FINAL REPORT

Water Availability Model (WAM) Update
Phase I - Rio Grande Basin
Contract No. 582-20-13331

submitted to:

Texas Commission on Environmental Quality
Austin, TX

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submitted by:

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Austin, TX

in association with

Crespo Consulting Services, Inc.
Kennedy Resource Company
Freese and Nichols, Inc.

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NOTICE

During final review of this report and the updated naturalized flow workbooks, it was determined that certain changes needed to be made to the workbooks for the Pecos River at Langtry and the Devils River near Pafford Crossing primary control points. These changes related to properly adjusting for channel losses when adding incremental naturalized flows to the total naturalized flows at an upstream primary control point to estimate missing flows at a downstream primary control point. After comparing the naturalized flows and the WAM-simulated regulated flows before and after these changes were made, it is apparent that the effects of these changes are miniscule compared to normal flow magnitudes. Therefore, even though the naturalized flow workbooks and the naturalized flows used in the final updated Rio Grande WAM have been revised to correct for the channel loss issue, no corresponding changes have been made in the tables and figures presented in this report, all of which are based on the prior naturalized flows without the channel loss correction. Revising the tables and figures has been considered unnecessary because the resulting differences in the displayed numbers are infinitesimally small and indiscernible. Consequently, as a note of caution, values related to the updated naturalized flows and WAM-simulated regulated flows stated in this report may not agree exactly with the final values in the updated naturalized flow workbooks or from the updated Rio Grande WAM.

1.0 INTRODUCTION

This report has been prepared pursuant to Contract No. 582-20-13331 issued by the Texas Commission on Environmental Quality ("TCEQ") to Robert J. Brandes Consulting ("RJBCO") as authorized by House Bill 723, 86th Texas Legislature, 2019, and it presents the background, approach and results from an investigation undertaken to update the Rio Grande water availability model ("WAM"). The work performed in this investigation is an extension of the previous effort undertaken in the early 2000s when the original Rio Grande WAM was developed[1]. Specifically, this effort has involved extending the Rio Grande WAM's existing naturalized flow and net evaporation datasets, which previously represented 1940-2000 historical conditions, to include additional data for the 2001-2018 period. Also, during the course of this work, some errors and/or inconsistencies have been noted in the existing data and procedures used to develop the original WAM datasets and/or in the representation of these data in the original WAM datasets, and these issues have been addressed either by providing further explanation or by replacing or revising some of the original data in the 1940-2000 datasets.

This investigation has produced revised naturalized flow and net evaporation datasets for the 1940-2000 period and extensions of these existing datasets to include naturalized flows and net evaporation data for the 2001-2018 period. The methodology and the calculations used to derive the revised naturalized flows for the entire 1940-2018 period are documented in Excel workbooks. Finally, these revised and updated naturalized flow and net evaporation datasets have been incorporated into the Rio Grande WAM data files, along with revisions to certain other WAM datasets, and this updated model has been operated to produce revised water availability results for the entire 1940-2018 period. This report includes comparisons of these results with those from the existing WAM for the 1940-2000 period.

1.1 Project Team

For this investigation, Robert J. Brandes Consulting ("RJBCO") has served as the prime contractor with the TCEQ and has directed and been responsible for all of the technical work undertaken to produce the revised and updated WAM datasets. The following entities, serving as subcontractors to RJBCO, have performed specific technical work tasks and assignments pursuant to developing the updated naturalized flows and net evaporation datasets:

Kennedy Resource Company
Crespo Consulting Services, Inc.
Russel T Melton, P.E.

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[1] R. J. Brandes Company; "Final Report, Water Availability Modeling for the Rio Grande basin, Water Availability Assessment"; prepared for Texas Commission on Environmental Quality; March 2004; Austin, Texas.

Mr. Tom Gooch and Mr. Jon Albright with Freese and Nichols, Inc. have provided Independent Peer Review of all of the technical work performed and the outputs produced in this investigation. Responses to their major comments are included in Section 10.0 of this report.

1.2 Scope of Work

The technical approach used for extending the naturalized flows and for compiling net evaporation data for the 2001-2018 period for the Rio Grande WAM has been essentially the same as what was initially employed in the early 2000s for developing the original Rio Grande WAM. This approach involved the same basic work tasks and subtasks, as listed below, with some modifications to accommodate an alternate procedure that has been used for representing Mexico tributary inflows to the Rio Grande as described in Section 3.0 of this report.

