 1**	**Run 16a**	**Run 16a minus Run 1**	
Effects of Alternate Scenario				
FHG Deliveries (Mar - Oct)				***% Diff.***
EBID	167.6	183.3	15.7	*9%*
EPCWID (incl. EPW)	139.9	138.8	-1.0	*-1%*
HCCRD	32.8	32.3	-0.6	*-2%*
Total	340.3	354.4	14.1	*4%*
FHG Deliveries (Nov - Feb)				
EBID	0.0	0.0	0.0	*122%*
EPCWID (incl. EPW)	0.2	1.8	1.6	*873%*
HCCRD	2.4	2.8	0.4	*15%*
Total	2.6	4.6	2.0	*77%*
Irrigation Pumping				
EBID	140.4	124.8	-15.6	*-11%*
EPCWID (Mesilla Valley)	7.4	6.8	-0.5	*-7%*
EPCWID (El Paso Valley)	40.1	38.2	-1.9	*-5%*
HCCRD	4.2	4.5	0.3	*6%*
Total	192.1	174.3	-17.8	*-9%*
Other Inflows/Outflows				
Net Reservoir Evaporation	125.3	130.6	5.3	*4%*
Riparian ET	70.9	70.4	-0.5	*-1%*
River Evaporation + Incidental Canal Loss	30.3	30.9	0.5	*2%*
Total	226.6	231.9	5.3	*2%*
Rio Grande at Fort Quitman				
Reservoir Spills	33.3	39.4	6.1	*18%*
Nov-Feb Flows	21.4	19.3	-2.1	*-10%*
Mar - Oct Flows	41.1	32.5	-8.6	*-21%*
Underflow (GW Model)	0.2	0.2	0.0	*-5%*
Total	96.0	91.3	-4.6	*-5%*

Run 16a - Conj Use 1a: Hist All Acres D1/D2 (1978 M&I)

Comparison of ILRG Model Runs

Run 16a v. Run 1

1951 - 2017 Annual Average

(1,000 acre-feet)

Run No.	1	16a	16a - 1	
Simulated Input or Output	**Run 1**	**Run 16a**	**Run 16a minus Run 1**	
Effects of Alternate Scenario (continued)				
Change in Storage				***% Diff.***
Reservoir Storage	-4.7	-7.0	-2.3	*50%*
Alluvial GW Storage (RW Model)	-23.6	-19.7	3.9	*-16%*
Non-alluvial GW Storage (GW Models)	-96.4	-90.8	5.6	*-6%*
Soil Moisture Storage	0.6	0.7	0.2	*26%*
Total	-124.0	-116.7	7.3	*-6%*
Summary of Effects				
FHG Deliveries (Mar-Oct)	340.3	354.4	14.1	*4%*
FHG Deliveries (Nov-Feb)	2.6	4.6	2.0	*77%*
Irrigation Pumping	192.1	174.3	-17.8	*-9%*
Riparian ET + Evaporation	226.6	231.9	5.3	*2%*
Fort Quitman Flow	96.0	91.3	-4.6	*-5%*
Change in Storage	-124.0	-116.7	7.3	*-6%*
Total	733.6	739.8	6.3	*1%*
Other Effects of Alternate Scenario				
Rio Grande at El Paso				***% Diff.***
Reservoir Spills	49.4	60.0	10.7	*22%*
Nov-Feb Flows	22.8	24.5	1.7	*7%*
Mar - Oct Flows	263.8	244.6	-19.1	*-7%*
Total	336.0	329.2	-6.8	*-2%*
Rio Grande below Caballo				
Reservoir Spills	65.9	79.9	14.1	*21%*
Nov-Feb Flows	0.5	0.3	-0.1	*-32%*
Mar - Oct Flows	541.3	524.4	-16.9	*-3%*
Total	607.6	604.6	-3.0	*0%*
Surface Water Diversions (Mar - Oct)				
EBID	366.5	394.0	27.6	*8%*
EPCWID (incl. EPW)	236.8	218.6	-18.2	*-8%*
HCCRD	67.5	64.1	-3.5	*-5%*
Total	670.8	676.7	5.9	*1%*
Surface Water Diversions (Nov - Feb)				
EBID	0.0	0.0	0.0	*0%*
EPCWID (incl. EPW)	14.3	15.9	1.5	*11%*
HCCRD	14.2	14.2	0.0	*0%*
Total	28.5	30.1	1.5	*5%*

Run 16a - Conj Use 1a: Hist All Acres D1/D2 (1978 M&I)
Annual Differences in ILRG Model Outputs
Run 16a minus Run 1
1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1940	-53	-53	7	-1	2	-2	-2	-2	3	2	2	2	-47	-23	-55
1941	-159	-159	-7	-12	-3	-4	-4	-4	-1	0	-2	-5	39	67	13
1942	-33	-33	1	-3	-1	0	0	0	3	8	0	-1	28	12	-27
1943	-64	-64	-5	-8	3	3	-14	-14	-13	-13	2	-1	-23	-12	-84
1944	-81	-81	-145	-137	-110	-92	-5	-5	17	-1	-99	-101	-173	-165	-43
1945	2	2	-17,012	-5,525	1,399	925	-53	-53	-305	6,380	1,082	989	-10,953	-10,435	-16,299
1946	36	36	-10,406	-11,162	-393	-7,351	-110	-111	-718	3,365	-77	-241	-18,289	-17,701	-18,269
1947	56	56	-12,900	-6,767	701	-5,755	-15	-16	3,975	11,149	926	1,022	-10,371	-10,445	-19,232
1948	11	11	-10,723	-6,735	133	-4,672	-15	-16	-1,979	4,593	411	236	-8,615	-8,639	-10,836
1949	47	47	-20,112	-15,398	1,548	3,242	-52	-53	624	6,507	-293	-545	-18,804	-18,225	-19,519
1950	29	29	-22,153	-18,183	-9,753	-11,080	-12	-12	-2,685	2,576	239	421	-20,596	-20,223	-17,827
1951	1,031	1,031	-11,340	-5,770	-648	-2,850	546	545	-3,518	1,746	-208	-2,200	-8,571	-8,416	-12,003
1952	1,000	1,000	-10,361	-6,996	-860	-2,145	3,908	3,903	-3,061	-31	-2,254	529	-25,067	-18,571	-11,123
1953	375	375	-15,146	-11,776	-850	-1,993	2,378	2,377	-2,553	402	-1,254	629	-6,064	-11,485	-15,960
1954	20,494	20,494	5,816	6,889	-708	321	15,843	15,843	17,425	18,414	-186	824	17,441	12,937	-11,777
1955	32,352	32,352	20,903	21,004	2,054	3,056	17,019	17,019	20,883	20,821	1,998	2,946	50,778	25,749	388
1956	694	694	1,159	1,165	628	596	-2,258	-2,258	551	428	437	285	-1,497	944	-25
1957	11	11	-591	-757	507	453	73	73	552	502	670	569	-1,747	-568	-3
1958	-1	-1	-3,376	-3,576	700	1,752	290	290	-178	-170	65	43	-13,555	-3,327	1,336
1959	6	6	-10,187	-9,864	550	1,454	99	99	-542	-340	6	23	-14,411	-10,311	1,133
1960	8	8	-10,550	-10,095	-550	-804	52	52	-1,419	-879	0	0	-13,095	-11,461	-1,291
1961	15	15	97	1,132	654	819	55	55	1,134	2,196	634	-425	355	-377	1,671
1962	9	9	-13,813	-12,407	-2,138	-2,291	-12	-12	-1,532	-333	10	-320	-17,970	-15,688	-1,815
1963	8,891	8,891	-5,684	-3,795	-1,274	-1,583	4,851	4,852	-925	786	-513	-515	1,691	-2,160	-1,615
1964	23,604	23,604	8,507	9,452	-406	267	12,110	12,110	18,851	19,489	748	679	24,270	12,383	-3,995
1965	7,442	7,442	950	943	2,097	2,127	3,949	3,949	3,457	3,444	959	995	-1,688	2,487	286
1966	-31	-31	-11,023	-10,332	-3,002	-3,099	249	249	-237	131	-2,942	-841	-14,868	-9,371	-1,125
1967	15,316	15,316	3,502	4,274	1,300	1,731	8,586	8,586	3,822	3,595	621	1,679	10,536	5,905	-611
1968	7,816	7,816	4,866	5,703	1,778	1,265	6,309	6,309	1,299	1,014	1,714	1,368	7,983	7,767	183
1969	-14	-14	-15,919	-15,417	-9,692	-9,382	239	239	25	355	-9,300	-7,727	-21,260	-16,252	-1,579
1970	3	3	-21,567	-20,864	-7,833	-7,409	42	42	-1,265	-578	-309	4,357	-25,992	-23,158	-10,290
1971	28,902	28,902	-7,531	-6,096	-1,584	-3,315	17,630	17,630	-682	207	-294	-1,639	8,397	-4,292	-1,422
1972	-1,862	-1,862	-8,585	-7,848	-1,477	-1,619	-3,792	-3,792	-6,318	-6,292	-1,696	-1,826	-12,187	-6,474	-1,223
1973	-94	-94	2,899	2,901	675	836	729	729	609	424	594	844	522	2,778	6
1974	-7	-7	-9,064	-8,755	-4,105	-4,184	251	251	403	676	-3,578	-2,510	-9,595	-9,129	-1,923
1975	-235	-235	-17,901	-17,273	-12,929	-12,489	1,176	1,176	-325	220	-12,691	-12,566	-22,096	-17,985	386
1976	7	7	-18,365	-17,533	-17,231	-17,454	723	723	-859	-138	-2,743	3,548	-21,598	-20,148	-19,601
1977	51,179	51,179	23,605	25,227	9,139	9,566	21,760	21,760	14,206	16,538	8,478	9,432	44,584	32,370	1,612
1978	15,244	15,244	-1,280	479	-3,115	-3,412	7,976	7,976	9,369	10,814	-2,846	-3,204	9,226	4,158	-1,211

Run 16a - Conj Use 1a: Hist All Acres D1/D2 (1978 M&I)
Annual Differences in ILRG Model Outputs
Run 16a minus Run 1
1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1979	55	55	-23,524	-20,053	-346	1,701	3,304	3,312	3,198	6,630	-471	1,535	-42,558	-11,869	5,271
1980	-75	-75	-31,768	-27,701	-5,345	-3,237	785	786	-1,284	2,177	-2,198	-2,069	-44,997	-31,184	-1,862
1981	-64	-64	-28,915	-26,060	-6,442	-7,208	866	866	-1,537	1,799	953	1,273	-34,914	-31,288	-8,342
1982	-12	-12	-28,406	-25,790	-4,200	-4,849	58	58	-1,805	1,479	-1,147	891	-32,686	-30,795	-6,877
1983	-15	-15	-28,775	-26,395	-11,379	-11,735	2	3	-2,408	633	0	0	-33,700	-31,916	-12,564
1984	-52	-52	-26,697	-24,594	-16,867	-17,468	83	86	-1,513	1,795	371	371	-24,092	-23,403	-18,063
1985	-251	-251	-27,158	-25,057	-11,977	-11,684	693	699	-1,770	785	0	0	70,207	64,516	41,038
1986	-98	-98	-39,439	-38,273	-7,422	-6,249	419	442	-1,571	-93	0	0	87,166	91,493	70,462
1987	-225	-225	-48,108	-45,809	-6,405	-5,920	1,300	1,312	-568	2,719	0	0	-219	688	-45,431
1988	-18	-18	-46,157	-43,231	-6,179	-6,090	206	215	-4,123	52	0	0	-47,111	-39,691	-36,302
1989	3	3	-37,055	-33,377	-10,288	-10,961	-40	-30	-4,710	47	0	0	-49,446	-46,555	-36,243
1990	1,037	1,037	17,358	20,949	-1,434	-1,912	-7,444	-7,436	18,831	24,184	0	0	-18,580	-7,523	-18,909
1991	873	873	-39,203	-35,165	-14,918	-15,274	1,221	1,232	-7,584	-1,296	0	0	-39,224	-39,587	-30,207
1992	3,356	3,356	36,126	38,909	28,900	29,568	-9,960	-9,956	30,572	35,098	0	0	99,843	106,675	79,727
1993	550	550	-51,876	-47,688	-8,671	-8,894	1,026	1,042	-8,847	-2,164	0	0	-10,167	-11,086	343
1994	393	393	-36,706	-33,470	-3,199	-3,174	241	269	-31	5,082	0	0	16,747	17,060	13,443
1995	892	892	-32,459	-28,541	-830	-1,045	448	465	1,786	8,189	0	0	13,222	16,063	9,083
1996	-90	-90	-46,190	-43,526	-5,866	-5,128	577	596	-5,774	-1,582	0	0	-63,641	-52,977	-38,712
1997	-52	-52	-32,740	-30,203	-9,814	-11,095	321	336	-7,372	-2,213	0	0	-34,746	-30,737	-23,288
1998	-50	-50	-31,772	-29,653	-655	-1,591	619	640	-2,077	1,458	0	0	-20,698	-13,713	-17,842
1999	-1,292	-1,292	-49,620	-48,576	26,534	25,956	-10,168	-10,155	-18,682	-17,151	0	0	-2,482	7,830	21,426
2000	-365	-365	-19,777	-19,931	4,907	4,540	-7,221	-7,213	-2,945	-2,963	0	0	-27,724	-14,037	-11,014
2001	265	265	-15,822	-16,021	-2,730	-2,534	422	432	8,959	8,952	0	0	-17,568	-17,492	-22,495
2002	-42	-42	-27,960	-27,931	-1,649	-746	411	418	-2	1	0	0	-33,470	-27,260	-27,816
2003	100,416	100,416	16,216	16,449	11,207	12,322	54,067	54,081	17,881	17,903	0	0	68,064	42,900	8,935
2004	34,561	34,561	-26,139	-25,264	-1,293	592	24,223	24,225	-750	-732	0	0	-27,330	-14,022	-10,214
2005	2,986	2,986	-12,986	-12,749	-6,310	-5,520	6,212	6,216	6,624	6,630	0	0	-34,384	-12,008	-14,436
2006	69,817	69,817	-13,191	-12,769	2,027	3,614	46,429	46,440	2,843	2,861	0	0	24,407	3,949	-2,688
2007	150,366	150,366	-21,009	-19,962	-7,796	-6,721	96,729	96,736	1,167	1,208	0	0	24,069	-6,367	-7,132
2008	178,658	178,658	-23,951	-22,761	-14,153	-12,811	113,901	113,943	-2,209	-2,125	0	0	48,762	3,822	2,099
2009	135,903	135,903	-46,916	-45,195	-5,945	-4,740	88,198	88,236	-14,681	-14,605	0	0	-17,190	-3,981	7,362
2010	211,026	211,026	-32,156	-30,129	-12,631	-11,764	136,591	136,645	-8,088	-7,993	0	0	42,177	6,732	13,066
2011	83,246	83,246	-94,298	-92,275	-37,537	-39,791	36,672	36,681	-55,533	-55,481	-12,671	-12,445	-108,422	-90,823	-11,593
2012	92,854	92,854	12,616	12,777	-6,131	-9,738	44,356	44,356	15,729	16,029	3,811	4,334	57,992	13,565	-16,101
2013	-37,660	-37,660	-45,363	-45,495	-9,919	-9,449	-20,662	-20,662	-32,046	-32,035	-5,314	-5,574	-98,715	-49,719	-9,518
2014	81,516	81,516	11,439	11,371	-140	-555	35,096	35,096	11,948	11,956	-418	-419	101,194	10,849	-7,245
2015	120,356	120,356	-38,188	-38,000	-4,492	-5,743	57,882	57,882	-20,321	-20,305	1,076	919	13,977	-47,873	-17,851
2016	106,390	106,390	-70,094	-69,645	-11,954	-13,918	54,092	54,092	-42,297	-42,274	0	0	-58,081	-75,425	-36,494
2017	299,940	299,940	-18,902	-17,195	-1,971	-2,441	179,461	179,498	-7,500	-7,427	0	0	107,957	1,313	-2,883
Averages															
1951-2017	27,571	27,571	-18,202	-16,687	-3,457	-3,455	15,704	15,711	-1,035	607	-595	-242	-3,013	-6,800	-4,649
1951-1978	7,577	7,577	-4,285	-3,214	-1,726	-1,778	4,313	4,313	2,470	3,337	-853	-179	-1,981	-2,918	-3,271
1979-2005	5,285	5,285	-26,650	-24,398	-2,692	-2,505	2,321	2,331	463	3,608	-92	74	-10,537	-5,182	-4,848
2006-2017	124,368	124,368	-31,668	-30,773	-9,220	-9,505	72,396	72,412	-12,582	-12,516	-1,126	-1,099	11,510	-19,496	-7,415
1985-2017	49,553	49,553	-28,227	-26,589	-4,204	-4,209	28,070	28,084	-4,035	-2,039	-410	-400	2,018	-6,467	-5,377
1985-2005	6,802	6,802	-26,260	-24,198	-1,338	-1,183	2,741	2,754	850	3,948	0	0	-3,407	978	-4,212

Notes:

EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

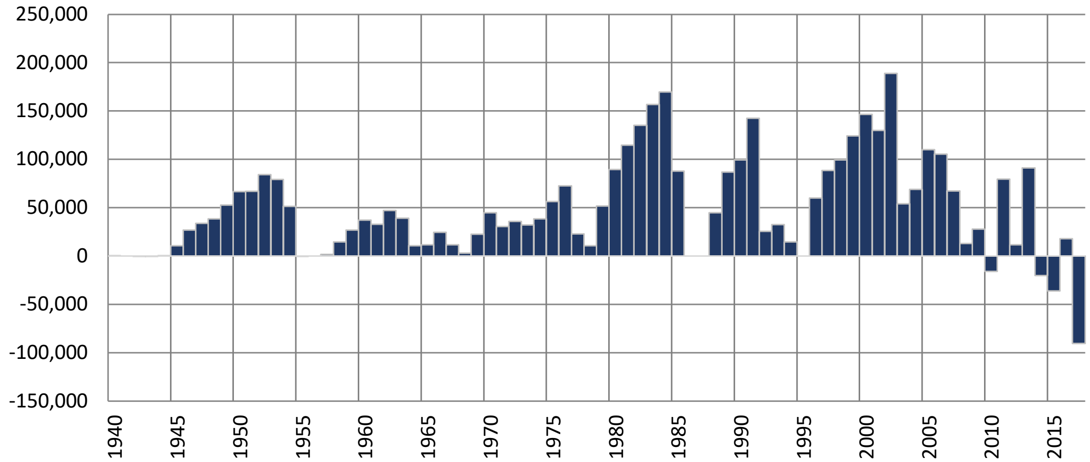
Run 16a - Conj Use 1a: Hist All Acres D1/D2 (1978 M&I)

Simulated Differences in ILRG Model Outputs

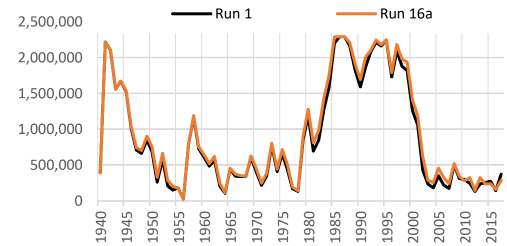
Run 16a minus Run 1

1940 - 2017 (acre-feet)

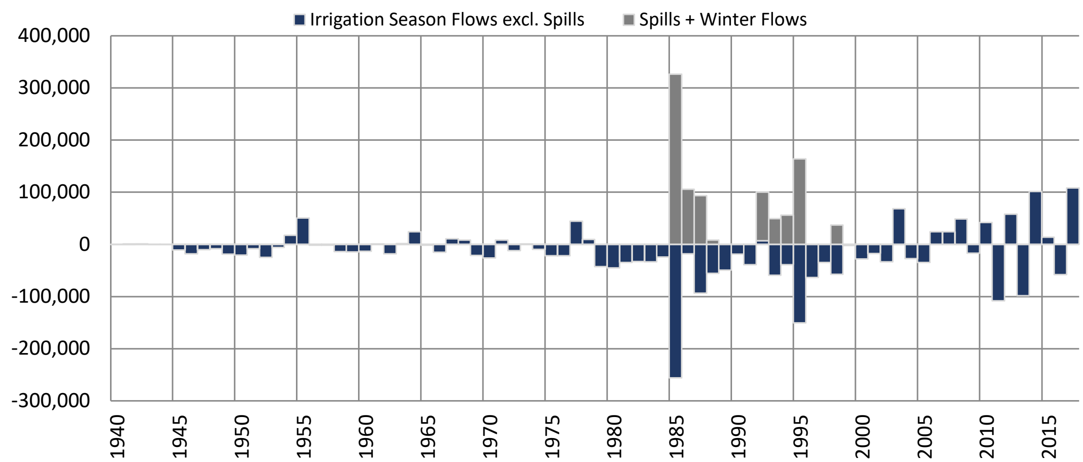
Total Project Storage (Year End)



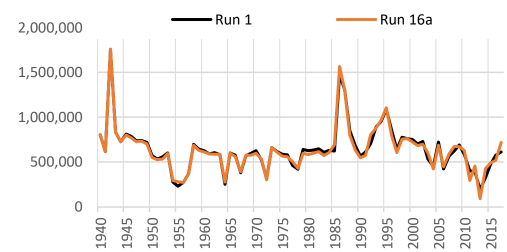
Period	Average Difference
1951-2017	-2,345
1951-1978	-1,996
1979-2005	3,675
2006-2017	-16,703
1985-2017	-7,885
1985-2005	-2,846



Caballo Reservoir Outflows (Annual)



Period	Average Difference: Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	-16,926	13,913	-3,013
1951-1978	-1,981	0	-1,981
1979-2005	-45,062	34,525	-10,537
2006-2017	11,510	0	11,510
1985-2017	-26,230	28,248	2,018
1985-2005	-47,797	44,390	-3,407



Notes:

Reservoir storage does not include storage attributed to SJC, CO, or NM credit waters.

Average differences calculated as (Final Storage - Initial Storage)/(no. years).

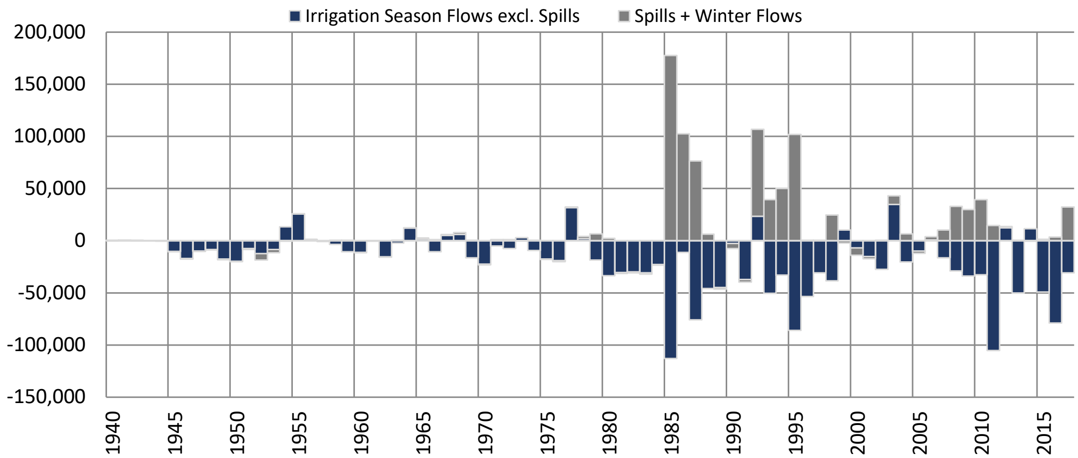
Run 16a - Conj Use 1a: Hist All Acres D1/D2 (1978 M&I)

Simulated Differences in ILRG Model Outputs

Run 16a minus Run 1

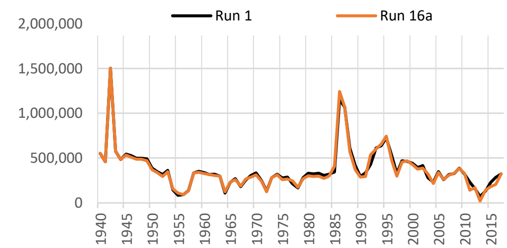
1940 - 2017 (acre-feet)

Rio Grande at El Paso (Annual)

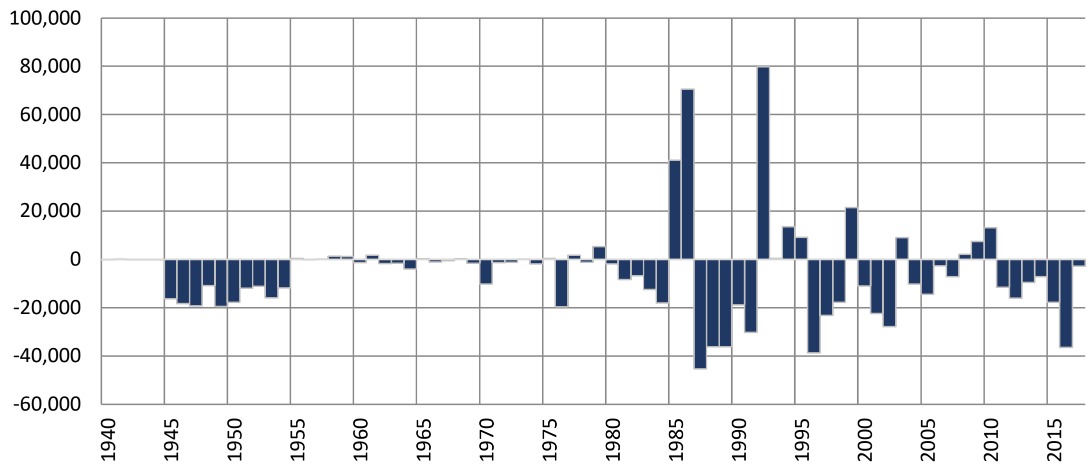


Average Difference

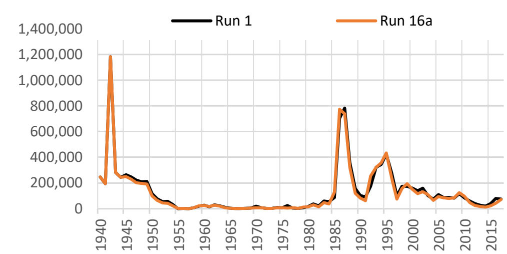
Period	Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	-19,143	12,343	-6,800
1951-1978	-2,844	-74	-2,918
1979-2005	-29,667	24,485	-5,182
2006-2017	-33,494	13,997	-19,496
1985-2017	-31,412	24,945	-6,467
1985-2005	-30,222	31,200	978



Rio Grande at Fort Quitman (Annual)



Period	Average Difference
1951-2017	-4,638
1951-1978	-3,263
1979-2005	-4,833
2006-2017	-7,408
1985-2017	-5,367
1985-2005	-4,201



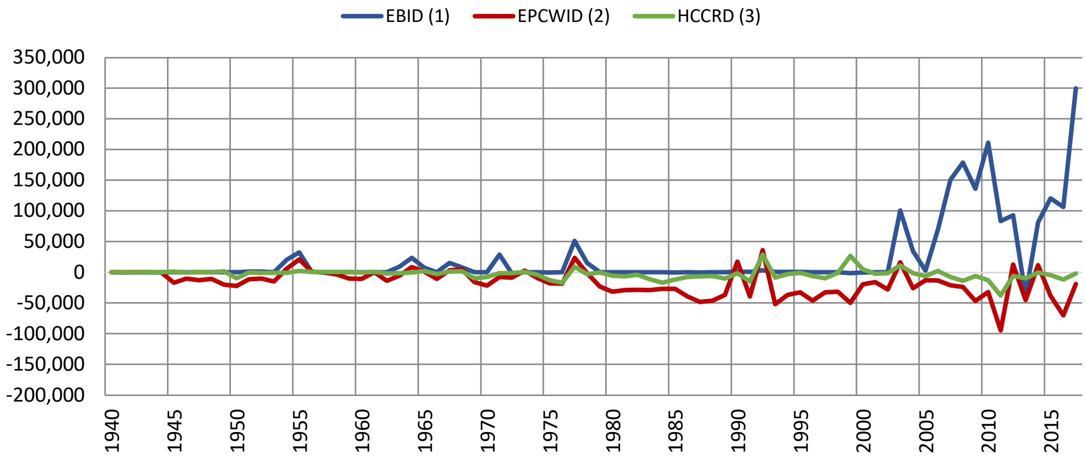
Run 16a - Conj Use 1a: Hist All Acres D1/D2 (1978 M&I)

Simulated Differences in ILRG Model Outputs

Run 16a minus Run 1

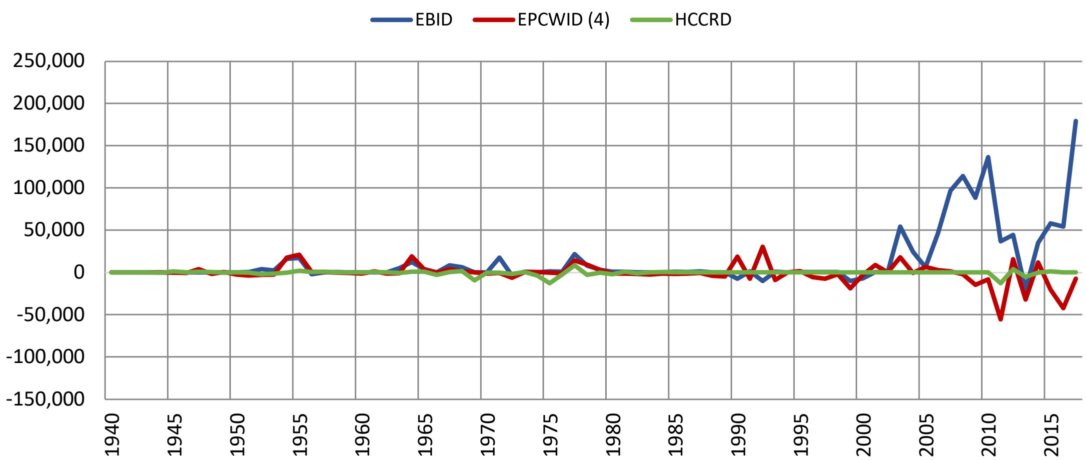
1940 - 2017 (acre-feet)

River Headgate (RHG) Diversions (Irrigation Season)



	Average Difference		
Period	EBID	EPCWID	HCCRD
1951-2017	27,571	-18,202	-3,457
1951-1978	7,577	-4,285	-1,726
1979-2005	5,285	-26,650	-2,692
2006-2017	124,368	-31,668	-9,220
1985-2017	49,553	-28,227	-4,204
1985-2005	6,802	-26,260	-1,338

Farm Headgate (FHG) Deliveries (Irrigation Season)



	Average Difference		
Period	EBID	EPCWID	HCCRD
1951-2017	15,704	-1,035	-595
1951-1978	4,313	2,470	-853
1979-2005	2,321	463	-92
2006-2017	72,396	-12,582	-1,126
1985-2017	28,070	-4,035	-410
1985-2005	2,741	850	0

Notes:

(1) EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

(2) EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

(3) HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

(4) EPCWID FHG values include deliveries to Rogers WTP and R/U WTP.

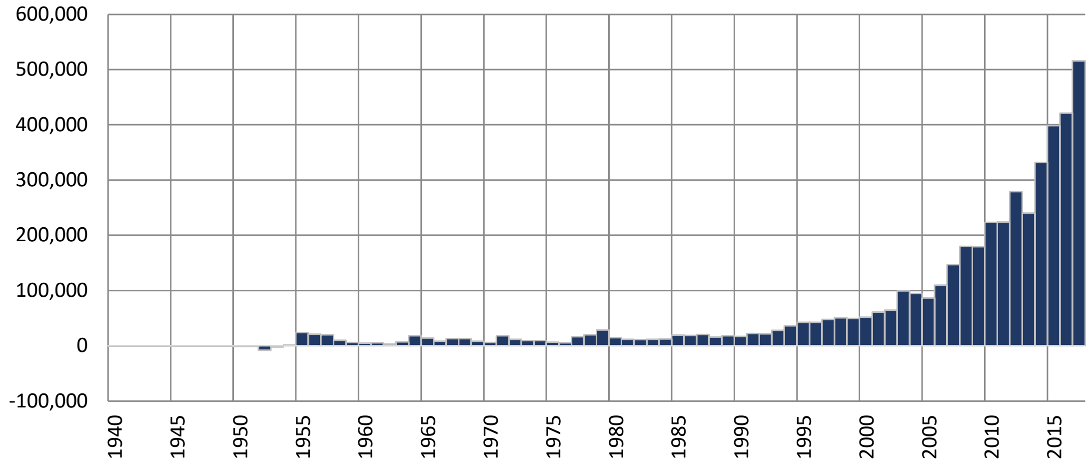
Run 16a - Conj Use 1a: Hist All Acres D1/D2 (1978 M&I)

Simulated Differences in ILRG Model Outputs

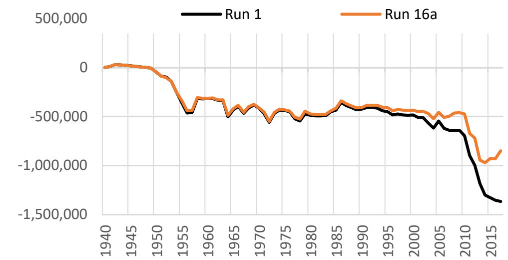
Run 16a minus Run 1

1940 - 2017 (acre-feet)

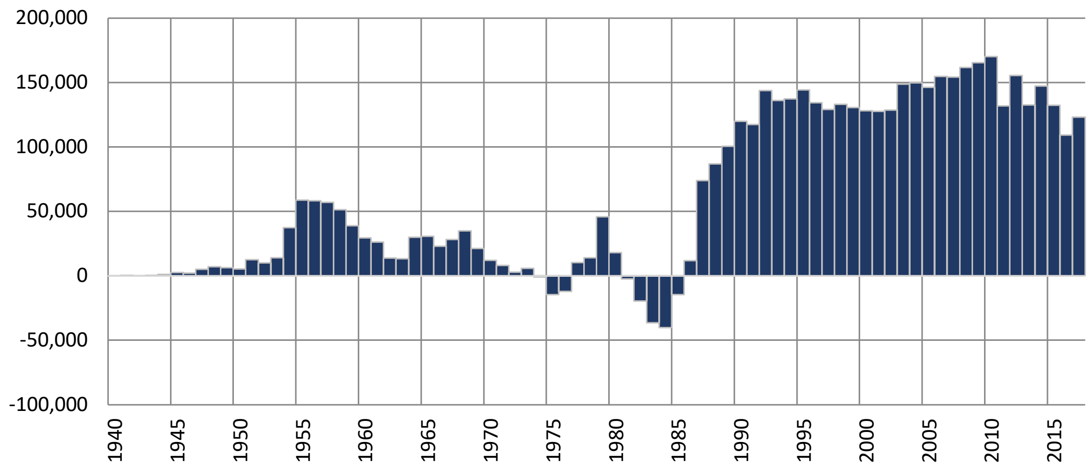
Cumulative Annual Rincon-Mesilla Groundwater Storage



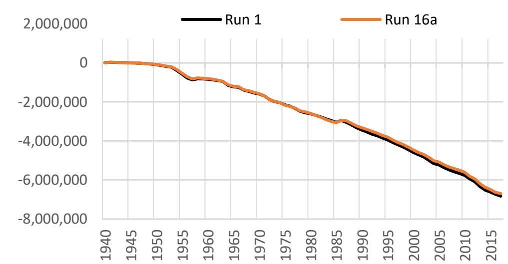
Period	Average Difference
1951-2017	7,710
1951-1978	738
1979-2005	2,470
2006-2017	35,772
1985-2017	15,253
1985-2005	3,528



Cumulative Annual Hueco Groundwater Storage



Period	Average Difference
1951-2017	1,761
1951-1978	318
1979-2005	4,891
2006-2017	-1,915
1985-2017	4,955
1985-2005	8,880



Notes:
Cumulative storage change in alluvial and non-alluvial aquifers.
Average differences calculated as (Final Storage - Initial Storage)/(no. years).

Run 16a - Conj Use 1a: Hist All Acres D1/D2 (1978 M&I)

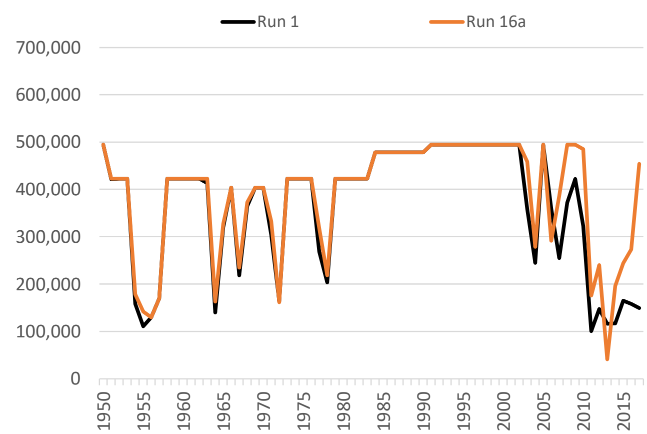
Annual Allocation and Charges

Run 16a v. Run 1

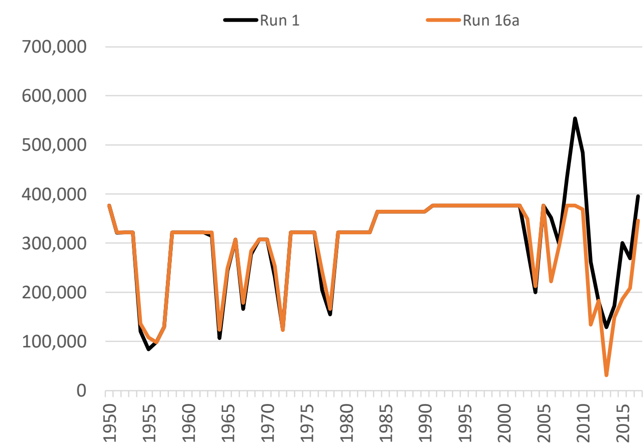
ILRG Model

1950 - 2017 (acre-feet)

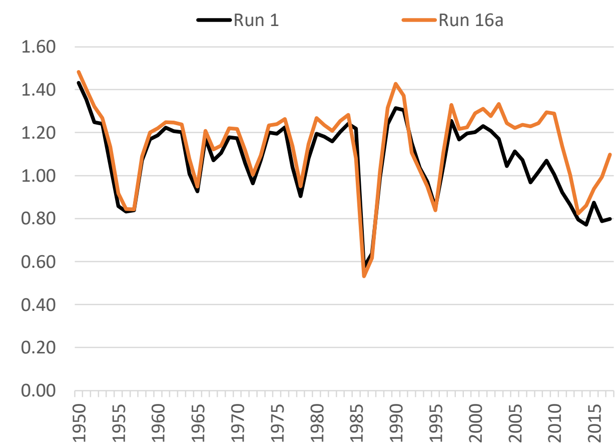
Total Allocation - EBID



Total Allocation - EPCWID

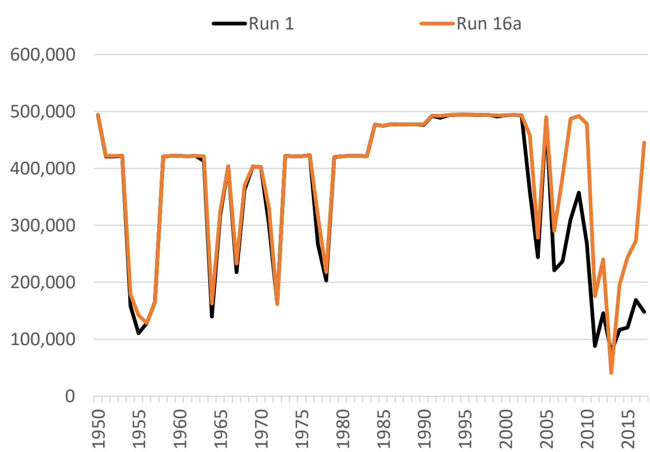


Diversion Ratio

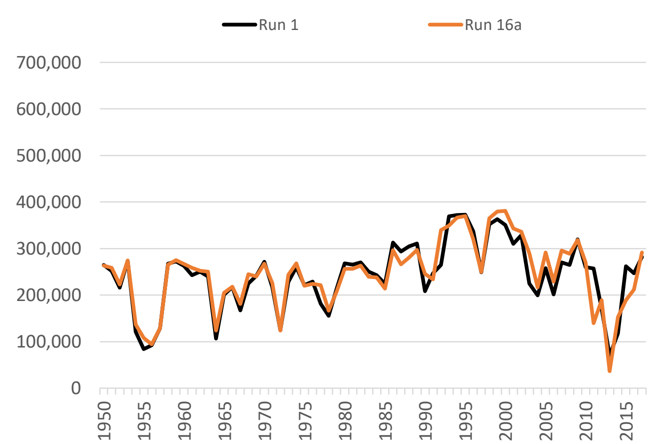


Note:
Computed as Total Charges/Caballo Release.

Annual Delivery Charges - EBID

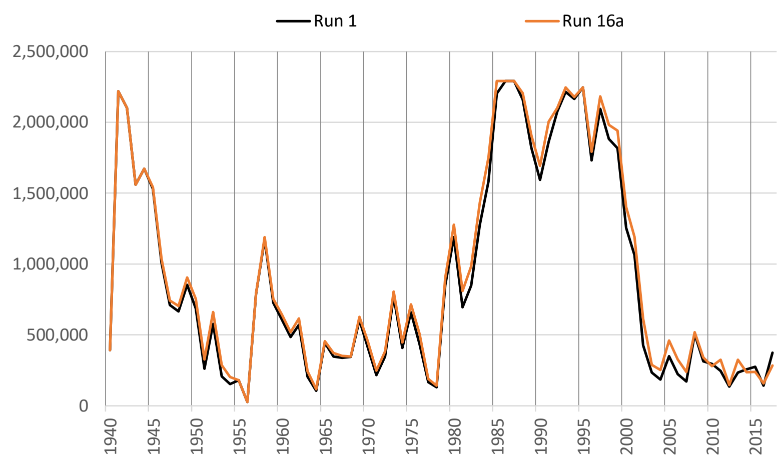


Annual Delivery Charges - EPCWID

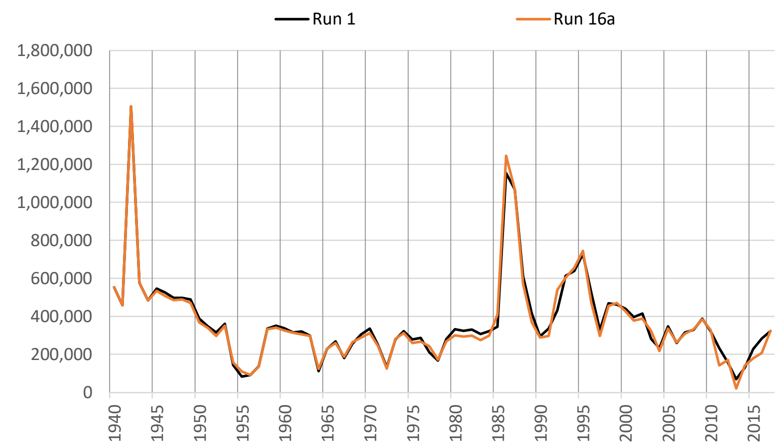


Run 16a - Conj Use 1a: Hist All Acres D1/D2 (1978 M&I)
Annual Summary of Project Storage and Rio Grande Flows
Run 16a v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

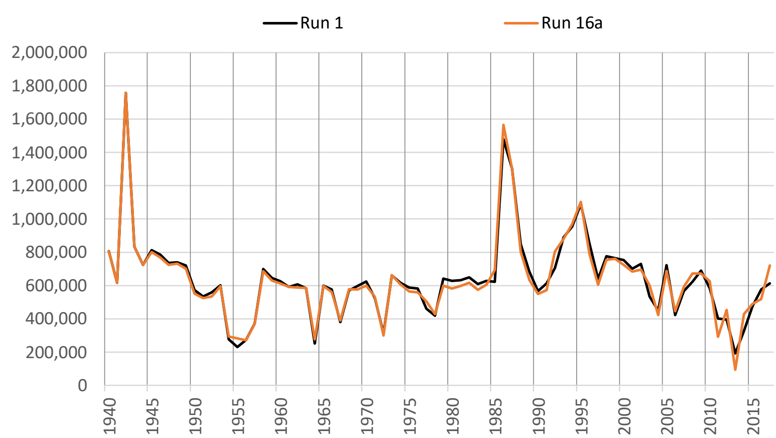
Total Year-End Project Reservoir Storage



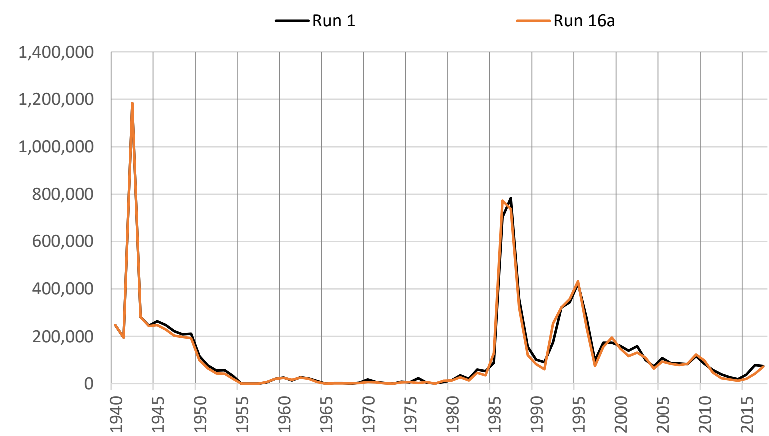
Rio Grande at El Paso



Rio Grande Below Caballo



Rio Grande at Fort Quitman

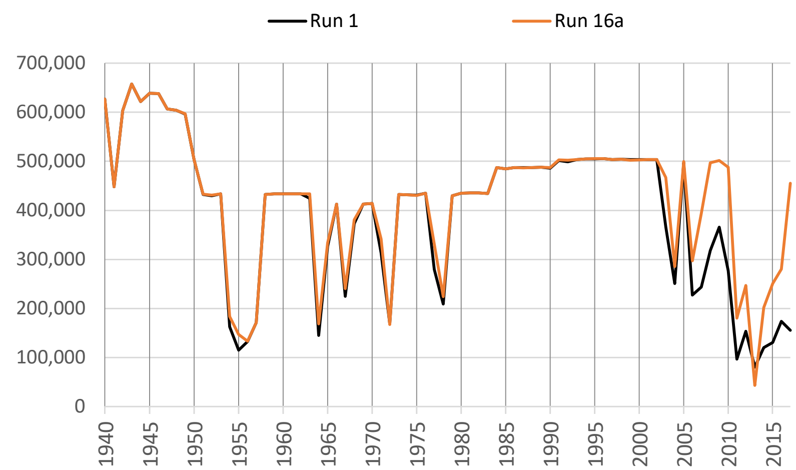


***Note different scales.**

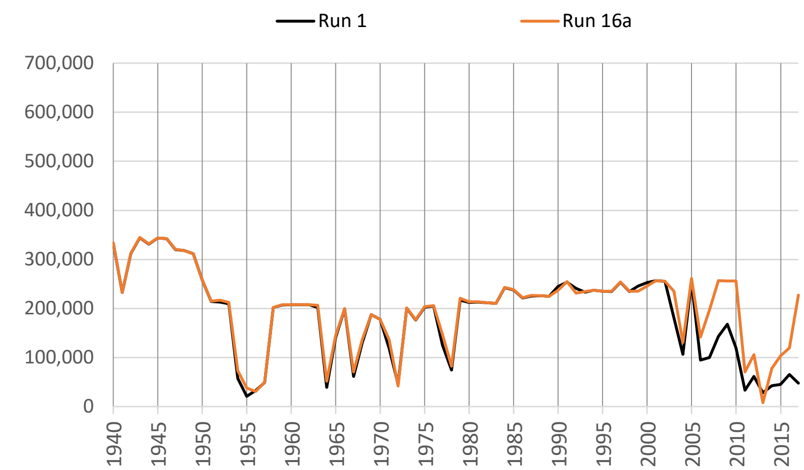
Run 16a - Conj Use 1a: Hist All Acres D1/D2 (1978 M&I)
Irrigation Season Summary of Irrigation Operations
Run 16a v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

EBID Total

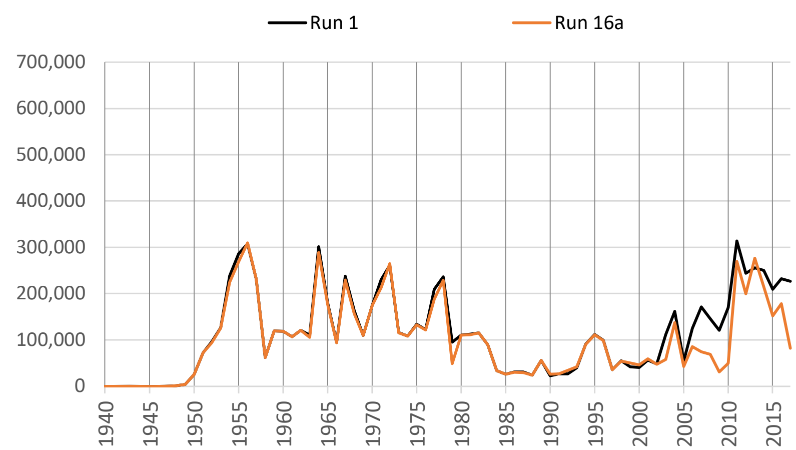
Net River Headgate Diversions



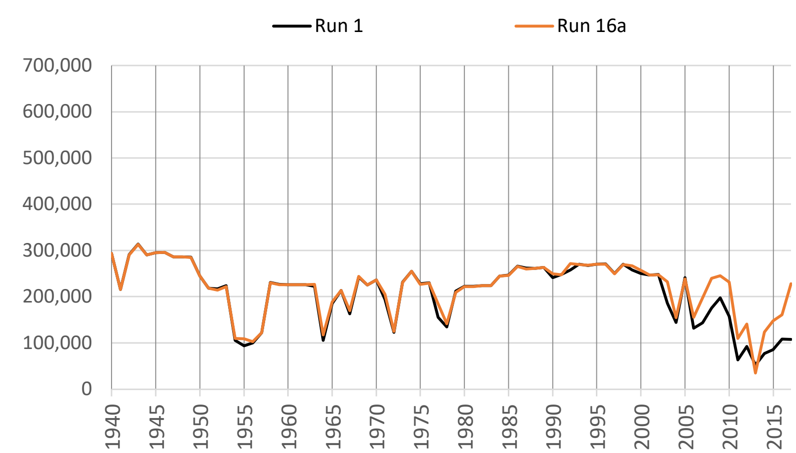
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries



Notes: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).
Pumping includes Supplemental and Primary groundwater pumping.

Run 16a - Conj Use 1a: Hist All Acres D1/D2 (1978 M&I)

Irrigation Season Summary of Irrigation Operations

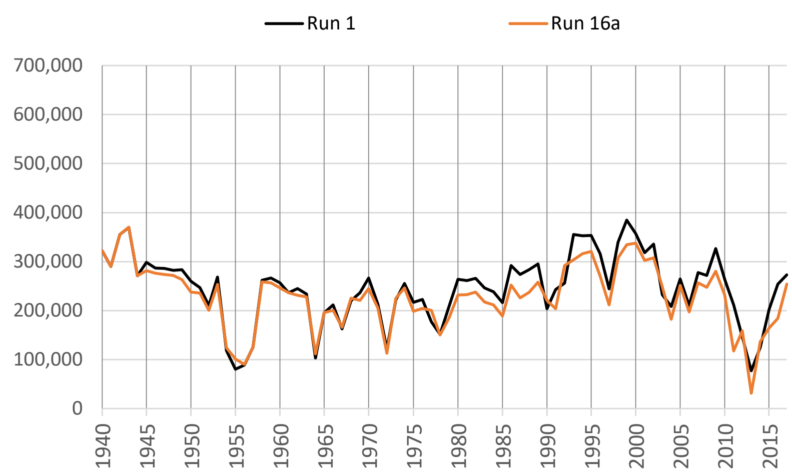
Run 16a v. Run 1

ILRG Model

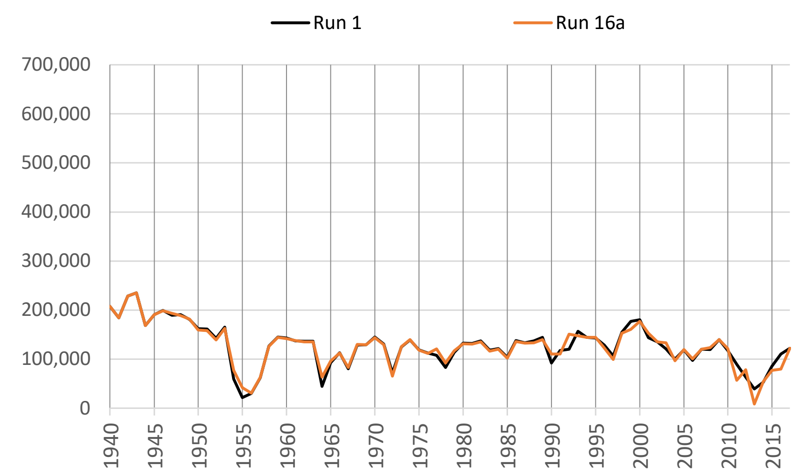
1940 - 2017 (acre-feet)

EPCWID Total

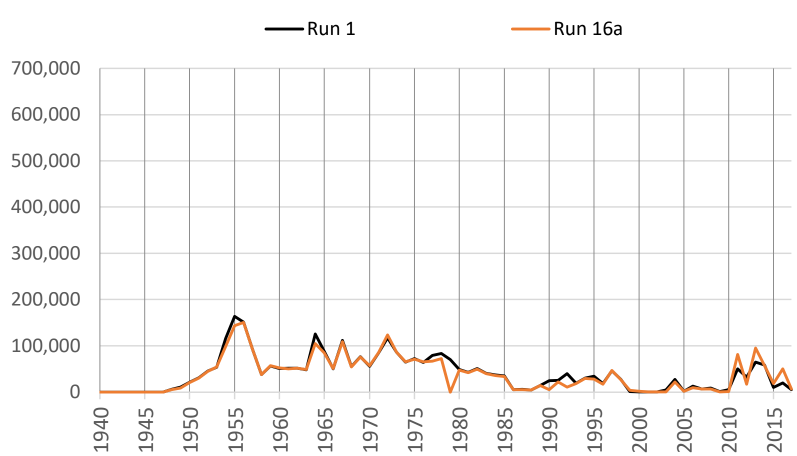
Net River Headgate Diversions



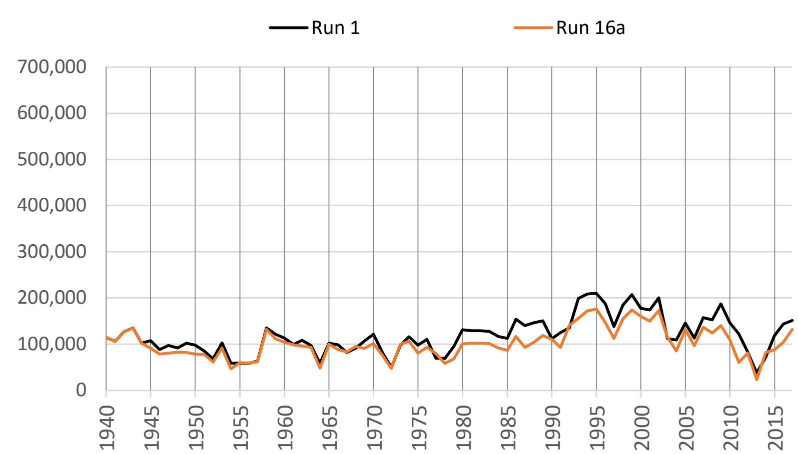
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries

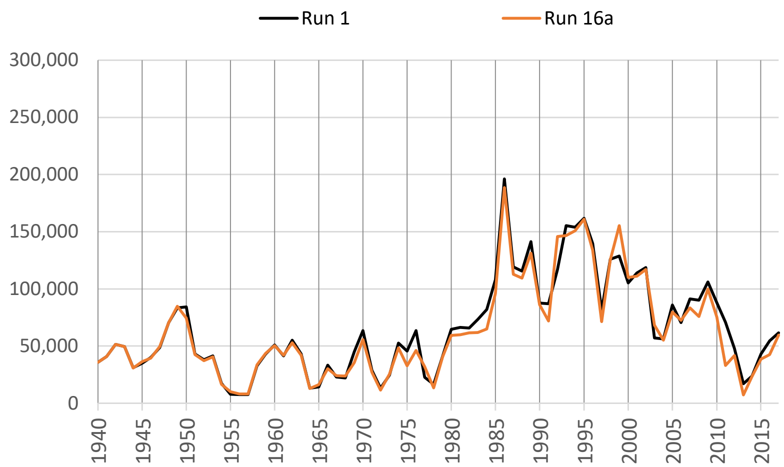


Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

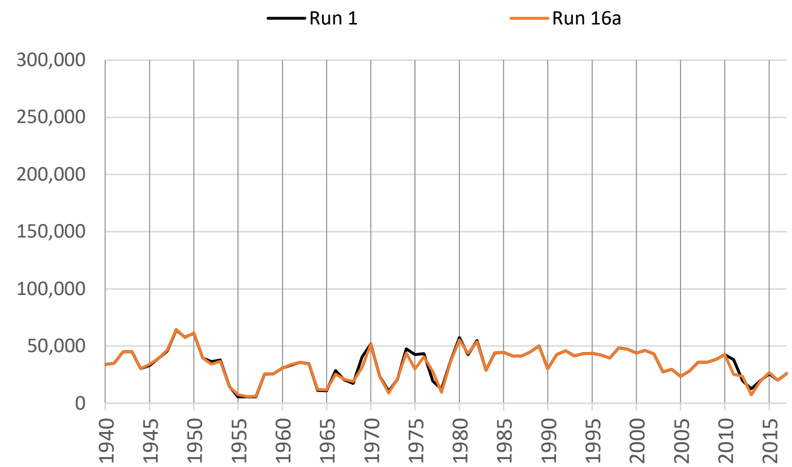
Run 16a - Conj Use 1a: Hist All Acres D1/D2 (1978 M&I)
Irrigation Season Summary of Irrigation Operations
Run 16a v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

HCCRD Total

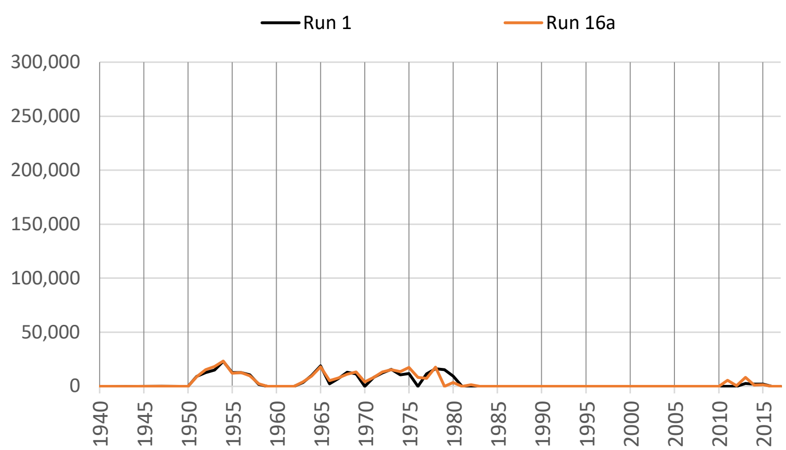
Net River Headgate Diversions



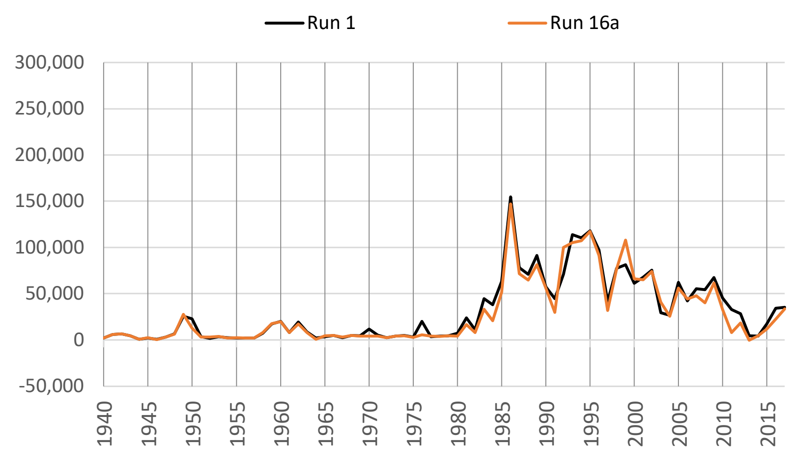
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries



Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

Run 16a - Conj Use 1a: Hist All Acres D1/D2 (1978 M&I)

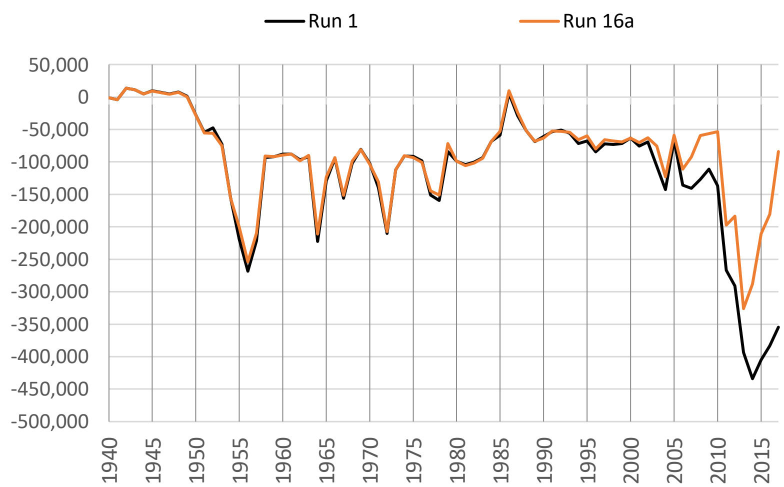
Cumulative Change in Ground Water Storage

Run 16a v. Run 1

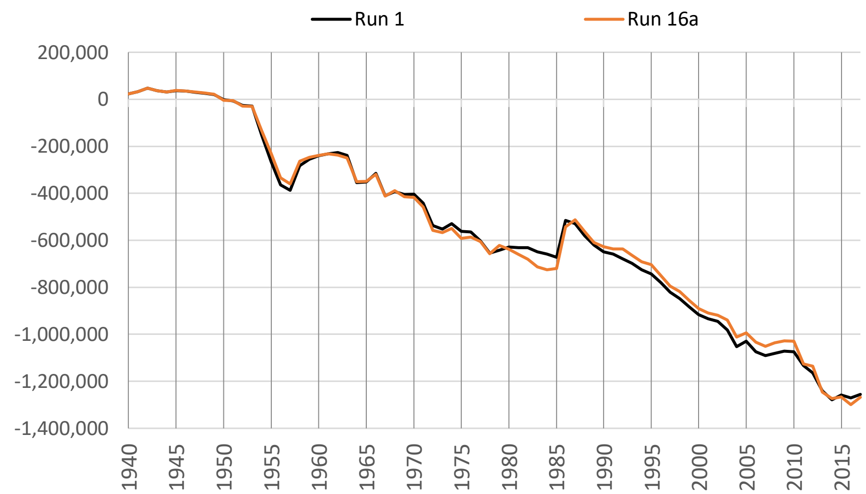
ILRG Model

1940 - 2017 (acre-feet)

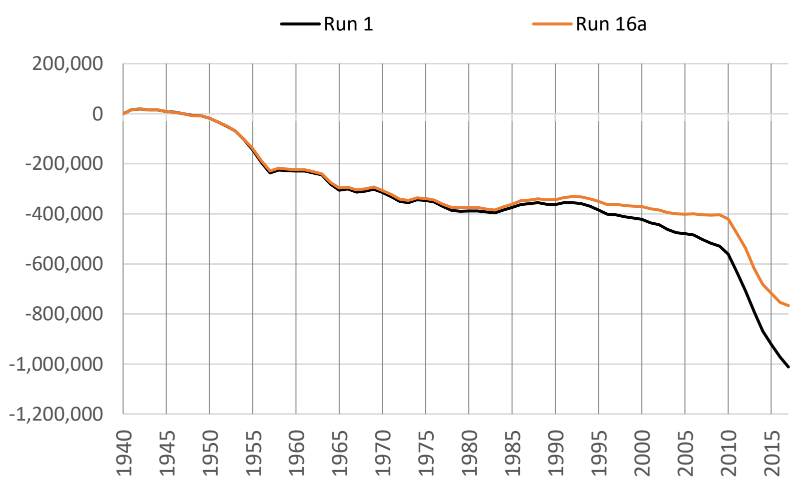
Rincon-Mesilla Alluvial Aquifer



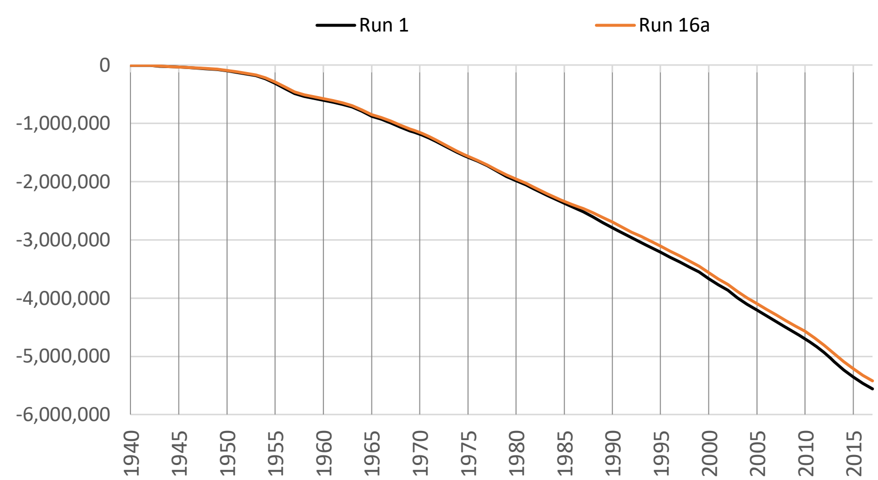
Hueco Alluvial Aquifer



Rincon-Mesilla Non-Alluvial Aquifer



Hueco Non-Alluvial Aquifer



***Note different scales.**

Run 16a - Conj Use 1a: Hist All Acres D1/D2 (1978 M&I)

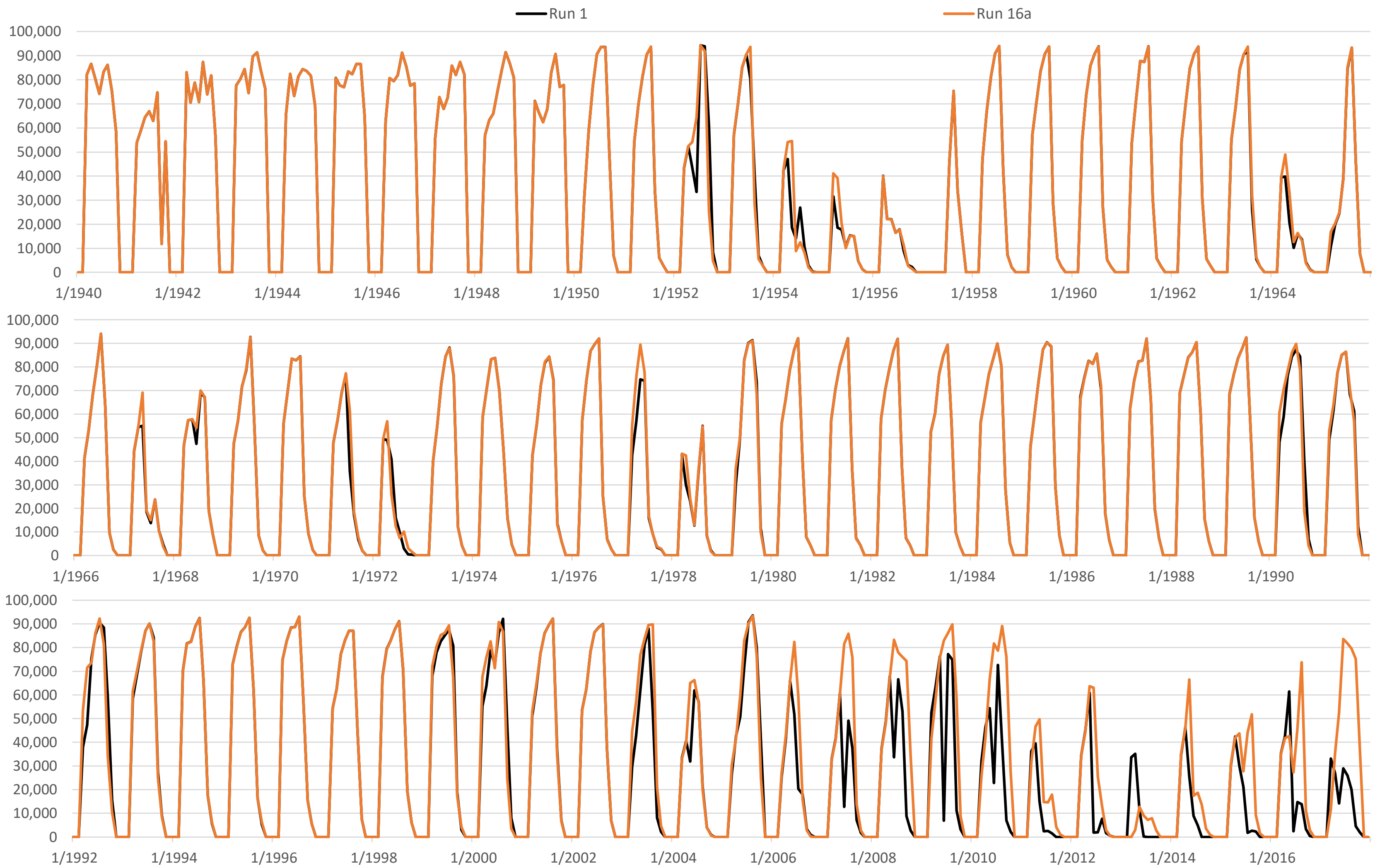
Monthly Net RHG Diversions

Run 16a v. Run 1

ILRG Model

1940 - 2017 (acre-feet)

EBID Total



Note: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

Run 16a - Conj Use 1a: Hist All Acres D1/D2 (1978 M&I)

Monthly Net RHG Diversions

Run 16a v. Run 1

ILRG Model

1940 - 2017 (acre-feet)

EPCWID Total

Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

Run 16a - Conj Use 1a: Hist All Acres D1/D2 (1978 M&I)

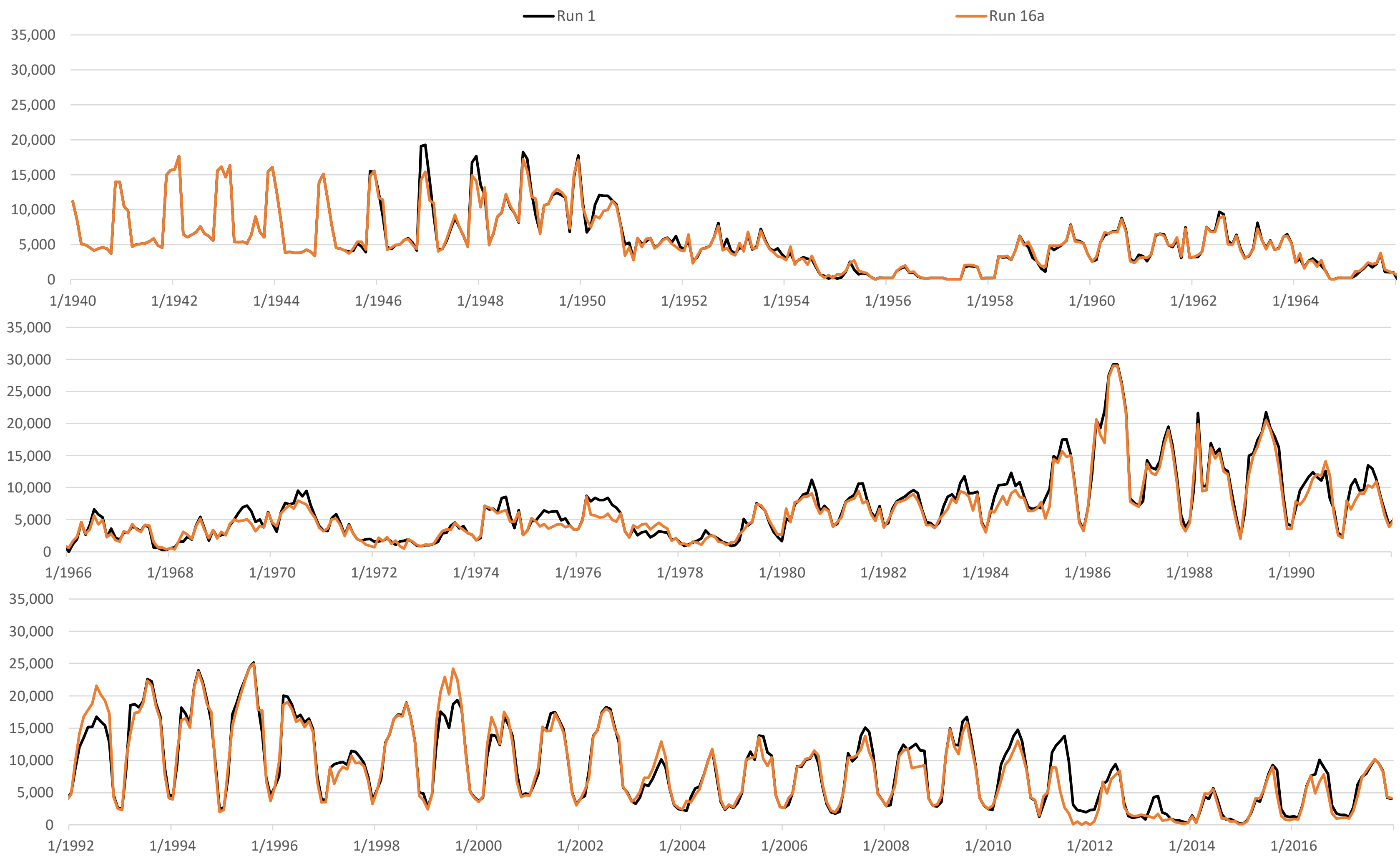
Monthly Net RHG Diversions

Run 16a v. Run 1

ILRG Model

1940 - 2017 (acre-feet)

HCCRD Total



Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

Run 16a - Conj Use 1a: Hist All Acres D1/D2 (1978 M&I)

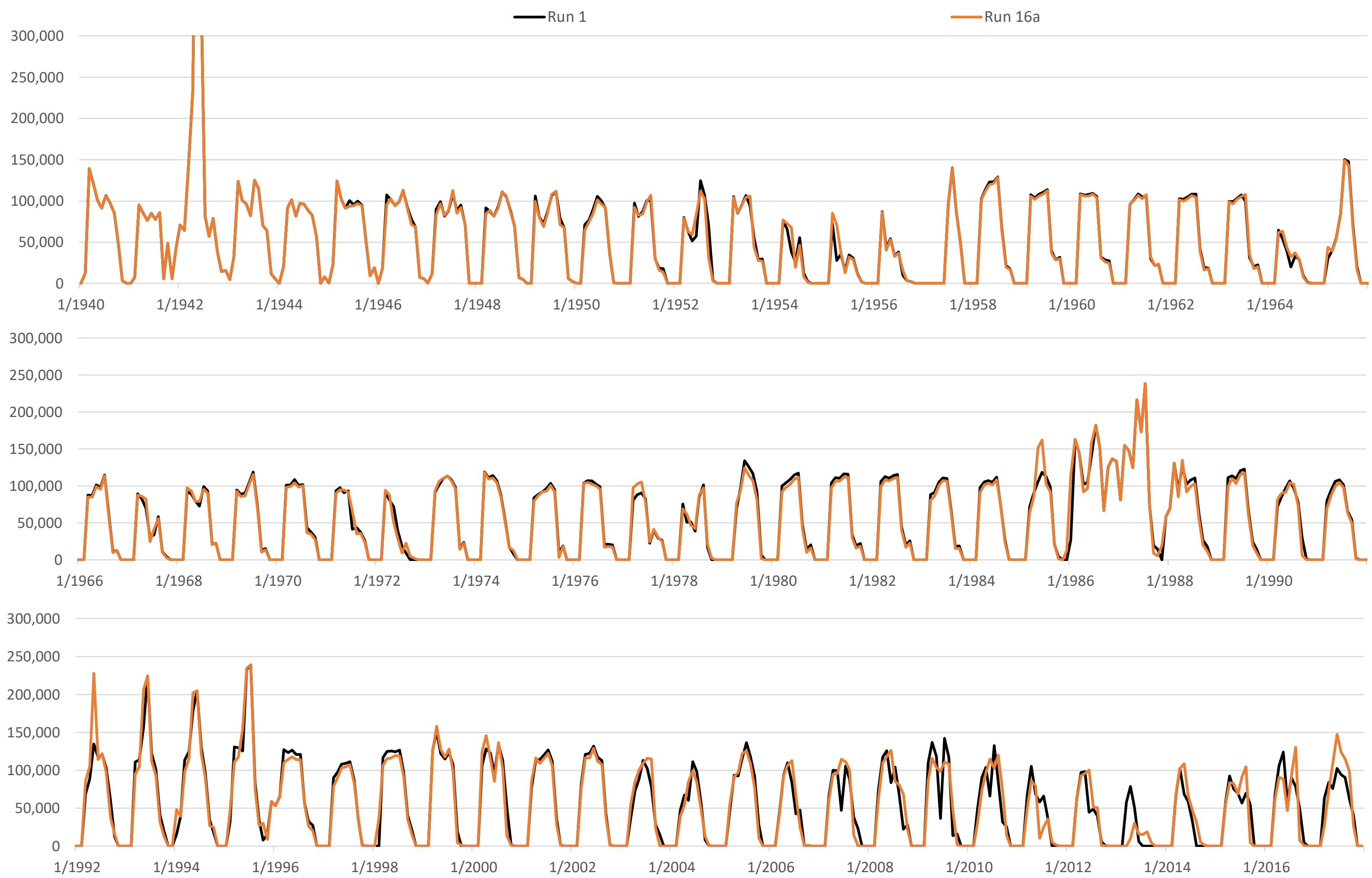
End of Month Reservoir Storage (Elephant Butte + Caballo)

Run 16a v. Run 1

ILRG Model

1940 - 2017 (acre-feet)

Run 16a - Conj Use 1a: Hist All Acres D1/D2 (1978 M&I)
Monthly Caballo Releases
Run 16a v. Run 1
ILRG Model
1940 - 2017 (acre-feet)



Run 16a - Conj Use 1a: Hist All Acres D1/D2 (1978 M&I)
Monthly Rio Grande at El Paso Flow
Run 16a v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

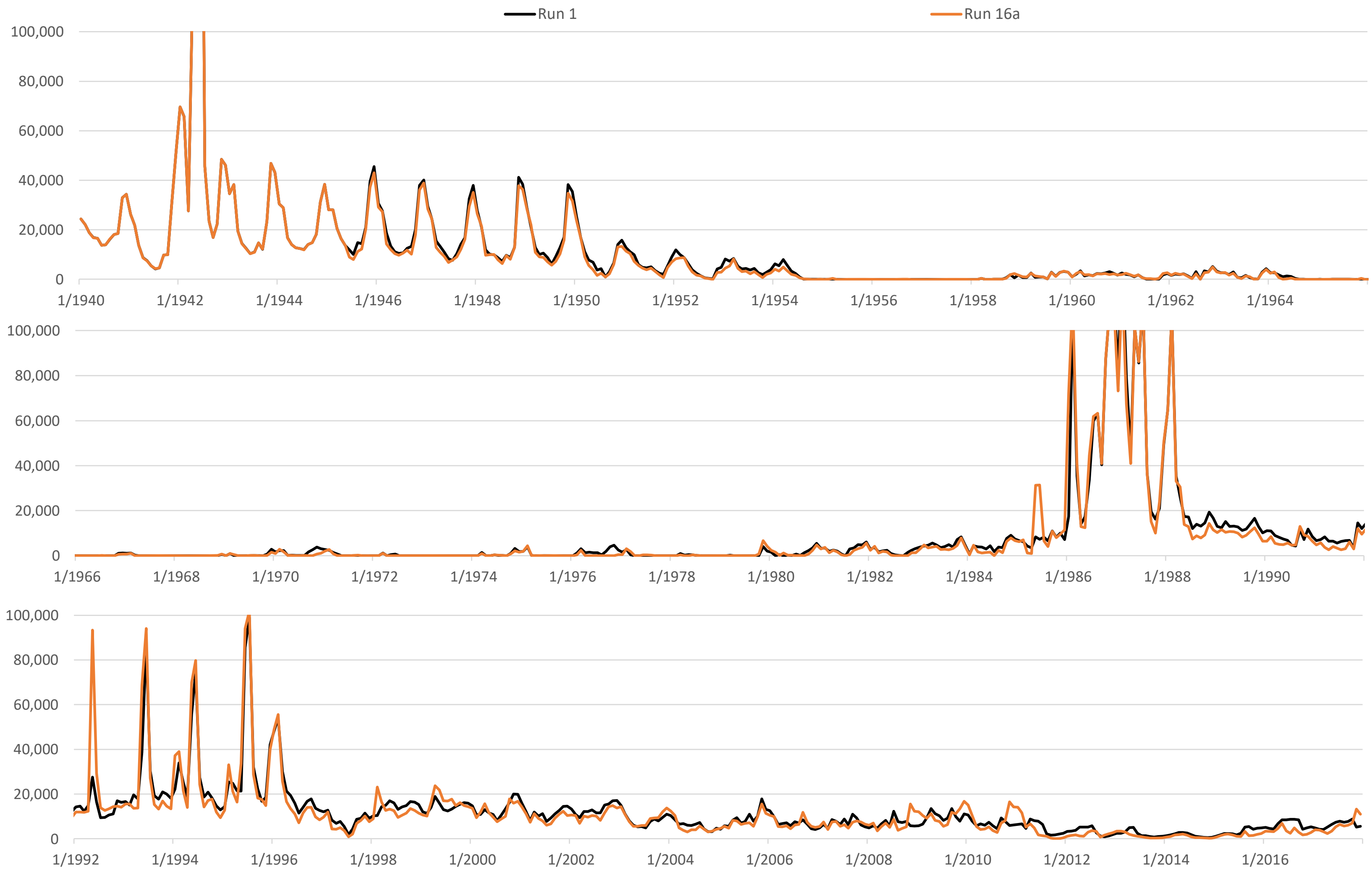
Run 16a - Conj Use 1a: Hist All Acres D1/D2 (1978 M&I)

Monthly Rio Grande at Fort Quitman Flow

Run 16a v. Run 1

ILRG Model

1940 - 2017 (acre-feet)



Appendix 30Y

Comparison of ILRG Model Runs
Run 17 v. Run 1

Model Run Specifications

Model Version: LRG_v116

Name: **Run 17 - Conj Use 2: Hist Proj Acres (Hist M&I)**

Run ID: LRG_v116_Operational_Run17
Date: 8/28/2020

Name: **Run 1 - Historical Base Run (All Pumping On)**

Run ID: LRG_v116_Operational_Run1
Date: 8/23/2020

Selected Model Inputs

	Pumping and Returns	Run 17	Run 1
(1)	Irrigation Pumping	Conj	On
(2)	Irrigated Area	Project	Hist
	Non-Irrigation Pumping	On	On
	Non-Irrigation Pumping Returns	On	On
	Las Cruces Jornada Pumping Returns	Off	On

	Project Allocation Rules	Run 17	Run 1
	1950-2005	D1/D2	D1/D2
	2006-2007	D1/D2	D3
	2008-2017	D1/D2	D3 + CO

	EPCWID Operations	Run 17	Run 1
	Charge EPCWID for Use of WWTP Returns	On	Off
	ACE and Haskell Credits for EPCWID	Off	On
(3)	Increased EPCWID Use of Fabens Drain Flows	On	Off
	Charge EPCWID for Fabens Drain Flow Use	On	Off

Notes:
(1) Conjunctive use pumping on historical Project acres; no pumping on NM GW only acres.
(2) Project acres set to historical. New Mexico groundwater only acres set to 0.
(3) Starting in July 1945, use 70% of simulated Fabens drain flow up to 6,000 AF/month.

Run 17 - Conj Use 2: Hist Proj Acres (Hist M&I)

Comparison of ILRG Model Runs

Run 17 v. Run 1

1951 - 2017 Annual Average

(1,000 acre-feet)

Run No.	1	17	17 - 1	
Simulated Input or Output	**Run 1**	**Run 17**	**Run 17 minus Run 1**	
Effects of Alternate Scenario				
FHG Deliveries (Mar - Oct)				***% Diff.***
EBID	167.6	186.0	18.4	*11%*
EPCWID (incl. EPW)	139.9	140.4	0.5	*0%*
HCCRD	32.8	32.6	-0.3	*-1%*
Total	340.3	359.0	18.7	*5%*
FHG Deliveries (Nov - Feb)				
EBID	0.0	0.0	0.0	*59%*
EPCWID (incl. EPW)	0.2	1.9	1.7	*888%*
HCCRD	2.4	2.8	0.4	*16%*
Total	2.6	4.7	2.1	*79%*
Irrigation Pumping				
EBID	140.4	106.4	-34.1	*-24%*
EPCWID (Mesilla Valley)	7.4	6.8	-0.5	*-7%*
EPCWID (El Paso Valley)	40.1	37.9	-2.2	*-6%*
HCCRD	4.2	4.5	0.2	*6%*
Total	192.1	155.5	-36.6	*-19%*
Other Inflows/Outflows				
Net Reservoir Evaporation	125.3	132.1	6.8	*5%*
Riparian ET	70.9	71.3	0.4	*1%*
River Evaporation + Incidental Canal Loss	30.3	31.0	0.7	*2%*
Total	226.6	234.4	7.9	*3%*
Rio Grande at Fort Quitman				
Reservoir Spills	33.3	41.4	8.1	*24%*
Nov-Feb Flows	21.4	20.1	-1.3	*-6%*
Mar - Oct Flows	41.1	33.5	-7.6	*-18%*
Underflow (GW Model)	0.2	0.2	0.0	*0%*
Total	96.0	95.2	-0.8	*-1%*

Run 17 - Conj Use 2: Hist Proj Acres (Hist M&I)
Comparison of ILRG Model Runs
Run 17 v. Run 1
1951 - 2017 Annual Average
(1,000 acre-feet)

Run No.	1	17	17 - 1	
Simulated Input or Output	**Run 1**	**Run 17**	**Run 17 minus Run 1**	
Effects of Alternate Scenario (continued)				
Change in Storage				***% Diff.***
Reservoir Storage	-4.7	-7.0	-2.3	*49%*
Alluvial GW Storage (RW Model)	-23.6	-20.0	3.5	*-15%*
Non-alluvial GW Storage (GW Models)	-96.4	-93.8	2.6	*-3%*
Soil Moisture Storage	0.6	0.8	0.2	*30%*
Total	-124.0	-120.0	4.0	*-3%*
Summary of Effects				
FHG Deliveries (Mar-Oct)	340.3	359.0	18.7	*5%*
FHG Deliveries (Nov-Feb)	2.6	4.7	2.1	*79%*
Irrigation Pumping	192.1	155.5	-36.6	*-19%*
Riparian ET + Evaporation	226.6	234.4	7.9	*3%*
Fort Quitman Flow	96.0	95.2	-0.8	*-1%*
Change in Storage	-124.0	-120.0	4.0	*-3%*
Total	733.6	728.8	-4.8	*-1%*
Other Effects of Alternate Scenario				
Rio Grande at El Paso				***% Diff.***
Reservoir Spills	49.4	61.9	12.5	*25%*
Nov-Feb Flows	22.8	25.7	2.9	*13%*
Mar - Oct Flows	263.8	247.7	-16.1	*-6%*
Total	336.0	335.2	-0.7	*0%*
Rio Grande below Caballo				
Reservoir Spills	65.9	81.4	15.5	*24%*
Nov-Feb Flows	0.5	0.4	-0.1	*-14%*
Mar - Oct Flows	541.3	521.2	-20.0	*-4%*
Total	607.6	603.0	-4.6	*-1%*
Surface Water Diversions (Mar - Oct)				
EBID	366.5	397.1	30.6	*8%*
EPCWID (incl. EPW)	236.8	220.4	-16.4	*-7%*
HCCRD	67.5	64.8	-2.8	*-4%*
Total	670.8	682.3	11.5	*2%*
Surface Water Diversions (Nov - Feb)				
EBID	0.0	0.0	0.0	*0%*
EPCWID (incl. EPW)	14.3	16.2	1.8	*13%*
HCCRD	14.2	14.4	0.2	*2%*
Total	28.5	30.6	2.1	*7%*

Run 17 - Conj Use 2: Hist Proj Acres (Hist M&I)
Annual Differences in ILRG Model Outputs
Run 17 minus Run 1
1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1940	-53	-53	7	0	1	-3	-2	-2	3	3	1	1	-47	-22	-56
1941	-161	-161	1	-4	-2	-3	-4	-4	-1	0	-1	-4	39	69	15
1942	-32	-32	1	-3	0	0	0	0	3	8	0	-1	28	9	-24
1943	-64	-64	-5	-7	3	3	-14	-14	-13	-13	3	0	-23	-11	-51
1944	-81	-81	-143	-136	-73	-72	-5	-5	17	-1	-62	-64	-161	-154	-77
1945	2	2	-17,009	-5,529	1,397	918	-53	-53	-309	6,372	1,082	989	-10,931	-10,413	-16,332
1946	36	36	-10,387	-11,148	-392	-7,349	-110	-111	-718	3,359	-75	-239	-18,237	-17,651	-18,286
1947	56	56	-12,882	-6,764	698	-5,758	-15	-15	3,974	11,138	922	1,018	-10,315	-10,391	-19,245
1948	-731	-731	-10,605	-6,629	136	-4,668	443	446	-1,907	4,651	410	237	-9,038	-8,638	-10,948
1949	-1,761	-1,761	-20,135	-15,464	1,552	3,218	87	93	574	6,443	-292	-545	-21,157	-18,336	-19,823
1950	34	34	-22,030	-18,087	-9,742	-11,051	1,090	1,092	-2,643	2,575	239	421	-21,480	-18,949	-17,136
1951	1,030	1,030	-11,183	-5,661	-628	-2,813	1,865	1,866	-3,429	1,783	-195	-2,179	-12,503	-7,038	-11,101
1952	1,131	1,131	-10,202	-6,873	-840	-2,131	5,988	5,984	-2,937	55	-2,250	534	-33,323	-17,725	-10,510
1953	387	387	-14,992	-11,598	-831	-1,994	4,103	4,101	-2,469	512	-1,235	636	-12,609	-8,862	-15,405
1954	32,647	32,647	13,668	15,715	-601	655	20,961	20,961	24,601	25,602	341	1,572	37,156	27,455	-10,091
1955	29,822	29,822	18,441	19,808	2,654	2,913	15,997	15,997	20,866	20,792	2,878	3,108	34,917	25,155	474
1956	7,900	7,900	7,772	7,928	1,288	1,255	-347	-347	3,666	3,545	1,017	846	8,703	8,292	-25
1957	35	35	-697	169	457	391	226	226	607	544	574	435	-4,879	608	-2
1958	-38	-38	-4,528	-4,067	456	1,873	1,977	1,977	-112	-206	-83	-68	-37,931	-2,324	1,570
1959	-1	-1	-11,806	-11,047	783	2,240	1,713	1,713	-647	-389	6	23	-27,509	-10,021	2,161
1960	10	10	-10,956	-10,145	-495	-584	1,633	1,633	-1,459	-829	0	0	-22,995	-10,388	-473
1961	9	9	-406	1,053	715	1,027	1,578	1,579	1,116	2,320	661	-446	-9,699	353	2,311
1962	24	24	-14,159	-12,401	-2,058	-2,097	1,652	1,653	-1,520	-197	17	-306	-27,690	-14,796	-1,450
1963	8,883	8,883	-6,126	-3,827	-1,228	-1,423	6,384	6,385	-966	906	-486	-485	-3,356	3,567	-1,084
1964	32,095	32,095	10,297	11,602	427	1,292	26,437	26,437	20,253	20,886	1,432	1,363	21,471	19,095	-3,500
1965	39,578	39,578	15,846	15,836	3,136	3,537	21,668	21,668	18,431	18,382	2,607	3,028	23,229	24,537	1,369
1966	1,316	1,316	17,465	19,815	9,730	10,903	-8,659	-8,659	15,537	16,654	-2,495	-2,851	-7,166	25,577	16,069
1967	23,405	23,405	8,722	10,525	2,502	3,634	13,029	13,029	11,334	11,497	1,984	1,998	16,387	12,407	1,414
1968	10,724	10,724	661	2,487	2,693	2,114	9,434	9,434	1,929	1,650	2,665	2,209	-5,852	7,439	1,152
1969	-34	-34	-17,854	-16,949	-8,961	-7,873	1,927	1,927	-268	73	-8,329	-6,852	-33,641	-16,532	-868
1970	-18	-18	-22,589	-21,352	-7,268	-6,453	1,276	1,276	-1,434	-583	100	4,592	-36,576	-22,740	-9,632
1971	53,002	53,002	27,446	29,994	9,350	9,209	20,679	20,679	16,667	18,077	7,697	7,820	46,234	40,940	5,372
1972	-5,536	-5,536	-12,267	-10,906	-711	357	-5,035	-5,035	-6,798	-6,345	-895	215	-26,595	-10,821	-917
1973	-68	-68	2,143	2,165	800	959	2,261	2,261	735	550	738	759	-11,345	2,948	32
1974	-53	-53	-9,412	-8,767	-4,002	-3,882	1,740	1,740	459	763	-3,542	-2,322	-19,860	-8,131	-1,527
1975	-206	-206	-18,674	-17,751	-12,501	-11,800	1,768	1,769	-570	51	-12,167	-12,058	-30,996	-16,774	708
1976	-15	-15	-18,687	-17,508	-17,167	-17,134	2,301	2,302	-814	-15	-2,355	3,911	-31,508	-19,194	-19,452
1977	77,828	77,828	24,370	27,562	9,162	10,572	37,684	37,684	14,809	16,595	8,543	10,358	51,789	37,961	1,995
1978	35,367	35,367	5,548	10,021	-2,418	-714	20,102	20,102	15,457	16,966	-2,118	-478	19,422	17,950	-1,016

Run 17 - Conj Use 2: Hist Proj Acres (Hist M&I)
Annual Differences in ILRG Model Outputs
Run 17 minus Run 1
1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1979	720	720	-7,256	-5,046	-2,338	-689	154	156	7,551	8,874	-2,200	-547	-36,132	-6,325	-22
1980	-14	-14	-24,317	-22,038	-4,584	-3,273	2,140	2,141	-243	1,641	-1,154	-407	-40,650	-24,511	-4,357
1981	-100	-100	-27,561	-24,583	-6,124	-6,578	2,618	2,618	-1,173	1,946	926	1,234	-43,512	-28,550	-7,465
1982	-50	-50	-29,001	-25,819	-4,172	-4,571	1,679	1,679	-1,741	1,835	-1,159	872	-44,793	-30,123	-6,181
1983	-40	-40	-28,876	-26,195	-11,283	-11,438	1,728	1,729	-2,403	625	0	0	-44,345	-30,437	-11,899
1984	-147	-147	-26,551	-24,114	-16,732	-17,020	2,090	2,094	-1,309	1,952	356	356	-31,756	-20,359	-16,617
1985	-316	-316	-28,709	-26,291	-6,336	-5,902	-138	-131	-1,355	1,668	0	0	104,758	108,717	70,535
1986	-113	-113	-41,920	-40,555	-5,674	-4,222	2,612	2,631	-1,899	-123	0	0	87,161	102,665	82,595
1987	-514	-514	-52,256	-49,488	-7,438	-6,591	2,677	2,688	-713	3,425	0	0	-219	9,749	-5,380
1988	-101	-101	-50,254	-46,902	-6,789	-6,293	2,199	2,206	-4,720	-7	0	0	-57,573	-40,326	-32,309
1989	4	4	-43,683	-39,058	-12,023	-12,608	2,015	2,019	-5,771	522	0	0	-54,203	-41,928	-29,445
1990	961	961	14,044	18,123	-2,040	-2,064	-5,780	-5,777	18,301	24,124	0	0	-27,521	-8,001	-16,961
1991	856	856	-39,780	-36,102	-15,108	-15,226	3,181	3,185	-7,905	-2,174	0	0	-45,547	-37,642	-26,808
1992	3,062	3,062	36,945	39,809	29,516	30,312	-8,096	-8,102	31,444	36,066	0	0	121,075	136,620	111,402
1993	468	468	-51,861	-47,677	-8,035	-8,202	3,272	3,274	-8,774	-2,150	0	0	-5,948	612	10,538
1994	393	393	-36,337	-33,145	-3,005	-2,818	2,606	2,616	240	5,238	0	0	11,521	22,670	19,668
1995	892	892	-32,246	-28,358	-656	-789	2,797	2,800	1,936	8,295	0	0	18,098	29,893	22,099
1996	-78	-78	-45,928	-43,282	-5,735	-4,932	2,578	2,578	-5,626	-1,471	0	0	-71,383	-51,045	-36,621
1997	3	3	-32,585	-29,901	-9,926	-10,992	2,248	2,253	-7,355	-2,249	0	0	-38,880	-28,214	-21,758
1998	-49	-49	-31,635	-29,490	-498	-1,434	2,834	2,839	-1,921	1,618	0	0	-18,158	-4,363	-8,080
1999	-1,301	-1,301	-49,705	-48,648	26,570	26,035	-8,610	-8,609	-18,835	-17,311	0	0	-6,139	10,833	24,095
2000	-392	-392	-19,739	-19,814	4,962	4,638	-5,373	-5,372	-2,994	-3,013	0	0	-31,962	-11,492	-8,533
2001	288	288	-15,654	-15,845	-2,558	-2,321	2,249	2,250	8,968	8,961	0	0	-20,922	-15,075	-20,505
2002	-55	-55	-27,797	-27,738	-1,556	-604	2,506	2,507	33	36	0	0	-38,045	-24,673	-24,785
2003	111,630	111,630	17,543	17,830	11,433	12,637	62,374	62,375	18,816	18,841	0	0	76,621	52,295	15,104
2004	39,350	39,350	-22,973	-21,780	-524	1,645	28,483	28,484	1,453	1,476	0	0	-26,544	-7,097	-6,046
2005	2,705	2,705	-12,787	-12,447	-5,869	-4,916	7,702	7,700	7,078	7,082	0	0	-40,544	-10,601	-11,648
2006	76,905	76,905	-11,188	-10,660	2,202	3,849	51,465	51,466	4,622	4,640	0	0	27,754	8,595	-697
2007	158,420	158,420	-15,535	-14,441	-7,290	-5,990	102,912	102,912	4,731	4,775	0	0	28,136	-195	-4,396
2008	178,407	178,407	-24,607	-23,296	-13,732	-12,149	115,244	115,280	-1,947	-1,863	0	0	42,673	4,780	4,570
2009	135,714	135,714	-46,367	-44,647	-5,779	-4,527	89,666	89,685	-14,269	-14,194	0	0	-20,593	-2,403	9,175
2010	219,126	219,126	-30,915	-28,893	-12,254	-11,324	143,121	143,170	-7,016	-6,917	0	0	50,294	13,025	17,032
2011	86,936	86,936	-91,647	-89,526	-36,700	-38,784	39,196	39,198	-53,613	-53,562	-12,017	-11,731	-112,225	-87,508	-10,096
2012	98,153	98,153	16,038	16,264	-4,991	-8,345	47,721	47,721	17,875	18,105	4,724	5,334	58,728	16,350	-14,678
2013	-33,792	-33,792	-44,407	-44,281	-9,331	-8,590	-20,918	-20,918	-30,121	-30,113	-5,157	-5,434	-96,363	-48,020	-8,623
2014	82,432	82,432	11,922	11,921	913	699	36,002	36,002	12,599	12,604	566	598	94,518	11,604	-6,240
2015	124,873	124,873	-35,076	-34,741	-4,921	-6,042	61,106	61,106	-17,754	-17,741	1,174	1,069	10,810	-44,930	-16,968
2016	112,054	112,054	-66,285	-65,618	-10,938	-12,714	59,036	59,036	-39,303	-39,281	0	0	-59,769	-67,772	-32,494
2017	305,878	305,878	-15,093	-13,293	-913	-1,268	183,213	183,249	-3,972	-3,898	-165	-170	110,258	6,113	453
Averages															
1951-2017	30,633	30,633	-16,361	-14,536	-2,773	-2,528	18,401	18,404	537	2,208	-284	98	-4,598	-718	-818
1951-1978	12,472	12,472	-1,149	565	-556	-213	7,512	7,512	5,109	6,059	-175	549	-4,883	3,176	-1,872
1979-2005	5,854	5,854	-26,329	-24,021	-2,464	-2,156	4,250	4,253	781	3,916	-120	56	-11,316	1,974	2,245
2006-2017	128,759	128,759	-29,430	-28,434	-8,645	-8,765	75,647	75,659	-10,681	-10,620	-906	-861	11,185	-15,863	-5,247
1985-2017	51,600	51,600	-27,893	-26,120	-3,789	-3,631	30,670	30,676	-3,266	-1,169	-330	-313	2,117	98	1,339
1985-2005	7,509	7,509	-27,015	-24,798	-1,014	-698	4,968	4,972	971	4,231	0	0	-3,064	9,219	5,103

Notes:

EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

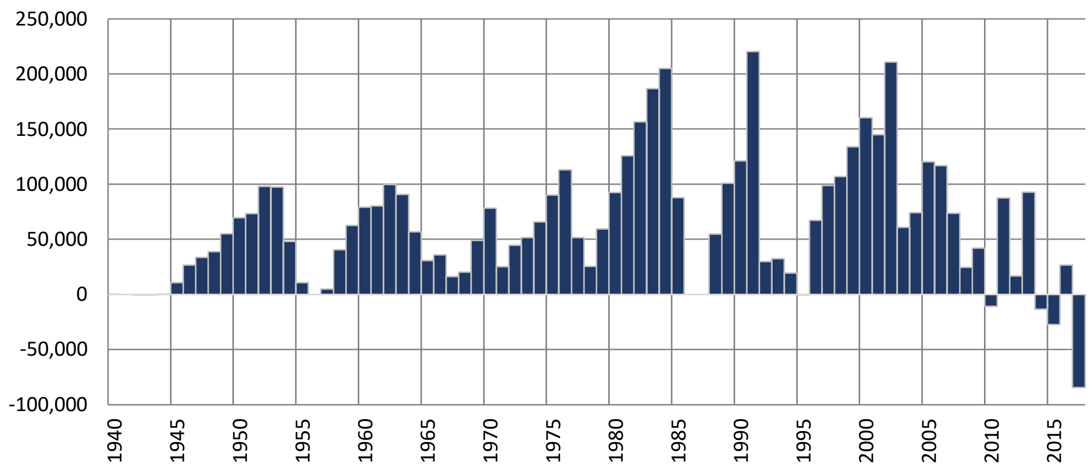
Run 17 - Conj Use 2: Hist Proj Acres (Hist M&I)

Simulated Differences in ILRG Model Outputs

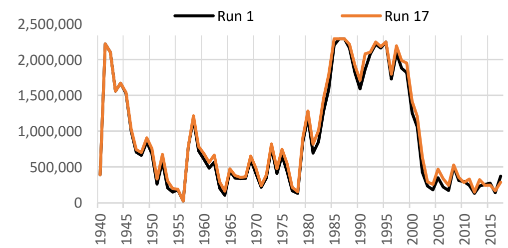
Run 17 minus Run 1

1940 - 2017 (acre-feet)

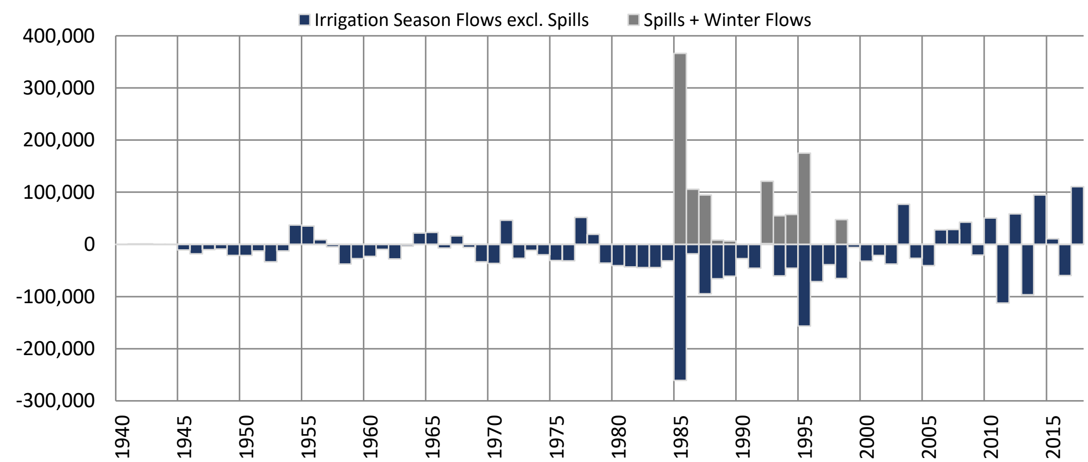
Total Project Storage (Year End)



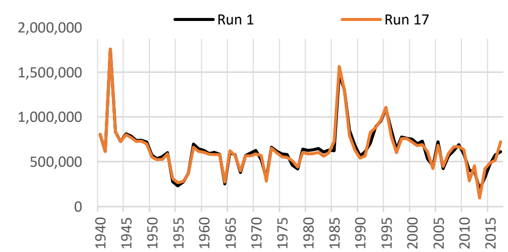
Period	Average Difference
1951-2017	-2,301
1951-1978	-1,580
1979-2005	3,516
2006-2017	-17,074
1985-2017	-8,772
1985-2005	-4,029



Caballo Reservoir Outflows (Annual)



	Average Difference		
Period	Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	-20,036	15,438	-4,598
1951-1978	-4,883	0	-4,883
1979-2005	-49,626	38,310	-11,316
2006-2017	11,185	0	11,185
1985-2017	-29,227	31,344	2,117
1985-2005	-52,320	49,255	-3,064



Notes:

Reservoir storage does not include storage attributed to SJC, CO, or NM credit waters.

Average differences calculated as (Final Storage - Initial Storage)/(no. years).

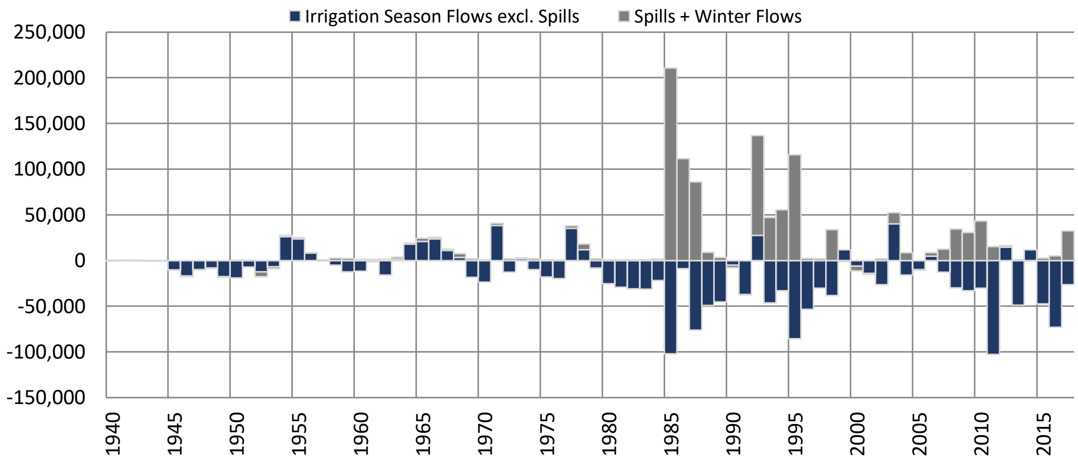
Run 17 - Conj Use 2: Hist Proj Acres (Hist M&I)

Simulated Differences in ILRG Model Outputs

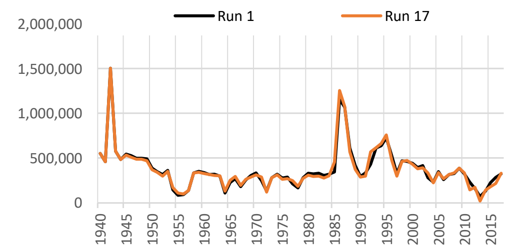
Run 17 minus Run 1

1940 - 2017 (acre-feet)

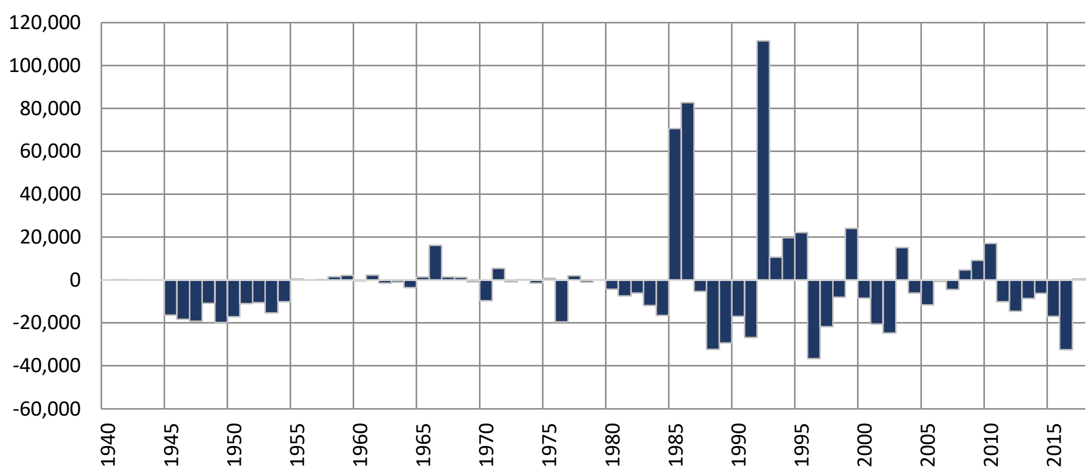
Rio Grande at El Paso (Annual)



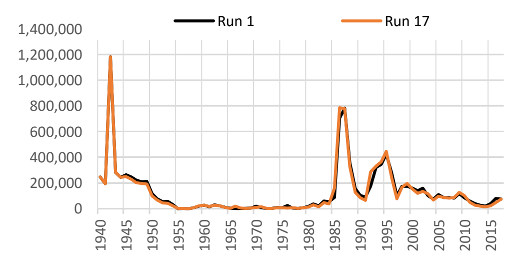
Period	Average Difference Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	-16,051	15,333	-718
1951-1978	1,763	1,414	3,176
1979-2005	-27,828	29,802	1,974
2006-2017	-31,118	15,255	-15,863
1985-2017	-29,625	29,723	98
1985-2005	-28,771	37,990	9,219



Rio Grande at Fort Quitman (Annual)



Period	Average Difference
1951-2017	-817
1951-1978	-1,875
1979-2005	2,248
2006-2017	-5,243
1985-2017	1,342
1985-2005	5,105



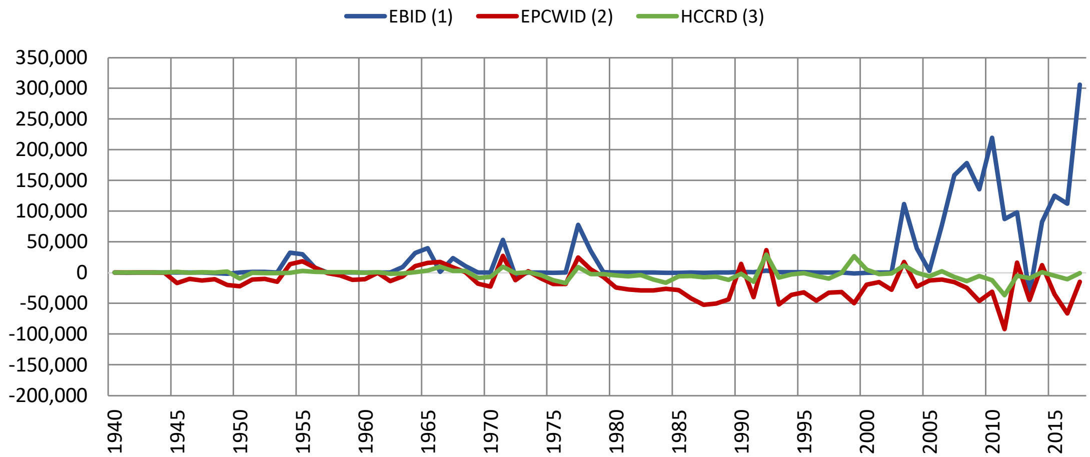
Run 17 - Conj Use 2: Hist Proj Acres (Hist M&I)

Simulated Differences in ILRG Model Outputs

Run 17 minus Run 1

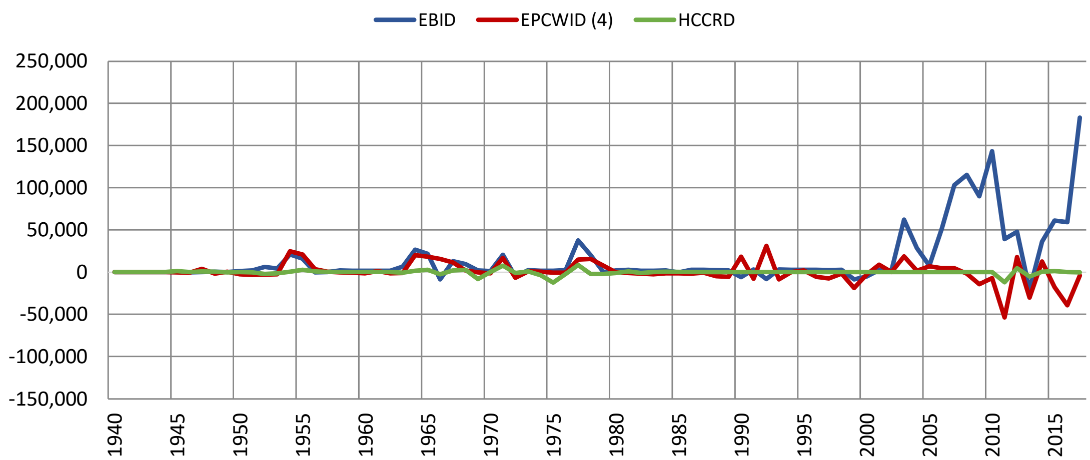
1940 - 2017 (acre-feet)

River Headgate (RHG) Diversions (Irrigation Season)



	Average Difference		
Period	EBID	EPCWID	HCCRD
1951-2017	30,633	-16,361	-2,773
1951-1978	12,472	-1,149	-556
1979-2005	5,854	-26,329	-2,464
2006-2017	128,759	-29,430	-8,645
1985-2017	51,600	-27,893	-3,789
1985-2005	7,509	-27,015	-1,014

Farm Headgate (FHG) Deliveries (Irrigation Season)



	Average Difference		
Period	EBID	EPCWID	HCCRD
1951-2017	18,401	537	-284
1951-1978	7,512	5,109	-175
1979-2005	4,250	781	-120
2006-2017	75,647	-10,681	-906
1985-2017	30,670	-3,266	-330
1985-2005	4,968	971	0

Notes:

(1) EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

(2) EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

(3) HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

(4) EPCWID FHG values include deliveries to Rogers WTP and R/U WTP.

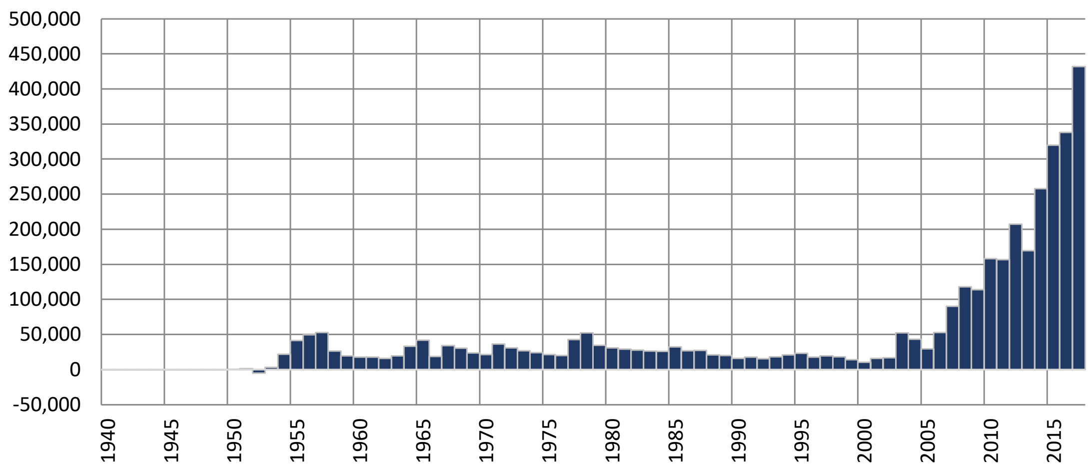
Run 17 - Conj Use 2: Hist Proj Acres (Hist M&I)

Simulated Differences in ILRG Model Outputs

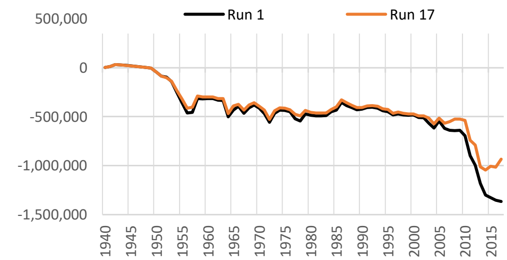
Run 17 minus Run 1

1940 - 2017 (acre-feet)

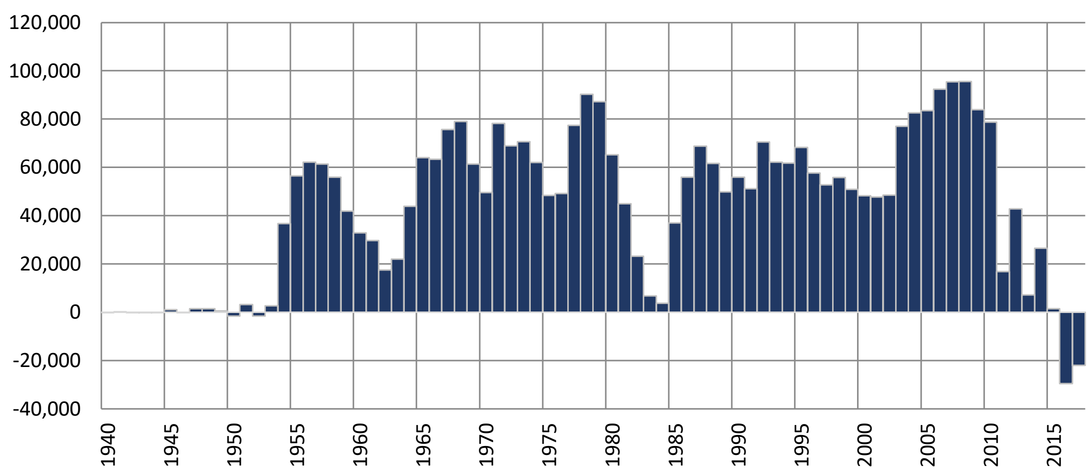
Cumulative Annual Rincon-Mesilla Groundwater Storage



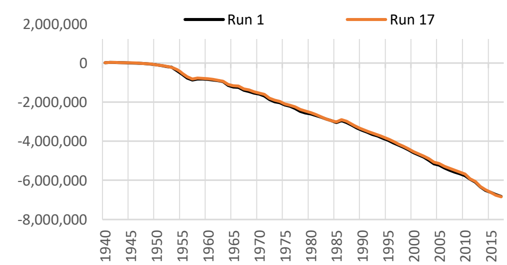
Period	Average Difference
1951-2017	6,444
1951-1978	1,862
1979-2005	-846
2006-2017	33,537
1985-2017	12,308
1985-2005	177



Cumulative Annual Hueco Groundwater Storage



Period	Average Difference
1951-2017	-304
1951-1978	3,286
1979-2005	-251
2006-2017	-8,796
1985-2017	-780
1985-2005	3,800



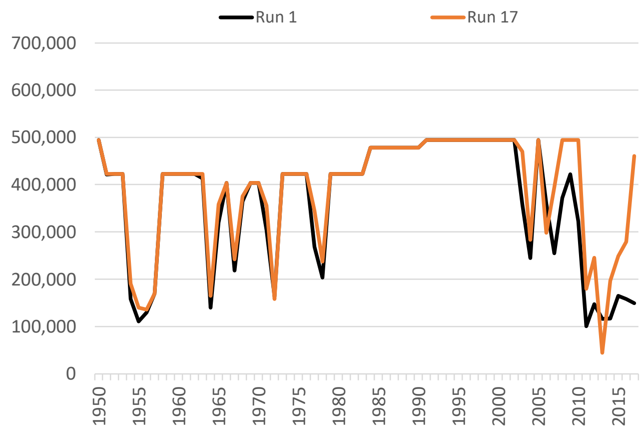
Notes:

Cumulative storage change in alluvial and non-alluvial aquifers.

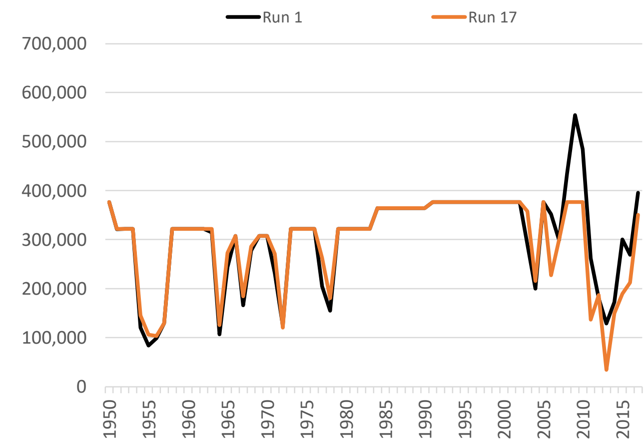
Average differences calculated as (Final Storage - Initial Storage)/(no. years).

Run 17 - Conj Use 2: Hist Proj Acres (Hist M&I)
Annual Allocation and Charges
Run 17 v. Run 1
ILRG Model
1950 - 2017 (acre-feet)

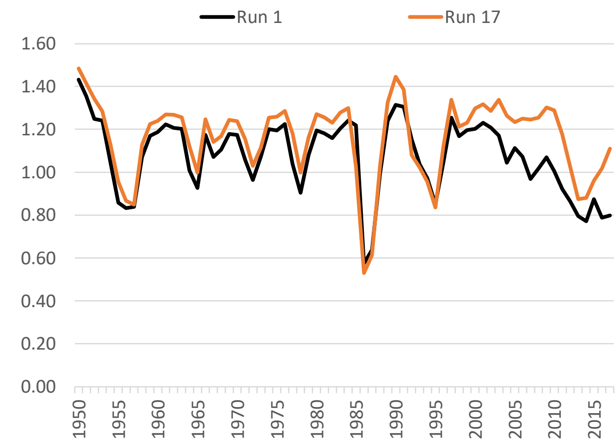
Total Allocation - EBID



Total Allocation - EPCWID

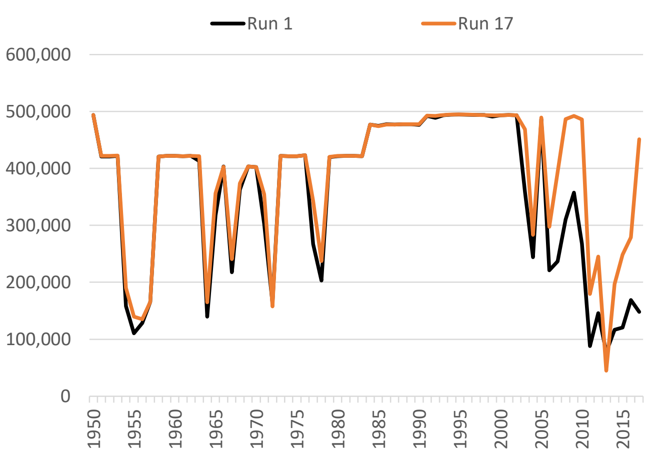


Diversion Ratio

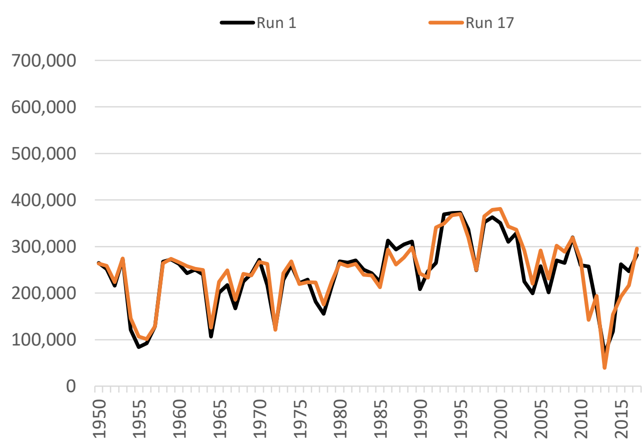


Note:
Computed as Total Charges/Caballo Release.

Annual Delivery Charges - EBID



Annual Delivery Charges - EPCWID



Run 17 - Conj Use 2: Hist Proj Acres (Hist M&I)

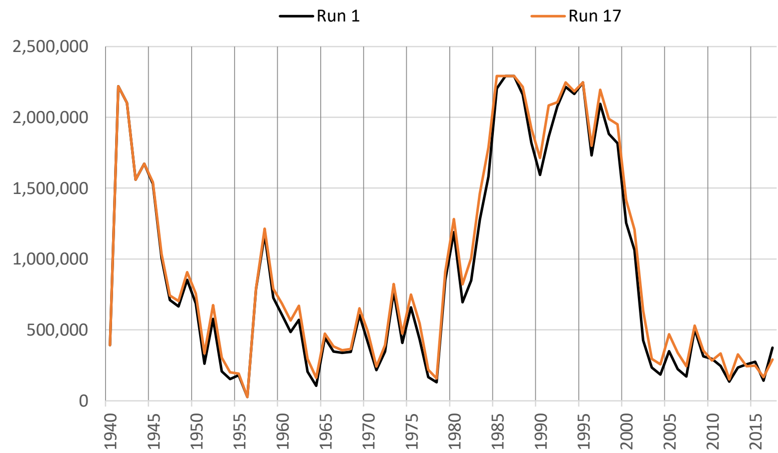
Annual Summary of Project Storage and Rio Grande Flows

Run 17 v. Run 1

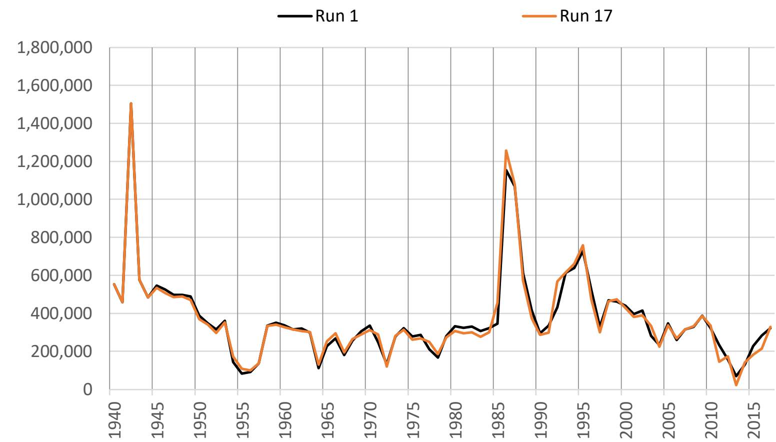
ILRG Model

1940 - 2017 (acre-feet)

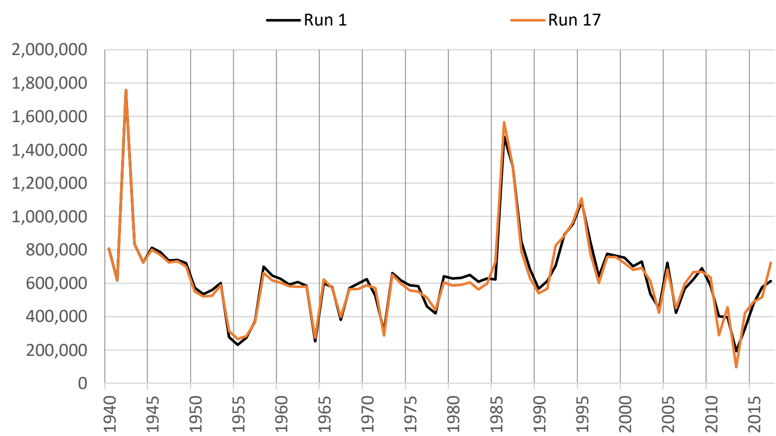
Total Year-End Project Reservoir Storage



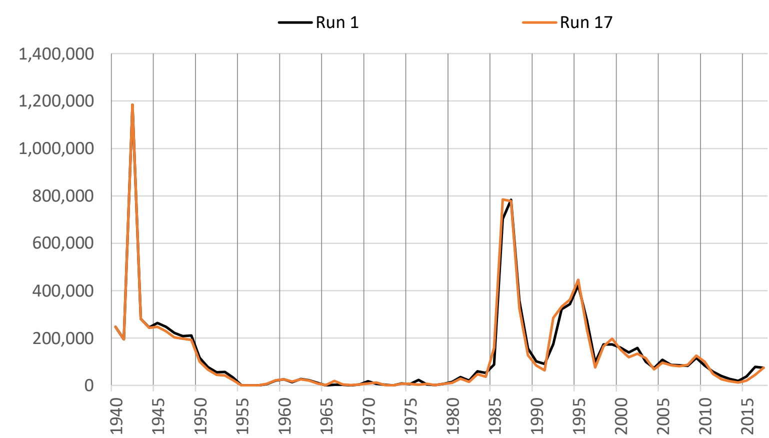
Rio Grande at El Paso



Rio Grande Below Caballo



Rio Grande at Fort Quitman

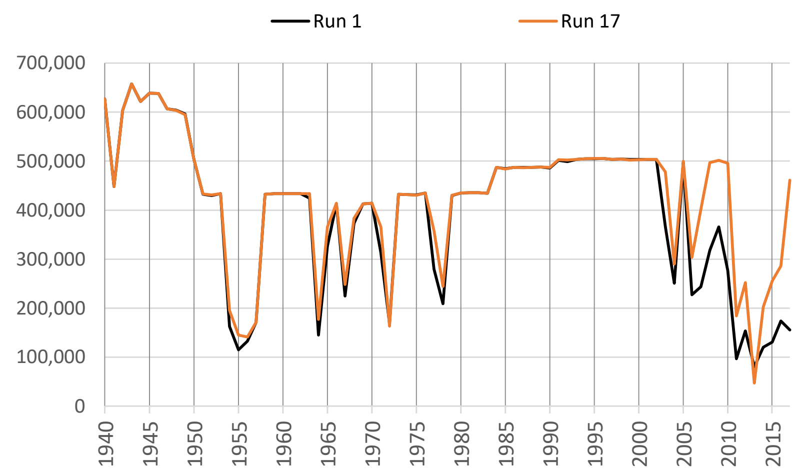


***Note different scales.**

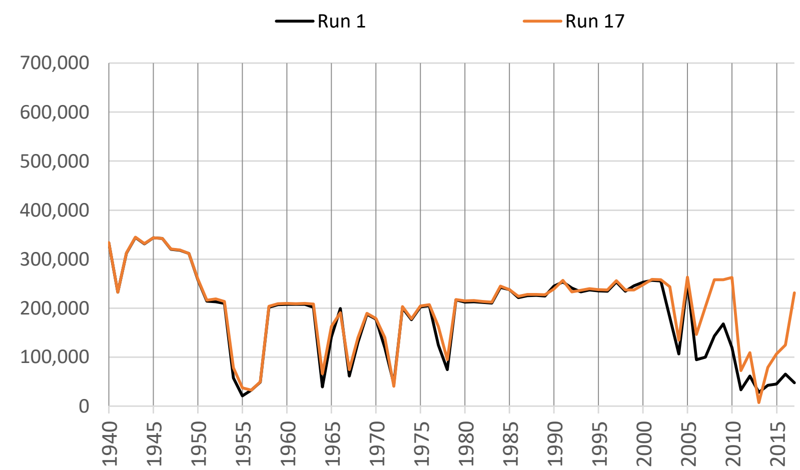
Run 17 - Conj Use 2: Hist Proj Acres (Hist M&I)
Irrigation Season Summary of Irrigation Operations
Run 17 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

EBID Total

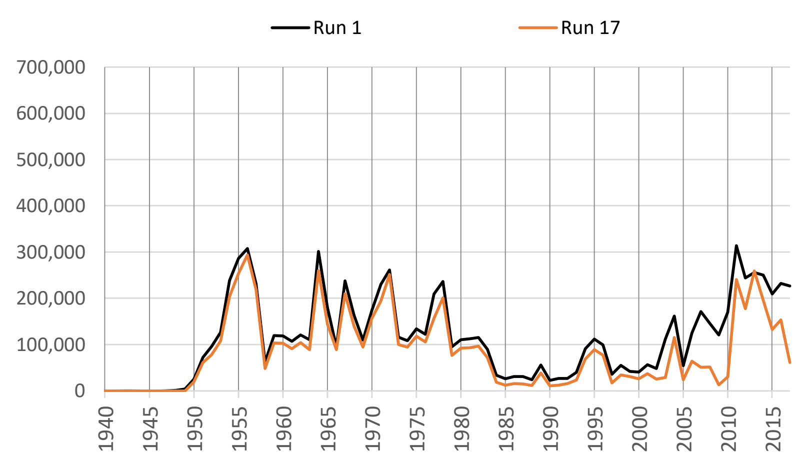
Net River Headgate Diversions



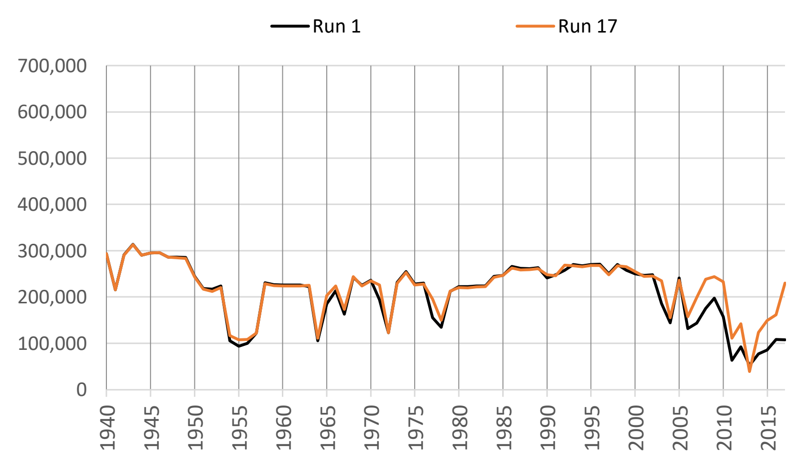
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries

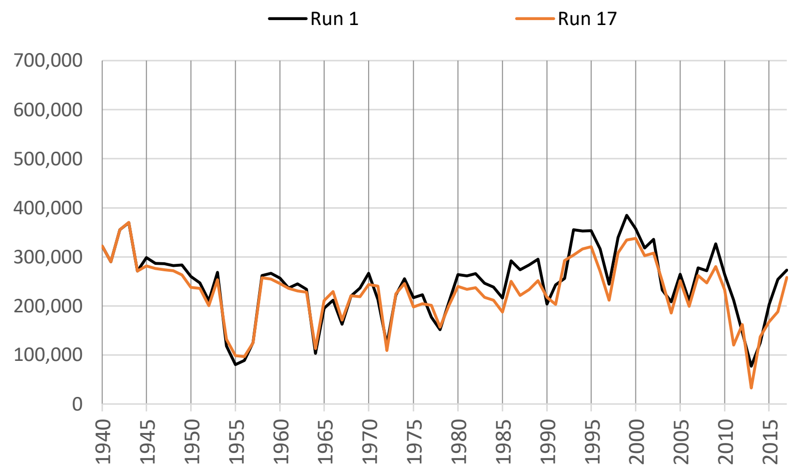


Notes: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).
Pumping includes Supplemental and Primary groundwater pumping.

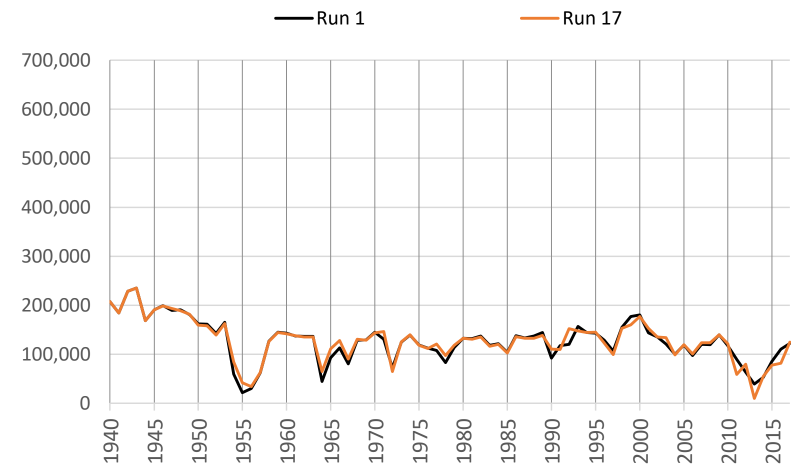
Run 17 - Conj Use 2: Hist Proj Acres (Hist M&I)
Irrigation Season Summary of Irrigation Operations
Run 17 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

EPCWID Total

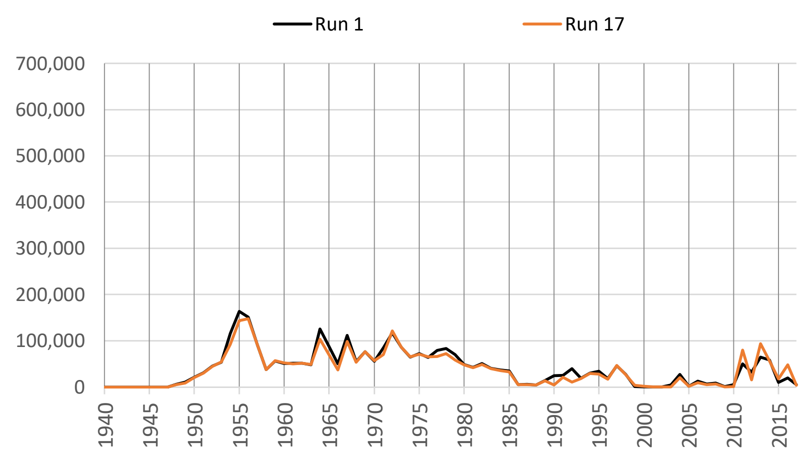
Net River Headgate Diversions



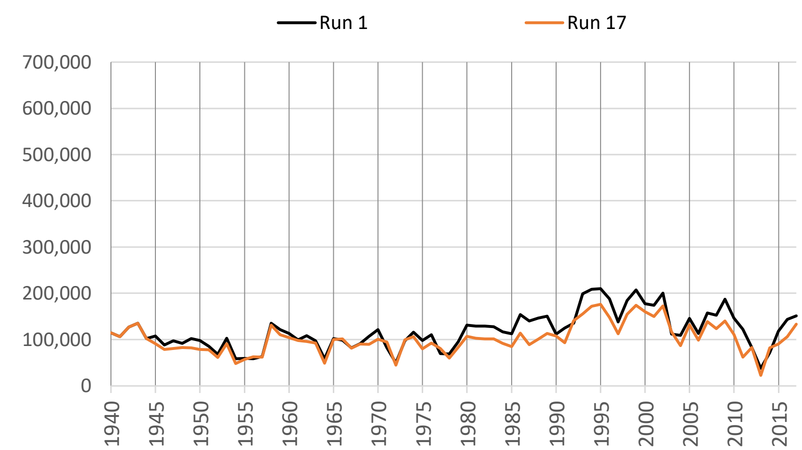
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries

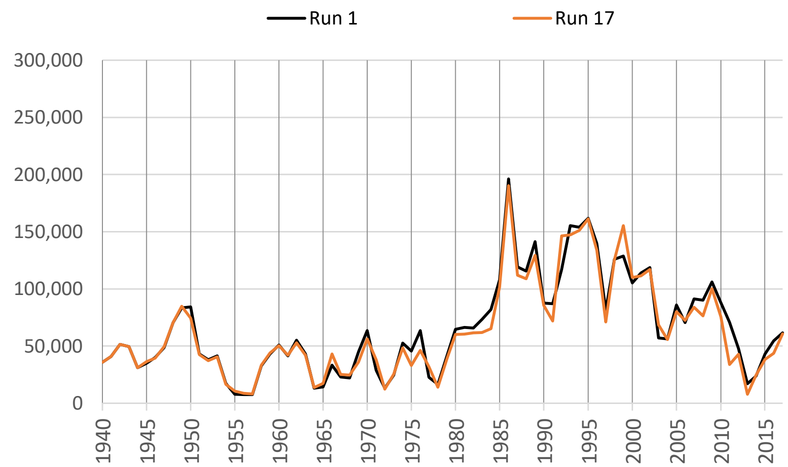


Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

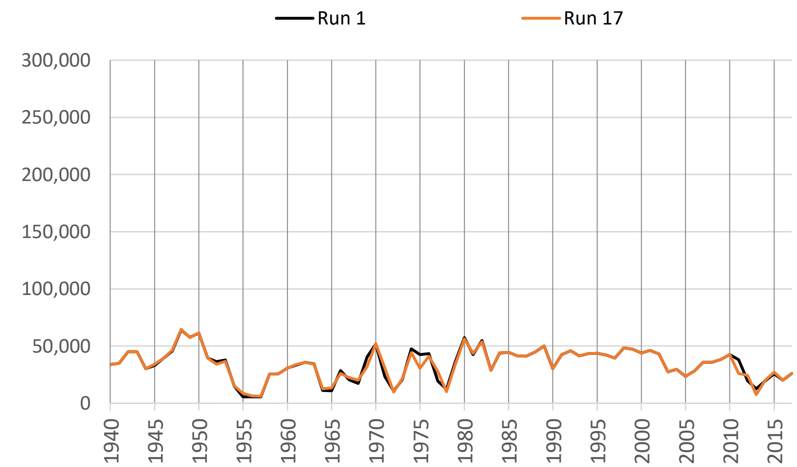
Run 17 - Conj Use 2: Hist Proj Acres (Hist M&I)
Irrigation Season Summary of Irrigation Operations
Run 17 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

HCCRD Total

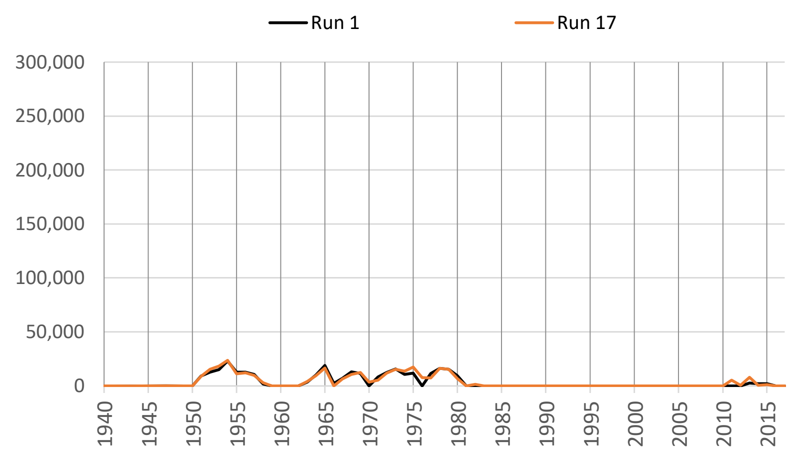
Net River Headgate Diversions



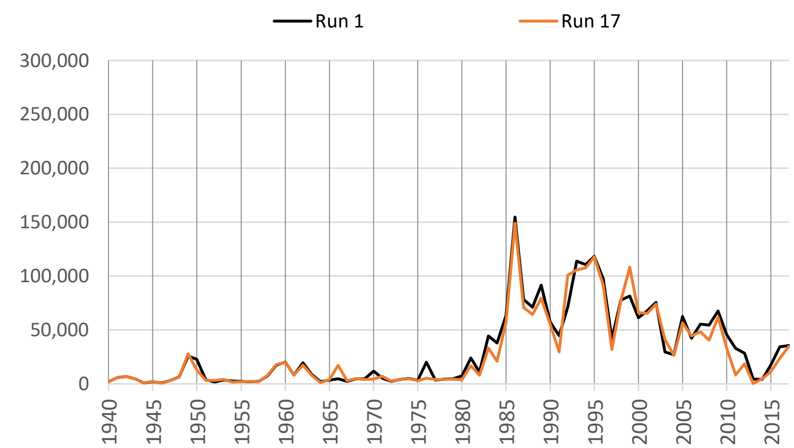
Farm Headgate Deliveries



Pumping



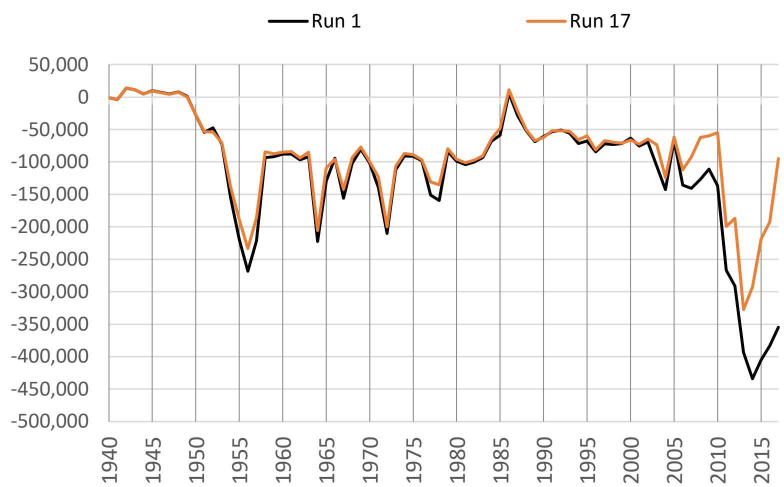
RHG Diversions - FHG Deliveries



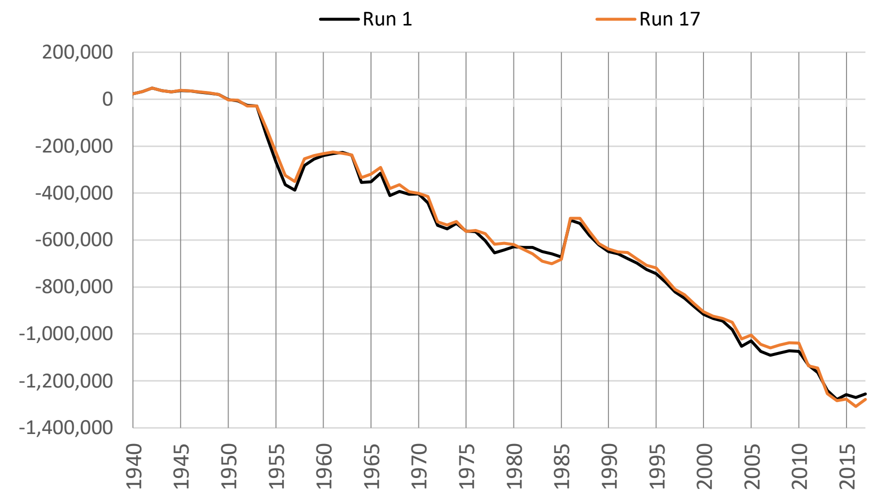
Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

Run 17 - Conj Use 2: Hist Proj Acres (Hist M&I)
Cumulative Change in Ground Water Storage
Run 17 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

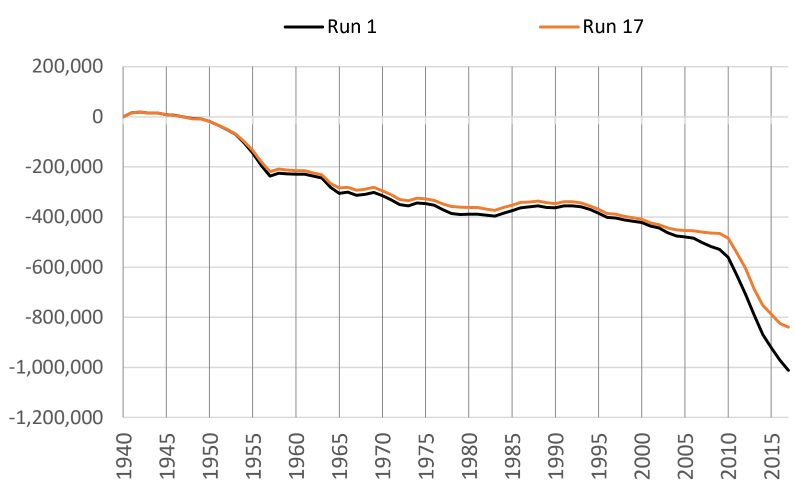
Rincon-Mesilla Alluvial Aquifer



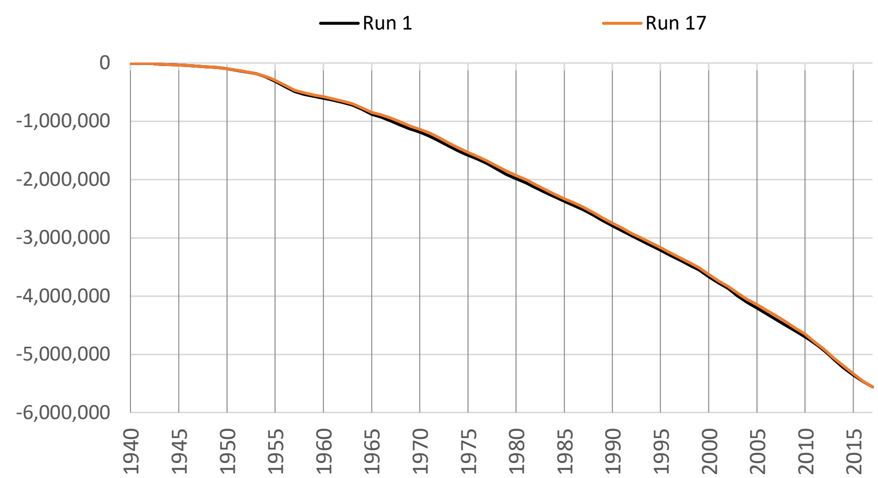
Hueco Alluvial Aquifer



Rincon-Mesilla Non-Alluvial Aquifer

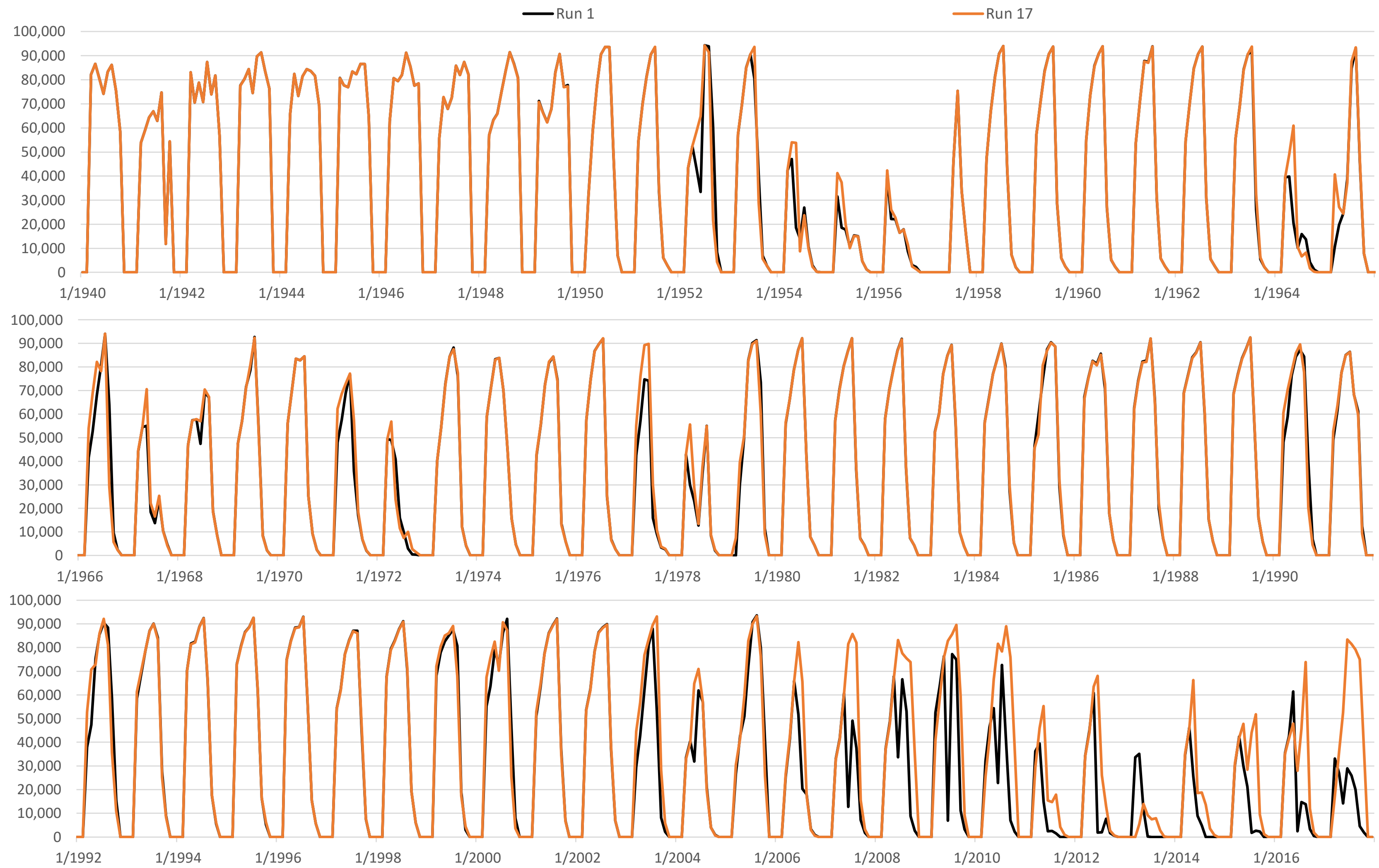


Hueco Non-Alluvial Aquifer



***Note different scales.**

Run 17 - Conj Use 2: Hist Proj Acres (Hist M&I)
Monthly Net RHG Diversions
Run 17 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
EBID Total

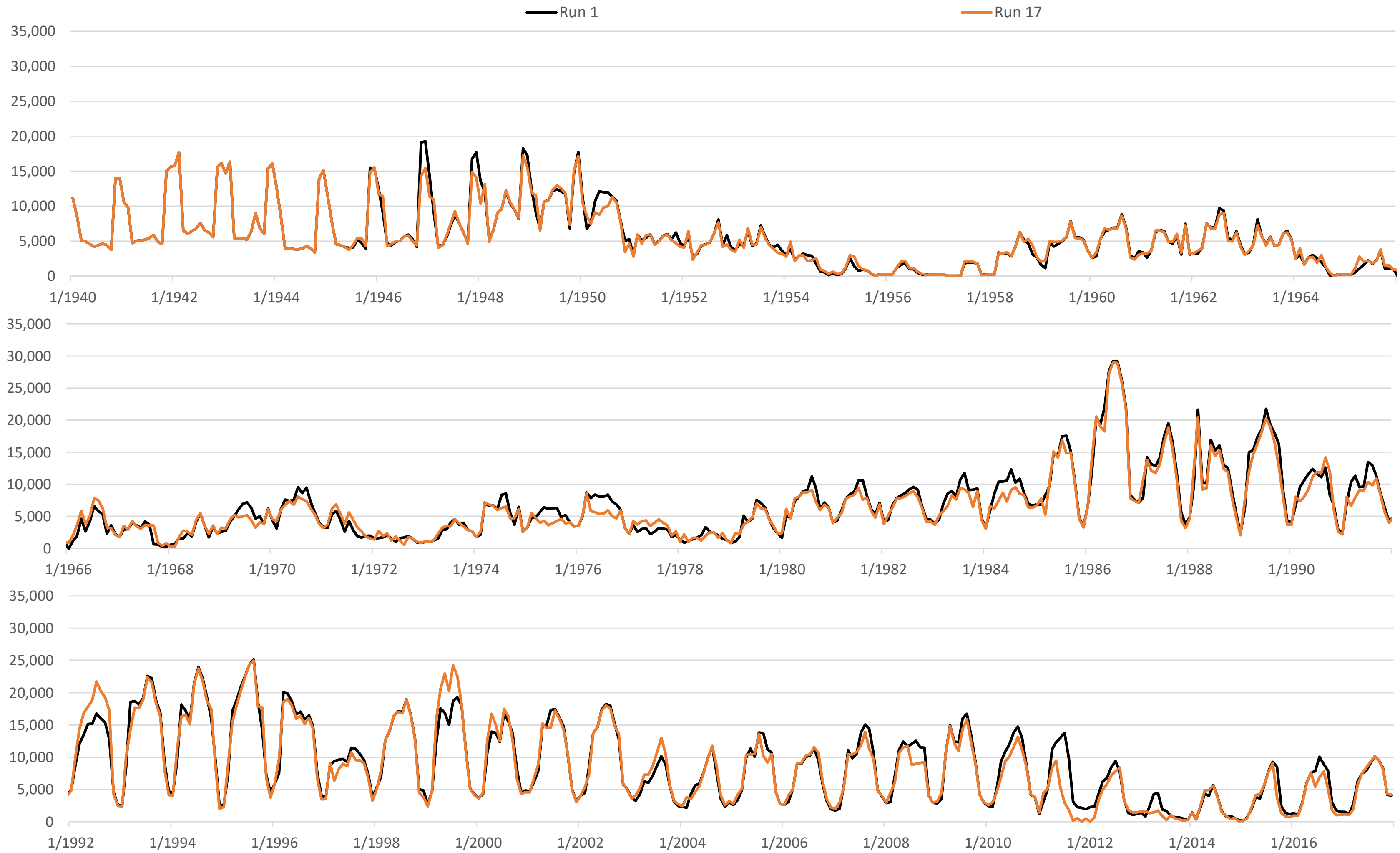


Note: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

Run 17 - Conj Use 2: Hist Proj Acres (Hist M&I)
Monthly Net RHG Diversions
Run 17 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
EPCWID Total

Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

Run 17 - Conj Use 2: Hist Proj Acres (Hist M&I)
Monthly Net RHG Diversions
Run 17 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
HCCRD Total



Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

Run 17 - Conj Use 2: Hist Proj Acres (Hist M&I)

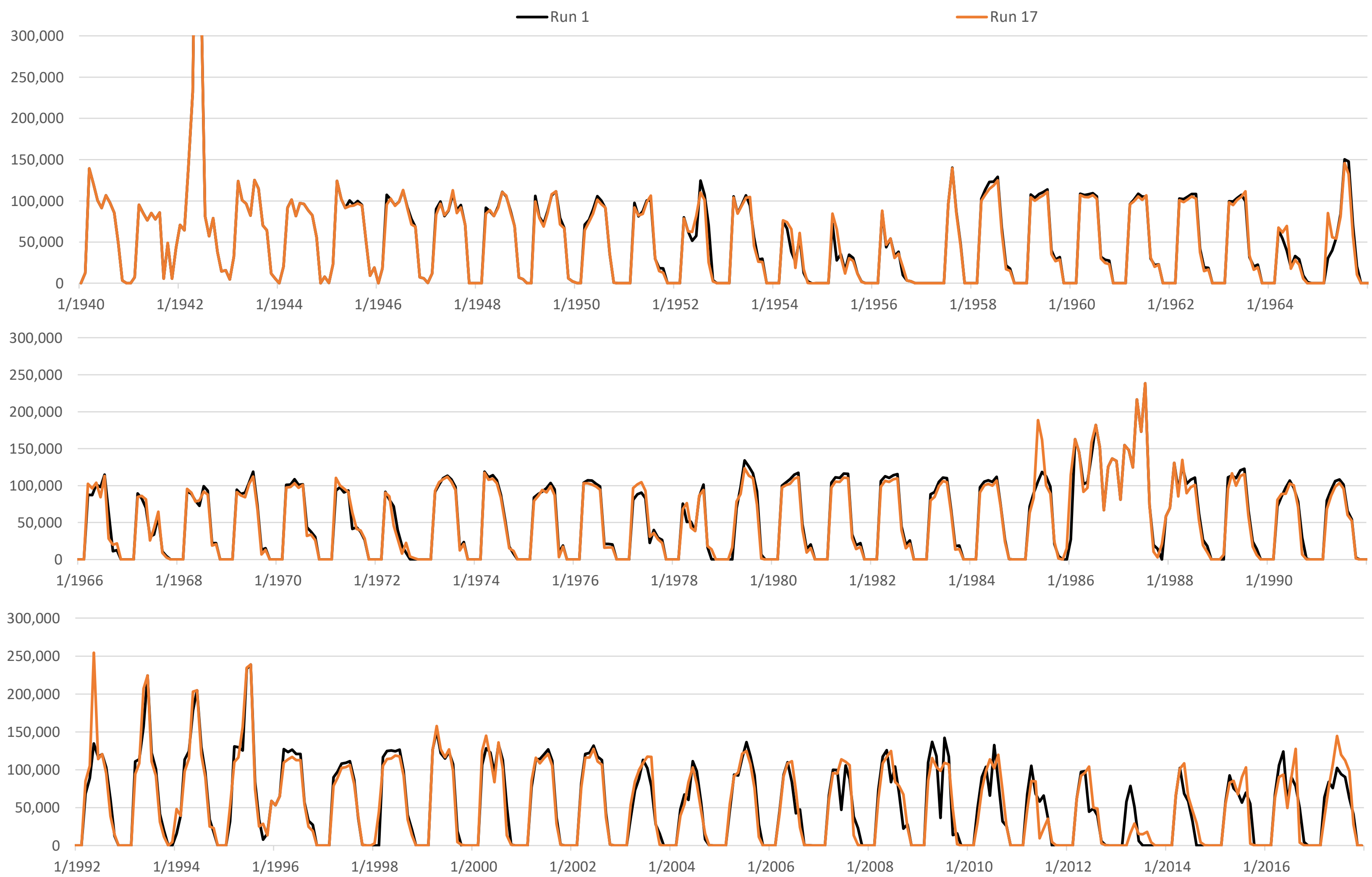
End of Month Reservoir Storage (Elephant Butte + Caballo)

Run 17 v. Run 1

ILRG Model

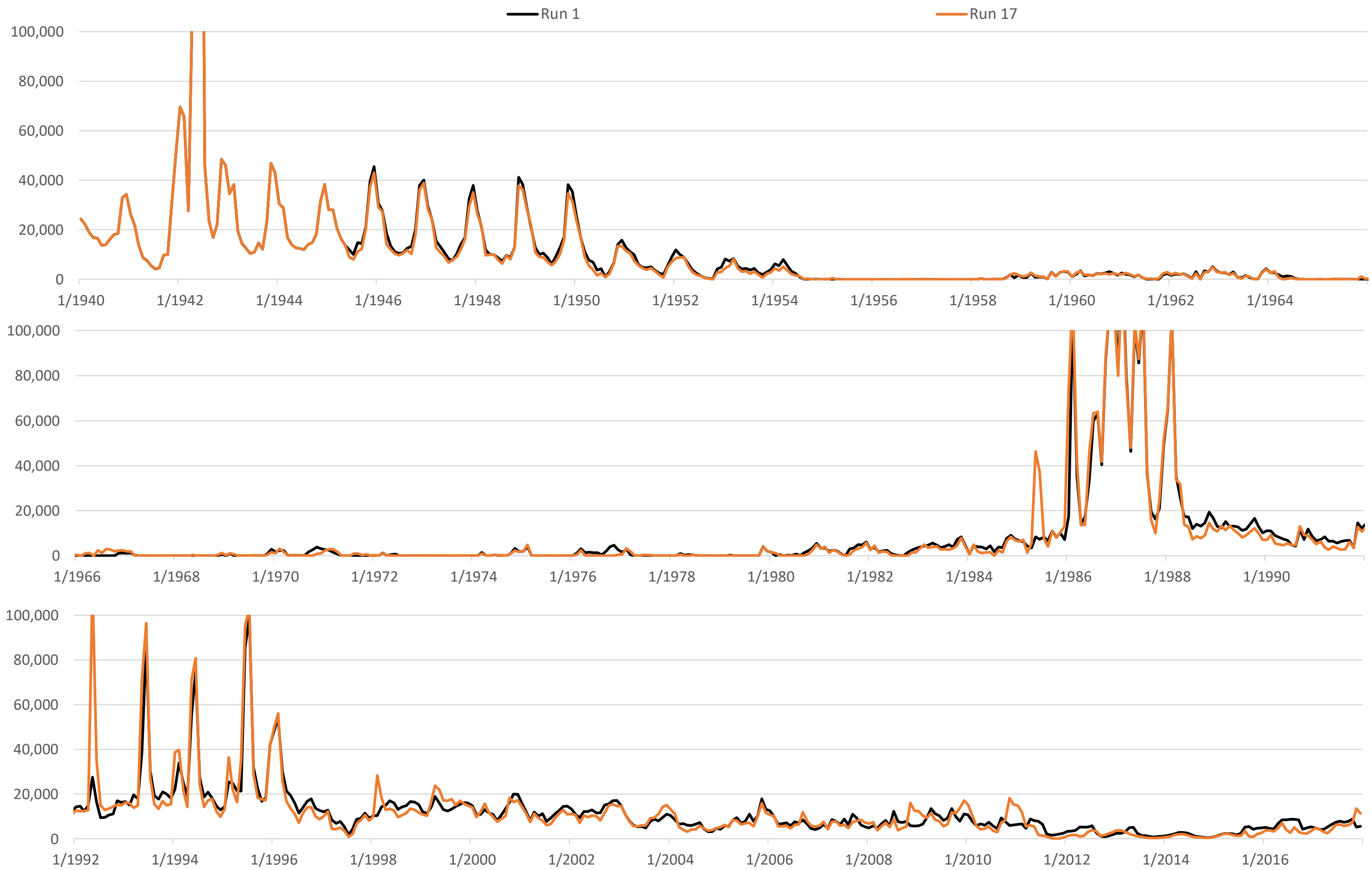
1940 - 2017 (acre-feet)

Run 17 - Conj Use 2: Hist Proj Acres (Hist M&I)
Monthly Caballo Releases
Run 17 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)



Run 17 - Conj Use 2: Hist Proj Acres (Hist M&I)
Monthly Rio Grande at El Paso Flow
Run 17 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

Run 17 - Conj Use 2: Hist Proj Acres (Hist M&I)
Monthly Rio Grande at Fort Quitman Flow
Run 17 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)



Appendix 30Z

Comparison of ILRG Model Runs
Run 17a v. Run 1

Model Run Specifications

Model Version: LRG_v116

Name: **Run 17a - Conj Use 2a: Hist Proj Acres (Pre-Comp M&**

Run ID: LRG_v116_Operational_Run17a
Date: 8/31/2020

Name: **Run 1 - Historical Base Run (All Pumping On)**

Run ID: LRG_v116_Operational_Run1
Date: 8/23/2020

Selected Model Inputs

	Pumping and Returns	Run 17a	Run 1
(1)	Irrigation Pumping	Conj	On
(2)	Irrigated Area	Project	Hist
(3)	Non-Irrigation Pumping	Pre-Comp	On
	Non-Irrigation Pumping Returns	Pre-Comp	On
	Las Cruces Jornada Pumping Returns	Off	On

Project Allocation Rules		
1950-2005	D1/D2	D1/D2
2006-2007	D1/D2	D3
2008-2017	D1/D2	D3 + CO

	EPCWID Operations		
	Charge EPCWID for Use of WWTP Returns	On	Off
	ACE and Haskell Credits for EPCWID	Off	On
(4)	Increased EPCWID Use of Fabens Drain Flows	On	Off
	Charge EPCWID for Fabens Drain Flow Use	On	Off

Notes:
(1) Conjunctive use pumping on historical Project acres; no pumping on NM GW only acres.
(2) Project acres set to historical. New Mexico groundwater only acres set to 0.
(3) Limit M&I pumping to pre-compact levels. Reduce corresponding return flows.
(4) Starting in July 1945, use 70% of simulated Fabens drain flow up to 6,000 AF/month.

Run 17a - Conj Use 2a: Hist Proj Acres (Pre-Comp M&I)
Comparison of ILRG Model Runs
Run 17a v. Run 1
1951 - 2017 Annual Average
(1,000 acre-feet)

Run No.	1	17a	17a - 1	
Simulated Input or Output	**Run 1**	**Run 17a**	**Run 17a minus Run 1**	
Effects of Alternate Scenario				
FHG Deliveries (Mar - Oct)				***% Diff.***
EBID	167.6	190.7	23.0	*14%*
EPCWID (incl. EPW)	139.9	142.9	3.1	*2%*
HCCRD	32.8	33.5	0.6	*2%*
Total	340.3	367.1	26.7	*8%*
FHG Deliveries (Nov - Feb)				
EBID	0.0	0.0	0.0	*228%*
EPCWID (incl. EPW)	0.2	0.8	0.6	*317%*
HCCRD	2.4	2.5	0.1	*4%*
Total	2.6	3.3	0.7	*27%*
Irrigation Pumping				
EBID	140.4	102.0	-38.4	*-27%*
EPCWID (Mesilla Valley)	7.4	6.5	-0.8	*-11%*
EPCWID (El Paso Valley)	40.1	37.3	-2.8	*-7%*
HCCRD	4.2	3.5	-0.7	*-16%*
Total	192.1	149.5	-42.7	*-22%*
Other Inflows/Outflows				
Net Reservoir Evaporation	125.3	133.8	8.5	*7%*
Riparian ET	70.9	74.4	3.5	*5%*
River Evaporation + Incidental Canal Loss	30.3	30.9	0.6	*2%*
Total	226.6	239.2	12.6	*6%*
Rio Grande at Fort Quitman				
Reservoir Spills	33.3	44.4	11.1	*33%*
Nov-Feb Flows	21.4	23.7	2.3	*11%*
Mar - Oct Flows	41.1	38.7	-2.4	*-6%*
Underflow (GW Model)	0.2	0.2	0.0	*7%*
Total	96.0	107.0	11.0	*11%*

Run 17a - Conj Use 2a: Hist Proj Acres (Pre-Comp M&I)
Comparison of ILRG Model Runs
Run 17a v. Run 1
1951 - 2017 Annual Average
(1,000 acre-feet)

Run No.	1	17a	17a - 1	
Simulated Input or Output	**Run 1**	**Run 17a**	**Run 17a minus Run 1**	
Effects of Alternate Scenario (continued)				
Change in Storage				***% Diff.***
Reservoir Storage	-4.7	-6.0	-1.4	*29%*
Alluvial GW Storage (RW Model)	-23.6	-2.5	21.0	*-89%*
Non-alluvial GW Storage (GW Models)	-96.4	-23.5	72.8	*-76%*
Soil Moisture Storage	0.6	0.9	0.3	*46%*
Total	-124.0	-31.2	92.8	*-75%*
Summary of Effects				
FHG Deliveries (Mar-Oct)	340.3	367.1	26.7	*8%*
FHG Deliveries (Nov-Feb)	2.6	3.3	0.7	*27%*
Irrigation Pumping	192.1	149.5	-42.7	*-22%*
Riparian ET + Evaporation	226.6	239.2	12.6	*6%*
Fort Quitman Flow	96.0	107.0	11.0	*11%*
Change in Storage	-124.0	-31.2	92.8	*-75%*
Total	733.6	834.7	101.2	*14%*
Other Effects of Alternate Scenario				
Rio Grande at El Paso				***% Diff.***
Reservoir Spills	49.4	64.0	14.6	*30%*
Nov-Feb Flows	22.8	31.8	9.0	*40%*
Mar - Oct Flows	263.8	264.6	0.8	*0%*
Total	336.0	360.4	24.4	*7%*
Rio Grande below Caballo				
Reservoir Spills	65.9	81.6	15.7	*24%*
Nov-Feb Flows	0.5	0.4	-0.1	*-11%*
Mar - Oct Flows	541.3	518.6	-22.7	*-4%*
Total	607.6	600.5	-7.1	*-1%*
Surface Water Diversions (Mar - Oct)				
EBID	366.5	402.1	35.6	*10%*
EPCWID (incl. EPW)	236.8	230.0	-6.8	*-3%*
HCCRD	67.5	68.6	1.1	*2%*
Total	670.8	700.7	29.9	*4%*
Surface Water Diversions (Nov - Feb)				
EBID	0.0	0.0	0.0	*0%*
EPCWID (incl. EPW)	14.3	14.5	0.1	*1%*
HCCRD	14.2	14.2	0.0	*0%*
Total	28.5	28.6	0.1	*0%*

Run 17a - Conj Use 2a: Hist Proj Acres (Pre-Comp M&I)

Annual Differences in ILRG Model Outputs

Run 17a minus Run 1

1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1940	-54	-54	-7	9	16	26	-1	-1	-24	-25	0	0	-31	15	227
1941	-256	-256	36	624	50	251	-6	-5	1	115	30	41	59	109	884
1942	-107	-107	-89	-223	-60	-44	-3	-1	-60	-111	-13	-10	432	451	-336
1943	-169	-169	-20	-200	-56	-61	3	6	-2	-69	-52	-226	2,051	2,114	970
1944	-173	-173	-353	-369	-209	-192	-28	-24	191	153	-224	-318	-2,415	-2,169	311
1945	-108	-108	-17,272	-6,278	1,381	846	-58	-55	-214	6,280	1,033	946	-12,166	-11,390	-15,886
1946	-80	-80	-10,300	-11,454	-321	-7,209	-101	-97	-359	3,326	-74	-246	-18,519	-17,645	-17,661
1947	-54	-54	-12,948	-7,286	638	-5,841	-15	-8	4,500	11,403	837	936	-11,913	-11,555	-18,882
1948	-875	-875	-11,022	-7,341	-30	-4,811	434	445	-1,461	4,833	356	173	-12,471	-11,651	-11,066
1949	-1,928	-1,928	-20,447	-16,359	1,497	3,042	89	104	903	6,471	-290	-542	-22,928	-19,731	-19,653
1950	37	37	-22,020	-18,838	-9,737	-10,963	1,250	1,263	-2,236	2,323	249	439	-22,312	-19,350	-16,402
1951	1,032	1,032	-11,222	-6,165	-558	-2,653	1,996	2,007	-2,919	1,877	-173	-2,116	-12,942	-6,721	-10,185
1952	1,203	1,203	-10,262	-7,462	-689	-1,850	7,175	7,178	-2,656	-122	-1,981	820	-35,747	-16,512	-9,822
1953	247	247	-15,266	-12,637	-663	-1,729	4,399	4,403	-2,688	-352	-1,066	805	-14,715	-5,581	-14,132
1954	38,979	38,979	17,530	19,000	-281	945	26,049	26,049	26,999	27,848	551	1,904	45,082	38,047	-8,445
1955	29,659	29,659	18,867	19,263	3,109	3,304	16,038	16,038	20,426	20,212	3,171	3,596	32,942	30,491	740
1956	9,004	9,004	6,035	3,725	1,155	589	2,056	2,056	2,590	2,170	807	211	10,716	12,787	32
1957	-66	-66	-1,012	-1,079	846	466	291	291	-574	-811	865	428	-6,344	6,245	-1
1958	-304	-304	-2,983	-2,205	922	2,170	2,725	2,726	263	180	56	-141	-47,931	10,311	2,279
1959	-263	-263	-11,360	-10,743	894	2,173	2,493	2,494	-1,150	-1,135	-6	-22	-36,993	-1,712	2,302
1960	-274	-274	-12,776	-12,677	-115	-554	2,482	2,483	-1,995	-1,720	0	0	-30,487	-1,100	835
1961	-305	-305	-2,789	-2,484	1,077	1,313	2,496	2,497	237	758	880	-644	-17,908	10,224	4,477
1962	-309	-309	-15,058	-14,718	-882	-1,070	2,614	2,615	-1,831	-1,198	213	81	-34,580	-3,159	215
1963	8,494	8,494	-7,385	-6,334	-487	-618	7,521	7,522	-1,562	-503	-6	6	-10,602	18,254	1,542
1964	51,050	51,050	27,389	26,532	1,114	1,992	27,132	27,132	32,004	32,097	2,246	2,438	62,565	52,729	-1,192
1965	34,553	34,553	8,560	7,646	3,282	4,079	20,044	20,045	15,018	14,612	2,991	4,060	-5,139	35,806	2,593
1966	784	784	14,302	16,022	10,908	12,527	-7,308	-7,308	14,770	15,242	-2,873	-3,003	-25,853	38,358	19,584
1967	48,161	48,161	25,939	27,849	4,003	6,603	27,398	27,398	21,610	21,381	2,916	4,296	41,261	45,053	3,674
1968	15,588	15,588	5,300	7,652	5,608	7,780	15,116	15,117	702	331	5,652	6,944	-19,221	28,909	3,036
1969	-796	-796	-12,389	-11,717	-4,825	-3,318	4,007	4,008	407	429	-4,243	-3,561	-46,045	-459	1,292
1970	-432	-432	-17,269	-16,574	-2,718	-2,073	2,731	2,731	-1,364	-916	762	1,780	-43,063	-7,591	-2,654
1971	74,569	74,569	36,609	38,572	11,144	11,327	34,620	34,620	17,006	17,645	8,700	8,888	57,141	68,064	8,852
1972	7,107	7,107	-1,315	-372	-1,479	-1,650	1,349	1,349	-5,500	-5,556	-1,746	-2,318	-10,570	16,746	433
1973	-987	-987	14,942	14,516	4,521	2,633	4,575	4,576	1,412	1,182	4,418	2,695	-24,905	28,524	239
1974	-767	-767	1,840	2,515	750	425	4,038	4,040	649	943	-288	9	-30,029	16,103	1,699
1975	807	807	24,496	24,967	11,311	11,340	-8,813	-8,812	15,837	16,568	10,175	10,074	-11,791	37,356	3,195
1976	-257	-257	-7,100	-7,454	-11,441	-12,294	3,858	3,860	-918	-404	-297	-2,022	-30,188	-321	-8,560
1977	80,287	80,287	39,054	41,387	11,319	12,915	40,148	40,148	15,210	15,471	10,135	11,320	62,118	70,001	5,415
1978	31,035	31,035	10,890	13,781	1,484	4,125	19,206	19,206	10,118	10,146	2,456	3,084	14,608	41,694	1,367

Run 17a - Conj Use 2a: Hist Proj Acres (Pre-Comp M&I)
Annual Differences in ILRG Model Outputs
Run 17a minus Run 1
1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1979	289	289	11,232	11,914	1,421	3,084	2,118	2,124	5,842	5,873	1,619	3,404	-32,174	33,259	2,858
1980	-623	-623	-6,671	-5,961	71	821	4,036	4,043	299	791	1,040	928	-38,565	9,443	279
1981	-656	-656	-7,424	-7,026	-1,356	-2,118	4,489	4,493	129	612	49	49	-37,340	4,626	-952
1982	-593	-593	-7,476	-7,510	-70	-785	3,406	3,410	204	723	44	199	-34,913	6,580	-1,141
1983	-525	-525	-6,838	-7,015	-2,979	-3,620	3,513	3,518	1	454	0	0	-34,654	5,326	-3,042
1984	-725	-725	-4,711	-4,482	-7,255	-8,101	4,139	4,149	177	719	0	0	-25,200	14,563	-5,477
1985	-912	-912	-6,714	-6,402	-1,844	-2,696	5,325	5,343	-178	493	0	0	75,749	105,022	58,320
1986	-1,139	-1,139	-20,564	-20,677	2,356	1,862	4,092	4,127	58	96	0	0	87,161	130,523	148,238
1987	-1,414	-1,414	-31,595	-30,132	-1,027	-1,937	4,050	4,076	635	3,151	0	0	-153	36,023	46,250
1988	-789	-789	-26,544	-25,130	-906	-2,393	4,271	4,292	-2,799	-500	0	0	-57,280	-13,183	-14,669
1989	-551	-551	-13,046	-11,726	2,741	747	4,485	4,501	-1,898	-119	0	0	-44,328	-4,840	-12,678
1990	438	438	44,601	45,569	10,646	9,210	-3,988	-3,974	21,431	23,058	0	0	-17,187	31,726	1,994
1991	-145	-145	-21,342	-20,668	-9,747	-10,789	4,717	4,737	-3,635	-2,543	0	0	-46,146	-9,448	-12,960
1992	2,291	2,291	50,022	50,790	34,088	34,171	-6,269	-6,255	33,244	34,894	0	0	100,845	145,293	120,131
1993	-62	-62	-48,520	-47,007	-5,505	-6,022	5,572	5,596	-5,188	-2,528	0	0	-2,484	29,692	35,183
1994	-108	-108	-36,277	-35,052	-1,909	-2,169	5,473	5,507	3,313	5,533	0	0	-4,016	44,460	44,473
1995	311	311	-34,364	-33,155	-1,125	-1,788	5,904	5,929	5,108	7,329	0	0	32,748	78,094	67,838
1996	-704	-704	-45,113	-44,337	-5,342	-5,286	5,655	5,677	-2,633	-1,088	0	0	-91,836	-30,025	-23,998
1997	-579	-579	-30,176	-30,475	-5,593	-7,472	5,280	5,303	-5,827	-5,614	0	0	-49,447	544	-8,589
1998	-742	-742	-28,331	-28,382	984	-463	6,094	6,128	755	1,264	0	0	-16,707	40,114	35,417
1999	-1,840	-1,840	-47,002	-48,227	27,492	27,034	-5,469	-5,449	-17,405	-16,392	0	0	-18,180	37,795	47,349
2000	-907	-907	-15,480	-18,001	6,802	6,701	-2,212	-2,196	-3,728	-3,728	0	0	-46,081	15,880	7,034
2001	-343	-343	-12,356	-15,324	801	760	6,269	6,287	9,611	9,626	0	0	-44,602	5,156	-10,880
2002	-614	-614	-31,634	-33,370	-1,865	-1,649	6,128	6,144	392	419	0	0	-68,860	-12,334	-13,600
2003	135,314	135,314	35,837	34,273	16,278	16,730	80,149	80,183	20,892	20,957	0	0	97,211	102,926	44,585
2004	76,300	76,300	5,279	5,121	4,601	5,795	55,128	55,138	16,491	16,546	0	0	-3,199	46,550	12,580
2005	1,513	1,513	-15,034	-17,299	-1,079	-358	10,617	10,639	9,272	9,320	0	0	-80,194	5,459	5,288
2006	118,920	118,920	21,138	19,600	13,545	15,229	74,858	74,873	18,898	18,937	0	0	53,810	67,692	39,070
2007	194,557	194,557	-12,122	-13,426	-1,382	-447	128,817	128,846	12,911	12,992	0	0	28,043	32,096	17,518
2008	177,329	177,329	-35,813	-36,411	-5,239	-4,637	118,900	118,966	-2,448	-2,296	0	0	-1,078	18,678	32,301
2009	134,978	134,978	-47,858	-49,032	-3,169	-2,198	93,251	93,308	-11,243	-11,122	0	0	-44,521	20,059	44,973
2010	218,710	218,710	-31,667	-32,677	-2,697	-1,432	146,656	146,753	-2,552	-2,388	0	0	22,698	30,524	43,703
2011	178,637	178,637	-30,256	-30,403	-16,380	-15,895	96,406	96,419	-3,323	-3,244	0	0	-5,805	5,246	12,570
2012	111,777	111,777	29,317	26,744	1,298	136	57,910	57,910	20,273	20,321	0	0	37,014	51,357	9,818
2013	-11,936	-11,936	-29,229	-31,682	-6,887	-6,837	-14,727	-14,727	-27,956	-27,927	-2,794	-3,031	-41,592	-15,638	-6,064
2014	61,402	61,402	3,631	260	-2,821	-4,537	24,389	24,389	407	426	-2,540	-3,715	54,277	12,047	-7,535
2015	129,129	129,129	-22,738	-25,230	-5,077	-6,487	64,714	64,714	-19,363	-19,327	306	350	12,176	-4,771	-15,293
2016	113,989	113,989	-62,220	-64,129	-10,940	-12,976	62,199	62,199	-38,986	-38,937	0	0	-91,925	-38,451	-25,907
2017	328,247	328,247	-11,806	-12,309	225	-434	201,363	201,417	1,882	2,000	0	0	72,010	35,915	14,983
Averages															
1951-2017	35,612	35,612	-6,810	-6,680	1,052	1,010	23,047	23,060	3,062	3,659	627	713	-7,065	24,426	11,027
1951-1978	15,279	15,279	4,413	5,386	1,761	2,104	9,516	9,517	6,146	6,656	1,583	1,772	-6,022	20,091	315
1979-2005	7,499	7,499	-12,972	-12,952	2,247	1,825	8,258	8,277	3,132	4,050	102	170	-14,809	31,823	21,105
2006-2017	146,312	146,312	-19,135	-20,725	-3,294	-3,376	87,895	87,922	-4,292	-4,214	-419	-533	7,925	17,896	13,345
1985-2017	59,426	59,426	-16,908	-17,524	949	590	38,061	38,085	800	1,503	-152	-194	-3,087	30,309	22,347
1985-2005	9,777	9,777	-15,636	-15,696	3,374	2,857	9,584	9,606	3,710	4,770	0	0	-9,380	37,401	27,491

Notes:

EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

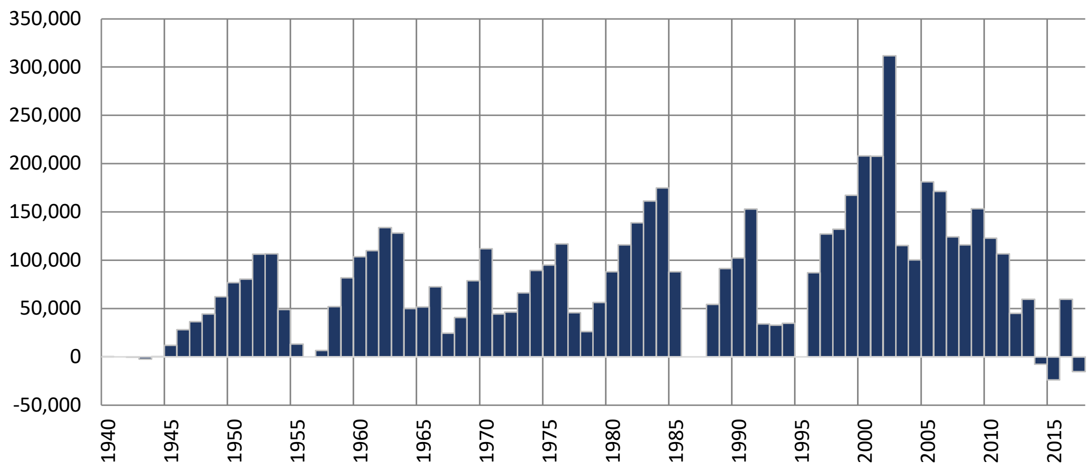
Run 17a - Conj Use 2a: Hist Proj Acres (Pre-Comp M&I)

Simulated Differences in ILRG Model Outputs

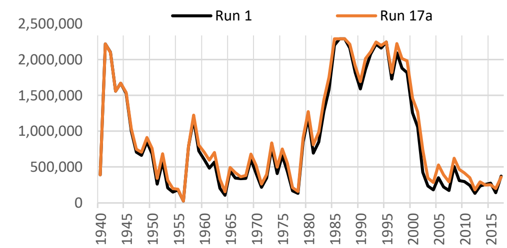
Run 17a minus Run 1

1940 - 2017 (acre-feet)

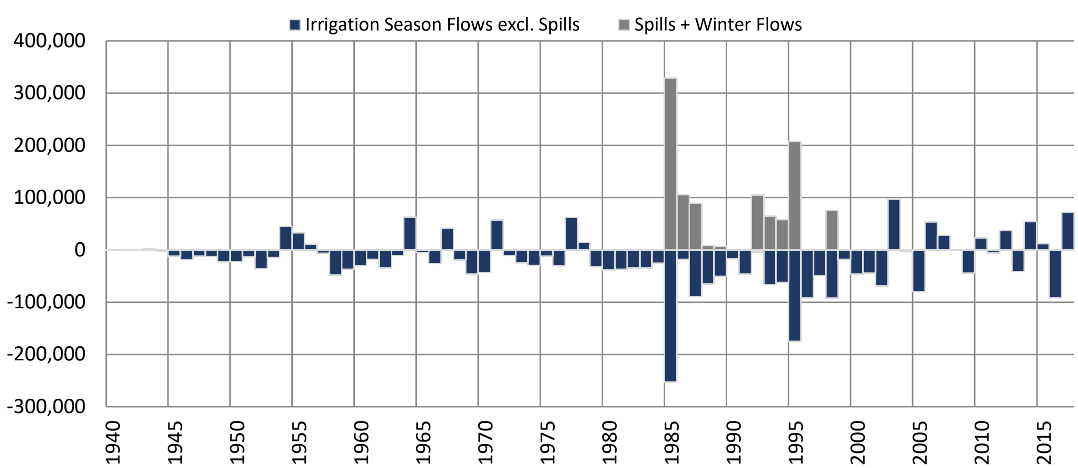
Total Project Storage (Year End)



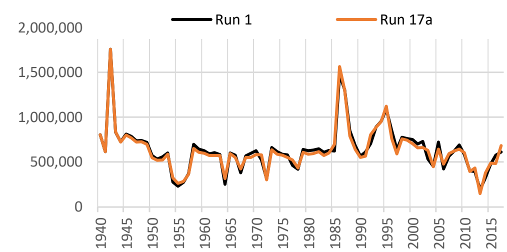
Period	Average Difference
1951-2017	-1,373
1951-1978	-1,806
1979-2005	5,744
2006-2017	-16,378
1985-2017	-5,765
1985-2005	299



Caballo Reservoir Outflows (Annual)



	Average Difference		
Period	Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	-22,711	15,646	-7,065
1951-1978	-6,022	0	-6,022
1979-2005	-53,633	38,825	-14,809
2006-2017	7,925	0	7,925
1985-2017	-34,853	31,766	-3,087
1985-2005	-59,298	49,917	-9,380



Notes:

Reservoir storage does not include storage attributed to SJC, CO, or NM credit waters.