Task 1 – Development of Project Management Plan and Detailed Work Plan

Task 2 – Development of Naturalized Flow Data Sets

- Subtask 2.1 – Data Assembly, Compilation and Presentation
- Subtask 2.2 – Interstate and International Rio Grande Considerations
- Subtask 2.3 – Data Fill-in, Organization and Analyses
- Subtask 2.4 – Development of Naturalized Streamflow Workbooks
- Subtask 2.5 – Results Assembly and Preparation of Reports

A substantial part of this effort has involved performing Subtasks 2.1 and 2.3. These encompass the basic data compilation and analysis activities that are required to construct complete histories of the hydrologic and climatic data needed to develop the naturalized flows for the 2001-2018 period. This includes: (1) monthly values of historical gaged streamflows for the Rio Grande and its major tributaries in Mexico and Texas, (2) reservoir storage and net evaporation for the mainstem reservoirs and tributary reservoirs in Texas, (3) Mexico diversions from the Rio Grande and all diversions by Texas water users in the Rio Grande basin, (4) all wastewater and irrigation return flows discharged into the Rio Grande and into Texas tributaries, and (5) springflows for major springs in Texas that influence gaged streamflows. Since much of this information involved Mexico, it was necessary to acquire data from the United States Section of the International Boundary and Water Commission ("IBWC"), as well as from TCEQ. Personnel in these agencies are to be commended for their assistance with data acquisition.

It should be noted that the contract authorizing this work includes a list of specific chapters or sections that address specific topics that are required to be included in the final report. These are listed below with the section number in this report where each topic is discussed noted in parentheses:

1) Data collection (Section 4.0),
2) Data analysis (Section 5.0),
3) Changes to the existing naturalized flow, evaporation, and flow adjustment datasets (Section 6.0),
4) Any changes to TCEQ's water availability model main input, flow distribution, or flow adjustment files necessary to incorporate the extended naturalized streamflow, evaporation, and flow adjustment datasets (Section 8.0),
5) Detailed description of the procedure for addressing negative incremental flows (Section 7.7),
6) Results of the independent peer review and any changes to the extended naturalized streamflow datasets resulting from the review (Section 10.0), and
7) Final naturalized streamflow, evaporation and flow adjustment datasets (Section 7.8).

1.3 Independent Peer Review

An important element of the quality assurance/quality control effort for this investigation has been performed by the Independent Peer Review ("IPR") team. In general, the IPR has involved review and analysis of the technical approach and procedures and assumptions employed as part of the various work tasks and subtasks involved in the development of the extended naturalized flows. The IPR team was active during the development of the Detailed Work Plan at the start of the project to validate the proposed technical approach and the proposed methods and procedures for analyzing, organizing, and estimating data for use in the naturalized flow process. An important function of the IPR team also was to examine the naturalized flow workbooks and other products of the work, including the draft final report, to ensure that the technical approach and procedures were correctly applied and that the resulting 2001-2018 updated naturalized flows were reasonable and consistent with those for the 1940-2000 period.

The IPR team has reported directly to the Project Manager for the contract. None of the IPR team members have been directly involved in the performance of the actual technical work for developing the extended naturalized flows; however, the IPR team has been available throughout the course of the work for consultation, particularly during the development of the Project Management Plan and Detailed Work Plan and after the initial extended naturalized flows were developed and the Draft Report was produced. Issues or changes to the naturalized flow development process or the resulting extended naturalized flows that have been identified through the IPR process have been documented, with responses to major items summarized in Section 10.0 of this report.

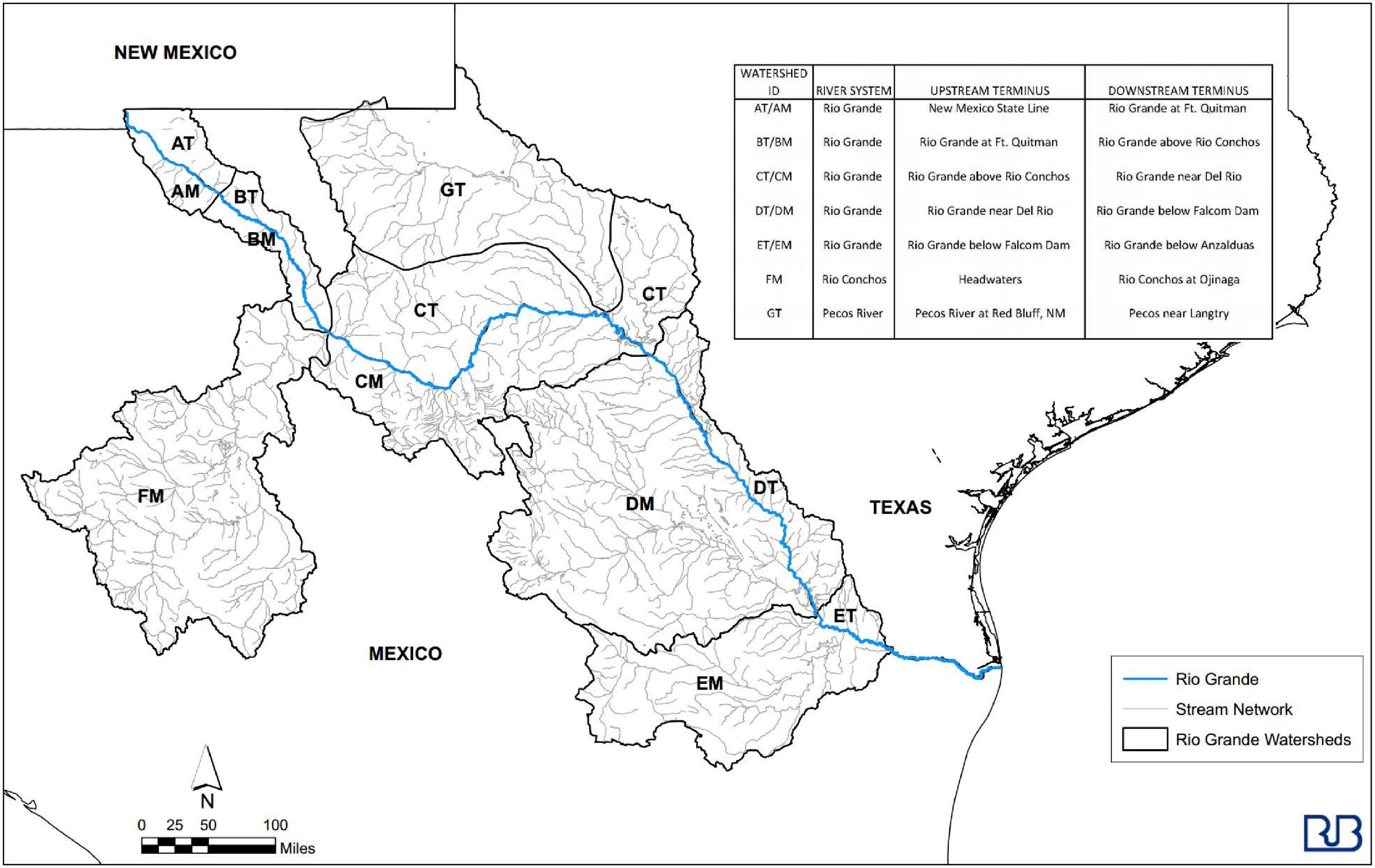
1.4 Rio Grande Basin

The Rio Grande basin covers 335,000 square miles and includes portions of southern Colorado, New Mexico, west and south Texas, and parts of the Mexican states of Chihuahua, Durango, Coahuila, Nuevo Leon, and Tamaulipas. Much of the basin is non-contributing with respect to flows in the Rio Grande, with the contributing drainage area equal to about 176,000 square miles split about equally between the United States and Mexico. This report focuses primarily on the contributing portion of the basin in Texas and Mexico, with about 40,000 square miles in Texas and about 87,000 square miles in Mexico.

The Rio Grande is about 1,900 miles long and is the second longest river in the United States. Through Texas, the river forms the border between the United States and Mexico from near El Paso to the river's mouth at the Gulf of Mexico below Brownsville. The basin comprises all or parts of 31 counties in Texas. Figure 1 presents a map of the contributing portion of the basin in Texas and Mexico and shows the subwatersheds established for purposes of developing the naturalized flows and structuring of the original Rio Grande water availability model.

The Rio Grande stream network within Texas and Mexico consists principally of the mainstem of the Rio Grande and nine major tributaries. The Pecos and Devils Rivers are the primary tributaries in Texas. Rios Conchos, San Diego, San Rodrigo, Escondido, Salado, Alamo, and San Juan are the primary tributaries in Mexico. There are 26 major reservoirs in this portion of the basin, three on the mainstem, five in Texas, and 18 in Mexico, including associated off-channel reservoirs. Major reservoirs are defined as having a conservation storage capacity of 5,000 acre-feet or greater. Water from the Rio Grande and its tributaries is used extensively throughout the entire basin for municipal, industrial and irrigation purposes, with streamflows substantially diminished in some stream segments by diversions and sustained in others by return flows and reservoir releases. In Texas and Mexico, the vast majority of water diverted from the Rio Grande and its tributaries is used for irrigation to support significant large-scale agriculture.