Average differences calculated as (Final Storage - Initial Storage)/(no. years).

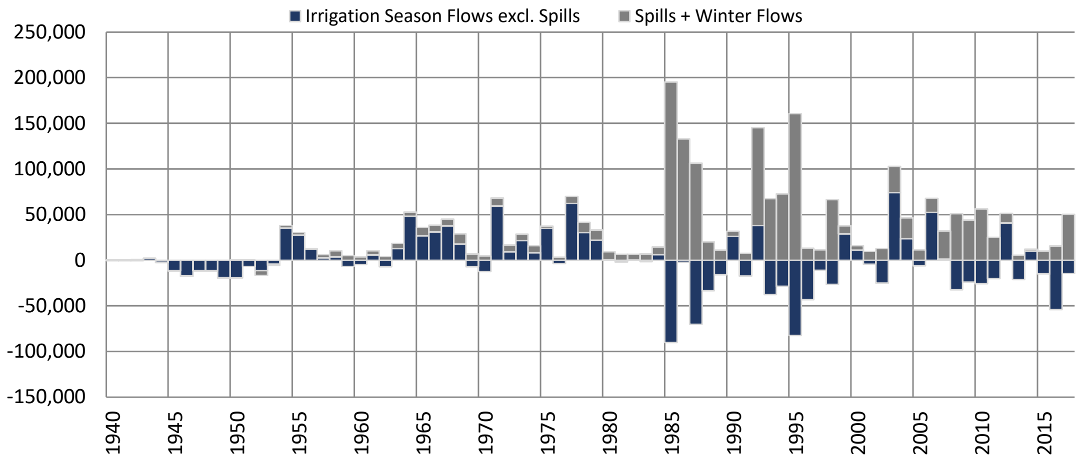
Run 17a - Conj Use 2a: Hist Proj Acres (Pre-Comp M&I)

Simulated Differences in ILRG Model Outputs

Run 17a minus Run 1

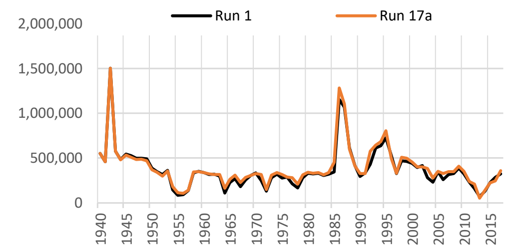
1940 - 2017 (acre-feet)

Rio Grande at El Paso (Annual)

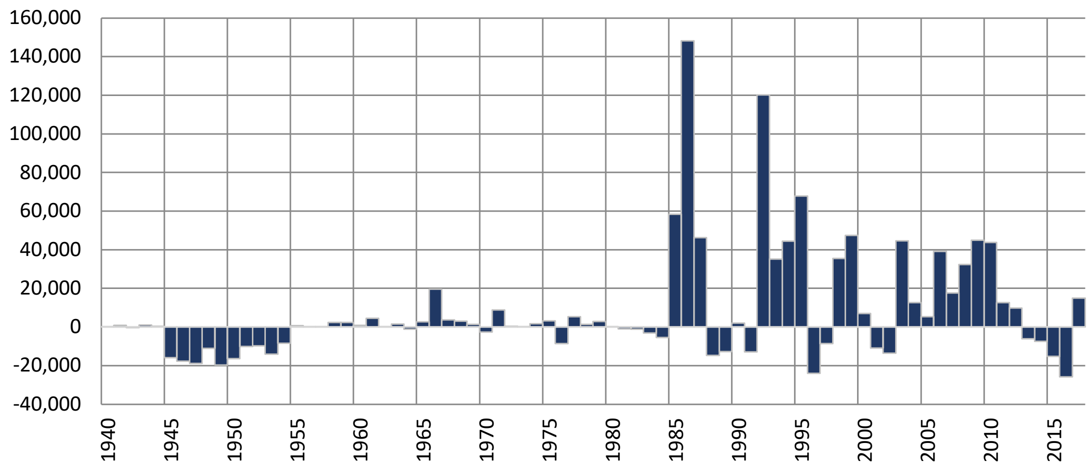


Average Difference

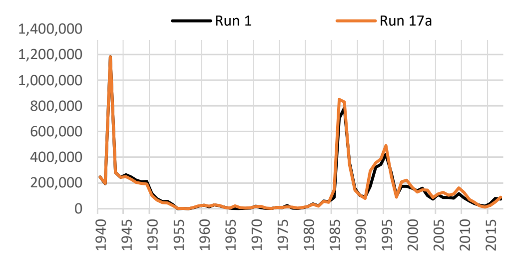
Period	Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	809	23,617	24,426
1951-1978	15,105	4,985	20,091
1979-2005	-9,887	41,710	31,823
2006-2017	-8,484	26,380	17,896
1985-2017	-11,946	42,254	30,309
1985-2005	-13,924	51,325	37,401



Rio Grande at Fort Quitman (Annual)



Period	Average Difference
1951-2017	11,011
1951-1978	296
1979-2005	21,087
2006-2017	13,341
1985-2017	22,338
1985-2005	27,478



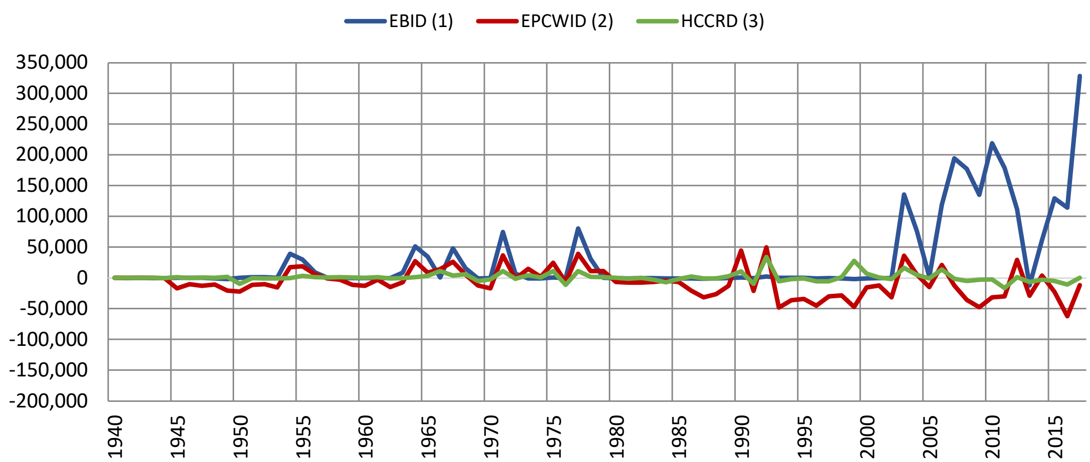
Run 17a - Conj Use 2a: Hist Proj Acres (Pre-Comp M&I)

Simulated Differences in ILRG Model Outputs

Run 17a minus Run 1

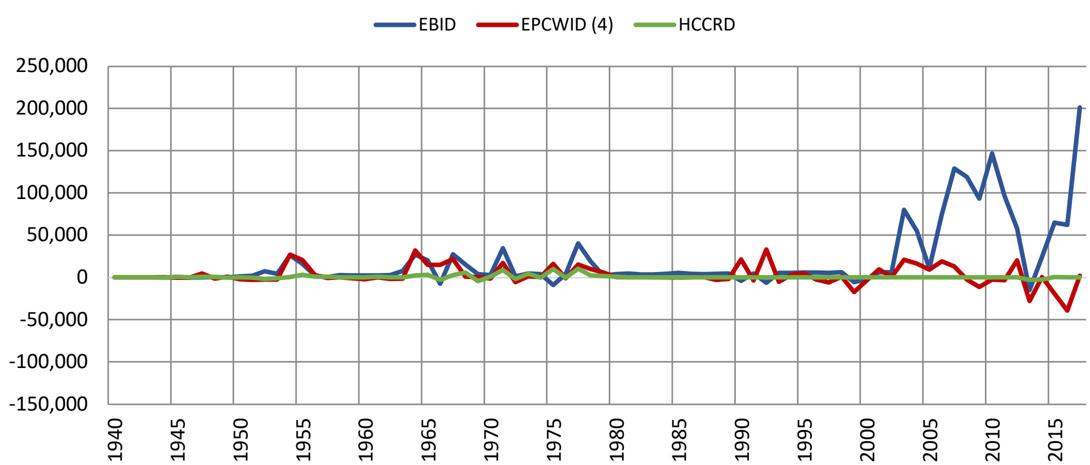
1940 - 2017 (acre-feet)

River Headgate (RHG) Diversions (Irrigation Season)



	Average Difference		
Period	EBID	EPCWID	HCCRD
1951-2017	35,612	-6,810	1,052
1951-1978	15,279	4,413	1,761
1979-2005	7,499	-12,972	2,247
2006-2017	146,312	-19,135	-3,294
1985-2017	59,426	-16,908	949
1985-2005	9,777	-15,636	3,374

Farm Headgate (FHG) Deliveries (Irrigation Season)



	Average Difference		
Period	EBID	EPCWID	HCCRD
1951-2017	23,047	3,062	627
1951-1978	9,516	6,146	1,583
1979-2005	8,258	3,132	102
2006-2017	87,895	-4,292	-419
1985-2017	38,061	800	-152
1985-2005	9,584	3,710	0

Notes:

(1) EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

(2) EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

(3) HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

(4) EPCWID FHG values include deliveries to Rogers WTP and R/U WTP.

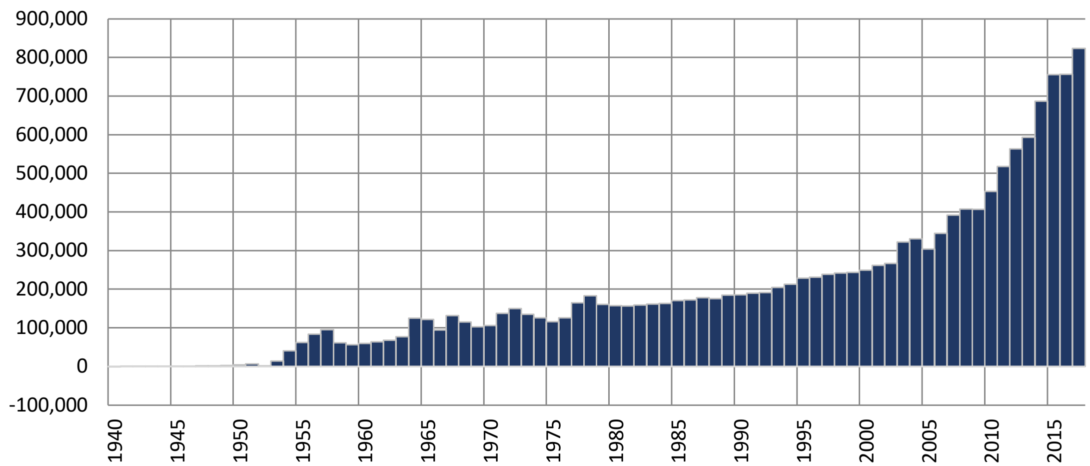
Run 17a - Conj Use 2a: Hist Proj Acres (Pre-Comp M&I)

Simulated Differences in ILRG Model Outputs

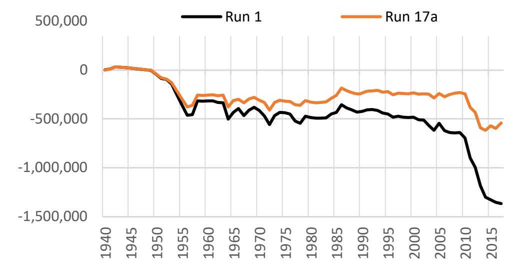
Run 17a minus Run 1

1940 - 2017 (acre-feet)

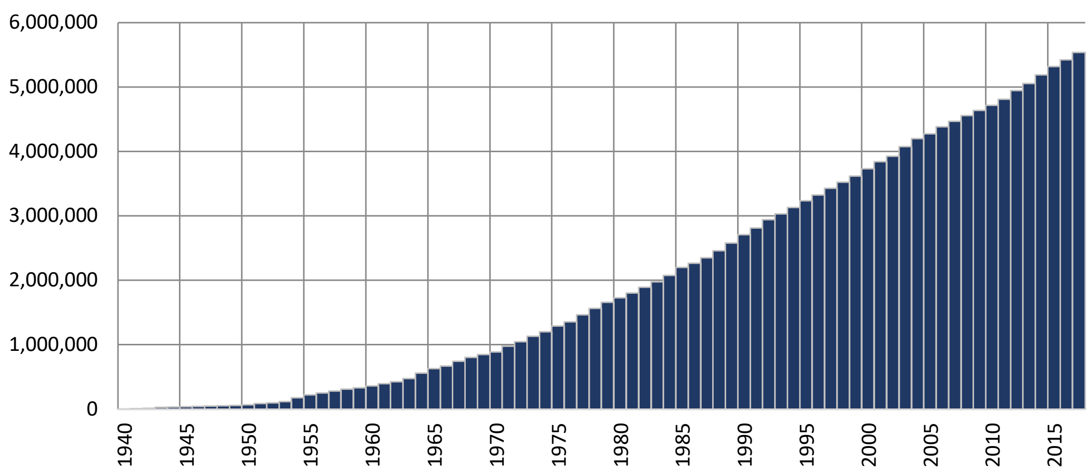
Cumulative Annual Rincon-Mesilla Groundwater Storage



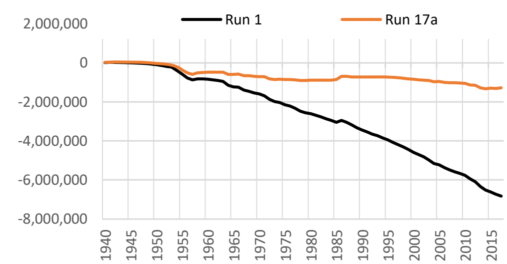
Period	Average Difference
1951-2017	12,238
1951-1978	6,386
1979-2005	4,499
2006-2017	43,306
1985-2017	20,023
1985-2005	6,718



Cumulative Annual Hueco Groundwater Storage



Period	Average Difference
1951-2017	81,627
1951-1978	53,476
1979-2005	100,319
2006-2017	105,256
1985-2017	104,913
1985-2005	104,718



Notes:

Cumulative storage change in alluvial and non-alluvial aquifers.

Average differences calculated as (Final Storage - Initial Storage)/(no. years).

Run 17a - Conj Use 2a: Hist Proj Acres (Pre-Comp M&I)

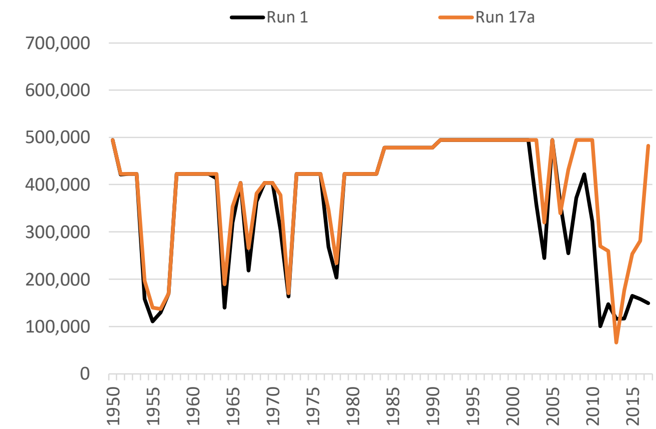
Annual Allocation and Charges

Run 17a v. Run 1

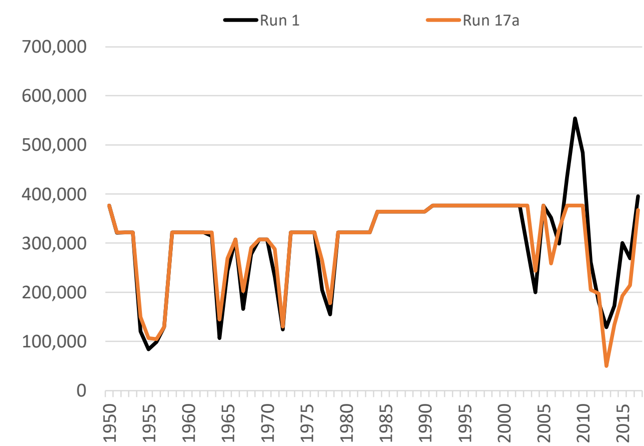
ILRG Model

1950 - 2017 (acre-feet)

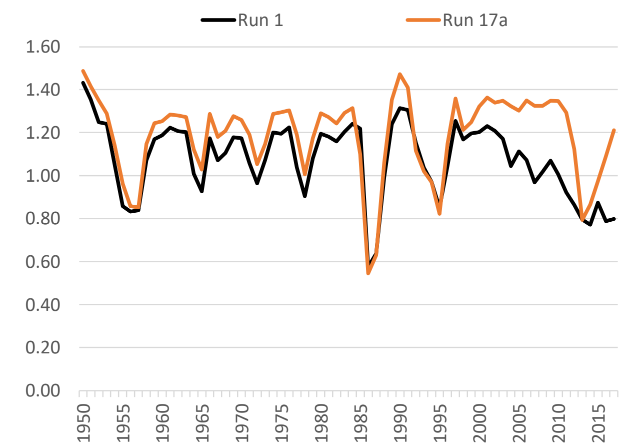
Total Allocation - EBID



Total Allocation - EPCWID



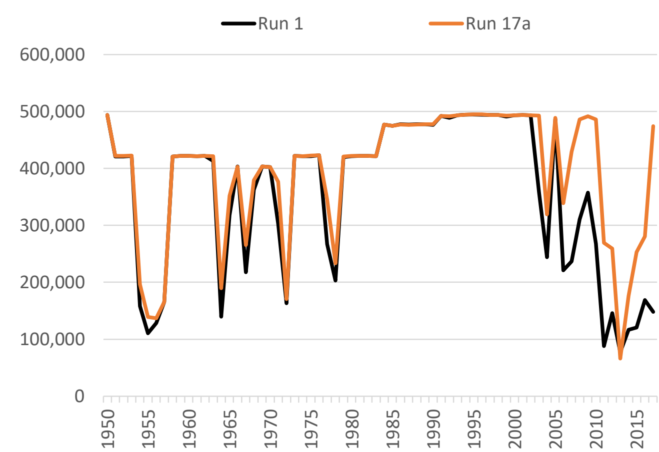
Diversion Ratio



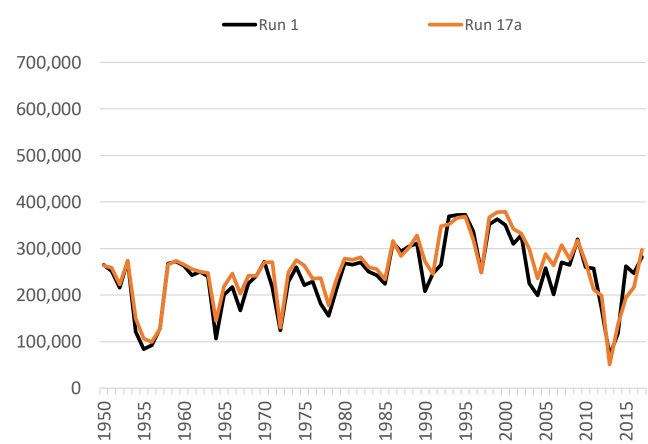
Note:

Computed as Total Charges/Caballo Release.

Annual Delivery Charges - EBID



Annual Delivery Charges - EPCWID

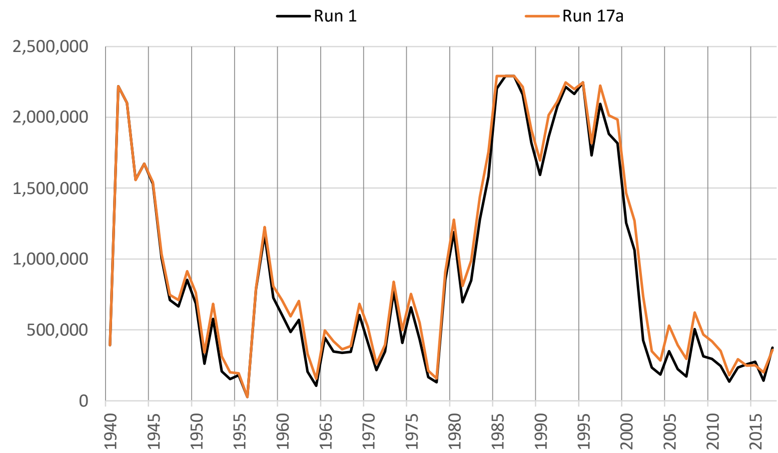


Run 17a - Conj Use 2a: Hist Proj Acres (Pre-Comp M&I)
Annual Summary of Project Storage and Rio Grande Flows
Run 17a v. Run 1

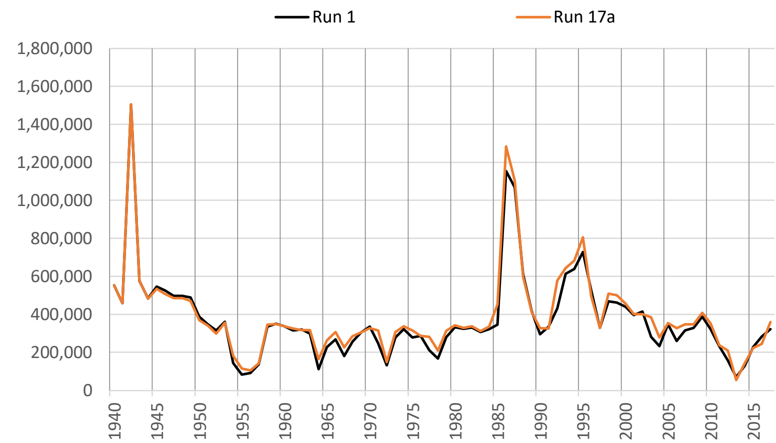
ILRG Model

1940 - 2017 (acre-feet)

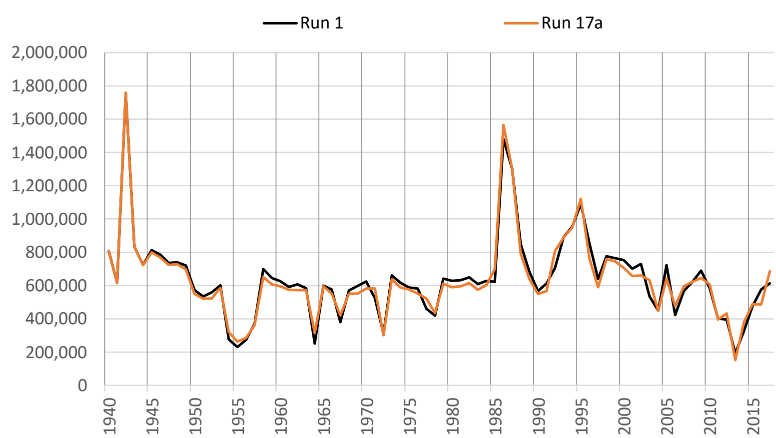
Total Year-End Project Reservoir Storage



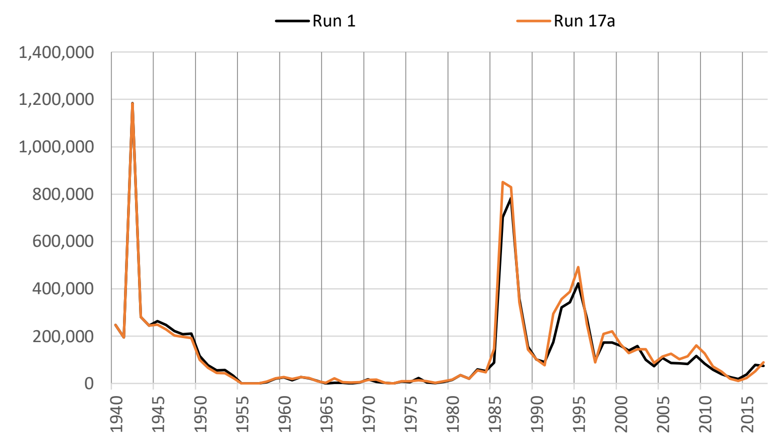
Rio Grande at El Paso



Rio Grande Below Caballo



Rio Grande at Fort Quitman

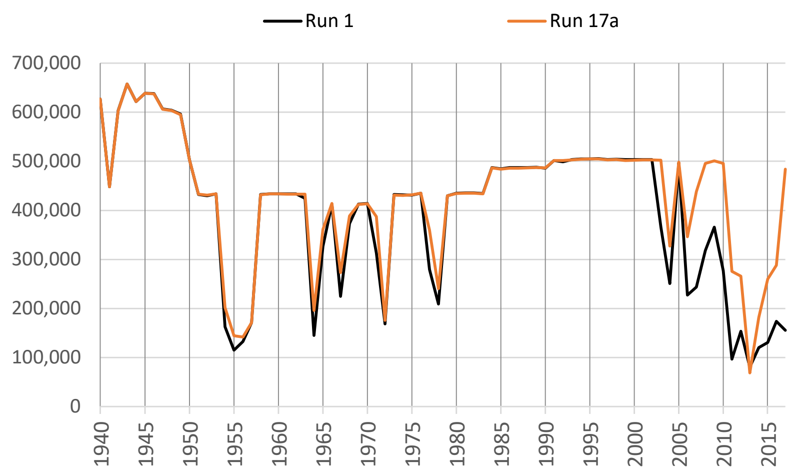


***Note different scales.**

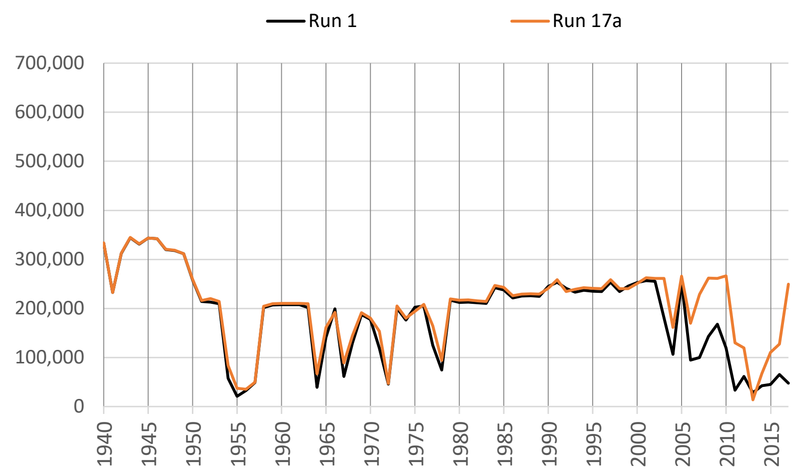
Run 17a - Conj Use 2a: Hist Proj Acres (Pre-Comp M&I)
Irrigation Season Summary of Irrigation Operations
Run 17a v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

EBID Total

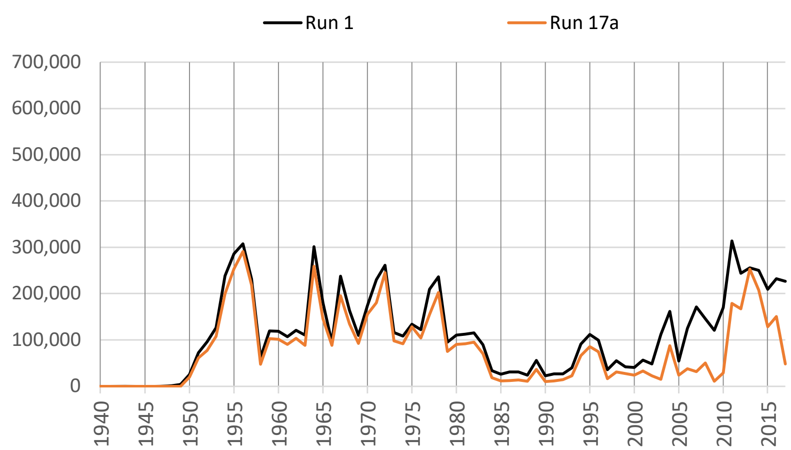
Net River Headgate Diversions



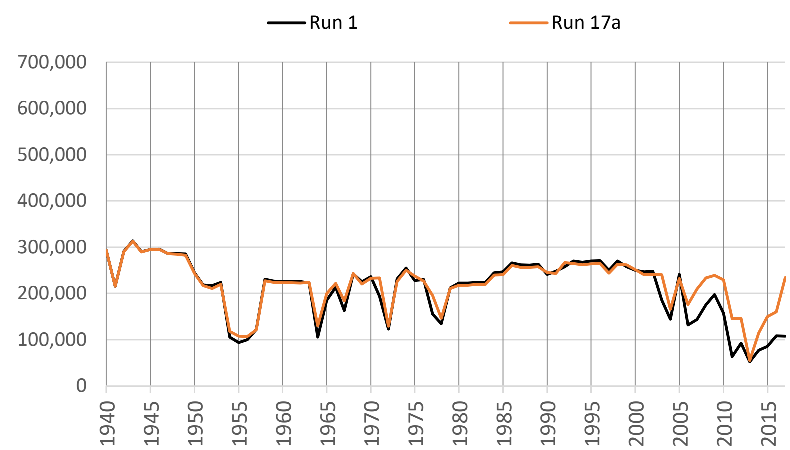
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries



Notes: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).
Pumping includes Supplemental and Primary groundwater pumping.

Run 17a - Conj Use 2a: Hist Proj Acres (Pre-Comp M&I)

Irrigation Season Summary of Irrigation Operations

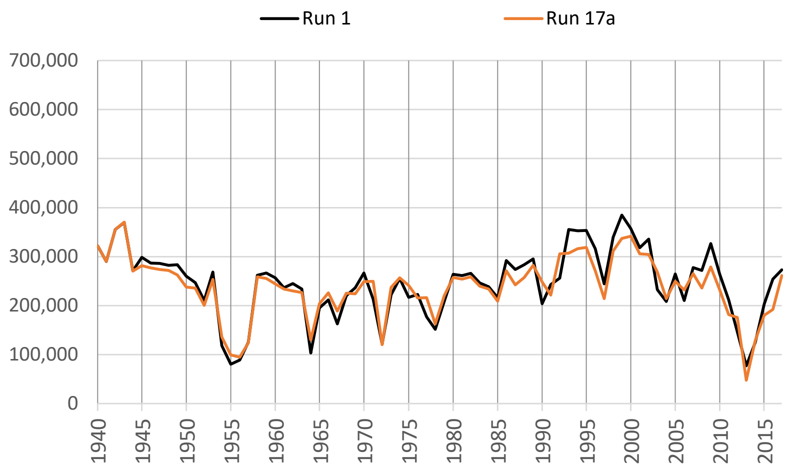
Run 17a v. Run 1

ILRG Model

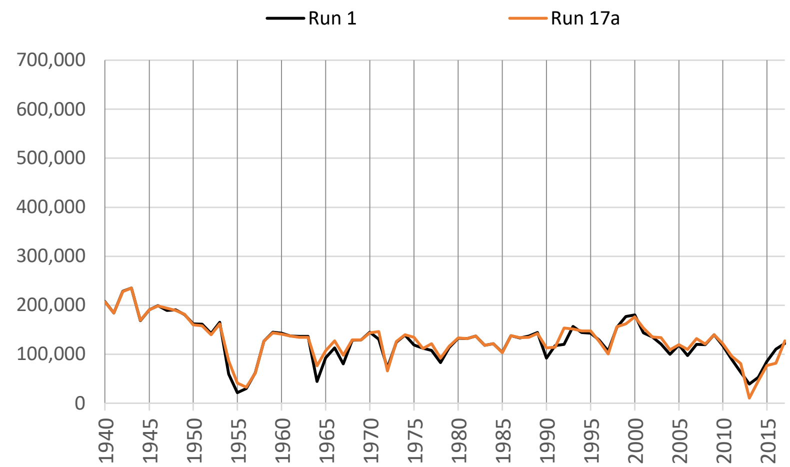
1940 - 2017 (acre-feet)

EPCWID Total

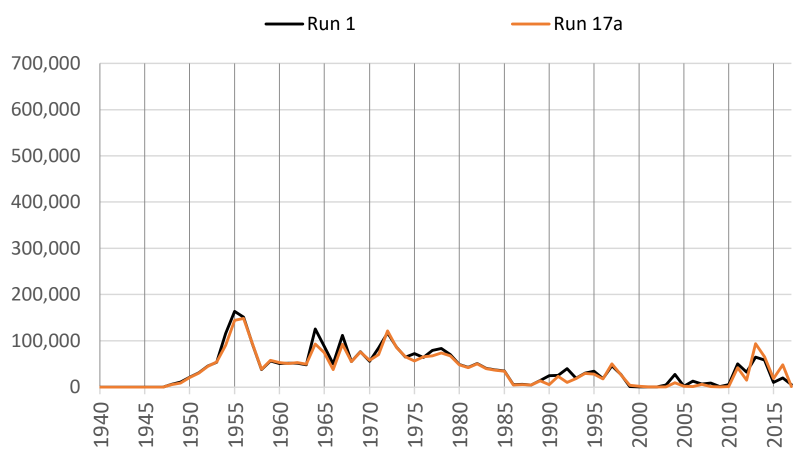
Net River Headgate Diversions



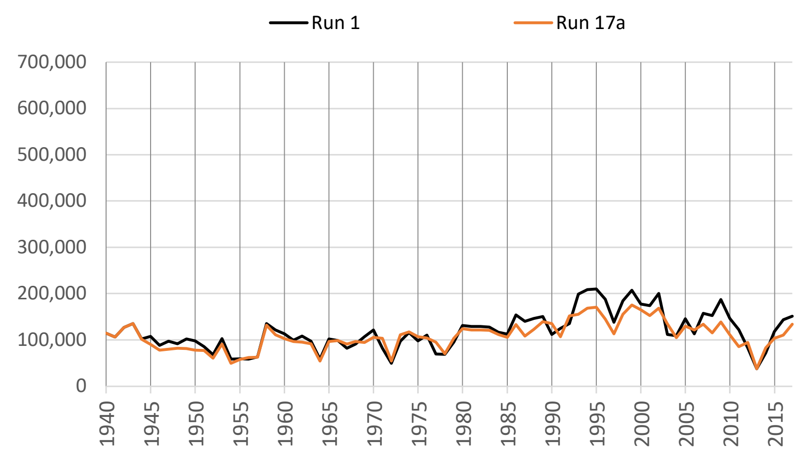
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries

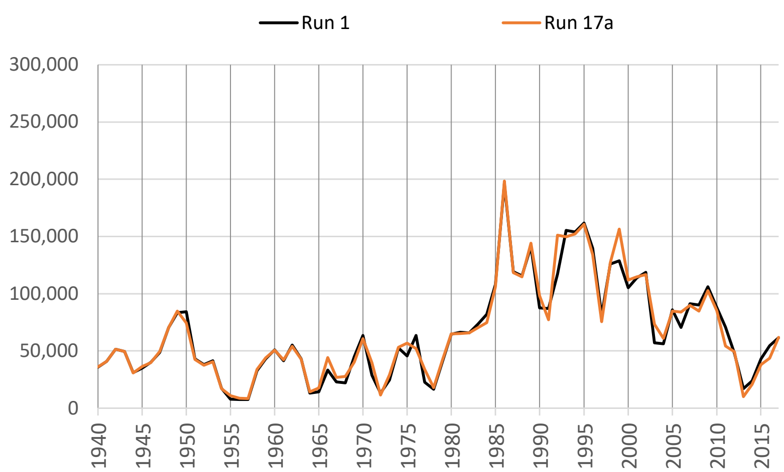


Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

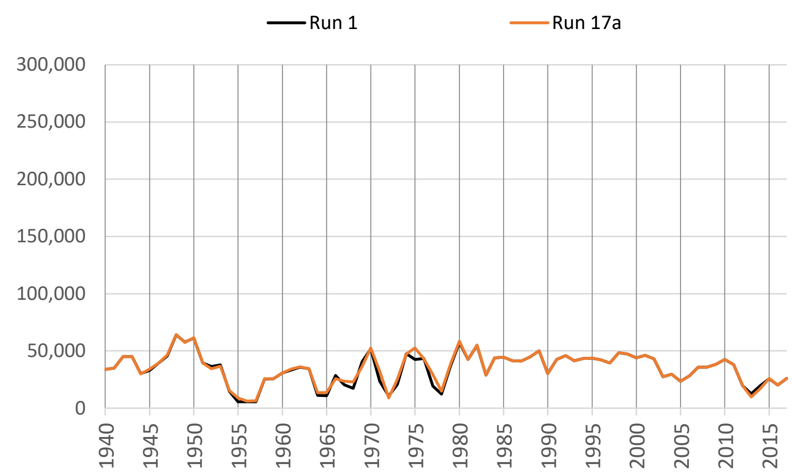
Run 17a - Conj Use 2a: Hist Proj Acres (Pre-Comp M&I)
Irrigation Season Summary of Irrigation Operations
Run 17a v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

HCCRD Total

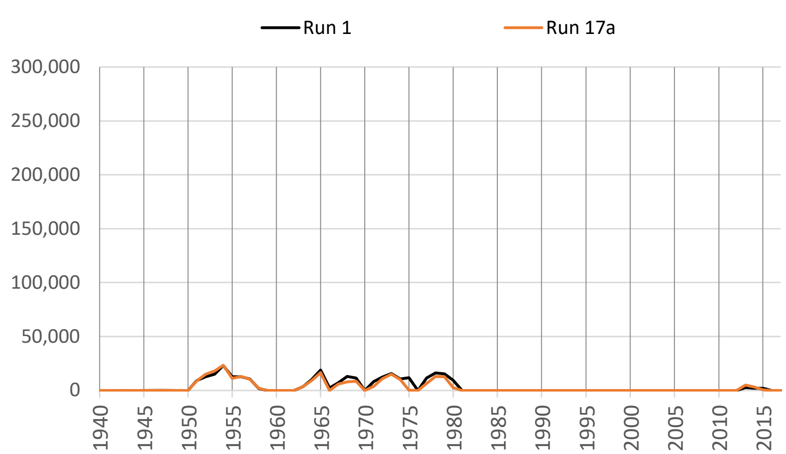
Net River Headgate Diversions



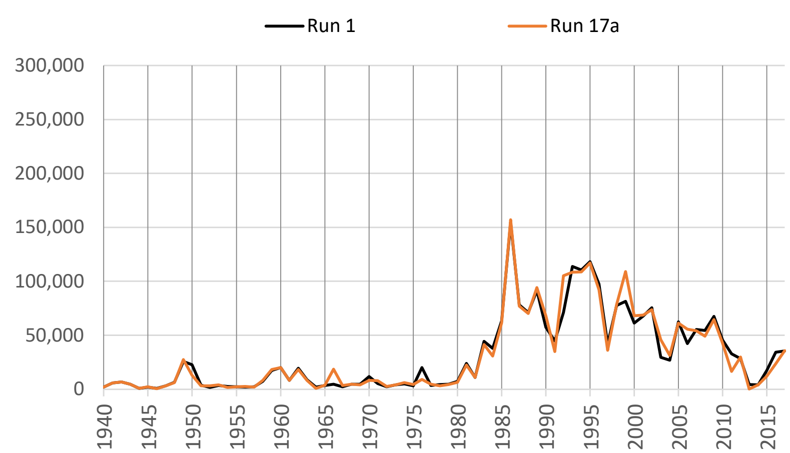
Farm Headgate Deliveries



Pumping



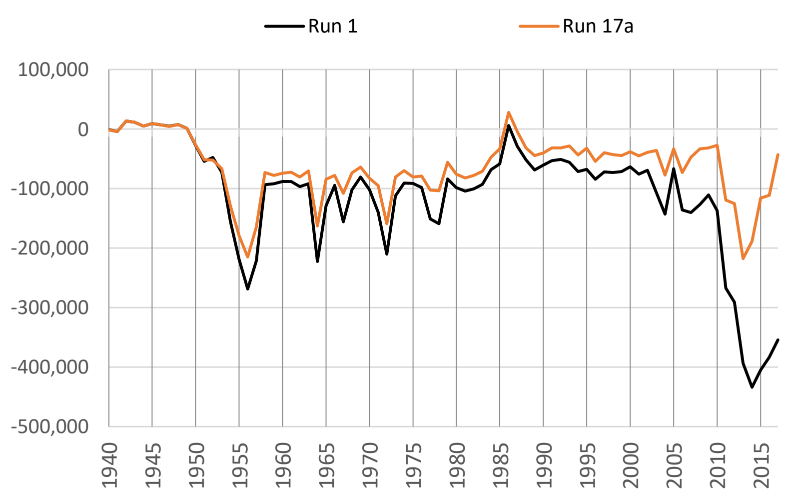
RHG Diversions - FHG Deliveries



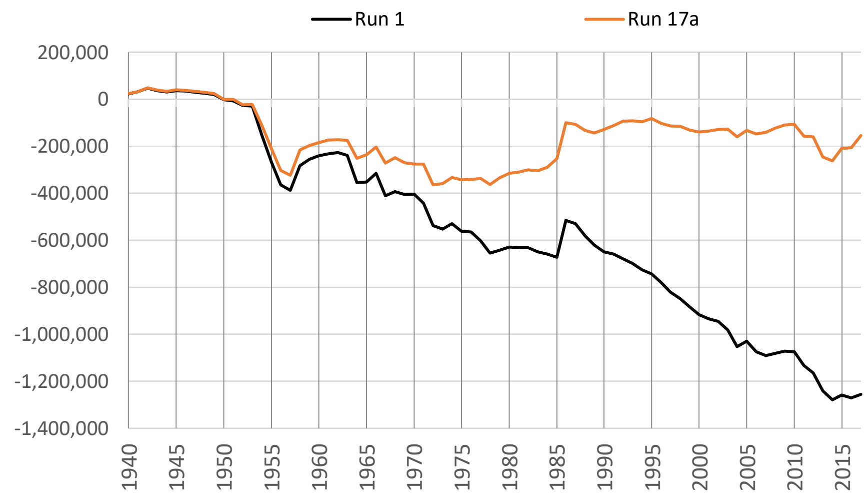
Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

Run 17a - Conj Use 2a: Hist Proj Acres (Pre-Comp M&I)
Cumulative Change in Ground Water Storage
Run 17a v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

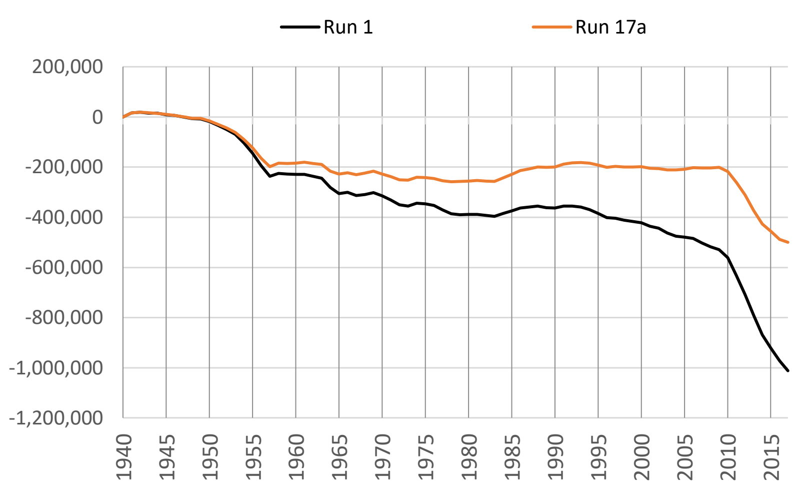
Rincon-Mesilla Alluvial Aquifer



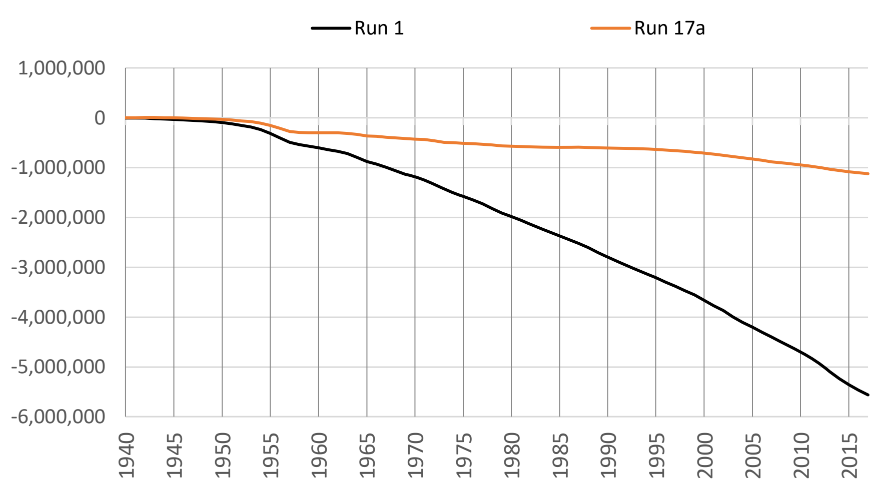
Hueco Alluvial Aquifer



Rincon-Mesilla Non-Alluvial Aquifer



Hueco Non-Alluvial Aquifer



***Note different scales.**

Run 17a - Conj Use 2a: Hist Proj Acres (Pre-Comp M&I)

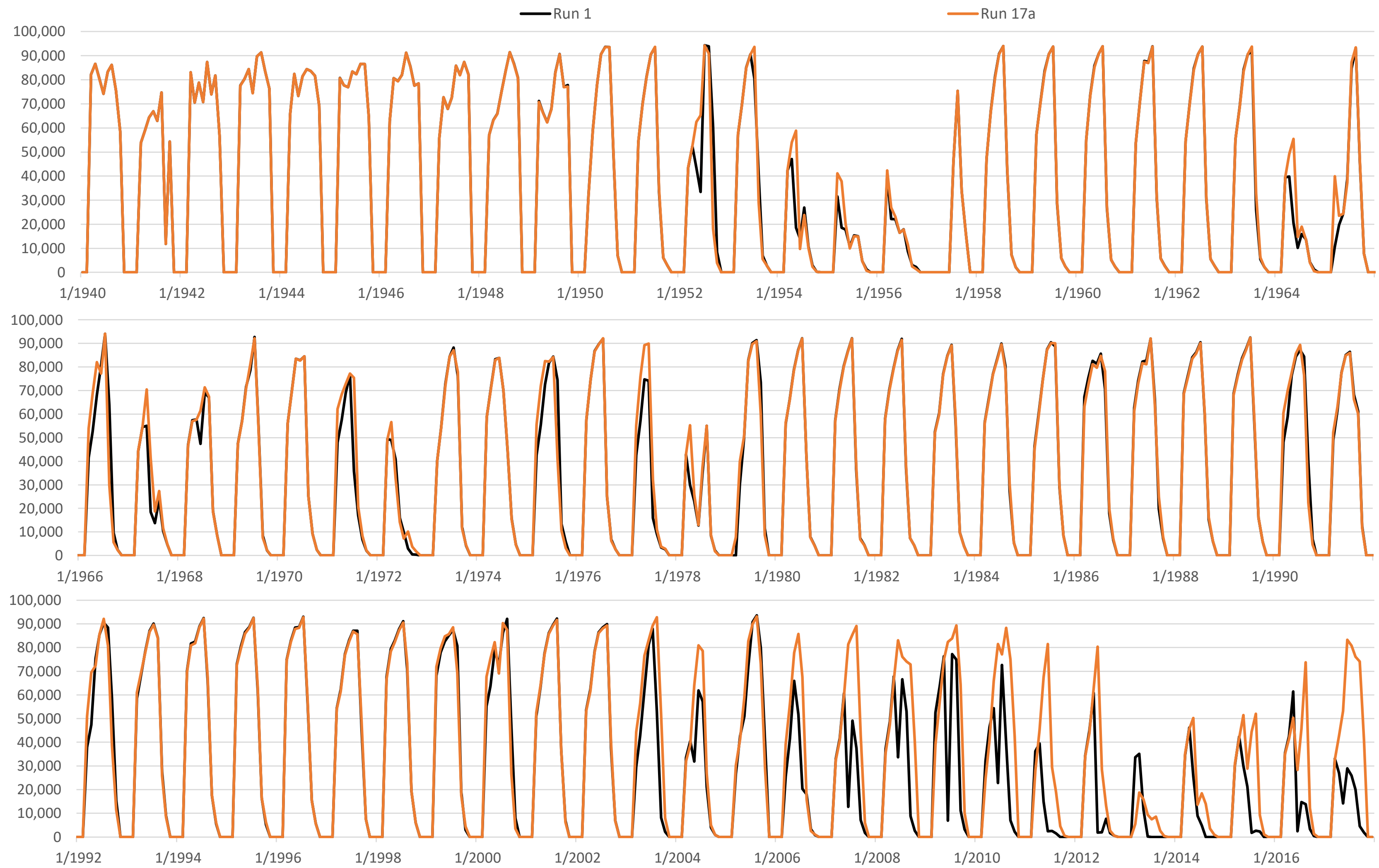
Monthly Net RHG Diversions

Run 17a v. Run 1

ILRG Model

1940 - 2017 (acre-feet)

EBID Total



Note: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

Run 17a - Conj Use 2a: Hist Proj Acres (Pre-Comp M&I)
Monthly Net RHG Diversions
Run 17a v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
EPCWID Total

Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

Run 17a - Conj Use 2a: Hist Proj Acres (Pre-Comp M&I)

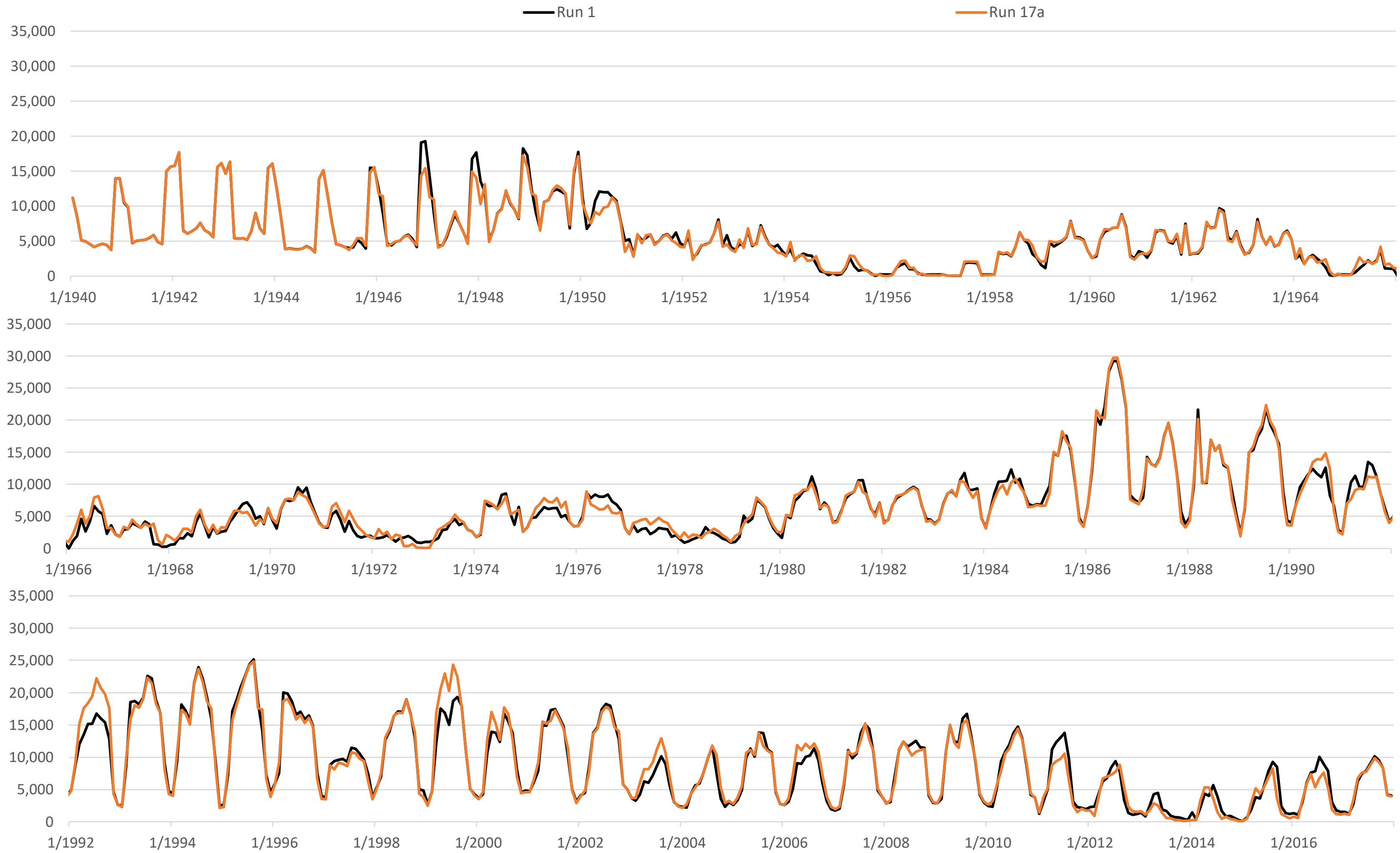
Monthly Net RHG Diversions

Run 17a v. Run 1

ILRG Model

1940 - 2017 (acre-feet)

HCCRD Total



Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

Run 17a - Conj Use 2a: Hist Proj Acres (Pre-Comp M&I)

End of Month Reservoir Storage (Elephant Butte + Caballo)

Run 17a v. Run 1

ILRG Model

1940 - 2017 (acre-feet)

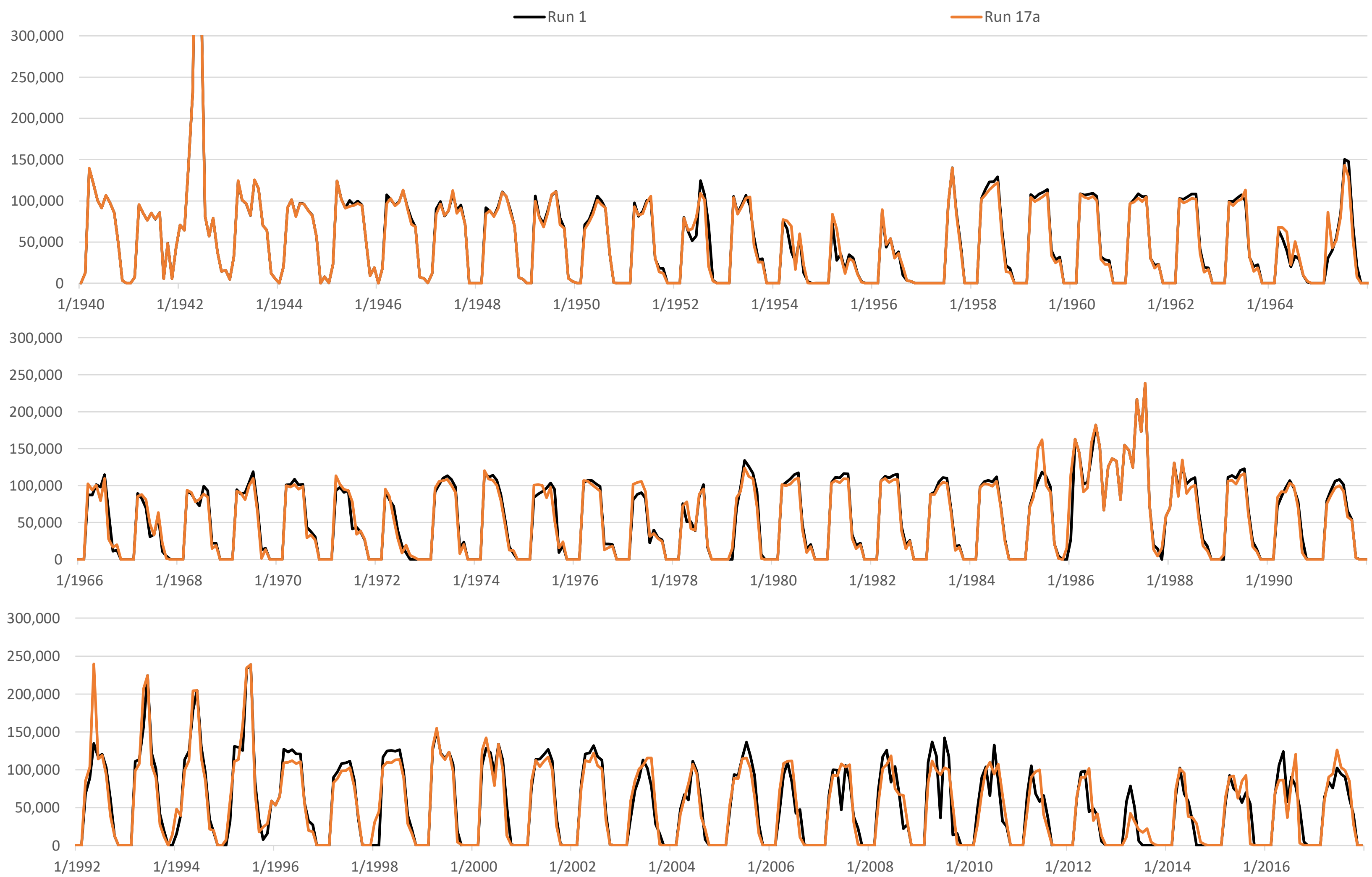
Run 17a - Conj Use 2a: Hist Proj Acres (Pre-Comp M&I)

Monthly Caballo Releases

Run 17a v. Run 1

ILRG Model

1940 - 2017 (acre-feet)



Run 17a - Conj Use 2a: Hist Proj Acres (Pre-Comp M&I)
Monthly Rio Grande at El Paso Flow
Run 17a v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

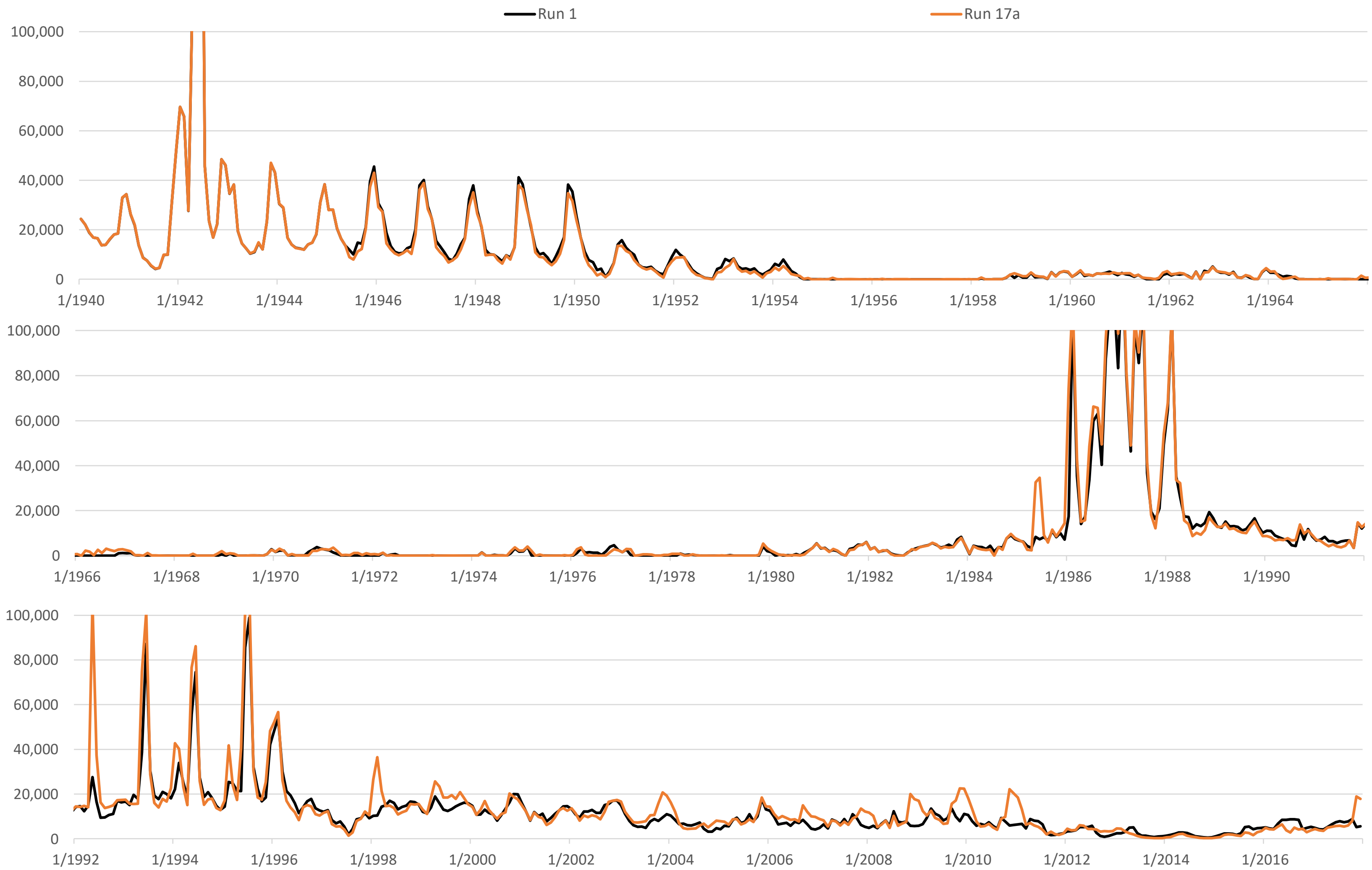
Run 17a - Conj Use 2a: Hist Proj Acres (Pre-Comp M&I)

Monthly Rio Grande at Fort Quitman Flow

Run 17a v. Run 1

ILRG Model

1940 - 2017 (acre-feet)



Appendix 30AA

Comparison of ILRG Model Runs
Run 18 v. Run 1

Model Run Specifications

Model Version: LRG_v116

Name: **Run 18 - Conj Use 3: Auth Proj Acres (Pre-Comp M&I)**

Run ID: LRG_v116_Operational_Run18
Date: 8/31/2020

Name: **Run 1 - Historical Base Run (All Pumping On)**

Run ID: LRG_v116_Operational_Run1
Date: 8/23/2020

Selected Model Inputs

	Pumping and Returns	**Run 18**	**Run 1**
(1)	Irrigation Pumping	Conj	On
(2)	Irrigated Area	Authorized	Hist
(3)	Non-Irrigation Pumping	Pre-Comp	On
	Non-Irrigation Pumping Returns	Pre-Comp	On
	Las Cruces Jornada Pumping Returns	Off	On
	Project Allocation Rules		
	1950-2005	D1/D2	D1/D2
	2006-2007	D1/D2	D3
	2008-2017	D1/D2	D3 + CO
	EPCWID Operations		
	Charge EPCWID for Use of WWTP Returns	On	Off
	ACE and Haskell Credits for EPCWID	Off	On
(4)	Increased EPCWID Use of Fabens Drain Flows	On	Off
	Charge EPCWID for Fabens Drain Flow Use	On	Off

Notes:
(1) Conjunctive use pumping on historical Project acres; no pumping on NM GW only acres.
(2) Acres set to authorized Project acres every year. HCCRD set to max historical acres.
(3) Limit M&I pumping to pre-compact levels. Reduce corresponding return flows.
(4) Starting in July 1945, use 70% of simulated Fabens drain flow up to 6,000 AF/month.

Run 18 - Conj Use 3: Auth Proj Acres (Pre-Comp M&I)
Comparison of ILRG Model Runs
Run 18 v. Run 1
1951 - 2017 Annual Average
(1,000 acre-feet)

Run No.	1	18	18 - 1	
Simulated Input or Output	**Run 1**	**Run 18**	**Run 18 minus Run 1**	
Effects of Alternate Scenario				
FHG Deliveries (Mar - Oct)				***% Diff.***
EBID	167.6	177.8	10.2	*6%*
EPCWID (incl. EPW)	139.9	144.4	4.5	*3%*
HCCRD	32.8	39.6	6.7	*20%*
Total	340.3	361.7	21.4	*6%*
FHG Deliveries (Nov - Feb)				
EBID	0.0	0.0	0.0	*83%*
EPCWID (incl. EPW)	0.2	1.1	0.9	*463%*
HCCRD	2.4	3.6	1.2	*51%*
Total	2.6	4.7	2.1	*81%*
Irrigation Pumping				
EBID	140.4	144.2	3.7	*3%*
EPCWID (Mesilla Valley)	7.4	11.9	4.6	*63%*
EPCWID (El Paso Valley)	40.1	68.0	27.9	*70%*
HCCRD	4.2	18.4	14.2	*337%*
Total	192.1	242.6	50.4	*26%*
Other Inflows/Outflows				
Net Reservoir Evaporation	125.3	119.9	-5.4	*-4%*
Riparian ET	70.9	74.0	3.1	*4%*
River Evaporation + Incidental Canal Loss	30.3	30.2	-0.2	*-1%*
Total	226.6	224.0	-2.5	*-1%*
Rio Grande at Fort Quitman				
Reservoir Spills	33.3	22.9	-10.4	*-31%*
Nov-Feb Flows	21.4	14.9	-6.5	*-30%*
Mar - Oct Flows	41.1	30.5	-10.5	*-26%*
Underflow (GW Model)	0.2	0.2	0.0	*-18%*
Total	96.0	68.6	-27.4	*-29%*

Run 18 - Conj Use 3: Auth Proj Acres (Pre-Comp M&I)
Comparison of ILRG Model Runs
Run 18 v. Run 1
1951 - 2017 Annual Average
(1,000 acre-feet)

Run No.	1	18	18 - 1	
Simulated Input or Output	**Run 1**	**Run 18**	**Run 18 minus Run 1**	
Effects of Alternate Scenario (continued)				
Change in Storage				***% Diff.***
Reservoir Storage	-4.7	-8.0	-3.4	*72%*
Alluvial GW Storage (RW Model)	-23.6	-10.0	13.6	*-58%*
Non-alluvial GW Storage (GW Models)	-96.4	-32.5	63.8	*-66%*
Soil Moisture Storage	0.6	0.2	-0.4	*-72%*
Total	-124.0	-50.3	73.7	*-59%*
Summary of Effects				
FHG Deliveries (Mar-Oct)	340.3	361.7	21.4	*6%*
FHG Deliveries (Nov-Feb)	2.6	4.7	2.1	*81%*
Irrigation Pumping	192.1	242.6	50.4	*26%*
Riparian ET + Evaporation	226.6	224.0	-2.5	*-1%*
Fort Quitman Flow	96.0	68.6	-27.4	*-29%*
Change in Storage	-124.0	-50.3	73.7	*-59%*
Total	733.6	851.2	117.6	*16%*
Other Effects of Alternate Scenario				
Rio Grande at El Paso				***% Diff.***
Reservoir Spills	49.4	35.7	-13.7	*-28%*
Nov-Feb Flows	22.8	26.0	3.2	*14%*
Mar - Oct Flows	263.8	291.6	27.8	*11%*
Total	336.0	353.2	17.3	*5%*
Rio Grande below Caballo				
Reservoir Spills	65.9	44.7	-21.2	*-32%*
Nov-Feb Flows	0.5	0.3	-0.2	*-32%*
Mar - Oct Flows	541.3	570.6	29.4	*5%*
Total	607.6	615.7	8.1	*1%*
Surface Water Diversions (Mar - Oct)				
EBID	366.5	377.9	11.4	*3%*
EPCWID (incl. EPW)	236.8	239.7	2.9	*1%*
HCCRD	67.5	65.9	-1.7	*-2%*
Total	670.8	683.5	12.7	*2%*
Surface Water Diversions (Nov - Feb)				
EBID	0.0	0.0	0.0	*0%*
EPCWID (incl. EPW)	14.3	13.5	-0.9	*-6%*
HCCRD	14.2	11.7	-2.5	*-18%*
Total	28.5	25.2	-3.4	*-12%*

Run 18 - Conj Use 3: Auth Proj Acres (Pre-Comp M&I)
Annual Differences in ILRG Model Outputs
Run 18 minus Run 1
1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1940	28,809	28,809	21,394	23,210	1,560	2,298	19,743	19,755	13,556	13,636	2,409	8,669	54,025	32,660	-8,928
1941	19,819	19,819	15,798	17,647	1,316	2,296	14,143	14,155	10,176	10,242	1,675	6,163	-5,932	-6,320	-23,774
1942	5,018	5,018	13,183	6,642	260	-4,010	3,485	3,479	6,951	7,148	2,546	6,982	-33,419	-41,332	-89,534
1943	-1,490	-1,490	12,880	12,577	2,404	2,289	-1,066	-1,062	3,801	3,631	2,793	5,779	16,894	16,699	-15,559
1944	267	267	3,533	3,493	82	-46	192	196	-445	-568	869	4,181	7,530	7,180	-16,091
1945	-3,088	-3,088	-11,974	-1,091	1,559	812	-2,169	-2,166	-388	5,938	1,774	3,915	-3,416	-1,311	-34,102
1946	-6,406	-6,406	-6,266	-7,487	-397	-7,564	-4,498	-4,497	-2,030	1,303	293	939	-14,339	-9,533	-35,716
1947	-9,979	-9,979	-12,190	-7,381	551	-6,115	-6,645	-6,646	-44	6,159	667	504	-11,878	-5,965	-36,077
1948	-10,477	-10,477	-10,135	-7,297	0	-5,499	-6,253	-6,249	-5,856	109	1,197	1,816	-8,758	-3,608	-26,801
1949	-19,383	-19,383	-22,475	-19,040	1,310	2,342	-11,910	-11,906	-5,644	-547	1,797	1,851	-31,752	-18,398	-37,065
1950	-160	-160	-22,225	-19,575	-9,652	-11,280	529	544	-6,711	-2,466	2,096	2,502	-13,364	-10,623	-24,258
1951	933	933	-8,074	-3,242	-291	-2,573	1,640	1,653	-4,796	-309	-142	-2,445	-7,902	1,653	-16,909
1952	600	600	-8,070	-5,331	-675	-1,874	4,581	4,587	-4,027	-1,622	-2,446	619	-27,145	-4,396	-12,616
1953	-22	-22	-15,381	-12,627	-1,251	-2,488	3,398	3,404	-5,218	-2,845	-1,841	708	-19,948	-1,375	-17,867
1954	21,580	21,580	6,166	7,032	-1,671	-1,120	16,571	16,572	18,064	18,979	-1,093	-430	13,818	22,710	-14,516
1955	34,937	34,937	24,558	22,870	1,839	1,439	18,476	18,476	16,224	16,235	1,824	1,657	57,741	35,817	978
1956	-802	-802	-2,347	-4,750	1,562	1,070	-2,762	-2,762	-3,291	-3,664	1,060	635	-4,094	3,121	145
1957	-317	-317	-694	-3,601	1,995	1,535	-190	-190	-1,288	-1,365	2,459	2,053	-1,886	2,294	230
1958	826	826	36,020	35,352	5,041	4,367	2,134	2,134	18,471	18,380	8,949	11,844	37,475	60,657	-2,017
1959	425	425	19,806	20,228	632	-2,864	2,495	2,495	10,350	10,359	12,971	18,200	18,751	39,798	-17,735
1960	410	410	12,323	12,288	-1,437	-5,951	2,223	2,224	12,462	12,543	14,683	17,484	15,975	34,269	-18,706
1961	501	501	27,519	28,035	1,126	-317	2,595	2,596	20,016	20,579	4,467	12,599	31,928	48,397	-5,066
1962	-1,510	-1,510	-32,537	-32,138	-12,602	-13,680	13,082	13,084	-5,619	-5,143	2,829	13,813	-30,376	-15,596	-24,311
1963	-31,185	-31,185	11,201	12,390	-321	-1,743	-15,184	-15,184	8,527	9,131	3,832	16,008	-13,348	30,702	-11,327
1964	-18,163	-18,163	-16,827	-20,125	-1,952	-2,083	-9,781	-9,781	-5,084	-4,943	-1,201	1,647	-24,952	-5,938	-7,330
1965	-1,599	-1,599	14,596	11,878	2,401	928	-30	-30	8,085	7,795	3,059	2,011	25,954	35,957	390
1966	492	492	21,720	22,035	-3,019	-6,072	2,696	2,696	23,548	23,566	-2,908	-3,319	24,138	45,344	-944
1967	-30,577	-30,577	-28,633	-31,192	-6,058	-7,356	-5,382	-5,382	-22,031	-22,542	-6,939	-4,876	-49,011	-13,196	-1,113
1968	5,950	5,950	50,361	48,521	3,192	698	3,479	3,479	22,993	22,600	3,187	1,740	77,511	70,220	119
1969	-291	-291	13,957	14,121	-3,059	-5,203	-2,851	-2,849	18,144	18,162	-2,672	1,124	17,967	35,698	-3,069
1970	438	438	8,501	9,664	1,646	-817	2,252	2,252	15,237	15,845	9,376	17,196	7,079	30,253	-14,246
1971	-49,078	-49,078	-31,981	-36,479	-1,390	-6,156	-25,816	-25,816	-20,162	-19,738	718	1,689	-83,888	-22,743	-5,494
1972	-7,504	-7,504	-7,007	-12,129	-3,768	-7,819	-6,062	-6,062	-21,714	-21,580	-3,296	-6,600	9,919	2,435	-699
1973	218	218	59,176	57,383	9,900	7,029	2,385	2,385	25,082	24,846	11,057	8,455	78,088	88,731	828
1974	366	366	48,145	48,606	12,129	10,135	2,038	2,040	29,315	29,687	11,381	11,197	56,249	82,146	1,116
1975	-1,195	-1,195	21,124	21,548	4,229	4,251	-7,412	-7,405	21,492	22,165	5,873	4,934	35,693	48,223	4,217
1976	-123	-123	60,926	62,654	11,156	10,705	2,044	2,045	50,811	51,895	28,524	38,093	79,524	97,824	-19,321
1977	-115,180	-115,180	-65,364	-69,323	-4,747	-7,389	-59,432	-59,432	-44,364	-43,784	-2,230	-2,377	-184,587	-68,168	-971
1978	3,536	3,536	-3,286	-10,467	-796	-5,342	2,547	2,547	-25,503	-25,506	1,045	-1,338	29,015	5,890	-509

Run 18 - Conj Use 3: Auth Proj Acres (Pre-Comp M&I)

Annual Differences in ILRG Model Outputs

Run 18 minus Run 1

1940 - 2017 (acre-feet)

	Net River Headgate Diversions						Farm Headgate Deliveries						Annual Flows		
	EBID		EPCWID (incl. EPW)		HCCRD		EBID		EPCWID (incl. EPW)		HCCRD				
Year	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Mar - Oct	Annual	Caballo Releases	Rio Grande at El Paso	Rio Grande at Fort Quitman
1979	-2,129	-2,129	40,871	38,325	-254	-3,033	-273	-268	12,025	12,042	1,984	104	74,715	81,123	-265
1980	-3,354	-3,354	46,429	46,786	885	-6,856	2,567	2,570	32,317	32,323	3,375	1,646	67,361	96,084	-7,727
1981	-1,898	-1,898	38,932	38,531	-2,064	-8,561	1,538	1,539	35,305	35,578	16,351	22,139	56,591	77,844	-28,420
1982	-2,491	-2,491	33,038	32,244	-1,943	-7,399	1,827	1,828	32,865	32,868	3,968	8,156	50,912	70,963	-10,986
1983	452	452	46,554	46,024	-2,958	-8,159	3,666	3,668	45,974	46,610	29,531	36,911	94,301	92,105	-41,607
1984	636	636	41,041	41,179	4,000	-1,167	3,547	3,549	38,969	40,445	9,955	8,206	72,237	82,571	-7,454
1985	2,184	2,184	41,870	43,031	-16,215	-21,553	11,177	11,186	41,946	43,956	8,588	8,474	28,306	43,906	-27,474
1986	-542	-542	28,637	29,502	-13,887	-23,239	7,183	7,171	36,272	37,528	6,383	6,094	-328,978	-306,960	-281,384
1987	446	446	28,647	31,151	10,227	7,341	6,025	6,031	45,719	49,641	7,426	7,489	72	6,228	-191,591
1988	-95	-95	21,597	23,989	9,151	6,485	5,727	5,732	37,555	41,324	6,035	5,697	10,089	19,098	-107,832
1989	-1,594	-1,594	25,272	27,401	13,650	10,960	4,948	4,954	33,381	36,382	1,236	276	60,023	68,452	-23,683
1990	1,209	1,209	39,592	41,151	421	-2,314	5,393	5,400	42,120	44,890	12,375	12,409	60,207	74,462	-32,843
1991	1,901	1,901	3,942	5,628	-6,178	-8,484	6,447	6,459	21,694	24,201	5,461	3,727	29,131	44,780	-29,968
1992	2,525	2,525	-13,110	-12,081	-14,124	-14,527	12,214	12,222	20,026	21,555	7,358	7,393	-18,941	-5,107	-65,874
1993	509	509	-26,629	-24,179	3,182	1,844	8,074	8,086	7,490	11,379	8,708	8,722	-124,784	-110,493	-144,569
1994	-418	-418	-29,350	-27,134	3,048	1,965	3,384	3,403	7,312	11,037	8,058	7,889	6,346	14,054	-25,516
1995	326	326	-33,375	-31,262	1,924	643	4,777	4,790	6,668	10,415	6,577	6,347	14,483	25,714	-17,984
1996	274	274	-113	1,729	8,219	8,068	4,727	4,741	32,080	35,332	5,408	5,284	11,799	33,220	-18,651
1997	897	897	-5,653	-5,207	-536	-2,496	5,472	5,483	-1,359	1,017	6,530	6,711	-233	26,044	-13,363
1998	17	17	-10,173	-9,092	8,319	7,065	5,657	5,670	6,169	8,834	7,446	7,439	-1,241	20,847	-13,715
1999	-1,208	-1,208	-36,962	-38,186	2,743	2,690	13,530	13,547	-3,847	-2,513	7,021	7,053	-21,739	-3,637	-30,346
2000	-1,124	-1,124	-5,892	-8,675	9,968	10,104	7,945	7,959	463	453	11,042	11,209	58	31,914	-13,766
2001	-1,230	-1,230	32,808	29,595	15,268	15,231	4,932	4,946	34,097	34,085	10,809	10,747	48,914	69,894	2,242
2002	-838	-838	15,449	13,116	11,822	11,739	5,196	5,203	31,032	31,019	7,260	6,841	23,221	44,457	-10,012
2003	-40,935	-40,935	-8,258	-11,605	3,225	165	-20,433	-20,430	1,749	1,729	23,717	26,675	-40,244	3,154	-39,391
2004	2,588	2,588	-30,441	-34,174	-10,577	-15,927	4,206	4,206	-34,753	-34,769	12,853	15,850	-9,838	-12,084	-59,304
2005	-21,655	-21,655	52,838	49,532	-1,631	-4,902	-7,107	-7,119	11,383	11,366	35,844	38,997	41,008	65,740	-59,727
2006	-35,313	-35,313	-78,400	-81,751	-30,279	-33,850	-15,772	-15,769	-61,710	-61,724	6,698	8,511	-118,784	-83,418	-56,319
2007	129,662	129,662	-10,734	-13,865	-2,968	-6,629	83,970	83,972	-19,801	-19,796	27,892	28,616	65,982	28,955	-49,734
2008	183,233	183,233	46,189	44,043	4,111	1,886	119,499	119,532	20,529	20,609	10,754	10,598	133,747	80,397	-1,635
2009	122,595	122,595	-15,373	-16,945	-5,364	-5,284	89,210	89,240	13,426	13,514	9,573	9,437	18,554	22,282	-2,575
2010	105,688	105,688	412	-1,149	4,950	5,366	67,597	67,612	4,301	4,359	8,815	8,681	40,952	40,023	28,958
2011	-24,472	-24,472	-160,346	-162,808	-58,689	-62,884	-17,968	-17,967	-125,103	-125,084	-24,703	-24,632	-225,599	-159,881	-30,587
2012	77,330	77,330	9,961	5,800	-15,647	-22,335	33,544	33,544	-14,026	-14,030	10,002	10,094	87,052	14,648	-35,605
2013	-65,094	-65,094	-63,635	-66,964	-15,421	-18,040	-23,612	-23,612	-43,310	-43,314	-11,049	-11,197	-142,856	-58,575	-24,806
2014	98,813	98,813	32,990	29,196	1,756	-570	44,473	44,473	-14,271	-14,274	3,900	2,689	169,412	44,289	-4,637
2015	96,901	96,901	-38,936	-42,562	-11,925	-14,891	42,535	42,535	-55,442	-55,439	3,064	3,066	31,310	-42,812	-34,039
2016	76,447	76,447	-73,674	-77,162	-19,831	-24,418	34,856	34,856	-84,873	-84,864	11,738	12,597	-44,340	-77,354	-75,510
2017	251,734	251,734	-5,344	-6,808	-12,862	-18,292	160,027	160,033	-48,712	-48,684	20,022	23,320	150,829	5,337	-60,560
Averages															
1951-2017	11,427	11,427	2,934	2,083	-1,682	-4,223	10,156	10,160	4,498	5,369	6,724	7,949	8,056	17,298	-27,388
1951-1978	-6,655	-6,655	7,711	6,900	493	-1,382	-1,795	-1,794	5,562	6,062	3,662	5,797	6,060	24,669	-6,669
1979-2005	-2,428	-2,428	12,502	12,493	1,322	-1,641	4,161	4,168	21,283	22,916	10,048	10,685	7,547	24,236	-48,193
2006-2017	84,794	84,794	-29,741	-32,581	-13,514	-16,662	51,530	51,537	-35,749	-35,727	6,392	6,815	13,855	-15,509	-28,921
1985-2017	29,114	29,114	-8,066	-8,992	-3,762	-6,336	21,752	21,760	-1,570	-299	8,571	8,882	-1,396	-983	-47,024
1985-2005	-2,703	-2,703	4,319	4,487	1,810	-435	4,737	4,745	17,962	19,946	9,816	10,063	-10,111	7,318	-57,369

Notes:

EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

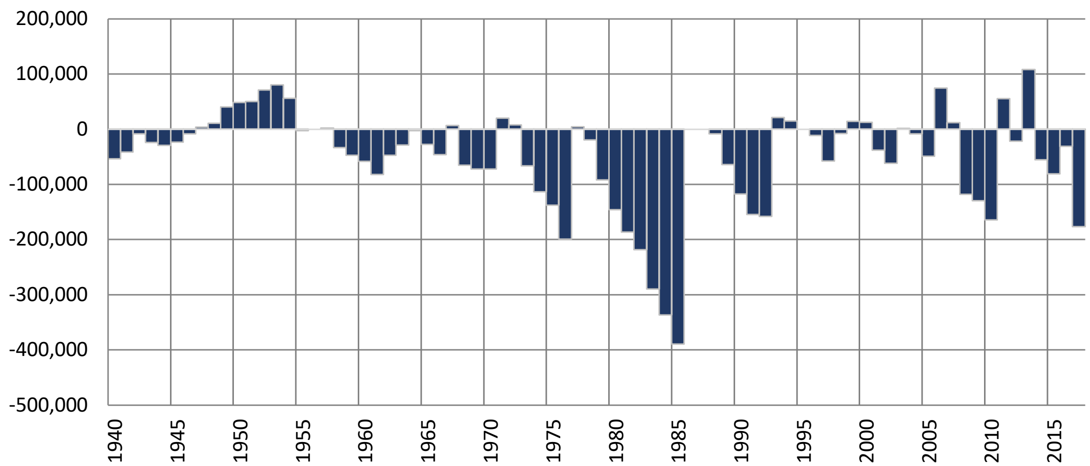
Run 18 - Conj Use 3: Auth Proj Acres (Pre-Comp M&I)

Simulated Differences in ILRG Model Outputs

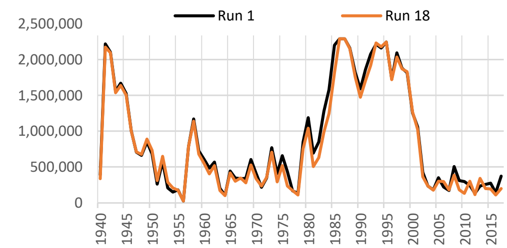
Run 18 minus Run 1

1940 - 2017 (acre-feet)

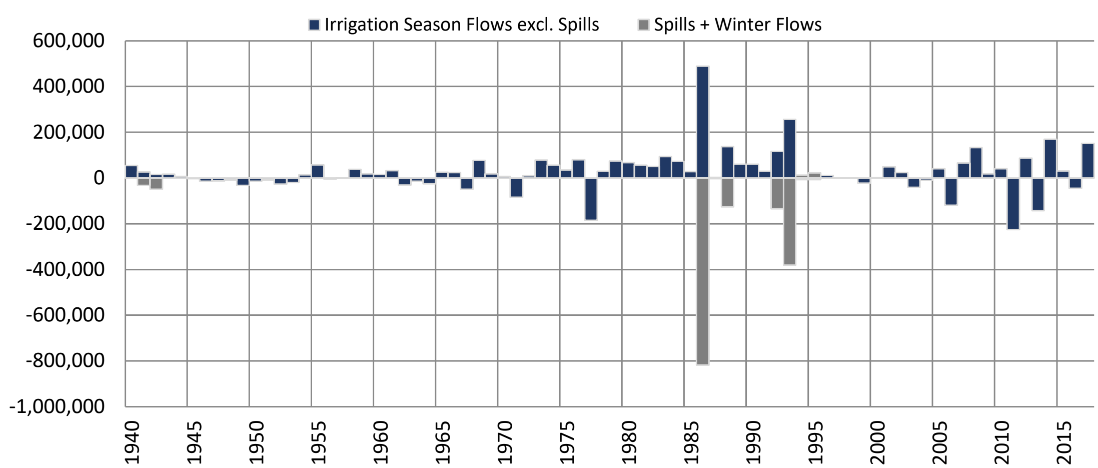
Total Project Storage (Year End)



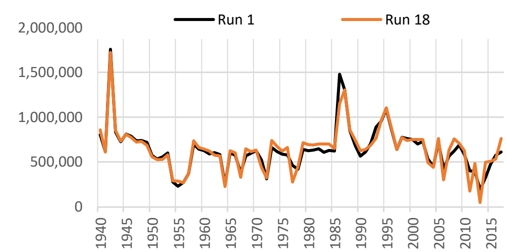
Period	Average Difference
1951-2017	-3,361
1951-1978	-2,427
1979-2005	-1,099
2006-2017	-10,631
1985-2017	4,848
1985-2005	13,693



Caballo Reservoir Outflows (Annual)



	Average Difference		
Period	Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	29,364	-21,309	8,056
1951-1978	6,060	0	6,060
1979-2005	60,425	-52,877	7,547
2006-2017	13,855	0	13,855
1985-2017	41,867	-43,263	-1,396
1985-2005	57,874	-67,985	-10,111



Notes:

Reservoir storage does not include storage attributed to SJC, CO, or NM credit waters.

Average differences calculated as (Final Storage - Initial Storage)/(no. years).