The climate in the Rio Grande basin varies widely. The western portion of the basin in Texas is desert, with an annual precipitation of approximately 10 inches. Precipitation increases toward the east and southeast; the southeastern portion of the basin is humid subtropical with a maximum annual precipitation of approximately 24 inches near the coast. Average annual lake surface (gross) evaporation ranges from about 72 to 80 inches along the upper and middle Rio Grande to 56 inches near the coast. Elevations range from about 4,000 feet at El Paso to over 8,000 feet in the mountains of west Texas, and to sea level at the coast. The climatic variation in northern Mexico is even more extreme than in Texas. Because of the extreme topographical variation in Mexico and the moisture arriving from the Gulf of Mexico, annual precipitation exceeds 40 inches in the



WATERSHED ID	RIVER SYSTEM	UPSTREAM TERMINUS	DOWNSTREAM TERMINUS
AT/AM	Rio Grande	New Mexico State Line	Rio Grande at Ft. Quitman
BT/BM	Rio Grande	Rio Grande at Ft. Quitman	Rio Grande above Rio Conchos
CT/CM	Rio Grande	Rio Grande above Rio Conchos	Rio Grande near Del Rio
DT/DM	Rio Grande	Rio Grande near Del Rio	Rio Grande below Falcom Dam
ET/EM	Rio Grande	Rio Grande below Falcom Dam	Rio Grande below Anzalduas
FM	Rio Conchos	Headwaters	Rio Conchos at Ojinaga
GT	Pecos River	Pecos River at Red Bluff, NM	Pecos near Langtry

FIGURE 1 RIO GRANDE BASIN IN TEXAS AND MEXICO WITH DESIGNATED SUBWATERSHEDS

11,500-foot mountains near Monterrey in the southern portion of the basin. The upper watershed of the Rio Conchos in the northwestern portion of the basin has a mean elevation that exceeds 5,000 feet and an annual precipitation ranging between 20 and 32 inches. However, lower elevations are desert with an annual precipitation of 8 to 12 inches. The higher elevation reservoir La Boca, located in northeastern Mexico, has a measured annual gross evaporation loss of 59 inches. However, the large low-elevation reservoirs Luis Leon and Venustiano Carranza located within the arid regions of the states of Chihuahua and Coahuila have measured gross evaporation rates of approximately 100 inches per year.

1.5 Texas Water Rights in Existing Rio Grande WAM

The Rio Grande WAM as originally developed included a representation of every individual Texas water right in the Rio Grande basin, a total of approximately 960 water rights with approximately 1,450 authorized water right activities, i.e., primarily diversions and reservoir storage. These water rights can be categorized into three different groups as described below based on their location within the Rio Grande basin and their legal basis for diverting and using water from the Rio Grande and its tributaries:

Group 1 Water rights that are located on the mainstem of the Rio Grande downstream of Amistad Reservoir and that are entitled to use stored United States water released from Amistad and Falcon Reservoirs. Allocations of reservoir inflows to individual water right's reservoir storage accounts are based on three different types of use: 1) Domestic, Municipal and Industrial ("DMI") rights with the highest allocation priority, 2) Class A Irrigation and Mining rights, and 3) Class B Irrigation and Mining rights, with the Class A rights allocated 1.7 times as much water as the Class B rights after full allocations to the DMI rights. As simulated with the Rio Grande WAM, Group 1 water rights have access to available streamflows at their location on the Rio Grande first and then to reservoir releases (after accounting for losses during delivery) to meet their demands.

Group 2 Water rights that are located on tributaries of the Rio Grande downstream of Amistad Reservoir that are dependent on available streamflows and that are administered with regard to water availability in accordance with the prior appropriation doctrine. Group 2 water rights only have access to available streamflows at their location and do not have access to water released from Amistad and Falcon Reservoirs.

Group 3 Water rights that are located upstream of Amistad Reservoir either on the mainstem of the Rio Grande or on Rio Grande tributaries that also are dependent on available streamflows at their location and that are administered with regard to water availability in accordance with the prior appropriation doctrine.

In accordance with TCEQ Rules, Chapter 303 - Operation of the Rio Grande, the available supply of Amistad-Falcon water for all water rights within each of the three different types of use in Group 1 is the same per acre-foot of authorized diversion amount. Stated another way, the allocation for all DMI water rights is the same per acre-foot of diversion authority, the allocation for all Class A water rights is the same per acre-foot of diversion authority, and the allocation for all Class B water rights is the same per acre-foot of diversion authority. Because of these uniform allocation procedures by water right type, and the fact that in the WAM the demand for each water right is specified at its authorized diversion amount, the reliability of all Amistad-Falcon water rights within each of the three different designated types of use is the same. Consequently, the simulation process in the WAM for these water rights that are allocated water from Amistad and Falcon Reservoirs can be greatly simplified by combining all of these water rights by their type of use (DMI, Class A or Class B) and by general location (below or above Falcon Reservoir), and then simulating water availability for each of these different sets of water rights rather than for each individual water right.