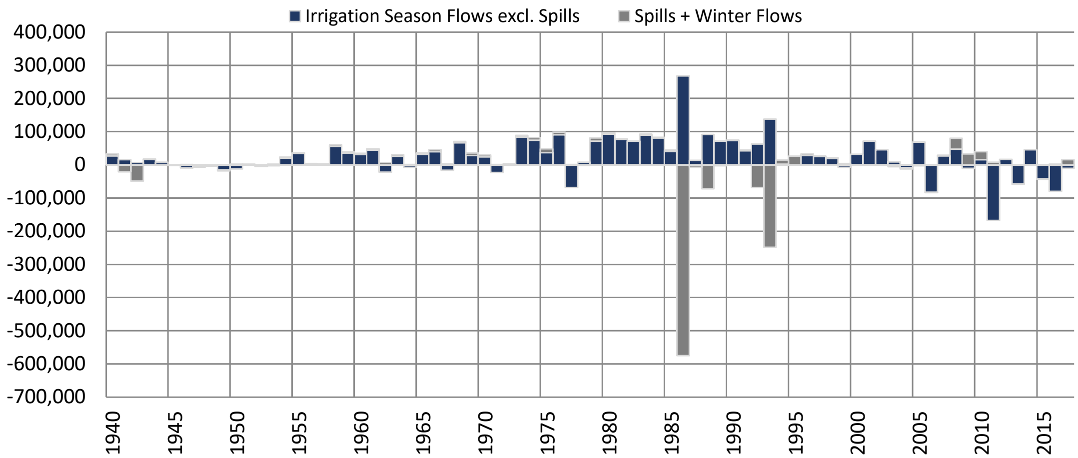
Run 18 - Conj Use 3: Auth Proj Acres (Pre-Comp M&I)

Simulated Differences in ILRG Model Outputs

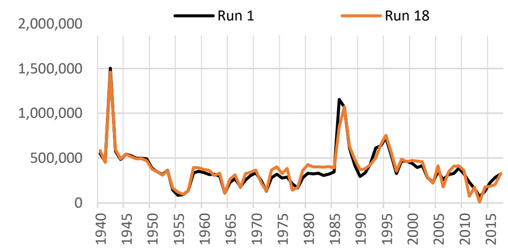
Run 18 minus Run 1

1940 - 2017 (acre-feet)

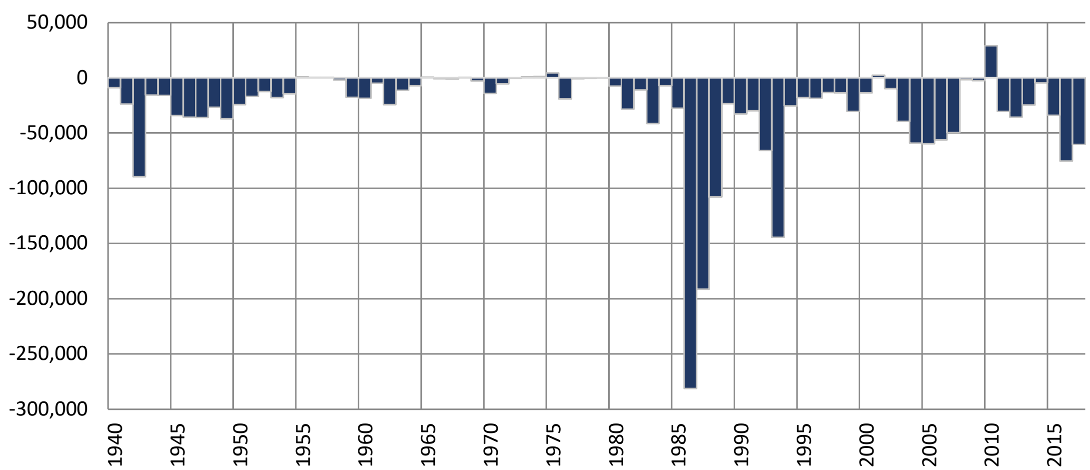
Rio Grande at El Paso (Annual)



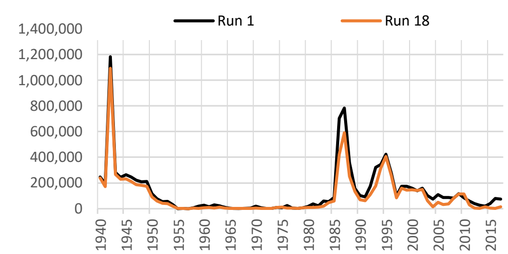
	Average Difference		
Period	Irr Season (excl. Spills)	Nov-Feb and Spills	Annual
1951-2017	27,833	-10,535	17,298
1951-1978	21,320	3,349	24,669
1979-2005	58,056	-33,819	24,236
2006-2017	-24,968	9,459	-15,509
1985-2017	23,797	-24,780	-983
1985-2005	51,663	-44,344	7,318



Rio Grande at Fort Quitman (Annual)



Period	Average Difference
1951-2017	-27,350
1951-1978	-6,633
1979-2005	-48,155
2006-2017	-28,880
1985-2017	-46,991
1985-2005	-57,341



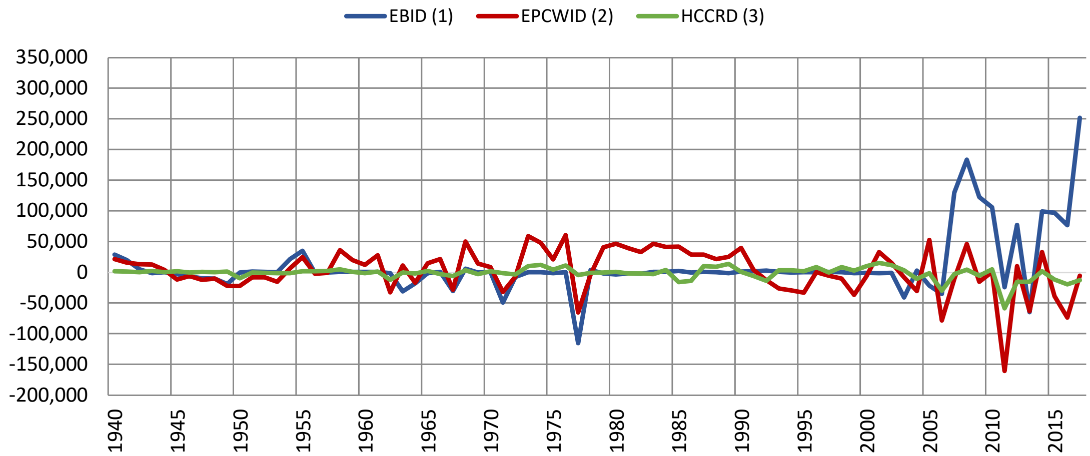
Run 18 - Conj Use 3: Auth Proj Acres (Pre-Comp M&I)

Simulated Differences in ILRG Model Outputs

Run 18 minus Run 1

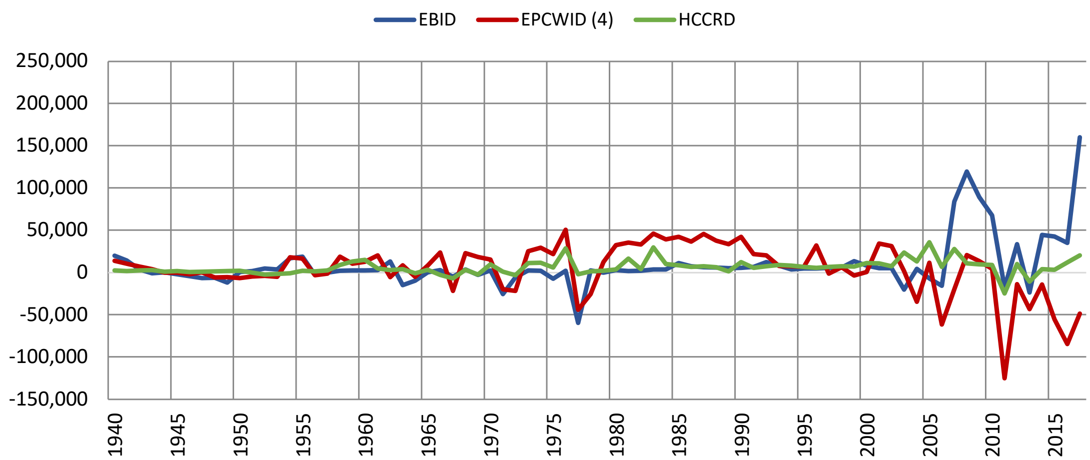
1940 - 2017 (acre-feet)

River Headgate (RHG) Diversions (Irrigation Season)



	Average Difference		
Period	EBID	EPCWID	HCCRD
1951-2017	11,427	2,934	-1,682
1951-1978	-6,655	7,711	493
1979-2005	-2,428	12,502	1,322
2006-2017	84,794	-29,741	-13,514
1985-2017	29,114	-8,066	-3,762
1985-2005	-2,703	4,319	1,810

Farm Headgate (FHG) Deliveries (Irrigation Season)



	Average Difference		
Period	EBID	EPCWID	HCCRD
1951-2017	10,156	4,498	6,724
1951-1978	-1,795	5,562	3,662
1979-2005	4,161	21,283	10,048
2006-2017	51,530	-35,749	6,392
1985-2017	21,752	-1,570	8,571
1985-2005	4,737	17,962	9,816

Notes:

(1) EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

(2) EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

(3) HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

(4) EPCWID FHG values include deliveries to Rogers WTP and R/U WTP.

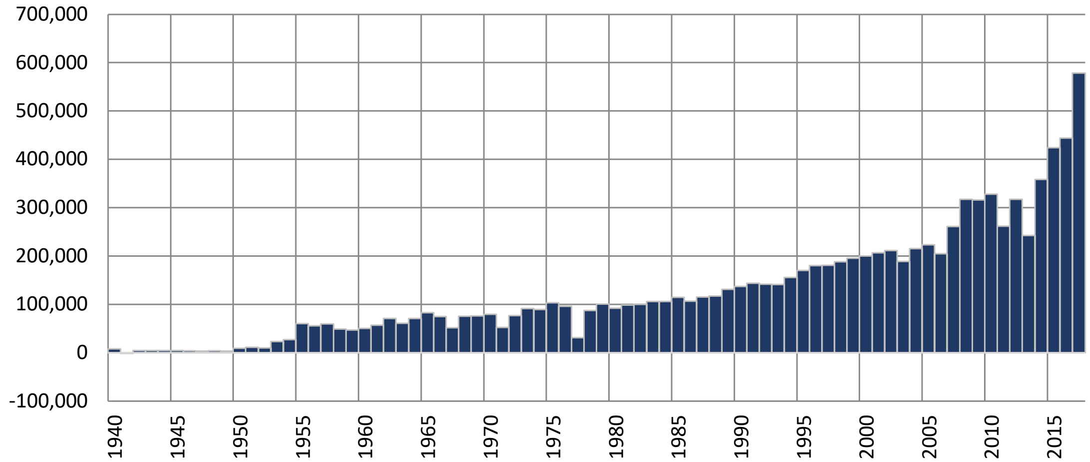
Run 18 - Conj Use 3: Auth Proj Acres (Pre-Comp M&I)

Simulated Differences in ILRG Model Outputs

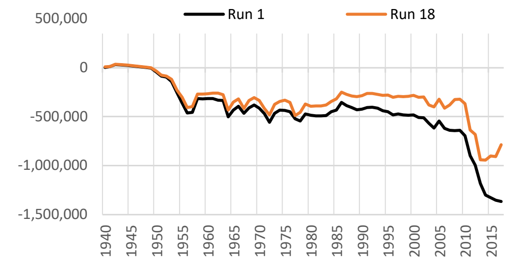
Run 18 minus Run 1

1940 - 2017 (acre-feet)

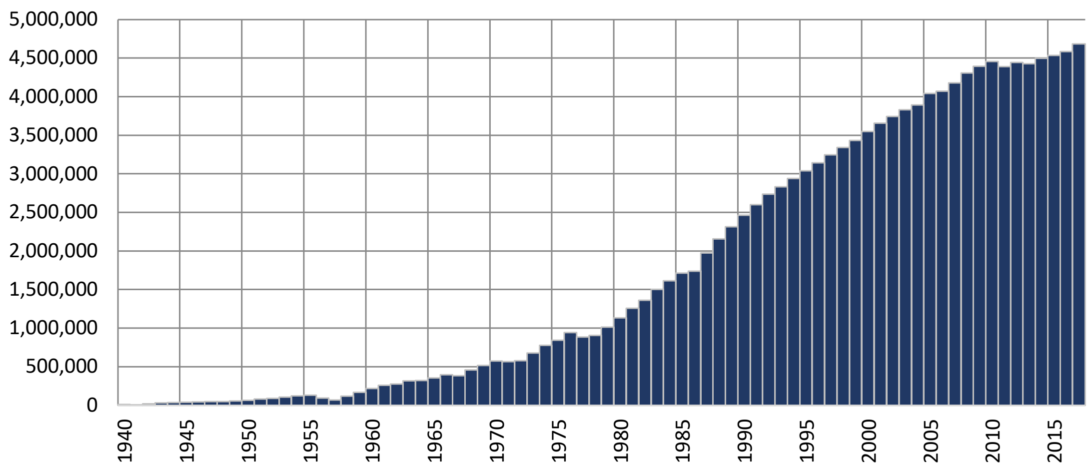
Cumulative Annual Rincon-Mesilla Groundwater Storage



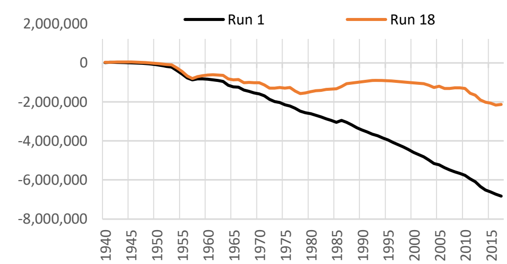
Period	Average Difference
1951-2017	8,502
1951-1978	2,799
1979-2005	5,026
2006-2017	29,633
1985-2017	14,320
1985-2005	5,570



Cumulative Annual Hueco Groundwater Storage



Period	Average Difference
1951-2017	68,950
1951-1978	29,958
1979-2005	116,180
2006-2017	53,664
1985-2017	93,028
1985-2005	115,521



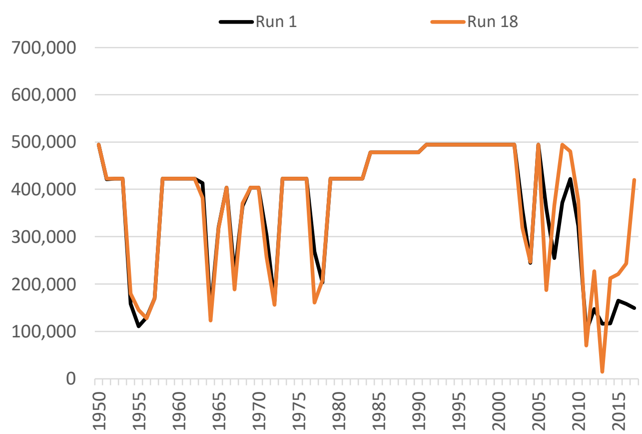
Notes:

Cumulative storage change in alluvial and non-alluvial aquifers.

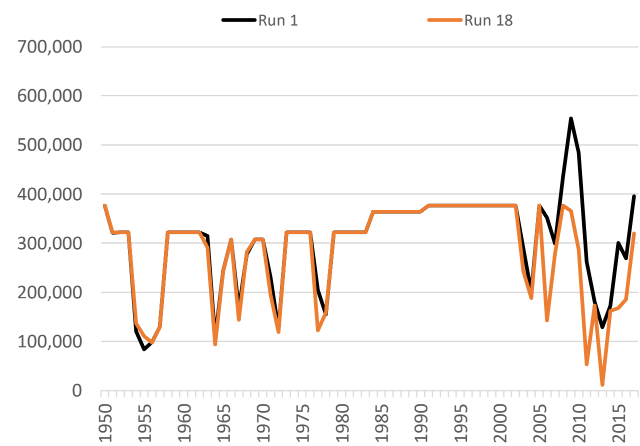
Average differences calculated as (Final Storage - Initial Storage)/(no. years).

Run 18 - Conj Use 3: Auth Proj Acres (Pre-Comp M&I)
Annual Allocation and Charges
Run 18 v. Run 1
ILRG Model
1950 - 2017 (acre-feet)

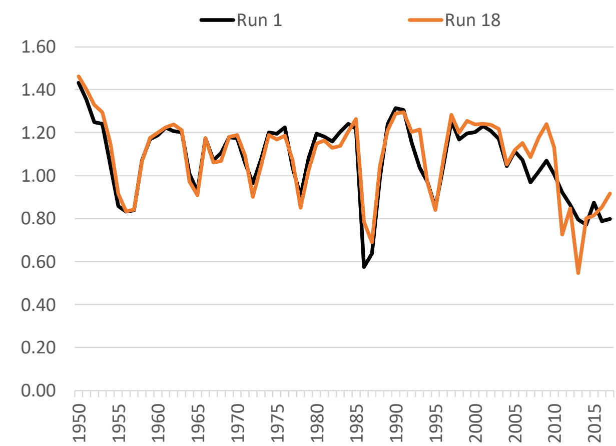
Total Allocation - EBID



Total Allocation - EPCWID

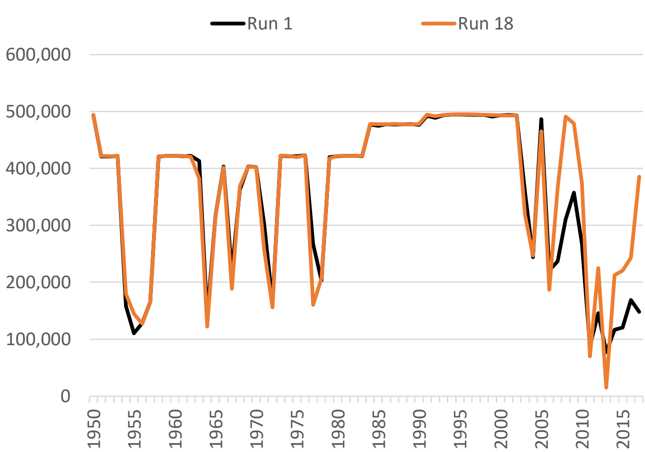


Diversion Ratio

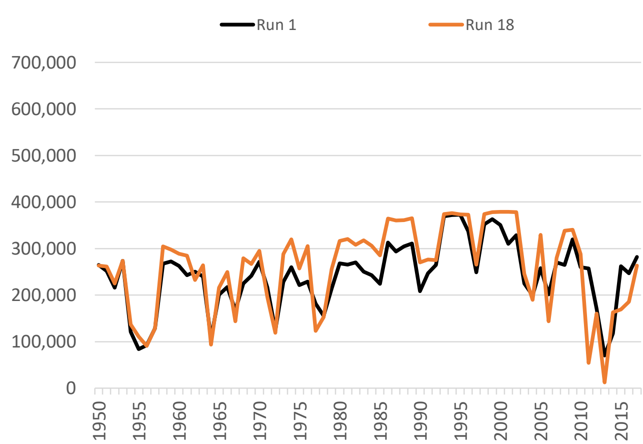


Note:
Computed as Total Charges/Caballo Release.

Annual Delivery Charges - EBID

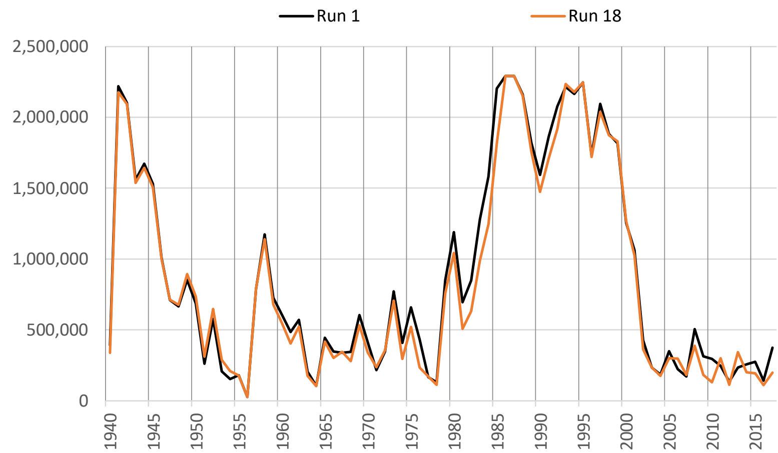


Annual Delivery Charges - EPCWID

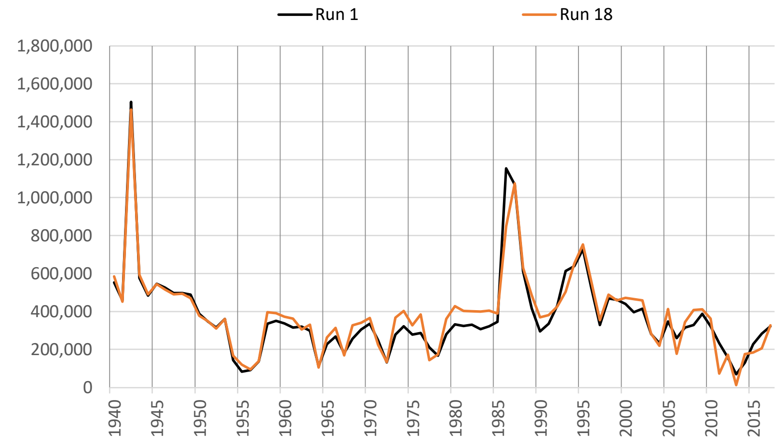


Run 18 - Conj Use 3: Auth Proj Acres (Pre-Comp M&I)
Annual Summary of Project Storage and Rio Grande Flows
Run 18 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

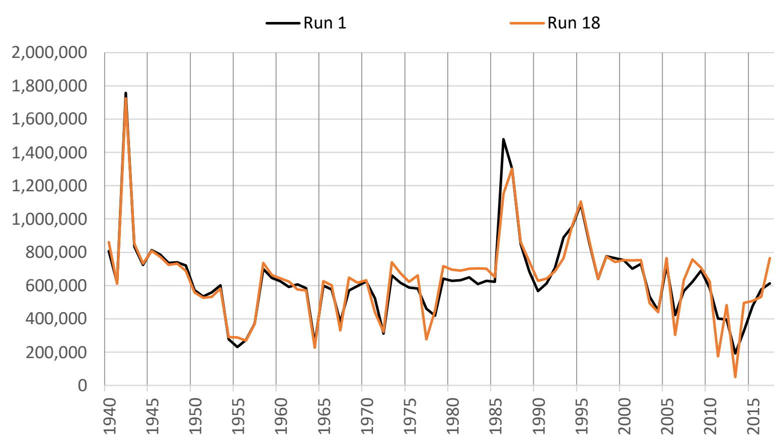
Total Year-End Project Reservoir Storage



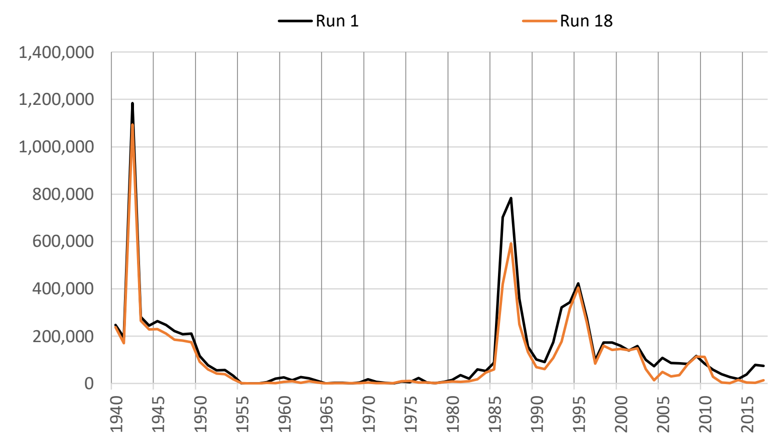
Rio Grande at El Paso



Rio Grande Below Caballo



Rio Grande at Fort Quitman

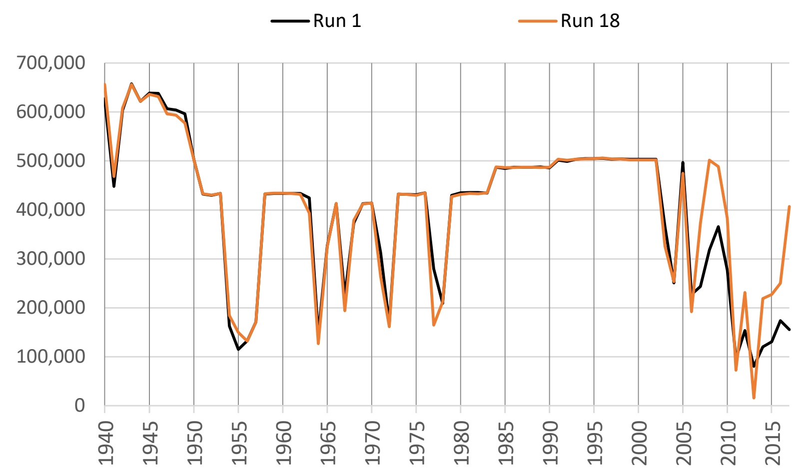


***Note different scales.**

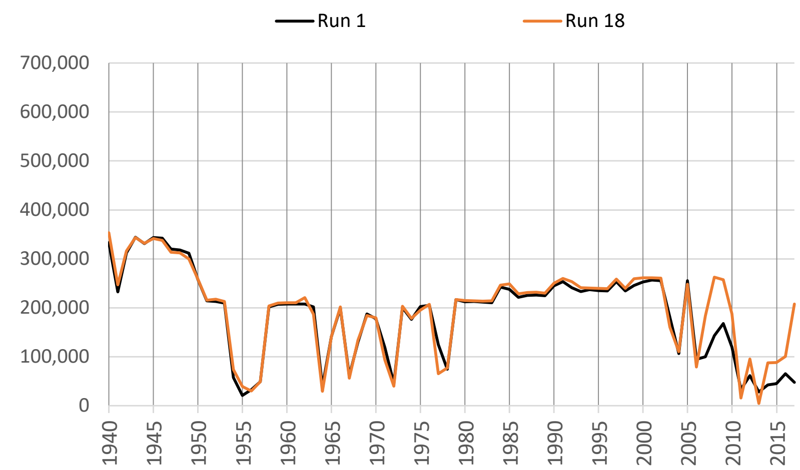
Run 18 - Conj Use 3: Auth Proj Acres (Pre-Comp M&I)
Irrigation Season Summary of Irrigation Operations
Run 18 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

EBID Total

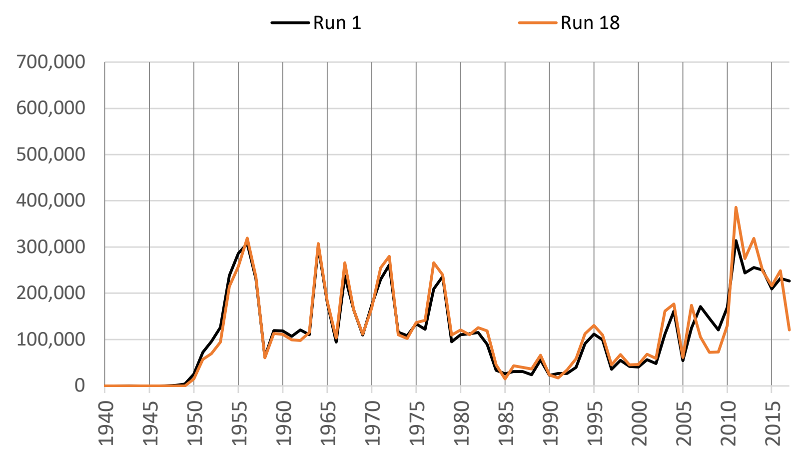
Net River Headgate Diversions



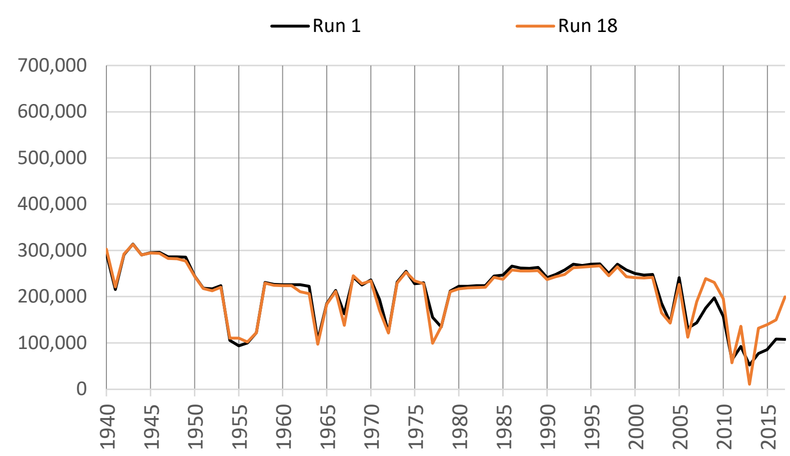
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries

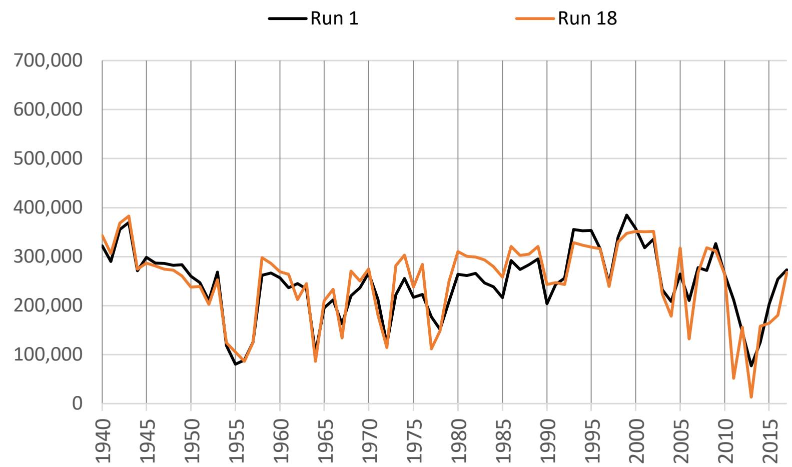


Notes: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).
Pumping includes Supplemental and Primary groundwater pumping.

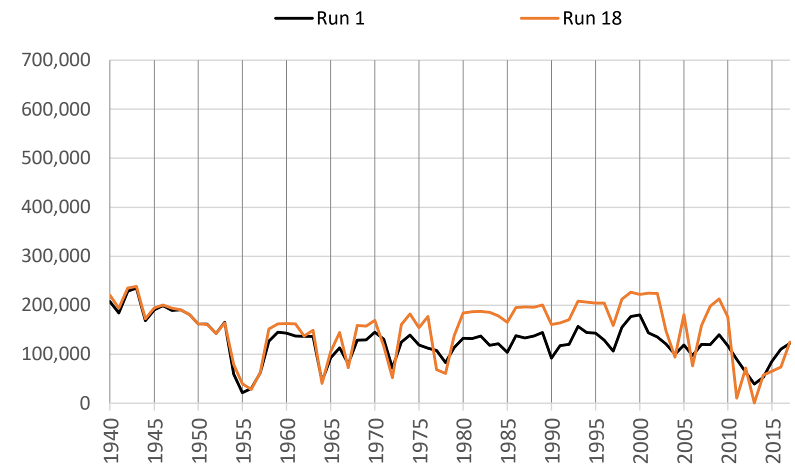
Run 18 - Conj Use 3: Auth Proj Acres (Pre-Comp M&I)
Irrigation Season Summary of Irrigation Operations
Run 18 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

EPCWID Total

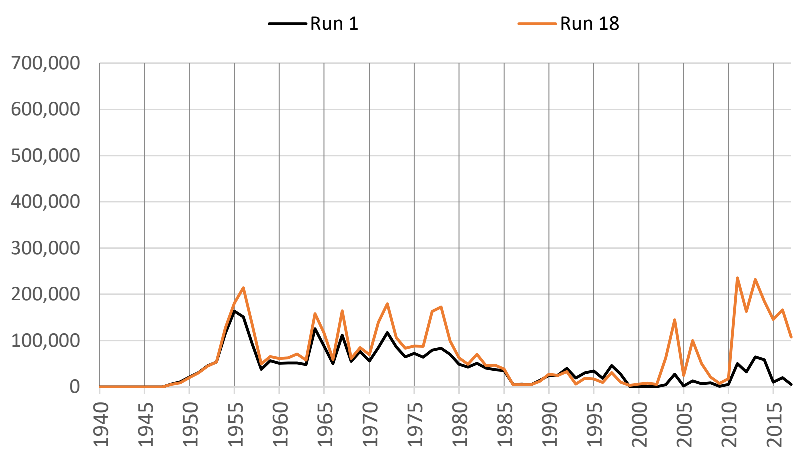
Net River Headgate Diversions



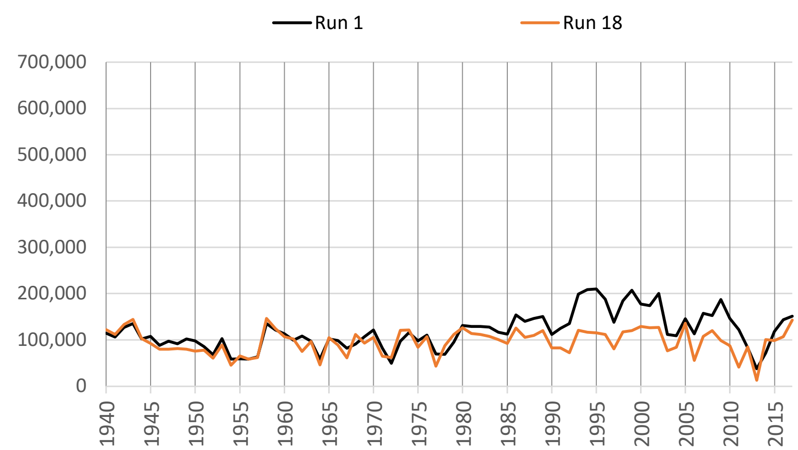
Farm Headgate Deliveries



Pumping



RHG Diversions - FHG Deliveries



Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

Run 18 - Conj Use 3: Auth Proj Acres (Pre-Comp M&I)

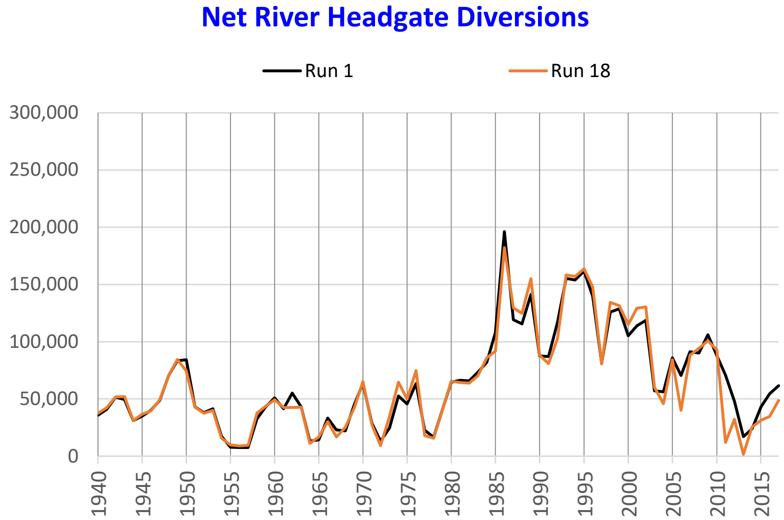
Irrigation Season Summary of Irrigation Operations

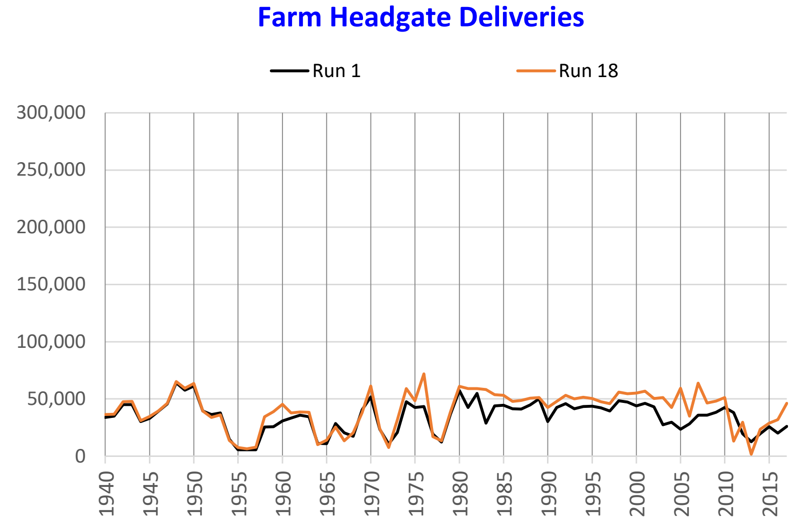
Run 18 v. Run 1

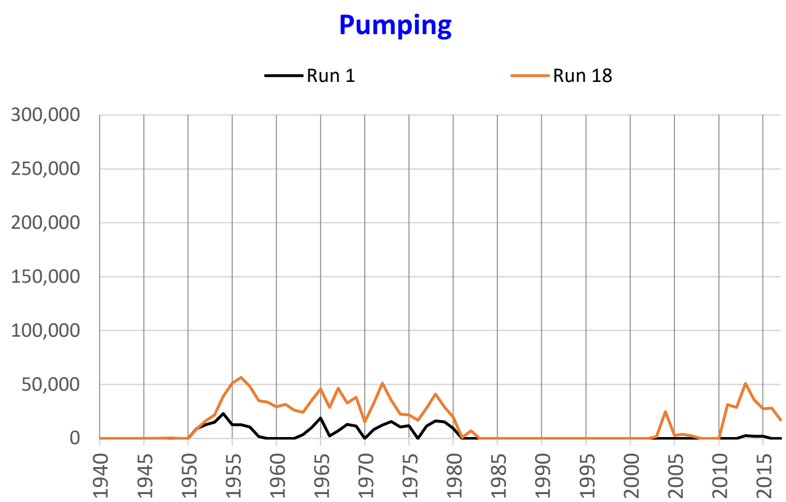
ILRG Model

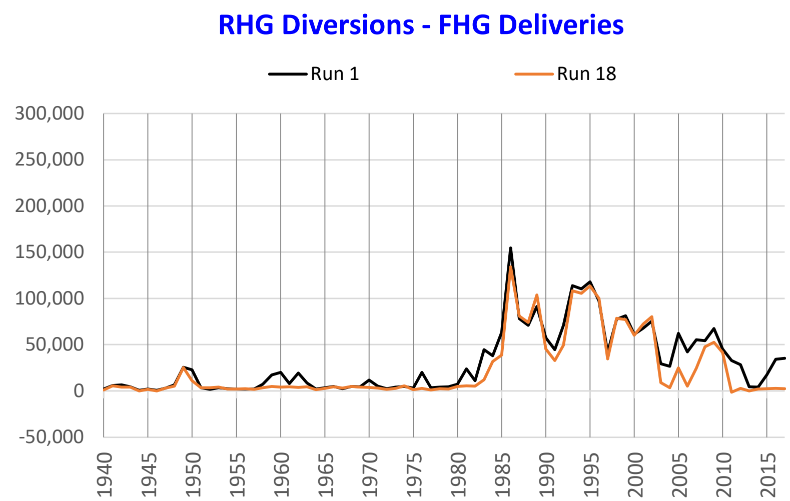
1940 - 2017 (acre-feet)

HCCRD Total









Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

Run 18 - Conj Use 3: Auth Proj Acres (Pre-Comp M&I)

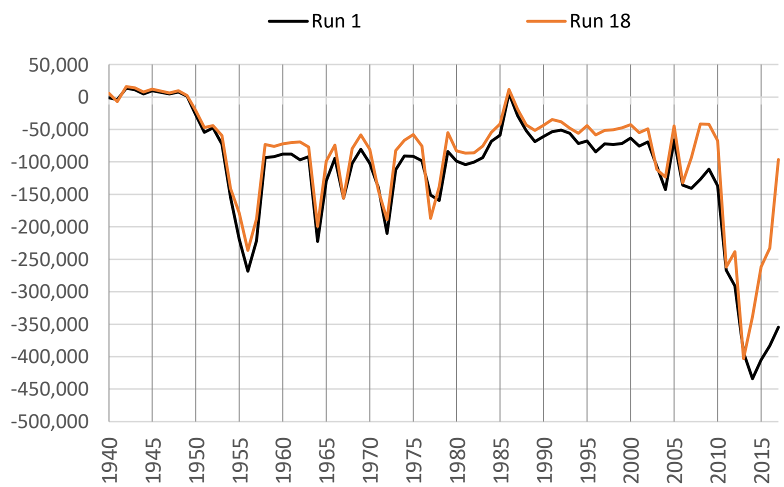
Cumulative Change in Ground Water Storage

Run 18 v. Run 1

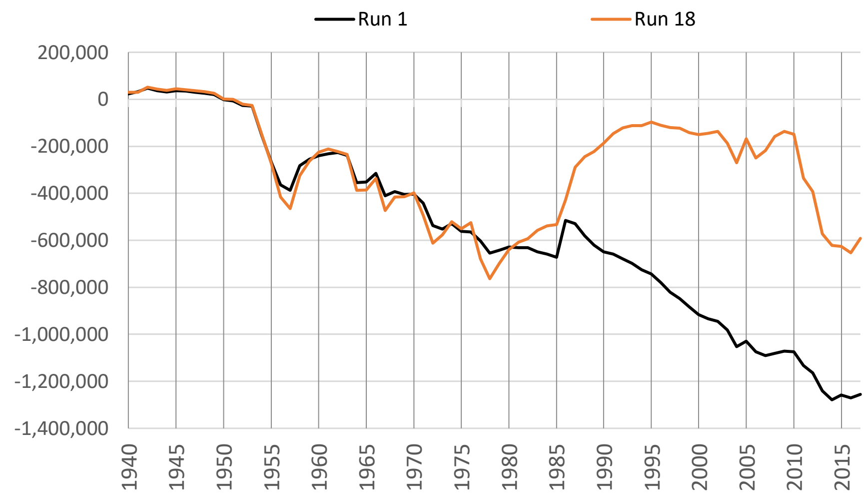
ILRG Model

1940 - 2017 (acre-feet)

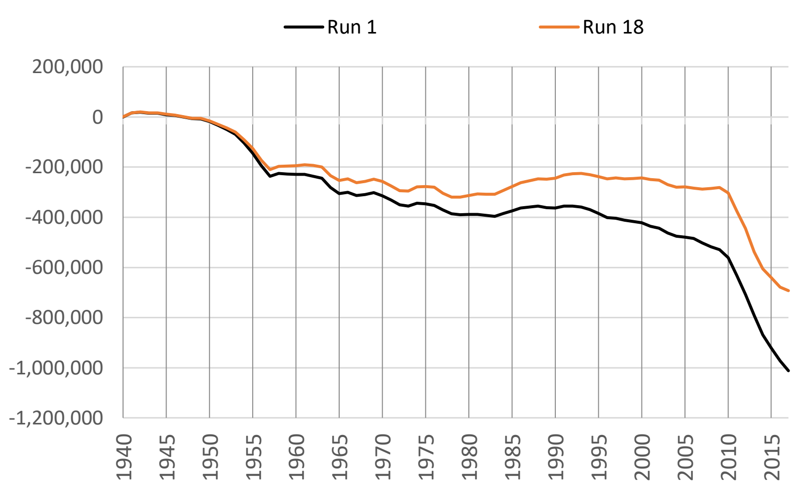
Rincon-Mesilla Alluvial Aquifer



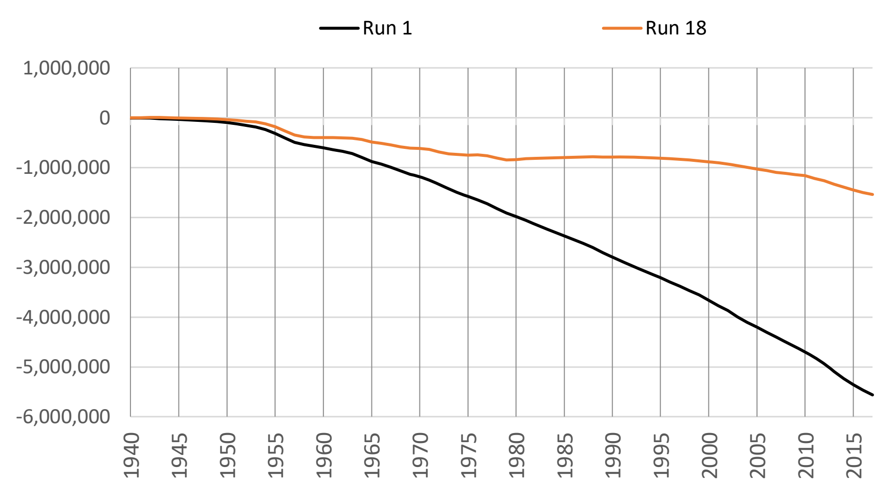
Hueco Alluvial Aquifer



Rincon-Mesilla Non-Alluvial Aquifer



Hueco Non-Alluvial Aquifer



***Note different scales.**

Run 18 - Conj Use 3: Auth Proj Acres (Pre-Comp M&I)

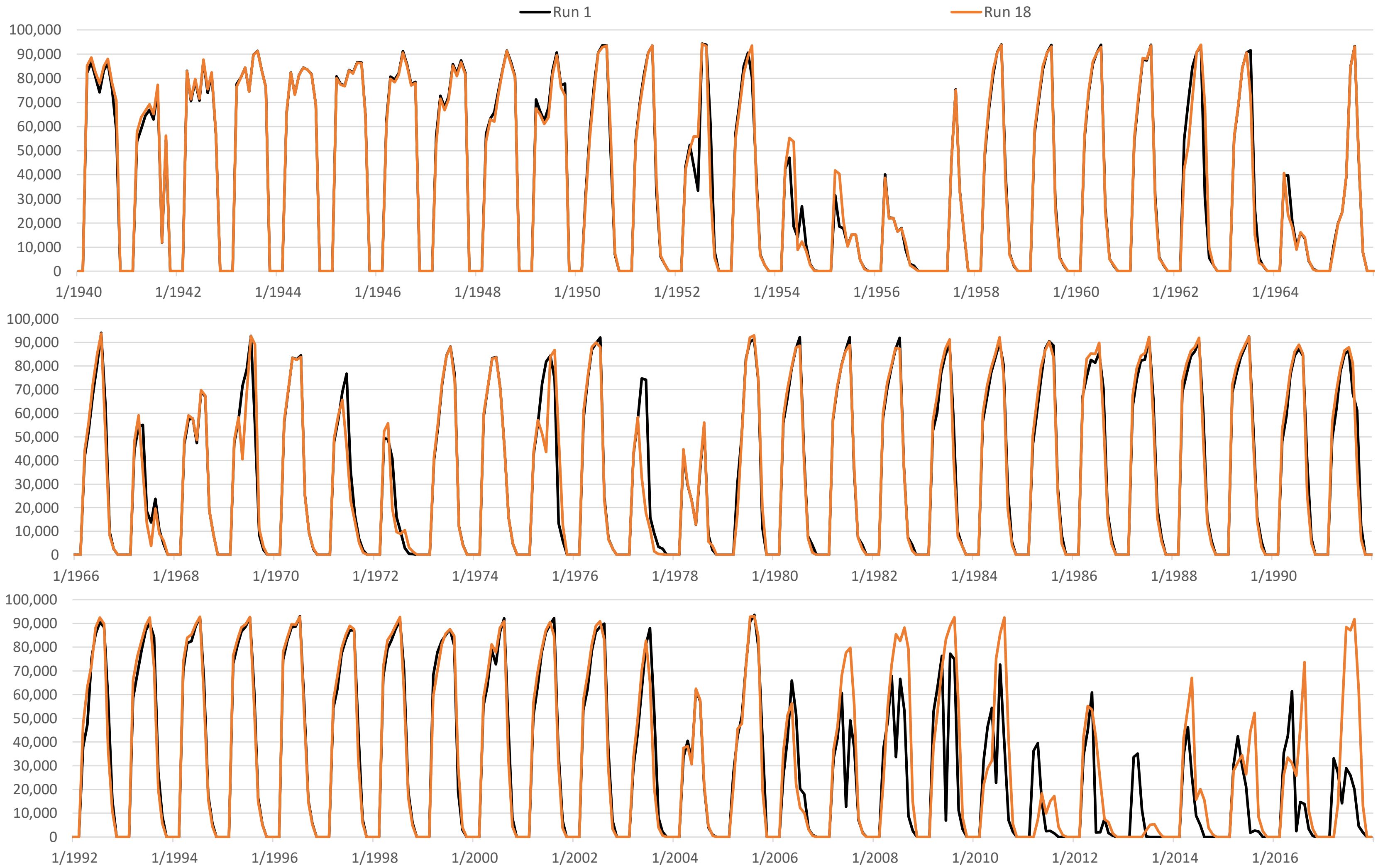
Monthly Net RHG Diversions

Run 18 v. Run 1

ILRG Model

1940 - 2017 (acre-feet)

EBID Total



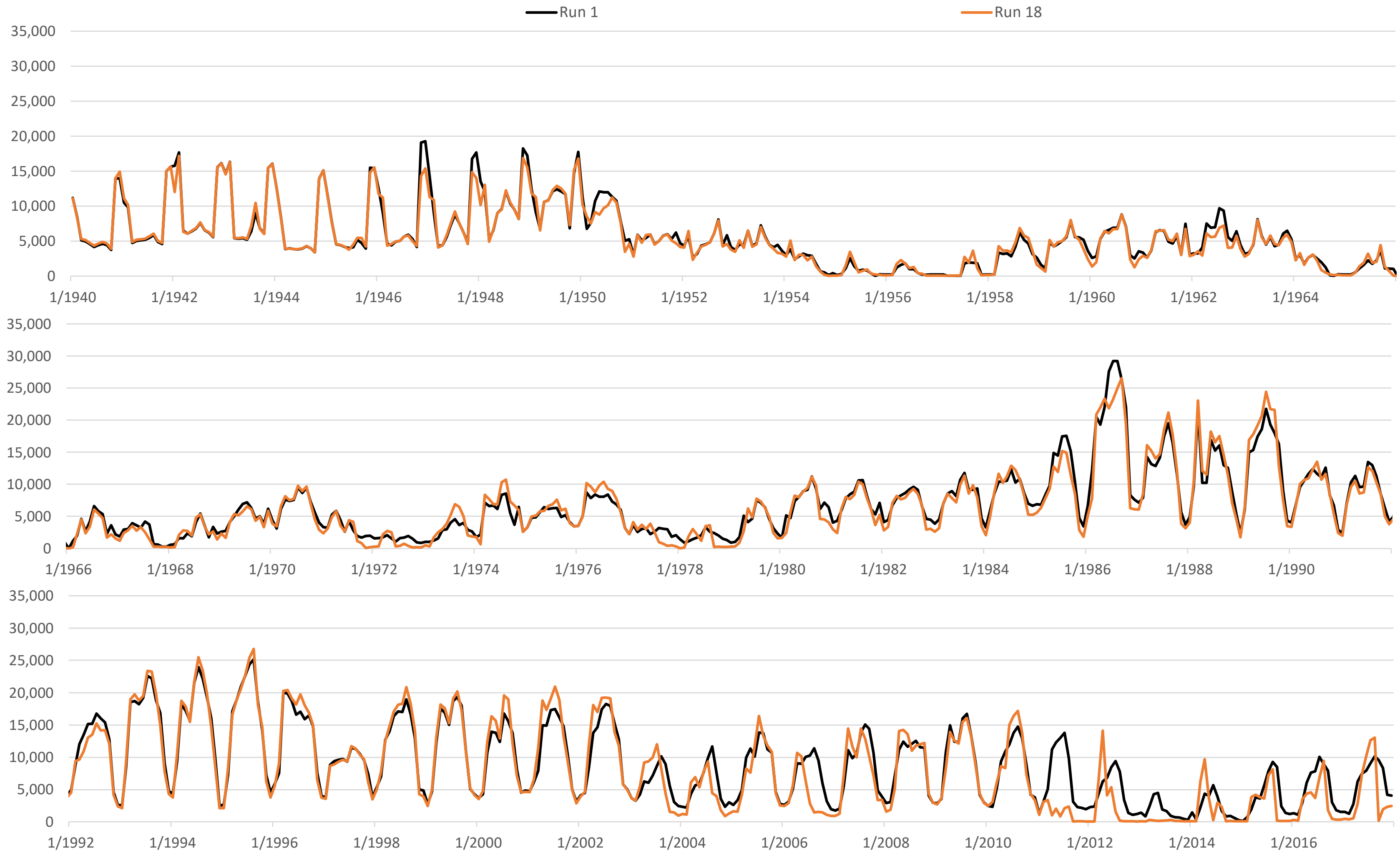
Note: EBID Net RHG Diversions are sum of Arrey, Leasburg, Eastside, and Westside minus EPV carriage, increased spill diversions, and flows to TX Mesilla (x 1.15 or 1.2 for losses).

Run 18 - Conj Use 3: Auth Proj Acres (Pre-Comp M&I)
Monthly Net RHG Diversions
Run 18 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

EPCWID Total

Note: EPCWID Net RHG Diversions are sum of Franklin Canal gage, Riverside Canal gage, Rogers WTP, R/U WTP, TX Mesilla minus Ascarate Wasteway and increased spill diversions.

Run 18 - Conj Use 3: Auth Proj Acres (Pre-Comp M&I)
Monthly Net RHG Diversions
Run 18 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)
HCCRD Total



Note: HCCRD Net RHG diversions are sum of Hudspeth Feeder Canal, Tornillo Drain, and Tornillo Canal at Alamo Alto.

Run 18 - Conj Use 3: Auth Proj Acres (Pre-Comp M&I)

End of Month Reservoir Storage (Elephant Butte + Caballo)

Run 18 v. Run 1

ILRG Model

1940 - 2017 (acre-feet)

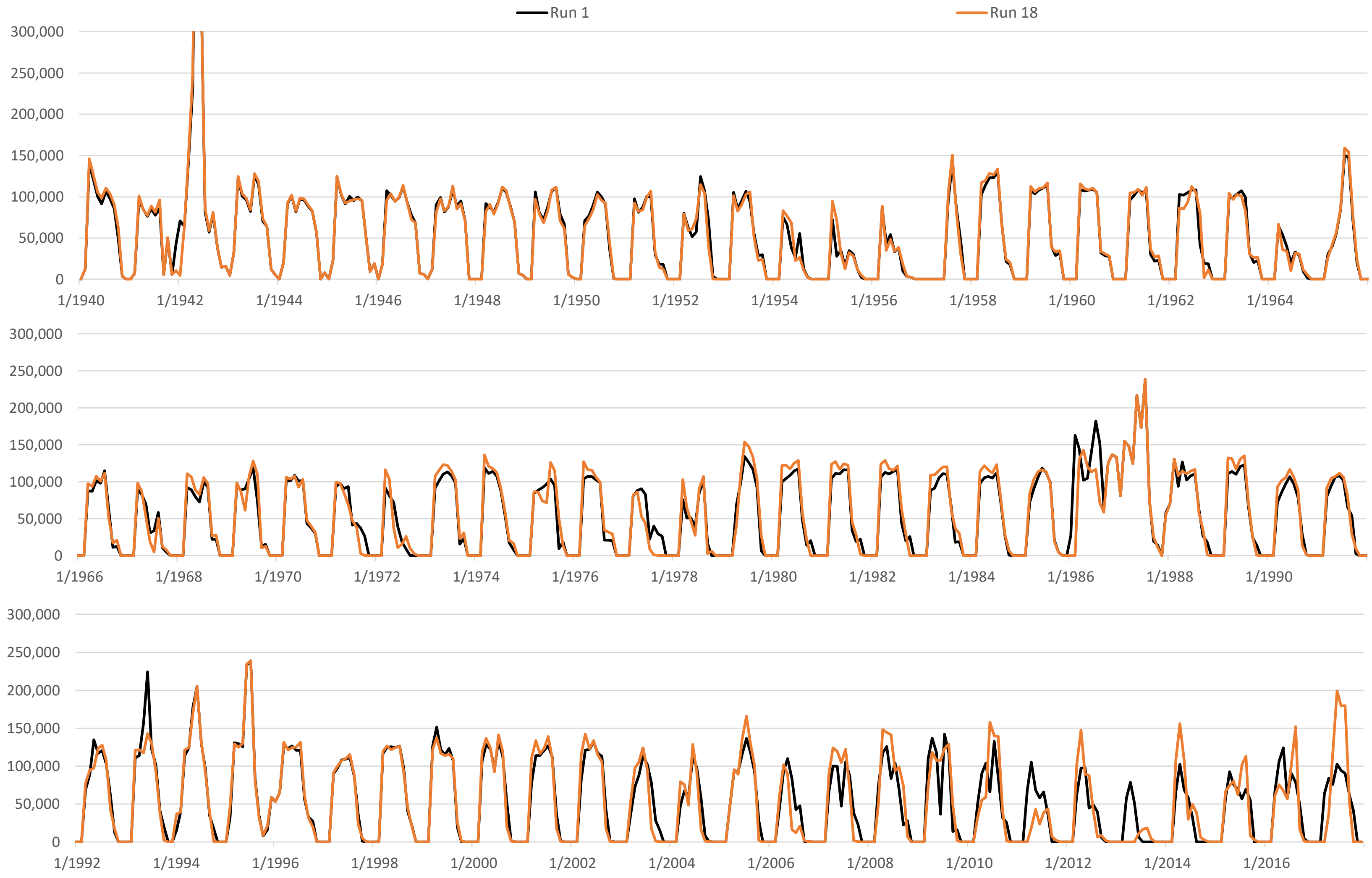
Run 18 - Conj Use 3: Auth Proj Acres (Pre-Comp M&I)

Monthly Caballo Releases

Run 18 v. Run 1

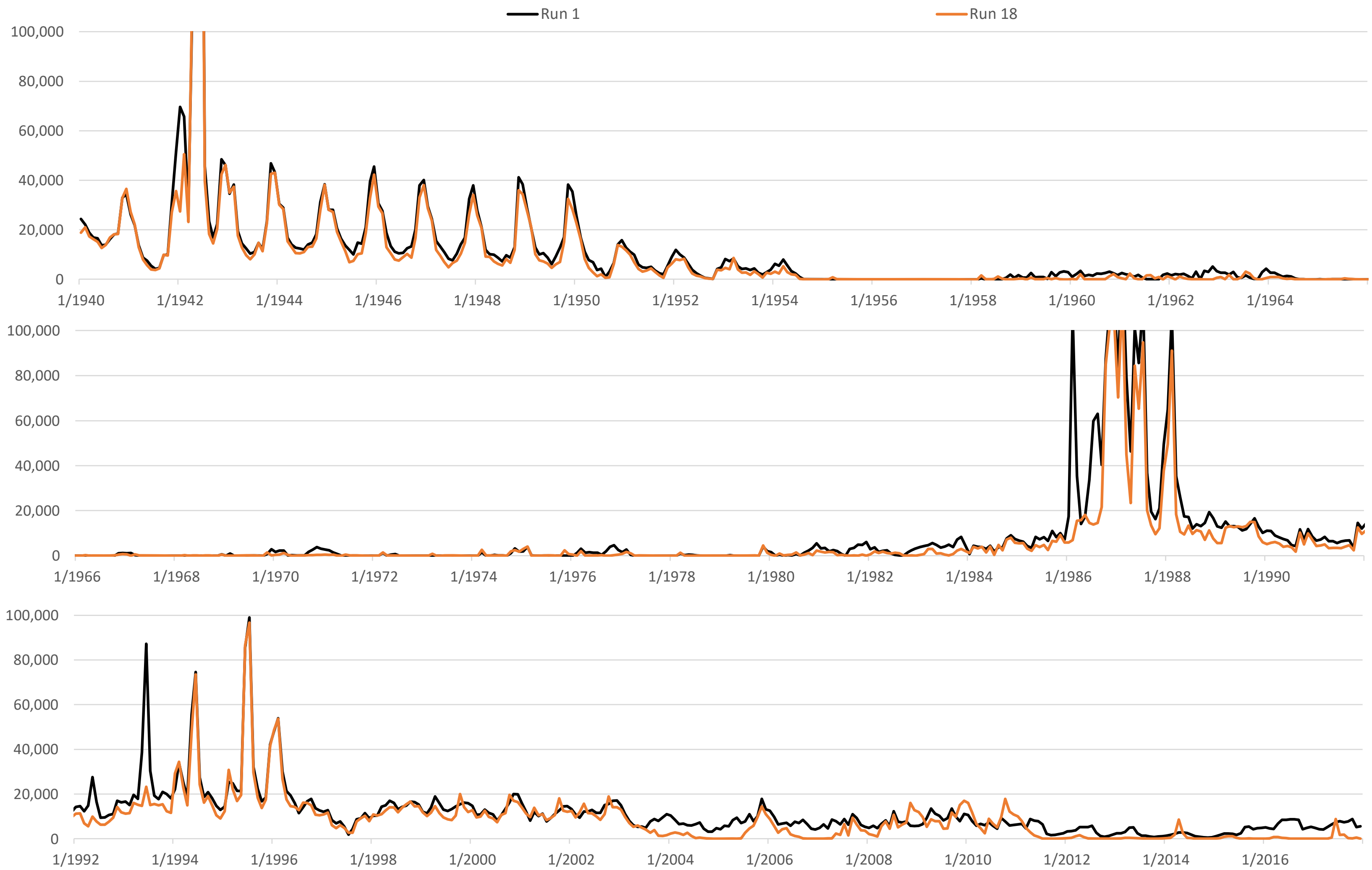
ILRG Model

1940 - 2017 (acre-feet)



Run 18 - Conj Use 3: Auth Proj Acres (Pre-Comp M&I)
Monthly Rio Grande at El Paso Flow
Run 18 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)

Run 18 - Conj Use 3: Auth Proj Acres (Pre-Comp M&I)
Monthly Rio Grande at Fort Quitman Flow
Run 18 v. Run 1
ILRG Model
1940 - 2017 (acre-feet)



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THE HISTORY OF INTERSTATE WATER USE ON THE RIO GRANDE: 1890-1955

STEVENS HISTORICAL RESEARCH ASSOCIATES

THE HISTORY OF INTERSTATE WATER USE ON THE RIO GRANDE: 1890-1955

Prepared for the New Mexico Office of the Attorney General
In the Matter of *State of Texas v. State of New Mexico and State of Colorado No. 141, Original*

STEVENS HISTORICAL RESEARCH ASSOCIATES
Jennifer Stevens, PhD.

Completed October 28, 2019

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List of Figures

List of Important People

Name	Role
Prof. Frank Adams	National Resources Committee, Co-Head of Rio Grande Joint Investigation
Prof. Harlan Barrows	National Resources Committee, Co-Head of Rio Grande Joint Investigation
John Bliss	New Mexico Engineering Advisor
Major Richard Burgess	Texas legal adviser
Delph Carpenter	Colorado Rio Grande Compact Commissioner, 1920s
Ralph Carr	Colorado legal advisor
Frank Clayton	Texas Rio Grande Compact Commissioner, 1930s
George Corlett	Colorado legal adviser
E.B. Debler	Reclamation Chief Engineer, 1930s, also United States engineering advisor during Compact negotiations
L.R. Fiock	Rio Grande Project Superintendent, 1920s-1940s
S.O. Harper	Reclamation Asst. and later, Chief Engineer 1930s, and United States representative/chair, Rio Grande Compact Commission Chair
Roland Harwell	Manager of EPCWID, 1920s, 1930s
M.C. Hinderlider	Colorado State Engineer, Rio Grande Compact Commissioner, 1930s
L.M. Lawson	Rio Grande Project Superintendent,1920s; International Boundary Water Commission, 1930s
Thomas McClure	New Mexico State Engineer, RG Compact Commissioner, 1920s-1930s
T.H. McGregor	Texas State Engineer, Rio Grande Compact Commissioner, 1920s-early 1930s
Elwood Mead	Commissioner, Reclamation Service/Bureau of Reclamation, 1924-1936
Ralph I. Meeker	Colorado irrigation engineer, 19teens and 1920s
John C. Page	Commissioner, Reclamation Service/Bureau of Reclamation, 1936-1943
Harlow M. Stafford	Engineer in Charge, Rio Grande Joint Investigation
Royce J. Tipton	Colorado engineering adviser
F.E. Weymouth	Reclamation Chief Engineer, 1920s
Francis Wilson	Texas Rio Grande Compact Commissioner, 1920s

Statement of Qualifications

Author's Background and Scope of Work

My name is Jennifer Stevens. I earned a Ph.D. in History at University of California, Davis in 2008. Prior to that, I earned a Master of Arts Degree in History in 1995, and Bachelor of Arts Degrees in Political Science and History in 1993, all at University of California, Santa Barbara. I have been conducting historical research in the public sector for litigation and other purposes since 1995. I am a Professor of Practice and an Assistant Clinical Professor in the School of Public Service at Boise State University, where I teach classes in Urban and Environmental History.

Trial and Deposition Experience

In the past five years, I have provided deposition and trial testimony as follows:

Deposition Testimony

2018: United States v. Pioneer Natural Resources Company et al, Civil Action 1:17-CV-00168-WJM-NYW

2018: Billings County, et.al v. United States of America 1-12-CV-00102-DLG-CSM

2016: Cyprus Amax Minerals Company v. TCI Pacific Communications and CBS Operations, Inc. (11-CV-252-JED-PJC, Federal District Court, N.D. Okla)

2015: Snake River Basin Adjudication Subcase Nos. 63-33732, 63-33733, and 63-33734

2014: Shoshone-Bannock Tribes Land Use Department and Fort Hall Business Council vs. FMC Corporation (C-06-0069, C-07-0017, C-07-0035)

Trial Testimony

March 2018: David Stanley v. Board of County Commissioners of Mora County, et. al. (D-809-CV-2011-00252, Taos District Court, State of New Mexico).

February 2018: Cyprus Amax Minerals Company v. TCI Pacific Communications and CBS Operations, Inc. (11-CV-252-JED-PJC, Federal District Court, N.D. Okla)

April 2014: Shoshone-Bannock Tribes Land User Department and Fort Hall Business Council vs. FMC Corporation (C-06-0069, C-07-0017, C-07-0035)

History of Western Rivers Experience

I have investigated the history of several western rivers on behalf of clients engaged in matters related to water development and management in the West since the 1990s. Some of those rivers are listed here:

- Boise River (Idaho);
- Big Wood River (Idaho);
- Columbia River (Washington/Oregon);

- Deschutes River (Oregon);
- Duwamish River (Washington);
- Gila River (Arizona)
- Kern River (California);
- Little Missouri River (North Dakota);
- Little Salmon River (Idaho);
- Missouri River (North Dakota);
- North Platte River (Nebraska);
- Payette River (Idaho);
- Pecos River (New Mexico);
- Salmon River (Idaho);
- Salt River (Arizona);
- Snake River (Idaho);
- Verde River (Arizona).

I have worked on behalf of irrigation districts as well as state agencies. Additional details about my educational and professional background can be found in Appendix B at the back of this report.

Methodology and Materials Consulted

For the current matter, I was contacted by counsel for the New Mexico Office of the Attorney General in 2013 to investigate the history of New Mexico and Texas's use of the Rio Grande waters, especially leading up to and during negotiations for the Rio Grande Compact of 1938. Broadly speaking, I was tasked with exploring the following overarching questions:

- What were the Compact Commissioners' understandings of the intent of the 1938 Compact and how it would impact the management of Project water within the states?
- How did officials manage groundwater, and what connections did they make between groundwater use and Project surface water?
- What was the intent regarding the water that was allowed to be delivered to the Hudspeth County Conservation and Reclamation District No. 1?

To conduct this study, I employed the typical and accepted historical research methodology. I began by reviewing materials provided to me by counsel, all of which can be found at the New Mexico Office of the State Engineer (NM OSE) Library. I then traveled to and/or reviewed primary sources from a variety of repositories:

- El Paso Times and El Paso Herald, 1917-1923 (newspapers.com);
- Records of the Bureau of Reclamation, R.G. 115 (U.S. National Archives, Denver);

- Elephant Butte Irrigation District Records, 1906-1969, MS235 (New Mexico State University Library);
- Raymond A. Hill Papers, 1890-1945 (University of Texas, Austin);
- New Mexico State Engineer Records, 1888-[ongoing] (New Mexico State Records and Archives);
- Governor Clyde K. Tingley Papers (New Mexico State Records Center and Archives);
- Governor John E. Miles Papers (New Mexico State Records Center and Archives);
- Miscellaneous papers boxes (New Mexico Interstate Stream Commission, Basement);
- Rio Grande Compact Commission Records, 1924-1942 (University of Texas, Austin);
- Rio Grande Compact Commission Records, 1939-1968, MS406 (University of Texas, El Paso);
- Frank Adams Papers (University of California, Riverside);
- Records of the National Resources Planning Board, Region VII, R.G. 187 (U.S. National Archives, Denver);
- Records of the Geological Survey, R. G. 57 (U.S. National Archives, II);
- Records of Texas Governor James Allred, 193101939 (Texas State Library and Archives Commission);
- Records of the Texas Water Commission, 1913-1986 (Texas State Library and Archives Commission);
- Records of the Texas Reclamation Engineer, Historical Files, ca. 1908-1960, Acc. 1982/006 (Texas State Library and Archives Commission);
- Records of Boundary and Claims Commissions and Arbitrations, 1716-1994, R.G. 76 (U.S. National Archives, II);
- International Boundary & Water Commission, R.G. 76 (U.S. National Archives, Fort Worth);
- Records of the National Resources Planning Board, R.G. 187 (U.S. National Archives, II);
- Records of the Soil Commission Service, R.G. 114 (U.S. National Archives, II);
- Records of the Office of the Chief of Engineers, R. G. 77 (U.S. National Archives, Denver);
- General Records of the Department of State, R. G. 59 (U.S. National Archives, II);
- El Paso (Texas) Irrigation Study Records, 1994 (University of Texas, Austin);
- Richard Fenner Burges Papers, 1897-1940 (University of Texas, Austin);
- Texas Water Commission Minutes, 1991/041, 1992/043 (Texas State Library and Archives Commission);
- Records of the Texas Natural Resource Conservation Commission, Water Rights Application Files (Texas State Library and Archives Commission);

After gathering relevant documents, I reviewed and analyzed them, after which I wrote the following report. My primary conclusions are listed below in “Expert Opinions.”

All publications as well as all matters in which I have offered testimony over the previous four years can be found in Appendix B.

Statement of Compensation

I am compensated at a rate of $150 per hour for the work performed in this matter. My compensation is not dependent on the substance of my opinions or the outcome of this litigation.

Expert Opinions

1. The use of the waters of the Rio Grande's Upper Basin evolved over time, often resulting in significant interstate and international tensions. Operations on the river were in near-constant flux after the federal government began engineering and controlling its flows. The Bureau of Reclamation and other federal agencies made frequent changes to Rio Grande Project infrastructure aimed at attempting to make the system operate more efficiently and/or solving international issues with Mexico. The 1938 Rio Grande Compact built flexibility into its administration to accommodate such ongoing and anticipated future changes.

2. The success of the Rio Grande Project depends upon the administration of the water to the lands within the project boundary as a single unit, with an equal allocation of water to each Project acre. In fact, the compromise at the 1904 Irrigation Congress in El Paso depended upon this conceptual administration and permitted the parties to finally agree to the Elephant Butte Dam over the International Dam at El Paso. This concept of a unified Project was recognized by the framers of the 1938 Rio Grande Compact.

3. Lands in the Hudspeth County Conservation and Reclamation District have never been included within the Rio Grande Project boundaries and, despite several unsuccessful efforts to join the Project or to secure a reliable source of water, have never been entitled to receive water other than the unavoidable waste from the Project. Reclamation consistently and repeatedly informed Hudspeth that waste water delivered to its boundary at the lower end of the Project would always be unreliable and secondary to uses on Project lands. Reclamation officials recognized the obligation to operate the Project as efficiently as possible, and chose to attempt to improve Project efficiencies over time, even knowing that such increases in efficiencies could lead to reductions in "unavoidable waste" at the end of the Project, which would have the effect of reducing water available to Hudspeth users. Therefore, Hudspeth's water supply was always in jeopardy, even after the 1938 Compact was signed. Any concept that the framers of the 1938 Rio Grande Compact intended to maintain a supply of water for Hudspeth users at the levels they were receiving at the time the Compact was negotiated and signed is contrary to the entire body of historical evidence.

4. During the negotiations leading to the 1938 Rio Grande Compact, Texas used the issue of water quality to demand and receive a higher "normal release" of water from Elephant Butte Reservoir than would otherwise have been justified based on the needs of irrigable Project acreage alone, but not to provide any additional supply of water for lands below the Project.

5. The United States' Rio Grande Project water filings with the New Mexico Territorial Engineer in 1906 and 1908 did not include, nor were they intended to include, the Upper Rio Grande Basin's groundwater. The scientific understanding of connections between groundwater and surface water was too nascent in the first decades of the 20th century for Reclamation to have intended such an overreach, and the historical record provides no support for a contradictory conclusion.

6. Scientific understanding of the relationship between surface and groundwater supplies in the Upper Rio Grande Basin was still in its infancy at the time of the 1938 Rio Grande Compact negotiations, and the Rio Grande Joint Investigation gave scant attention to the issue of groundwater, particularly in the area below Elephant Butte Reservoir, partly at the insistence of Texas. Simply put, the Compact

framers did not evince an intent to preclude future groundwater development in the basin. All parties understood that the 1938 Rio Grande Compact was not intended to freeze development in the Upper Rio Grande Basin, as had been the intent of the 1929 temporary Compact, but instead understood that it was designed to provide a realistic path forward for future additional development throughout the basin, consistent with the rights of each compacting state.

Introduction

The Rio Grande rises in Colorado's San Juan Mountains, and flows 1900 miles through Colorado, New Mexico, Texas, and Mexico to the Gulf of Mexico. The Upper Rio Grande Basin stretches from the river's headwaters south through many valleys of rich farmland as well as major American and Mexican cities that have grown in population over the past 150 years, ending at the narrows below Fort Quitman, the natural dividing point of the river from the Lower Rio Grande Basin. Policy makers have always deemed the location of this former Army fort (abandoned in the 1880s) to be the natural hydrological dividing point of the river, since below this point, tributaries with headwaters on the Mexican side of the river contribute their runoff to the Rio Grande, constituting the majority of its volume thereafter. Along the river's route from Colorado to Fort Quitman, both farmers and cities divert and return the Rio Grande's water over and over, using it to water crops, provide drinking water, and power factories. The major agricultural valleys in downstream order are the San Luis Valley in Colorado, the Middle Rio Grande, the Palomas, Rincon, and Mesilla Valleys in New Mexico, and the El Paso and Hudspeth Valleys in Texas. Likewise, the major cities along the river in downstream order include Albuquerque and Las Cruces in New Mexico, El Paso in Texas and Juarez in Mexico, the latter two of which are situated across the Rio Grande from one another. Fort Bliss, a United States Army base, is located in metropolitan El Paso, northeast of the city.

In prehistoric times, the river's water was ample to provide for the needs of the small communities situated along its banks. The regular spring floods scoured the valley floor and the silt-laden water brought nutrients to the surrounding lands, making fertile soil for agriculture. But as white American settlement encroached in the mid-19th century, increasing demands on the limited resource led to battles over the right to use it. The battles were fought farmer to farmer, county to county, state to state, and even country to country.

As a result, the Rio Grande today is highly engineered and tightly regulated, the resource having been legally relegated to strict use limits after many courtroom fights. Water is stored behind several dams, including the Rio Grande Project's Elephant Butte Dam, the system's largest, from which water is released during the dry summer months and delivered to canals and laterals that serve arid lands which claim long-standing water rights. Because the Bureau of Reclamation's Rio Grande Project controls such a large volume of water in a long stretch of the river between New Mexico and Texas, operation of the river system as a unit has been a fundamental tenet of the river's management. With varying degrees of scientific understanding, Project managers have historically recognized that many factors can affect delivery of water along the entire river, whether downstream or upstream, and that any change to a single factor could result in wholesale changes to the Rio Grande's operations in any given year. From the earliest years of river management at the turn of the 20th century all the way up to the present, comprehension of the effects related to illegal excess diversions, volume of irrigated acreage, duty of water, and groundwater pumping have gradually improved and become more precise, leading to an evolution of management decisions over the decades.

This report will provide the history of water use on the Rio Grande as well as the interlocking work of various federal entities from the 1890s forward. Specifically, it will detail the history of the years leading up to and including the formation of the Rio Grande Project ("Project"), examining the role of international diplomacy in the river's management as well as the domestic policy goals that were incorporated into the Project's development. It will also examine the role that the United States has played in protecting domestic users from infringements on the resource by Mexican water users. Finally, the report will investigate the role of the Project in the 1938 Rio Grande Compact ("Compact") negotiations, the parties' goals during the agreement's lengthy negotiation process, and the Compact's implementation in the years following ratification.

Chapter 1: Setting the Stage: 1890s to 1920s

Origins of Conflict

The years leading up to the authorization of the Rio Grande Project in 1905 were rife with tension and dissent among river users. Along the river's entire length, disputes had arisen about excess depletions. Up near the river's headwaters in southern Colorado, a wave of settlers had descended upon the San Luis Valley in the late 1880s and early 1890s, settling on and proving up lands for new farmsteads. Meanwhile, hundreds of miles away, Mexico's downstream uses were also expanding, and that country complained that Colorado settlers' actions were harming their water rights.

Other downstream users located in New Mexico and Texas also blamed Colorado for water shortages, and it was easy to see how they drew that conclusion. The federal government had granted homestead patents to hundreds of thousands of acres in Colorado in the late 19th century. By 1891, more than 2,000 artesian wells had been dug to water lands in the San Luis Valley,[1] and by 1892, 925 irrigation ditches were diverting enough water from the surface waters of the Rio Grande to irrigate 400,000 acres in Colorado alone.[2] With those numbers, it was logical to conclude that Colorado's rapid increase in depletions were the cause of shortages for downstream users.

Several responses to the shortages emerged from the downstream water users. First, citizens in New Mexico and Texas formed the Rio Grande Dam & Irrigation Company in 1893 for the express purpose of building a storage dam at Elephant Butte in New Mexico's Palomas Valley, and obtained a right of way from the Secretary of the Interior to construct the structure over public lands.[3] Second, Mexico engaged in diplomatic negotiations with the U.S. State Department, registering official complaints about the United States' taking of Mexican water that belonged to that country by prior right.[4] Third, under the authority of the 1889-established International Boundary Commission, the U.S. Army Corps of Engineers and engineers from Mexico initiated an investigation of water use along the Rio Grande in 1896 to provide data to the U.S. government with which to make informed decisions about the river's management. The purpose of the 1896 study was two-fold. First, the United States needed to determine whether its citizens had in fact taken Mexico's water which they claimed belonged to them by "ancient right of prior appropriation."[5] Second, the United States wanted to assess whether there was adequate water in the river to construct a dam for storage at El Paso – in addition to the private dam planned upstream at Elephant Butte – which could assist the United States in compensating Mexico some of its water.[6]

The findings of the 1896 study were devastating to Colorado. Civil Engineer W.W. Follett, who worked for the International Boundary Commission, found that water use in Colorado had increased by 200% since 1879 and concluded that expanding diversions there led to downstream flows at El Paso that were 1,000 cubic feet per second (cfs) lower than they would have been without Colorado's increasing depletions.[7] The study also found

1 James A. French, "Report of James A. French. San Luis Valley, Colo.," 1910, 18, New Mexico Office of State Engineer Library. Hereafter "NM OSE Library."

2 W. W. Follett, "A Study of the Use of Water for Irrigation on the Rio Grande Del Norte Above Fort Quitman, Texas" (Proceedings of the International Boundary Commission, November 1896), 160, NM OSE Library.

3 George B. Anderson, History of New Mexico: Its Resources and People, vol. II (Los Angeles: Pacific States Publishing, 1907), 1001; W. W. Follett, "A Study of the Use of Water for Irrigation on the Rio Grande Del Norte Above Fort Quitman, Texas," 5.

4 Ottamar Hamele, "The Embargo on the Upper Rio Grande," November 11, 1924, 1–28, NM OSE Library.

5 W. W. Follett, "A Study of the Use of Water for Irrigation on the Rio Grande Del Norte Above Fort Quitman, Texas," 1.

6 W. W. Follett, 1.

7 W. W. Follett, 170.

that there was not enough water in the river to support construction of both the private dam at Elephant Butte as well as a government dam at El Paso; "one of these projects, in the opinion of the [International Boundary] commission must give way to the other, or at least, if both are built, that at Elephant Butte must in some way be restrained from using water already appropriated by the citizens of the El Paso Valley, both Mexicans and Americans."[8]

The United States government responded to the study results with swift and firm actions, some of which were recommended by Mexico. First, on December 5, 1896, the U.S. Secretary of the Interior directed its sub-agency, the General Land Office, to suspend all right-of-way applications for irrigation through public lands in the Rio Grande Basin in Colorado and New Mexico.[9] This action became known as "the embargo," and the restriction (with some modifications) remained in place until the 1920s. Second, following a series of discussions and actions, the U.S. Attorney General officially opined that the Rio Grande was a navigable river. His ruling had the effect of suggesting that right of way granted to the Rio Grande Dam and Irrigation Company was invalid, since the Secretary of the Interior had not possessed the legal power to grant it. Instead, the Secretary of War was the only official empowered to grant such a right over navigable waters.[10] The United States had determined that solving the diplomatic water dispute with Mexico would require the construction of a government-sponsored project that could deliver water annually to Mexico. Since the company was unwilling to give up the right-of-way voluntarily, and Follett's report had clearly stated that there was not enough water in the river for two dams, the United States would have to do everything in its power to stop the private dam from being built. The Attorney General's opinion provided the basis, then, for the United States to file a lawsuit against the Rio Grande Irrigation & Land Company (successor to Rio Grande Dam & Irrigation Company) in 1897 to enjoin it from constructing the dam at Elephant Butte.[11]

Choosing a Site: Locating the Rio Grande Project

The dispute regarding the construction of a dam on the stretch of the Rio Grande between the New Mexico Territory/Texas state line sorted people into two camps according to which site they preferred. Those who supported the privately constructed dam at Elephant Butte were mostly New Mexicans, including water users in the Mesilla Valley whose irrigation through community ditches and artesian wells stretched back hundreds of years.[12] These farmers were suffering through the first years of what proved to be a very long period of lower-than-average precipitation in the basin lasting from the early 1890s through 1904; in fact, at least one hydrographer from the U.S. Geological Survey (USGS) who studied irrigation in the Mesilla Valley, F.C. Barker, believed in contrast to Follett that the ongoing drought was more responsible for downstream shortages than Colorado's increased diversions upstream, and that the United States perhaps should not base the policy decision on a dam on the current drought and the dispute with Mexico.[13] New Mexico's official stance also favored the Elephant Butte project. The New Mexico Territorial Governor called the United States' assertions of the Rio Grande's navigability "preposterous,"[14] and accused downstream users of orchestrating the lawsuit

8 W. W. Follett, 188; Hamele, "The Embargo on the Upper Rio Grande," 11.

9 Hamele, "The Embargo on the Upper Rio Grande," 14–16. This embargo language was altered in January 1897 to specify only those tributaries entering the Rio Grande above where the river becomes the international boundary.

10 Hamele, 15–16.

11 Governor Miguel A. Otero, "Report of the Governor of New Mexico to the Secretary of the Interior, 1899" (Government Printing Office, 1899), 303–4, NM OSE Library.

12 F.C. Barker, "Irrigation in Mesilla Valley, New Mexico" (Washington, D.C.: Government Printing Office, 1898), 12–13, NM OSE Library.

13 Barker, 17–19.

14 Otero, "Report of the Governor of New Mexico to the Secretary of the Interior, 1899," 304.

because they feared monopolization of the water by New Mexican farmers.[15] However, it was not true that everyone downstream in Texas supported the alternative dam, as evidenced by the El Paso Chamber of Commerce (which later established the El Paso Valley Water Users Association)[16] resolving to support the Elephant Butte Dam in 1900.[17]

Meanwhile, most citizens who depended on river water downstream of New Mexico, including farmers in the El Paso and Juarez areas, were concerned that construction of a private dam upstream would further constrain water use in Texas and Mexico, as opposed to helping their situation. Therefore, in support of a dam further downstream and closer to them, they took steps to make possible what they called the International Dam at El Paso. This was the position the United States government supported, as well, much to the frustration of upstream users. Nathan Boyd, leader of the Rio Grande Dam and Irrigation Company which had proposed the private dam at Elephant Butte, wrote letters to several high-ranking officials in the United States government, including the Secretary of State and the Attorney General, to argue for the value of his plan, and disagree with the attorney general's finding regarding the ability to navigate the river above Fort Quitman. He accused the federal government of sacrificing the irrigation rights of Colorado and New Mexico in the interest of an international dam "scheme."[18] However, even with the United States on the losing side of the early decisions in the legal battles with Boyd's company in both New Mexico Supreme Court and the United States Supreme Court,[19] diplomats in the State Department faced such pressure from the Mexican government that its officials continued to push for the dam they believed could permanently solve the diplomatic impasse, despite the support enjoyed by Boyd's plan both in New Mexico and some parts of Texas.[20]

Developing the Rio Grande Project

Mexico, while somewhat mollified by the 1895 embargo on upstream uses, nevertheless continued to pressure the United States to guarantee Mexico's prior water rights into the 1900s and believed that construction of a storage dam at El Paso would serve that purpose. During the several years it took for the legal dispute between the United States and Nathan Boyd's company to wind its way through the courts, Congress passed the Newlands (or Reclamation) Act in 1902.[21] This law created the United States Reclamation Service, a federal agency empowered to identify, fund, and construct irrigation systems across the arid western states. Because of the international dispute over the Rio Grande and the increasingly tense regional situation, the new Reclamation Service proposed the Rio Grande Project – comprised of a single large storage site on the Rio Grande and related irrigation infrastructure – as one of its first projects.

In 1903, two figures who were intimately familiar with the river's inner workings exchanged confidential letters. USGS Chief Engineer F.H. Newell, who had conducted the earlier study of irrigation in the Mesilla Valley and favored the Elephant Butte site, wrote to W.W. Follett, who had conducted the 1896 investigation for the International Boundary Commission and favored the El Paso dam site. Newell, who was investigating the best location for a Reclamation-sponsored dam, wanted Follett's opinion as to which location on the river was truly best for water storage. Newell acknowledged that Follett was officially "committed to the project of water storage at El Paso," but

15 Otero, 304.

16 Douglas R. Littlefield, Conflict on the Rio Grande: Water and the Law, 1879-1939 (Norman: University of Oklahoma Press, 2008), 117.

17 "Ernest E. Russell, Secretary of El Paso Chamber of Commerce, to the Attorney General," September 8, 1900, NM OSE Library.

18 "Nathan E. Boyd to the Honorable John W. Griggs, Attorney General," August 29, 1900, NM OSE Library; "Nathan E. Boyd to Hon. A. A. Adee, Acting Secretary of State," August 28, 1900, NM OSE Library.

19 United States v. Rio Grande Dam and Irrigation Company, 174 U.S 690 (1899).

20 Nathan E. Boyd, "History of the Rio Grande Dam and Irrigation Company, Etc.," Report No. 1755, 56th U.S. Congress, 2nd Session, Senate, January 22, 1901, NM OSE Library; "Ernest E. Russell, Secretary of El Paso Chamber of Commerce, to the Attorney General," September 8, 1900.

21 "An Act Appropriating the Receipts from the Sale and Disposal of Public Lands in Certain States and Territories to the Construction of Irrigation Works for the Reclamation of Arid Lands," Pub. L. No. 57–161, 32 Stat. 1093 (1902).

wondered if Follett might tell him confidentially whether he believed "this is the best use of the water of the river."[22] Follett responded that from an engineering perspective, a different dam entirely, located in the lower Espanola Valley (near Santa Fe) might be the most ideal. But in his mind, there was far more than engineering at stake: "our National honor in our treatment of a weaker power" was the more significant issue. Follett remained committed to the El Paso dam because it was, in his mind, the best way to provide absolute justice for Mexico's claim.[23] Following Reclamation surveys conducted in 1903-1904 during which agency engineers took borings of the bedrock at Elephant Butte to determine its safety and stability among other testing, Reclamation determined in 1904 that the Elephant Butte site was superior to the El Paso site.[24] Even Boundary Commissioner Follett – who had long supported the El Paso site – came to support the Elephant Butte Dam site in later years, since it could store more water while also serving to provide a diplomatic solution with Mexico.

Events over the next few years led to resolution of the two key outstanding issues on the river: the diplomatic impasse with Mexico and the equitable delivery of water to American farmers in both New Mexico and the El Paso valley as well as Mexican farmers. Reclamation engineer Benjamin M. Hall, speaking at a meeting of the (non-binding but highly influential) National Irrigation Congress in 1904, compared the two dam proposals succinctly. At the El Paso meeting, Hall explained that the International Boundary Commission's proposal for a dam at El Paso had been made at a time when: 1) the Elephant Butte site was believed to be unavailable due to the right of way previously granted to the Rio Grande Dam & Irrigation Company to build a private dam there, and, 2) before the Newlands Act had become law. The El Paso site posed problems, because while it solved the delivery of water to Mexico to assure that country's prior rights, it would flood 40,000 acres of productive farmland in the Mesilla Valley of New Mexico. Hall stated that a government-sponsored dam at the Elephant Butte site – designed to be taller and with a much larger capacity to store water than the private proposal – would better serve all needs downstream in Texas and Mexico as well as lands in New Mexico without flooding fertile ground.[25] He also believed that a federal dam at the Elephant Butte site would resolve the water right conflicts between farmers in Mesilla Valley and those in the El Paso area.[26] Hall believed Elephant Butte was a better site, and the compromise that came out of the 1904 meeting paved the way for its construction. Reclamation counted on the Elephant Butte site becoming available after the litigation ceased, and proceeded accordingly.

One small problem was that delivering water to the lands in El Paso through infrastructure built with federal Reclamation money would require a change to the 1902 Reclamation law, which had not included Texas in its original jurisdiction. With the support of the House Committee on Foreign Affairs whose members recognized the value of the change to the United States/Mexico relations,[27] Congress effectively made that change in February 1905 when it approved the construction of a dam in the New Mexico Territory near Engle (Elephant Butte), extending the Reclamation Act to portions of Texas that bordered the Rio Grande and laying the foundation for the project to move forward.[28]

22 "F. H. Newell, Chief Engineer, to Mr. W.W. Follett, International (Water) Boundary Commission," January 28, 1903, NM OSE Library.

23 "W.W. Follett, Consulting Engineer, to Mr. F. H. Newell, Chief Engineer, U.S.G.S.," February 6, 1903, NM OSE Library.

24 Hamele, "The Embargo on the Upper Rio Grande," 18; U.S. Bureau of Reclamation, "Rio Grande Project: Texas - New Mexico, From Inception to December 31, 1912, Exclusive of Elephant Butte Reservoir," n.d., 6–7, NM OSE Library.

25 Hamele, "The Embargo on the Upper Rio Grande," 19–20.

26 Douglas R. Littlefield, "Lower Rio Grande Stream System and Underground Water Basin Adjudication State of New Mexico Ex Rel. Office of the State Engineer vs. Elephant Butte Irrigation District et al., No. CV-96-888 Third Judicial District," Expert Historian Report Prepared for State of New Mexico Office of the State Engineer and City of Las Cruces, January 7, 2015, chap. 2, 20-23.

27 Mr. Perkins, "Dam and Reservoir on the Rio Grande, in New Mexico" (Report No. 3990, 58th U.S. Congress, 3rd Session, House of Representatives, January 20, 1905), NM OSE Library.

28 "An Act Relating to the Construction of a Dam and Reservoir on the Rio Grande, in New Mexico, for the Impounding of the Flood Waters of Said River for Purposes of Irrigation," Pub. L. No. 58–104, § 798, 33 Stat. 814 (1905); Congress passed an additional law in 1906 that

In anticipation of the Project's construction, water users in New Mexico and Texas formed Reclamation law-compliant associations to organize and administer both water deliveries and repayment obligations. In the north, landowners formed the Elephant Butte Water Users Association to represent farmers in the valleys of New Mexico, while downstream landowners in the El Paso Valley created the El Paso Water Users Association. Reclamation law required formation of these associations with which the federal government then contracted to ensure repayment for the infrastructure it financed.[29] These later became the Elephant Butte Irrigation District (EBID) and the El Paso County Water Improvement District No. 1 (EPCWID) respectively in 1918, according to New Mexico and Texas state laws.[30]

The Territorial Legislature of New Mexico also made preparations for development of the Rio Grande by creating the office of the Territorial Irrigation Engineer in 1905 through the adoption of an irrigation code that recognized the doctrine of prior appropriation.[31] To comply with the fundamental tenet that state law still applied to federal Reclamation projects, in January 1906 the United States submitted an application to the New Mexico Irrigation Engineer stating its intention to store 730,000 acre-feet of water annually in the Elephant Butte Reservoir.[32] The notice, provided by Reclamation Supervising Engineer Benjamin Hall who had engineered the 1904 Compromise at the Irrigation Congress, requested that "the waters above described be withheld from further appropriation and that the rights and interests of the United States in the premises be otherwise protected."[33]

While plans proceeded for Rio Grande Project construction by the U.S. Reclamation Service, the U.S. State Department continued its involvement in water supply, too, presiding over Mexican interests concerning the construction of the new dam.[34] Both Mexico and the United States perceived the Reclamation Dam as solving the international dispute over the river's supplies, and planned to deliver the storage water to Mexico as recompense. By April 1906, the United States had submitted a draft treaty to Mexico offering to provide enough water to irrigate 20,000-25,000 acres free of charge, in exchange for Mexico's agreement to waive its claims "in the international controversy or any other rights."[35] When Reclamation Service Director Frederick Newell testified in Congress in favor of the project and the proposed treaty, he explained that the water in the reservoir would be divided as such: enough water for 20,000-25,000 acres in Mexico; water for 110,000 acres in New Mexico, "and the balance below El Paso on the Texan side of the river."[36] On May 20, 1906 the United States signed a treaty which guaranteed Mexico 60,000 acre-feet of water annually – the compromise reached by the two countries and enough water to irrigate the Mexican acreage – delivered in the riverbed at the head of the Acequia Madre

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officially extended the Reclamation Act to all of Texas, see "An Act To Extend the Irrigation Act to the State of Texas," Pub. L. No. 59–225, 34 Stat. 259 (1906).

29 Donald J. Pisani, To Reclaim a Divided West: Water. Law, and Public Policy, 1848-1902 (Albuquerque: University of New Mexico Press, 1992), chap. 8. For pre-Reclamation Act law on irrigation districts, see p. 102-104.

30 U.S. Bureau of Reclamation, "Project History: Rio Grande Project, Year 1919," n.d., 372, NM OSE Library.

31 "An Act Creating the Office of Territorial Irrigation Engineer, to Promote Irrigation Development and Conserve the Waters of New Mexico for the Irrigation of Lands and for Other Purposes," 1905 Acts of the Legislative Assembly of the Territory of New Mexico, March 16, 1905, 270.

32 "B. M. Hall, Supervising Engineer, to Mr. David L. White, Territorial Irrigation Engineer," January 23, 1906, NM OSE Library; "Director to Secretary of the Interior," June 8, 1907, NM OSE Library.

33 "B. M. Hall, Supervising Engineer, to Mr. David L. White, Territorial Irrigation Engineer." In another notice to the Territorial Engineer sent by a Reclamation Supervising Engineer on April 14, 1908, the Reclamation Service specified a volume of water of 2,000,000 acre-feet and reserved "all the unappropriated water of the Rio Grande and its tributaries." See "Louis C. Hill, Supervising Engineer, to Mr. Vernon L. Sullivan, Territorial Engineer," Supplemental notice of the intention of the United States to use waters of the Rio Grande for irrigation purposes on the Rio Grande project, April 14, 1908, NM OSE Library.

34 "Chief Engineer to Mr. Felix Martinez, Chairman, Executive Committee, El Paso Valley Water Users Ass'n," April 10, 1905, NM OSE Library.

35 Hearings Before the Committee on Irrigation of Arid Lands of the House of Representatives Relating to the Reclamation Work of the Government Under the National Irrigation Act. April 16 to 30, 1906 (Washington, D.C.: Government Printing Office, 1906), 222.

36 Hearings Before the Committee on Irrigation of Arid Lands of the House of Representatives Relating to the Reclamation Work of the Government Under the National Irrigation Act. April 16 to 30, 1906, 222.

Canal above the city of Juarez.[37] The treaty clearly laid out the water delivery schedule as well as plans for times of drought, and elucidated Mexico's waiver of any claim to the river's water between the head of the Acequia Madre downstream to Fort Quitman.[38]

By 1906, then, the system that became known as the Rio Grande Project, including the dam planned at Elephant Butte and a regulated system of water delivery, solved more than a single problem. It stored flood waters and spring runoff for use during the dry growing season, thereby regulating the river's irregular flow and supplying a more reliable water supply to American growers. But as significantly, the Project was a physical monument symbolizing the United States government's recognition of its role in solving an international dispute with Mexico. Mexico believed that farmers in the United States had stolen water that belonged to Mexican users through ancient rights, and this project provided those users with an assured annual supply.

The international importance of this project led to Congressional departure from the normal method of funding such Reclamation work. Under the typical structure, Reclamation Service projects were financed by the federal government advancing the funding to build the project infrastructure, and water users, organized into associations, paying back the cost of the dam and related infrastructure over time. However, in this case Congress decided that American farmers should not be burdened with the proportionate costs associated with treaty obligations to Mexico. Therefore, Congress appropriated non-Reclamation funds for a portion of Elephant Butte Dam's construction; out of an estimated $7.2 million cost, $1,000,000 of non-Reclamation money was slated to pay for Mexico's share of the dam's construction, at $4/acre, thereby relieving the Reclamation fund (and American farmers) from having to cover that portion of the cost.[39] This was done with the full approval of the Secretary of State, who agreed with Reclamation Director Frederick Newell (who had transferred from the USGS) that the United States should monetarily fulfill the country's treaty obligations with Mexico instead of burdening American farmers.[40] Finally, in March 1907, Congress authorized the dam's construction.[41] The State Department and the Department of Interior jointly instructed W.W. Follett – still working with the International Boundary Commission – to work with Reclamation engineers "in all matters pertaining to Reclamation work on the Rio Grande watershed."[42] A few years later, the U.S. Supreme Court resolved the litigation between the United States and the Rio Grande Dam and Irrigation Company in favor of the government,[43] and the Reclamation Service became free to construct a dam at the now unencumbered Elephant Butte site for its Rio Grande Project.[44]

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37 "61st Congress, 3rd Session, House of Representatives, Document No. 1262: Fund for Reclamation of Arid Lands. Message from the President of the United States Transmitting a Report of the Board of Army Engineers in Relation to the Reclamation Fund" (Washington, D.C.: Government Printing Office, 1911), NM OSE Library; "Convention between the United States and Mexico Providing for the Equitable Distribution of the Waters of the Rio Grande for Irrigation Purposes" 34 Stat. 2953 (May 21, 1906).

38 "Convention between the United States and Mexico Providing for the Equitable Distribution of the Waters of the Rio Grande for Irrigation Purposes."

39 Hearings Before the Committee on Irrigation of Arid Lands of the House of Representatives Relating to the Reclamation Work of the Government Under the National Irrigation Act. April 16 to 30, 1906, 223.

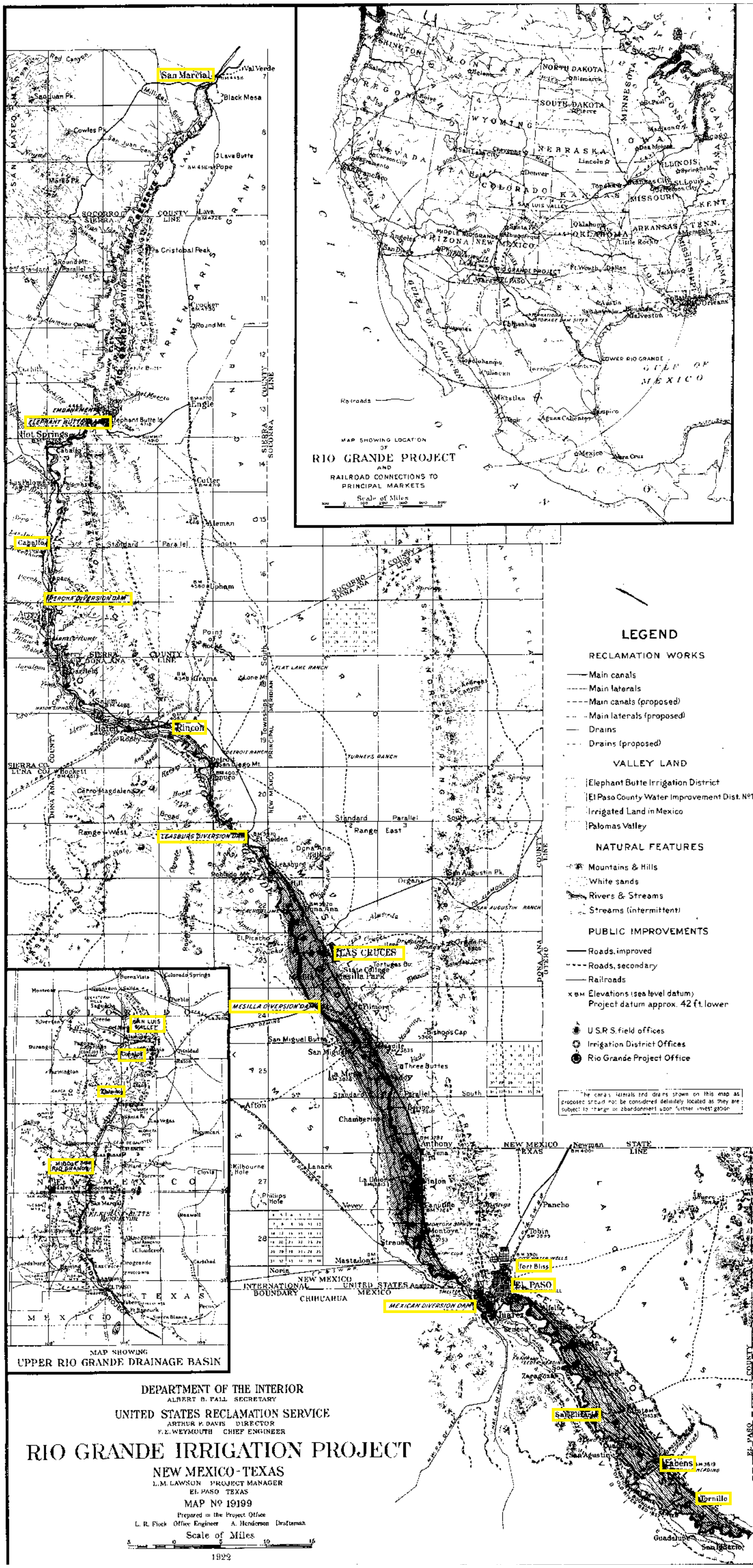
40 "59th Congress, 2nd Session, House of Representatives, Document No. 548: Convention with Mexico. Letter from the Secretary of the Treasury, Transmitting a Copy of a Communication from the Acting Secretary of State Submitting an Estimate of Appropriation for Carrying out Convention with Mexico as to Distribution of the Waters of the Rio Grande" (Washington, D.C.: Government Printing Office, 1907), NM OSE Library.

41 F. H. Newell, "Tenth Annual Report of the Reclamation Service, 1910-1911" (Washington, D.C.: Government Printing Office, 1912), HathiTrust; "An Act Making Appropriations for Sundry Civil Expenses of the Government for the Fiscal Year Ending June Thirtieth, Nineteen Hundred and Eight, and for Other Purposes," Pub. L. No. 59–253, 34 Stat. 1295 (1907), 1357.

42 "Director to Secretary of the Interior," June 8, 1907.

43 This litigation is described in great detail in Hamele, "The Embargo on the Upper Rio Grande," 16–17; Douglas R. Littlefield, Conflict on the Rio Grande: Water and the Law, 1879-1939, chap. 3.

44 Hamele, "The Embargo on the Upper Rio Grande," 16–17.



Rio Grande Project Map. New Mexico Office of the State Engineer Library.pdf

Expansion of Project Boundaries

Between 1908 and 1924, the Reclamation Service built out the Rio Grande Project's infrastructure, including Elephant Butte Dam as well as diversion dams, canals, and laterals. Although the United States intended for the Project to provide a more reliable water supply for previously developed farms, the storage water behind Elephant Butte Dam would also permit the new development of irrigable acres that were not yet developed into farms. It was engineered to hold more than two million acre-feet of water, assuring an annual supply of between 750,000 and 800,000 acre-feet, enough to deliver treaty water to Mexico and to water 155,000 acres in the United States, with 110,000 of those in New Mexico and 45,000 in Texas.[45] To determine the water necessary for 155,000 acres, engineers assumed the following: duty of water at the farm – the amount of water necessary to deliver to the field to produce a successful crop – would be three acre-feet per acre, plus a 20 percent loss in the distribution system. The reservoir would also store 60,000 acre-feet to meet the United States' obligation to Mexico. Taken together, the requirement for release from the reservoir would be approximately 800,000 acre-feet. However, the system design also assumed that a portion of the water diverted in the upper reaches of the Project would return to the system for re-use further downstream: "losses in transit…will be partly offset by the return seepage in upper parts of the valley, which will be available for diversion lower down. It, therefore, appears that the available supply accords closely with the demand."[46] Nowhere did the documentation mention groundwater. Initial estimates had put the per-acre cost at $40/acre, but by the time the Secretary of the Interior finally authorized the dam in spring 1910, the total cost had risen to $9,665,000, or $56/acre for each of the 155,000 acres.[47]

Infrastructure construction began soon after the 1907 authorization and continued apace. In its final design stage, the Project consisted of the Elephant Butte Dam, four diversion dams, and all associated canal and lateral systems. Together the system would deliver water (in downstream order) to lands in the Rincon, Mesilla, and El Paso Valleys.[48] The Leasburg Unit in the Mesilla Valley, comprised of the Leasburg Diversion Dam and the Leasburg Canal, was the first project-related construction approved. Authorized and funded in 1907 and completed in 1908, it watered 25,000 acres in that valley by 1911. Reclamation constructed it first because it would offer the fastest relief to water users.[49] The other diversion dams and canals were not constructed in any geographical order, but instead in order of importance when funding was available. In New Mexico, construction began in 1914 on the Mesilla Diversion Dam, which diverted water into the East and West Side Canals in the Mesilla Valley, lying south of the city of Las Cruces, New Mexico.[50] Next was the Percha Dam, 25 miles south of Elephant Butte, constructed in 1918 to divert water to lands north of Las Cruces in the Arrey, Hatch, Garfield, and Rincon Districts in the Rincon Valley.[51] In the El Paso Valley in Texas, Reclamation purchased the pre-existing Franklin Canal from the private Franklin Irrigation Company in 1912 and enlarged it in ensuing years to carry 450

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45 "61st Congress, 3rd Session, House of Representatives, Document No. 1262: Fund for Reclamation of Arid Lands. Message from the President of the United States Transmitting a Report of the Board of Army Engineers in Relation to the Reclamation Fund," 106.

46 "61st Congress, 3rd Session, House of Representatives, Document No. 1262: Fund for Reclamation of Arid Lands. Message from the President of the United States Transmitting a Report of the Board of Army Engineers in Relation to the Reclamation Fund," 106.

47 "61st Congress, 3rd Session, House of Representatives, Document No. 1262: Fund for Reclamation of Arid Lands. Message from the President of the United States Transmitting a Report of the Board of Army Engineers in Relation to the Reclamation Fund," 107.

48 U.S. Bureau of Reclamation, "Rio Grande Project: Texas - New Mexico, From Inception to December 31, 1912, Exclusive of Elephant Butte Reservoir," 3–4.

49 Newell, "Tenth Annual Report of the Reclamation Service, 1910-1911," 178–80; U.S. Bureau of Reclamation, "Rio Grande Project: Texas - New Mexico, From Inception to December 31, 1912, Exclusive of Elephant Butte Reservoir," 19.

50 U.S. Bureau of Reclamation, "Rio Grande Project History, Calendar Year 1914," n.d., 61–62, NM OSE Library.

51 U.S. Bureau of Reclamation, "Rio Grande Project: New Mexico - Texas, History of the Project, 1916," n.d., 45–46, NM OSE Library; U.S. Bureau of Reclamation, "Annual Project History and Operation and Maintenance Report, Rio Grande Project, New Mexico - Texas, Year 1918," n.d., 87.

cfs to 45,000 acres in the El Paso Valley.[52] The Franklin was just upstream from the Acequia Madre canal, where Mexico took its treaty water on the Mexican side of the river. Elephant Butte Dam was finally completed in 1916 and began storing water that year, with a holding capacity of 2,639,000 acre-feet.

As was true on Reclamation projects across the West, the Rio Grande Project evolved over time. Although engineers surveyed the Elephant Butte Dam site and sketched the early outlines of the rest of the system, it was Congressional authorization (and regular appropriations) that provided the green light to comprehensively build the Project out, and the devil was in the details. Securing a reliable water supply for previously irrigated lands was an important piece of the Project's intent but extending irrigation to new lands for cultivation in the Rio Grande watershed, like in all Reclamation projects, constituted another significant Project aim. The Reclamation Service was an important tool in fulfilling the United States' policy and vision of settling the American West with small farmers. In 1915, as part of the Project's evolution, the Reclamation Service decided to survey lands that lay south of El Paso in the Tornillo Valley, downstream of both El Paso and Fabens, Texas, "in case it should be decided to incorporate this valley in the project later on." Prior to this survey, these extreme downstream lands had not "been investigated in connection with the Rio Grande project."[53] However, landowners there expressed their interest in becoming part of the Project and believed that if infrastructure could in fact be extended to reach them, their lands would benefit from the reliable irrigation offered by the Project. Whether the canals would be extended that far south, however, remained questionable as late as 1918. When the El Paso Water Users Association petitioned the Reclamation Service to extend the Project to include these Tornillo Valley properties, it was clear that the Tornillo landowners were willing and wanted to become a part of the Project, which meant forming and financially contributing to a water users association to pay back Reclamation construction costs.[54] Irrigable land totaling 7,600 acres in their area could obtain irrigation water if the main Tornillo Canal – already serving lands in upper districts – could be extended an additional 14 miles down the river.[55] To obtain Project water, landowners representing an existing 4,600 privately owned acres formed a new irrigation district called the El Paso County Conservation and Reclamation District No. 2 (EP2) in early 1919.[56] By the end of the year (a year in which 3,221 acres were already cropped in the district thanks to the area's preexisting community ditches),[57] the district was negotiating a service contract with the Reclamation Service and would officially become part of the Project.[58]

52 U.S. Bureau of Reclamation, "Rio Grande Project: Texas - New Mexico, From Inception to December 31, 1912, Exclusive of Elephant Butte Reservoir," 31; U.S. Bureau of Reclamation, "Rio Grande Project: New Mexico - Texas, 1913," n.d., 8, NM OSE Library; "Walter L. Fisher, Secretary, to the Honorable, The Secretary of State," November 25, 1911, 2, Records of the Bureau of Reclamation, R.G. 115, 115-54-A-81, Office of chief Engineer, Denver, Colorado, General Correspondence Files, 1902-42, Box 1130, 249-I, Rio Grande, Franklin Canal, Thru 1935, 249-I, U.S. National Archives, Denver; U.S. Bureau of Reclamation, "Reconstruction of Franklin Canal, Station 0 to 780 - El Paso Valley - Rio Grande Project" (Communications and Records Unit, BLDG. 53, D.F.C., 1914), 5, Engineering and Research Center, Project Reports, 1910-55, Code 510 Box 722, Reconstruction of Franklin Canal, Station 0 to 780 - El Paso Valley - Rio Grande Project, U.S. National Archives, Denver.

53 U.S. Bureau of Reclamation, "Rio Grande Project: New Mexico - Texas, Project History, 1915," n.d., 53, NM OSE Library.

54 "Chief of Construction to Director of U.S. Reclamation Service," Memorandum: Irrigation of lands in Tornilla [sic] District - Rio Grande Project, April 12, 1918, NM OSE Library.

55 For a time, estimates ranged as high as 10,000 acres, but the contract signed with the Reclamation Service in 1919 was for 7,600 acres. U.S. Bureau of Reclamation, "Rio Grande Project: New Mexico - Texas, Project History, 1915," 62; U.S. Bureau of Reclamation, "Project History: Rio Grande Project, Year 1919," 113; U.S. Bureau of Reclamation, "Project History: Rio Grande Project, Year 1920," n.d., 142, NM OSE Library.

56 "Project Manager to Chief of Construction," Memorandum: Draft of Contract for Water Service, Tornillo District, Rio Grande Project, November 20, 1919, Records of the Bureau of Reclamation, R.G. 115, Entry 7, General Administrative and Project Records, 1919-1945, Project Files, 1919-1929, Rio Grande 223.02, Box 907, 223.02, Transfer Case, Rio Grande, Lease of Water Contracts, El Paso County Conservation and Reclamation Dist. # 2, Thru 1929, U.S. National Archives, Denver.

57 U.S. Bureau of Reclamation, "Project History: Rio Grande Project, Year 1919," 201.

58 U.S. Department of Interior, Eighteenth Annual Report of the Reclamation Service, 1918-1919 (Washington: Government Printing Office, 1919), 265.

The Reclamation Service struggled internally over the next few years to determine how and whether to include other new lands in the Project. In 1919, Reclamation conducted topographic surveys in the newly incorporated Tornillo District but also in the unincorporated Fort Hancock area, located even further downstream in Hudspeth County.[59] However, Reclamation officials expressed concern over the water quality for lands so far south. They were committed to running an efficient Project and knew that the further downstream from Elephant Butte they delivered water to new lands, the poorer the water quality would be, due to the salts picked up by return flows. If the water was too salty, it was useless for crop development. Nevertheless, since the full project acreage was not yet developed needed for crops upstream, excess storage water was temporarily available in these lower lands to dilute the salty water and create a usable supply in the downstream areas.[60] Tornillo lands fell into that class, as did Fort Hancock lands, but Reclamation's internal dialogue in 1919 and 1920 demonstrated concern that such excess would not be available indefinitely. [Tornillo's and Fort Hancock – or "Hudspeth's" – water quality is discussed in detail in Chapter 5 below.]

The Reclamation Service had initially approached the irrigation of Tornillo Valley lands through the drafting of a contract under the Warren Act, a 1911 law enabling the agency to rent surplus water generated by its projects.[61] The agency's uncertainty with regard to future water supply for Tornillo's lands led first to a one-year Warren Act contract, offering rental water to EP2 landowners. But as the agency looked to the future, Reclamation officials saw the opportunity to create water use efficiencies, and asked EP2 landowners to consolidate their river headings into a single diversion in order to create a system that met the efficiency demands of the Project and the water quality demands of EP2 lands.[62] Simultaneously, the Reclamation Service had been internally discussing whether to bring the Tornillo District into the official fold of the Rio Grande Project. Bringing Tornillo lands into the official Project boundaries would provide the landowners with access to Reclamation project funding to make the infrastructure changes recommended for efficiency but would also ensure that the Reclamation Service would receive repayment for its investment. A draft contract was prepared but not initially shared with the district because Reclamation could not yet offer funds to execute on the recommended construction.[63]

Eventually, the Project included the Tornillo lands through a permanent contract signed in 1920 between Reclamation and EP2, incorporating these lands into the Project on par with the other Project lands and giving Tornillo District landowners the same rights and obligations as other Project participants.[64] Once fully developed,

59 U.S. Bureau of Reclamation, "Project History: Rio Grande Project, Year 1919," 81.

60 "Acting Chief of Construction to Director," Memorandum: Rental of water to lands outside of the limits of the Rio Grande Project, March 31, 1920, Records of the Bureau of Reclamation, R.G. 115, Entry 7, Project Administrative and Project Records, 1919-1945, Project Files, 1919-1929, Rio Grande 223.02, Box 907, 223.02, Transfer Case, Rio Grande, Corres. Re Lease of Sale of Water, Thru 1929, 2 of 2, U.S. National Archives, Denver; "Project Manager to Director and Chief Engineer," Memorandum: Draft of Contract for Water Service, Tornillo District, Rio Grande Project, January 3, 1920, Records of the Bureau of Reclamation, R.G. 115, Entry 7, General Administrative and Project Records, 1919-1945, Project Files, 1919-1929, Rio Grande 223.02, Box 907, 223.02, Transfer Case, Rio Grande, Lease of Water Contracts, El Paso County Conservation and Reclamation Dist. # 2, Thru 1929, U.S. National Archives, Denver.

61 "An Act To Authorize the Government to Contract for Impounding, Storing, and Carriage of Water, and to Cooperate in the Construction and Use of Reservoirs and Canals under Reclamation Projects, and for Other Purposes," Pub. L. No. 61–406, 34 Stat. 295 (1911).

62 "Warren Act Contract between the U.S. Reclamation Service and the El Paso County Conservation and Reclamation District No. 2, Draft," n.d., Records of the Bureau of Reclamation, R.G. 115, Entry 7, General Administrative and Project Records, 1919-1945, Project Files, 1919-1929, Rio Grande 223.02, Box 907, 223.02, Transfer Case, Rio Grande, Lease of Water Contracts, El Paso County Conservation and Reclamation Dist. # 2, Thru 1929, U.S. National Archives, Denver.

63 "Project Manager to Director and Chief Engineer," January 3, 1920.

64 "Warren Act Contract between the U.S. Reclamation Service and the El Paso County Conservation and Reclamation District No. 2," July 26, 1920; "Warren Act Contract between the U.S. Reclamation Service and the El Paso County Conservation and Reclamation District No. 2, 3rd Draft," 1919, Records of the Bureau of Reclamation, R.G. 115, Entry 3, General Administrative and Project Records, 1902-1919, Rio Grande 330-330B, Box 816, 330-A RIO GRANDE, Irri. Dist. Contract with El Paso Co. Imp. Dist. #1 and El Paso Val. WUA for Drainage and

the Tornillo District would be served by a single canal that took its water at a diversion near Fabens, Texas, several miles downstream from El Paso; 12 miles of a 150-cfs capacity main canal; 18 miles of lateral canals to cover 160-acre farms; a trunk line drain to empty at the lower end of the Project; and 17 miles of lateral drains.[65] By 1920, with the Tornillo District now boasting more than 4,000 acres in production, EPCWID and EP2 merged into a single organization, with the Tornillo District lands coming under the administration of EPCWID.[66] Officials probably hoped that improvements to delivery efficiencies (e.g. a single diversion instead of many) would help solve the water quality issue, as well, but salty water continued to be an issue for those landowners well into the future.

Although officially part of the Project now, Tornillo District lands were not immediately reachable by Project facilities, nor was the consolidation of the district lands into the Project simple. In the years leading up to 1923 when construction of the Tornillo Canal was completed,[67] lands in that and other districts diverted their stored water directly from the river through old community ditches that had predated the Project's construction.[68] As noted above, in order to properly deliver water of useable quality to Tornillo, it would be necessary for Reclamation to combine the diversions into a single canal heading. Nevertheless, annual Reclamation project reports included Tornillo District acreage as soon as they were officially a part of the Project, while specifically excluding acreage (and enumerating the exclusion) in other districts nearby, including Fort Hancock.[69]

Fort Hancock lands were excluded from reports because the Reclamation Service had briefly considered bringing these extreme downstream lands into the Project during this same era. However, when Reclamation offered Project status to water users in the Fort Hancock District these water users had reportedly "refused to bring the same within the limits of the Rio Grande Project."[70] Although the historical record is scant regarding the reasons for the Fort Hancock water users' refusal, the local papers also reported that although the initial plans for Project expansion had included these farmers, "this was given up."[71]

Despite Fort Hancock landowners' refusal to join the Rio Grande Project, irrigation was critical to their lands' development. Their refusal, however, had left them in a suboptimal position when it came to Project water delivery. Although Reclamation was committed generally to providing irrigation to as many acres as possible, Fort Hancock users' choice not to join the Project meant that they (and any other non-Project user) had no permanent or assured right to any of the Project's water. For example, although Reclamation's Board of Engineers met in 1919 and established the Rio Grande Project limits at 150,000 acres, a new landowner who had purchased 10,000 acres in the Fort Hancock area in late 1919 and wanted water delivered through the system was told in no uncertain terms that his lands could only be served "on a *temporary* basis from surplus stored

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other Construction Work and Repayment of Same, Box-461 E.P., Folder 3 of 3, U.S. National Archives, Denver; "Acting Chief of Construction to Director," March 31, 1920; "Project Manager to Chief of Construction, Denver, Colorado," Memorandum: Fort Hancock Lands - Rio Grande Project, March 25, 1920, Records of the Bureau of Reclamation, R.G. 115, Entry 7, Project Administrative and Project Records, 1919-1945, Project Files, 1919-1929, Rio Grande 223.02, Box 907, 223.02, Transfer Case, Rio Grande, Corres. Re Lease of Sale of Water, Thru 1929, 2 of 2, U.S. National Archives, Denver.

65 "A.P. Davis, Chief Engineer, to Secretary of the Interior," August 11, 1919, Records of the Bureau of Reclamation, R.G. 115, Entry 7, Project Administrative and Project Records, 1919-1945, Project Files, 1919-1929, Rio Grande 222, Box 903, 222, Transfer Case, Rio Grande Project, Irrigation Districts, El Paso County Conserv. And Recla. Dist. #2, Thru 1929, U.S. National Archives, Denver; "Warren Act Contract between the U.S. Reclamation Service and the El Paso County Conservation and Reclamation District No. 2."

66 U.S. Bureau of Reclamation, "Project History: Rio Grande Project, Year 1920," 311–21.

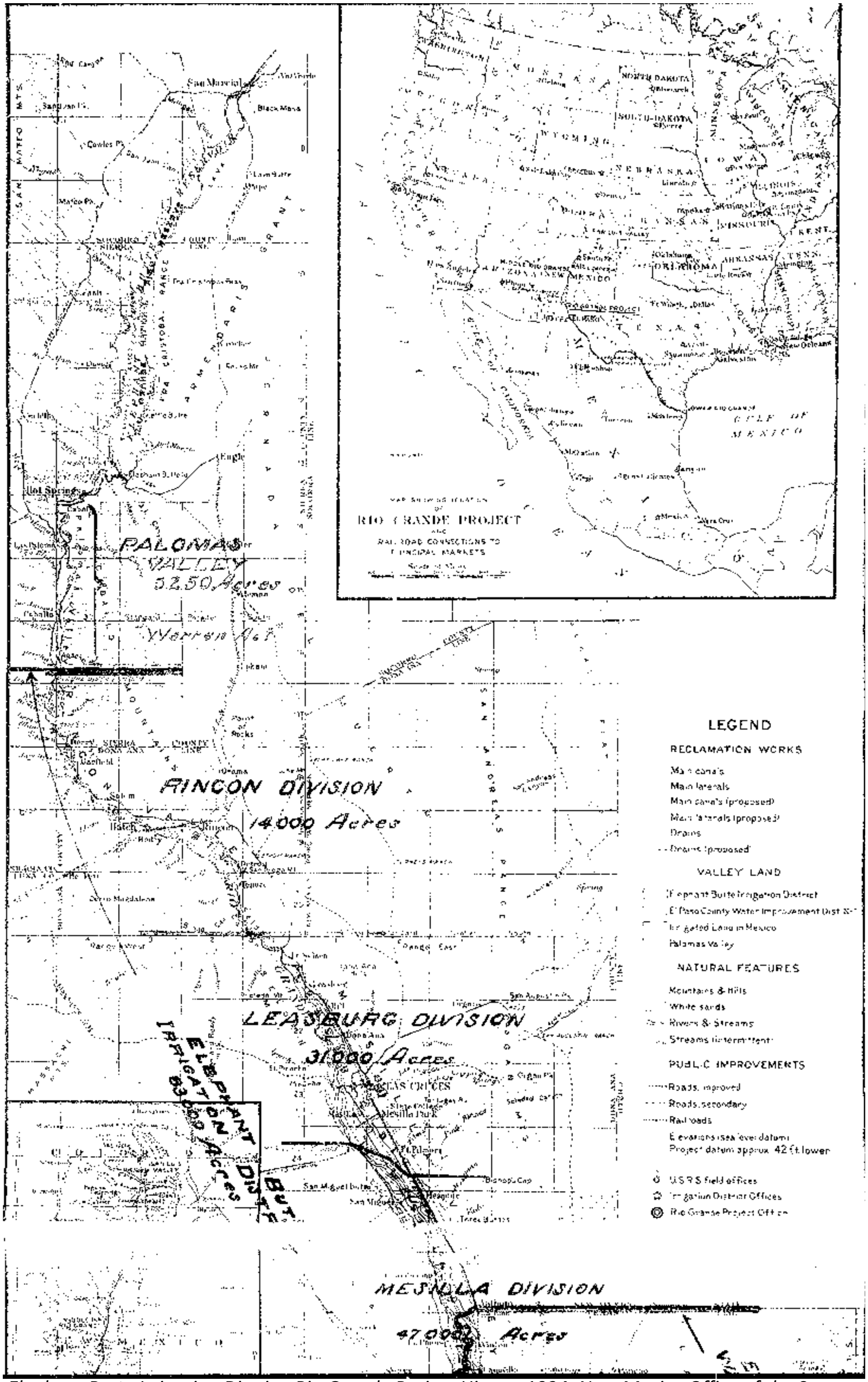
67 U.S. Bureau of Reclamation, "Project History: Rio Grande Project, 1923," n.d., 74, NM OSE Library.

68 U.S. Bureau of Reclamation, "Project History: Rio Grande Project, 1921," n.d., 296, NM OSE Library.

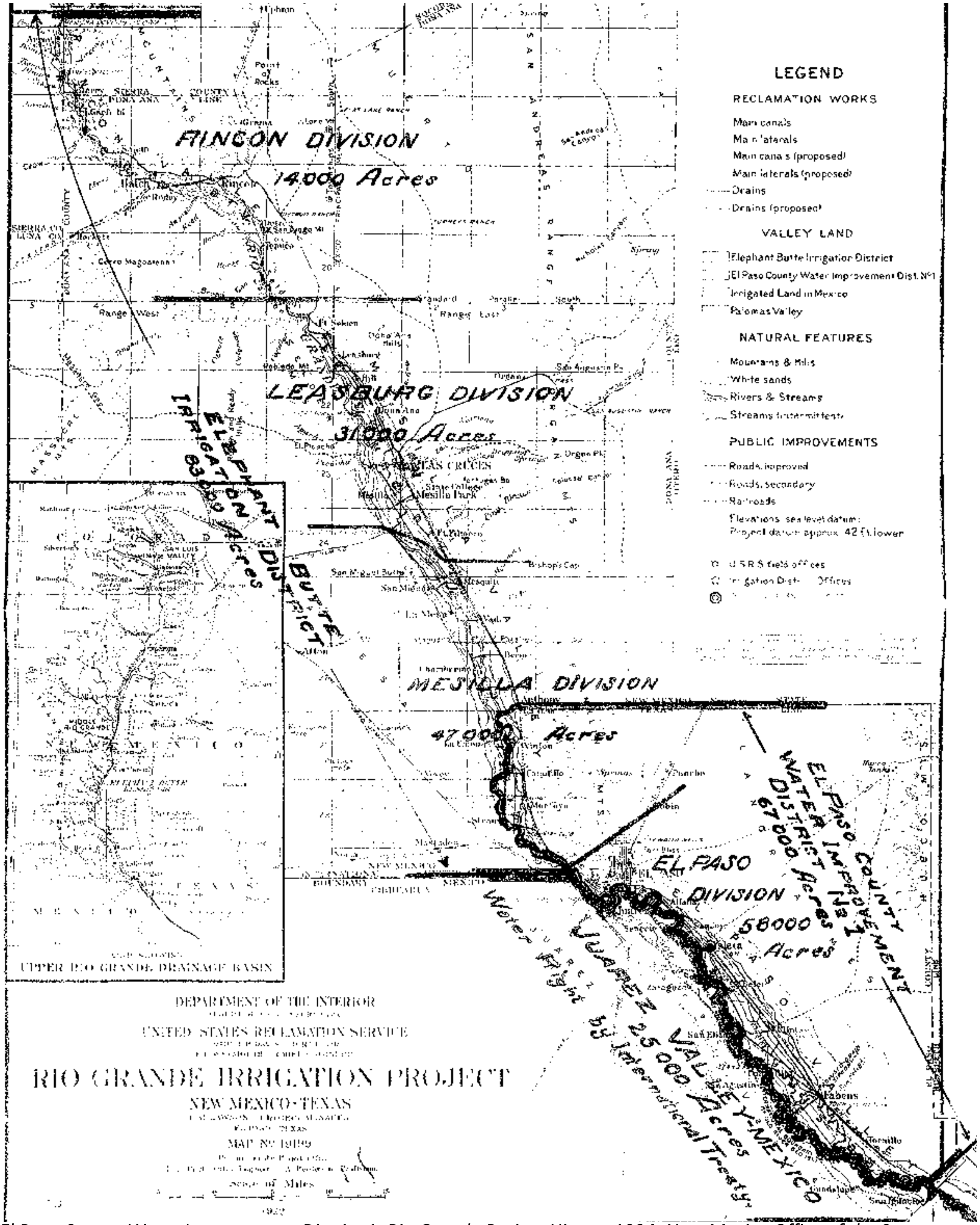
69 U.S. Bureau of Reclamation, "Project History: Rio Grande Project, 1921," 296.

70 "Project Manager to Chief of Construction, Denver, Colorado," March 25, 1920; "Acting Chief of Construction to Director," March 31, 1920.

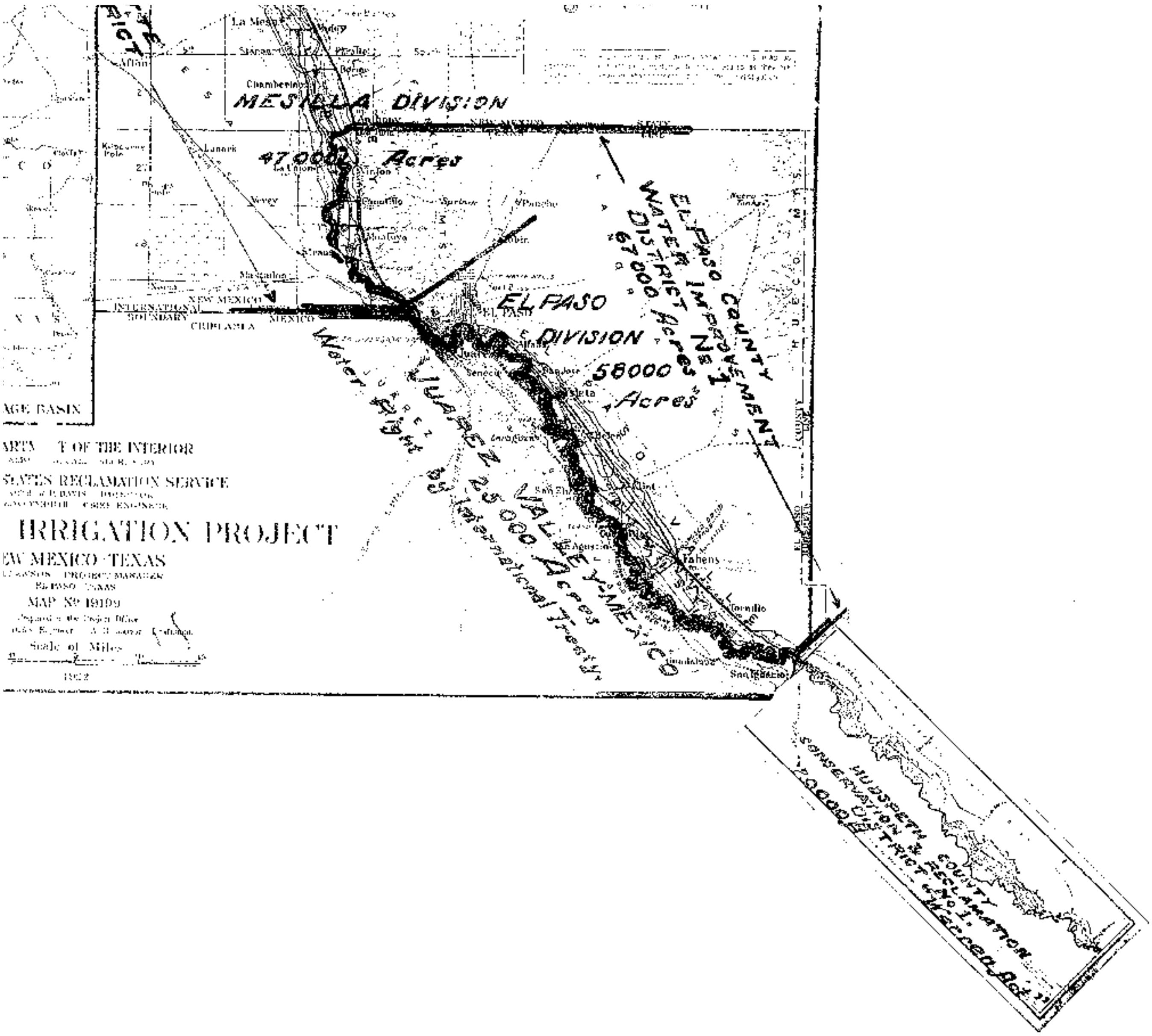
71 "Petition for New Irrigation District Ready," El Paso Times, November 25, 1918, Newspapers.com.



Elephant Butte Irrigation District. Rio Grande Project History 1924. New Mexico Office of the State Engineer Library.



El Paso County Water Improvement District 1. Rio Grande Project History 1924. New Mexico Office of the State Engineer Library.



Hudspeth County Conservation and Reclamation District 1. Rio Grande Project History 1924. New Mexico Office of the State Engineer Library.

water."[72] [Emphasis added.] This temporary status was made abundantly clear in internal correspondence, which demonstrated Reclamation's intent to operate the Project as efficiently as possible and not to let excess water run to waste once the Project was fully operable and acreage fully developed: "As far as possible the amount of water wasted at the lower end of the Project will be kept at the lowest possible minimum."[73] In fact, when the Chief of Construction for the Rio Grande Project wrote to Reclamation director A.P. Davis to address the Fort Hancock landowner situation, he wrote: "As only about one-half of the [project] irrigable area is now in cultivation, there is during the year 1920 and *may be* during some future years, some excess water available in the Elephant Butte Reservoir which might be used on other lands *temporarily*, provided the rental of this water under temporary contracts to these lands outside of the present and contemplated project limits does not involve the Service in a controversy which might prove of a serious nature when the water supply requires that

72 "Project Manager to Chief of Construction, Denver, Colorado," March 25, 1920.

73 "Project Manager to Director and Chief Engineer," January 3, 1920.

delivery of water to these lands be discontinued."[74] [Emphasis added.]

Despite such apprehension, Reclamation executed a Warren Act contract a few years later with Fort Hancock landowners who were now organized under Texas laws as the Hudspeth County Conservation and Reclamation District No. 1, or "Hudspeth." The language of the Warren Act contract underscored the temporary and uncertain nature of the water supply, as well as the water's character, providing only "for the sale to the District [Hudspeth] of such water from the project as *may be available without the use of storage from Elephant Butte reservoir*, delivery to be made at the terminus of the Tornillo Main canal during 1925, and thereafter, during such irrigation seasons as established on the Rio Grande project."[75] [Emphasis added.] By 1924, the official annual Rio Grande Project histories described the Tornillo Canal's systemic function as "collecting waste and surplus waters throughout the project for use on Tornillo lands *and* for sale as surplus water to the recently organized Hudspeth County Conservation and Reclamation District No. 1."[76] [Emphasis added.] More about Hudspeth's development and role in the Project is described in several sections below.

Completing the Rio Grande Project Construction

In addition to building the Project's primary delivery infrastructure, Reclamation Project officials soon recognized that other work would need to be completed to operate the Project efficiently. For example, in order to properly collect Project data moving forward, the agency found in early years that it had to conduct "farm surveys" in the Mesilla and El Paso Valleys, since so much of the land being watered had been part of Spanish land grants and consequently had non-existent or poorly described legal boundaries.[77] Additionally, as irrigated acreage expanded on the Project, farmers and Project engineers recognized that drains were going to be needed to prevent Project lands from becoming swamped, a problem that was also occurring on other projects across the West.

Nevertheless, by the mid-1920s, the Project was functioning smoothly, with Elephant Butte storing water for the farmers, and various diversion dams and canal headgates completed and delivering said water to the farmers during the irrigation season. Having started from an incomplete and inefficient preexisting system comprised of hundreds of community ditches and multiple headings on the river, the farmland stretching from the Rincon Valley in the north to the Hudspeth County line in the south was now receiving a more dependable supply of water than ever before, and irrigated acreage was increasing as a result. However, although much of the basic Project infrastructure was in place, continuing efforts to improve water delivery efficiency meant that the Project as a whole continued to evolve indefinitely.

74 "Acting Chief of Construction to Director," March 31, 1920.
75 U.S. Bureau of Reclamation, "Project History: Rio Grande Project, 1924," n.d., 17–18, NM OSE Library.
76 U.S. Bureau of Reclamation, 10.
77 U.S. Bureau of Reclamation, "Rio Grande Project History, Calendar Year 1914," 4.

Chapter 2: Project Operation and the First Rio Grande Compact

With the international water crisis with Mexico averted by the signing of the 1906 Treaty and the near complete buildout of the major Rio Grande Project infrastructure, irrigation-minded people again turned their attention to the potential for new reclamation and development projects on the river. The demands on the waters of the Rio Grande never ceased. Whether they originated downstream of the Project as they did with the Hudspeth District, or upstream of the Elephant Butte Dame in northern New Mexico and Colorado, supply seemed always to be outstripped by demand. However, with the Project infrastructure having changed the river system so dramatically, officials contemplated whether the development embargo that had been imposed in 1895 could and should be withdrawn. As early as 1919, engineers saw the potential for an irrigation and drainage project upstream from Elephant Butte in a section known as the Middle Rio Grande Valley.[1] Other engineers were examining development potential even further upstream in Colorado's San Luis Valley, too. The existing embargo precluded them both. With the unceasing demands on the river from every segment, however, the three states (Texas, New Mexico, and Colorado) recognized that a permanent agreement to apportion the river's resources was necessary. Knowing that any new irrigation project would cause dissent among water users, Colorado and New Mexico Legislatures adopted laws granting permission for the states to negotiate an interstate compact for the division of Rio Grande waters between them.[2] Texas, concerned about upstream projects' effects on their downstream users, joined the group shortly thereafter. Compact discussions began in 1925, but it wasn't until February 1929 that the three states signed a temporary agreement, or truce, designed to last for six years.[3]

Downstream Lands and Hudspeth's Relationship to the Rio Grande Project

In 1919, as engineers began discussing the possibility of more irrigation development on the Rio Grande, water users located south of Elephant Butte Dam inevitably felt threatened by the proposed development of upstream lands. However, not all the lands downstream of Elephant Butte were included in the Rio Grande Project, and therefore not all had an equal claim to its water. In fact, there was a distinct difference between Project lands and non-Project lands, and a significant gap between their respective credibility in fighting upstream developments. In particular, neither the Reclamation Service nor the two Project irrigation districts (EBID and EPCWID) quite knew how to handle the Fort Hancock/Hudspeth farmers once that group rejected Project status.[4] While the Hudspeth farmers' concerns about upstream development were the same as those of the

1 Harold Conkling, Engineer and Erdman Debler, Asst. Engineer, "Water Supply for and Possible Development of Irrigation and Drainage Projects on Rio Grande River, Above El Paso, Texas," n.d., 76–98, Sub-Series 4.10 Reports: Rio Grande Basin, Box 53, Folder 1383, Water Supply and Possible Development of Irrigation and Drainage Projects on Rio Grande River above El Paso, Texas, June 1919, Harold Conkling and Erdman Debler, New Mexico State Records Center and Archives.

2 "An Act Providing for the Appointment of a Commissioner on Behalf of the State of Colorado to Negotiate a Compact or Agreement Respecting the Use, Control and Disposition of the Waters of the Rio Grande River and for Other Purposes," in Laws Passed at the Twenty-Fourth Session of the General Assembly of the State of Colorado (Denver: The Bradford-Robinson Printing Co., 1923), 175–76; "An Act Providing for the Appointment of a Commissioner on Behalf of the State of New Mexico to Negotiate a Compact or Agreement Respecting the Use, Control and Disposition of the Waters of the Rio Grande River and for Other Purposes," in Laws of the State of New Mexico Passed by the Sixth Regular Session of the Legislature of the State of New Mexico (Albuquerque, N.M.: Valiant Printing Co., 1923), 702–5.

3 T. H. McGregor, "Rio Grande Compact. Report of T. H. McGregor, Commissioner for Texas, to the Honorable Dan Moody, Governor of Texas," n.d., 3, Box 2F471, Rio Grande Compact Records, 1924-1941, 1970, Rio Grande Compact Commission, 1924-1941, 1970, Richard Burges Papers: Rio Grande Commission Conference Reports, Statements, Proposals by Commissioners, 1929, Center for American History, University of Texas at Austin.

4 "Project Manager to Chief of Construction, Denver, Colorado," Memorandum: Fort Hancock Lands - Rio Grande Project, March 25, 1920, Records of the Bureau of Reclamation, R.G. 115, Entry 7, Project Administrative and Project Records, 1919-1945, Project Files, 1919-1929, Rio Grande 223.02, Box 907, 223.02, Transfer Case, Rio Grande, Corres. Re Lease of Sale of Water, Thru 1929, 2 of 2, U.S. National

Project districts', their refusal to officially join the Rio Grande Project put all the leverage for water delivery in the hands of the Project irrigation districts and the Reclamation Service. Unlike the Project irrigation districts, which could make a legal claim to water based on the Reclamation Service's filings of 1906 and 1908, Hudspeth had no such claims to the river's water, only to the Project's waste. Although the Reclamation Service was generally invested in providing water to as many acres as possible, engineers had already reduced the actual Project's estimated fully developed acreage to 155,000 acres, based on the finite water supply and the lack of Project efficiencies. Thus Hudspeth's contracts for rental water were made one year at a time in order to prevent any unrealistic expectations of water delivery, leaving the farmers of that region little to stand on in the discussions of upstream use.

In addition to having an unreliable year-by-year water delivery contract, the Hudspeth District also lacked a consolidated diversion structure, making the delivery of the quantity of water they needed very difficult and further imperiling the region to increased upstream usage. In the earliest years of Hudspeth's contract status, Reclamation delivered water to Hudspeth directly in the riverbed, with Project drains dumping excess water at the end of the Project back into the channel only to be re-diverted further downstream. For Hudspeth's many ditches to physically receive the water, however, Reclamation had to release excess supplies from Elephant Butte so that the volume was big enough to reach into the ditch headings. Although the 1911 Warren Act under which Reclamation executed contracts with water users did anticipate that so-called "excess" water from Reclamation projects could be made available for sale by the Secretary of Interior, it seemed unlikely that such an excess would exist permanently on the Rio Grande Project. As such, correspondence between the Reclamation and Hudspeth as well as language in each contract consistently placed Hudspeth in the position of subordination, due precisely to the uncertain supply of water. Uncertainty aside, parties worked together to solve the problem of inefficient delivery by determining that the extension of Project infrastructure – the Tornillo Canal – would help matters. By extending the Tornillo Main Canal into the Hudspeth District and contracting with Reclamation for the use of the waste water that came through this canal, Hudspeth water users would solve two serious problems:[5] they would obviate the need for excess storage water released into the river bed, and, because Tornillo's diversion was upstream from where the river became the international boundary, they would also prevent illegal Mexican diversions of their water supply on the Mexican side of the river across from Hudspeth's lands.[6] Nevertheless, the infrastructure changes were not enough to solve the unreliable water supply the district faced by not being part of the Rio Grande Project.

In 1923, Reclamation directed Hudspeth landowners to take some action "which would make unnecessary the enormous waste of water on the Project, which could not be continued in case of low water years or with the increasing area of the original Project being put in cultivation."[7] Later that year, Reclamation's chief engineer

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Archives, Denver; "Acting Chief of Construction to Director," Memorandum: Rental of water to lands outside of the limits of the Rio Grande Project, March 31, 1920, Records of the Bureau of Reclamation, R.G. 115, Entry 7, Project Administrative and Project Records, 1919-1945, Project Files, 1919-1929, Rio Grande 223.02, Box 907, 223.02, Transfer Case, Rio Grande, Corres. Re Lease of Sale of Water, Thru 1929, 2 of 2, U.S. National Archives, Denver; "D.C. Henny and L. W. Lawson to Board of Engineers," Memorandum: Point of Diversion for Irrigation of San Elizario Island, Rio Grande Project, January 12, 1918, NM OSE Library.

5 "W.T. Young, President Hudspeth County Conservation and Reclamation District No. 1, to the Secretary of the Interior," August 16, 1923, Entry 7, General Administrative and Project Records, 1919-1945, Project Files, 1919-1929, Rio Grande 301.4-303, Box 919, 303, Rio Grande Project, Transfer Case, Petitions for Construction, Fort Hancock, Thru 1929, U.S. National Archives, Denver.

6 "Project Manager to Chief Engineer, Denver, Colorado," Memorandum: Organization and Petition of the Hudspeth County Conservation and Reclamation District No. 1 - Rio Grande Project, August 23, 1923, Entry 7, General Administrative and Project Records, 1919-1945, Project Files, 1919-1929, Rio Grande 301.4-303, Box 919, 303, Rio Grande Project, Transfer Case, Petitions for Construction, Fort Hancock, Thru 1929, U.S. National Archives, Denver.

7 "Project Manager to Chief Engineer, Denver, Colorado," Memorandum: Disposition of Surplus Water - Rio Grande Project, April 28, 1923, Entry 7, General Administrative and Project Records, 1919-1945, Project Files, 1919-1929, Rio Grande 301.4-303, Box 919, 303, Rio Grande Project, Transfer Case, Petitions for Construction, Fort Hancock, Thru 1929, U.S. National Archives, Denver.

wrote to the Commissioner of Reclamation that "until it has been demonstrated that less water than heretofore assumed is required, or that the return water from the El Paso Valley area will be of such quality as to permit its use without large waste of storage for dilution therefor for irrigation purposes, it is believed inadvisable to include any large area of additional land in the Project, or agree to supply water to lands outside the Project, by which farms will be developed depending on this water supply, which must later be discontinued, thus resulting in large losses to the owners."[8] Having realized their 1918 mistake of not joining the Project when they had the opportunity, the Hudspeth farmers now approached the situation another way, proposing to merge with the El Paso County Water Improvement District No. 1 and become part of the Project through that entity.[9]

Such a merger would entail expanding the irrigated acreage under the Rio Grande Project, however, and Project officials now recognized that the Project's supplies were already stretched to or even beyond their limits by the 1920s. Both Project districts (EBID and EPCWID) balked at the suggestion,[10] with Reclamation arguing against the proposal to include Hudspeth on the districts' behalf. Reclamation made clear that "it is absolutely impossible to continue present methods of water delivery...because of the large waste which such method necessitates."[11] Project Manager L.M. Lawson explained it this way in 1923: "Assuming that the entire project water supply is sufficient for 150,000 acres, which area is nearly approached by the present limits of the irrigation district for New Mexico and that of Texas, the inclusion of the Fort Hancock area on the same basis, insofar as permanent water right is concerned, is obviously impossible. In the determination of the Project water supply, however, the recovered water from the Juarez and El Paso valleys below the International Dam [aka the Acequia Madre's diversion dam] was not included. Irrigation of these sixty or seventy thousand acres will undoubtedly provide a run-off which, if properly collected, would probably supply irrigation demands for the area now in cultivation in the Fort Hancock district." Because the Project was still incompletely developed, however, it was "difficult to determine the actual present water status for areas outside of the present project limits."[12]

Tellingly, although a 1923 draft of the base contract – outlining the key obligations and how water delivery and payment would be determined each year – allowed for surplus water that had been stored in Elephant Butte Reservoir to be provided to Hudspeth when return flows and wastewater were insufficient, and when Elephant Butte Reservoir spilled.[13] But newly appointed Reclamation Commissioner Dr. Elwood Mead, one of the world's

8 "Chief Engineer to Commissioner," Memorandum: Petition of the Hudspeth County Conservation and Reclamation District No. 1 - Rio Grande Project, October 29, 1923, Entry 7, General Administrative and Project Records, 1919-1945, Project Files, 1919-1929, Rio Grande 301.4-303, Box 919, 303, Rio Grande Project, Transfer Case, Petitions for Construction, Fort Hancock, Thru 1929, U.S. National Archives, Denver.

9 "W.T. Young, President Hudspeth County Conservation and Reclamation District No. 1, to the President and Board of Directors of El Paso County Water Improvement District No. 1," August 18, 1923, Entry 7, General Administrative and Project Records, 1919-1945, Project Files, 1919-1929, Rio Grande 301.4-303, Box 919, 303, Rio Grande Project, Transfer Case, Petitions for Construction, Fort Hancock, Thru 1929, U.S. National Archives, Denver.

10 "Chief Clerk to Director of Finance, Denver, Colo.," Memorandum: Contract with Hudspeth County Conservation and Reclamation District, No.1 - Rio Grande Project, August 8, 1924, 115-54-A-81, Office of the Chief Engineer, Denver, Colorado, General Correspondence Files, 1902-1942, (Engineering), Rio Grande, Box. 1133, 249-T, Rio Grande, Hudspeth County Conservation and Reclamation District #1, Thru 1925, U.S. National Archives, Denver.

11 "Project Manager to Chief Engineer, Denver, Colorado," August 23, 1923; "L.M. Lawson, Project Manager, to Mr. Roland Harwell, Manager, El Paso County Water Improvement District No. 1," September 21, 1923, Entry 7, General Administrative and Project Records, 1919-1945, Project Files, 1919-1929, Rio Grande 301.4-303, Box 919, 303, Rio Grande Project, Transfer Case, Petitions for Construction, Fort Hancock, Thru 1929, U.S. National Archives, Denver.

12 "L.M. Lawson, Project Manager, to Mr. Roland Harwell, Manager, El Paso County Water Improvement District No. 1," September 21, 1923.

13 "Commissioner to Director of Finance, Denver, Colo.," Memorandum: Proposed Contract with the Hudspeth Conservation and Reclamation District No. 1, Rio Grande Project, October 18, 1924, 115-54-A-81, Office of the Chief Engineer, Denver, Colorado, General Correspondence Files, 1902-1942, (Engineering), Rio Grande, Box. 1133, 249-T, Rio Grande, Hudspeth County Conservation and Reclamation District #1, Thru 1925, U.S. National Archives, Denver.

foremost experts on irrigation development, expressed concerns over this language. When commenting on the first draft of a contract with Hudspeth, he opined that the document appeared "to provide a permanent right," and that it was "quite unlike any other water contract heretofore made by the Government." Mead offered the opinion that if the contract was executed as written, lands would be permanently developed, "with the thought that this contract provides for a permanent and substantial water right."[14] He urged against such language, clearly recognizing that Hudspeth had no such guaranteed right to the waters of the Rio Grande. As a result, the government would only sign a contract in which this clause had been deleted, leaving only wastewater in the contract. That version of the contract was signed in December 1924. The Secretary of Interior himself was even involved, writing to farmers in Hudspeth to let them know that "such flow as has been available at the lower end of the project during the past year of large upper river discharge cannot be maintained in future years of full project development and low water periods."[15]

Since 1924 then, the Hudspeth District has operated as a wholly separate entity apart from the Rio Grande Project and has only enjoyed contracts for Project return flows and wastewater,[16] with no guarantee to the district for any water at all. From the start, the contracts between Reclamation and Hudspeth were for seepage, waste, and return flows recovered from the Rio Grande Project and delivered to the district at the terminus of the Tornillo Main Canal and delivered into the Hudspeth Main Canal at that point; the historic record is replete with documents stating this intent and noting that Hudspeth farmers were not entitled to *any water*. Project Superintendent Lawson further assured EPCWID's manager Roland Harwell that any quantity furnished to Fort Hancock would be "on a surplus basis and subject to prior project demands,"[17] with Reclamation's chief engineer agreeing and stating that, even if the Tornillo Canal were extended to the upper end of the Hudspeth lands, that it "be understood…that no water can be turned out of the Elephant Butte Storage for its [Hudspeth's] benefit."[18] Thus, Hudspeth's 1918 refusal to join the Rio Grande Project remained irreversible.

The base contract negotiated at the end of 1924 was essentially for *water rental* during each irrigation season starting in 1925, and stipulated that the rental was "secondary and inferior" to the rights of Rio Grande Project lands.[19] The Hudspeth District agreed to pay for the water on a per acre-foot basis, with the Secretary of the Interior fixing the specific charge every year to correspond to 6% of the construction costs for any Rio Grande Project works that directly affected the district, plus a proportionate amount of the yearly operation and maintenance fees associated with those works. The contract did not represent a permanent right to these waters, and the United States was not obligated to deliver *any* amount of water. Instead, the Project retained the right to use this wastewater itself, and the Reclamation Service made it clear that it had plans to develop and manage the Project to a degree of efficiency such that eventually there may be no wastewater at all.[20] In commenting on the final contract

14 "Commissioner to Director of Finance, Denver, Colo."

15 "Hubert Work, Secretary, to Mr. Paul D. Thomas," November 28, 1924, Entry 7, General Administrative and Project Records, 1919-1929,Project Files,1919-1929, Rio Grande 223.02- Box 908, 223.02 Rio Grande Lease of Water Contracts Hudspeth County Conservation & Reclamation Dist., thru Sept. 30, 1929, 2 of 2 Transfer Case, U.S. National Archives, Denver.

16 "Chief Engineer to Commissioner," October 29, 1923; "L.M. Lawson, Project Manager, to Mr. Roland Harwell, Manager, El Paso County Water Improvement District No. 1," September 21, 1923.

17 "L.M. Lawson, Project Manager, to Mr. Roland Harwell, Manager, El Paso County Water Improvement District No. 1," September 21, 1923.

18 "Chief Engineer to Commissioner," October 29, 1923.

19 "Contract Between the United States and Hudspeth County Conservation and Reclamation District No. 1, Providing for Rental of Water to the District" (Department of the Interior, Bureau of Reclamation, Rio Grande Irrigation Project, December 1, 1924), 2, Entry 7, General Administrative and Project Records, 1919-1945, Project Files, 1919-1929, Rio Grande 223.02, Box 907, 223.02, Transfer Case, Rio Grande, Water, Hudspeth County Conservation and Reclamation District, Thru 1929, U.S. National Archives, Denver.

20 "Contract Between the United States and Hudspeth County Conservation and Reclamation District No. 1, Providing for Rental of Water to the District"; "Commissioner to the Secretary of the Interior," Memorandum: Proposed Contract with the Hudspeth Conservation and Reclamation District No. 1, Rio Grande Project, November 10, 1924, 115-54-A-81, Office of the Chief Engineer, Denver, Colorado, General Correspondence Files, 1902-1942, (Engineering), Rio Grande, Box. 1133, 249-T, Rio Grande, Hudspeth County Conservation and Reclamation District #1, Thru

language, Hudspeth's own attorney, Major Richard Burges, noted that whether they liked the language or not, the district had "not a vestige of right in the waters of the Rio Grande," and so the district had to accept the contract words.[21]

The requirement in the December 1924 "base" contract that a cost be negotiated each year caused a great deal of headache for all parties in the two ensuing decades, which will be discussed at some length below. However, even with the several recurring issues and sticking points surrounding Hudspeth's water supply and water contract, the Project districts and the federal government never wavered from the position that Hudspeth's claim to water was always subordinate to and subject to Project operations and thus Hudspeth was much more vulnerable to upstream development than were Rio Grande Project participants.

New Rio Grande Development and Revocation of the Embargo

Meanwhile, continued westward migration throughout the young 20th century had put ongoing pressure on the upstream resources of the Rio Grande. The San Luis Valley in southern Colorado remained a magnet for agriculturally minded citizens thanks to the fertility of its soil. However, the valley had begun to experience major drainage problems due to the over-application of water on the lands. In the San Luis Valley, the problem was particularly acute, since land in the northern end of the valley sat in what was known as the Closed Basin, the geology of which let very little water drain back to the riverbed. Therefore, neither irrigated acreage nor production in the valley had increased as a result of growth, but instead had declined, as more and more land became seeped and alkalized and water applied to the land had unfortunate effect of raising the water table and/or evaporating.[22] The solution, proposed by Colorado's Irrigation Engineer Ralph I. Meeker who reported on the area in 1919 and again in 1924, was to drain the area and conserve the recovered water in a storage reservoir. His proposal would reclaim the swamped lands and provide a reliable supply of water to the San Luis Valley as well as the Middle Rio Grande Valley, just south of the Colorado/New Mexico border.[23] Meeker argued in 1919 that his Colorado storage project could proceed "without injury to the Rio Grande Project water supply or the Mexican treaty obligation."[24] (Emphasis in original.) Still, the Colorado engineers did not have a clear understanding of the hydrogeology of the basin until the late 1920s, and downstream users were skeptical of Meeker's assurances.[25] Meeker nevertheless advocated the revocation of the federal embargo that had been in place since 1895 and Colorado engineers began developing plans for several Colorado reservoirs including one called the Vega-Sylvester, high in the basin.

Just downstream of the Colorado/New Mexico border, residents of the Middle Rio Grande Valley saw development potential in their own region, as well, and were frustrated at having been deprived of water by "vigorous development in Colorado above and the Reclamation Organization below."[26] A 1919 report written

1925, U.S. National Archives, Denver.

21 "Richard F. Burges to Mr. Louis C. Hill," February 18, 1925, Box 4X188, Hudspeth District, 1924-1931, Center for American History, University of Texas at Austin.

22 R.I. Meeker, "Water Supply, Irrigation and Drainage, Present and Future Conditions, San Luis Valley, Colorado" (Denver, May 1924), 4–6, NM OSE Library.

23 Meeker, 6–7.

24 R.I. Meeker, "Review of Water Supply, Drainage, Irrigated Areas, and Consumptive Use of Water, Rio Grande Basin above Fort Quitman, Texas" (Denver, August 1924), 14, NM OSE Library.

25 "E.F. Osgood to Mr Herbert Yeo, State Engineer," September 14, 1927, Box 2F468, Rio Grande Compact Commission Records, 1924-1941, 1970, Rio Grande Compact Commission Records, 1924-1941, 1970 Richard Burges Papers: Correspondence, 1924-1935, 1927, Center for American History, University of Texas at Austin.

26 C.R. Hedke, "A Report on the Irrigation Development and Water Supply of the Middle Rio Grande Valley, N. M., As It Relates to the Rio

at the same time as Meeker's Colorado study had hinted at possible avenues for development in this valley and residents were eager to pursue this development further.[27] Following the establishment of the Rio Grande Compact Commission in 1924, the New Mexico Legislature appropriated $25,000 for a cooperative investigation between New Mexico and the Reclamation Service to study and report on the irrigation development and water supply of the Middle Rio Grande Valley.[28] Reclamation Engineer Homer Gault issued a detailed report on a potential Reclamation Service project in the Middle Rio Grande Valley in 1924.[29] Similar to lands in Colorado, Middle Rio Grande lands were suffering from a lack of drainage, rendering many of them swamped and not susceptible to cultivation; the water table in more than 90% of the valley had risen to a depth of less than four feet.[30] According to a New Mexico engineer who assessed Gault's report during compact negotiations in 1925, the combination of seeped lands and increased Colorado diversions had reduced irrigated acreage in the Middle Rio Grande from a high of 125,000 in 1880 to 40,000 acres in 1925. He said that the middle valley was 200,000 acre-feet short of its necessary water supply, but assured downstream users that reverting to irrigation of the full 125,000 acres in the Middle Valley would not "endanger nor injure" the water supply of basins further south.[31] Furthermore, Middle Rio Grande development proponents believed that a great deal of return water would be developed and usable downstream of the middle valley if a Middle Rio Grande project were to move forward.[32] The New Mexico engineer believed that the newly formed Rio Grande Compact Commission could, by allowing for development of the Middle Rio Grande, correct the injustices heaped upon New Mexico over the years by upstream users and provide "the general defense of its entire water rights wherever endangered."[33]

Just a few months after the engineer issued his report, on May 20, 1925, Secretary of Interior Hubert Work did in fact revoke the longstanding embargo. Work's action cleared the way for reservoir right-of-way applications in Colorado and New Mexico and it wasn't long before applicants submitted proposals for the Vega-Sylvester Reservoir and others in Colorado, as well as for Gault's proposals for storage for Middle Valley users. Contemporaneously, the New Mexico Supreme Court affirmed the constitutionality of the Middle Rio Grande Conservancy District (MRGCD), clearing the way for a development project to take place in that region.[34]

Unsurprisingly, the specter of new development reignited latent hostilities between the three Rio Grande states. There was a great sense of urgency to construct new projects, since Secretary Work's order reversing the embargo was accompanied by a stipulation that abrogation of water rights would occur if proposed developments were not completed within five years.[35] Colorado's reservoir construction plans, therefore, in combination with New Mexico's middle valley project, brought the promise of an interstate lawsuit. It was unclear whether New Mexico would sue Colorado, with Texas acting as intervenor, or if Texas would file the original suit against both upstream states. Regardless, the threat of an interstate battle to prevent further upstream depletions on the river loomed.[36]

Grande Compact" (Santa Fe: State of New Mexico, the Rio Grande Valley Survey Commission, January 1925), 2, NM OSE Library.

27 Homer J. Gault, "Report on the Middle Rio Grande Reclamation Project: New Mexico" (Denver: U.S. Reclamation Service, March 1924), 17, NM OSE Library.

28 Gault, 8–9.

29 Gault, "Report on the Middle Rio Grande Reclamation Project: New Mexico."

30 Gault, 43.

31 Hedke, "A Report on the Irrigation Development and Water Supply of the Middle Rio Grande Valley," 15.

32 "E.F. Osgood to Mr Herbert Yeo, State Engineer," September 14, 1927.

33 Hedke, "A Report on the Irrigation Development and Water Supply of the Middle Rio Grande Valley," 8.

34 Pearce C. Rodey, Attorney and J.L. Burkholder, Engineer, "The Middle Rio Grande Valley Project: Status and Information Relative to Development of Official Plan for Flood Control, Drainage, and Irrigation, Prepared for U.S. Bureau of Indian Affairs" (Albuquerque, New Mexico: The Middle Rio Grande Conservancy District, January 1, 1927), 4, NM OSE Library.

35 "San Luis Defies New Mexico to Halt Dam Plan: Mass Meeting Votes to Push Reservoir Project; Fight Suits If Filed," Press Release, Denver Evening News, March 10, 1928.

36 "Richard Burges to Mr. J.W. Taylor, President, Elephant Butte Irrigation District," July 2, 1927, Box 2F468, Rio Grande Compact

Despite the threat of litigation, water engineers found themselves extremely busy gathering data, assessing plans, and preparing for construction in all three states. Colorado was intent on building the Vega-Sylvester Dam for which it had received a right-of-way from the federal government but was also investigating the Wagon Wheel Gap Reservoir. This alternative reservoir, located about 70 miles downstream from Vega-Sylvester, had more support from Texas and New Mexico because it would have a larger capacity and would provide better flood control to the two lower states than the Vega-Sylvester Dam.[37] Meanwhile the Middle Rio Grande Project seemed to garner the support of both Texas and New Mexico, which both accepted the conclusions of studies proclaiming that "re-habilitation of the project will improve the river regimen and conserve water."[38] On that project, Chief Engineer Joseph Burkholder's final report to the MRGCD suggested that drainage of the Middle Valley lands would result in the irrigation of a net 129,000 acres of land, restoring the area's previous productivity.[39] Through construction of a storage reservoir called El Vado on the Rio Chama (a tributary of the Rio Grande located just south of the Colorado-New Mexico State line and northwest of Santa Fe), Burkholder asserted that the Rio Grande's flow could be regulated, with flood protection provided in the spring and water available during irrigation season, as well.[40] Importantly, Burkholder concluded that Middle Valley development would "not infringe on the water supply for lands dependent on the Elephant Butte Reservoir."[41] Earlier studies had reached the same conclusion.[42] With what appeared to be widespread agreement on the value of the MRGCD Project to the upper basin at large, the focus remained on Colorado's development plans. Tension over Colorado's development made clear that the Rio Grande states needed a system that would permanently and equitably divide the river before additional projects moved forward. The recent conclusion of the Colorado River Compact in 1922 provided a model to these three states as they continued to tussle over the Rio Grande. (See map next page).

Negotiating the Truce

As engineering plans moved rapidly forward in all three Rio Grande states, the Compact Commission remained largely out of the process. Following brief negotiations between only New Mexico and Colorado early in the commission's existence and the joining of Texas in 1926, several months of intensive data collection by engineers followed. Then, the commission was inactive for several years.[43] By the summer of 1928, the commission had made a little progress toward negotiation of a truce, but major disagreements remained.

Commission Records, 1924-1941, 1970, Rio Grande Compact Commission Records, 1924-1941, 1970 Richard Burges Papers: Correspondence, 1924-1935, 1927, Center for American History, University of Texas at Austin.

37 E.P. Osgood, "Report on Irrigation in the Rio Grande Basin, in Texas above Fort Quitman, and in New Mexico," 1928, NM OSE Library; E.P. Osgood, "Preliminary Report Upon the Use, Control & Disposition of the Rio Grande and Its Tributaries Above Fort Quitman, Texas," March 31, 1928, 16, Sub-Series 4.10 Reports: Rio Grande Basin, Box 54, Folder 1406, Preliminary Report Upon Use, Control & Disposition of the Waters of the Rio Grande and its Tributaries Above Fort Quitman, Texas, by E.P. Osgood, Confidential, New Mexico State Records Center and Archives.

38 Osgood, "Preliminary Report Upon the Use, Control & Disposition of the Rio Grande and Its Tributaries Above Fort Quitman, Texas," 13.

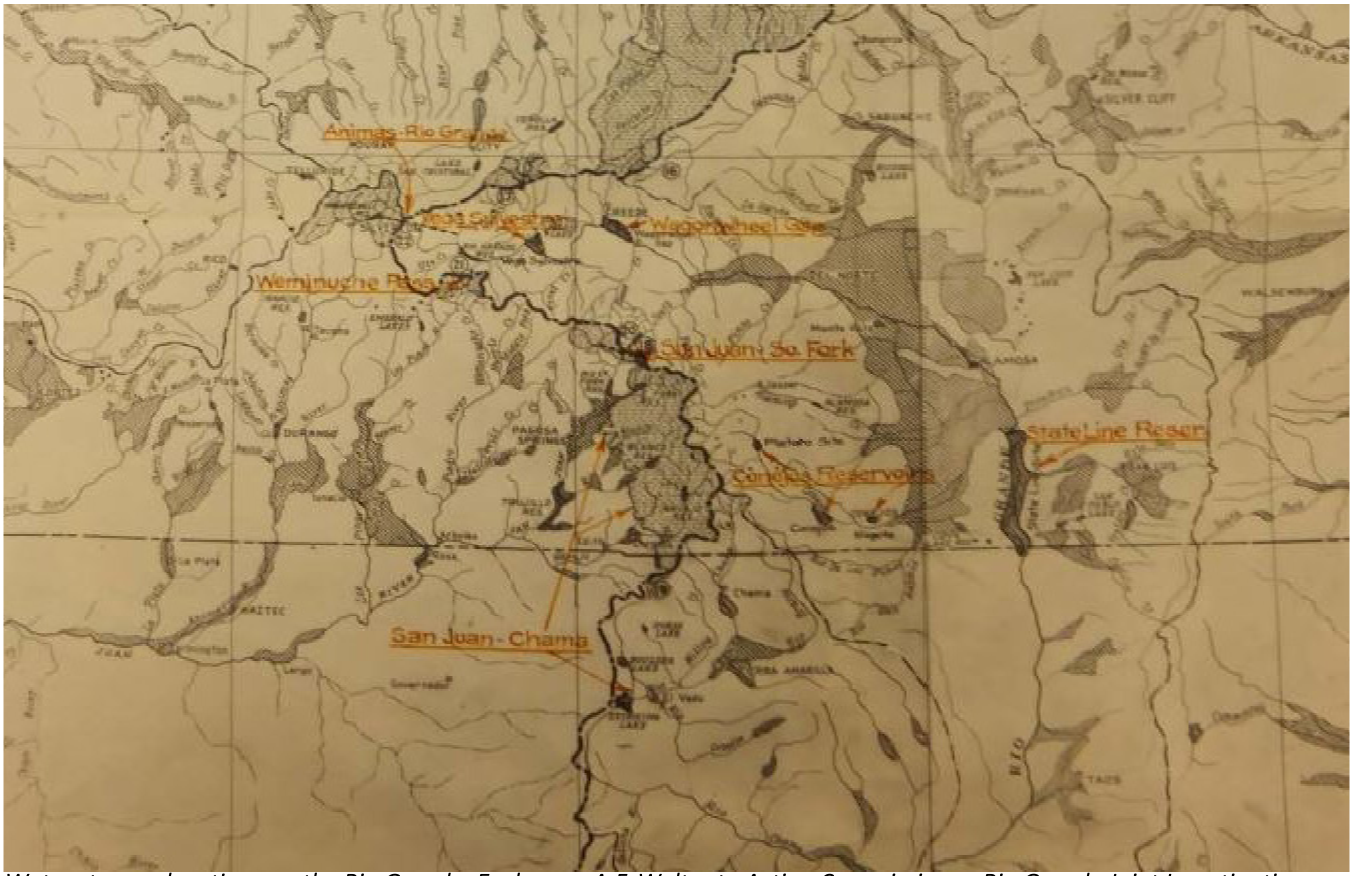
39 Joseph L. Burkholder, "Report of the Chief Engineer Joseph L. Burkholder: Submitting a Plan for Flood Control, Drainage and Irrigation of the Middle Rio Grande Conservancy Project" (State of New Mexico, Middle Rio Grande Conservancy District, August 15, 1928), 56, NM OSE Library.

40 Burkholder, 53.

41 Burkholder, 96.

42 Burkholder, 198.

43 McGregor, "Rio Grande Compact. Report of T. H. McGregor, Commissioner for Texas, to the Honorable Dan Moody, Governor of Texas," 7; "Minutes of Conference of Rio Grande Water Users Held June 8, 1926, in the Assembly Room of the Chamber of Commerce at Albuquerque, New Mexico," June 8, 1926, Box 2F471, Rio Grande Compact Records, 1924-1941, 1970, Box 2F471, Rio Grande Compact Records, 1924-1941, 1970, Center for American History, University of Texas at Austin.



Water storage locations on the Rio Grande. Enclosure, A.F. Walter to Acting Commissioner, Rio Grande Joint Investigations. October 20, 1936. Records of the Bureau of Reclamation, Entry 7, Box 937, Folder 301, Rio Grande Basin Engineering and Board Reports on Construction Features, 1930-1937 (August). U.S. National Archives, Denver.

Speculation was rampant about what each state would demand at an interstate negotiation. MRGCD engineer R.G. Hosea predicted that Colorado would argue for a specific volume of water delivered at the Colorado/New Mexico state line, leaving Colorado officials to otherwise independently manage the water within state boundaries.[44] Hosea believed, however, that downstream parties would only agree to such a position if Colorado built a reservoir on the state line to guard "against shortage to lower interests, keeping it full in intermediate periods,"[45] a concept that became known as the State Line Reservoir. The idea behind constructing a storage facility on the state line was that the state would store excess water "below any possible diversion by Colorado," ensuring that lower states would receive their share of the resource. Without such guarantees, Hosea doubted whether a treaty or compact could ever be achieved.[46] New Mexico and Texas, meanwhile, favored a division of water based on proportionate flow. New Mexico consulting engineer D.C. Henny proposed a delivery schedule for Colorado in an elaborate table of monthly surpluses and shortages, a method to which Meeker and other Colorado engineers objected, believing that the "inelastic" schedule would impose an impossible burden on Colorado during periods of shortage as well as unfairly restrict San Luis Valley development.[47] Because

44 R.G. Hosea, "Report on Irrigation in the Rio Grande Valley" (State of New Mexico, the Rio Grande Survey Commission, 1928), 74, NM OSE Library.

45 Hosea, 82.

46 Hosea, 82.

47 "D.C. Henny, Consulting Engineer for New Mexico and Texas, to Mr. Francis C. Wilson, Compact Commissioner for New Mexico," January 23, 1929, Box 2F469, Rio Grande Compact Commission Records, 1924-1941, 1970, Rio Grande Compact Commission Records, 1924-1941, 1970, Richard Burges Papers: Correspondence, 1924-1935, 1929 (Folder 1 of 2), Center for American History, University of Texas at Austin; "D.C. Henny to Francis C. Wilson," January 28, 1929, NM OSE Library.

their recommended method presented potentially insurmountable problems, the two downstream states alternatively suggested that calculations be based on the amount of water in Elephant Butte at any given time as well as the meeting of MRGCD's water rights. In other words, if Elephant Butte was full, Colorado would have few restrictions on use (other than obligations to MRGCD), and conversely, if it were empty, lower states would demand all discharge feasible from Colorado.[48] Colorado's response to the proportionate flow discussion was to suggest a schedule substituting calendar year flows for monthly flows, as well as a period of ten years for calculations, a method to which Texas and New Mexico objected since it gave Colorado an uncomfortable amount of flexibility in meeting the terms of any proposed compact.[49] There seemed to be no outward agreement during this speculative phase of negotiations.

The proposals and speculations were, however, moving the agreement process forward. By the time the parties met in January 1929 to work out the details of what was now thought of as a temporary compact, Colorado had agreed not to deplete the Rio Grande's flow at the state line for the life of the compact and to furnish water to the Middle Valley, *if* it was permitted to construct a Closed Basin drain in the San Luis Valley, the intent of which was to free up the water in the Closed Basin that was currently trapped. Colorado agreed with Texas and New Mexico that a State Line Reservoir – if constructed – would help to regulate flood flows for the downstream states, and all three states agreed that the Middle Valley should be permitted to divert or store water equivalent to any spill from Elephant Butte Reservoir. According to Hosea, the proposed compact, including the projects and conditions outlined above, represented no more than a "six-year cessation of hostilities," as opposed to a permanent solution.[50] Following several days of meetings in Santa Fe, the commission arrived at a draft compact, and each state signed it on February 12, 1929.[51]

Though called a compact, the document was more accurately a six-year truce, "during which period of time Colorado agrees not to impair the flow of the river by new or increased diversions or storage within the limits of Colorado, unless and until such depletion is offset by increase of drainage return,"[52] a reference to the Closed Basin drain, a compromise to which Colorado had only reluctantly agreed.[53] New Mexico was more positive about the compact and its potential to successfully guide the future development of the river. New Mexico compact commissioner Francis C. Wilson reported to New Mexico Governor Richard Dillon on the compact and spent a considerable amount of time explaining both the situation concerning the San Luis Valley's Closed Basin drain and the need for the State Line Reservoir, both of which were proposed in the compact. Wilson felt strongly that the construction of the drain from the Closed Basin of the San Luis Valley to the Rio Grande was feasible and would augment the flow of the Rio Grande by 175,000 acre-feet per year thereby providing "a steady and equated flow throughout the year" to downstream users.[54] Plus, for every bit of water returned to the Rio Grande at the state line by the drain, Colorado could use an equivalent amount without damage to

48 "Comments Bearing on Compact Negotiations," n.d., Box 2F471, Rio Grande Compact Records, 1924-1941, 1970, Rio Grande Compact Commission Records, 1924-1941, 1970, Richard Burges Papers, Memoranda and Comments, Undated, Center for American History, University of Texas at Austin.

49 "D.C. Henny, Consulting Engineer for New Mexico and Texas, to Mr. Francis C. Wilson, Compact Commissioner for New Mexico," January 23, 1929; "D.C. Henny to Francis C. Wilson," January 28, 1929.

50 Burkholder, "Report of the Chief Engineer Joseph L. Burkholder: Submitting a Plan for Flood Control, Drainage and Irrigation of the Middle Rio Grande Conservancy Project," 231.

51 Francis C. Wilson, "Rio Grande Compact Report of Francis C. Wilson, Commissioner for New Mexico" (Interstate River Commission for the State of New Mexico, n.d.), Box 2F471, Rio Grande Compact Records, 1924-1941, 1970, Rio Grande Compact Commission, 1924-1941, 1970, Richard Burges Papers: Rio Grande Commission Conference Reports, Statements, Proposals by Commissioners, 1929, Center for American History, University of Texas at Austin.

52 Wilson, 1.

53 "D.C. Henny to Francis C. Wilson," January 28, 1929.

54 Wilson, "Rio Grande Compact Report of Francis C. Wilson, Commissioner for New Mexico," 17.

water users in the downstream states. Wilson argued that the drain would thus benefit both Colorado and New Mexico. As to the State Line Reservoir, Wilson explained that its construction would allow Colorado to deliver to the state line a regular amount of water regardless of the time of year and would thus make the most efficient use of the water in both states. This regulated flow would be of particular use to the MRGCD. Wilson concluded that the compact would lead to cooperation between the three states, would use the water of the Rio Grande the most efficiently, would maintain a set flow at the state line between Colorado and New Mexico for six years regardless of developments in Colorado, would avoid litigation, would lead to the drainage of the Closed Basin and thereby augment the flow of the Rio Grande, would lead to the construction of the State Line Reservoir and thereby stabilize the water supply in New Mexico, and would allow a more permanent compact to be drawn up in six years.[55]

Soon after the compact conference, Colorado's representative Delph Carpenter informed the commission that even though Colorado's representatives had signed the draft compact during the meeting in Santa Fe, the state government would not sign the document to make it final. The upstream state had developed two major concerns about the draft. First, the draft compact required Colorado to deliver a monthly volume at the Colorado/New Mexico state line based on data that included an era when Colorado's San Luis Valley was far less developed, and therefore less water-hungry. State officials believed these data unfairly represented the current situation. Second, Colorado's studies had demonstrated a large volume of water being wasted at the downstream end of the Project, a fact which historical research has proven to be true. Colorado felt that it should not be asked to conserve resources when so much water was being allowed to flow out of the Project unused.[56] Consulting engineers for the downstream states took issue with Colorado's stance. They maintained that Colorado could simply not be permitted to increase its water use unless the water supply was augmented from another source, such as a sump drain in the Closed Basin or more efficient drainage in all of Colorado's swamped areas.[57]

In the days following Colorado's announcement that it had backed out, compact commissioners altered the compact's final language so that all three states would find it acceptable, which they ultimately did, and signed. Most important, perhaps, was the inclusion of Article V, which established that Colorado "must not cause the flow at the State line to be depleted."[58] Although the article lacked the specificity desired by the downstream states, all parties knew that construction of the Closed Basin drain and the State Line Reservoir in the ensuing years would be critical to reaching permanent compact terms in 1935, when the temporary compact was set to expire.[59] All three states began to lobby the federal government to include funding to construct the Colorado infrastructure as part of the bill ratifying the compact. They argued to federal representatives that funding the State Line Reservoir should be seen by the government as compensation to American water users for the water the United States promised to Mexico in the 1906 treaty,[60] since that treaty had "permanently deprived these

55 Wilson, 17.

56 Delph E. Carpenter, "Statement by Delph E. Carpenter, Commissioner for Colorado," February 6, 1929.

57 "D.C. Henny, et al to Hon. Francis C. Wilson, Commissioner for New Mexico and Hon. T.H. McGregor, Commissioner for Texas," February 7, 1929, NM OSE Library.

58 "Francis C. Wilson, Interstate River Commissioner for N.M., to Hon. T.H. McGregor, Rio Grande Compact Commissioner for Texas," February 22, 1929, Box 2F469, Rio Grande Compact Commission Records, 1924-1941, 1970, Rio Grande Compact Commission Records, 1924-1941, 1970, Richard Burges Papers: Correspondence, 1924-1935, Correspondence with T.H. McGregor, 1926-1930, Center for American History, University of Texas at Austin.

59 "Francis C. Wilson, Interstate River Commissioner for N.M., to Hon. T.H. McGregor, Rio Grande Compact Commissioner for Texas."

60 "Francis C. Wilson, Interstate River Commissioner for N.M., to Maj. Richard F. Burges," March 18, 1929, Box 2F469, Rio Grande Compact Commission Records, 1924-1941, 1970, Rio Grande Compact Commission Records, 1924-1941, 1970, Richard Burges Papers: Correspondence, 1924-1935, 1929 (Folder 1 of 2), Center for American History, University of Texas at Austin.

states of the use of that amount of water for their development."[61] The animosity between the states aside, they were united in asking the federal government to ratify the compact and to help fund the infrastructure its success relied upon.

The federal government seemed set to comply with the Rio Grande states' desires when opposition came from what was now known as the Bureau of Reclamation, or the former Reclamation Service. The head of that agency, Commissioner Elwood Mead, did not like the compact terms, and he also did not like the federal bill proposed to ratify it, the draft of which included federal funding for Colorado's infrastructure. In Commissioner Mead's words, the compact was meant only to be a "temporary expedient" in which Colorado agreed not to "cause or suffer the water supply at the state line of Colorado and New Mexico to be impaired by new or increased diversions for storage within the limits of that state," unless those depletions were offset by drainage returns and/or until the State Line Reservoir was constructed, but no later than June 1, 1935.[62] Mead did not like that the compact held his agency hostage and demanded financial support from it, nor did he believe that the compact did the job that a real interstate compact should do. He persuaded Secretary of the Interior Ray Lyman Wilbur of his beliefs, who subsequently informed Congress of his own opposition on the same basis. Additionally, Wilbur noted that the bill and the compact generally provided "for Federal expenditures for reimbursement of which no provision is made, and of a character which would set an undesirable precedent."[63] In the end, Congress passed the compact into law without the provision for federal funding of Colorado infrastructure. Without funding, and to the dismay of Rio Grande water users who were hopeful about the potential for an augmented supply, no State Line Reservoir was ever constructed.

Nevertheless, with a temporary compact in place and ratified into law, many downstream users could be more confident that upstream diversions would not radically affect their irrigation practices. The compact would allow for Rio Grande Project water users to continue receiving the same allotments of water, and Middle Valley residents had hope that their developments would soon enhance the irrigation of their own valley without interference from Colorado users. The Hudspeth District, however, remained in limbo. Their status as contract-users of excess Rio Grande Project water was not in any way protected by the temporary compact and as use of the river increased there was likely to be less "excess" than ever before.

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61 "Richard F. Burges to Senator Tom Connally," November 1, 1929, Box 2F469, Rio Grande Compact Commission Records, 1924-1941, 1970, Rio Grande Compact Commission Records, 1924-1941, 1970, Richard Burges Papers: Correspondence, 1924-1935, 1929 (Folder 2 of 2), Center for American History, University of Texas at Austin.

62 "Elwood Mead, Commissioner, to the Secretary," Memorandum for the Secretary of Interior, August 2, 1929, Box 2F469, Rio Grande Compact Commission Records, 1924-1941, 1970, Rio Grande Compact Commission Records, 1924-1941, 1970, Richard Burges Papers: Correspondence, 1924-1935, 1929 (Folder 2 of 2), Center for American History, University of Texas at Austin.

63 Francis C. Wilson, "Memorandum on the Objections Urged by the Secretary of the Interior to the Approval by Congress of the Rio Grande Compact," 1929, Box 2F471, Rio Grande Compact Records, 1924-1941, 1970, Rio Grande Compact Commission Records, 1924-1941, 1970, Richard Burges Papers, Memoranda and Comments, Undated, Center for American History, University of Texas at Austin.

Chapter 3: The First Compact Era: 1929-1935

Implementing the Compact

Regulating a river in the midst of a worldwide economic depression and in the face of interstate and international tension was a challenge. Little did anyone know when they signed the 1929 Compact how dramatically the world would change that October. Nevertheless, the 1929 Compact – signed before the October 1929 stock market crash which launched the Great Depression – quelled immediate tensions between the states and provided temporary relief through various Compact articles that addressed each of their concerns, as well as through a requirement that maintenance of the "status quo on the river" be the primary consideration of this temporary Compact.[1] For instance, the Compact addressed Texas and New Mexico's concerns over Colorado's development through Articles II, IV, V, and VIII with Articles II and IV identifying the draining of the Closed Basin (and returning of that water to the river) to be of the utmost importance as a means of compensating Rio Grande users for waters given to Mexico in 1906 treaty. Then Article V prohibited Colorado from further depleting the Rio Grande until such depletions were offset by drainage returns, and Article VIII provided Colorado's consent for a storage reservoir to be constructed below the lower state bridge, i.e. just north of the state line in Colorado. As far as Colorado's concerns about water being wasted at the lower end of the Rio Grande Project, the Compact's Article III required New Mexico and Texas to establish and maintain gauging stations between Elephant Butte Dam and the lower end of the Rio Grande Project in order to monitor all releases, flows, distribution, and waste of water. Meanwhile, the Compact addressed Texas's concerns about New Mexico's water use in the Middle Valley in Article XII, which assured the other two states that New Mexico would not "cause or suffer the water supply of the Elephant Butte Reservoir to be impaired by new or increased diversion or storage within the limits of New Mexico unless and until such depletion is offset by increase of drainage return."[2] The clear language of the Compact dictated, however, that no future negotiations for a permanent compact were bound by any part of this document, which also meant that the negotiations leading up to it were quite distinct from those leading to the 1938 Compact.[3] Finally, because so much of the 1929 truce depended on the construction of both a drain and a reservoir in Colorado, it was not clear to any of the parties how the interstate dispute would be resolved if those projects never came to pass.