In 2013, as part of the Region M Rio Grande Water Planning Study[2], this simplified simulation approach was incorporated into the original version of the WAM with all of the Amistad-Falcon water rights distributed into 14 individual sets. These 14 sets of water rights are listed below with their associated authorized annual diversion amounts as currently included in the existing Rio Grande WAM. These have not been changed as part of this study.

		Ac-Ft/Year
(1)	Domestic, Municipal and Industrial rights below Falcon Reservoir	253,428
(2)	Class A Irrigation rights below Falcon Reservoir	1,411,050
(3)	Class A Mining rights below Falcon Reservoir	1,077
(4)	Class A Municipal rights below Falcon Reservoir	465
(5)	Class B Irrigation rights below Falcon Reservoir	131,682
(6)	Class B Mining rights below Falcon Reservoir	5,020
(7)	Class B Municipal rights below Falcon Reservoir	3,823
	TOTAL DIVERSIONS BELOW FALCON RESERVOIR:	1,806,545
(8)	Domestic, Municipal and Industrial rights between Falcon and Amistad Reservoirs	74,216
(9)	Class A Irrigation rights between Falcon and Amistad Reservoirs	156,946
(10)	Class A Mining rights between Falcon and Amistad Reservoirs	9,173
(11)	Class A Municipal rights between Falcon and Amistad Reservoirs	2,051
(12)	Class B Irrigation rights between Falcon and Amistad Reservoirs	18,051
(13)	Class B Mining rights between Falcon and Amistad Reservoirs	10,177
(14)	Class B Municipal rights between Falcon and Amistad Reservoirs	63
	TOTAL DIVERSIONS BETWEEN FALCON AND AMISTAD RESERVOIRS:	270,677
	TOTAL DIVERSIONS FOR AMISTAD-FALCON RESERVOIR SYSTEM:	2,077,222

2 Rio Grande Regional Water Planning Group; "2016 Rio Grande Regional Water Plan, Volume I"; prepared by Black & Veatch and Subconsultants; December 1, 2015.

As shown, the sum of the authorized diversions for all of these water rights totals 2,077,222 acre-feet per year, with the vast majority of these diversions (87%) for water rights located below Falcon Reservoir. Additionally, the majority of the diversions are authorized for irrigation use: 85% for water rights located downstream of Falcon Reservoir and 65% for water rights located between Falcon and Amistad Reservoirs. It should be noted that each of the individual water rights in the sets listed above as Nos. 4, 7, 11 and 14 are legally designated as Class A or Class B Irrigation and Mining rights, but according to language in their individual certificates of adjudication, they are actually authorized for municipal use. In the simplified WAM, these four special sets of water rights were created to facilitate more accurate representations of their patterns of water use.

With the 14 sets of Amistad-Falcon water rights incorporated into the simplified WAM, the model can be operated in the same way as the original WAM, with water availability simulated: 1) for each of the individual water rights located on the mainstem of the Rio Grande and on its tributaries above Amistad Reservoir, 2) for each of the individual water rights located on Rio Grande tributaries below Amistad Reservoir, and 3) for each of the 14 sets of water rights. Simulated reliability results for each of the 14 sets of Amistad-Falcon water rights from the simplified WAM are directly applicable to each of the individual water rights within each of the sets. For example, if the authorized diversion for one of the 14 sets of water rights as simulated with the simplified WAM is indicated to be fully satisfied 75% of the time, then the authorized diversion for each of the individual water rights within this particular set also is fully satisfied 75% of the time. This simplified version of the Rio Grande WAM as developed for the Region M study was adopted by the TCEQ for purposes of water rights administration in 2014[3], and this is the version of the Rio Grande WAM that has been updated in this current study with the addition of 2001-2018 naturalized flows and net evaporation data.

[3] TCEQ letter, "Region M changes to the Rio Grande WAM," dated January 14, 2014 from Dr. Kathy Alexander, Water Availability Division to Ms. Connie Townsend, TWDB.

2.0 GENERAL STREAMFLOW NATURALIZATION PROCESS

For the Rio Grande basin, naturalized streamflows are derived from actual historical measurements of streamflows that are made at gaging stations operated by either the IBWC or the U. S. Geological Survey ("USGS"). Mean daily flow values from these gages are summed to derive monthly streamflows for use in the naturalization process. Sometimes, when adequate data are not available from streamflow gages, historical records of end-of-month reservoir storage, together with corresponding data for reservoir evaporation, rainfall, diversions, return flows, releases, and spills can be used to calculate, or deduce, historical monthly reservoir inflows. These calculated or deduced reservoir inflows then can be used as representations of actual historical streamflows at that location.