The river system was constantly changing as the Rio Grande Project neared complete development with regard to irrigated acreage as well as canal and diversion dam infrastructure. The Compact accounted for the river's changing behavior by demanding the acquisition of data. In addition to the articles described above, one of the provisions of the Compact was the creation of a Compact Commission, which was to meet annually and prepare an annual report while working towards drafting a more permanent compact. In order to draft this compact, the commissioners needed a better understanding of the ever-changing river. At the commission's first annual meeting, that body asserted that the clauses of the truce that demanded rigorous data collection were intended to "provide for the accumulation and preservation of such data as may be necessary to a final and definite apportionment between the signatory states of the use of the waters of the Rio Grande and its tributaries

1 Language not from compact, but rather Francis C. Wilson, "Rio Grande Compact: Report of Commissioner for New Mexico and Memorandum of Law on Interstate Compacts on Interstate Streams" (State of New Mexico, 1929), 16, NM OSE Library.

2 Supreme Court of the United States, October Term, 1935, No.--, Original, the State of Texas, Complainant, vs. the State of New Mexico, et al., Bill of Complaint (October 1935); Wilson, "Rio Grande Compact: Report of Commissioner for New Mexico and Memorandum of Law on Interstate Compacts on Interstate Streams," 15.

3 Wilson, "Rio Grande Compact: Report of Commissioner for New Mexico and Memorandum of Law on Interstate Compacts on Interstate Streams," 9–10.

above Fort Quitman, and for the purpose of enlisting the federal government in augmenting and stabilizing the stream flow, on account of deliveries of water to Mexico under treaty obligations."[4] The commissioners were in agreement at this first meeting that accurate water supply data would be "indispensable in the formulation of the final compact to which the present compact looks."[5] They also further noted – repeatedly over the ensuing years – that the "object of all Signatory states is to permit the maximum use and future development of the Rio Grande consistent with the rights of the respective states." It was clear that none of the states desired to permanently limit the uses of the river; to the contrary, each state wanted to maximize their uses within the limits of the law.[6]

As such, determination of data collection methods dominated the early years of the temporary Compact's implementation on the Rio Grande. The three states, with the cooperation of the International Boundary Commission and the U.S. Geological Survey, installed gauges and determined agreed-upon methods of measuring the river. Once those procedural issues were set, the collection and analysis of data (per Article IV of the 1929 Compact) began, with each member of the Compact Commission receiving identical data annually including daily gauge heights, discharge curves, and storage stage in Elephant Butte Reservoir.[7] With new gauges all along the river, there was more information available than ever before, despite dozens of previous investigations. Presumably, this new data would have helped all three states understand the river's behavior in light of developments along the Rio Grande over the previous several decades.

The three Rio Grande states used the opportunity of the new data sets to launch new analyses. One of the novel studies that emerged from the Compact negotiation data was published in 1931. Not surprisingly, the 300+ page report examined water use and geology in the San Luis Valley. New Mexico State Engineer Herbert Yeo led the study and examined all previous data collected, including investigations performed by Colorado's Meeker and Tipton, as well as the new data being gathered pursuant to the 1929 Compact. Recognizing that Colorado was awaiting entitlements to construct one of two reservoirs upstream – the Vega-Sylvester and/or the Wagon Wheel Gap, several miles downstream – in addition to the State Line Reservoir, Yeo's study found that construction of Vega-Sylvester (in the northern part of the San Luis Valley) would "seriously menace the water supply furnished by the Rio Grande to New Mexico," since he conjectured that all of the water stored would simply be consumed downstream in the southern part of the San Luis Valley and remain in Colorado.[8] If accompanied by a compact and guarantee, however, Yeo thought that the Wagon Wheel Gap site – located nearly 70 miles further downstream in the San Luis Valley – could be effectively used to regulate flow into New Mexico thanks to that proposed reservoir's greater holdover storage capacity. Yeo concluded that possible depletions associated with increased irrigation in Colorado posed "a future threat upon the water resources of [New Mexico] of such magnitude that it may seriously impair the agriculture dependent thereon."[9]

4 "First Annual Report of the Rio Grande Compact Committee" (Rio Grande Compact Committee, January 16, 1931), Box 2F470, Rio Grande Compact Commission Records, 1924-1941, 1970, Center for American History, University of Texas at Austin. This report is unpaginated.

5 "First Annual Report of the Rio Grande Compact Committee." Report unpaginated.

6 "First Annual Report of the Rio Grande Compact Committee"; "Second Annual Report of the Rio Grande Compact Committee" (Rio Grande Compact Committee, February 12, 1932), Box 2F470, Rio Grande Compact Commission Records, 1924-1941, 1970, Center for American History, University of Texas at Austin; "Third Annual Report of the Rio Grande Compact Committee" (Rio Grande Compact Committee, January 26, 1933), Box 2F470, Rio Grande Compact Commission Records, 1924-1941, 1970, Center for American History, University of Texas at Austin. As the Third Annual Report states, "'…the primary purpose of the Rio Grande Compact is the maximum development and conservation of the available supply of the Rio Grande and its tributaries above Fort Quitman'" (4).

7 "State Engineer to L.R. Fiock, Superintendent," January 20, 1931, NM OSE Library.

8 Herbert W. Yeo, "Report on Water Supply, Irrigation and Drainage, in the San Luis Valley and Adjacent Mountain Areas in the State of Colorado," 1951, 286, NM OSE Library.

9 Yeo, 303.

Rio Grande: R.J. Tipton Measuring River at Tornillo Gauging Station. Top photo, page 6. Nieto Box 1 (Water Records), R.G. Compact Correspondence 1930-1933, Folder 17. New Mexico Interstate Stream Commission.

Compact parties were all too aware that the 1929 truce would expire in 1935, and that its temporary demand regarding Colorado's obligation to deliver the existing amount of Rio Grande water at the state line could be "renewed, abrogated, or changed."[10] New Mexico's Yeo hoped that when the parties negotiated a permanent compact, his state's compact representatives could use his data as evidence against any greater claims for water that Colorado might attempt to make. To no one's surprise, Colorado was also conducting its own investigation of conditions in the San Luis Valley, and Yeo suspected that the state would vie for even more water from the Rio Grande in the next round of negotiations, "regardless of the results [or impacts] south of the State Line."[11] Yeo wrote that New Mexico and Colorado engineers did not and could not see eye-to-eye on these issues and that "there is small chance of an amicable agreement as to facts and prospects."[12] Yeo urged that before the 1929 Rio Grande Compact expired, New Mexico had to "establish that use of water in the San Luis Valley is wasteful, extravagant and needlessly injurious to water users on the lower Rio Grande."[13] Meanwhile, Colorado was also investigating downstream wastes by the Project, sending engineer R.J. Tipton and Colorado Commissioner M.C. Hinderlider Texas to measure the river at the Tornillo Gaging Station, the Tornillo Ditch, and the head of the Hudspeth County Canal in order to study potential waste at the southern end of the Rio Grande Project.

Meanwhile, in spite of their differences, all three states came together to lobby the United States to fund drain construction in Colorado. During the spring of 1933 representatives from New Mexico, Texas, and Colorado approached Congress to appropriate funds for both the construction of the Closed Basin drain and surveys for a reservoir along the Colorado-New Mexico state line. Delegations from Colorado and Texas travelled to Washington D.C. to persuade members of Congress in person of the need for construction of the Closed Basin drain.[14] Additionally, each state's governor and state engineer wrote to congressmen who sat on the House and

10 Yeo, 303.
11 Yeo, 304.
12 Yeo, 313.
13 Yeo, 313.
14 "State Engineer to Hon. E.K. Neumann," May 31, 1933, NM OSE Library.

Tornillo Ditch: Tipton and Hinderlider Measuring Same. September 1930. Bottom photo, page 6. Nieto Box 1 (Water Records), R.G. Compact Correspondence 1930-1933, Folder 17. New Mexico Interstate Stream Commission.

Senate Committees on Irrigation and Reclamation.[15] Finally, the Rio Grande Compact Commission's third annual report explicitly recommended the passage of legislation authorizing the construction of the drain[16] and all three state legislatures passed memorials that pressed Congress to fund the project.[17] (See map in Chapter 2 for locations)

In 1935, likely in response to this lobbying effort, the federal Public Works Administration (PWA) commissioned a study by engineers on the San Luis Valley Drain Committee regarding the feasibility and worth of the Closed Basin drain project. In the resulting report, authors O.V.P. Stout, F.H. Fowler, and E.B. Debler presented information on the cost, water supply, and water quality associated with draining the so-called "dead area."[18] Their work began with field investigations carried out in February 1935 that were aimed at revealing whether some of the projections about the Closed Basin drain were accurate. For example, proponents of the project asserted that the amount of water recovered by the drain would and should allow Colorado the freedom to pursue equivalent water development and storage projects in other locations. But the PWA investigation found that the early estimates on the amount of recoverable water from the drain were "greatly exaggerated," offering a picture of the project that was far too optimistic.[19] Further, they found it likely that the recovered drain water would in fact be used locally to bring more Colorado lands under cultivation rather than being released to the Rio Grande for downstream use as was claimed. For this reason, the authors wrote that "no regular dependence can be placed on [the drain] securing water in material amount" for downstream users because the overall amount of water that could be developed was less than that promised in the proponents' proposal. [20] Additionally, the authors noted that water quality, and especially salinity, had to be a significant consideration because the drain water was intended for irrigation use. By diverting the drain water to the Rio Grande and allowing Colorado to store an equivalent amount of water in the watershed's headwaters, the project would, in effect, replace fresh water entering the Rio Grande with already used, saline water for downstream users. While the quantity of water in the Rio Grande at El Paso might be unaffected by this trade, the salt content would increase by 3-5% at El Paso, a notable, but not critical, decline in the water's quality. Although this would "increase the menace

15 "Sam Branton to Hon. Geo. M. Neel, State Engineer," May 22, 1933, NM OSE Library; "Dennis Chavez to Mr. Geo. M. Neel, State Engineer," May 23, 1933, NM OSE Library.

16 "State Engineer to Hon. Sam G. Bratton, United States Senator," May 17, 1933, NM OSE Library.

17 "Governor to Hon. Bronson Cutting, United States Senator," May 15, 1933, NM OSE Library.

18 "Report of San Luis Valley Drain Committee to Administrator Harold L. Ickes" (Denver, Colorado: Federal Emergency Administration of Public Works, February 26, 1935), letter of transmittal, NM OSE Library.

19 "Report of San Luis Valley Drain Committee to Administrator Harold L. Ickes," 4.

20 "Report of San Luis Valley Drain Committee to Administrator Harold L. Ickes," 6.

of salt" it would not "be on an extent to cause alarm," the authors concluded.[21] Despite lukewarm support, the engineers wrapped up by estimating that the project – at a cost of $580,000 – would recover an average of 40,000 acre-feet of water per year that would otherwise not drain into the Rio Grande, and that the drain water would not *significantly* alter the water quality of the Rio Grande in its lower stretches. The drain would "continuously salvage a considerable amount of water that is now lost," especially in years of high runoff[22] and that the project cost as well as the annual maintenance cost ($10,000) was "well within the economic value of such water in this territory."[23] Therefore they suggested that, if the United States paid for the construction cost as proposed, the annual maintenance fee that would be paid by farmers would be a worthwhile investment for San Luis Valley interests to take on.[24] However, the investigators made it clear that the drain would be unlikely to augment supplies for users in downstream states.

Despite the generally positive federal recommendation, the United States did not invest in the drain and the drain was not constructed. The onset and deepening of the Great Depression was at least one reason for inaction during the years that the river was regulated by the 1929 Compact. Regardless of the reasons for inaction, as the deadline for the Compact's expiration neared without any implementation of the solution supported and advocated by all parties in 1929, panic set in for the three states. Exacerbating the already tense situation was a period of low water on the Rio Grande in 1934 and 1935,[25] as well as the geographic proximity of what became known as the Dust Bowl, which affected all three Rio Grande states. While that devastating set of circumstances was not directly related to the Rio Grande, it nevertheless served as a constant reminder of the Rio Grande Basin's overall scarcity of water. Parties intensified their studies of the basin around 1935, so they each would have a better understanding of the situation and data for the battles to come. Some of these studies revealed that the amount of water in Elephant Butte Reservoir at the beginning of the 1935 season was less than half the average amount held by the lake in the previous 15 years.[26] In response to the shortage, some water users began to seek new sources of water, others abandoned their lands, while still others looked upstream to find a scapegoat for the shortage.

Hudspeth Water in the Inter-Compact Years

The data revealing the shortage in Elephant Butte was the latest in a string of events that led farmers downstream in the Hudspeth District to unite in seeking a more reliable source of water. In addition to the water supply shortage from the Project, Hudspeth was also competing with Mexican farmers who were diverting excess water from the Rio Grande below the Acequia Madre diversion and across the border from Hudspeth lands. They approached their water insecurity in two ways. First, they aimed to change the language of their 1924 base contract with the Bureau of Reclamation, and when that raised eyebrows, they tried to officially join the Project again. Both efforts failed.

Hudspeth had begun discussions to renegotiate its contract with the Bureau of Reclamation in the late 1920s, when farmers in the district began to suffer from seeped lands and demanded drainage to maintain production. Hudspeth had been late in its payments to Reclamation for the 1929 water year, a circumstance that had become

21 "Report of San Luis Valley Drain Committee to Administrator Harold L. Ickes," 25.
22 "Report of San Luis Valley Drain Committee to Administrator Harold L. Ickes," 3.
23 "Report of San Luis Valley Drain Committee to Administrator Harold L. Ickes," 26.
24 "Report of San Luis Valley Drain Committee to Administrator Harold L. Ickes," 26.
25 "Regional Planning: Part VI--The Rio Grande Joint Investigation in the Upper Rio Grande Basin in Colorado, New Mexico, and Texas, 1936-1937" (Government Printing Office, February 1938), 102.
26 "Superintendent L.R. Fiock to Chief Engineer," Memorandum: Project Water Supply, 1935 - Rio Grande Project, July 2, 1935, NM OSE Library.

common under the stipulations of the original contract, and during the annual negotiations over new rates, the parties batted around the idea of signing a new base contract in order to avoid similar disputes in the future. Hudspeth proposed a new contract in February 1930 which contained simple language in Section 4, stating that "the United States will have available at the terminus of said Tornillo Main Canal, certain water developed from the Rio Grande project." In Section 6, the proposed contract simply stated that the United States, "will deliver to the district at the terminus of the Tornilla [sic] Main Canal during each irrigation season as established on the Rio Grande Project, such water as may be available at said terminus without the use of storage from the Elephant Butte reservoir, and as may be required for the proper irrigation of district lands."[27] As prospects for infrastructure development in Colorado under the 1929 Compact declined and awareness of Elephant Butte's water shortage emerged, Hudspeth farmers were under even greater pressure to act. However, several recurring issues and sticking points made the renegotiation process difficult, leaving issues that remained unresolved by the time the Rio Grande states signed the permanent 1938 Compact.

The first difficulty Hudspeth encountered in renegotiating its 1924 contract was related to Hudspeth's repayment of Rio Grande Project costs. The way that Hudspeth's original contract was written, Hudspeth farmers reimbursed EBID and EPCWID a proportionate amount of their respective repayment costs to the United States,[28] depending on the volume of water those districts supplied to Hudspeth. One of the negotiating points for a new contract was whether Hudspeth should have to pay construction, operation, and maintenance fees for the entire Rio Grande Project infrastructure or just for the Rio Grande Project drains in the El Paso area that fed the district its water. The issue boiled down to the origin of Hudspeth's water: was it water that had been stored in Elephant Butte, meaning that the district should help pay for the dam's construction; or was it water derived from Project drainage in the El Paso Valley, and Hudspeth was off the hook for Elephant Butte costs?[29] The Hudspeth District argued that the benefits of Elephant Butte Reservoir's storage were expressly omitted from the 1924 contract, and therefore the district could not be expected to pay for the reservoir's construction, operation, and maintenance. The two Rio Grande Project irrigation districts, on the other hand, which benefitted from Hudspeth's payments offsetting their own, argued that the drains did not actually create a water supply, but instead allowed for the collection of water that was originally derived from Elephant Butte Reservoir.[30] As they saw it, Hudspeth owed the Project districts a greater offset.

The second sticking point also related to payment. Would Hudspeth be required to pay for all the water available at the end of the Tornillo Canal, regardless of their ultimate use of it, or could it get away with paying only for water that it used beneficially? Reclamation and the two Project districts argued for the former scenario, noting that if the contract obligated the United States to deliver all of its wastewater to Hudspeth rather than use it elsewhere, then reciprocity dictated that Hudspeth had to pay for it all.[31] The Hudspeth District, on the other

27 "Contract Between the United States and Hudspeth County Conservation and Reclamation District No. 1, Providing for Rental of Water to the District" (Department of the Interior, Bureau of Reclamation, Rio Grande Irrigation Project, Draft 1930), Entry 7, General Administrative and Project Records, 1919-1945, Project Files, 1919-1929, Rio Grande 223.02, Box 907, 223.02, Transfer Case, Rio Grande, Water, Hudspeth County Conservation and Reclamation District, Thru 1929, U.S. National Archives, Denver.

28 "Contract Between the United States and Hudspeth County Conservation and Reclamation District No. 1, Providing for Rental of Water to the District" (Department of the Interior, Bureau of Reclamation, Rio Grande Irrigation Project, December 1, 1924), 3, Entry 7, General Administrative and Project Records, 1919-1945, Project Files, 1919-1929, Rio Grande 223.02, Box 907, 223.02, Transfer Case, Rio Grande, Water, Hudspeth County Conservation and Reclamation District, Thru 1929, U.S. National Archives, Denver.

29 "Hudspeth County Conservation and Reclamation District No. 1 to Hon. Elwood Mead, Commissioner," July 6, 1928, 115-54-A-81, Office of the Chief Engineer, Denver, Colorado, General Correspondence Files, 1902-1942, (Engineering), Rio Grande, Box. 1133, 249-T, Rio Grande, Hudspeth County Conservation and Reclamation District #1, 1928 thru 1930, U.S. National Archives, Denver.

30 "Roland Harwell, General Manager, to Mr. H.J. Devries, District Counsel," July 12, 1928, Entry 7, General Administrative and Project Records, 1919-1929,Project Files,1919-1929, Rio Grande 223.02- Box 908, 223.02 Rio Grande Lease of Water Contracts Hudspeth County Conservation & Reclamation Dist., Oct. 1927 thru Dec. 1929, 1 of 2 Transfer Case, U.S. National Archives, Denver.

31 "H.J.S. Devries, District Counsel to Commissioner, Washington D.C.," Memorandum: Water charges - Hudspeth County Conservation

hand, argued that it should be obligated to pay only for water that it used, not for water that simply flowed from the Tornillo Canal through the Hudspeth Main Canal and back into the Rio Grande, unused.[32]

The contract language Hudspeth proposed in 1930 concerned EBID farmers and the irrigation district's Board of Directors. When they met to discuss the issue, their actions indicated well-placed concerns regarding Hudspeth's efforts to usurp Project water rights. Specifically, EBID took issue with the language in the sections 4 and 6 (quoted above) and recommended changes that would better protect EBID's users and leave no doubt as to Hudspeth's secondary status. The language recommended by EBID is highly relevant to today's dispute and helps to discern the beliefs and intent of the EBID water users and their representatives. EBID farmers wanted to ensure that new Hudspeth contract language protected EBID users from any future Hudspeth claims to Project water. For Section 4, the EBID board thus recommended this substitute language, which put important words from the original 1924 contract back into the newly proposed contract: "Whereas the United States will have for disposal at the terminus of the Tornillo Canal certain water which represents *operating and unavoidable wastes* of the Rio Grande Federal Irrigation Project, as well as drainage water return from the lands of this project all of which water may be used for the irrigation of lands within the district." [Emphasis added.] EBID also recommended more precise language for Section 6 of the proposed new contract:

> The United States will provide for the uses of the District at the terminus of the Tornillo Main Canal and at other points where its diversion is possible into the canals and distributaries of the district and during each irrigation season as established by the Superintendent of the Project, such waste and other water from said project as may be available *without the use or release of stored water from Elephant Butte Reservoir specifically for the irrigation of district lands*. The Secretary of the Interior shall be the sole judge of the availability of such water unless and until the control of the reservoir shall pass into the hands of the waters [sic] on said federal project."[33] [Emphasis added.]

EBID also objected to another clause that they believed might leave room for misunderstandings in the future: "we do protest against the clause which reads: 'and as may be required for the proper irrigation of district lands.' This undoubtedly would leave a loophole," EBID's manager wrote to Rio Grande Project Superintendent L.M. Fiock, "for many future arguments and disagreements as to what water may be required for a 'proper irrigation.' It is conceivable that both quantity and quality of water might be brought in question." In other words, EBID objected to any language that could be interpreted as requiring Project districts to deliver a quantity designed to achieve a particular quality of water for Hudspeth irrigation.[34] Any water delivered to Hudspeth was explicitly secondary and not guaranteed.[35]

Recognizing EBID's concerns, Hudspeth proposed yet another alternative plan. Having engaged in controversial negotiations over rates every year since the first year of its contract with the Rio Grande Project, Hudspeth requested instead to officially become part of the Rio Grande Project so as to obtain government assistance with

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and Reclamation District No. 1, Rio Grande Project, August 11, 1928, 115-54-A-81, Office of the Chief Engineer, Denver, Colorado, General Correspondence Files, 1902-1942, (Engineering), Rio Grande, Box. 1133, 249-T, Rio Grande, Hudspeth County Conservation and Reclamation District #1, 1928 thru 1930, U.S. National Archives, Denver.

32 "Hudspeth County Conservation & Reclamation District No. 1 to Hon. Elwood C. Mead, Commissioner," July 23, 1928, Entry 7, General Administrative and Project Records, 1919-1929,Project Files,1919-1929, Rio Grande 223.02- Box 908, 223.02 Rio Grande Lease of Water Contracts Hudspeth County Conservation & Reclamation Dist., Oct. 1927 thru Dec. 1929, 1 of 2 Transfer Case, U.S. National Archives, Denver.

33 "B. P. Fleming, Manager, to Mr. L. R. Fiock, Project Superintendent," March 12, 1930, Entry 7, General Administrative and Project Records, 1919-1945, Project Files, 1919-1929, Rio Grande 223.02, Box 907, 223.02, Transfer Case, Rio Grande, Water, Hudspeth County Conservation and Reclamation District, Thru 1929, U.S. National Archives, Denver.

34 "B. P. Fleming, Manager, to Mr. L. R. Fiock, Project Superintendent."

35 "B. P. Fleming, Manager, to Mr. L. R. Fiock, Project Superintendent."

its drainage construction and of course, to obtain a reliable source of water.[36] Reclamation Commissioner Elwood Mead expressed support for the plan but mentioned, not surprisingly, that the two Project irrigation districts were opposed to Hudspeth becoming a part of the Project on equal terms with their own districts.[37] With some optimism, Hudspeth formally proposed to join EPCWID.[38] Engineer Louis Hill, working on behalf of Hudspeth, suggested in October 1930 that Hudspeth be given a "first class water right and pay her full proportion of the cost of Elephant Butte Dam."[39]

Just a few months later, Project Superintendent Fiock wrote to the Commissioner of Reclamation and recommended that negotiations be suspended, with the Depression and drought having thrown Project operations into chaos.[40] Although Hudspeth negotiations and discussions continued throughout the 1930s, there was little progress. In 1935, Reclamation's Chief Engineer E.B. Debler wrote to Commissioner Elwood Mead to let him know that Hudspeth had again made additional attempts to secure a water supply, a "repetition of efforts made years ago." Expressing his disapproval, Debler continued that in the context of Rio Grande Compact negotiations (which had recommenced), "the set-back to Colorado irrigation through the [previous] construction of the Rio Grande project should not be amplified by the allocation of a water supply to the Hudspeth District. There is, of course, no objection to the district using the *waste waters* of the Rio Grande project, but it is very doubtful that the district can stay in cultivation if its water supply is so limited for the reason that the waste waters of the Rio Grande Project will become increasingly saline and of more erratic flow as the project attains a higher duty of water."[41] From Debler's and many other United States professionals' perspectives, it was imperative to keep Hudspeth at arm's length and to maintain that district's subservient water supply position.

Shifting Alliances: The Changes of 1935

In 1935, the political landscape along the Rio Grande began to shift. Several issues (set against the context of the Depression and the Dust Bowl) converged at once to cause panic in Rio Grande states. The driving force behind the panic was the temporary Compact's June 1935 expiration date and the need for a permanent apportionment of the river. Second, the MRGCD completed construction of its project, storing nearly 200,000 acre-feet of water

36 "A. H. Kelly, Chairman Committee, to Honorable Ray Lyman Wilbur, Secretary of the Interior," May 12, 1931, Entry 7, General Administrative and Project Records, 1919-1945, Project Files, 1919-1929, Rio Grande 223.02, Box 907, 223.02, Transfer Case, Rio Grande, Water, Hudspeth County Conservation and Reclamation District, Thru 1929, U.S. National Archives, Denver; "Louis C. Hill to Dr. Elwood Mead, Commissioner of Reclamation," October 28, 1930, Entry 7, General Administrative and Project Records, 1919-1945, Project Files, 1919-1929, Rio Grande 223.02, Box 907, 223.02, Transfer Case, Rio Grande, Water, Hudspeth County Conservation and Reclamation District, Thru 1929, U.S. National Archives, Denver; "Hudspeth County Conservation & Reclamation District No. 1, Wade H. Miller, to Secretary of the Interior," October 15, 1930, Entry 7, General Administrative and Project Records, 1919-1945, Project Files, 1919-1929, Rio Grande 223.02, Box 907, 223.02, Transfer Case, Rio Grande, Water, Hudspeth County Conservation and Reclamation District, Thru 1929, U.S. National Archives, Denver.

37 "Elwood Mead, Commissioner, to Mr. Dobbel," Memorandum for Mr. Dobbel re letter from Chairman Hudspeth County Conservation and Reclamation District No. 1, May 20, 1931, Entry 7, General Administrative and Project Records, 1919-1945, Project Files, 1919-1929, Rio Grande 223.02, Box 907, 223.02, Transfer Case, Rio Grande, Water, Hudspeth County Conservation and Reclamation District, Thru 1929, U.S. National Archives, Denver.

38 "Superintendent to the Commissioner, Washington, D.C.," Memorandum: Hudspeth County Conservation and Reclamation District No. 1 Consolidation - Rio Grande Project, November 8, 1930, Entry 7, General Administrative and Project Records, 1919-1945, Project Files, 1919-1929, Rio Grande 223.02, Box 907, 223.02, Transfer Case, Rio Grande, Water, Hudspeth County Conservation and Reclamation District, Thru 1929, U.S. National Archives, Denver.

39 "Louis C. Hill to Dr. Elwood Mead, Commissioner of Reclamation," October 28, 1930.

40 "Superintendent to the Commissioner, Washington, D.C.," Memorandum: Hudspeth County Conservation and Reclamation District No. 1, Supplementary Contract, change of due date - Rio Grande Project, May 27, 1931, Entry 7, General Administrative and Project Records, 1919-1945, Project Files, 1919-1929, Rio Grande 223.02, Box 907, 223.02, Transfer Case, Rio Grande, Water, Hudspeth County Conservation and Reclamation District, Thru 1929, U.S. National Archives, Denver.

41 "E. B. Debler to Dr. Elwood Mead, Commissioner, Bureau of Reclamation," February 27, 1935, NM OSE Library.

behind the El Vado Dam on the Rio Chama, a tributary to the Rio Grande, located just south of the Colorado-New Mexico state line and northwest of Santa Fe, leading to concerns that less water was being contributed to the main stem of the Rio Grande below the Colorado/New Mexico state line.[42] Third, illegal and unaccounted-for Mexican diversions continued to increase, the impacts of which were progressively more acute. Finally, the Hudspeth District's attempts to renegotiate its base 1924 contract threatened to require that more water be released from Elephant Butte Reservoir for downstream users. Together, these concurrent concerns created a firestorm on the Rio Grande, inciting new disputes between parties, challenging the status quo, and forging new alliances.

1929 Compact Extension

The problem of the expiring temporary compact was paramount. As it had done annually since 1929, the Compact Commission gathered on January 28, 1935. This meeting began with heated opening statements. When United States delegate S.O. Harper later reflected on it, he said that the Colorado delegation came to the meeting with a chip on its shoulder, carrying residual anger over the 1895 embargo and steadfastly refusing to entertain any permanent compact that would require it to deliver a specific volume of water to the New Mexico state line. In private conversations with the Colorado delegation, Harper informed the Coloradans that without a compact, the courts would have to get involved, a situation that everyone hoped to avoid. Meanwhile, Major Richard Burges, representing the Rio Grande Project districts, explained that New Mexico and Texas were unwilling to negotiate a permanent compact until the Closed Basin drain in the San Luis Valley was constructed. Harper suspected that the real reason for their reluctance was that they had simply not done enough compilation and analysis of data yet to support their case against additional Colorado water development and used the drain as a stalling tactic.[43] Regardless of reasoning, each state finally conceded to extend the existing agreement, realizing that a solution designed by the courts could result in a worse situation for any one of the states. Therefore, they agreed in mid-February 1935 to extend the current truce for two additional years to June 1937, believing that each state would act in good faith. In the interim, each state hoped to obtain research data collected by the other two states so that all of them would be working with the same information when they came back together to determine an apportionment.[44]

Development of MRGCD

Up until 1935, Colorado had long served as both New Mexico and Texas's primary target of blame for water shortages in the basin. But the 1929 Compact had required Colorado to cease development until the Closed Basin drain and State Line Reservoir were constructed, neither of which had yet occurred. And, while small developments had in fact gone forward in the state, Colorado had not permitted the development of any major storage projects, in accordance with the agreement. New Mexico, meanwhile, had permitted (with the informal approval of the other two states) the MRGCD project to move forward with work that involved draining the swamped lands inside that district's boundaries and completing the El Vado Reservoir on the Rio Chama in 1935. Of course, this work was not done in secret, but Colorado and Texas suspected that the project they had informally sanctioned in the 1920s had expanded beyond its original scope. To ensure that New Mexico was complying with Article XII of the 1929 Compact and not causing any additional depletions in the Middle Valley, representatives of EBID and EPCWID inspected the MRGCD project in July 1934. That inspection revealed that

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42 "El Vado Dam," Bureau of Reclamation, accessed September 25, 2019, https://www.usbr.gov/projects/index.php?id=96.

43 "S. O. Harper, Assistant Chief Engineer, to Dr. Elwood Mead, Commissioner, Bureau of Reclamation," February 21, 1935, Entry 7, Project Correspondence File 1930-1945, Rio Grande Basin, Box 936, 032.1 Rio Grande Basin - Corres re Compact between States of Colorado; New Mexico + Texas re Rio Grande Basin Water Rights, U.S. National Archives, Denver.

44 "Richard F. Burges to Hon. William E. Clayton, House of Representatives," February 16, 1935, Box 2F470, Rio Grande Compact Commission Records, 1924-1941, 1970, Center for American History, University of Texas at Austin.

MRGCD had developed new, previously uncultivated lands rather than simply draining the previously cultivated (but now swamped) lands, an action which the Project districts believed was a violation of MRGCD's original approvals. When, in 1935, MRGCD applied for funding from the Public Works Administration for an additional 10,000-acre pumping project near Albuquerque, Bureau of Reclamation Commissioner Elwood Mead assured downstream users that Reclamation had given no approval for such additional plans.[45] In fact, although Reclamation had thoroughly supported the project's development, the agency's chief engineer E.B. Debler asserted that his previously given opinion was based on a certain scenario. He had opined that that the MRGCD's original plans would not harm the Rio Grande Project or the flow into Elephant Butte Reservoir, an opinion that had had been predicated on the assumption that MRGCD's developments would be "confined to the river bottom lands." If now it was shown that the MRGCD moved to cultivate previously uncultivated "virgin" lands, then "the conclusions heretofore reached can no longer be supported."[46] As such, the blame for perceived water shortages on the southern end of the Rio Grande Project in Texas was shifting from Colorado squarely to New Mexico.

Thus, the MRGCD's developments drove a new wedge between Texas and New Mexico, one that the United States' delegate to the Compact Commission S.O. Harper predicted would have to be the subject of a "sub-compact" between the two states.[47] Taking the issue up, Texas's new Rio Grande Compact Commissioner T.H. McGregor wrote to Thomas McClure, State Engineer for New Mexico on April 13, 1935, regarding the shortages that Texas believed the El Vado Dam on the Chama River was causing at Elephant Butte. McGregor noted that although all parties had previously assumed that the El Vado Dam would "conserve as much water through prevention of evaporation as it would store," meaning that it would not "constitute a diversion of the run-off" which normally flowed into Elephant Butte, this had not been the case for much of 1935, and the water supply of Elephant Butte had been "seriously impaired by storage of waters at El Vado Dam." Aside from noting the actual problems Texas believed that El Vado Dam was causing, McGregor also explained that the fact that El Vado Dam had impounded waters destined for storage at Elephant Butte constituted a violation of Article XII of the Rio Grande Compact, and proposed that McClure confer with all interested parties to make an arrangement that would not "impair the rights of the lower Rio Grande interests."[48] New Mexico's McClure took the issue directly to Chief Engineer Anderson of MRGCD, noting that, "I had planned to take this matter up with the new Interstate Stream Commission at their first meeting, but the date for this is so indefinite I have decided to forward a copy of the letter, and will appreciate a statement regarding the contents of same."[49] Anderson responded that the MRGCD would "do everything possible to bring about an amicable settlement of any differences which might exist between our District and those in the Lower Valley."[50] However, two weeks later, a more detailed response from Anderson to McClure explained that MRGCD had studied the matter of the El Vado Dam and had determined that Texas's protest lacked substantive support. The district saw "no basis for the statement that our works have in any way impaired the water supply of the Elephant Butte Reservoir."[51] In fact, Anderson asserted the returns from MRGCD drainage water had *benefitted* the lower valley since the beginning of such flows from

45 "E.B. Debler to Dr. Elwood Mead, Commissioner, Bureau of Reclamation," February 27, 1935, NM OSE Library; "Elwood Mead, Commissioner, to Mr. F. E. Schnepfe, Director, Projects Division, Public Works Administration," May 2, 1935, NM OSE Library.

46 "E.B. Debler to Dr. Elwood Mead, Commissioner, Bureau of Reclamation," February 27, 1935; "Elwood Mead, Commissioner, to Mr. F. E. Schnepfe, Director, Projects Division, Public Works Administration," May 2, 1935.

47 "S. O. Harper, Assistant Chief Engineer, to Dr. Elwood Mead, Commissioner, Bureau of Reclamation," February 21, 1935.

48 "Rio Grande Compact Commissioner for Texas to Mr. Thomas McClure, State Engineer," April 13, 1935, Box 2F467, Rio Grande Commission, 1936-1941, 1970, Rio Grande Commission (1936-1939), Center for American History, University of Texas at Austin.

49 "State Engineer to Mr. Carl A. Anderson, Chief Engineer, Middle Rio Grande Conservancy District," May 13, 1935, NM OSE Library.

50 "Middle Rio Grande Conservancy District, C. A. Anderson, to Mr. Thomas M. McClure, State Engineer," May 15, 1935, NM OSE Library.

51 "Middle Rio Grande Conservancy District, C. A. Anderson, to Mr. Thomas M. McClure, Rio Grande Compact Commissioner," May 27, 1935, NM OSE Library.

the middle valley in 1930. Anderson concluded his letter by writing that "no water was stored at El Vado prior to this year [1930], hence there can be no reason for a protest, considering drainage return over the past four years and also that being returned to the river during the current year."[52] Texas did not concur with this conclusion, and MRGCD's operations would continue to be contentious in the near-term future.

United States-Mexico Relations

In addition to domestic tensions along the Rio Grande in the mid-1930s, international strife between the United States and Mexico grew during these years, as well. As noted above, EPCWID water users were concerned over unauthorized Mexican diversions downstream of the Acequia Madre (where Mexico received its treaty water in Juarez, across from El Paso and just downstream from the Project's Franklin Canal) as early as the 1920s, and these concerns grew more acute into the 1930s as all farmers faced drought conditions. Rio Grande Project users as well as non-Project downstream farmers had gathered in 1926 to argue that Mexico's diversions violated the terms of the 1906 treaty between the two countries,[53] and in response, the American section of the International Boundary Commission collected data, making "extensive preliminary surveys, plans, and estimates and negotiating with the Mexico Section of the Commission for river rectification and flood control from El Paso to Fort Quitman."[54] River rectification and the associated infrastructure would play a very important role in water deliveries to American farmers on the Rio Grande and formed a significant backdrop to negotiations of the 1938 Compact. [See the history of the rectification project below in Chapter 5.]

The International Boundary Commission and the Bureau of Reclamation worked together on river issues, and in March 1935, the latter agency produced a report on Mexican canal diversions, written by Project Hydrographer W.F. Resch. Rio Grande Project Superintendent L.R. Fiock had directed Resch to use "available and estimated Mexican records," a river flow analysis, and water distribution records from El Paso to Fort Quitman dating from 1931 to 1934. While the data was not thought to be 100% accurate, the investigation still showed "that in 1932 a large increase in the diversions by the Mexican canals was made and has continued."[55] Resch accused Mexico of withholding the official Mexican diversion records because they showed "a much greater volume being diverted than is allowed in the treaty of 1906."[56]

Resch believed that one of the most significant challenges of administering the river was that there had never been a way to measure or control the 60,000 acre-foot treaty delivery obligation to Mexico. The Acequia Madre – located just downstream but nearly across from the Franklin Canal and in the vicinity of El Paso – did not have a controlled intake or headgate of any kind. This uncontrolled intake "seriously interfered with the operation of

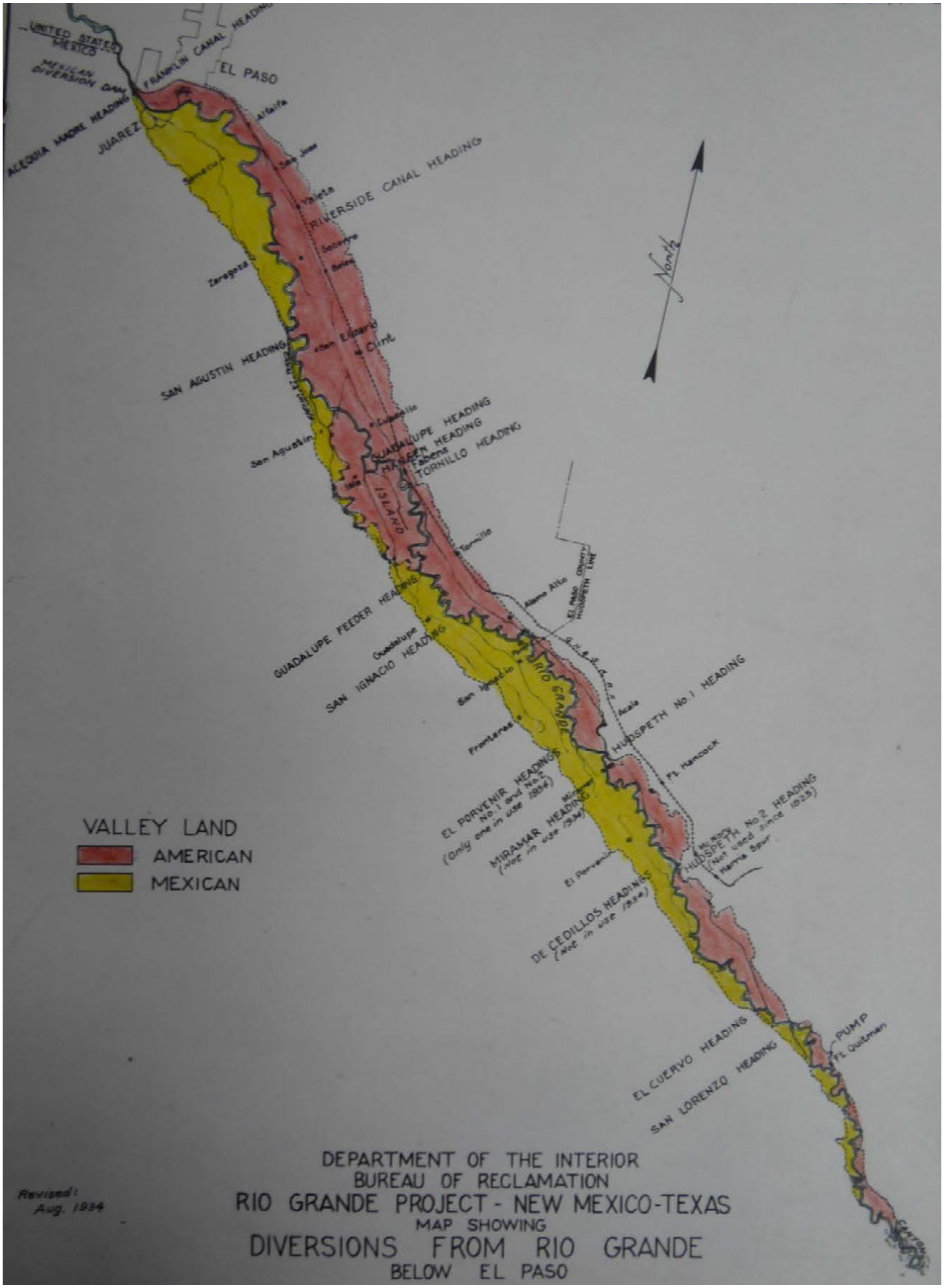
52 "Middle Rio Grande Conservancy District, C. A. Anderson, to Mr. Thomas M. McClure, Rio Grande Compact Commissioner."

53 "Minutes of Conference of Rio Grande Water Users Held June 8, 1926, in the Assembly Room of the Chamber of Commerce at Albuquerque, New Mexico," June 8, 1926, Box 2F471, Rio Grande Compact Records, 1924-1941, 1970, Box 2F471, Rio Grande Compact Records, 1924-1941, 1970, Center for American History, University of Texas at Austin.

54 "Project History: Rio Grande Project, Calendar Year 1928," n.d., 15–16, NM OSE Library.

55 W. F. Resch, "Mexican Canal Diversions in the Vicinity of El Paso, Texas" (El Paso, Texas: Department of the Interior, Bureau of Reclamation, Rio Grande Irrigation Project, March 29, 1935), Engineering and Research Center, Project Reports, 1910-55, Code 510 Box 722, Mexican Canal Diversions in the Vicinity of El Paso, Texas, U.S. National Archives, Denver. This report is unpaginated.

56 The report was accompanied by a letter from Resch to Fiock in which Resch admitted that he was "not greatly impressed with the absolute accuracy of the conclusions" in the report, given that he had amassed discharge records from various different canals, wasteways, drains, and gauging stations, and combined them with evaporation, transpiration, and seepage estimates over a stretch of river 136 miles long. Resch guessed that the wasteway figures, based on ditchriders' estimates, were probably the source of the largest amount of error. Another large source of error was the lack of information on drainage water in the upper Juarez Valley, especially from 1932 onwards, a time period in which there had been much drain construction but little data collection. Resch was also hesitant because of "very meager data on the diversion and use of water" in the Juarez Valley. Despite all this, in his letter to Fiock Resch argued that the investigation data clearly showed that Mexico was taking more than its treaty rights. See Resch, letter of transmittal.



Diversions from the Rio Grande Below El Paso. 1926. Records of the Bureau of Reclamation. Engineering and Research Center Project Reports, 1910-1955, Box 722, Mexican Canal Diversions in the Vicinity of El Paso. U.S. National Archives, Denver.

the Franklin Canal by 'running' most of the water around the International [diversion] Dam through the Acequia Madre head, then to the river through one of the two wasteways."[57] (See photos next page). Thus, in the fall of 1934, a low water year, badly needed water in the Rio Grande bypassed the intake of the Franklin Canal completely. This was not an anomaly, Resch argued, but rather such conditions and operations happened year after year, for the entire irrigation season. He argued that the omission of a headgate was responsible for the current situation of illegal diversions of river water to Mexico and the resulting and currently increasing difficulty of distributing water below the City of El Paso on the American side of the river. In compiling the records, he reported that the Acequia Madre diverted 57,241 acre-feet in 1916 and a similar amount in 1917, but diverted almost 90,000 acre-feet in 1919, and 81,000 acre-feet in 1920 and 1924. 1925 saw 94,000 acre-feet diverted to the Acequia Madre.[58] The unpredictability of the diversion made planning on the American side impossible. Furthermore, it was a well-known fact that in addition to excessive and unpredictable diversions in the Acequia Madre, Mexican farmers were also taking water directly out of the river below the Acequia Madre, a direct violation of the 1906 Treaty in which Mexico disclaimed all water below the Acequia Madre all the way to Fort Quitman.

Heightening the volatility of the situation and Mexico's excessive diversions was the fact that Mexico was openly entertaining new demands on the water supply from farmers in the lower end of the Juarez Valley *below* the Acequia Madre heading. A Mexican engineer was studying valley conditions, and a Mexican presidential candidate had overtly promised "to do everything possible to secure additional water from the Rio Grande for the lands in the vicinity of Guadalupe and San Ignacio, below Juarez."[59] The increased demand for water was the result of Mexico having expanded its irrigated acreage, an increase that Resch thought had begun around 1930. Initially, this increase in irrigated acreage in the lower end of the valley had coincided with – and was balanced out by – a decrease in irrigated acreage in the upper Juarez Valley due to waterlogged and alkaline conditions. But, like in the United States, Mexico had drained its waterlogged lands in recent years through the construction of at least 100 miles of drains, then gradually reclaimed those lands again for cultivation, creating an even greater draft on the Rio Grande. Resch estimated that there were 55,000 to 65,000 acres of land in the Juarez Valley that would come under irrigation again with the new drainage, clearly much higher than the original 25,000 acres anticipated by the 1906 treaty and used as the baseline for Mexico's 60,000 acre-foot allotment of Rio Grande water. Resch wasn't sure if the development of the lower part of the Juarez Valley for irrigation was officially sanctioned by the Mexican government, but he noted that there was a clear effort to pass Rio Grande water in excess of 60,000 acre-feet down to the lower valley. Once the river rectification project was complete, Mexico planned to conduct more infrastructure work on its canals so that the middle step of wasting back to the river would not have to occur.[60] This connection would allow water in the Acequia Madre to travel all the way down the valley to Guadalupe and San Ignacio.[61] Meanwhile, rectification would have important consequences on the United States' side of the river, as well.

Resch concluded his report by noting that "the only permanent solution" to the lack of American control of the

57 Resch, "Mexican Canal Diversions in the Vicinity of El Paso, Texas."

58 Resch, Exhibit No. 4; "T.D. Porcher, El Paso County Water Improvement District No. One, et. al, to the Honorable Secretary of State," June 2, 1926, Entry 7, General Administrative and Project Records, 1919-1945, General Files, 1919-1929, 032.3-032.5, Box 36, 032.5, Transfer Case, Correspondence re Proposed Agreements with Mexico Involving Settlement of Water Rights of International Streams (Colorado, Rio Grande, & Tia Juana Rivers), 1925 thru 1927, 1 of 2, U.S. National Archives, Denver.

59 Resch, "Mexican Canal Diversions in the Vicinity of El Paso, Texas," No page.

60 Resch, No page.

61 Resch, No page.

Head wall of Acequia Madre (foreground) with water recorder and bridge in background showing the absence of a control structure at the entrance to the canal - taken from the American end of the International Dam. Records of the Bureau of Reclamation. Engineering and Research Center Project Reports, 1910-1955, Box 722, Mexican Canal Diversions in the Vicinity of El Paso. U.S. National Archives, Denver.

Rio Grande, Acequia Madre, and Franklin Canal below the International Dam with arrows indicating the locations of headgates of the two canals. Records of the Bureau of Reclamation. Engineering and Research Center Project Reports, 1910-1955, Box 722, Mexican Canal Diversions in the Vicinity of El Paso. U.S. National Archives, Denver.

proper amount of water delivered to Mexico "is the construction of a diversion dam above the point where the Rio Grande becomes the International Boundary and an All American Canal built from the diversion dam along the American side of the river to the present Franklin Canal" so as to convey all of the water needed for the El Paso Valley directly to the Franklin Canal.[62] He thought the United States needed to step up and take responsibility for limiting Mexico's diversions under the 1906 treaty so that American Project farmers' crops would not fail. He also thought that Hudspeth District water deliveries needed to be protected against excess Mexican diversions going forward, since although Hudspeth had no Reclamation Project rights, the United States was certainly more invested in American farmers obtaining water than Mexican farmers.[63]

Other planned changes to the river also aimed to give the Bureau of Reclamation much better control over the water released from Elephant Butte Dam and deprive Mexico of any water other than its allotted 60,000 acre-feet. Furthermore, the construction of an All-American Canal upstream from the Mexican Acequia Madre diversion would add to the Bureau's control and result in a significant savings of water.[64] These changes – and others, including a wholesale rectification of the river channel that was discussed as early as 1926 but implemented in the 1935-1938 period (see Chapter 5 below) – would help to limit Mexico to its treaty rights and nothing more.[65]

Closing Out 1935

The shifting landscape and uncertain ground of 1935 led to significant events toward the end of the year. First, President Franklin Roosevelt issued a directive in September that there could be no new projects using Rio Grande waters unless the newly formed National Resources Committee provided an affirmative opinion. Roosevelt had created this New Deal federal agency and charged it with efficient regional development of natural resources; it was a quintessential part of Roosevelt's deep belief in the power of regional and resource planning.[66] Second, Texas filed a complaint against New Mexico in November in the United States Supreme Court alleging that New Mexico had violated terms of the 1929 Compact by permitting the construction of the El Vado Dam and development of the MRGCD, and arguing that the MRGCD had adversely affected flow into Elephant Butte Reservoir and negatively altered the salt content of the water therein.[67] Third, in December 1935, the Rio Grande Compact Commission acquiesced to basin-wide assistance from the National Resources Committee's Water Resources Group. At President Roosevelt's urging, the commission voted to permit this agency to facilitate a full investigation of the Rio Grande basin and its current patterns and data. Some of the findings in what became the multi-agency Rio Grande Joint Investigation Report would ultimately form the basis of the 1938 Rio Grande Compact.

62 Resch, No page.

63 Resch, No page.

64 "Frank B. Clayton, Attorney for Hudspeth County Conservation and Reclamation District No. 1, to Hon. John C. Page, Commissioner, Bureau of Reclamation," March 7, 1939, Entry 7, Project Correspondence File 1930-1945, Rio Grande Project, Box 927, 301. Rio Grande Project - Board + Engineering Reports on Construction Features Jan. 1, 1937, U.S. National Archives, Denver.

65 "L.M. Lawson, Superintendent, to Bureau of Reclamation," Telegram, February 28, 1926, NM OSE Library.

66 "Franklin D. Roosevelt to Federal Agencies Concerned with Projects or Allotments for Water Use in the Upper Rio Grande Valley above El Paso," Memorandum, September 23, 1935, Entry 7, Project Correspondence File 1930-1945, Rio Grande Basin, Box 936, 032.02 Rio Grande Basin - Corres re the "Rio Grande Embargo" involving prohibition agains constr. Of Irrigation Works Within the Rio Grande Basin. 1930 thru-, U.S. National Archives, Denver.

67 Supreme Court of the United States, October Term, 1935, No. --, Original, the State of Texas, Complainant, vs. the State of New Mexico, et al., Bill of Complaint.

Chapter 4: Arriving at an Equitable Apportionment: The 1938 Rio Grande Compact

Authorization and Scope of the Rio Grande Joint Investigation

Under the shadow of litigation in December 1935, the Compact Commission met to continue discussing apportionment and distribution of the Rio Grande. One of the focal points of this particular meeting was the presentation by Professors Frank Adams (University of California) and Harlan Barrows (University of Chicago), representing the National Resources Committee. This committee offered to design a comprehensive study of water use in the Rio Grande Basin to assist the states in dividing the waters of the river. While commissioners were slightly wary of handing over water investigations to a federal committee, they each recognized that a lack of data on water availability and water use in the basin still prevailed, particularly now that there were even more changes to the system with the construction of El Vado. They understood that arriving at an equitable apportionment depended upon closing any data gaps. In fact, Reclamation engineer and U.S. Compact representative S.O. Harper described the Compact Commission as having "reached a point where it was impossible to make any further progress without some workable plan for the collection and correlation of all pertinent data by a single agency."[1] Thus, an outline of this investigation's scope and findings – which became known as the Rio Grande Joint Investigation or "RGJI" – is critical to understanding the Compact, since the 1938 agreement was based on the data collected therein.

The professors began their presentation by posing several questions to the commission to guide the commissioners toward a resolution that would green-light and help guide the committee's study. Among the questions that Barrows and Adams felt the Commission should address in order to properly guide the study were: "What investigations are needed to determine the extent a) of the present use of water in the area, and b) of its use at the adoption of the compact?" And, "What, in the long run, will be your needs for water, not for irrigation supply, but for all other purposes, for city and town water supply, for industry, and the like? What are the prospects with respect to growth in population and the prospects for new and greater needs for water associated with that growth?"[2] Although there was some consensus among the commissioners regarding the benefits of laying the issues before "an unbiased tribunal,"[3] Barrows balked at this term, noting that the NRC's role would merely be that of an "eager assistant," and not that of a tribunal.[4] As discussions continued into the meeting's second day, New Mexico specified its desire to obtain data about the potential of augmenting the Rio Grande's flows, through storage, trans-mountain diversions, drainage, and the reduction of waste.[5] The other two states also commented on the study's content. Perhaps most significant at this stage were two points upon which the three states' representatives agreed: 1) that the investigation be purely fact-finding and non-binding on any one state;[6] and 2) that each state would seek funds to contribute funding for the work. After some negotiation over the resolution's wording, the commissioners resolved to move forward with the NRC's study and the RGJI was born. The expressed intent of the RGJI was to provide information that would permit the states

1 "S.O. Harper, Assistant Chief Engineer, to Dr. Elwood Mead, Commissioner, Bureau of Reclamation," December 7, 1935, Entry 7, Project Correspondence File 1930-1945, Rio Grande Basin, Box 936, 131 Rio Grande - Cooperation - National Resources Committee, U.S. National Archives, Denver.

2 "Proceedings of the Rio Grande Compact Conference" (Santa Fe, New Mexico, December 10, 1934), 6, NM OSE Library.

3 "Proceedings of the Rio Grande Compact Conference," 8.

4 "Proceedings of the Rio Grande Compact Conference," 9.

5 "Proceedings of the Rio Grande Compact Conference," 17.

6 "Proceedings of the Rio Grande Compact Conference," 23.

to make an equitable division of the waters of the Rio Grande without resorting to the courts.[7] It would be led by the two professors and Engineer in Charge Harlow Stafford, upon whose appointment all state representatives agreed.[8]

In the weeks following the commission meeting, the NRC began to facilitate the necessary studies. There were two critical components: compiling any relevant data that had previously been collected and obtaining any new data necessary to fill in the gaps. By the end of January 1936, the NRC had initiated communications with several federal agencies that would conduct different pieces of the new studies: the U.S. Geological Survey (USGS), the U.S. Bureau of Reclamation (Reclamation), and the U.S. Bureau of Agricultural Engineering (BAE). Each agency negotiated a memorandum of agreement with the NRC to conduct the research that fell within their respective areas of expertise. The investigations consisted of: water supply studies (of surface water, return flows, and, to a small extent, groundwater) to be conducted by the USGS; consumptive use studies of irrigated crops as well as natural vegetation, to be conducted by the BAE; studies of potential storage opportunities and stream augmentation, to be prosecuted by Reclamation; and water quality studies, also spearheaded by the USGS with help from the BAE. The NRC defined the underlying "problem" each of these studies would address in this way:

> The major problem of the Middle and Elephant Butte-Fort Quitman sections is the maintenance of an adequate water supply for irrigation of the lands of the Middle Rio Grande Conservancy District in the Middle section and of the Rio Grande Project and Hudspeth County Conservation and Reclamation district in the Elephant Butte-Fort Quitman section. With respect to the latter section, there is the further problem of maintaining satisfactory control of salinity in the irrigated areas.[9]

By compiling the results of each independent study as well as previously collected data, the NRC's RGJI intended to determine how best to protect existing rights (as they currently *existed in the law*)[10] as well as how to expand development within the limits of the resource.

Despite the definition of the overall "problem" to be solved by this investigation, constricted resources and limited funds meant that the studies the NRC commissioned focused on the resources under greatest threat and where the greatest controversies had occurred: those upstream of Elephant Butte. For instance, the USGS divided its study of water supply in the basin into surface and ground water investigations. The agency agreed to research stream and canal gaugings; measurements of return flows and waste; and underground water studies. They also worked with the BAE on water quality sampling. However, of the $109,000 budget outlined for the USGS's work, only $7000 of it was budgeted for *any* work downstream of Elephant Butte Reservoir.[11] Mostly, the agency reflected the Compact Commission's concern about the quality of water flowing *into* the reservoir as a measure of – in their minds – what was, in turn, being released downstream.[12] Furthermore, at a meeting of RGJI representatives on April 30 and May 1, 1936, consensus for "essential work" below Elephant Butte dam

7 "Proceedings of the Rio Grande Compact Conference," 4; "S.O. Harper, Assistant Chief Engineer, to Dr. Elwood Mead, Commissioner, Bureau of Reclamation," December 7, 1935.

8 "Proceedings of the Rio Grande Compact Conference Held in Santa Fe, New Mexico," December 2, 1935, 10, NM OSE Library.

9 "Regional Planning: Part VI--The Rio Grande Joint Investigation in the Upper Rio Grande Basin in Colorado, New Mexico, and Texas, 1936-1937" (Government Printing Office, February 1938), 12.

10 As noted in Chapter 3, the Hudspeth Irrigation District was entitled only to unavoidable waste at the downstream extreme of the Rio Grande Project; that use and the limitations to which it was subject was to be protected.

11 "Rio Grande Joint Investigation: Stream and Canal Gagings, Measurements of Return Flow and Waste, and Underground Water Studies" (Water Resources Branch, U.S. Geological Survey, n.d.), Entry 454, Records Concerning Rio Grande Joint Investigation, Box 1, National Resources Committee - Rio Grande Investigation - Ground Water, U.S. National Archives, II.

12 "Regional Planning: Part VI--The Rio Grande Joint Investigation in the Upper Rio Grande Basin in Colorado, New Mexico, and Texas, 1936-1937," see Part V for a discussion of the relationship between salt content of water flowing into the reservoir and the salt content of the water being released.

provided only one line item for the Texas lands: "measurement of wastes below [the City of] El Paso only."[13] A memorandum of agreement between the USGS and the NRC reflected that this geographic and substantive breakdown of work was finally approved on February 28, 1936.[14] Thus the areas downstream of Elephant Butte, including those in Hudspeth County, saw little USGS study under the RGJI, demonstrated by the RGJI final report section related to the USGS's water quality and surface water studies, which stated that the "area of irrigated land in Hudspeth County…[was] not included in the Elephant Butte project or in the present investigation."[15]

The Bureau of Reclamation's work on storage opportunities also focused only on the upstream areas in Colorado and New Mexico above Elephant Butte. Reclamation divided its research into three sections: reservoirs, trans-mountain diversions, and power studies.[16] Reclamation's reservoir studies included examination of capacity, feasibility, and cost for several potential sites, including Wagon Wheel Gap, Vega Sylvester, and Conejos (a tributary to the Rio Grande) in Colorado; and the State-line, and Willow Creek (on the Chama) in New Mexico. (See map in Chapter 2.) Minimal study was needed on trans-mountain diversions, especially on the project known as the San Juan Diversion, considering that a fair amount of investigation had already transpired on that project. Finally, Reclamation's power studies constituted a minimal amount of work, with the estimate of work for this portion of the study totaling only $5,000.[17] In addition, the BAE would examine consumptive use in the basin from Colorado to Fort Quitman, examining evaporation, varying needs of different crops being cultivated such as alfalfa and cotton, and water consumed by natural vegetation. The agency examined and mapped vegetative cover and history of past water use, calculating water requirements along the way.[18]

Despite the Compact Commission's unanimous agreement on the joint need for more data collection at their meeting in December 1935, Texas immediately became the state which slowed things down. Not long after the Compact Commission agreed to work with the NRC, Texas's engineer adviser Raymond Hill wrote at length in late January 1936 to Texas colleague and Compact Commissioner Frank Clayton to express reservations about the RGJI's evolution and its focus. Texas's uncertainty and its consequent failure to allocate or commit funds was already jeopardizing the RGJI. Hill's six-page letter to Clayton is telling on several fronts related to Texas's position going into both the 1935 lawsuit against New Mexico as well as negotiations for a permanent compact. First, Hill felt that the price tag for various parts of the RGJI was far too high, and that "in-kind" contributions made by individual states through previously collected data as opposed to cash should be acceptable and would permit the federal investigation to continue. Second, Hill objected to the groundwater research being designed by USGS, arguing that the agency "should be limited in extent," and that "groundwater supplies along the Rio Grande *are of little importance in relation to the total supply*." He never contended that the Rio Grande Project owned groundwater rights, and he argued that groundwater should be studied only in the San Luis Valley because of the

13 "Proceedings of Inspection Trip, General Conference and Committee Meeting in Connection with Visit of Consulting Committee, April 27 - May 2, 1936" (National Resource Committee: Rio Grande Joint Investigation, 1936), 36, Box 2F463, Center for American History, University of Texas at Austin.

14 "Progress Report on Ground-Water Studies, Rio Grande Joint Investigation (as of April 24, 1936)" (Water Resources Branch, U.S. Geological Survey, n.d.), Entry 454, Records Concerning Rio Grande Joint Investigation, Box 1, National Resources Committee - Rio Grande Investigation - Ground Water, U.S. National Archives, II.

15 "Regional Planning: Part VI--The Rio Grande Joint Investigation in the Upper Rio Grande Basin in Colorado, New Mexico, and Texas, 1936-1937," 446.

16 "Memorandum of Agreement: National Resources Committee and Bureau of Reclamation, Rio Grande Joint Investigation," February 25, 1936, Entry 7, Project Correspondence File 1930-1945, Rio Grande Basin, Box 936, 131 Rio Grande - Cooperation - National Resources Committee, U.S. National Archives, Denver.

17 "Alan Laflin to Mr. Roland Harwell and Mr. N. B. Phillips," February 8, 1936, Box 2F464 Rio Grande Commission 1935-1938 Pamphlets, Rio Grande Commission (Pamphlets), Center for American History, University of Texas at Austin.

18 "National Resources Committee: Rio Grande Joint Investigation, Progress Report - August 1, 1936," 1936, 6, Entry 412, Water Resources Division, General Correspondence Files, 1907-1954, Box 34, National Resources Committee Reports and Pamphlets, U.S. National Archives, II.

Closed Basin and its potential to augment supplies, and even there only "if stations are favorable to the development of groundwater." [Emphasis added.] Instead, he wanted the USGS to focus on return flows and waste control. Finally, Hill complained generally about the social economic turn that he believed the study had taken by including a New Deal agency focused on rehousing the poor called the Resettlement Administration; Hill believed the agency's work was beyond the limits of what the commission had agreed to in December.[19] Commissioner Clayton concurred with Hill's assessment, and conveyed their concerns to the NRC just a few days later. Clayton told the NRC that Texas should bear a smaller cost for the study than the upstream states both because he believed Texas's own records were up to date and in good order, and because consequently, "little or no investigation will be necessary south of Elephant Butte dam." Clayton argued that "the acreage benefiting from the investigation is very much smaller in Texas than in either Colorado or New Mexico."[20] Finally, Clayton justified Texas's lower monetary contribution by pointing to the disproportionate amount of work to be done in Colorado's Closed Basin, the benefit of which was negligible to Texas.[21] When the engineers met informally in Santa Fe in early February 1936 to discuss the RGJI survey resources, Texas representatives voiced these concerns again to the group.[22] Nevertheless, the budget was set, and the hard work of collecting and analyzing data began. The group reiterated its demand that Texas contribute its monetary share of the work, a contribution that would take quite some time to obtain.[23]

Relationship of RGJI to Texas v. NM

As RGJI-affiliated studies progressed and evolved in 1936 and 1937, a picture of water use on the Rio Grande emerged in a new, more comprehensive way. As such, the RGJI became a tool not only to collect data to form the basis for a new, permanent compact, but also to make progress toward settlement of the ongoing lawsuit between Texas and New Mexico, which Texas had initiated in 1935 over what it claimed was a violation of the 1929 Compact by New Mexico through its development of the MRGCD and construction of El Vado Reservoir.

However, as the work progressed, more thorough studies into the basin's quality of water came to form a larger part of the RGJI than had originally been scoped.[24] In part, that was because Texas's Compact delegation and its litigation team recognized the difficulty of their state's case against New Mexico. Because it was proving hard to demonstrate that MRGCD construction was to blame for a decrease in water quantity into Elephant Butte Reservoir, Texas had begun to push the matter of declining water *quality* as a key argument in that lawsuit. The new focus on water quality may also have been related to salt incursion into the city of El Paso's municipal supplies that began in 1934. (This is discussed in detail in Chapter 5.) In September 1936, as Texas was preparing for upcoming hearings in front of

19 "Raymond A. Hill to Mr. Frank B. Clayton," January 27, 1936, Box 2F464 Rio Grande Commission 1935-1938 Pamphlets, Rio Grande Commission (Pamphlets), Center for American History, University of Texas at Austin.

20 "Frank B. Clayton, Rio Grande Compact Commissioner for Texas, to National Resource Committee," February 1, 1936, Box 2F464 Rio Grande Commission 1935-1938 Pamphlets, Rio Grande Commission (Pamphlets), Center for American History, University of Texas at Austin.

21 As survey details and costs were ironed out, the states' collective contributions were figured to be $55,000, or approximately $18,500 each. Texas's legislature was not scheduled to meet again until January 1937, and Governor John Allred had no authority to allocate funds without the legislature. Although Texas's late or potentially nonexistent contribution was controversial among the RGJI participants, the state did ultimately contribute its equal portion of the $55,000, in the amount of $18,333.33, once its legislature convened in early 1937. "Frank B. Clayton, Rio Grande Compact Commissioner for Texas, to Mr. Harlowe M. Stafford, Engineer in Charge, Rio Grande Joint Investigation," March 17, 1937, Box 2F464 Rio Grande Commission 1935-1938 Pamphlets, Business & Legal 1938, Center for American History, University of Texas at Austin.

22 "Alan Laflin to Mr. Roland Harwell and Mr. N. B. Phillips," February 8, 1936.

23 Federal funds for the project were made available through June 1937, and eventually, each state contributed as well. "John C. Page, Acting Commissioner, to Mr. S.O. Harper, Bureau of Reclamation," October 13, 1936, Entry 7, Project Correspondence File 1930-1945, Rio Grande Basin, Box 937, 301. Rio Grande Basin - Engineering + Board Reports on Construction Features. 1930 thru 1937 (August), U.S. National Archives, Denver.

24 "Proceedings of Inspection Trip, General Conference and Committee Meeting in Connection with Visit of Consulting Committee, June 15 to June 20, 1936" (National Resource Committee: Rio Grande Joint Investigation, 1936), 2–7, Box 2F463, Center for American History, University of Texas at Austin.

U.S. Supreme Court-appointed Special Master Charles Warren in the *Texas v. New Mexico* case, Hill explained the two "distinct divisions" of evidence that the state planned to pursue. The first was New Mexico's violation of the 1929 Compact, and especially the provision prohibiting New Mexico from allowing the water supply of Elephant Butte Reservoir to be "impaired." Hill interpreted this language to mean that no change could "reduce the value of the water supply."[25] Nevertheless, Hill anticipated that proving this point was going to be difficult for Texas, since accurate records were lacking. He even stated that "definite proof" of New Mexico's Compact violation would be "very difficult, if not impossible."[26] It would be very difficult to determine, for example, whether New Mexico had in fact increased its diversions, although Hill was convinced that New Mexico has seen an "increase in the amount of acreage served." As a result of these challenges in Texas's case, Hill had concluded that to prove New Mexico's Compact violation, Texas's second prong should focus on a *water quality* demand instead of water quantity, arguing that "there must be passed out of the Valley at least as much salt" as was brought *into* the valley. This second "division" of Texas's case would depend on a demand for what he called "equivalent service." He made the most succinct statement of this in a September 1936 letter to Clayton: "the lands in the *lower end of the El Paso Valley Division of the Rio Grande Project* are entitled to and should receive service equivalent to that of the lands in the Mesilla Valley. This has not been the case in the past and in order to accomplish this more reservoir water must be passed down the river for use on lands in the lower end of the Project, *regardless of the amount or quality of water which the Hudspeth District diverts into its canal*."[27] (Emphasis added.) Hill felt confident that Texas could show that more (not less) water was needed in the lower part of the Project lands "to give equivalent service and to maintain the salt balance" throughout the Rio Grande Project. However, it is important to note that neither Hill nor his contemporaries ever suggested that lands *below* the Project were entitled to this same service.[28] Ultimately, the takeaway from Hill's correspondence to Clayton was that Texas used the concept of water quality as a way to demand bigger releases from Elephant Butte to satisfy Texas's concerns over a potential decrease in *quantity*.[29]

Hill did recognize the challenging nature of the position he was recommending that Texas adopt, and correctly anticipated the substance of New Mexico's defense. Even after hearings in front of the Special Master had commenced, Hill told legal advisor Major Richard Burges that Texas would be hard pressed to prove that the MRGCD development had caused "any material continuing reduction in the *quantity* of water reaching Elephant Butte Reservoir," and that Texas "must rely largely on the fact that reduction in *quality* will necessitate the use of more water on the lands below Elephant Butte."[30] [Emphasis added.] Hill speculated that New Mexico's legal defense would focus on problems related to Project waste, illegal diversions to Mexico, and the delivery of water to Hudspeth, and would argue that without these problems, Project lands would have more water than they "could possibly use." Hill did not seem to have any ideas on how to refute these claims.[31]

To press its case, Texas focused on the quality of water being delivered to Project lands under the Riverside and Tornillo Canals in the El Paso Valley. Texas would somehow have to demonstrate that the construction of the MRGCD infrastructure (El Vado dam and drainage throughout that district's boundaries) had caused a lower

25 "Raymond A. Hill to Mr. Frank B. Clayton," September 20, 1936, Box 2F467, Rio Grande Commission, 1936-1941, 1970, Rio Grande Commission (1936-1939), Center for American History, University of Texas at Austin.

26 "Raymond A. Hill to Mr. Frank B. Clayton."

27 "Raymond A. Hill to Mr. Frank B. Clayton."

28 "Raymond A. Hill to Mr. Frank B. Clayton."

29 "Raymond A. Hill to Mr. Frank B. Clayton."

30 "Raymond A. Hill to Major Richard F. Burges," Memorandum Re: Texas v. New Mexico, Diversion to Mexico, December 5, 1936, Box 4X191, Elephant Butte - El Paso Co. Dists. Officials, Attorneys, Correspondence G351 1936, Center for American History, University of Texas at Austin.

31 "Raymond A. Hill to Major Richard F. Burges," December 23, 1936, NM OSE Library.

quality of water to be delivered to Elephant Butte, and consequently, to Project lands downstream, especially those in the El Paso Valley. In the months of correspondence regarding these studies, however, Hill never expressed concern over the quality of water being delivered to the Hudspeth District. In fact, Hill's concern was that the delivery of water to Hudspeth would be one of New Mexico's best arguments against Texas's position.[32]

In managing the case before him, Special Master Warren recognized the value of the investigative work being prosecuted by the RGJI to the issues being litigated in his court. Following many days of testimony in fall 1936, Hill characterized Warren as remaining dissatisfied with the "definiteness of proof" related to the effect of MRGCD on quality of water downstream on the EPCWID Project lands.[33] As a result, despite the fact that the official RGJI was due to conclude in June 1937, Warren requested that additional data be gathered on these issues. Consequently, attorneys for Texas, New Mexico, and the MRGCD signed a stipulation agreeing to continue parts of the general program of the RGJI. The stipulation (the content of which was facilitated by the Special Master) first required New Mexico to continue collecting data in the Middle Rio Grande Valley, and second, it demanded that Texas continue the program of measurements in the El Paso and Hudspeth Valleys, and either continue or institute quality of water studies at "all regular gauging stations between Elephant Butte and Fort Quitman and drain waters in the El Paso and Hudspeth County districts," into and during 1937.[34] The stipulation included both valleys (instead of only El Paso) since farmers in both areas did in fact receive water from Elephant Butte, and both therefore, would suffer from a quality impairment if one existed; however, without the data it would be impossible to know. Once the stipulation was executed, a new round of negotiations over cost responsibility and specific study tasks ensued before the continuing and new work began, since the majority of the RGJI work was complete and funding nearly depleted.

Texas found itself in a bit of a pickle with this stipulation. Having provided only lukewarm support for the RGJI in early 1936, the state now faced a dubious Special Master in a lawsuit which *it* had initiated. Texas knew it needed to gather data to prove its case, but again faced a funding problem. When the State of Texas failed to allocate funds for the work to which the parties had stipulated, Hill was left to seek other sources to foot the bill. Even Clayton expressed his concern early on about the costs,[35] but Hill plodded forward, recognizing that Texas's existing data was *not* enough to meet the demands of the stipulation and telling Project district colleagues that, "a rather comprehensive program of water analyses covering the area between Courchesne and Fort Quitman will be necessary."[36] In fact, Hill approached the Project districts – EBID and EPCWID – for a contribution to the study costs: "The State of Texas, which is in effect the two Districts…is obligated to determine with as great an accuracy as practicable the magnitude of all diversions from the Rio Grande below Courchesne [a measuring point near El Paso], all waste back to the river, and the discharge of all drains between El Paso and Fort Quitman."[37] Hill pleaded with the district managers to contribute $40,000 toward the study effort, arguing that, "it should be realized by each Board of Directors that the expense approximates 1% of the gross crop return, which is small insurance against a permanent reduction in production which is inevitable if irrigation developments upstream cannot be prevented."[38] Hill worked tirelessly to meet the demands of the stipulation by herding the different federal agencies and even the International Boundary Commission into agreeing to assist

32 "Raymond A. Hill to Mr. Frank B. Clayton," September 20, 1936.

33 "Raymond A. Hill to Mr. Roland Harwell, Manager, El Paso Co. Water Improvement Dist No. 1," March 26, 1937, Box 4X191, Elephant Butte Irrigation District G351, Center for American History, University of Texas at Austin.

34 No. 12, Original, In the Supreme Court of the United States, State of Texas v. State of New Mexico (n.d.).

35 "Frank B. Clayton, Rio Grande Compact Commissioner for Texas, to Mr. Raymond A. Hill," May 10, 1937, Box 4X191, Elephant Butte - El Paso Co. Dist. Officials, Attorneys, Correspondence G351 1937, Center for American History, University of Texas at Austin.

36 "Raymond A. Hill to Mr. Roland Harwell, Manager, El Paso Co. Water Improvement Dist No. 1," March 26, 1937.

37 "Raymond A. Hill to Mr. Roland Harwell, Manager, El Paso Co. Water Improvement Dist No. 1."

38 "Raymond to Roland," n.d., Box 4X191, Elephant Butte Irrigation District G351, Center for American History, University of Texas at Austin.

with resources, asking the latter to install and operate new river stations between Courchesne and Fort Quitman to obtain the measurements required by the agreement.[39] But each agency had its own mission to consider as it offered assistance; none were obligated to do Texas's bidding.

By June 1937, unlikely partner New Mexico had stepped up. That state was as doubtful as the Special Master as to the effects of MRGCD's actions on water quality and wanted a full set of data for different reasons: to disprove Texas's claims. Additionally, MRGCD's manager H.C. Neuffer had spoken with McClure and expressed his district's interest in seeing the data, as well.[40] Finally, New Mexico expressed well-founded skepticism that Texas would itself be able to execute on the data gathering required by the stipulation.[41] By the end of the month, "New Mexico's general interest in this problem and particularly her interest in including Hudspeth County," State Engineer McClure said, was enough to convince the state to allocate $10,000 in order to obtain detailed data on the salt content "before the [Special Master] hearings start again next January [1938]."[42] Hill also convinced the Bureau of Reclamation to assist with the required stipulation measurements, with Reclamation in turn charging EBID through normal operation and maintenance fees.[43]

With the stipulated studies funded, Texas maintained that equivalent service must be provided only *on Project lands.* With the Bureau of Reclamation now at the helm of taking measurements, and in consideration of that agency's limited personnel, Hill maintained that it was necessary to restrict Hudspeth District measurements so that no more than two days a week would be devoted to that work; Hill was concerned about spending too much time on Hudspeth – what he deemed "data of secondary importance" – and expressed concern that too much time spent on Hudspeth would sacrifice the work he deemed to be of "primary importance."[44] Ultimately, the program would measure 11 wasteways and three drains in Hudspeth County.[45] As for any groundwater observations in Hudspeth, Hill recommended simply taking measurements at some of the existing wells a few times a year but noted that no major work was necessary to improve or add wells. As for salinity, sampling would continue at various points between San Marcial (above Elephant Butte Reservoir) and Fort Quitman.[46]

RGJI and the Rio Grande Compact

At the same time that New Mexico and Texas were determining the details of the stipulation studies, the NRC's role and mission in the RGJI was evolving. In March 1937, roughly a year after the studies had begun, Professor Barrows found support from the commission for an expanding role, and requested authorization from the

39 "Raymond A. Hill to Mr. Roland Harwell, Manager, El Paso Co. Water Improvement Dist No. 1," March 26, 1937.

40 "Thomas M. McClure, State Engineer, by John H. Bliss, Engineer, to Mr. C.S. Scofield, Principal Agriculturalist, Division of Western Irrigation Agriculture," June 24, 1937, Box 2F464 Rio Grande Commission 1935-1938 Pamphlets, Business & Legal 1938, Center for American History, University of Texas at Austin.

41 "Raymond A. Hill to Mr. Frank B. Clayton, Rio Grande Compact Commissioner for State of Texas," June 1, 1937, Box 2F467, Rio Grande Commission, 1936-1941, 1970, Rio Grande Commission (1936-1939), Center for American History, University of Texas at Austin; "Thomas M. McClure, State Engineer, by John H. Bliss, Engineer, to Mr. C.S. Scofield, Principal Agriculturalist, Division of Western Irrigation Agriculture," June 24, 1937.

42 "Thomas M. McClure, State Engineer, to Mr. Reginald S. Laughlin," June 26, 1937, Cabinet 5, Drawer 2, Texas v. New Mexico - 1935 Motion for leave to file Bill of Complaint and Bill of Complaint RG A-71, New Mexico Interstate Stream Commission; "Thomas M. McClure, State Engineer, to the Director, U.S. Geological Survey," April 8, 1937, Cabinet 5, Drawer 2, Texas v. New Mexico - 1935 Motion for leave to file Bill of Complaint and Bill of Complaint RG A-71, New Mexico Interstate Stream Commission.

43 "Raymond A. Hill to Mr. Frank B. Clayton, Rio Grande Compact Commissioner for State of Texas," June 1, 1937.

44 "Raymond A. Hill to Mr. L.R. Fiock, Superintendent, Rio Grande Project," June 2, 1937, Box 4X190, Elephant Butte - El Paso Dists. Fiock Correspondence G-352 1938, 1937, Center for American History, University of Texas at Austin.

45 "Thomas M. McClure, State Engineer, to Mr. L.R. Fiock, Superintendent, Bureau of Reclamation," May 21, 1937, Cabinet 5, Drawer 2, Texas v. New Mexico - 1935 Motion for leave to file Bill of Complaint and Bill of Complaint RG A-71, New Mexico Interstate Stream Commission.

46 "Raymond A. Hill to Mr. L.R. Fiock, Superintendent, Rio Grande Project," May 18, 1937, Box 2F467, Rio Grande Commission, 1936-1941, 1970, Rio Grande Commission (1936-1939), Center for American History, University of Texas at Austin.

Compact Commission to create a special committee within the NRC to recommend a plan for a permanent Compact based on the findings of the RGJI.[47] Barrows also urged another extension of the temporary compact at the March meeting of the Compact Commission, since the NRC needed more time for the RGJI to be completed and to work out the details of a proposed compact based thereon. The commissioners agreed, and extended the temporary compact another six months to October 1, 1937.[48] The proposal to transition the NRC's study from merely providing data for the commission to providing recommendations and a proposal for the equitable apportionment of the Rio Grande was ultimately accepted by each state's delegation,[49] representing a dramatic change from the commission's early reluctance to permit such analysis.

Even as investigative work pursuant to the legal stipulation in *Texas v. New Mexico* continued, the RGJI study itself wrapped up, and the final report went into production over the summer of 1937. To determine next steps toward a permanent compact, the Compact Commission scheduled its next meeting for September 27 – October 1, 1937. The NRC provided Compact Commission members with some of the voluminous Joint Investigation report prior to the meeting, but with too little time for them to conduct a thorough review before convening. Nevertheless, the report's contents formed the very foundation of the meeting. At the meeting's opening, Commission Chair and U.S. Compact Commissioner S.O. Harper announced that the goal of the gathering was to review the RGJI's findings and to establish the basis for a permanent compact. When RGJI Engineer in Charge Harlow Stafford took the floor, the lengthy discussion began.

Mirroring the ongoing controversies between the states, the study had focused on key problem areas: potential storage in Colorado and at the Colorado-New Mexico state line; irrigated acreage and water quantity and quality in and downstream of the MRGCD; and drainage return on the Project lands in the El Paso Valley. Stafford explained that the results were reported in five sections. Part I, the General Report, provided an overview and conclusions of the entire investigation. Therein, the authors (several from each agency, plus Stafford, Barrows, and Adams) noted that the "prime purpose" of the RGJI was "to determine the basic facts needed in arriving at an accord" among the three states "on an allocation and use of Rio Grande waters in the *future development of the upper [Rio Grande] basin [in Colorado, New Mexico, and Texas].*"[50] [Emphasis added.] Part II was comprised of the findings from the USGS related to groundwater in the basin. Part III was the BAE's report on water utilization, and Part IV represented the report of the Bureau of Plant Industry related to water quality. Finally, Part V detailed the Bureau of Reclamation's results related to water storage and possible stream augmentation. Stafford reported to the commission on the report's findings, which are summarized below.[51]

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47 "Harlan H. Barrows to Mr. Frank B. Clayton, Rio Grande Compact Commissioner for Texas," March 9, 1937, Box 2F464 Rio Grande Commission 1935-1938 Pamphlets, Business & Legal (1935-1937), Center for American History, University of Texas at Austin.

48 "S.O. Harper, Chairman, Rio Grande Compact Commission, to The Secretary of the Interior," March 6, 1937, "Straights Files" - Office of the Chief Engineer, General Correspondence, Entry 790-E Compact Treaties, Box 833, 790-E Straights Compacts and Treaties - Colorado - New Mexico - Texas January 1936 thru December 1937 790-E, U.S. National Archives, Denver.

49 "Frank B. Clayton, Rio Grande Compact Commissioner for Texas, to Mr. Harlowe M. Stafford, Engineer in Charge, Rio Grande Joint Investigation," March 17, 1937; "S.O. Harper, Charman, Rio Grande Compact Commission, to Prof. Harlan H. Barrows, University of Chicago," April 10, 1937, Box 2F464 Rio Grande Commission 1935-1938 Pamphlets, Business & Legal 1938, Center for American History, University of Texas at Austin; "State Engineer to Prof. Harlan H. Barrows," March 19, 1937, "Straights Files" - Office of the Chief Engineer, General Correspondence, Entry 790-E Compact Treaties, Box 833, 790-E Straights Compacts and Treaties - Colorado - New Mexico - Texas January 1936 thru December 1937 790-E, U.S. National Archives, Denver; "Thomas M. McClure, Rio Grande Compact Commissioner for New Mexico, to Mr. S.O. Harper, Bureau of Reclamation," March 18, 1937, "Straights Files" - Office of the Chief Engineer, General Correspondence, Entry 790-E Compact Treaties, Box 833, 790-E Straights Compacts and Treaties - Colorado - New Mexico - Texas January 1936 thru December 1937 790-E, U.S. National Archives, Denver.

50 "Regional Planning: Part VI--The Rio Grande Joint Investigation in the Upper Rio Grande Basin in Colorado, New Mexico, and Texas, 1936-1937," 10.

51 "Proceedings of the Meeting of the Rio Grande Compact Commission Held in Santa Fe, New Mexico, September 27 to October 1, 1937," 1937, 8–9, NM OSE Library.

Key Findings of the RGJI

Part 1 – or the "General Report" of the RGJI publication – provided a succinct yet detailed summary of each section of the study, and is useful for explaining the investigation's findings. First, the investigators explained their methods. In an effort to estimate supply for "the major units of the upper basin under given future conditions of irrigation development," they examined existing conditions, taking return flows into consideration due to their significant role in watering the basin.[52] The entire investigation covered 2,093,000 acres, on which they found an average of 3,860,000 acre-feet of water was consumed annually.[53] The report authors compiled all of the previously available data as well as the new data that was collected during the investigation and ran 11 different "combinations" – or what we might today call models – to determine how various scenarios of storage and draft on supplies would operate and function throughout the basin. They looked at storage in various potential facilities upstream from Elephant Butte, including Wagon Wheel Gap and Vega Sylvester, and evaluated how flows would compare at different gauging points along the river under each of those 11 scenarios.[54]

Their findings provided the Compact Commission with a basis for devising a permanent compact, and are therefore important to understand. First, study authors found that in a year of normal supply, an average surplus of 177,000 acre-feet existed in the upper basin, and reported that the average flow past Fort Quitman over the previous 13-year record was 211,000 acre-feet.[55] They explained that the study considered trans-mountain diversions from the upper San Juan River Basin and the "salvage of present wastes and losses" to be the only potential new sources of water in the Rio Grande Basin, the latter being consistent with and anticipatory of Reclamation's efforts to run the Project efficiently as well as with overall contemporary efforts toward conservation of resources.[56] Despite there being no groundwater data to speak of in the stretch between Elephant Butte and Fort Quitman, the General Report opined that groundwater use would not contribute extensively to the overall supply.

The report did make findings related to groundwater nevertheless, calling it "another source of water supply in the upper basin,"[57] and commenting that nowhere in the basin had this supply been yet "utilized to any appreciable extent as a primary or basic source of supply for irrigation." The authors continued: "there appears to be no immediate probability of extensive ground-water development as a basic supply."[58] Despite these comments, the authors recognized that the studies that formed the RGJI had not focused a great deal of attention on groundwater development, and where they did, their focus was on the area upstream from the Project in Colorado's San Luis Valley and New Mexico's Middle Valley sections. In fact, the report specifically called out that groundwater data for the downstream Rincon, Mesilla, and El Paso valleys "are very meager and no study of ground-water conditions in them was included in the Rio Grande joint investigation. These valleys comprise the Rio Grande Project, which is well provided with open drains that satisfactorily ground-water

52 "Regional Planning: Part VI--The Rio Grande Joint Investigation in the Upper Rio Grande Basin in Colorado, New Mexico, and Texas, 1936-1937," 49.

53 "Regional Planning: Part VI--The Rio Grande Joint Investigation in the Upper Rio Grande Basin in Colorado, New Mexico, and Texas, 1936-1937," 14.

54 "Regional Planning: Part VI--The Rio Grande Joint Investigation in the Upper Rio Grande Basin in Colorado, New Mexico, and Texas, 1936-1937," 17.

55 "Regional Planning: Part VI--The Rio Grande Joint Investigation in the Upper Rio Grande Basin in Colorado, New Mexico, and Texas, 1936-1937," 14.

56 "Regional Planning: Part VI--The Rio Grande Joint Investigation in the Upper Rio Grande Basin in Colorado, New Mexico, and Texas, 1936-1937," 15.

57 "Regional Planning: Part VI--The Rio Grande Joint Investigation in the Upper Rio Grande Basin in Colorado, New Mexico, and Texas, 1936-1937," 55.

58 "Regional Planning: Part VI--The Rio Grande Joint Investigation in the Upper Rio Grande Basin in Colorado, New Mexico, and Texas, 1936-1937," 56.

levels at the depths below ground surface required to prevent waterlogging and seeping of the land."[59] In other words, the scientists' concerns in these lower valleys – when they expressed them at all –were not over whether groundwater could provide an additional source of water, but whether the drains were functioning to prevent seeped lands. As discussed in detail below in Chapter 5, the knowledge of groundwater's relationship to surface supplies in these lower valleys was still nascent and developing, and several additional studies completed in the years following the RGJI underscored how little scientists and water managers knew about these lower groundwater basins at the time of the RGJI or during negotiations of the Compact between 1935 and 1938. It is relevant to note as well that RGJI authors never state or suggest anywhere in the entire 600-page report that the Rio Grande Project had filed on or owned groundwater rights in these lower valleys.

In addition to examining supply, Part 1 of the RGJI also reviewed and quantified existing diversion requirements down to the lower end of the Project, detailing the storage capacity and stream depletion for each section of the river, starting upstream with the San Luis Valley and moving downstream to the Rio Grande Project. Hydrologists arrived at their numbers for the Elephant Butte to Fort Quitman section by examining the actual diversions and use of water for the years 1930-1936.[60] Then, the engineers modified the numbers to account for several factors: increased water to control salinity; decreased water to account for efficiencies that would be gained when the American diversion dam was in effect (particularly as it related to limiting Mexican diversion into Acequia Madre to the 60,000 acre-foot limit); and increased water when the Project's full expected irrigated acreage (155,000) was developed.[61] The report noted that the final figure did not include the Hudspeth district, since "its water supply is derived from and entirely dependent on residual flow drainage return, and waste from Rio Grande project."[62]

The investigation did also report its findings on municipal demands, but characterized them as "relatively minor."[63] The annual total depletion by cities in the study area excluding El Paso was estimated to be 21,000 acre-feet, assumed to be a draft on surface water, while El Paso was reported to take its 14,000 acre-feet for annual municipal and industrial demands from deep wells, assumed to be separate from surface supplies.[64] [See Chapter 5 below for a more detailed explanation of El Paso's water use and planned development.] Authors explained that "it is the use of water for irrigation and the disposition of it for that purpose which give rise to the problems of the basin with which this investigation is chiefly concerned."[65]

As for water quality, while the authors reported that generally speaking, the salt concentrations increased as the river made its way to the Gulf, they acknowledged that the data was "indefinite" at best, which was consistent with Special Master Warren's skepticism.[66] Although the report included tables showing the results

59 "Regional Planning: Part VI--The Rio Grande Joint Investigation in the Upper Rio Grande Basin in Colorado, New Mexico, and Texas, 1936-1937," 62.

60 "Regional Planning: Part VI--The Rio Grande Joint Investigation in the Upper Rio Grande Basin in Colorado, New Mexico, and Texas, 1936-1937," 99.

61 "Regional Planning: Part VI--The Rio Grande Joint Investigation in the Upper Rio Grande Basin in Colorado, New Mexico, and Texas, 1936-1937," 99–101. Details on method can be found on p. 103.

62 "Regional Planning: Part VI--The Rio Grande Joint Investigation in the Upper Rio Grande Basin in Colorado, New Mexico, and Texas, 1936-1937," 15.

63 "Regional Planning: Part VI--The Rio Grande Joint Investigation in the Upper Rio Grande Basin in Colorado, New Mexico, and Texas, 1936-1937," 14.

64 "Regional Planning: Part VI--The Rio Grande Joint Investigation in the Upper Rio Grande Basin in Colorado, New Mexico, and Texas, 1936-1937," 15.

65 "Regional Planning: Part VI--The Rio Grande Joint Investigation in the Upper Rio Grande Basin in Colorado, New Mexico, and Texas, 1936-1937," 87.

66 "Regional Planning: Part VI--The Rio Grande Joint Investigation in the Upper Rio Grande Basin in Colorado, New Mexico, and Texas, 1936-1937," 14, 102.

of sampling for dissolved solids gleaned from locations along the river, the accompanying narrative pointed out just how unclear the data was, and underscored Special Master Warren's skepticism about the effects of upstream development on downstream water quality. As it related to consumptive use, irrigation requirements, and concentration of the irrigation water and soil solution, Part 1 of the report stated: "Several equations have been developed to express the relationship between these elements, but as the *quantitative factors involved are yet somewhat indefinite*, it has been considered best, in this report, to *proceed more or less arbitrarily in assuming allowances to maintain the desired salt balance*."[67] [Emphasis added.] To arrive at a diversion demand and release from Elephant Butte Reservoir, the authors reported that they had arbitrarily provided a 60% increase in diversion requirement for the Rio Grande Project "and Mexican area" to account for salinity control in getting water to Tornillo, reporting that final number to be 773,000 acre-feet.[68] Further, they noted that in light of the indefinite numbers, and "after due consideration of the available information regarding adverse salinity conditions in the valley below El Paso, it was determined to assume the need for such additional water only in the area of the Rio Grande Project that lies under the Tornillo canal,"[69] excluding Hudspeth in those calculations.