Regardless of the source of the historical monthly streamflows, adjustments to these values are made according to the following general equation to derive the corresponding naturalized streamflows at a particular location.

Naturalized Streamflows	=	Historical Streamflows
	+	Historical Upstream Diversions
	–	Historical Upstream Return Flows
	+	Historical Changes in Upstream Reservoir Storage
	+	Historical Upstream Reservoir Evaporation Loss
	-	Historical Upstream Miscellaneous Adjustments

This equation can be simplified as:

Naturalized Streamflows	=	Historical Streamflows
	+	Cumulative Upstream Historical Adjustments

As stated, all upstream diversions are added to the historical gaged streamflows at a particular location, and all upstream return flows consisting of municipal and industrial wastewater discharges and agricultural drain flows are subtracted from the historical gaged streamflows at that location. The effects of all upstream reservoirs are captured based on historical changes in reservoir storage (with positive being a storage increase) and the historical reservoir net evaporation loss (negative when rainfall exceeds evaporation). The sum of all of these adjustments upstream of a particular location where naturalized flows are being calculated (normally a gage site) is referred to as the Cumulative Upstream Historical Adjustments. For each of the individual adjustments included in the Cumulative Upstream Historical Adjustments term at a particular location, streamflow channel losses are accounted for from the upstream locations where the adjustment activities occur downstream to the location where naturalized flows are being calculated. These streamflow channel loss factors are discussed in Section 7.2.

In some cases, it may be appropriate to remove upstream spring discharges from the measured streamflows at a downstream gage location so that the gaged flows only represent watershed runoff - this can be accomplished using the Historical Upstream Miscellaneous Adjustments term in the above equation. Once removed from the gaged flows, the spring discharges then can be specified in the WAM (using time series FA records) at the actual location of the spring. This concept is discussed in more detail in Sections 4.2 and 5.2 of this report.

Streamflow losses attributable to channel seepage, evaporation, aquatic plant uptake, and other unaccounted-for factors must be considered in deriving the naturalized streamflows for the Rio Grande basin. While such losses are embedded in historical gaged flows to the extent that they actually occurred along a particular channel reach, the corresponding losses associated with the various streamflow adjustments that are required to naturalize the gaged flows (to remove the effects of historical diversions, return flows, and reservoir storage/evaporation) must be accounted for separately. These additional streamflow losses have been factored into the streamflow naturalization process for those stream reaches that have exhibited losses, and this issue is addressed in more detail in Section 7.2 of this report.

The term referred to as "Historical Upstream Reservoir Evaporation Loss" in the general streamflow naturalization equation has a special meaning that is unique to the naturalization process. First of all, it actually means "Net Evaporation Loss," which is defined as the net loss of water from a reservoir's surface area due to the difference between the evaporation and the precipitation that occurs during any given month. On average in the Rio Grande basin, the total or gross annual evaporation from the water surface of a reservoir (outflow) exceeds the annual precipitation that falls on the surface of the reservoir (inflow); therefore, the net evaporation term is positive for most months, although it certainly can be negative during wet periods. Second, the Historical Upstream Reservoir Evaporation Loss term also includes an additional adjustment for the amount of runoff that would have occurred, and appeared at the downstream gage, if all upstream reservoirs had not been in place. By simply taking the difference between the gross evaporation rate and the amount of precipitation that fell on the surface of the reservoir during a given month to define the net evaporation loss in the streamflow naturalization equation, the effect of precipitation in the evaporation adjustment term is overstated by the amount of runoff that would have occurred from the reservoir area (in the absence of the reservoir) and that eventually would have contributed to streamflow at the gage. To account for this local runoff, the evaporation rate that is used for calculating the Historical Upstream Reservoir Evaporation Loss in the streamflow naturalization equation is defined by the following relationship and referred to as the "Adjusted Net Reservoir Evaporation".

Adjusted Net Reservoir Evaporation	=	Gross Reservoir Evaporation
	–	Precipitation on the Reservoir Surface
	+	Runoff from Reservoir Area without Reservoir