Coming to Compact Terms

After Stafford reported on the substance of the report's findings at the September 1937 meeting, the RGJI committee (Stafford, Barrows, and Adams) had also planned to announce its recommendations for compact terms. But before they did, each state announced the terms that it believed were necessary for its own interests. Not surprisingly, each state differed over how to calculate delivery requirements and how to account for Project storage in Elephant Butte. Based on the history of the previous ten years, each state's stance during negotiations came as no surprise. Colorado was concerned about inefficient water use in the two downstream states and insisted that any permanent compact would need to "include the necessary regulation of these waters for the most efficient use of the same."[70] Colorado also insisted that it be permitted to develop the San Luis Valley, and Commissioner Hinderlider presented graphs containing data taken from the RGJI showing that construction of a reservoir with a storage capacity equal to the Wagon Wheel Gap Reservoir could be constructed without harming downstream supply.[71] New Mexico's presentation insisted on two key things among a longer list. First, it demanded that the Compact prohibit Colorado and Texas from interfering with New Mexico's right to the development, irrigation, and cultivation of the 123,000 acres in the MRGCD, and second, as a means toward compromise with Texas, New Mexico insisted that the commission fix a "definitive amount of water" to which the Rio Grande Project would be entitled,[72] but noted that deliberations with Texas could only move forward if excess Mexican diversions were curtailed, and that country's 60,000 acre-feet limit was enforced following construction of the All American Diversion Dam and Canal.[73] Finally, Texas came with its own position. First, it

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67 "Regional Planning: Part VI--The Rio Grande Joint Investigation in the Upper Rio Grande Basin in Colorado, New Mexico, and Texas, 1936-1937," 65.

68 "Regional Planning: Part VI--The Rio Grande Joint Investigation in the Upper Rio Grande Basin in Colorado, New Mexico, and Texas, 1936-1937," 103.

69 "Regional Planning: Part VI--The Rio Grande Joint Investigation in the Upper Rio Grande Basin in Colorado, New Mexico, and Texas, 1936-1937," 102–3.

70 Exhibit No. 1: Statement of the Views as to the Essentials for a Permanent Compact on the Rio Grande, Submitted by The Commissioner for Colorado at the Conference of the Rio Grande Compact Commission at Santa Fe, New Mexico, September 28, 1937 in "Proceedings of the Meeting of the Rio Grande Compact Commission Held in Santa Fe, New Mexico, September 27 to October 1, 1937," 56.

71 Exhibit No. 1: Statement of the Views as to the Essentials for a Permanent Compact on the Rio Grande, Submitted by The Commissioner for Colorado at the Conference of the Rio Grande Compact Commission at Santa Fe, New Mexico, September 28, 1937 in "Proceedings of the Meeting of the Rio Grande Compact Commission Held in Santa Fe, New Mexico, September 27 to October 1, 1937," 54–56.

72 Exhibit No. 2: Statement Submitted by Thomas M. McClure, Commissioner for New Mexico in "Proceedings of the Meeting of the Rio Grande Compact Commission Held in Santa Fe, New Mexico, September 27 to October 1, 1937," 59.

73 Exhibit No. 2: Statement Submitted by Thomas M. McClure, Commissioner for New Mexico in "Proceedings of the Meeting of the Rio Grande Compact Commission Held in Santa Fe, New Mexico, September 27 to October 1, 1937," 59.

insisted that New Mexico be limited to a maximum of water it could store in reservoirs above Elephant Butte, based on 30% of the amount stored at any given time in the reservoirs between San Marcial and Fort Quitman, which included Elephant Butte and the new authorized Caballo Reservoir, discussed below in Chapter 5. It also crafted a formula demanding that additional water be delivered for specific increases in dissolved solids.[74]

One of the most challenging areas for compromise came in trying to determine Rio Grande Project water needs. Colorado disputed the 773,000 acre-foot number in the RGJI report, and held fast to a maximum of 750,000 acre-feet release from Elephant Butte, demanding that its own accumulated debits for under-delivery at the Colorado/New Mexico state line be reduced when releases from Elephant Butte exceeded that amount.[75] By October, Texas had calculated that more than the 773,000 acre feet be considered normal release, determining that 800,000 acre-feet was the proper amount, a number that Texas eventually found difficult to justify. Nevertheless, that number was consistent with Texas's position that although the Rio Grande Project had been operated properly over the previous 20 years, its error has been in releasing too little water – "in recent years, especially."[76]

After each state presented its position, Professor Barrows provided a document to the Compact Commission that outlined nine suggestions from the RGJI Committee to serve as the basis of a new compact. The document recommended the following:

1. That all three states cooperate in funding and constructing the San Juan-Chama Diversion;
2. That Colorado and New Mexico agree to maintain a schedule of state line and Elephant Butte flows, respectively, and be permitted to construct storage and develop its irrigation at will within the limits of that obligation;
3. That Colorado be permitted to reduce the scheduled flow at the state line commensurate with the amount imported from the San Juan Basin;
4. That the states form a Compact Commission with appointees from the governor of each state and a federal representative appointed by the United States President;
5. That the Commission appoint a water supervisor to maintain records, conduct investigations, and serve as an adviser;
6. That the states share administration costs equitably;
7. That they revise compact terms after a short-term trial;
8. That they adopt a provision permitting temporary adjustments of the flow schedule when a surplus of water was expected; and
9. Finally, that the parties agree to arbitration for any disputes that arose.[77]

Following the presentation of these points, the Commission adjourned, with plans to meet again later in the fall.

74 Exhibit No. 6: Schedule Submitted by Texas, Deliveries at San Marcial in "Proceedings of the Meeting of the Rio Grande Compact Commission Held in Santa Fe, New Mexico, September 27 to October 1, 1937," 64–65.

75 Exhibit No. 4: Schedule Submitted by Colorado in "Proceedings of the Meeting of the Rio Grande Compact Commission Held in Santa Fe, New Mexico, September 27 to October 1, 1937," 61–62.

76 "Raymond A. Hill to Mr. Frank B. Clayton," September 20, 1936.

77 "Proceedings of the Meeting of the Rio Grande Compact Commission Held in Santa Fe, New Mexico, September 27 to October 1, 1937," 47–48.

A great deal of negotiating took place in the ensuing weeks, particularly among the state's advisory engineers, also known as the Committee of Engineers, comprised of E. B. Debler for the United States, Royce J. Tipton for Colorado, John H. Bliss for New Mexico, and Raymond A. Hill for Texas. In fact, the engineering committee was charged with taking the RGJI recommendations and working with them to come up with a detailed set of terms for a permanent compact. Informal negotiations continued that fall through written correspondence, until the three state engineers held a meeting in late November in Santa Fe to further hammer out the details and try to smooth out remaining sticking points. New Mexico's Bliss told Hill that the water quality in Texas was influenced by "so many factors" that New Mexico refused to take responsibility for delivering to Texas "additional water for salinity control in case that quality should change adversely."[78] Colorado remained committed to ensuring present uses and was opposed to any state line delivery schedule that would restrict Colorado's uses prior to the construction of storage. New Mexico, too, was wary of a guaranteed delivery schedule into Elephant Butte because of the factors that remained out of their control. Texas took the opportunity during the November meeting to discuss the issue of salinity with New Mexico's Bliss. According to Hill:

> Bliss recognizes the validity of our position but does not know how to measure the effect upon the water supply produced by any irrigation development above Elephant Butte. I believe, however, that if allowance is made for change in quality at Lovatos [sic] and use-averages over a reasonable period of years, rather than for individual years, are used, Bliss will recommend that some allowance be made for change in quality of water.

Finally, Hill summarized the conversation between the commissioners related to Texas's position regarding the 800,000 acre-feet requirement. Hill showed the others "by different methods of calculation" how he had arrived at this figure in order that "equivalent service" be provided "to lands below El Paso, in the Rio Grande project, or to maintain a salt balance in the El Paso area." Although Hill recognized that the Project's recent releases had been closer to 730,000 acre-feet, making it "very difficult to substantiate the 800,000 acre-feet requirement, especially as we can look to some reduction in diversion, particularly on that to Mexico," he remained committed to it, when other solutions became untenable.[79] For example, at one point, engineers drafted and considered language that addressed the total salt burden by volume, limiting it at certain points along the river and calculating new water delivery formulas when there were increased salt loads.[80] Such specificity did not make the final cut of the proposed compact due to push back from New Mexico and Colorado who recognized their arbitrary nature, but Texas's Hill felt confident that Texas's "salt problem" would nevertheless be addressed in the final compact in some other form.[81]

At the end of December 1937, the Committee of Engineers met once more, this time in Los Angeles and subsequently submitted a report reflecting their consensus to the Rio Grande Compact Commission. The report summarized the discussions of the engineering advisors during their meetings in November and December 1937, meetings that focused on the discharge of the Rio Grande at the Texas-New Mexico state line, the delivery of water to Elephant Butte Reservoir, and the development of detailed schedules of water deliveries. While the engineers had not dealt with the relative rights of water users in the three states, they had worked under the

78 "Thomas M. McClure, State Engineer, to Mr. Raymond A. Hill," November 16, 1937, Box 2F467, Rio Grande Commission, 1936-1941, 1970, Rio Grande Commission (1936-1939), Center for American History, University of Texas at Austin.

79 "Raymond A. Hill to Mr. Clayton," Memorandum In re Meeting of Committee of Engineers, at Santa Fe, November 22 to 24, 1937, November 26, 1937, Box 2F467, Rio Grande Commission, 1936-1941, 1970, Rio Grande Commission (1936-1939), Center for American History, University of Texas at Austin.

80 Committee of Engineering Advisors, "Preliminary Draft of Report of Committee to Rio Grande Compact Commissioners," December 22, 1937, Cabinet 13, Drawer 3, Envelop [sic] 2, Rio Grande Compact Negotiations, Engineering Committee Data, New Mexico Interstate Stream Commission.

81 "Raymond to Frank B. Clayton," Telegraph, December 24, 1937, NM OSE Library.

Compact Commission's guidance that current water uses (subject to the same limitations as noted above) were to be protected in the Compact.[82] The engineers used 10 years of data to establish water delivery schedules at various points along the river. They established one schedule for deliveries from the Conejos River (a Rio Grande tributary in Colorado) and one schedule for the Rio Grande above Del Norte, Colorado, which, added together, represented the total water that Colorado was obligated to deliver to the Colorado-New Mexico state line. They established a year-round schedule for water deliveries into Elephant Butte Reservoir as well as one for deliveries into Elephant Butte Reservoir in all months except July, August, and September. These Elephant Butte deliveries represented the water that New Mexico was obligated to deliver to San Marcial, a measuring point just above the reservoir, but the authors noted that this obligation would have to be adjusted as the amount of natural runoff changed and as diversions increased between the Lobatos gauge and Elephant Butte.[83] The report, having accepted Hill's arguments, stated that "normal release" from Elephant Butte should be an average of 800,000 acre-feet per year, adjusted as necessary for any new downstream reservoirs. The engineers defined the limits on water delivery debits for each state, making sure to state that accumulated water debits in any state could never exceed the amount of water in storage at one time in that state.[84] In years with "unusable spill" from Elephant Butte Reservoir, all Colorado and New Mexico accrued debits would be cancelled. Another limitation that the engineers imposed was that neither Colorado nor New Mexico could increase the amount of water stored in reservoirs built after 1929 whenever there was less than 400,000 acre-feet of stored Rio Grande Project water. In addition, if Colorado built irrigation works to deliver water from the Closed Basin in the San Luis Valley into the Rio Grande system, that water would be credited to Colorado.[85] If changes in diversion or loss to Mexico occurred and affected the normal release from Elephant Butte Reservoir, the engineers stipulated that the effects of this loss would be shared equally between Texas and New Mexico. The engineers concluded that "these schedules and provisions would permit the maximum practicable use of the waters of the Rio Grande."[86] They recommended that the Compact Commission consider and include their schedules, limits, and recommendations in the final Compact. Finally, and very important to their understanding of the river system's dynamic nature, the engineers recommended that "provision be made for review of these matters after five years and for adjustments within the intent of the Compact."[87]

In the two months that passed between sending the engineers' report to the Compact Commission and the engineers meeting for a third time in early March 1938, several important players opined on the engineers' recommendations. One notable complaint was registered by MRGCD's H.C. Neuffer, whose January 8, 1938 memorandum expressed vociferous dissatisfaction with the 800,000 acre-feet recommended by the engineers as the normal release for Elephant Butte. Neuffer, speaking for MRGCD, noted that the mean release from the reservoir for the years 1927 to 1936 was 781,000 acre-feet, including "excessive quantities of water delivered to Mexico, avoidable project wastes, and savings which can be made after the channel rectification is completed." Using data from the RGJI report for support, Neuffer urged the commissioners to reduce the 800,000 acre-feet of Elephant Butte release to only 700,000, a number that Neuffer believed to be a "liberal allowance."[88] Correspondence between the commissioners transpired over the next month regarding similar details from the

82 "Report of Committee of Engineers to Rio Grande Compact Commissioners," December 27, 1937, 1, NM OSE Library.

83 "Report of Committee of Engineers to Rio Grande Compact Commissioners," 8.

84 "Report of Committee of Engineers to Rio Grande Compact Commissioners," 10.

85 "Report of Committee of Engineers to Rio Grande Compact Commissioners," 12.

86 "Report of Committee of Engineers to Rio Grande Compact Commissioners," 14.

87 "Report of Committee of Engineers to Rio Grande Compact Commissioners," 2.

88 "H.C. Neuffer to Rio Grande Commission," Memorandum: Report of Committee of Engineers to Rio Grande Commissioners, December 27, 1937, January 6, 1938, NM OSE Library.

engineers' report.

The concerns of MRGCD water users were taken up by New Mexico's delegation to the Commission but caused further tension between New Mexico and Texas. In a letter dated January 25, 1938, New Mexico's Compact Commissioner Thomas McClure channeled many of Neuffer's complaints in a letter regarding several of the report's provisions. He claimed that the engineers' report was "too vague and indefinite" and that it did not sufficiently set up the data the committee used to "work out the relationship of the flow at various stations." He also disagreed with the manner in which the report fixed the basis for water supply to Texas – e.g. the 800,000 acre-feet – stating that he and "others in authority in New Mexico," believed the basis to be "so far out of reason that it could not be considered as a basis for negotiating." McClure claimed that the engineers took too much liberty in their report, compromised the basic data, and overstepped their authority and he suggested that the commissioners reconvene at their earliest convenience in order to "give the matter further study."[89] Texas Commissioner Clayton responded just a few days later, expressing adamant disagreement with McClure. Clayton opined that he and "those interested" in protecting Texas's water supply found within the report "no recommendations for the benefit of Texas than what she is plainly entitled to." Clayton conceded to using the engineers' December 27, 1937 report as the basis for further negotiations in the interest of "an amicable settlement" to the three states' common problems. Clayton conceded that New Mexico and Colorado likely had no intention nor desire to "further deplete the waters of the Rio Grande system," and so "the basis suggested in the report will do no more than preserve the status quo as far at the *water supply* is concerned, while, at the same time, permitting New Mexico and Colorado to proceed with certain desired development."[90] [Emphasis added.] As an aside, Clayton criticized New Mexico for giving MRGCD too much influence and losing sight of the fact that there was "a very extensive section of [New Mexico] lying below the Elephant Butte Dam," and that its large vested interests were "likewise entitled to representation and protection, along with the Middle Rio Grande Conservancy District."[91] MRGCD's Neuffer was vehemently opposed to any compact provision that would require a fixed amount of water to be delivered into Elephant Butte, and certainly did not approve of the 800,000 acre-foot figure in the engineers' recommendations. As Texas's Hill put it: New Mexico "relies more upon the judgment of [MRGCD] than that of his own deputy and…apparently forgets that the New Mexico boundary extends almost to El Paso." Hill observed that "the Middle Rio Grande Conservancy District considers that a proper Compact would provide no restrictions on their use of water and at the same time would limit the Rio Grande Project to perhaps 700,000 acre feet per year." Hill maintained that it was not advantageous for the committee of engineers to meet again to consider these objections.[92] Colorado agreed with Texas.[93] When the United States' S.O. Harper responded to all the correspondence, it was merely to announce that the Compact Commission should plan to meet again in early March 1938.

The Texas delegation was frustrated with New Mexico's general lack of adequate representation on behalf of EBID in the ongoing discussions of the Rio Grande Compact Commission. Hill believed that New Mexico State Engineer McClure had lost sight of that district's interests, and suggested that it was time that Texas "cease being

89 "Thomas M. McClure, State Engineer, to S.O. Harper, Chairman, Rio Grande Compact Commission," January 25, 1938, Box 2F466 Rio Grande Compact Commission Records, 1924-1941, 1970, Rio Grande Commission (1938), Center for American History, University of Texas at Austin.

90 "Frank B. Clayton, Rio Grande Compact Commissioner for Texas, to Mr. S.O. Harper, Chairman, Rio Grande Compact Commission," January 27, 1938, Box 2F466 Rio Grande Compact Commission Records, 1924-1941, 1970, Rio Grande Commission (1938), Center for American History, University of Texas at Austin.

91 "Frank B. Clayton, Rio Grande Compact Commissioner for Texas, to Mr. S.O. Harper, Chairman, Rio Grande Compact Commission."

92 "Raymond A. Hill to Mr Frank B. Clayton," February 3, 1938, NM OSE Library.

93 "M.C. Hinderlider, Commissioner for Colorado, to S.O. Harper, Chairman, Rio Grande Compact Commission," February 4, 1938, NM OSE Library.

the direct representative of an irrigation district situated in New Mexico." Hill assumed that as long as Texas continued to "bear the burden of protecting the rights of all lands under the Rio Grande Project," New Mexico would continue to side with MRGCD. Hill believed that the commissioners ultimately would insist that the use of water below Elephant Butte Dam be reduced, even if this reduction would only benefit Colorado, and that if such an agreement were to come to pass, then Texas would be in an "untenable position." To emphasize the Project districts' needs, Hill proposed that EBID representatives begin to "sit in on all conferences of New Mexico interests to the end that the Elephant Butte District may be given the same consideration by New Mexico that the Middle Rio Grande Conservancy District is given." According to Hill, this would position EBID to "demand of McClure the schedule of deliveries into Elephant Butte Reservoir," that would protect the interests of EBID; and at the same time Texas would demand the same deliveries so as to protect the lands in Texas.[94]

It is important to briefly recognize the role that Mexican diversions played in these negotiations, as well, since the international nature of the river remained a significant consideration in its overall administration, and all parties recognized the illegal and excessive diversions being made in that country. Estimates for the amount of water diverted by Mexican users ranged as high as three times the amount of that country's treaty rights to 60,000 acre-feet. Using the 1928-1937 period, John Bliss recommended that a 150,000 acre-feet figure be used as the "Mexican takings" above the Tornillo gauging station for the era,[95] and that the figure be used as the basis for determining the amount of water to be saved and credited to the three states.[96]

The engineers met again from March 3-9, 1938 in Santa Fe to discuss these recent developments and concerns. Bliss, representing New Mexico, recommended that the "normal" Elephant Butte release be decreased from 800,000 to 775,000 acre-feet.[97] The ultimate number arrived at by the engineers was 790,000 acre-feet, a number they ultimately defined as "actual release."[98] Furthermore, the engineers noted that the effect of changes to salinity in the Elephant Butte supply since 1930 "was left for future adjustment."[99]

Following the engineers' final meeting in March, their committee sent a letter to the Compact Commissioners, explaining how they arrived at their suggestions for the final compact. This letter was, perhaps, in response to complaints following the first engineers' report which had resulted in suggestions that were not substantiated by detailed reasoning. In contrast to the simplicity of the engineers' first attempt at making recommendations, this letter provided much greater detail on how the engineers arrived at each of their conclusions. First the letter described that the engineers "avoided discussion of the relative rights of water users in the three states, and were guided throughout...by the general policy…that present users of water in each of the three states must be protected in the formulation of a Compact for administration of the Rio Grande above Fort Quitman." The letter noted that rather than dividing river use by state, the engineers divided the Rio Grande above Fort Quitman into three sections: the San Luis Valley, the Middle Rio Grande, and Rio Grande Basin below Elephant Butte.[100]

The letter continued on to describe how the engineers had arrived at their detailed scheduled deliveries at Lobatos station, explaining the relationship that existed between the combined inflow of major streams to the San Luis Valley and the outflow of the Rio Grande River at the Lobatos station. According to the engineers, development of storage reservoirs upstream from the Lobatos gauging station could potentially disrupt the

94 "Raymond A. Hill to Mr. Frank B. Clayton," February 8, 1938, NM OSE Library.
95 John H. Bliss, "Probable Mexican Diversions -- El Paso to Fort Quitman," February 23, 1938, 6, NM OSE Library.
96 "Objections of New Mexico to the Engineering Report Filed with the Rio Grande Compact Commission on December 27, 1937.," February 23, 1938, NM OSE Library.
97 John H. Bliss, "Memo of Suggested Changes to Be Made in Engineering Advisors' Report," March 3, 1937, NM OSE Library.
98 "Committee of Engineering Advisers to the Rio Grande Compact Commission," March 11, 1938, 1, NM OSE Library.
99 "Committee of Engineering Advisers to the Rio Grande Compact Commission," 12.
100 "Committee of Engineering Advisers to the Rio Grande Compact Commission," March 9, 1938, 1–13, NM OSE Library.

relationship, which prompted the engineers to prepare two separate schedules for the Conejos (tributary) and Rio Grande systems. The letter included a table that displayed the “Conejos Index Supply” and “Conejos River at Mouths” for the last 10 years. The letter also included another table which showed the quantity of thousands of acre feet of water in the “Rio Grande at Del Norte” and “Rio Grande at Lobatos less Conejos at Mouths.” Importantly, the engineers’ letter maintained that “the obligation of Colorado to deliver water in the Rio Grande at the Colorado-New Mexico State Line [sic] in each calendar year shall be 10,000 acre feet less than the sum of the quantities set forth in the above tabulations, except for such departures from normal deliveries.” The engineers found that three provisions existed which would allow for adjustments within their preferred system. The provisions included any change in locations of gauging stations, any new or increased depletion of natural runoff above gauging stations, and any trans-mountain diversions.[101]

Next, the engineers’ letter discussed scheduled deliveries into Elephant Butte Reservoir, detailing that the relationship between Rio Grande water above New Mexico’s agricultural areas and inflow to Elephant Butte Reservoir was erratic due to variations in the discharges. The engineers attempted to use a formula that would minimize the influence of tributary inflow and finding “a reasonable relationship between the discharges of Rio Grande at the Otowi Bridge and San Marcial gauging stations when the months of July, August, and September were excluded.” Therefore, the engineers inserted a table which displayed the “Otowi Index Supply” verses the “San Marcial Index Supply” in quantities of thousands of acre-feet, representing the head and lower end of the Middle Rio Grande valley, respectively. The engineers also outlined that the San Marcial supply comprised the recorded flow at the San Marcial gauging station during the calendar year, except for the months of July, August, and September, and concluded that the table outlining historic flows should be the basis of New Mexico’s obligatory deliveries to the San Marcial gauge. The engineers’ report outlined four provisions upon which adjustments would have to be made, including any change in gauging station locations, depletion after 1929 in New Mexico’s natural runoff at Otowi Bridge, depletion of runoff during July, August, and September between Otowi Bridge and San Marcial due to construction after 1937, and any trans-mountain diversions into the Rio Grande between Lobatos and San Marcial.[102]

Additionally, the committee of engineers recommended a provision that would prevent both Colorado and New Mexico from increasing the amount of storage water in reservoirs constructed after 1929 if storage in the Rio Grande Project fell to an amount less than 400,000 acre feet, and further recommended that should works be “constructed after 1937 for the purpose of delivering water into the Rio Grande from the Closed Basin in San Luis Valley, Colorado shall be credited with the amount of such water delivered, provided the proportion of sodium ions shall be less than 45% of the total positive ions in that water.” In recognition of the difficulty of securing reliable records for stream flow at San Marcial and other gauging stations, the engineers recommended that the Commission operate several gauging stations in cooperation with the appropriate federal agency.[103]

The engineers’ March report concluded with a summary: first, they requested the commissioners take into consideration the factors that had influenced their conclusions and recommended that provisions be reviewed again in five years. Importantly, the engineers suggested that “the normal release from Elephant Butte Reservoir be deemed to be an average of 790,000 acre feet per annum, adjusted for any gain or loss of usable water resulting from the operation of any reservoir below Elephant Butte.” Lastly, the engineers stated that “it is our opinion that the application of all of the recommendations and provisions set forth herein will be equitable to each State and will permit the maximum practicable use of the waters of the Rio Grande.” All four engineers

101 “Committee of Engineering Advisers to the Rio Grande Compact Commission,” 4–5.
102 “Committee of Engineering Advisers to the Rio Grande Compact Commission,” 5–7.
103 “Committee of Engineering Advisers to the Rio Grande Compact Commission,” 11–12.

personally signed the letter, as did a representative from MRGCD, under a statement that merely stated "I Concur."[104] Although Texas had not been able to convince the other states of the need for an 800,000 acre-foot "normal release" from Elephant Butte Reservoir, the draft compact's 790,000, based on the engineers' report, was not far off, and the March engineers' report formed the basis for the compact that commission lawyers then drafted.

Once the draft was complete and signed by each state's commissioners, Clayton touched base confidentially with lower Rio Grande water users to let them know that, "Texas got everything in this compact that could reasonably be hoped for [but] I would not want this opinion voiced in the press, for the reason that it might defeat ratification in the two upper States."[105] He emphasized this point just a week later, again asking that his opinion remain quiet for fear that Colorado and New Mexico might "get the idea that water allotted to Texas by the Compact is more than sufficient to take care of the needs of the Rio Grande Project" and therefore not ratify the Compact in their respective legislatures. Clayton maintained that "as a matter of fact, while I feel that Texas will receive under the Compact all the water she can reasonably expect, the amount is not more than enough to take care of the Project's needs, without reference to the lands below the project line....My opinion is that if ratification fails, particularly through any fault of Texas, the projects sought by Colorado and New Mexico will probably be given favorable consideration by the federal agencies, and then Texas will then be in the position of having to resort to litigation."[106]

The Compact Ratified

From the engineers' negotiations, the 1938 Rio Grande Compact was drafted, and all three states' commissioners signed it in March, with all three states also ultimately ratifying it. In describing this achievement in narrative format, engineer Bliss provided a few important explanations. First, he explained that the Compact and division of the river's waters were based on two calculated schedules: one, to the Colorado-New Mexico state line, and the other to the San Marcial gauge at the head of Elephant Butte Reservoir. According to Bliss, the location for the second schedule was chosen because "the Elephant Butte Project must be operated as a unit."[107] He also noted that while each state recognized that importation from another basin would be the only way to augment supply, that credit water "particularly in the Middle Valley, is the saving effected by the reclamation and drainage of seeped and swampy lands which formerly consumed large quantities of water."[108] In other words, water saved through drainage or reduction of water-thirsty riparian vegetation would be credited to the state in which such efficiencies occurred. As for the Rio Grande Project, Bliss explained that it would "receive all the water she has received in the past prior to 1930 whenever it is required for her normal releases; she may make annual releases averaging 790,000 acre feet whenever her available supply is sufficient to do so."[109] New Mexico seemed satisfied, but the Compact pleased the other two states, as well. Clayton's comments make clear his belief that the volume of water to be considered "normal release" would be only enough for the Project lands – not for Hudspeth – and that Texas was more than satisfied with the Compact terms. As Texas's Clayton put it, the Compact "represented a fair and equitable settlement of the controversies that have raged almost continuously

104 "Committee of Engineering Advisers to the Rio Grande Compact Commission," 12–13.
105 "Frank B. Clayton, Rio Grande Compact Commissioner for Texas, to Hon. F.S. Robertson, Secretary, Water Conservation Association," March 19, 1938, NM OSE Library.
106 "Frank B. Clayton, Rio Grande Compact Commissioner for Texas, to Hon. F.S. Robertson, Secretary, Water Conservation Association," March 26, 1938, NM OSE Library.
107 J.H. Bliss, "Provisions of the Rio Grande Compact" (State Engineer's Office, April 2, 1938), 1, NM OSE Library.
108 Bliss, 7.
109 Bliss, 10.

for over forty years between the three states."[110] Clayton also stated that "We feel that we have secured in this compact exactly what we were entitled to and all that we could get, as a practical matter, as the result of litigation."[111]

As a result of the Compact's ratification by Congress in 1939, Special Master Warren dismissed the *Texas v. New Mexico* litigation, explaining that the "case presented…in the pending suit has therefore become moot; and the issues are, so long as the Compact remains in force and complied with, settled."[112] Warren's report left the two states to use the Compact and the Compact Commission to resolve any future disputes over the river. Meanwhile, the Hudspeth district, who was absent from providing input into the RGJI studies and Compact negotiations, would soon find itself fighting additional battles to protect any supplies.

110 "Frank B. Clayton, Rio Grande Commissioner for Texas, to the Honorable E.H. Thornton, Jr., Chairman," March 23, 1939, RIO Grande Compact Commission Records, 1924-1941, 1970, Box 2F466, Rio Grande Commission (1938-1940), Center for American History, University of Texas at Austin.

111 "Frank B. Clayton, Rio Grande Commissioner for Texas, to Hon. H. Grady Chandler, Assistant Attorney General," March 28, 1938, RIO Grande Compact Commission Records, 1924-1941, 1970, Box 2F466, Rio Grande Commission (1938-1940), Center for American History, University of Texas at Austin.

112 "Final Report of the Special Master, State of Texas v. State of New Mexico, et al, October Term 1939, No. 10 Original," Legal, n.d., 5–6, NM OSE Library.

Chapter 5: The Rio Grande Project and Other Development during Compact Negotiations and the Joint Investigation

It's tempting to view the Rio Grande Joint Investigation and Compact Commission negotiations in isolation, or as events occurring in a vacuum. However, as the first four chapters of this report show, the Rio Grande Basin had garnered a great deal of attention from the scientific and diplomatic communities over the decades leading up to the Compact, owing in part to the river's status as the third longest in the lower 48 states, its meandering course through significantly varied terrain, and its role as part of the international border with Mexico. Interest in the river was no less intense in the 1930s, 40s, and 50s than it had been in the preceding four decades.

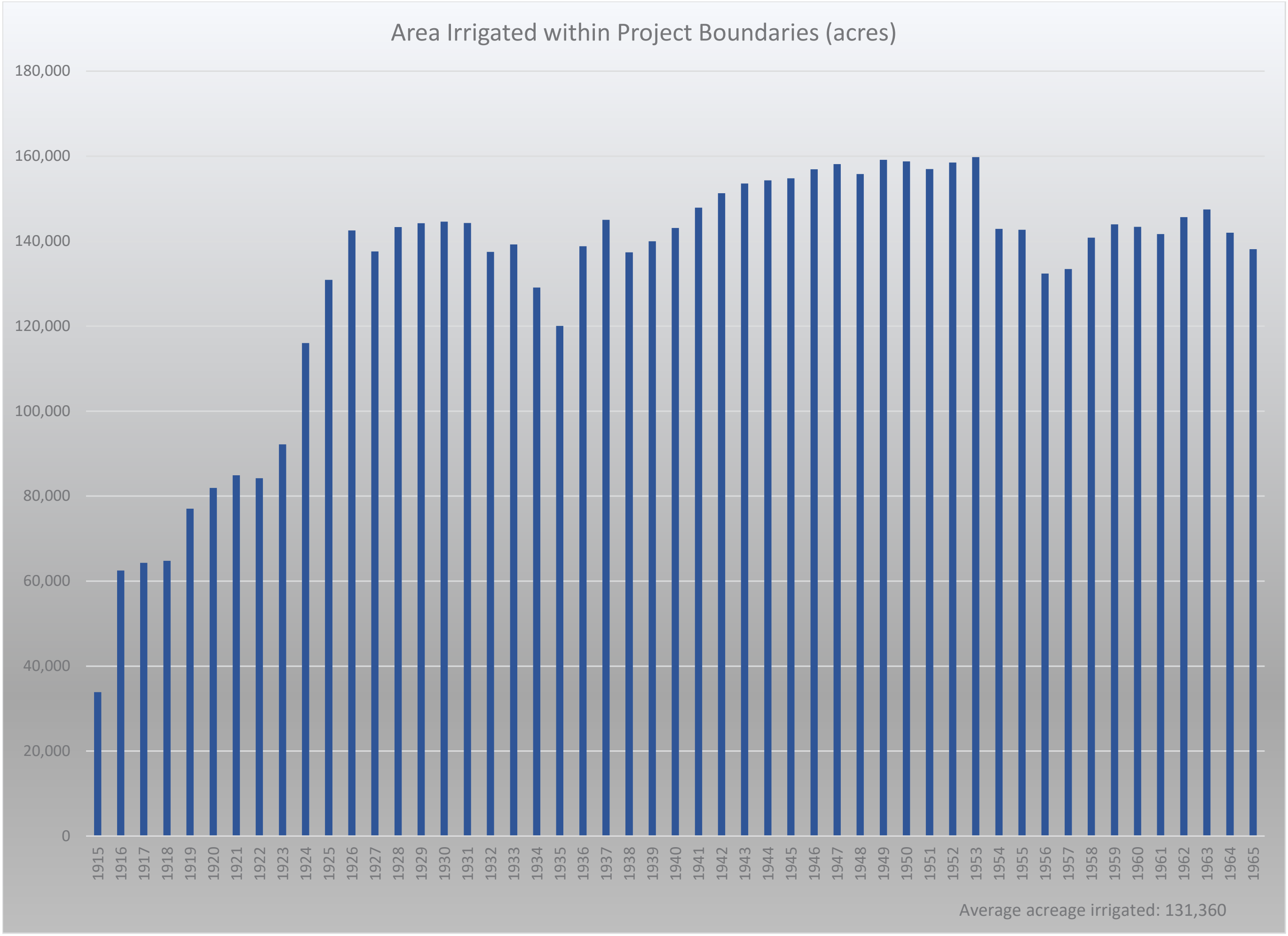
The river system changed dramatically during the years between the two compacts (1929-1938), and many studies were done as a result, as described in Chapter 4. But the Project evolved, too, both in terms of developed, irrigated acres as well as through changing water delivery infrastructure. Reclamation continually tweaked and refined the Project system to address efficiencies on the American side of the Project as well as to try to stop the continually increasing illegal Mexican diversions. The inter-compact years also witnessed localized interest in the administration of the Rio Grande, from investigations of municipal groundwater use in El Paso, to the signing of contracts between Project districts to provide more certainty and consistency on water delivery. Finally, these inter-compact years were important to international relations on the river, as well.

Then later, in the years following Compact ratification, water users and scientists undertook still additional investigations to find and locate supplementary sources of water, particularly for farmers in the Mesilla Valley. These detailed investigations, spanning the 1930s to the 1950s, demonstrated just how limited the understanding of groundwater/surface water relationships had been when the Project was authorized in the early 20th century, as well as when the Compact was signed in 1938. Although scientific knowledge of surface and groundwater connections was improving during Compact negotiations, the 1940s and 50s were a period of great growth in scientific understanding. Then, as the Upper Rio Grande Basin continued to evolve and operate under the 1938 Compact terms, severe drought struck the region beginning in 1946 and lasting into the 1950s, leading to groundwater exploration and discovery. Finally, other changes to the system eventually demanded that the 1938 Compact delivery schedules be slightly altered. This chapter will examine the developments of the 1930s that affected the basin's development and compact negotiations in less direct but still significant way, and will look at how the relationship between the Compact and scientific knowledge played out into the 1940s and 1950s when the region faced serious water shortages.

Inter-district Contracts

In the fall of 1937, just as Compact negotiations heated up, the two Project districts decided to negotiate an agreement regarding Project operation and maintenance costs as well as water allocation. The intent of the contract was to provide predictability and stability for the districts in the face of annual fluctuations that frequently occurred in irrigated acreage, project operation and maintenance costs, and water supply. During the first five years of the 1930s, the Depression had caused a significant decline in irrigated acreage in the Project, from 144,000 acres in 1930 to 120,000 in 1935. (See chart next page).

Such variations – split between the districts in myriad ways in any given year – could cause confusion and instability for things like operation and maintenance cost recovery as well as water delivery. The districts came



Irrigated Acreage Chart. Data from "Gross Crop Values - Rio Grande Project, New Mexico-Texas, Area Operated by Bureau of Reclamation" in Project History, Rio Grande Project, Vol. 54, Calendar Year 1965. New Mexico Office of the State Engineer Library.

to an agreement in September 1937 that was aimed at providing stability on these factors. They took their proposed contract to the Bureau of Reclamation and the Secretary of Interior for approval.

The inter-district contract was designed to address the annual variability in the cultivated lands of each district as well as the difficulty in knowing definitively the acreage to be irrigated each year. The contract outlined the two districts' basic understandings: there were 88,000 acres of irrigable land (57% of the Project total of 155,000) in the Elephant Butte district and 67,000 acres of irrigable land (43% of the Project total) in the El Paso district, and construction, operation, and maintenance charges for each district would remain constant every year based on these proportions, even if the irrigated acreage changed slightly in any given year. In fact, the contract provided that either district could increase its irrigated acreage by as much as 3% of its authorized irrigated acreage, or as much as 2,640 acres for Elephant Butte and 2,010 acres for EPCWID, while still maintaining constant operational charges. The small margin or buffer offered in the contract would also allow the districts to sustain minor losses in irrigated acreage "without disrupting the basic annual charges for construction repayment." EPCWID manager Roland Harwell assured Reclamation that despite small annual fluctuations, the accounting for each district would "remain in all respects unaltered, and unaffected by this agreement." Both districts hoped that the Secretary of the Interior would approve the contract. Harwell believed that, in this matter, the interest of the United States was the same as the interest of the districts.[1]

When the Bureau analyzed the contract in late October, however, Project Superintendent L.R. Fiock expressed his skepticism as to the contract's real intent. He believed instead that the districts' real goal with the contract was to have both districts "agree to and abide by the fixed percentage used in the allocation of construction costs of Project general features and in the allocation of water."[2] In other words, Fiock believed that the intent of the contract was to prevent one district from exceeding its allotted irrigable area to such an extent as to cause "a dispute or disturbance of balances between the two percentages agreed upon." He nevertheless believed the agreement prevented the districts from harming each other and thought the 3% margin reasonable. Fiock suggested that the districts add a clause limiting the amount of irrigation water applied to "suspended land under the water rental contracts," based on the amount of water in storage at Elephant Butte at the start of each irrigation season.[3]

Over the ensuing months – the same months during which the Compact Commission engineering advisors were hammering out the permanent Compact – the Secretary of the Interior and officials with the Bureau of Reclamation corresponded regarding the inter-district contract details. Reclamation Commissioner John Page (Elwood Mead's successor) wanted to ensure, for example, that the contract language did not obligate any district to pay a proportionate share of the cost for delivery systems that did not benefit their users; that the 57/43 cost split would only apply to common features of the Project system; and that, "in the event of a shortage of water for irrigation in any given year, the distribution of available supply in such year, shall so far as practicable, be made in the proportion of 67/155 (43%) thereof to the lands in the El Paso County Water Improvement District No. 1, and 88/155 (57%) to the lands within the Elephant Butte Irrigation District."[4] The United States and the districts made several alterations to the contract accordingly, specifically regarding the language surrounding the allocation of irrigated lands, irrigation water, and construction costs between the two districts. Reclamation officials were concerned that other contracts[5] being negotiated between the Bureau of Reclamation and EPCWID (these were related to repayment of drainage construction costs that were now necessary because of the Rio Grande Rectification project, discussed in the following section) would somehow be affected by the inter-district contract.[6] After addressing the concerns satisfactorily, the Reclamation Commissioner sent the revised contract to the Secretary of the Interior in November 1937, with no further objections.[7]

Finally, in February 1938, the presidents and secretaries of the two irrigation districts signed the revised contract.[8] The revised contract included language specifying that in the event of a water shortage the water

1 "Roland Harwell, Manager, to Mr. L. R. Fiock, Superintendent," October 22, 1937, NM OSE Library.

2 "Superintendent to the Commissioner, Washington, D.C.," Memorandum: Interdistrict Agreement Regarding Irrigable Area - Rio Grande Project, October 23, 1937, NM OSE Library.

3 "Superintendent to the Commissioner, Washington, D.C."

4 "Commissioner to Superintendent, El Paso, Texas," Memorandum: Interdistrict Agreement Regarding Irrigable Area - Rio Grande Project, November 2, 1937, NM OSE Library.

5 See "Contract between the United States and the El Paso County Water Improvement District No. 1 for Construction of Additional Works with Contributed Funds and Providing for Crediting of Certain Revenues," 1938, NM OSE Library; "District Counsel, El Paso, Texas, to Superintendent, El Paso, Texas," Memorandum: Proposed new contract with El Paso County Water Improvement District No. 1 - Advance of funds for certain drainage and other work and crediting certain storage rental revenues - Rio Grande project, June 20, 1938, NM OSE Library; "Additional Construction Under Consideration for Completion or Adjustment of the Irrigation and Drainage Systems in El Paso County Water Improvement District No. 1," April 19, 1938, NM OSE Library.

6 "John C. Page, Commissioner, to The Secretary of the Interior," November 29, 1937, NM OSE Library.

7 "John C. Page, Commissioner, to The Secretary of the Interior."

8 "Contract between Elephant Butte Irrigation District and El Paso County Water Improvement District No. 1," February 16, 1938, NM OSE

would be allocated in the proportion of 88/155 to the Elephant Butte District and 67/155 to the El Paso, or in a 57/43 percent split, respectively. The signed contract also stated that the agreement would only be effective "during the period when the proposed contracts under Public No. 249, Seventy-fifth Congress, 1st Session" between the United States and the two districts were in force, contracts that spelled out how development of power at Elephant Butte Dam would be accounted for financially with the districts.[9] If the Public 249 contracts were terminated, the inter-district contract would also be terminated. The final inter-district agreement also specified that the operation and maintenance costs of the Rio Grande Project works for 1938 and after would be distributed in the same manner and ratio as they were in 1937.[10] While conducted outside the official drafting of the Rio Grande Compact, the details of this inter-district contract played into the larger compact negotiations in important ways, cementing, in particular, the allocation of water based on these proportionate acreages.

Rio Grande Rectification Project and the Hudspeth District, 1935-1941

Significant physical changes to the river system were also transpiring during the 1930s. The Rio Grande Rectification Project, approved in 1933 by Mexico and the United States through signing of the 1933 Convention, changed the Rio Grande's channel downstream of El Paso. Plans for rectifying the river's course included straightening the Rio Grande's channel, reducing it from 155 miles in length to only 88,[11] and engineering it to flow on the south (rather than the north) side of San Elizario Island. The effect of the change would be to place the Tornillo Canal's heading, which fed Project lands in the lower El Paso Valley, entirely within the boundaries of the United States, thereby preventing Mexican users from having access to water in the riverbed below the Acequia Madre, the area Mexico had disclaimed all water by signing the 1906 Treaty. The 1933 Convention provided both for channel rectification as well as for the construction of Caballo Dam to better control the river's flow.[12] Caballo, situated 25 miles downstream from Elephant Butte in New Mexico, would be constructed between 1936 and 1938 and was planned to hold 100,000 acre-feet of water (it now holds 343,990) and control for flooding in the El Paso and Juarez Valleys.[13]

The U.S. Bureau of Reclamation worked with the International Boundary Commission to complete the project in response to long-standing disputes over the international boundary, the constant channel changes in the area below El Paso (where the river flattened out and was subject to damaging flood flows),[14] and as a means of preventing return flows from making their way back to the riverbed and becoming subject to illegal Mexican diversions. The project also included construction of the All-American Dam and Canal, designed to control the amount of 1906 treaty water diverted into Mexico's Acequia Madre at the old International Diversion Dam. The impacts of the project were significant, particularly in relation to Rio Grande Project operations at the lower end of the project.

Library.

9 "An Act Making Appropriations for the Department of the Interior for the Fiscal Year Ending June 30, 1938, and for Other Purposes," Pub. L. No. 75–249, 50 Stat. 564 593 (1937), 593.

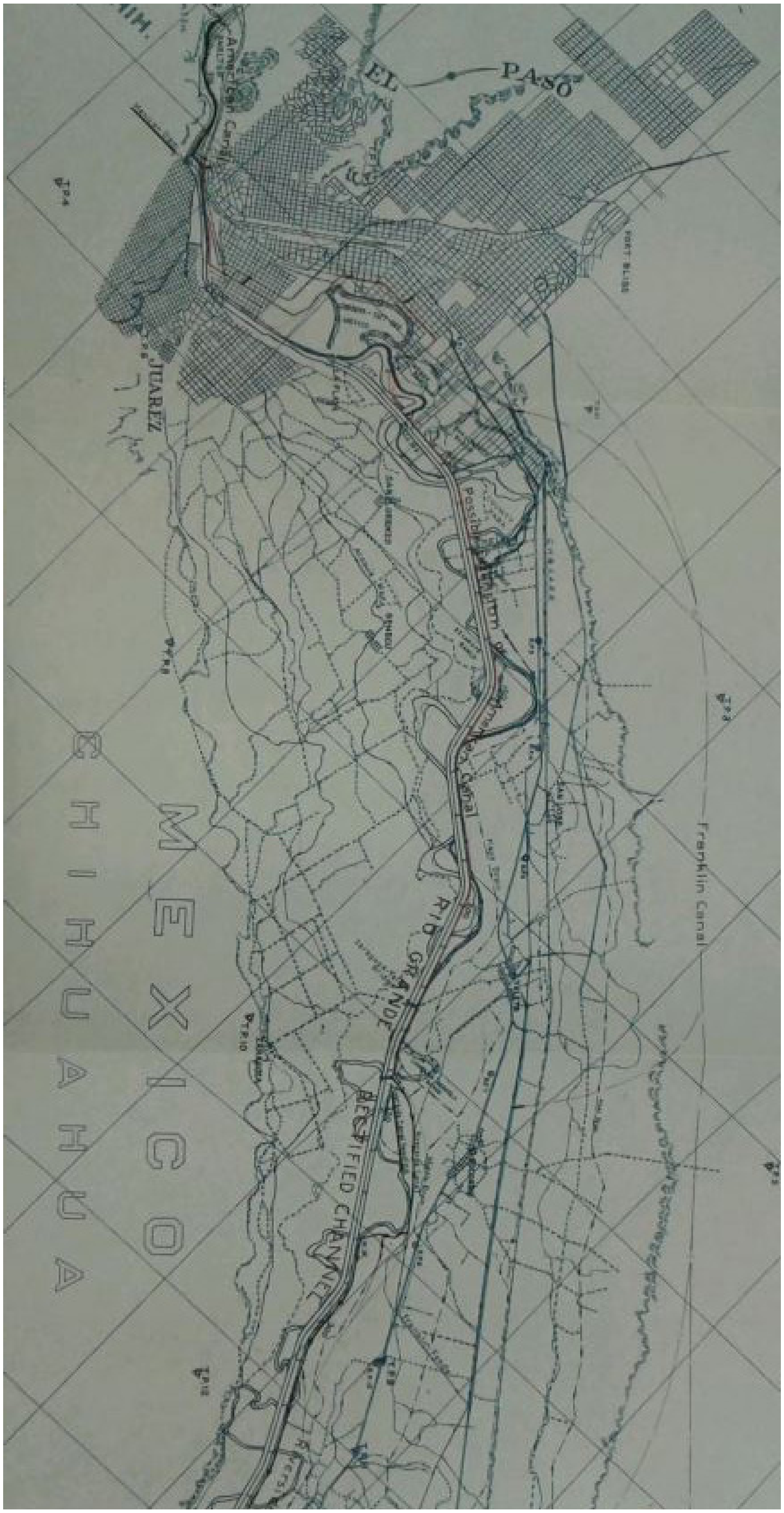
10 "Contract between Elephant Butte Irrigation District and El Paso County Water Improvement District No. 1."

11 "Treaty of 1933," International Boundary and Water Commission, 10, accessed September 25, 2019, https://www.ibwc.gov/Files/TREATY_OF_1933.pdf.

12 G. Frederick Reinhardt, "Rectification of the Rio Grande in the El Paso-Juarez Valley," The American Journal of International Law 31, no. No. 1 (n.d.): 44–54.

13 "Treaty of 1933," 19.

14 "Board of Engineers to Chief Engineer, Denver, Colorado," Memorandum: Rio Grande - El Paso to Fabens - Rio Grande Project, January 27, 1922, Records of the Bureau of Reclamation, R.G. 115, Upper Colorado Region, Salt Lake City, Utah, Reservoir Management, Rio Grande Project, 1918-1943, 8NS-115-97-470 Direct Accession, Box 1, 7714-0, River Cross Section and Profile, 1921-1925, Folder 2 of 2, U.S. National Archives, Denver.



Clip of International Boundary Commission Map of the Rio Grande El Paso to Juarez Valley, revised June 1938. Records of the Bureau of Reclamation, Entry 7, Box 909, Folder 032 Rio Grande Settlement of Water Rights - Mexico 1940 thru --. U.S. National Archives, Denver.

In the years leading up to the rectification project, Tornillo District water users, located at the extreme southern end of EPCWID and the Rio Grande Project and who irrigated about 8,600 acres, had frequently and "emphatically" complained about the quality of their water supply. They were the last diversion on the Project and a large percentage of their supply came from drainage return water which ran high in salts. When the Tornillo District was initially incorporated into the Project in 1919, the early operating model aimed to address the water quality by mixing the drainage return water with stored water from Elephant Butte in a 50/50 ratio in order to achieve a tolerance limitation within which crops could survive. This practice of dilution had concerned Reclamation since the start, however, since although this mixture created usable water for the Tornillo users, it also created a total stream discharge that was more than twice the quantity necessary for Tornillo irrigation requirements. The practice resulted in excess water at the end of the system, which in turn created a water supply for the Hudspeth District, but Reclamation officials recognized, as noted above, that this supply would be unreliable as Project efficiencies changed as a result of the infrastructure modifications. As early as 1919, just as Tornillo was negotiating its inclusion in the Project and before Hudspeth's Warren Act contract was in place, Rio Grande Project manager L.W. Lawson (who would later be affiliated with the International Boundary Commission) wrote to the Tornillo District president to inform him that a continuation of the practice of getting useable water to the district by "wasting" such large amounts of reservoir water was "practically impossible," and that "it will be impossible for us to release the large quantity of water which has been placed at the disposal of the Tornillo irrigation district"[15] into the future, since it resulted in "reservoir stored water going to waste."[16] Project water released for dilution also created tension with upstream water users who complained that the Project was wasting water and engaging in inefficient practices.

Changes to the river as a result of rectification had the effect of changing the Tornillo District's water supply and therefore calling Hudspeth's source of supply into question.[17] According to Rio Grande Project Superintendent Fiock, the Bureau was most interested in "conservation of the project's water supply and the improvement of the quality of water delivered to the Tornillo District…" Rectification's effect in this sense was the achievement of a situation whereby "there should be some means for the separation or keeping segregated [Tornillo's] irrigation and drain water, or mixing it in desired proportions so that when water is wasted, it would be straight drain water, except as a portion of the drain water may be needed to make up the irrigation requirements, unless, of course, the upper valley irrigation water supply available at Fabens is in excess of the requirements."[18] While the changes described by Fiock could have been accomplished before rectification, changes to the river channel made the process of implementing this separation system much less costly, "greatly facilitat[ing] the practicability of accomplishing the separation of the irrigation and drain water."[19] This was a great benefit to Tornillo,[20] but when Reclamation and the International Boundary Commission completed the river channel rectification work in July 1938, the effect of this separation was a major change to the water made available to the Hudspeth District. Previously, Hudspeth had relied on the Project's operational model of releasing excess

15 "L. M. Lawson, Project Manager, U.S. Reclamation Service, to Mr. H. C. Ivy, President, Tornillo Irrigation District," August 4, 1919, Records of the Bureau of Reclamation, R.G. 115, Entry 7, General Administrative and Project Records, 1919-1945, Project Files, 1919-1929, Rio Grande 223.02, Box 907, 223.02, Transfer Case, Rio Grande, Lease of Water Contracts, El Paso County Conservation and Reclamation Dist. # 2, Thru 1929, U.S. National Archives, Denver.

16 "Superintendent to The Commissioner, Washington, D.C.," Memorandum: Protest of Hudspeth County Conservation and Reclamation District No. 1 - Rio Grande Project, May 22, 1938, Records of the Bureau of Reclamation, R.G. 115, Entry 7, General Administrative and Project Records, 1930-1945, Box 921, 223.02 Rio Grande - Lease of Water Contracts Hudspeth County Consv. + Recl. Dist., U.S. National Archives, Denver.

17 "Superintendent to The Commissioner, Washington, D.C."

18 "Superintendent to The Commissioner, Washington, D.C."

19 "Superintendent to The Commissioner, Washington, D.C."

20 For a detailed description of the Project infrastructure changes in the El Paso Valley and their subsequent impact on Project supply, see Margaret Barroll Expert Report, 2019.

Elephant Butte water to improve the quality of Tornillo users' supply in order to obtain its own irrigation supply. But the new modifications would jeopardize Hudspeth's access to that water. When Reclamation proposed new irrigation works in the lower end of the Project valley to better control and segregate the water supply following the completion of rectification and two short months after the signing of the Compact, the Hudspeth District recognized the uncertainty these changes posed to its supply. Consequently, Hudspeth management passed a resolution protesting the proposed infrastructure for fear they would deplete the Project water the district was accustomed to using. Both Project districts commented on Hudspeth's protest, with EPCWID writing extensively on the subject in May 1938. In sum, EPCWID disputed the idea that Hudspeth deserved either a quantity or quality of water equal to that of the Project's Tornillo District:

> Since the supply of water heretofore delivered to the Hudspeth District is stated to have been substantially sufficient for successful agricultural operations, the [Hudspeth] proposal, in simplest analysis, is that the Hudspeth District shall enjoy the same character of water right that the Tornillo District has. Further, since the Tornillo District [within EPCWID] unquestionably has a primary water right and is entitled to receive water both in quality and quantity at parity with other District lands, or in reasonable approximation thereto, the Hudspeth proposal, if put into effect, would automatically place that area on a basis of enjoying the same character of water right as the Project lands have. Or, failing in this latter respect; that the Tornillo District shall continue to be denied its rights by maintaining the present status. Of course, it will be readily noted that *nothing in the original contract between the Bureau of Reclamation and Hudspeth Conservation and Reclamation District, or any of the various supplementary contracts thereto, will support this claim.* The Hudspeth District is presumed to have the right to the use of such surplus waters as may exist at the terminus of the Tornillo main canal on payment for the same under rates mutually satisfactory to the various interests involved. *Beyond this, we can find nothing to indicate any responsibility of the project proper to supply water which may be regarded as necessary for the Hudspeth District lands.*"[21] [Emphasis added.]

EBID, having seen EPCWID's comments, wrote to the Project superintendent and informed him that EBID stood "with [EPCWID] to oppose the resolution directed to the Commissioner of the Reclamation by the Hudspeth County Conservation and Reclamation District No. 1."[22]

When Project Superintendent Fiock addressed the situation in a letter to the Commissioner of Reclamation, he noted that Tornillo users, "have been emphatically asserting their right to the same quality of water for irrigation as other portions of the Rio Grande Project, or at least the same quality of water as the upper divisions of the El Paso Valley." In Fiock's expert opinion, the Project was obligated to tightly control and regulate the water supply to meet the needs of those Project lands with "the least amount of waste and without any regard to the requirements of the Hudspeth District." Fiock recognized that operation of the Project with the least amount of waste would leave Hudspeth with only the "unavoidable and uncontrollable waste at the end of the project," which might be "wholly inadequate in quantity and too uncertain in time and regularity of availability to be relied upon for irrigation."[23] Nevertheless, Fiock, with compact negotiations still no doubt fresh in his mind,

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21 "Roland Harwell, Manager, to Mr. L. R. Fiock, Superintendent, Bureau of Reclamation," May 1, 1939, Records of the Bureau of Reclamation, R.G. 115, Entry 7, General Administrative and Project Records, 1930-1945, Box 921, 223.02 Rio Grande - Lease of Water Contracts Hudspeth County Consv. + Recl. Dist., U.S. National Archives, Denver.

22 "N. B. Phillips, Treasurer-Manager, to Mr. L. R. Fiock, Superintendent, Bureau of Reclamation," May 1, 1939, Records of the Bureau of Reclamation, R.G. 115, Entry 7, General Administrative and Project Records, 1930-1945, Box 921, 223.02 Rio Grande - Lease of Water Contracts Hudspeth County Consv. + Recl. Dist., U.S. National Archives, Denver.

23 "Superintendent to The Commissioner, Washington, D.C.," May 22, 1938.

noted that Hudspeth's rights were "legal" questions,[24] and concluded his letter by stating that, "it does not seem...that the [Hudspeth] District has any right or justification to stand in the way of improvements designed for the conservation or improvement of the project water supply, or any portion thereof."[25] Ultimately, Reclamation officials (beyond just Fiock) argued that the Project had no responsibility to supply any water to Hudspeth, and denied the district's protests.[26] In return, Hudspeth asked merely for assurance that its water supply would not be harmed, an assurance that it never received. Despite this clear denial of any right to either water quantity or water quality, things looked up for Hudspeth just a few years later, as described in a below section.

The Living Rio Grande Compact

To deal with these and other changes that would undoubtedly emerge in the basin, the Rio Grande Compact Commission under the 1938 Compact had recognized the need for a clear method of enforcing the agreement's terms while also providing for an adjustment phase in the immediate aftermath of the Compact's ratification. Negotiations for Compact administration mechanisms began immediately after the Compact was signed in March 1938. The commissioners recognized there should be what Texas Commissioner Frank Clayton called "an experimental stage" during the Compact's early administration, during which the three states could work out some of the granular details of Compact administration. Each commissioner would be paid a salary, and travel expenses for meetings and other requirements would be reimbursed. But for other details, Clayton noted that "the provisions of the permanent compact are highly technical and much more detailed than those of the temporary compact, and will correspondingly require more time and expense for their proper administration."[27]

In fact, that was true, particularly in the first few years. The Compact went into effect on May 1, 1939, with the Compact's schedule of deliveries becoming effective on January 1, 1940.[28] During 1939, the commission met four times to design and adopt rules for the Compact's administration, including the collection of data, staffing, how to handle new or increased depletions, and the future rotation of meeting locations.[29]

Things went fairly smoothly in the first few years, with water supply fluctuating as usual, and changes to the Project infrastructure continuing.[30] But in 1944, New Mexico initiated a more significant change to the terms of the Compact when the state made a formal request for the Commission to evaluate New Mexico's nine-month delivery schedule, which excluded the months of July, August, and September. New Mexico Commissioner and State Engineer Thomas McClure justified his request by noting that "substantial quantities of New Mexico credit

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24 "Superintendent to The Commissioner, Washington, D.C."

25 "Superintendent to The Commissioner, Washington, D.C."

26 "Roland Harwell to L. R. Fiock," May 1, 1939, Records of the Bureau of Reclamation, R.G. 115, R.G. 115, Entry 7, Project Correspondence File 1930-1945, Rio Grande Project, Box 927, 301. Rio Grande Project - Board + Engineering Reports on Construction Features Jan. 1, 1937, U.S. National Archives, Denver.

27 "Frank B. Clayton, Rio Grande Commissioner for Texas, to the Honorable E.H. Thornton, Jr., Chairman," March 23, 1939, RIO Grande Compact Commission Records, 1924-1941, 1970, Box 2F466, Rio Grande Commission (1938-1940), Center for American History, University of Texas at Austin.

28 "First and Second Annual Reports of the Rio Grande Compact Commission, 1939 and 1940," Interstate Stream Commission, 3, accessed October 22, 2019, https://www.ose.state.nm.us/Compacts/RioGrande/RGCC%20Reports/Rio%20Grande%20Compact%20Commission%20 1939-1940%20First%20and%20Second%20Annual%20Report.pdf.

29 "First and Second Annual Reports of the Rio Grande Compact Commission, 1939 and 1940," 16–17.

30 See "Superintendent to Chief Engineer," Memorandum: Accelerated construction program for food production - Rio Grande Project, August 5, 1943, Entry 7, Project Correspondence File 1930-1945, Rio Grande Project, Box 927, 301. Rio Grande Project - Board + Engineering Reports on Construction Features Jan. 1, 1937, U.S. National Archives, Denver; "Acting Chief Engineer to Commissioner," Memorandum: Accelerated construction program for food production - Rio Grande Project, August 23, 1943, Entry 7, Project Correspondence File 1930-1945, Rio Grande Project, Box 927, 301. Rio Grande Project - Board + Engineering Reports on Construction Features Jan. 1, 1937, U.S. National Archives, Denver.

water have been delivered past San Marcial station from time to time during the July-September periods when no schedule accounting is made," and that New Mexico felt that a shift to a 12-month schedule would better serve the basic principles of the Rio Grande Compact.[31] Correspondence between the Rio Grande Compact Commissioners from July 1945 indicate that they all consented to the re-evaluation of New Mexico's delivery schedule, which occurred over the ensuing months.[32] With the data collected, the commissioners and the advising engineers worked out the details of New Mexico's new schedule in 1946. Texas's engineer Raymond Hill, with an established history of detailed Rio Grande analysis, reminded the commission that New Mexico's shift to an annual (12-month) schedule would have to comply with the limitations of the Compact's Article V which required that new stations and measurements result in by and large the same results "so far as the rights and obligations to deliver water are concerned, as would have existed if such substitution of stations and measurements had not been so made." In keeping with this requirement, New Mexico's future scheduled deliveries would be measured by something Hill called the Elephant Butte Effective Supply, defined as outflow plus or minus change in storage in Elephant Butte Reservoir, suggesting implicitly that the San Marcial gauge would be abandoned. Hill insisted that New Mexico's future deliveries (measured by the Elephant Butte Index) be equivalent to the quantity of water delivered to San Marcial during the three non-schedule months under the existing Compact. Finally, Hill maintained that adjustments would need to be made to "historical records to correct for such excess operating waste as did take place during July, August, and September," measured at San Marcial. Hill believed that the only adjustment possible that fell within the limits of Article V of the Compact was an allowance for operating water waste released from El Vado Reservoir during the three summer months of July, August, and September in excess of 25% of the total quantity released.[33]

By April 1947, the commission's engineering advisers had adopted a report recommending the replacement of the nine-month schedule with a 12-month schedule along the lines of Hill's recommendations. It had taken the advisers many months, but they ultimately found that the new schedule would reflect the old schedule "plus an evaluation of the deliveries of water through the middle valley to be expected during the three summer months which would result from the operation of the [MRGCD] under reasonable efficient conditions."[34] Ultimately, New Mexico's Bliss conferred with the state's attorney general, who believed that the change "would not be substantive in character," and that the Compact Commission could approve the change without legislative action.[35] In early 1948, the commission met in El Paso, and approved the change.[36]

The drought that began in the late 1940s, however, was another test of the Compact's provisions, and water users explored the potential of augmenting the supply with groundwater. That story and municipal use of groundwater will be discussed below.

31 "Thomas M. McClure, Rio Grande Compact Commissioner for New Mexico, to Mr. Berkeley Johnson, Chairman," June 2, 1944, NM OSE Library.

32 "J.E. Quaid, Commissioner for State of Texas, Rio Grande Compact Commission, to Mr. M.C. Hinderlider, Mr. Thomas M. McClure, and Mr. Berkeley Johnson," July 27, 1945, NM OSE Library; "Berkeley Johnson, Chairman, to Mssrs. Hinderlider, McClure & Quaid," July 24, 1945, NM OSE Library; "Royce Tipton to Mr. John Bliss," December 26, 1945, NM OSE Library.

33 "Raymond A. Hill to Mr. R.J. Tipton and Mr. J.H. Bliss," May 27, 1946, NM OSE Library.

34 "John H. Bliss, State Engineer, to Mr. Fred E. Wilson, Attorney for Interstate Stream Commission," April 10, 1945, NM OSE Library.

35 "John H. Bliss, State Engineer, to Mr. Fred E. Wilson, Attorney for Interstate Stream Commission."

36 S. E. Reynolds and Philip B. Mutz, "Water Deliveries Under the Rio Grande Compact," Natural Resources Journal 14 (April 1974): 204.

Groundwater: Municipal Supplies

Yet another ongoing side story to the Rio Grande Compact narrative not previously discussed also began around 1935. In addition to Texas filing suit against New Mexico that year (Chapter 4), and the Compact Commission authorizing the Rio Grande Joint Investigation that year as well (Chapter 4), the role of groundwater began to loom large in discussions over water supply in the Upper Rio Grande Basin. Two events transpired to bring groundwater into Rio Grande discussions: first, the city of El Paso became desperate for a better and more plentiful municipal water supply beginning in 1934, and second, a severe drought hit the region hard starting in the late 1940s. The intensive nature of the investigations that were launched in 1935 outside of the RGJI to contend with these challenges point to the previously inadequate understanding of the relationship between surface and groundwater during the 1930s, as well as to the Upper Rio Grande Basin water users' intentions to explore groundwater as a potential supplement to augment the basin's supply.

El Paso's Municipal Water and the Rio Grande Project

By at least the turn of the 20th century, El Paso had come to depend on groundwater for its municipal water supply. By the mid-1930s, as the city grew, its pumpage had increased dramatically as well, and salt incursion into the supply was causing problems for the city by 1934.[37] In 1935, responding to requests from city of El Paso officials,[38] the USGS and the Texas Board of Water Engineers determined that an "intensive investigation of ground-water conditions at El Paso should be started as soon as possible."[39] The municipal El Paso Water Board concurred, and a combination of city, state, and federal dollars funded the USGS investigation beginning that summer.[40] The goals of the study were: to solve the problem of saltwater intrusion into the valley; to determine the quantity of water that could be pumped near and in El Paso, and; to determine the best locations to develop new wells.[41] The study was separate and apart from the other work being conducted throughout the basin for the RGJI, and its extensiveness underscored that neither scientists nor water users in the 1930s had a clear understanding of the resource; in fact, the USGS was performing the studies to determine whether groundwater uses in different parts of the El Paso area were a possible source of augmenting the current municipal supply, and what the effects would be of tapping into these groundwater sources. USGS began its work in July 1935.[42]

At the end of the following year, El Paso's Water Works Superintendent Ashley Classen became impatient for the study's results. In a letter to the USGS director, Classen explained that the city planned "a considerable program of new construction," all of which depended on the conclusions they hoped to see in the USGS report. For this reason, the city was very anxious to receive the findings so that it could plan for the coming year. Classen expressed his hope that it would be ready by January 1937 at the latest,[43] and USGS assured Classen that it would. One of the study's authors, A.N. Sayre, planned to travel to El Paso and go over the findings with

37 A. N. Sayre and Penn Livingston, "Ground-Water Resources of the El Paso Area, Texas" (Washington, D.C.: Government Printing Office, 1945), 3, NM OSE Library.

38 Sayre and Livingston, 4.

39 "W. C. Mendenhall, Director, to Mr. W. E. Robertson, Chairman, El Paso Water Board," May 29, 1935, R.G. 57, Records of the Geological Survey, Entry 51, Director's Files, Central Classified Files, Box 461, 671 Texas (Ground Water), U.S. National Archives, II; Chief Hydraulic Engineer, "Memorandum for the Director," January 30, 1936, R.G. 57, Records of the Geological Survey, Entry 51, Director's Files, Central Classified Files, Box 461, 671 Texas (Ground Water), U.S. National Archives, II.

40 A brief overview of El Paso's use of groundwater is available in Sayre and Livingston, "Ground-Water Resources of the El Paso Area, Texas," 5–6.

41 "A. N. Sayre, Associate Geologist, to Mr. W. N. White," February 25, 1938, R.G. 57, Records of the Geological Survey, Entry 51, Director's Files, Central Classified Files, Box 461, 671 Texas (Ground Water), U.S. National Archives, II.

42 Sayre and Livingston, "Ground-Water Resources of the El Paso Area, Texas," 4.

43 "Ashley G. Classen, Superintendent, City Water Works, to Dr. W. C. Mendenhall, Director, United States Geological Survey," December 23, 1936, R.G. 57, Records of the Geological Survey, Entry 51, Director's Files, Central Classified Files, Box 461, 671 Texas (Ground Water), U.S. National Archives, II.

the El Paso Water Board at that time.[44] But in late January 1937, with El Paso's desperation increasing, Classen wrote again, explaining that it had become "imperative that we have two new well locations within the next thirty days." Classen exclaimed that El Paso was anticipating "a very acute shortage of water in our city during the coming summer" and would need to develop an additional water supply. The city's development depended entirely on the USGS survey's conclusions, and Classen emphasized how anxious the city was for this report so that they could select well sites, imploring the USGS to rush the report to completion.[45] A preview of the agency's conclusions and recommendations on the groundwater resources of the El Paso area suggested locations[46] where El Paso should drill its next wells, and recommendations on how to prevent further salt incursion.[47]

Although the USGS investigation into El Paso's groundwater supply was separate from the RGJI, the RGJI team was aware of El Paso's plight as well as of the city's dependence on groundwater supplies.[48] (See RGJI Report, (RIO30) p. 105) In fact, RGJI lead engineer Harlow Stafford requested data from Classen in January 1937, and Classen responded by sending El Paso's monthly pumping data from the city's wells for the five years between 1932 and 1936. The data showed that the city was fed by ten wells, each yielding 1,000 gallons of water per minute, averaging 3.5 million gallons per day during the winter and 7.5 million gallons per day during the summer. Classen informed Stafford about the USGS investigation and that the city was "contemplating the drilling and construction of 3 additional wells within the very near future," since the records clearly showed that "the static level of our ground water supply is slowly receding." With Classen's conclusion that "the pumpage in this area exceeds the recharge," he projected that if the groundwater supply recession continued for another 10 to 20 years, El Paso would need to seek a new water supply and warned that while the only other water supply available was the Rio Grande, he hoped that El Paso would not have resort to the river for many years, if at all.[49]

RGJI report writers, meanwhile, were wrapping up that investigation's report at the same time as the USGS report on El Paso groundwater was nearing completion. Although the RGJI mentioned the existence of municipal water uses in the basin, the authors more or less dismissed their significance to the overall depletions along the river in the upper basin, believing that some such uses affected the river while others did not. "The total use of water in the Upper Rio Grande Basin for purposes other than irrigation is but a small fraction of the irrigation use," they reported.[50] Nevertheless, they did display some understanding of the different underground basins' relationships to surface water, comparing Albuquerque's water use – a city with a population of 34,000 at the time the RGJI was written – with El Paso's (population 110,000). Albuquerque's "present use," they wrote, "is undoubtedly a draft, direct or indirect, on Rio Grande," but was nevertheless a modest 3,000 acre-feet total annually. In contrast, they believed that El Paso's 8,800 acre-feet annual supply of groundwater originated from precipitation falling on a large area east of the city, and they seem to have not considered El Paso's use a draft on

44 "Julian D. Sears, Acting Director, to Mr. Ashley G. Classen, Superintendent, City Water Works, El Paso, Texas," December 30, 1936, R.G. 57, Records of the Geological Survey, Entry 51, Director's Files, Central Classified Files, Box 461, 671 Texas (Ground Water), U.S. National Archives, II.

45 "Ashley G. Classen, Superintendent, City Water Works, to Mr. Julian D. Sears, Acting Director, United States Geological Survey," January 27, 1937, R.G. 57, Records of the Geological Survey, Entry 51, Director's Files, Central Classified Files, Box 461, 671 Texas (Ground Water), U.S. National Archives, II.

46 "W. C. Mendenhall, Director, to Ashley G. Classen, Superintendent, City Water Works, El Paso, Texas," February 2, 1937, R.G. 57, Records of the Geological Survey, Entry 51, Director's Files, Central Classified Files, Box 461, 671 Texas (Ground Water), U.S. National Archives, II.

47 Sayre and Livingston, "Ground-Water Resources of the El Paso Area, Texas," 97–99.

48 "Regional Planning: Part VI--The Rio Grande Joint Investigation in the Upper Rio Grande Basin in Colorado, New Mexico, and Texas, 1936-1937" (Government Printing Office, February 1938), 105.

49 "Ashley G. Classen, Superintendent, to Mr. Harlowe M. Stafford, Engineer, National Resources Committee," January 12, 1937, NM OSE Library.

50 "Regional Planning: Part VI--The Rio Grande Joint Investigation in the Upper Rio Grande Basin in Colorado, New Mexico, and Texas, 1936-1937," 104.

the Rio Grande.[51] In fact, the USGS still believed nearly a decade later in 1944 that groundwater dependence "for public supplies and industries" in the stretch of river between El Paso and Fort Quitman "relieves the demand on the flow of the Rio Grande."[52] In other words, scientists had a limited understanding of the relationship between groundwater and surface water and recognized that they did not have full scientific understanding related to every single underground basin along the Upper Rio Grande. Furthermore, contemporaries knew of El Paso's and other municipalities' dependence on groundwater, and also knew that these cities would grow. As such, it is not surprising to find a lack of evidence in the historic record indicating that Compact framers made any effort to preclude this resource's development.

In response to the USGS's El Paso groundwater findings, which provided detailed recommendations on which underground basins El Paso should pursue, the city began drilling new wells to gain a larger (and better quality) municipal water supply. When their efforts largely failed[53] (due to dry wells) El Paso was forced to approach the Bureau of Reclamation in the summer of 1940 to inquire about the possibility of acquiring Project water from the Rio Grande to supplement the city's supplies.[54] On June 8, 1940, W.E. Robertson, chairman of the Water Development Commission of the City of El Paso (successor to the El Paso Water Board) said that while the city's municipal water had mainly been pumped from underground wells for years, the water used had consistently exceeded the amount of recharge and had led to a higher risk of saltwater infiltration because of the lowered water table. To relieve El Paso's water woes, Robertson proposed to purchase land within the Rio Grande Project and thus acquire the associated water rights. The land purchased, then, would need to be taken out of cultivation. "There is no reliable, adequate, additional source," he pleaded, "except the waters of the Rio Grande."[55]

Reclamation officials did not immediately agree with El Paso's request. Although Reclamation Commissioner John Page passed the letter along to Superintendent Fiock with the hint that the proposal would "meet with [Page's] approval and co-operation,"[56] Fiock did not seem to share Page's feelings toward the proposal. "We believe the city showed poor taste in beginning its negotiations with an apparent endeavor to obtain water on more favorable conditions or charges than the project land," Fiock said, especially since El Paso "has been so dilatory through all the years of the project promotion and development, so far as we know never offering to bear any of the burden." Furthermore, Fiock felt that the city's claim of insufficient water was exaggerated for emphasis, and that some of the shortage might be explained by the city's delay in drilling a new well. He went on to say that it seemed that El Paso was faced more with a problem of water *quality* rather than quantity as the wells were depleted. He did acknowledge, however, that a supplemental supply from the river would extend the life of the city's underground supply by reducing the city's need to deplete it so rapidly, and despite apparent disagreement with some of the city's claims and the way they went about making their proposal, Fiock ultimately gave his

51 "Regional Planning: Part VI--The Rio Grande Joint Investigation in the Upper Rio Grande Basin in Colorado, New Mexico, and Texas, 1936-1937," 105.

52 "Geological Survey Water Plans for Rio Grande Basin (Except the Pecos)," c 1944, 12.

53 "W. E. Robertson, Chairman, to Honorable John C. Page, Commissioner, Bureau of Reclamation," June 8, 1940, Records of the Bureau of Reclamation, R.G. 115, Entry 7, General Administrative and Project Records, 1930-1945, Box 920, 223.02 Rio Grande Leases, Sales, + Rentals of Water El Paso, City of thru Dec 1941, U.S. National Archives, Denver.

54 "Superintendent to The Commissioner (Through Chief Engineer, Denver, Colorado)," Memorandum: Negotiations by City of El Paso for municipal water supply from project sources - Rio Grande Project, June 20, 1940, Records of the Bureau of Reclamation, R.G. 115, Entry 7, General Administrative and Project Records, 1930-1945, Box 920, 223.02 Rio Grande Leases, Sales, + Rentals of Water El Paso, City of thru Dec 1941, U.S. National Archives, Denver.

55 "W. E. Robertson, Chairman, to Honorable John C. Page, Commissioner, Bureau of Reclamation," June 8, 1940.

56 "W. E. Robertson, Chairman, Water Development Commission of the City of El Paso, to Mr. L. R. Fiock, Superintendent, Bureau of Reclamation," June 11, 1940, Records of the Bureau of Reclamation, R.G. 115, Entry 7, General Administrative and Project Records, 1930-1945, Box 920, 223.02 Rio Grande Leases, Sales, + Rentals of Water El Paso, City of thru Dec 1941, U.S. National Archives, Denver.

approval for the city to move forward with making arrangements, and directed city officials to seek approval from the Project irrigation districts.[57]

As negotiations proceeded with the Rio Grande Project, the City of El Paso relied upon the USGS studies to sustain its claim of a dire water supply situation in order to gain support for obtaining Project water. Doing so allowed the city to attempt to comply with the Act of February 25, 1920[58] requiring that "no such contract shall be entered into except upon a showing that there is no other practicable source of water supply for the purpose."[59] Having gained the support of the Bureau of Reclamation for the scheme, the city had negotiated all necessary contracts by early 1941. Key issues in these negotiations had included discussion over the city's repayment arrangements for Project water[60] and the amount of Project water to which the city would be limited.[61] El Paso felt that since it was purchasing land and taking it out of cultivation, it ought to be entitled to the same first-class water rights and the same deliveries as other qualified landowners. As such, El Paso disputed two particular clauses in the Reclamation contract. The first was one that allowed the Project Superintendent to decide not to supply the city with Project water in years when he might determine the delivery of water to the city to be "detrimental to the water service of the project or to the rights of any prior appropriator."[62] The second was the contract clause restricting the city to a maximum of 3.5 acre-feet/acre annually, arguing that no similar restriction was imposed upon any other landowner within the Project.[63] In the end, Reclamation removed the offending clause regarding "detriment" to other water users but retained the water volume limitations.[64]

The contract facilitating this purchase between Reclamation, the City of El Paso and EPCWID was executed March

57 "Superintendent to The Commissioner (Through Chief Engineer, Denver, Colorado)," June 20, 1940.

58 "An Act For Furnishing Water Supply for Miscellaneous Purposes in Connection with Reclamation Projects," Pub. L. No. 66–147, § 86, 41 Stat. 451 (1920).

59 "City of El Paso, Texas, by Mayor, Chairman Water Development Commission, Chairman Water Board, and Superintendent of the Water Works, to the Honorable, The Secretary of the Interior," August 31, 1940, Records of the Bureau of Reclamation, R.G. 115, Entry 7, General Administrative and Project Records, 1930-1945, Box 920, 223.02 Rio Grande Leases, Sales, + Rentals of Water El Paso, City of thru Dec 1941, U.S. National Archives, Denver; "The Ground-Water Supplies of the El Paso Area, Texas," August 17, 1940, Records of the Bureau of Reclamation, R.G. 115, Entry 7, General Administrative and Project Records, 1930-1945, Box 920, 223.02 Rio Grande Leases, Sales, + Rentals of Water El Paso, City of thru Dec 1941, U.S. National Archives, Denver; "S. O. Harper, Chief Engineer, Bureau of Reclamation, to The Honorable, The Secretary of the Interior (through Commissioner of Reclamation)," February 12, 1941, Records of the Bureau of Reclamation, R.G. 115, Entry 7, General Administrative and Project Records, 1930-1945, Box 920, 223.02 Rio Grande Leases, Sales, + Rentals of Water El Paso, City of thru Dec 1941, U.S. National Archives, Denver.

60 "Memorandum for Mr. Stinson: Rio Grande Project - Sale of Water to City of El Paso for Supplemental Supply for Municipal Purposes," January 16, 1941, Records of the Bureau of Reclamation, R.G. 115, Entry 7, General Administrative and Project Records, 1930-1945, Box 920, 223.02 Rio Grande Leases, Sales, + Rentals of Water El Paso, City of thru Dec 1941, U.S. National Archives, Denver.

61 "J. E. Anderson, Mayor, City of El Paso, Texas, and W. E. Robertson, Chairman, Water Development Commission of the City of El Paso, Texas, to Mr. L. R. Fiock, Superintendent, Rio Grande Project, Bureau of Reclamation," February 1, 1941, Records of the Bureau of Reclamation, R.G. 115, Entry 7, General Administrative and Project Records, 1930-1945, Box 920, 223.02 Rio Grande Leases, Sales, + Rentals of Water El Paso, City of thru Dec 1941, U.S. National Archives, Denver.

62 "J. E. Anderson, Mayor, City of El Paso, Texas, and W. E. Robertson, Chairman, Water Development Commission of the City of El Paso, Texas, to Mr. L. R. Fiock, Superintendent, Rio Grande Project, Bureau of Reclamation."

63 "J. E. Anderson, Mayor, City of El Paso, Texas, and W. E. Robertson, Chairman, Water Development Commission of the City of El Paso, Texas, to Mr. L. R. Fiock, Superintendent, Rio Grande Project, Bureau of Reclamation"; "J. E. Anderson, Mayor, City of El Paso, Texas, and W. E. Robertson, Chairman, Water Development Commission of the City of El Paso, Texas, to Mr. L. R. Fiock, Superintendent, Rio Grande Project, Bureau of Reclamation," February 5, 1941, Records of the Bureau of Reclamation, R.G. 115, Entry 7, General Administrative and Project Records, 1930-1945, Box 920, 223.02 Rio Grande Leases, Sales, + Rentals of Water El Paso, City of thru Dec 1941, U.S. National Archives, Denver.

64 "Superintendent and District Counsel to Commissioner (Through Chief Engineer, Denver, Colorado)," Memorandum: Water supply for the City of El Paso from the project water supply - Rio Grande Project, February 7, 1941, Records of the Bureau of Reclamation, R.G. 115, Entry 7, General Administrative and Project Records, 1930-1945, Box 920, 223.02 Rio Grande Leases, Sales, + Rentals of Water El Paso, City of thru Dec 1941, U.S. National Archives, Denver; "Contract to Supply Water to the City of El Paso for Municipal Purposes," February 18, 1941, Article 9, Records of the Bureau of Reclamation, R.G. 115, Entry 7, General Administrative and Project Records, 1930-1945, Box 920, 223.02 Rio Grande - Leases, Sales + Rentals of Water El Paso, City of Jan 1942 thru, U.S. National Archives.

7, 1941, stipulating that the city could obtain at most 2,000 acres of Project land in EPCWID and thereby obtain Project water rights for municipal use.[65] Both of the Project's irrigation districts approved the contract, which[66] provided that neither the United States nor EPCWID were liable for damages to the city if water quality was subpar or if water shortages occurred.[67]

As El Paso's municipal water shortage continued, the city proposed another analogous contract in late 1944, aiming to acquire the right to purchase up to 2000 acres of land in the Elephant Butte Irrigation District in New Mexico, and amending the 1941 contract such that the city's repayment arrangements would go to the districts and not to the United States.[68] All parties initially approved of this additional contract, but soon, New Mexico State Engineer and Compact Commissioner Thomas McClure intervened. In March 1945, McClure recognized a problem with the City of El Paso's plan. Writing to an El Paso city attorney, McClure explained that drying up land in New Mexico to benefit El Paso municipal uses was not in the best interests of his state; if El Paso needed water, he wrote, "they should dry up their own lands in Texas and not attempt to deprive New Mexico of her use of water." He added that if EBID was looking to abandon 6,000 acre-feet of water, New Mexico would surely find use for it "in New Mexico without selling it to Texas." He threatened that New Mexico's Interstate Stream Commission would not hesitate to use legal means to prevent this plan from moving forward.[69]

By 1949, El Paso's contract with EPCWID was in effect. But the one between the City of El Paso and EBID was in limbo. EBID water users had begun to feel the effects of the drought and were facing their own water shortages. As such, they sided with McClure, and expressed their own concerns over El Paso's efforts to sign contracts with EBID for Project water. EBID was further worried about El Paso's recently announced plan to construct a storage reservoir for city water, to be filled by using the city's allotted 3.5 acre-feet per acre of water for each acre it owned, plus any surplus water not needed by the Project, as determined periodically by the Project Manager.[70] EBID refused to approve the supplemental contract. Nevertheless, Reclamation's legal counsel eventually determined that EBID's approval was not necessary, and Project officials did not believe that the contract would be detrimental to EBID.[71] The waters to be contracted to El Paso consisted of water in several categories: 1. Flood waters accruing to the stream below Caballo Dam and below the last diversion point for EBID, after the needs of EPCWID and Hudspeth had been determined (Hudspeth did have an existing Warren Act contract that parties considered); 2) return flow waters during winter months, which were high in salinity and often unused by either Project or Hudspeth farmers because they needed dilution from storage water for irrigation use (and no waters were released during the winter months); and 3) "unavoidable waste" from sudden cold spells in the spring or from unexpected rainfall over irrigated areas during the summer months. A new gauging station was to be installed 16 miles above El Paso at the site of the proposed reservoir.[72]

As the drought worsened and there was no sign of it easing, El Paso launched additional groundwater studies with other partners, including the Army and the Air Force, both of which had bases in the region and also

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65 "Record of Execution of Contract," March 7, 1941, Records of the Bureau of Reclamation, R.G. 115, Entry 7, General Administrative and Project Records, 1930-1945, Box 920, 223.02 Rio Grande - Leases, Sales + Rentals of Water El Paso, City of Jan 1942 thru, U.S. National Archives; "Contract to Supply Water to the City of El Paso for Municipal Purposes," Article 10.

66 "John C. Page, Commissioner, to The Secretary of the Interior," February 17, 1941, NM OSE Library.

67 "Contract to Supply Water to the City of El Paso for Municipal Purposes," Article 17.

68 "J. Kennard Cheadle, Acting Commissioner, to The Secretary of the Interior," November 22, 1944, NM OSE Library.

69 "Thomas M. McClure, State Engineer, to Mr. R. F. Momsen, Assistant City Attorney," March 21, 1945, NM OSE Library.

70 "Commissioner to Secretary J. A. Krug," Memorandum: Proposed supplemental contract with City of El Paso for municipal water supply - Rio Grande Project, May 13, 1949, NM OSE Library.

71 "Commissioner to Project Manager," Memorandum: City of El Paso Water Supply - Rio Grande Project, August 19, 1949, NM OSE Library.

72 "Commissioner to Project Manager."

demanded water supplies. The city's reliance on groundwater from the turn of the century well into mid-century and beyond and the state of Texas's and the Project's participation in helping the city solve its supply problems underscore the conclusion that the Compact did not intend to preclude the development of the resource.

Mexico Treaty Violations, Infrastructure Changes, and the Effect on Hudspeth

Meanwhile, the relationship between Hudspeth, the two Project districts, and Reclamation officials remained tenuous at best during the late 1930s and into the 1940s as the river came under Compact administration. Hudspeth had to advocate for itself for more than just a water supply during the late 1930s; it was also troubled by existing payment arrangements with the Project districts. EPCWID and EBID had, like other irrigation districts throughout the West, obtained new repayment contracts with the United States in the face of the Depression's severity and the aggressive payment schedule demanded by the original contracts. While it made a certain amount of sense to modify Hudspeth's contract at the same time as the Project districts and offer a similar level of relief, an August 1938 letter from Superintendent Fiock to the two Project districts explained why 1938 was an inopportune time for such a modification. These reasons included: "the pending litigation [between Texas and New Mexico] and present status of compact negotiations and such changes that may be brought about in the *kind of service* to be rendered to the Hudspeth District in the future on account of certain changes in the Project irrigation and drainage works."[73] [Emphasis added.] In other words, no guarantee could be made to Hudspeth, *especially* in the face of the recently signed compact that was awaiting ratification. Fiock reiterated the reasons to hold off on a new contract with Hudspeth as late as December 1939. In a letter to the Commissioner of the Bureau of Reclamation, Fiock noted that "a new contract should be entered into with the Hudspeth District as soon as the temporary and changing conditions now existing on the project, which may ultimately have some affect [sic] on the services which can be rendered to the Hudspeth District, have reached a permanent status."[74] Reclamation Commissioner John Page reiterated the sentiment in a letter to the secretary of interior: "It is proposed that a new permanent basic contract ... be entered into with the Hudspeth District at some time in the future, but until certain temporary and changing conditions on the Rio Grande project have been adjusted and become permanent, it will be necessary to continue making water rental contracts on an annual basis."[75] Following the signing of the Compact, Reclamation officials saw that the negotiation of a supplemental contract with Hudspeth, one that included reduced water charges commensurate with expected reductions in the district's water supply, would better reflect the water supply that the district would now receive.[76]

73 "L. R. Fiock, Superintendent, to Mr. N.B. Phillips, Manager, Elephant Butte Irrigation District, and Mr. Roland Harwell, Manager, El Paso County Water Improvement District No. 1," August 19, 1938, Records of the Bureau of Reclamation, R.G. 115, Entry 7, General Administrative and Project Records, 1930-1945, Box 921, 223.02 Rio Grande - Lease of Water Contracts Hudspeth County Consv. + Recl. Dist., U.S. National Archives, Denver.

74 "Superintendent to The Commissioner (Through Chief Engineer, Denver, Colorado)," Memorandum: Hudspeth County Conservation and Reclamation District No. 1 - Contract for water rental charges for 1939 - Rio Grande Project, December 19, 1939, Records of the Bureau of Reclamation, R.G. 115, Entry 7, General Administrative and Project Records, 1930-1945, Box 921, 223.02 Rio Grande - Lease of Water Contracts Hudspeth County Consv. + Recl. Dist., U.S. National Archives, Denver.

75 "John C. Page, Commissioner, to The Secretary of the Interior," February 8, 1940, Records of the Bureau of Reclamation, R.G. 115, Entry 7, General Administrative and Project Records, 1930-1945, Box 921, 223.02 Rio Grande - Lease of Water Contracts Hudspeth County Consv. + Recl. Dist., U.S. National Archives, Denver.

76 "Superintendent to The Commissioner, Washington, D.C.," Memorandum: Application of Refinancing - Hudspeth County Conservation and Reclamation District - Rio Grande Project, December 7, 1940, Records of the Bureau of Reclamation, R.G. 115, 115-54-A-81, Office of the Chief Engineer, Denver, Colorado, General Correspondence Files, 1902-42 (Engineering), Rio Grande, Box No. 1132, 249-T, Rio Grande, Hudspeth County Conservation and Reclamation Districts #1, 1936 thru 1940, 249-T, U.S. National Archives, Denver; "Report on Item for Operation and Maintenance and Purchase of Equipment - Husdpeth District Application for R. F. C. Loan," December 7, 1940, Records of the Bureau of Reclamation, R.G. 115, 115-54-A-81, Office of the Chief Engineer, Denver, Colorado, General Correspondence Files, 1902-42 (Engineering), Rio Grande, Box No. 1132, 249-T, Rio Grande, Hudspeth County Conservation and Reclamation Districts #1, 1936 thru 1940,

With the terms of the Compact settled, Hudspeth's rights to Rio Grande water were clear: they had none. Even so, the district's water delivery – jeopardized by the changes wrought through river rectification, and not protected by any terms of the Compact – was actually improved in the late 1930s and early 1940s thanks to Mexican users' defiance of the 1906 Treaty terms that continued even after rectification was complete. According to Acting Secretary of State Sumner Welles, immediately after the All-American Dam and Canal construction and rectification, Mexican users had – during 1939 alone – promptly constructed 14 diversions downstream of the Acequia Madre, taking an estimated 81,000 acre-feet more than the country's treaty rights.[77] While this in itself did not help Hudspeth, the U.S. response to these continued illegal diversions did.