The value of the Runoff term in the above equation for a particular reservoir for a particular month must be determined based on the actual amount of precipitation that fell at the reservoir site and the estimated portion of that rainfall that would have occurred as runoff from the reservoir footprint. While estimates of historical monthly rainfall amounts generally are available from existing records, the estimation of the associated runoff from the reservoir site can involve a number of complex factors regarding the local reservoir watershed without the reservoir in place, including soil types, vegetative cover, land use, and antecedent soil moisture conditions. For purposes of deriving naturalized streamflows, however, an exact accounting of these factors is not necessary considering the accuracy of the overall streamflow naturalization process itself and the relative magnitude of the runoff term compared to the total precipitation volume (usually less than 20 percent). The process of evaluating runoff for a given amount of precipitation at a reservoir site during a given month can be simplified by applying a runoff coefficient to the rainfall. This is the approach that is used in this investigation. Historical monthly streamflows for selected streamflow gages throughout the basin were analyzed, in conjunction with corresponding historical monthly rainfall amounts, in the initial 2003 WAM study to calculate representative monthly runoff coefficients. In this investigation, these same runoff coefficients have been applied to historical monthly rainfall at reservoir sites to estimate runoff for purposes of calculating the Adjusted Net Reservoir Evaporation term used in the streamflow naturalization equation.

3.0 ALTERNATIVE APPROACH FOR MEXICO TRIBUTARY INFLOWS

As part of the preparation of the Detailed Work Plan at the outset of this investigation, an assessment was made of ways in which the effort required to develop naturalized flows for the Rio Grande WAM could possibly be minimized, particularly in light of the difficulties anticipated with acquiring from Mexico all of the data needed for naturalizing flows for all of the tributaries in Mexico. The existing Rio Grande WAM includes 12 primary control points on tributaries in the interior of the Mexico portion of the Rio Grande basin and eight primary control points on Mexico tributaries immediately at or near their confluence with the Rio Grande. Naturalizing the streamflows for all of these primary control points on the Mexico tributaries for the extended 2001-2018 period would be a challenging undertaking that would require extensive data for all of the gaged streamflows and upstream diversions, wastewater discharges and reservoir operations in Mexico. Considering the international complications with acquiring all of these data, particularly for the interior areas of the Mexico tributaries, and the considerable time that likely would be required to acquire these data from Mexican governmental entities or directly from Mexico municipalities and irrigation districts, an alternative approach has been conceived for representing the tributary inflows to the Rio Grande from Mexico that reflects the utilization of Mexico's surface water resources in a manner consistent with the WAM's assumption of full water rights utilization by Texas water users.

Instead of operating the WAM to simulate regulated flows for all of the major Mexico tributaries, including interior areas, this alternative approach involves using historical gaged flows as close representations of the regulated inflows to the Rio Grande for each of the Mexico tributaries for the extended 2001-2018 period. In the WAM, rather than inputting naturalized flows at all Mexico primary control points for every time step during the 2001-2018 period and then simulating regulated flows for all of the Mexico tributaries, which would require simulating all of Mexico's interior water use, return flow, and reservoir storage activities, under this alternative approach the historical gaged inflows to the Rio Grande for each of the Mexico tributaries have been used to directly represent the regulated Mexico inflows at each time step during the extended 2001-2018 WAM simulation period. This approach does not produce naturalized flows for the Mexico tributaries, but it does produce the necessary inputs for the Rio Grande WAM that would allow the effects of Mexico's full historical utilization of water within its tributary watersheds to be effectively represented in the extended 2001-2018 WAM simulation. Use of this alternative approach does not affect how the extended Rio Grande WAM simulates water use and flow conditions for Mexico's tributaries for the 1940-2000 portion of the total WAM simulation period. Naturalized flows for the 1940-2000 period are still used in the simulation of interior water use activities for all of Mexico's tributaries. This alternative approach only applies to the extended 2001-2018 period of the WAM simulation.

The most critical aspect of using this alternative approach for representing Mexico's regulated tributary inflows to the Rio Grande relates to provisions of the 1944 Treaty between the United States and Mexico ("Treaty"). Paragraph B(c) of Section II of Article 4 of the Treaty allocates to the United States one-third of the flow reaching the Rio Grande from Mexico's Rios Conchos, San Diego, San Rodrigo, Escondido and Salado and the Las Vacas Arroyo, *"provided that this third shall not be less, as an average amount in cycles of five consecutive years, than 350,000 acre-feet annually*". Hence, from the perspective of Texas Rio Grande water users, it is important that the inflows to the Rio Grande from the Mexico tributaries named in the Treaty be properly represented in the Rio Grande WAM since the United States is entitled to one-third of these inflows.

The Treaty further states that *"In the event of extraordinary drought or serious accident to the hydraulic systems on the measured Mexican tributaries, making it difficult for Mexico to make available the run-off of 350,000 acre-feet annually ..... any deficiencies existing at the end of the aforesaid five-year cycle shall be made up in the following five-year cycle with water from the said measured tributaries"*. Over the last 30 years or so, Mexico often has had difficulty meeting its obligation under the Treaty to provide an average of 350,000 acre-feet annually in designated five-year cycles to the Rio Grande from the six named tributaries. In fact, Mexico did not meet its Treaty obligation at the end of two consecutive five-year cycles ending in 2002 when Mexico's deficit was about one and half million acre-feet. With some timely runoff events during the subsequent cycle and through negotiations between the United States and Mexico, Mexico's deficit was eliminated by the end of September, 2005. Since then, while Mexico has accrued deficits during individual five-year cycles, it has been in compliance with the terms of the Treaty with regard to delivering to the United States an average of 350,000 acre-feet annually in consecutive five-year cycles to the Rio Grande from the six named tributaries.