When it came to illegal Mexican diversions, the United States remained deeply committed to protecting American water users, even those outside of the Rio Grande Project. In September 1940, for example, Reclamation's Chief Engineer S.O. Harper wrote to Superintendent Fiock and noted that recent Reclamation investigations had investigated ways of "eliminating diversions from the Rio Grande by Mexican interests below the All-American Dam and above Fort Quitman."[78] However, Harper also explained that "while the [Reclamation] Commissioner has mentioned the Hudspeth and other territory below the Rio Grande Project [in connection with proposed infrastructure changes], *it is understood that this reference was not intended to be a suggestion of providing a firm water supply to any areas below the Rio Grande Project, but on the contrary to insure that surplus waters which could be made available to these areas would not be taken by Mexican interests to the injury of possible United States users.*"[79] [Emphasis added.] Regarding lands below the Rio Grande Project boundaries, Fiock responded: "these lands below the project are, of course, as viewed by the Bureau and the Project Districts, *not considered as having any primary right in water from the project source of supply, but can be considered as entitled to all of the drainage and return flow and unavoidable project operating waste which may reach the lower end of the project, and thereafter be unavailable for project uses*."[80] [Emphasis added.] He continued in the same letter to state that "as pointed out above, it would appear that the Hudspeth District *is entitled to and can rely upon only the recovery of the drain discharge and operating waste from the lower end of the project for its normal supply*."[81] [Emphasis added.] To emphasize his point, Fiock enumerated the only circumstances under which excess water might flow to Hudspeth: "miscalculation in making reservoir releases to meet project requirements, unanticipated operating waste from upper divisions of the project above El Paso, slacking off of irrigation when rains occur on the project, or flood water originating from tributary arroyos below Caballo Reservoir."[82] Despite these caveats, the United States' commitment to American farmers (versus those in Mexico) led Harper to recommend that Reclamation investigate the excess Mexican water diversion problem in two phases: water supply for Rio Grande Project, and water supply for everything else below the Mexican Canal,

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249-T, U.S. National Archives, Denver.

77 "Sumner Wells, Acting Secretary, to Harold L. Ickes, Secretary of the Interior," July 20, 1940, Records of the Bureau of Reclamation, R.G. 115, Entry 7, Project Correspondence File, 1930-1945, Box 909 rio Grande Pro. 023.6-070.1, 032. Rio Grande - Settlement of Water Rights - Mexico 1940 thru -, U.S. National Archives, Denver.

78 "Chief Engineer to Superintendent, El Paso, Texas," Memorandum: Investigations for elimination of Mexican interference with water supply - Rio Grande Project, September 20, 1940, Records of the Bureau of Reclamation, R.G. 115, Entry 7, Project Correspondence File, 1930-1945, Box 909 rio Grande Pro. 023.6-070.1, 032. Rio Grande - Settlement of Water Rights - Mexico 1940 thru -, U.S. National Archives, Denver.

79 "Chief Engineer to Superintendent, El Paso, Texas."

80 "Superintendent to Chief Engineer, Denver, Colorado," Memorandum: Investigations for elimination of Mexican interference with water supply - Rio Grande Project, October 12, 1940, Records of the Bureau of Reclamation, R.G. 115, Entry 7, Project Correspondence File, 1930-1945, Box 909 rio Grande Pro. 023.6-070.1, 032. Rio Grande - Settlement of Water Rights - Mexico 1940 thru -, U.S. National Archives, Denver.

81 "Superintendent to Chief Engineer, Denver, Colorado."

82 "Superintendent to Chief Engineer, Denver, Colorado."

including Hudspeth.[83]

Harper explored several solutions for the first problem: reduce diversions into the Acequia Madre to compensate for illegal diversions downstream; enlarge the Project's Franklin Canal (located upstream of the Acequia Madre) to take more water; or provide a new feeder from the Franklin Canal to the Riverside heading to prevent return flows from returning to the river bed. Regarding water supply below the Project in Hudspeth County, Harper pointed out the following:

> The Tornillo unit [of the Rio Grande Project] is, first of all, entitled to a water supply suitable for satisfactory production of crops, but it *cannot be said* that the unit is entitled to water of the same quality as is delivered to the upper end of the El Paso Valley. Deliveries of water to this unit must be a compromise between an effort to deliver waters of the El Paso quality and the avoidance of undue waste of project water whether from operating waste or rejection of drain waters....Subject to providing the Tornillo unit with a suitable water supply, without unreasonable waste, every effort should be made to provide the Hudspeth District with the best supply that can be provided to the District out of the project waste and return flow ***net usable*** within the project...it seems advisable that the matter be covered by a separate report devoted solely to the plan for providing the Tornillo Unit with its water supply and general plans and estimates of providing the Hudspeth District with the best water that can be furnished.[84] [Emphasis added.]

By October 1941, Reclamation had instigated several infrastructure changes to assist with the problem of downstream delivery by circumventing return of drainage water to the riverbed and preventing Mexican diversions.

As noted above, earlier changes to the infrastructure had initiated a new era of water supply for Hudspeth in which its delivery quantity decreased by 30% in 1941 from the average supply of the previous five years.[85] However, the district seemed to survive these water supply reductions by making use of Tornillo Drain water at first, and, in 1941, taking advantage of the installation of few new feeder canals designed to divert Fabens drain waters straight to Hudspeth so that the district would not have to rely strictly on Tornillo Drain water, which had much higher dissolved solids.[86] Thus, in the face of changes to the Rio Grande system driven by the conservation of Rio Grande Project water and the reduction of illegal Mexican diversions, Hudspeth ultimately was able to take advantage of the U.S. Bureau of Reclamation's mission to make as much water available to American users as possible, even though it was widely acknowledged that the district itself had no legal right to Project water.[87]

83 It is important to note here that these comments were made two years after the Compact was signed. One would expect that Hudspeth's rights in this situation would have been more certain had the compact framers intended to include a supply of water for Hudspeth.

84 "Chief Engineer to Superintendent, El Paso, Texas," Memorandum: Investigations for elimination of Mexican interference with water supply - Rio Grande Project, November 12, 1940, Records of the Bureau of Reclamation, R.G. 115, Entry 7, Project Correspondence File, 1930-1945, Box 909 rio Grande Pro. 023.6-070.1, 032. Rio Grande - Settlement of Water Rights - Mexico 1940 thru -, U.S. National Archives, Denver.

85 "L. R. Fiock, Superintendent, to Mr. N. B. Phillips, Manager, Elephant Butte Irrigation District, and Mr. Roland Harwell, Manager, El Paso County Water Improvement District No. 1," October 10, 1941, Records of the Bureau of Reclamation, R.G. 115, 115-54-A-81, Office of the Chief Engineer, Denver, Colorado, General Correspondence Files, 1902-42 (Engineering), Rio Grande, Box No. 1132, 249-T, Rio Grande, Hudspeth County Conservation and Reclamation District #1, 1941 and 1942, 249-T, U.S. National Archives, Denver.

86 L. R. Fiock, "Available Irrigation Water Supply for Hudspeth County Conservation and Reclamation District No. 1," May 17, 1941, Records of the Bureau of Reclamation, R.G. 115, 115-54-A-81, Office of the Chief Engineer, Denver, Colorado, General Correspondence Files, 1902-42 (Engineering), Rio Grande, Box No. 1132, 249-T, Rio Grande, Hudspeth County Conservation and Reclamation District #1, 1941 and 1942, 249-T, U.S. National Archives, Denver.

87 "L. R. Fiock, Superintendent, to Mr. M. Phillips, Manager, Elephant Butte Irrigation District, and Mr. Roland Harwell, Manager, El Paso County Water Improvement District No. 1," October 10, 1941, Records of the Bureau of Reclamation, R.G. 115, Entry 7, General Administrative and Project Records, 1930-1945, Box 921, 223.02 Rio Grande - Lease of Water Contracts Hudspeth County Consv. + Recl

With the Compact signed and new infrastructure in place, the Bureau of Reclamation revisited the old issue of a base Hudspeth contract again in late 1943. In these negotiations, Reclamation recognized the instability of the Hudspeth water supply, and Reclamation's continuing efforts to eliminate as much Project waste as possible. "It is not yet believed," wrote Fiock,

> that it can be considered that the type or extent of service furnished to the District from the project can yet be considered as stabilized. Additional facilities are required for the District's salvaging of project waste and drain return flow water...*There is also the matter of the character and extent of service rendered by the project to the District, which cannot always be determined in advance*. *Charges should be somewhat in proportion to the amount and quality of water received by the District, character of service, and area irrigated or in cultivation, all of which can be, and are, variable from year to year.* In years of threatened or actual water shortage the service rendered to the District not only may be, but is, curtailed in greater proportion than the curtailment of service on the project, and depending upon the acuteness of the shortage, *may even result in a very limited service to the District, if any*.[88] [Emphasis added.]

Just a few months later in winter 1944, Fiock again offered his assessment of the Hudspeth supply situation in writing: "Until a thorough study and report can be made on the water supply available for the Hudspeth District, a new contract can be discussed only in a preliminary manner as the provisions of a new contract must naturally be predicated upon the water supply available for the District."[89] In March 1944, key Reclamation employees nevertheless met to discuss a new contract for Hudspeth, and District Counsel Spencer Baird drafted a document based on the consensus that emerged from that meeting. Baird opined that neither the uncertainty of supply nor the change in service should preclude a new Hudspeth agreement, since there had "never been complete satisfaction" with the original draft, and the annual negotiations were "cumbersome."[90] With the draft contract, the Bureau began negotiations with EPCWID and subsequently, the Hudspeth District, over specific contract terms.[91] Parties signed a final contract in 1945, a document that specified – in the event there was any doubt whatever – that "the right to use water hereafter is inferior to that of lands in the Project, and the District also agrees that its right to use any or all waters of the Rio Grande shall be subordinate to the use of such waters by the Project."[92] The contract also specified that the United States could not be held liable for any "insufficiency

District 1942 thru -, U.S. National Archives, Denver.

88 "Superintendent to Commissioner (Through District Counsel and General Supervisor)," Memorandum: Water rental charges to the Hudspeth County Conservation and Reclamation District No. 1 for the season of 1943 - Rio Grande Project, October 23, 1943, Records of the Bureau of Reclamation, R.G. 115, Entry 7, General Administrative and Project Records, 1930-1945, Box 921, 223.02 Rio Grande - Lease of Water Contracts Hudspeth County Consv. + Recl District 1942 thru -, U.S. National Archives, Denver.

89 "Superintendent to District Counsel," Memorandum: New permanent contract with Hudspeth County Conservation and Reclamation District to supersede the contract of December 1, 1924 - Rio Grande Project, January 25, 1944, Records of the Bureau of Reclamation, R.G. 115, Entry 7, General Administrative and Project Records, 1930-1945, Box 921, 223.02 Rio Grande - Lease of Water Contracts Hudspeth County Consv. + Recl District 1942 thru -, U.S. National Archives, Denver.

90 "District Counsel to Commissioner (Through Director of Operation and Maintenance)," Memorandum: Water rental charges to the Hudspeth County Conservation and Reclamation District No. 1 for the season of 1943 - Rio Grande Project, November 17, 1943, Records of the Bureau of Reclamation, R.G. 115, Entry 7, General Administrative and Project Records, 1930-1945, Box 921, 223.02 Rio Grande - Lease of Water Contracts Hudspeth County Consv. + Recl District 1942 thru -, U.S. National Archives, Denver.

91 "District Counsel to Commissioner," Memorandum: New permanent contract with Hudspeth County Conservation and Reclamation District to supersede the contract of December 1, 1924 - Rio Grande Project, March 27, 1944, Records of the Bureau of Reclamation, R.G. 115, Entry 7, General Administrative and Project Records, 1930-1945, Box 921, 223.02 Rio Grande - Lease of Water Contracts Hudspeth County Consv. + Recl District 1942 thru -, U.S. National Archives, Denver.

92 "Contract for the Rental of Water to Hudspeth Irrigation District - D.C. Draft," March 25, 1944, 1, NM OSE Library.

of water" to Hudspeth lands.[93] In other words, Hudspeth's subservient status was reiterated in this permanent contract.

Drought: The Role of Groundwater for Irrigation

As referenced above, the Upper Rio Grande Basin and the entire Southwest region was hit by a serious drought that began in 1946, accelerated in the winter of 1946-1947, and lasted well into the 1950s. Water users soon recognized the severity of the situation and wondered how they would obtain enough water for their crops. While the Compact had anticipated years of water shortage, the document did not have any insights into how groundwater could be used in such severe situations. Without any official guidance on how to supplement Rio Grande water supplies when supplies throughout the entire upper basin ran low, the districts sought new investigations. The 1935-36 (and ongoing) El Paso groundwater study offered inspiration.

In 1946, EBID followed the City of El Paso's lead and requested that the USGS study the groundwater supply in the Rincon and Mesilla Valleys.[94] Anticipation of continued drought was the driving force behind the study, demonstrated by storage levels as low as 317,000 acre-feet in Elephant Butte in August 1947. With another month of irrigation remaining in the season, water users' concerns about supplies for the following season were heightened, and they hoped that groundwater might supplement their surface supplies. To answer the district's questions, the USGS's Clyde Conover conducted a series of investigations in EBID between 1946 and 1947.[95]

Following a year of study, Conover issued a preliminary memorandum at the conclusion of studies. In it, he remarked that the primary objective of his research was to investigate groundwater, "mainly from the standpoint of productiveness of wells and the effect of pumping upon the surface-water supply in the rivers and drains."[96] Conover had examined "the quantities involved in the present irrigation with surface water exclusively" in order to fully understand the effects of groundwater pumping in the Mesilla and Rincon Valleys.[97] In his findings, Conover made several important points that affected future water use in the region. First, he recognized that more water was applied to crops than they consumed and asserted that the amount of water applied to the land in past years was "doubtless more than actually necessary, even though irrigation of crops requires an excess of water applied."[98] Second, Conover described the connections between surface and groundwater, noting that any surface water released from Caballo Dam that was not lost by transportation or evaporation, seeped underground "from the canals and irrigated lands to return to the river as drain flow."[99] The over-irrigation of Project lands and the relationship between surface and groundwater in irrigation systems that Conover elucidated would play important roles in future water negotiations.

As far as groundwater use was concerned, Conover remarked that of the many operational wells that had existed in the Mesilla Valley in the early 1900s, "very few" of these remained in operation.[100] Most of them had been

93 "Contract for the Rental of Water to Hudspeth Irrigation District - D.C. Draft," 4. This contract was dated March 25, 1944, but correspondence from the Reclamation's General Counsel in March 1945 suggests that this draft was the final; see "Regional Counsel, Region 5, to Superintendent, El Paso," March 3, 1945, NM OSE Library.

94 Clyde S. Conover, "Preliminary Memorandum on Ground-Water Supplies for Elephant Butte Irrigation District" (United States Geological Survey, September 1947), Counsel; Clyde S. Conover, "Chas V. Theis, District Geologist, to Mr. John L. Gregg, Manager, Elephant Butte Irrigation District" (United States Geological Survey, October 23, 1947), Counsel.

95 Conover, "Preliminary Memorandum on Ground-Water Supplies for Elephant Butte Irrigation District," 1.

96 Conover, 1.

97 Conover, 3.

98 Conover, 6.

99 Conover, 8.

100 Conover, 9.

abandoned "after a water supply was assured by Elephant Butte Dam."[101] However, Conover reported that in recent months, "a few irrigation wells" had been drilled due to the "contemplated shortages of water in 1948," although none of them had pumps installed at the time he wrote this memo.[102] Whether or not these wells – when engaged – would have a long-term effect on surface supplies, Conover concluded pumping would lower the water table, "at first in the vicinity of the well," but as time went on, "at greater and greater distances from the well," explaining that "all water pumped from wells" was "balanced by a loss of water from somewhere else in the ground-water system, either from the amount stored underground, from the amount seeping out of the aquifer, or, less commonly in arid countries, from the amount of surface water that the system is unable to absorb (rejects) because the aquifer is overfull under non-pumping conditions."[103] In other words, Conover concluded that pumping groundwater would only provide a small amount of net additional water to the Project as a whole, with water being diverted "to the pumps that would otherwise be available as surface supply lower down the valley."[104]

Despite these conclusions, however, Conover seemed to advocate for pumping as a short-term solution to the drought issue, a conclusion with which Reclamation agreed. Conover recognized that pumping would have the effect of drying out the drains of return flow, but also found that less waste (through transportation and evaporation) would be realized by pumping than through surface deliveries, at least a 10% savings, which was not insignificant during drought years.[105] In fact, Conover also concluded that *in years where surface water levels were only at 50% of the average supply*, he believed it would "*be necessary to pump some ground water*."[106] [Emphasis added.] Assuming that EPCWID also engaged in pumping for irrigation, he explained, such an effort would "save some of the water which would otherwise drain from the land, thus saving more water for the Project."[107] Conover recognized that the "pumping of wells would diminish the drain flow," which would "necessitate a corresponding decrease in the allowable diversions for the Elephant Butte Irrigation District"[108] but this did not dissuade him from his recommendation that pumping serve as a short-term drought solution.

In September 1947, Conover's USGS colleague Charles V. Theis sent a copy of Conover's preliminary findings to A.N. Sayre, the geologist in charge of the USGS groundwater division in Washington, D.C. This was the same man who had studied the City of El Paso's municipal groundwater use in the 1930s and early 1940s. Theis explained to Sayre that it was immediately necessary to release Conover's preliminary findings so that New Mexico's state engineer and EBID could "establish a policy" with regard to pumping, before "the situation gets out of hand."[109] With Sayre's approval, the USGS complied and sent the preliminary findings to the Project with a cautionary note explaining that detailed findings might differ in later reports. New Mexico State Engineer John Bliss also received a copy of the findings in October 1947.[110]

Despite the USGS's cautionary note, the Bureau of Reclamation took on the burden of working with Project

101 Conover, 9.
102 Conover, 9.
103 Conover, 12–13.
104 Conover, 13.
105 Conover, 16.
106 Conover, 7.
107 Conover, 15.
108 Conover, 16.
109 "Chas. V. Theis, District Geologist, to Mr. A. N. Sayre, Geologist in Charge, Division of Groundwater," September 10, 1947, R.G. 57, Records of the Geological Survey, Entry 575, Ground Water Branch, Administrative Correspondence, 1944-1954, Box 33, New Mexico, Albuquerque 1947, U.S. National Archives, II.
110 "Chas. V. Theis, District Geologist, to Mr. John H. Bliss, State Engineer of New Mexico," October 23, 1947, R.G. 57, Records of the Geological Survey, Entry 575, Ground Water Branch, Administrative Correspondence, 1944-1954, Box 33, New Mexico, Albuquerque 1947, U.S. National Archives, II.

farmers during times of shortage, encouraging them to be thrifty in their surface water applications but also to pump as a way to supplement limited surface supplies. During the 1947 irrigation season, Reclamation provided a packet for Project land owners, farmers, and irrigation districts called "Conservation in the Use of Irrigation Water: Principles and Practices to be Observed and Followed in the Control, Distribution, and Use of the Irrigation Water Supply for its Conservation and Maximum Production Results." One section of this packet, "Explanation of Principles for Conservation in the Use of Irrigation Water," explained to farmers the connection between irrigation, groundwater, and drainage, and warned farmers not to over irrigate, as "a limited portion of the water applied to the land must percolate on through the soil and by eventually making its way to the drains, provides the circulation needed to prevent the accumulation of alkali salts on the surface." The packet continued, "if excess water reaches the ground water table faster than it can escape to the drains, the water table rises resulting in seepage and alkali surface conditions."[111] Three years later, as the drought continued and conservation proved inadequate for its severity, Reclamation reported that if drought conditions continued, "pumping appears to be the most feasible for a short time" as a remedy.[112]

As the drought continued and Reclamation reduced annual per-acre water allotments from storage water, Reclamation tracked well data and encouraged farmers to continue the practice of supplemental pumping. Between 1951 and 1955, dwindling storage supplies in Elephant Butte led Reclamation to declare annual allotments ranging from just a few inches per acre to 2.5 acre-feet per acre so that all Project lands would receive an equal amount, but well below the 3.1 acre-feet needed by farmers for a successful crop. In 1951, the Rio Grande Project Manager told water users who were able to supply their water needs via pumping to arrange transfer of part of their unused allotment to those who needed more water.[113] Many of these users clearly took his advice to heart. The following year, in 1952, Reclamation reported that "1952 proved to be an excellent crop year for irrigation farmers" on the Ysleta branch (in EPCWID), because although storage was at a mere 10% of normal at the season's beginning, farmers had installed 220 wells during the 1950 and 1951 seasons, "which provided the necessary early water."[114] In 1955, the most severe season to date, the Project operated on a fluctuating allotment basis of five inches, but farmers supplemented their supply with 1650 wells, and the Bureau encouraged them to continue doing so.[115] Pumping was a way that the Bureau urged the farmers with wells to "help their neighbors" who were unable to dig wells.[116] By this time, with the drought extending to years, Conover's connections between ground and surface water and his encouragement to limit the amount of pumping seemed long forgotten and there was nothing to limit the use of the water of the Rio Grande that lay beneath the surface. But the appointment of Steve Reynolds to State Engineer in 1955 – a post he would hold for more than 30 years – altered the groundwater system in New Mexico with his focus on groundwater basin declarations and regulations.

111 "Conservation in the Use of Irrigation Water: Principles and Practices to be Observed and Followed in the Control, Distribution, and Use of the Irrigation Water Supply for its Conservation and Maximum Production Results" in U.S. Bureau of Reclamation, "Project History: Rio Grande Project, Calendar Year 1947," n.d., 78, NM OSE Library.

112 U.S. Bureau of Reclamation, "Project History: Rio Grande Project, Calendar Year 1950," n.d., 44, NM OSE Library.

113 L.R. Fiock, Project Manager, "Water Announcement: August 1, 1951" in U.S. Bureau of Reclamation, "Project History: Rio Grande Project, Calendar Year 1951," n.d., 100, NM OSE Library.

114 U.S. Bureau of Reclamation, "Project History: Rio Grande Project, Calendar Year 1952," n.d., 56, NM OSE Library.

115 U.S. Bureau of Reclamation, "Project History: Rio Grande Project, Calendar Year 1955," n.d., 6, NM OSE Library.

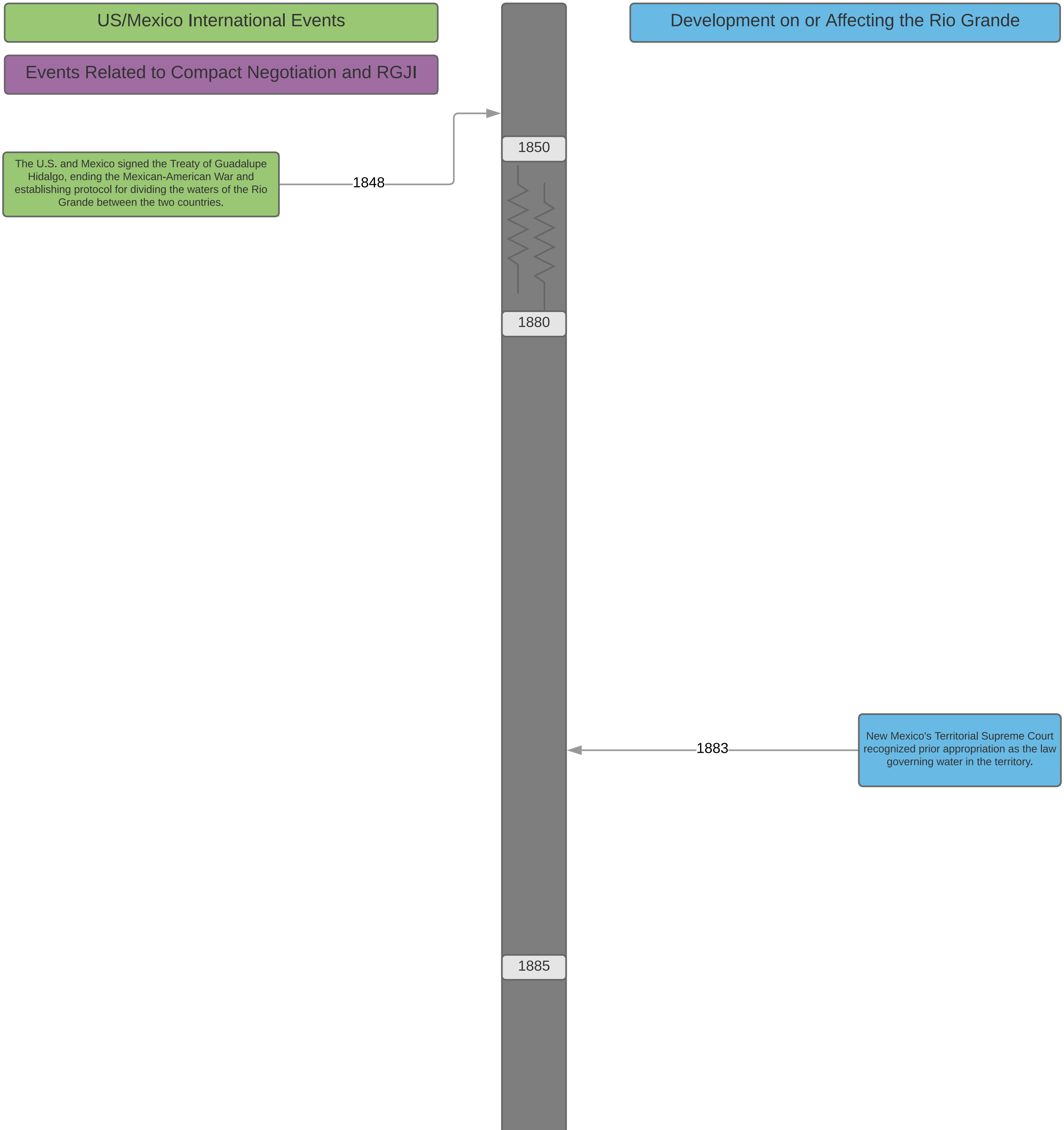
116 W. F. Resch, Project Manager, "Water Announcement: June 21, 1954) in U.S. Bureau of Reclamation, "Project History: Rio Grande Project, Calendar Year 1954," n.d., no page visible, NM OSE Library.

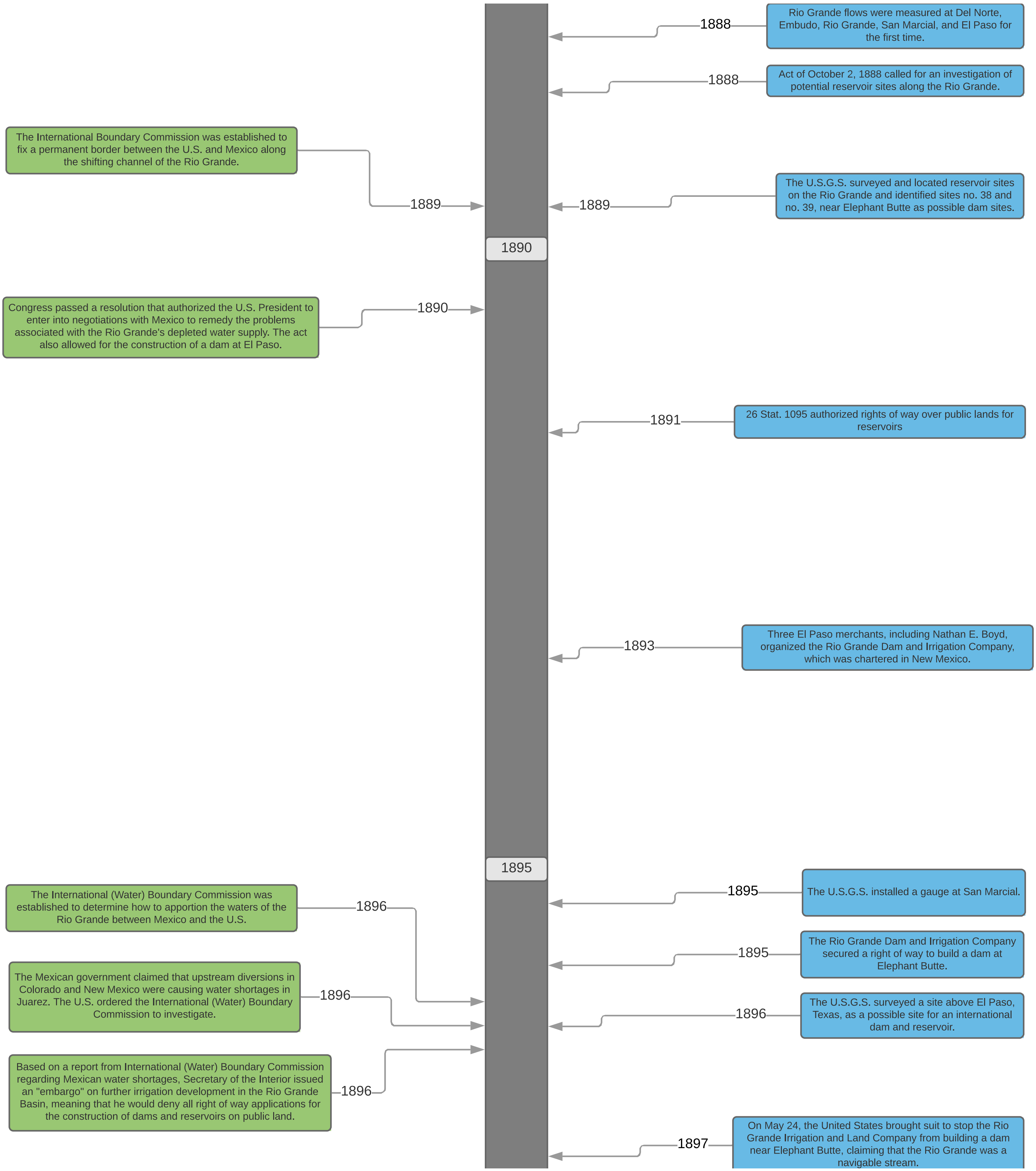
Conclusion

The Upper Rio Grande Basin continued to be a dynamic place from the late 1930s through the 1950s, as the United States made changes to the river itself while also gaining greater understandings of groundwater supplies. Changes to the infrastructure of the Project continued to alter exactly how Reclamation delivered water to the lands within the Project boundaries as well as outside of those boundaries, as did changes to the river that emerged from international diplomacy. As a means of contending with some of that uncertainty, the Project districts signed a contract in February 1938 which provided for a proportionate allocation of water to persist whether in times of drought, fluctuating volumes of irrigated acreage, or changes to the physical river system.

Furthermore, these decades represented a growing understanding of the role groundwater played in the supplies of the basin. The lateness of the groundwater studies in the region below Elephant Butte Dam (in relation to the onset of permanent Compact negotiations) combined with the absence in the historical record of any objection to these studies by water users make it abundantly clear that the Reclamation Service's Rio Grande Project water filings with the New Mexico Territorial Engineer in 1906 and 1908 had not included nor intended to include the basin's groundwater. The scientific understanding of connections between groundwater and surface water was too nascent in the first decade of the 20th century for Reclamation to have intended such an overreach, and the historical record provides no support for such a conclusion. It is also clear that no contemporary actors believed that Reclamation controlled the groundwater. Studies conducted in the 1930s were aimed at a better understanding of the resource's origin in different parts of the basin, its potential use, and possible connections between ground and surface water; these studies would have been unnecessary if water users believed that the Bureau of Reclamation had previously claimed it all. Furthermore, the absence in the historical record of any water users objecting to these studies or to actual groundwater pumping between the 1930s and the 1950s suggests that no one contemporarily believed that the Project owned a prior right to these supplies, nor that Texas's Compact Commissioner would have intended to preclude such resource development in the 1938 Compact. Finally, the Bureau of Reclamation's support and encouragement of Mesilla Valley farmers who turned to pumping as an *additional* supply in response to dwindling surface supplies in the late 1940s and into the 1950s, further emphasizes the Project's lack of a pre-existing groundwater claim. Rio Grande Project histories show that the U.S. Bureau of Reclamation viewed groundwater supplies as an excellent and necessary supplement during times of drought, viewing the lag time between the depletion from underground basins and the consequential effect on surface supplies as a window during which they expected and hoped precipitation and supplies would return to normal, with groundwater recharge taking place before significant surface drafts were realized. Therefore, the federal government encouraged such pumping and the redirection of surface supplies to farmers without access to wells. The pumping by the City of El Paso and the encouragement of groundwater use during the 1940s-1950s drought, in addition to the studies these trends engendered helped boost understanding of the hydrological connections between artesian basins and surface flows, *after* which time groundwater use became an issue which caused controversy at times.

Appendix A: Rio Grande Timeline



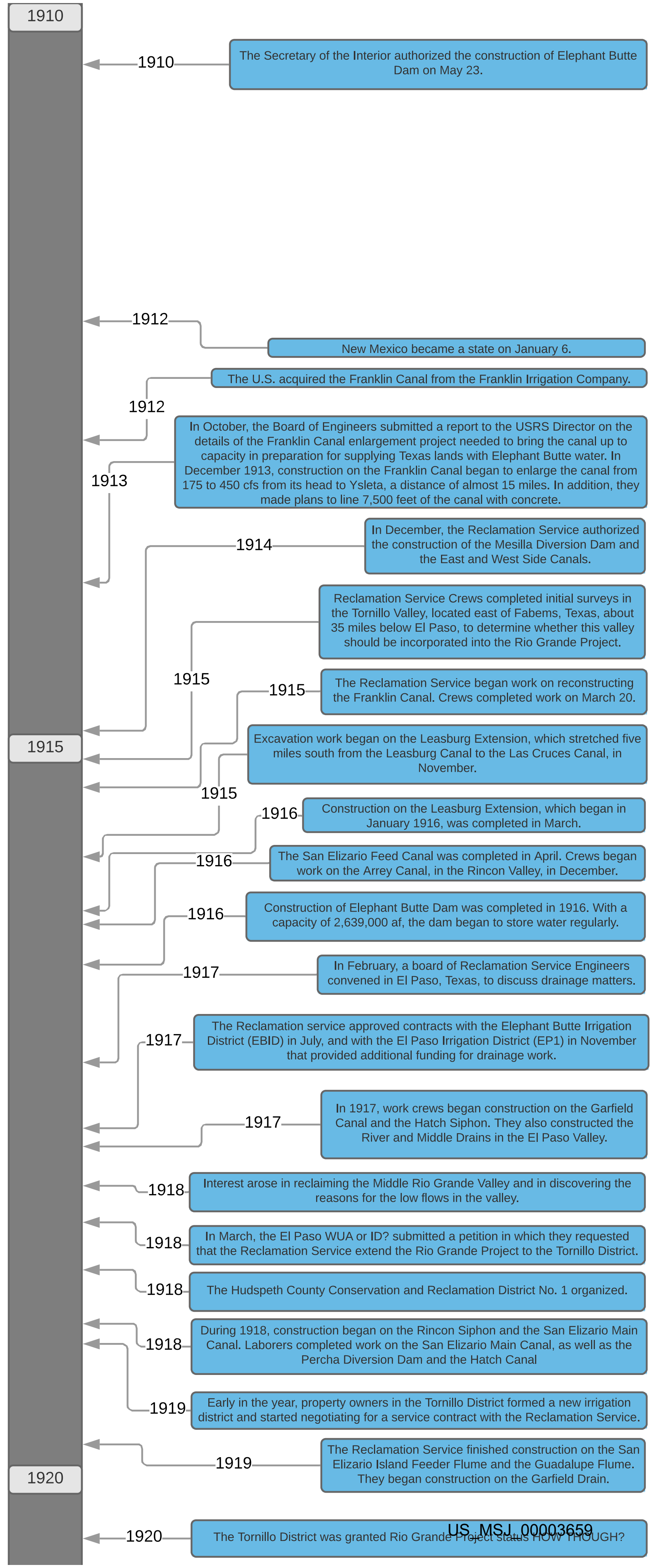

1888 Rio Grande flows were measured at Del Norte, Embudo, Rio Grande, San Marcial, and El Paso for the first time.
1888 Act of October 2, 1888 called for an investigation of potential reservoir sites along the Rio Grande.
1889 The International Boundary Commission was established to fix a permanent border between the U.S. and Mexico along the shifting channel of the Rio Grande.
1889 The U.S.G.S. surveyed and located reservoir sites on the Rio Grande and identified sites no. 38 and no. 39, near Elephant Butte as possible dam sites.
1890
1890 Congress passed a resolution that authorized the U.S. President to enter into negotiations with Mexico to remedy the problems associated with the Rio Grande's depleted water supply. The act also allowed for the construction of a dam at El Paso.
1891 26 Stat. 1095 authorized rights of way over public lands for reservoirs
1893 Three El Paso merchants, including Nathan E. Boyd, organized the Rio Grande Dam and Irrigation Company, which was chartered in New Mexico.
1895
1895 The U.S.G.S. installed a gauge at San Marcial.
1895 The Rio Grande Dam and Irrigation Company secured a right of way to build a dam at Elephant Butte.
1896 The International (Water) Boundary Commission was established to determine how to apportion the waters of the Rio Grande between Mexico and the U.S.
1896 The Mexican government claimed that upstream diversions in Colorado and New Mexico were causing water shortages in Juarez. The U.S. ordered the International (Water) Boundary Commission to investigate.
1896 The U.S.G.S. surveyed a site above El Paso, Texas, as a possible site for an international dam and reservoir.
1896 Based on a report from International (Water) Boundary Commission regarding Mexican water shortages, Secretary of the Interior issued an "embargo" on further irrigation development in the Rio Grande Basin, meaning that he would deny all right of way applications for the construction of dams and reservoirs on public land.
1897 On May 24, the United States brought suit to stop the Rio Grande Irrigation and Land Company from building a dam near Elephant Butte, claiming that the Rio Grande was a navigable stream.

1900

- **1900** — The American Section of the International (Water) Boundary Commission took over operation of the San Marcial gauge on January 1.
- **1902** — From 1892 to 1902, there was a dry period on the Rio Grande, and the river flowed at a third of its usual discharge, with the extreme low flow occurring in 1902.
- **1902** — On June 17, the U.S. Congress passed the Newlands Act (or the Reclamation Act), which sanctioned the federal government's construction of irrigation works and established the U.S. Reclamation Service.
- **1903** — The Reclamation Service began early reconnaissance and preliminary surveys for the Rio Grande Project. They paid close attention to possible dam sites no. 38 and no. 39 identified by the U.S.G.S. in 1889.
- **1904** — The National Irrigation Congress met in January to determine water apportionment of the Rio Grande. They agreed on the Rio Grande Project which included plans for federal construction of dam and reservoir at Elephant Butte. Following the conference, The El Paso Chamber of Commerce established the El Paso Valley Water Users' Association in January, and New Mexican water users met in Las Cruces to create the Elephant Butte Water Users' Association in December. The names of these organizations later changed from Water Users Associations to Irrigation Districts in accordance with state laws.

1905

- **1905** — The U.S. and Mexico signed the Banco Treaty, allowing for the exchange of land no greater than 617 acres when parcels (bancos) ended up on the opposite side of the int'l boundary when the river changed course.
- **1905** — Congress extended the Reclamation Act to the U.S. side of the El Paso Valley on February 25.
- **1905** — In March, New Mexico Territory created the office of Territorial Irrigation Engineer, responsible for overseeing, managing, and administering all water and irrigation related concerns with the territory.
- **1906** — In January, the U.S. Reclamation Service notified the New Mexican Territorial Irrigation Engineer that they intended to store all unappropriated waters of the Rio Grande, 730,000 af per year, in the proposed Elephant Butte Reservoir.
- **1906** — The U.S. and Mexico signed a treaty in which the U.S. agreed to deliver 60,000 af of water to Mexico annually in perpetuity at the head of the Mexican Canal near El Paso. In return Mexico agreed to waive all claims for damages. Congress ratified the treaty on June 26, 1906 and President Theodore Roosevelt approved it on January 16, 1907.
- **1906** — On June 12, 1906 Congress extended the Reclamation Act to include the state of Texas.
- **1906** — On September 27, the Dept. of the Interior issued an order that revoked all prior orders affecting the embargo on the Upper Rio Grande due to the settlement between the U.S. and Mexico in the Treaty of May 21, 1906. The order also mandated that applications involving waters of the Rio Grande in Colorado and New Mexico be directed to the USGS to ensure they would not interfere with reclamation projects or treaty obligations.
- **1907** — On March 4, Congress authorized construction of Elephant Butte Dam, thus creating Eagle Reservoir, and appropriated $1,000,000 for the cost of construction. The dam was to aid in delivering 60,000 acre-feet water to Mexico so the U.S. could fulfill the May 21, 1906 treaty.
- **1907** — In 1907, New Mexico's territorial water code created the Office of Territorial (later State) Engineer, tasked with "administering all matters relating to appropriation, transfer, and distribution of water."
- **1907** — New Mexico Territorial Engineer Frederick Newell issued an embargo preventing right-of-way for the storage of more than 1,000 acre-feet per year above Elephant Butte until there were enough data to understand the effect of upstream development on the Rio Grande project.
- **1908** — The Reclamation Service began surveying for a diversion dam at El Paso.
- **1908** — Authorized in 1905, workers finished construction on the Leasburg unit of the Rio Grande Project, which would irrigate 25,000 acres in the Mesilla Valley, New Mexico.
- **1909** — Litigation in U.S. v. Rio Grande Dam and Irrigation Company ended with the court ruling in favor of the U.S., paving the way for the federal construction of Elephant Butte Dam.



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1922 — In Februuary, soil experts from the Department of Agriculture studied and reported on the amount of alkali salts in the soil and the effect of drains in the El Paso Valley.

1923 — The Middle Rio Grande Conservancy District (MRGCD) organized.

1923 — In March, Colorado and New Mexico authorized the formation of an Interstate Compact Commission. The states appointed commissioners to study the water supply of the Rio Grande and to draft an interstate compact to address water shortages. New Mexico's first commissioner was J. C. Seth of Santa Fe, and Colorado's first commissioner was Delph E. Carpenter of Greeley.

1923 — In August, the directors of the Hudspeth County Conservation and Reclamation District No. 1 (Hudspeth) requested that the Secretary of the Interior allow them to consollidate with EP1 and operate as a single entity within the Rio Grande Project. This was denied.

1924 — At the first Interstate Compact Commission meeting, representatives of the Texas governor urged the committee to wait to conduct their meeting until 1925, when the Texas legislature could appoint a representative to the commission.

1924 — In December, the Bureau of Reclamation (BOR) and Hudspeth entered into a temporary Warren Act agreement in which the U.S. would supply seepage, waste, and return flow water to the district for the upcoming irrigation season on a rental basis. This water was to be delivered to the end of the Tornillo Main Canal.

1925

1925 — On February 5, the Secretary of the Interior modified an order of withdrawl made in 1896, and confirmed the Vega Sylvestre reservoir site as provided for under the right of way act of 1891.In May, he lifted the embargo against development of the Rio Grande in Colorado, opening the possibility of building additional reservoirs in the state.

1925 — The Texas legislature authorized the appointment of an Interstate Compact Commissioner. The first person to take on that role was T. H. McGregor of Austin.

1925 — The MRGCD was confirmed as legal and constitutional by the New Mexico Supreme Court in a decision handed down on December 12.

1926 — An omnibus bill passed in March authorized EP1 to enter into contract with the BOR covering the investigation and construction of a canal to protect their water supply from encroachment by Mexican diversions.

1926 — During the 1926 irrigation season, the Rio Grande Project watered approximately 80,000 acres in New Mexico, 60,000 acres in Texas, and 25,000 acres in Mexico.

1928 — In April, though 67,000 acres had been planned for, only 58,700 acres were irrigated in the EP1. Despite expansion in 1928, there would still be 4,000 extra acres, and the City of El Paso wanted to purchase the associated water.

1928 — The U.S.G.S. took over operation of the San Marcial gauge on August 8.

1928 — This year, the total irrigated area of the Rio Grande Project was 163,324 acres. of that, 139,598 acres were cropped, and of that cropped area more than 75% was planted with cotton.

1929 — On February 12, Commissioners agreed on a temporary Rio Grande Compact to maintain the status quo in the use of the waters of the Rio Grande and to provide for the accumulation and preservation of data regarding its use. It also acted as a set of guidelines for commissioners in drafting a new compact later on. It was set to expire on June 1, 1935.

1929 — On February 28, Richard F. Burges suggested that the definition of the Rio Grande "above Fort Quitman" be included in the compact because that section of the river was treated as a distinct entity in the 1906 U.S. Treaty with Mexico.

1930

1930 — Burges advised Colorado, New Mexico, and Texas to find an engineer to take charge of "obtaining, collecting, and correlating all data which would be useful both in administering the present compact and in preparing for the new one."

1931 — In 1931, New Mexico began regulating groundwater for the first time. The OSE amended the water code to include groundwater basins and declared them public property "subject to appropriation for beneficial use."

1931 — As a result of altering the Texas-New Mexico state line, 1,000 acres were transferred from EP1 to EBID.

1931 — In August, the International Water Commission took over maintenance and operation of the gaging stations at San Marcial, Courchesne, Tornillo Bridge, and Fort Quitman from the U.S.G.S.

1935

1940

- **1932** — At the start of the year, the U.S. and Mexico signed a treaty to adress the shifting channel of the Rio Grande through the rectification of the channel between El Paso and Juarez, as well as at the head of Box Canyon below Fort Quitman. The convention also allowed for the construction of Caballo Dam about 22 miles below Elephant Butte Dam.
- **1934** — The Rio Grande Compact Committee reaffirmed that the purpose of the 1929 Compact was to maintain the status quo in the use of water of the Rio Grande, and to provide for the accumulation and preservation of data regarding Rio Grande water use.
- **1935** — On February 16, the Gio Grande Compact commissioners signed a bill to extend the life of the 1929 compact for two more years, until June 1, 1937.
- **1935** — On October 28, Texas filed a bill of equity against New Mexico and the MRGCD claiming that New MExico had violated the Compact of 1929 by creating diversions above Elephant Butte that caused an increase in water salinity, which Texas claimed violated its water rights under the doctrine of prior appropriation.
- **1935** — In December, the National Resources Committee hosted a conference with Colorado, New Mexico, and Texas to determine if a cooperative approach to gethering information would result in a solution to the interstate water problems on the Rio Grande. The Commission agreed to let the NRC facilitate the RGJI, and the three states contributed to funding, although the majority of funds came from the federal government (U.S.G.S., BOR, and Bureau of Ag Engineering.)
- **1937** — In March, Engineers from Texas and New Mexico signed a stipulation to continue study on the Middle Rio Grande as well as the area between El Paso and Hudspeth, per request from the Special Master.
- **1937** — RGJI funding expired; studies concludeed.
- **1937** — The Rio Grande Compact Commissioners met on September 27 to consider the Rio Grande Joint Investigation report, confer with National Resources Committee consultants, and formulate a permanent compact.
- **1937** — The Engineer Advisors Committee met in Santa Fe on November 22 for three days to discuss Rio Grande Compact terms.
- **1937** — The final report from the Rio Grande Joint Investigation was submitted to the president. The report provided all interested parties with all essential data as to the sources and quantities of water and information on the development and use of said water.
- **1937** — The committee of the engineering advisers to the Rio Grande Compact Commission submitted a report from their December 1937 meetings. The report covered delivery schedules & related features for the Committee's consideration.
- **1938** — During the month of January 1938, commissioners discuss the Engineer Advisors' Committee Report. They determine that the Engineers should meet again in March to refine some of the numbers and formulas.
- **1938** — On March 15, the Engineer Advisor Committee met to finalize the report on which the new Rio Grande Compact would be based. On March 18, commissioners from Colorado, New Mexico, and Texas signed the 1938 Rio Grande Compact.
- **1938** — The Rio Grande rectification was completed in July.
- **1938** — Frank B. Clayton, Rio Grande Compact Commissioner for Texas, visited the Lower Rio Grande Valley in October to attempt to stem their objections to the compact.
- **1939** — The 1938 Compact became effective May 31. The parties involved dropped the Texas v. New Mexico lawsuit after the ratification of the compact.
- **1940** — 1940 was the first accounting year under the Rio Grande Compact of 1938. During this year N.M. accured a debit of 58,900 acre-feet.
- **1941** — Early in the year, the BOR began an investigation into the possibility of building canals to divert the waste and drain waters of the project directly into the Hudspeth County district for the purpose of preventing Mexican interference with the water supply. The investigation was short-lived as more pressing work arose and project personnel declined.

- **1934** — In October, the Texas Board of Water Engineers and the U.S.G.S. signed an agreement to jointly study the groundwater resources of Texas in 1935.
- **1935** — Begun the previous year, El Vado Reservoir on the Rio Chama, a tributary of the Rio Grande, was completed in 1935.
- **1937** — During A. N. Sayre and Penn Livingstion's visit to El Paso in February, it was decided that the city, through the Texas State Board of Engineers, would participate in an agreement with the U.S.G.S. for an investigation of its groundwater resources.
- **1937** — On July 1, 1937 the USGS and the Texas Board of Water Engineers entered into an agreement for an investigation of the groundwater resources of the State of Texas to run from July 1, 1937 to August 31, 1938. The two entities split the cost evenly.
- **1938** — Begun in 1937, the American Canal in the El Paso Valley was completed ia year later n 1938.
- **1939** — In a July 1939 memorandum...HUDSPETH INFO??? SEE REPORT.
- **1940** — The USGS and the City of El Paso signed a cooperative agreement providing for the continuation of the groundwater investigation in El Paso from July 1, 1940 through June 30, 1941.
- **1940** — In August, Hudspeth applied and was approved for a refinancing and rehabilitation loan so that it could refinance its outstanding indebtedness and pursue much needed rehabilitation works in the district.

1945

1950

1943 — 1943 was the first year that New Mexico failed to meet its water deliveries as stipulated by the 1938 Rio Grande Compact.

1944 — During the 1944 calendar year the BOR worked with the Hudspeth District to draft a contract providing a "permanent water rental basis."

1945 — Correspondence from July 1945 revealed that the all three of the Rio Grande Commissioners (McClure, Hinderlider, and Quaid) as well as U.S. representative Johnson consented to reviewing New Mexico's delivery schedules into San Marcial.

1946 — Berkeley Johnson explained that the Santa Fe District of the U.S.G.S. was to take over operation of the San Marcial gage following the ratification of a new treaty with Mexico.Transfer of operation of the San Marcial gage from the International Boundary Commission to the U.S.G.S. was suspended until Congress made the necessary funds available, which was presumably not going to be until July 1946.

1946 — Extreme drought conditions occurred in the southwest.

1946 — The U.S.G.S. in cooperation with the EBID began conducting a study of the groundwater supply in the Mesilla and Rincon Valleys

1947 — In the spring, a small storage reservoir was built for use by Hudspeth, which necessitated the relocation of the gaguing stations at the end of the Tornillo Canal and at the head of the Hudspeth Canal. A new canal, Hudspeth Feeder No. 1, was constructed to capture project waste water below Fabens and transport it directly to the reservoir without allowing it to reach the river.

1947 — The EBID was “exceedingly anxious” to take action regarding groundwater pumping and hoped to have Conover's groundwater memo released prior the next meeting's date in early October.

1948 — The Rio Grande Compact Commission met at El Paso on February 22 and discussed changing the gaging stations and measurements for the Rio Grande. New Mexico's deliver schedule was changed from a 9-month index to a 12-month index, and became known as the "Elephant Butte Effective Index Supply."

1948 — Congress authorized the Middle Rio Grande Project and gave permission to the Bureau of Rec. and the Corps of Engineers to rectify the Rio Grande channel, rehabilitate works of the MRGCD, construct levees, and other dam and reservoir projects.

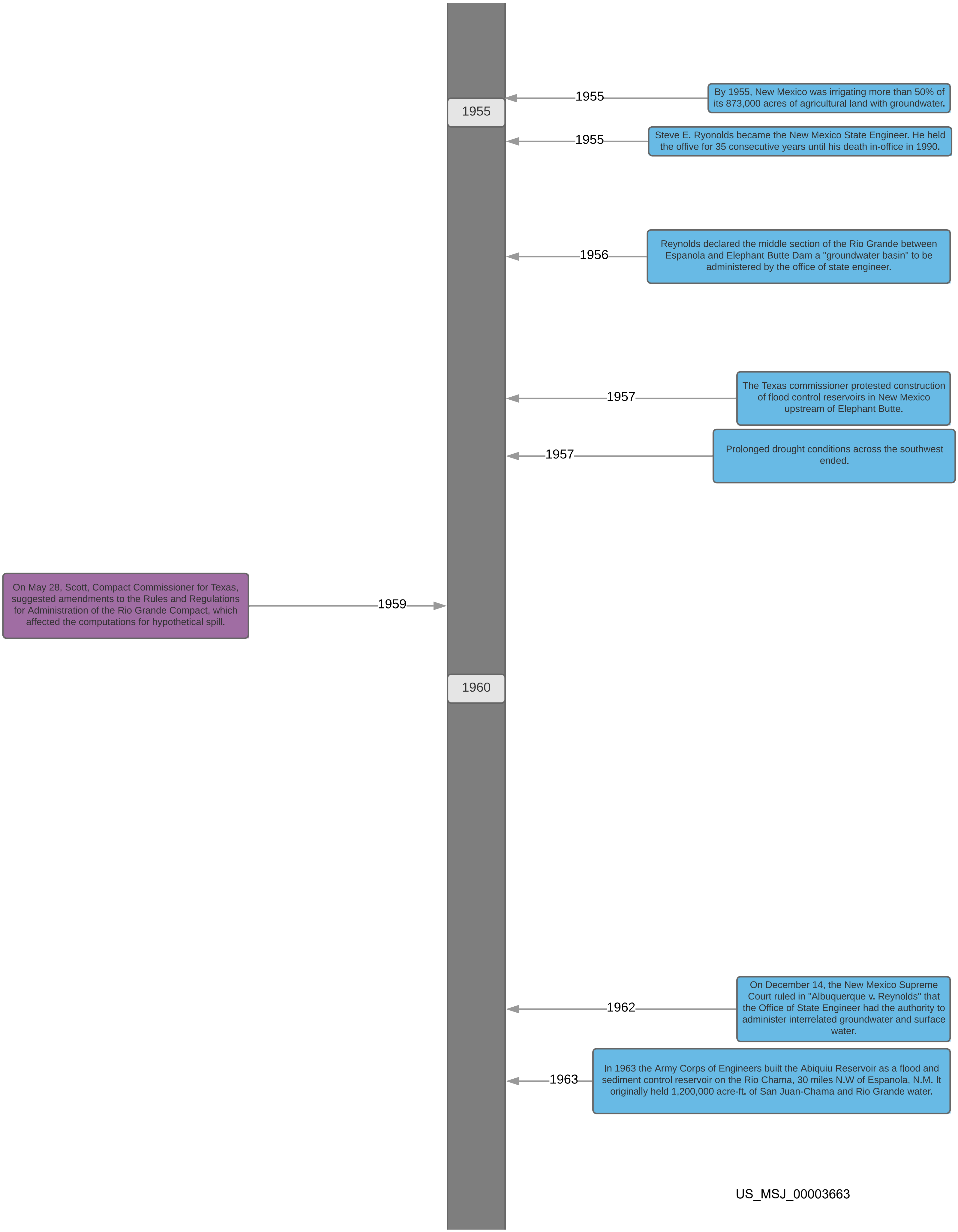
1950 — Prolonged drought conditions began in the southwest.

1950 — On December 28, Raymond Hill wrote to the El Paso County Water Improvement District No. 1 and acceded that the release of debit water from El Vado Reservoir was not adverse to the interests of Rio Grande Project water users.

1951 — MRGCD Engineer Hubert Ball foresaw completing the MRG project as the only means of remedying the drought situation. This project would drain the San Marcial swamps and end “wastage of 70,000-100,000 acre feet of water” each year.

1951 — In October, Texas filed a complaint against New Mexico in the U.S, Supreme Court, claiming that New Mexico violated the Rio Grande Compact of 1938 and asking that New Mexico be prevented from diverting waters above San Marcial.

1953 — MAYBE: THEIS GROUNDWATER STUDY



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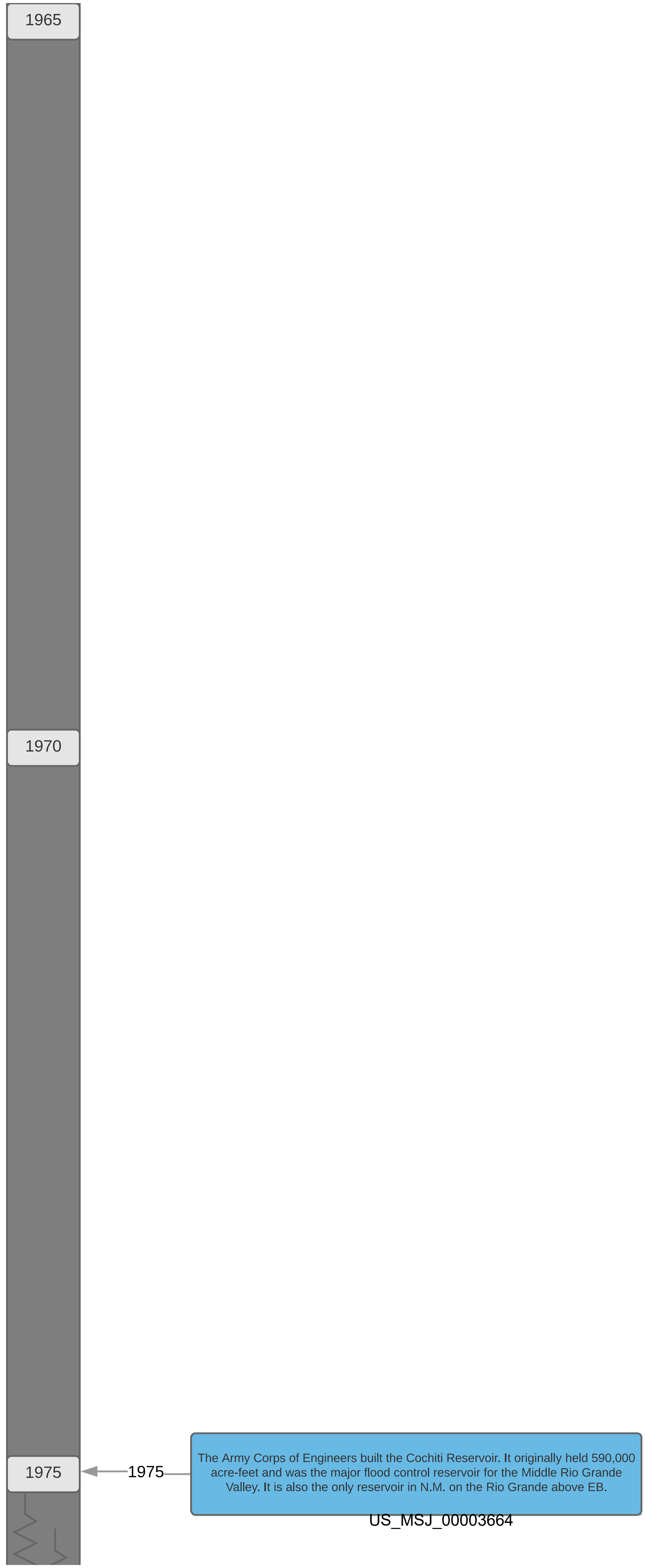
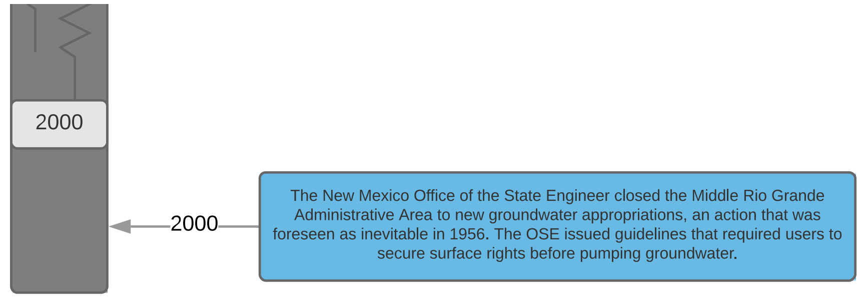

1965
1970
1975
1975
The Army Corps of Engineers built the Cochiti Reservoir. It originally held 590,000 acre-feet and was the major flood control reservoir for the Middle Rio Grande Valley. It is also the only reservoir in N.M. on the Rio Grande above EB.


2000
2000
The New Mexico Office of the State Engineer closed the Middle Rio Grande Administrative Area to new groundwater appropriations, an action that was foreseen as inevitable in 1956. The OSE issued guidelines that required users to secure surface rights before pumping groundwater.

Appendix B: Curriculum Vitae, Jennifer Stevens, Ph.D.

Principal, Stevens Historical Research Associates (SHRA)
Asst. Clinical Professor, School of Public Service, Boise State University
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Experience

Dr. Stevens is an urban/environmental/industrial historian. She offers expertise and historical consulting on a range of issues related to land and water use to private, public, and Native American clients across the country. She has researched and written extensively on issues related to water rights, stream navigability, irrigation facility development, land use and settlement, forest management, storm water disposal, mining development, mine waste disposal, historic surveys and boundaries, and Superfund liability and clean-up. Dr. Stevens is active in the history profession as well as civic matters, serving on professional committees and government commissions, including the governor-appointed Idaho State Historical Records Advisory Board and mayor-appointed City Planning and Zoning Commission.

Education

Ph.D., American History University of California, Davis. 2008.

Dissertation: Feminizing the Urban West: Green Cities and Open Space in the Postwar Era, 1950-2000

M.A., American History University of California, Santa Barbara. 1995.

B.A., History and Political Science University of California, Santa Barbara. 1993.

Skills

Archival research, writing, editing, expert witness work, oral histories, cultural resource management and Section 106 compliance, project management, public speaking.

Select Archival Experience

- U.S. National Archives: U.S. Army Corps of Engineers, U.S. War Industries Board, U.S. Bureau of Reclamation, U.S. Fish and Wildlife Service, U.S. Forest Service, U.S. General Land Office, U.S. Bureau of Land Management, Military Branch files, U.S. Geological Survey, U.S. Bureau of Indian Affairs, and many others

- State Archives: California, New Mexico, Arizona, Idaho, Oregon, Kansas, Washington, Oklahoma
- Special and Academic Collections: Huntington Library, Bancroft Library, many others
- Corporate Archives: Salt River Project, PG&E, J.R. Simplot Company, Idaho Power Company, others

Select Clients

Land O'Lakes; CBS/Viacom; J.R. Simplot Corporation; FMC; Idaho Power; Idaho Department of Lands; Tesoro/ Andeavor; British Petroleum (BP); multiple Idaho counties; Idaho Attorney General; New Mexico Attorney General; State of Washington Department of Ecology; Boise Project Board of Control; Pioneer Irrigation District; North Dakota County Consortium; U.S. Forest Service

Project History – Consulting/Litigation

Water Rights/Irrigation

2016-2017: Consulting historian for large landowner in California, researching the water rights, title history, and land use of a historic Central Valley Ranch dating to the mid-19th century. Produced lengthy report for potential use in future litigation.

2014-2018: Consulting historian for water users in Water District 63, the Boise River Basin. Conducted research on history of flood control and irrigation operations for use in Snake River Basin Adjudication late claim dispute with state over water rights. Testified at state agency hearing. *(SRBA Subcase Nos. 63-33732, 63-33733, and 63-33734)*

2013-present: Expert historian for Attorney General of New Mexico related to the history of interstate water use in *State of Texas v. State of New Mexico and State of Colorado No. 141, Original*.

2012-2015: Consulting historian for Nampa & Meridian Irrigation District in Idaho. Providing research on the history of the district, its facilities, and the historic (natural) state of the land and watercourses in the district for use in TMDL preparations and other Clean Water Act compliance. See report here: http://www.shraboise.com/wp-content/uploads/2015/04/Water-in-the-Boise-Valley-NMID.pdf

2012: Consulting historian for eastern Idaho canal company. Provided research on the history of Carey Act water development and water rights administration on the project. Dispute settled out of court.

2008-2013: Consulting historian/expert for Pioneer Irrigation District in *Pioneer Irrigation District v. City of Caldwell* (CV-08-556-C). Provided expert deposition testimony, primary historical research and authored a report on the history and development of the Irrigation District's facilities.

2009-2010: Expert historian for Boise City Canal Company in *Corn, et. al v. Boise City Canal Company.* Provided research on the historical construction of Boise City Canal Company's canal for use in litigation over damages. Case was settled out of court in 2011.

2008-2011: Expert historian for Settlers Irrigation District in *Ada County Highway District v. Settlers Irrigation District* (CV-0C-0605904). Provided expert testimony in deposition and an expert report regarding the history of the Settlers' canal system, land settlement in Ada County, and the historic presence of water in the area in question. Judge issued a favorable ruling on summary judgment motion with heavy reliance upon SHRA expert report. Case was settled out of court in 2011.

2010: Expert historian for Pioneer Irrigation District (Idaho) regarding water rights issues for the *Snake River Basin Adjudication.* Researched the District's water rights history in relation to other adjacent users.

2010: Expert historian for Middle Fork Holding Company in *Middle Fork Holding Company v. United States* (CV09-440-CWD). Provided research and expert report on the history of the Middle Fork Lodge's Challis National Forest holdings, including irrigation ditch being litigated as a potential R.S. 2339 canal. Case was settled out of court in 2010 in favor of client.

2007: Consulting historian for Surface Water Coalition in south central Idaho in the matter *of A&B Irrigation District et al. v. Idaho Department of Water Resources, et al* (Fifth Jud. District Case No. CV-2008-55I). Provided historical research on the development of water resources in south-central and south-eastern Idaho. Research included the history of ground water as well as surface water use developments.

2005-2007: Consulting historian for ERO resources in Boise, Idaho. Authored a consulting report entitled *The History of Water and Land Use in the Twin Falls, Idaho Region, 1870-1990*, for use in a legal dispute between water users in south central Idaho.

1998: Associate Historian and consultant for State of Kansas in litigation matters regarding the Republican River Compact and interstate Republican River adjudication.

1998: Associate Historian and consultant for water users in ongoing adjudication of the Snake River Basin. Provided research on the effects of Upper Snake River Dams on downstream salmon migration for use in legal conflict between Nez Perce Indians and water users.

1997-1998: Associate Historian and consultant for a municipal entity involved in the Rio Grande River Adjudication. Provided research and writing on early land and water use around the modern city limits, including groundwater, to determine municipal usage rights.

1997-1998: Associate Historian and consultant for Fort Hall Irrigation Project water users in Idaho, involved in water rights contract with the United States. Provided research on water right contract issues between the water users association and the United States.

1997-1998: Associate Historian and consultant for Kern Delta Water District regarding the historical water rights on the Kern River. Provided research and writing on the history of the famous *Lux v. Haggin* case and its subsequent agreements in order to determine Kern Delta's rights.

1996-1998: Associate Historian and consultant for the state of Idaho regarding the Snake River Basin Adjudication. Provided historical research on water rights of the Snake River islands located in the Deer Flat National Wi1995-1998: Associate Historian and consultant for Nebraska Department of Water Resources. Provided research on the history of *Nebraska v. Wyoming*, 325 U.S. 589 (1945), for use in litigation between Nebraska and Wyoming over the apportionment of North Platte River waters.

1995-1998: Associate Historian and consultant for federal client. Providing research on the history of *Rancho Santa Margarita v. Vail* for use in a water dispute over the Santa Margarita River in southern California.

Navigability

2017-2018: Consulting historian for Idaho Department of Land on a navigability study of 147 waterbodies throughout the state. To be completed in July 2018.

2015-2017: Consulting historian for the State of Idaho Department of Lands on a historic navigability study on the Weiser River in southern Idaho. Produced report opining on the river's navigability at statehood.

2016: Consulting historian for private client regarding the navigability of the Big Wood River. Dispute settled out of court.

2013-2016: Historian for State of Idaho Attorney General. Researched the historic navigability of the Payette River from Idaho's territorial period to statehood for litigation purposes. Case settled out of court favourably for the State.

2012-2015: Consulting historian for public utility. Researched and authored report on a river's historic navigability as it related to legal consideration of river beds and banks ownership. (Client confidential.)

1995-1998: Associate Historian and consultant for the Salt River Project (Arizona). Provided research on the commercial navigability of the Salt River, Gila River, and Verde River at the time of statehood (1912) for use in hearings in front of the Arizona Navigable Stream Adjudication Commission.

CERCLA/Superfund

2019: Expert historian for confidential client/Potentially Responsible Party, Land O' Lakes. Conducting research and writing expert report related to the history of waste management at a legacy oil and gas refinery in Oklahoma.

2018: Expert historian for Pioneer Natural Resources in related to liability on CERCLA site in the Creede mining district, Colorado. Provided original research, an expert report, and expert deposition testimony in September 2018. (*United States v. Pioneer Natural Resources Company* et al, Civil Action 1:17-CV-00168-WJM-NYW) Settled out of court favourably to SHRA's client.

2017-2018: Consulting historian for Potentially Responsible Party on a New York-area CERCLA site. Provided research and document discovery related to federal government contracts during World War I and World War II.

2015-2016: Consulting historian for Potentially Responsible Party on a 19th century western mining site (confidential) concerned with a surface water pathway. (Nevada)

2013-present: Historian for British Petroleum/Atlantic Richfield on a legacy CERCLA lead refinery site. Providing research on potentially responsible parties and historic corporate relationships.

2013-2015: Consulting historian for Potentially Responsible Party on Duwamish Waterway CERCLA site near Seattle, Washington. Researching the history of land use and water pollution during the 20th century. (Client confidential.)

2012-2018: Expert historian for defendant in litigation over liability for an Oklahoma CERCLA site in *Cyprus Amax Minerals Company v. TCI Pacific Communications and CBS Operations, Inc. (11-CV-252-JED-PJC)*. Researching potentially responsible parties, direct operator liability, and corporate relationships at the legacy site in a "piercing the veil" (phase one) and direct liability/allocation (phase two) case. Provided expert deposition testimony twice and testified at trial in February 2018.

2011-2014: Expert historian for mining company on the history of operations at a western mine site to determine liability under a CERCLA claim. (Client confidential.) (Idaho.)

2010-2013: Expert historian for Colville Confederated Tribes in *Joseph A. Pakootas, et al v. Teck Cominco Metals, Ltd.* (CV-04-0256-LRS), a civil action involving CERCLA claims against a mining company in eastern Washington State on the Columbia River. Provided comprehensive expert rebuttal report and deposition testimony regarding the history of mining in the region.

2008-2012: Consulting historian for mining company in eastern Idaho, regarding the history of river pollution and land use on a CERCLA-regulated site. Authored a comprehensive history regarding Resource and Conservation Recovery Act (RCRA) and CERCLA (Superfund) regulation and corporate land use on the site.

1999: Assistant Historian for Quivik Consulting Historian, Inc. Provided research and writing on mining history for the *Bunker Hill Superfund* litigation (*United States v. ASARCO, et al*) in northern Idaho, with particular attention to liability and corporate ownership issues.

1999: Assistant Historian for Quivik Consulting Historian, Inc. Provided research and writing on mining history for *Pinal Creek Group v. Newmont Mining Corp., et al.,* in Arizona.

1998: Associate Historian and consultant for the Sacramento Municipal Utility District (SMUD) in litigation *SMUD v. CalTrans, et al.* Provided research on the historical land use of a contaminated site adjacent to the Sacramento River to determine clean-up liability.

Native American Reservation History

2019: Consulting historian for Midwestern state regarding native use of significant waterway and treaty intent and understandings related to water use. (Client confidential.)

2017-present: Consulting historian for private entity regarding original Northwest Tribe's reservation boundary and Indian Claims Commission history. (Client confidential, Washington)

2015: Consulting historian for Skokomish Tribe regarding potential fishing and hunting litigation. Provided research on tribal history and aboriginal territory, as well as reservation boundaries. (Washington)

2013-2016: Expert historian for FMC Corporation on the Eastern Michaud Flats CERCLA site (phosphate processing) in Idaho for hearing in Tribal Court over matters relating to jurisdiction. Researching the site's Native American, corporate, river, and other land use and title history. Provided expert deposition testimony in *2014: Shoshone-Bannock Tribes Land Use Department and Fort Hall Business Council vs. FMC Corporation (C-06-0069, C-07-0017, C-07-0035)*, and trial testimony in 2015.

2010-2014: Consulting historian for a privately held mining company in the State of Washington in a dispute with the federal government over Indian Reservation boundary. Issues include historic creek location and historic treatment of lands bordering a creek in Washington State. (Client confidential)

R.S. 2477/Road Right of Way/1866 Mining Act

2019: Consulting historian for private landowner. Researching access history related to multiple roads on landowner's properties. (Idaho)

2015-2018: Expert historian for Attorney General of the State of New Mexico in a dispute over public roads in *David Stanley v. Board of County Commissioners of Mora County, et. al. (D-809-CV-2011-00252)*. Conducted archival research and prepared expert report and expert testimony at trial. Testified for three days in March 2018.

2015-present: Consulting historian for a consortium of counties in North Dakota in dispute with the U.S. Forest Service over historic roads. Researching the historic travel routes in the area as well as historic land use and economic development in the region dating back to the mid-19th century. Authored expert report and rebuttal report. Provided deposition testimony in May 2018.

2017: Consulting historian for private landowner in a dispute with county over road access in Valley County, Idaho. Provided research that assisted in settlement of dispute.

2017: Consulting historian for private landowner in a dispute with county over road access along Priest Lake in northern Idaho. Provided research and opinion regarding road history.

2015: Consulting historian for Franklin County, Idaho. Provided research and an expert report on the history of a rural road and settlement – Mink Creek Road – whose access was disputed.

2015-present: Consulting historian for State of New Mexico regarding history of state roads and public access.

2012: Consulting historian for Bear Lake County, Idaho, regarding historic roads for use in R.S. 2477 road validation proceedings under the 1866 Mining Law. Provided research on local land use and historic travel routes. Dispute settled out of court.

2010-2013: Consulting historian for Washington County, Idaho regarding the historic presence and use of roads in the County for use in R.S. 2477 road validation proceedings under the 1866 Mining Law. Provided expert testimony at a public hearing held in May 2012.

2010-2011: Expert historian for Baker City in *City of Baker City, OR v. United States of America, et al (*Civil No 2:08-cv-717-SU) regarding the historic presence of mining ditches in the surrounding National Forest for use in validation of ditch as an R.S. 2339 right-of-way under the 1866 Mining Law. Offered expert testimony and an expert report that were used for a successful trial outcome for Baker City in October 2011.

2009-present: Consulting historian for Valley County, located in central Idaho. Providing historical research on the presence of roads on federal land for potential litigation of R.S. 2477 roads claim under the 1866 Mining Law.

Other

(Public Health/Asbestos) 2016-2018: Consulting historian for large manufacturing corporation in its defense against asbestos claims. Researching and writing a corporate history, examining product development, government regulations and understanding related to asbestos use, mergers and acquisitions, and the history of the industry for contextual purposes.

(State Lands) 2017-present: Consulting historian for western state regarding history of state land management.

(Clean Water Act) 2010-2011: Expert historian for defendant in *United States of America v. Michael Rodriguez* (CR-09-279-S-BLW) regarding potential Clean Water Act violations. Issues include the historical nature of the land and the existence of wetlands thereupon. Provided expert report which helped settle this dispute out of court.

(Land Use/State Lands) 2012-2013: Consulting historian for State of Idaho Attorney General regarding historical management of state cottage site lands. Produced expert report; case settled out of court.

2010-2011: Consulting historian/grant writer for Boise State University. Worked with faculty members in the College of Social Sciences to write interdisciplinary grant materials for National Science Foundation funding related to water and land use in the Boise River Basin, Idaho.

(Mining) 2010: Consulting historian for Sima Muroff/Blackhawk on the River on the historical impact of the War Production Board's L-208 regulation closing all "non-essential" mines in the United States in 1942. Provided research and report on Idaho mines affected by order L-208.

(Land Use) 2003-2004: Consulting historian for City of Boise, Idaho. Authored a report entitled *Land Use and Conservation in the Boise Foothills, 1862-2001* for use in support of federal legislation dictating the terms of a land exchange between various state, federal, and local entities.

Cultural Resource Management and Other Public History

Exhibit/Museum Consulting

2017-present: Consulting historian, photo curator, and editor for museum exhibit on the history and role of geothermal resources in the development of Boise, Idaho at the Boise WaterShed Environmental Education Center.

2015-present: Consulting historian for Harris Ranch and Harris Family, Idaho. Conducting research on the history of the Barber Valley, the Harris Family business, and more recent urban development to author a book for publication due in late 2019.

2014-2016: Project historian for Idaho Power Company and managing the company's year-long centennial celebration throughout 2016. Providing research, project planning, writing, online and traditional exhibit planning, oral history, and documentary expertise. The project received the National Council on Public History's Award for Excellence in Consulting in 2017.

2012: Historian for the Idaho Education Association. Authored a 120-history of the teachers' union that was published and received Honorable Mention for Excellence in Consulting from the National Council on Public History.

National Historic Preservation Act Section 106 Mitigation

2016-2017: Consulting historian for the Idaho Transportation Department. Research and authored a history of travel routes along the Little Salmon River in central Idaho. Produced historical report approved by the State Historic Preservation Office.

2015-2016: Consulting historian for the Idaho Transportation Department. Researched the history of ferry transport on the Snake River to mitigate the loss of a historic bridge.

2010: Consultant to City of Boise. Authored the City's new Historic Preservation Plan. This project represented the first revision of the City's plan since the original was written in 1979.

Conference Presentations and Other Professional Talks

March 2019: National Council on Public History. Panel facilitator, "What You Need to Know About Consulting."

April 2018: National Council on Public History. Workshop leader and Roundtable Participant (two sessions) on "The Nuts and Bolts of Historical Consulting," and "Sustaining Your Consulting Business."

October 2017: Society for American City and Regional Planning History. "From Blue to Green: Boise's Industrial Past and Sustainable Future." Gave presentation on industrial history, brownfields, and greenwashing the Intermountain West. Cleveland, OH.

March 2017: American Society for Environmental History. Participant in panel entitled, *Changes in the Professional Landscape: Preparing Students to Practice Interdisciplinary Environmental History.*

October 2016: Presenting the history of Idaho Power Company at the Annual Meeting of the Western History Association on a panel entitled: *100 Years of Electricity in the West: Utilities and Their Publics*, St. Paul, MN.

April 2016: Invited and featured speaker for graduate students participating in the Mellon Public Scholars Program at the University of California, Davis.

March 2016: Presented research on the history of Idaho water at the Annual Meeting of the Society for Environmental History on a panel entitled: *Environmental Historians Doing Public History: Working with Agencies and Communities to Protect Ecosystems and Landscapes*, Seattle, WA.

January 2013: American Historical Association. Participant in panel entitled, *The Entrepreneurial Historian*. New Orleans, LA.

March 2010: American Society for Environmental History. Roundtable Organizer, *Alternate Voices, Shared Visions: Women in Post-WWII Environmentalism*. Portland, OR.

March 2010: Women's History Month speaker for Boise civic series put on by Boise State University's Center for History and Politics entitled Fettuccine Forum. Boise, ID.

October 2009: Western History Association. "The West is Healthy?: Smog and Its Impact on the Cities of the West: 1950-1980," as part of the panel, *Wiring Wellness in the West*. Denver, CO.

October 2009: Planning History/Society for American City and Regional Planning. "Telesis: A Roundtable." Presented research on Dorothy Erskine's role in what was a cutting edge planning group out of Berkeley, CA. Oakland, CA.

May 2009: Foothills Learning Center Sunset Series. "Hull's Angels: The History of Western Women and Open Space Campaigns." Boise, ID.

April 2009: Western Association of Women's Historians. "Living on the Edge: Hillside Women's Plans for a Wild Los Angeles, 1955-1970," as part of the panel: *Defining Los Angeles: A City's Identity in Flux, 1880-1980*. Santa Clara, CA.

March 2009: U.S. Bureau of Reclamation. "Women of the Urban West, Green Cities and Open Space

Battles in the Post War Era," in honor of Women's History Month. Boise, ID.

June 2008: Berkshire Conference on the History of Women. "Saving Us from Subdivisions and Giving Us Space: Women as Environmentalists in the Early Second Feminist Era," as part of the panel: *Battling Urban Sprawl, Pollution, and Poverty: Justifications for Women's Environmental Activism in the Twentieth Century*. Minneapolis, MN.

February 2008: American Society for Environmental History. "When the City Gets Too Close: Saving Hull's Gulch and Building Community in Boise, Idaho, 1980-2000," as part of the panel: *When Wild Isn't Wild Anymore: Negotiating the Boundaries Between Humans and the Wild*. (Also served as member of the Local Arrangements Committee for this conference.) Boise, ID.

October 2007: Western History Association. "Los Angeles: Sprawling Metropolis or Urban Park Haven? The Struggle for a City's Identity in the Santa Monica Mountains: 1960-1978," as part of the panel: *The Boundaries of Nature: Cities, Counties, and Tensions around Parks in the West*. Oklahoma City, OK.

March 2000: American Society for Environmental History. "Deschutes and After: The State's Rights Issue in River Management, 1947-1956," as part of the panel: *Whose Rivers Are They?: The Politics of River Management in the Pacific Northwest*. Seattle, WA.

Teaching/Academic Experience and Other Talks

In addition to teaching in the History, Urban Studies, and Environmental Studies Departments at Boise State University, Dr. Stevens also serves on graduate student committees, supervises graduate and undergraduate interns each semester, and advises graduate students on original research.

Boise State University, Boise, ID

Spring 2019: Urban Field School. A History of Brownfields and their Rehabilitation in Urban Centers.

Fall 2018: Urban Studies/History: U.S. Urban History, 1877-present.

Summer Session 2017: Investigate Boise Series: "Green Cities." Co-taught with Professor Amanda Ashley, Boise State University, Boise, Idaho.

Spring 2014/2015: Department of Environmental Studies. United States Urban Environmental History.

Fall 2013: Department of History. Upper-division Environmental History.

Spring 2010: Department of History. Upper-division Environmental History.

Spring 2010: Department of History. 3-day workshop entitled, "Women and the Urban West."

2006: Teacher/Leader. Department of History. 3-day workshop entitled "History of the Boise Foothills."

Interns Mentored and Graduate Student Committees

2019: Kathy Hansen, M.A. Boise State University (History)
2019: Jenna Shaw, B.A. Boise State University (Urban Studies)
2018: Jennifer Tucker, M.A., Boise State University (History)
2018: Maicee Byrd, B.A., Boise State University

2017: Erin Lozowski, B.A., Boise State University
2017: Cyrus Forman: Ph.D. Candidate, History, University of Washington
2017: Sam Jones, B.A., Boise State University
2016: Adam Behrman, Ph.D. Candidate, History, University of Wisconsin-Madison
2016: Molly Myers, B.A., College of William & Mary
2015: Sadi Mosko, B.A., Columbia University
2014: HannaLore Hein, M.A., Boise State University (History)

University of California

1999: Teaching Assistant. Department of History, Davis.

- United States Environmental History.
- United States History, 1860-present.
- Modern European History

1994-1995: Teaching Assistant. Department of History, Santa Barbara.

- United States History, 1860-present.

Other Invited Talks

May 2018: "This Ain't Going to be No Lunch Bucket Town: Boise's Evolving Urban Identity," an invited lecture at the Osher Institute for Lifelong Learning, Boise, Idaho.

January 2017: Invited speaker, Environmental and Natural Resources Law Section, Idaho State Bar: "Digging In: Historical Research in Your Natural Resources Case."

October 2014: Invited speaker, Idaho State Archives Opening Ceremony, Acquisition of the Snake River Basin Adjudication Collection.

August 2013: Featured Speaker, Idaho Environmental Forum's Boise River Conference: "History of Irrigation in Idaho."

April 2013: Featured Speaker, Boise 150 Celebration: "The History of Boise's Green Spaces."

October 2012: Online Panelist: "Careers for Consulting Historians," The Versatile Ph.D.

June 2015/July 2012/July 2011/July 2010: NBI, Inc. A class on historical research for attorneys earning Continuing Legal Education credit. Boise, Idaho.

June 2012: Speaker at the Idaho Water Users Association's Water Law Seminar on "Documenting Your Water History." Sun Valley, Idaho.

Grant Awards

2018-2019: National Endowment for the Humanities: Digital Projects for the Public. "'This Ain't No Lunch Bucket Town': The Evolution of Urban Identity in Boise, Idaho." ($30,000)

2018-2019: City of Boise Arts & History Grant. Oral histories "This Ain't No Lunch Bucket Town." ($4,000)

Professional and Academic Awards

2017: Mayor's Award for Excellence in History, Boise, Idaho. (Given to a single individual biennially.)

2017: Recipient of the Excellence in Consulting award, *National Council on Public History*, for *100 Years of Idaho Power History* Traveling Museum Exhibit.

2013: Honorable Mention for the Excellence in Consulting award, *National Council on Public History* for *Voices of Courage, Champions of Excellence*, a history of the Idaho Education Association.

2012: Woman of the Year Award, *Idaho Business Review*

2011: Accomplished Under 40 Award, *Idaho Business Review*

2007: Consortium for Women and Research, Research Grant, University of California

2008: Consortium for Women and Research, Travel Grant, University of California

1999: Department of History Research Block Grant Award, University of California, Davis.

Other Professional Experience and Service to the Profession

2017-2018: Program Evaluator. Invited community member for evaluation of Boise State University's Master's in Applied Historical Research.

February 2018: Invited commenter: Treasure Valley Water Atlas, a project supported by the National Science Foundation.

2017: Graduate student mentor and sponsor, University of Washington, for students desiring applied training outside of the academy.

2016-present and 2008-2013: Mayor-appointed member, Boise City Planning and Zoning Commission. Commission Chair, 2012-2013.

2014-2016: Board Member, Idaho Environmental Forum.

2012-present: Member and chair, Consultant's Committee, National Council on Public History.

2012-present: Contributor, *Consultant's Corner*, National Council on Public History.

2011-present: Governor-appointed member, Idaho State Historical Records Advisory Board.

2012-2014: Member, Education Committee, *Preservation Idaho*.

2007- 2008: Member, vice-president of the Board of Trustees, Land Trust of the Treasure Valley.

2005-2008: Chair, Boise City Historic Preservation Commission.

2003-2008: Member, Boise City Historic Preservation Commission.

2004: Graduate, Leadership Boise Program, Boise Chamber of Commerce

2002-2003: Historic Preservation Chair, Newsletter Editor, and Board Member, North End Neighborhood Association. Worked with local historians and architects to preserve and maintain the historic resources of Boise's North End neighborhood.

2001-2002: Market Intelligence Manager, PeopleSoft, Inc., Pleasanton, CA. Collaborated with executives, including CEO, to determine competitive positioning for sales and marketing in the dynamic e-business software sector. Planned international expansion of market intelligence team. Interacted regularly with industry analysts.

1999-2001: Manager, Competitive Intelligence, Siebel Systems, Inc., San Mateo, CA. Worked closely with executive team, including COO, to devise corporate strategies to remain ahead of the competition in the software industry. Traveled internationally to present strategies to sales teams and executives.

1995: Water Policy Researcher/Analyst. Environmental Policy Center, San Francisco, CA. Researched local government policies regarding water efficiency and water quality. Updated information on the Center's Web site, followed trends in policy making and assisted local government clients in implementing policies.

Conferences Attended

American Society for Environmental History: 2017, Chicago; 2016, Seattle; 2014, San Francisco; 2008, Boise; 2006, St. Paul; 2000, Seattle; 1999, Tucson; 1995, Las Vegas.

National Council on Public History: 2019, Hartford; 2018, Las Vegas; 2016, Baltimore; 2010, Portland**.**

American Historical Association: January 2013, New Orleans.

Western Association of Women Historians: May 2009, Santa Clara.

Berkshire Conference on the History of Women: June 2008, Minneapolis.

Society for American City and Regional Planning: October 2017, Cleveland; October 2009, Oakland.

Western History Association: 2016, St. Paul; 2012, Denver; 2009, Denver; 2008, Salt Lake City; 2007, Oklahoma City.

FORUM, National Association for Preservation Commissions: July 2006, Baltimore.

California Committee for the Promotion of History: October 1995, Sacramento.

Professional Affiliations

American History Association, American Society for Environmental History, Western History Association, Society for American City and Regional Planning History, Western Association of Women Historians, National Council on Public History, Coordinating Council on Women in History, Mining History Association

Publications and Other Scholarly Works

"From Archive to Evidence: Historians and Natural Resource Litigation," *The Public Historian* Vol. 37, No. 1 (February 2015): 68-87.

Voices of Courage: Champions of Excellence: The Story of the Idaho Education Association since 1892. (SweetGrass Publishers, 2012). A project completed on behalf of the Idaho Education Association.

"Feminizing Portland, Oregon: A History of the League of Women Voters in the Postwar Era, 1950-1975," in *Breaking the Wave: Women, Their Organizations, and Feminism, 1945-1985* (Routledge: 2010).

Forthcoming: *Women, Bulldozers, and the West: Early Environmentalism in Western Cities, 1950-1975. (*Under Contract with University of California Press.)

"One State's Challenge to the National Defense Effort: Oregon, Fish, and the Feds, 1949-1953." Partial fulfillment for Ph. D.

"In Name But Not in Practice: The Role of the Agrarian Myth in Western Water Development and State Building." Partial fulfillment for M.A. Degree.

"Dam the Progressives: Multi-Purpose River Development, 1900-1914." Partial fulfillment for M.A. Degree.

Book Reviews

Bradley D. Snow, *Living with Lead: An Environmental History of Idaho's Coeur D'Alenes, 1885–2011.* Intersections: Environment, Science, and Technology Series. (Pittsburgh: University of Pittsburgh Press, 2017). Reviewed for the *Western Historical Quarterly*, Vol. 49, No. 2 (April 2018): 226.

Peter A. Kopp, *Hoptopia: A World of Agriculture and Beer in Oregon's Willamette Valley*. California Studies in Food and Culture Series. By Peter A. Kopp. (Oakland: University of California Press, 2016). Reviewed for *The Western Historical Quarterly*, Vol. 48, No. 4 (October 2017): 465.

Ellen Stroud, *Nature Next Door: Cities and Trees in the American Northeast* (Seattle and London: University of Washington Press, 2012). Reviewed for *The Public Historian*, Vol. 36, No. 3 (August 2014): 164-165.

Charles Hummel and Tim Woodward, *Quintessential Boise: An Architectural Journey* (Boise: Boise State University, 2010). *Idaho Yesterdays*.

Richard Widick, *Trouble in the Forest: California's Redwood Timber Wars* (Minneapolis: University of Minnesota Press, 2009). Reviewed for H-Net and H-California History, July 2010.

William D. Rowley, Reclaiming *the Arid West; The Career of Francis G. Newlands* (Bloomington and Indianapolis: Indiana University Press, 1996), in *Journal for the History of Technology* (October 1997).

John O. Baxter, *Dividing New Mexico's Waters, 1700-1912* (Albuquerque: University of New Mexico Press, 1997), in *The Western Historical Quarterly* (Summer 1998).

Professional Blogs

June 22, 2017: http://ncph.org/history-at-work/whats-in-a-name-2/

April 1, 2016: http://ncph.org/history-at-work/to-expand-or-not-to-expand/

March 21, 2016: http://ncph.org/history-at-work/ask-a-consulting-historian-jennifer-stevens/

June 8, 2015: http://ncph.org/history-at-work/public-history-and-policy-a-synergy/

June 18, 2014: http://ncph.org/history-at-work/from-independence-to-collaboration/

January 18, 2013: http://ncph.org/history-at-work/hustling-historian/

June 13, 2012: http://ncph.org/history-at-work/858-2/

Deposition Testimony

2018: United States v. Pioneer Natural Resources Company et al, Civil Action 1:17-CV-00168-WJM-NYW

2018: Billings County, et.al v. United States of America 1-12-CV-00102-DLG-CSM

2016: Cyprus Amax Minerals Company v. TCI Pacific Communications and CBS Operations, Inc. (11-CV-252-JED-PJC, Federal District Court, N.D. Okla)

2015: Snake River Basin Adjudication Subcase Nos. 63-33732, 63-33733, and 63-33734

2014: Shoshone-Bannock Tribes Land Use Department and Fort Hall Business Council vs. FMC Corporation (C-06-0069, C-07-0017, C-07-0035)

2013: Cyprus Amax Minerals Company v. TCI Pacific Communications and CBS Operations, Inc. (11-CV-252-JED-PJC, Federal District Court, N.D. Okla)

2011: Joseph A. Pakootas, et al v. Teck Cominco Metals, Ltd. (453 F3d 1066)

2008: Ada County Highway District v. Settlers Irrigation District (CV-0C-0605904, 4th Judicial District Court, State of Idaho)

2008: Pioneer Irrigation District v. City of Caldwell (CV-08-556-C, 3rd Judicial District Court, State of Idaho)

Trial Testimony

March 2018: David Stanley v. Board of County Commissioners of Mora County, et. al. (D-809-CV-2011-00252, Taos District Court, State of New Mexico).

February 2018: 2013: Cyprus Amax Minerals Company v. TCI Pacific Communications and CBS Operations, Inc. (11-CV-252-JED-PJC, Federal District Court, N.D. Okla)

April 2014: Shoshone-Bannock Tribes Land User Department and Fort Hall Business Council vs. FMC Corporation

(C-06-0069, C-07-0017, C-07-0035)

*October 2011: City of Baker City, OR v. United States of America, et al (*Civil No 2:08-cv-717-SU, U.S. District Court, District of Oregon, Pendleton Division)