While Mexico has argued that much of these deficits have been the result of "extraordinary drought", and in some years it may have been, the fact is that Mexico normally operates all of its reservoirs on the named tributaries, and likely on all of its tributaries, <u>essentially to fully retain all inflows, including flood flows, except for what has to be spilled or what may be required to be released for downstream uses only in Mexico</u>. While Mexico has on a few occasions released some water from its tributary reservoirs in an effort to overcome accumulated deficits in its Treaty deliveries to the United States, typically only flood spills or releases from its tributary reservoirs and local inflows to the Rio Grande from the watersheds below its tributary reservoirs have contributed to Mexico's Treaty obligation of delivering to the United States an average of 350,000 acre-feet of Rio Grande inflows annually in five-year cycles.

Because of the circumstances described above regarding Mexico's reservoir operations and its historical performance pursuant to satisfying the Treaty tributary inflow obligations, the historical flows that have reached the Rio Grande from the six named tributaries, as well as from other Mexico tributaries, very likely represent close to the maximum amounts that can be expected. In essence, Mexico tributary flows that are not diverted and used directly by Mexico's own internal water users are retained in Mexico's tributary reservoirs, and those flows that do reach the Rio Grande from these tributaries generally represent either reservoir flood spills, irrigation return flows, or runoff from the watersheds below the tributary reservoirs that cannot be utilized in Mexico. For these reasons, with regard to extending the Rio Grande WAM's naturalized flow database, it is not likely that under normal flow conditions, modeling of Mexico's tributaries will result in inflows to the Rio Grande that are significantly different from the historical gaged inflows. Essentially, the gaged tributary flows that reached the Rio Grande from Mexico during the 2001-2018 period represent, under normal non-flood conditions, close to the maximum possible inflows to the river given Mexico's operation of its reservoirs. These inflows already reflect substantially full water consumption within Mexico, either by Mexico's water users in the tributary basins or by the full retainage of inflows in tributary reservoirs, which is consistent with what the WAM would simulate if the streamflows in Mexican were to be naturalized. Furthermore, Mexico already has extensive conservation storage capacity in its tributary reservoirs, over six million acre-feet with more than three million acre-feet of flood storage capacity, and it is unlikely that Mexico would construct an appreciable amount of additional reservoir storage capacity since most of its existing reservoirs already are less than full much of the time.

There is one situation, however, where there could be significant differences between the gaged tributary inflows to the Rio Grande and the corresponding simulated regulated flows from the WAM. This would be for those Mexico tributaries with reservoirs that have substantial flood storage capacity above their conservation pools. In this case, because reservoirs modeled with the WAM are not assigned storage capacity above their conservation storage capacity, any inflows to these reservoirs in excess of available conservation storage capacity, such as what would occur during flood events, are calculated as spills in the model immediately during each monthly time step of the simulation and allowed to flow downstream. This is in contrast to how these Mexico tributary reservoirs have been operated whereby the excess inflows are retained in the flood pools and then gradually released either to minimize downstream flooding or to meet the needs of downstream Mexico water users. These retained flood flows typically are not released to meet Mexico's obligation under the Treaty to supply water to the United States. Under these circumstances, the actual tributary inflows to the Rio Grande with flood storage in the Mexico reservoirs could be substantially less than the tributary inflows simulated with the WAM with no reservoir flood storage accounted for. This would suggest that the high tributary inflows simulated with the WAM likely are overstated, and the actual gaged flows are likely a better representation of how much of the Mexico tributary inflows are contributed to the United States under the Treaty.

An evaluation of the appropriateness of using the alternative approach for representing Mexico tributary inflows to the Rio Grande in the WAM has been made by comparing historical gaged inflows for the major Mexico tributaries to the corresponding regulated inflows simulated with the existing Rio Grande WAM for the 1940-2000 period. These evaluations are discussed in the following sections for all of the major Mexico tributaries.

3.1 Rio Conchos

Figure 2 presents a comparison of 1970-2000 annual gaged flows and the annual simulated regulated flows from the Rio Grande WAM for the Rio Conchos at Ojinaga. The Rio Conchos is the largest and most upstream of the six Mexico tributaries named in the 1944 Treaty that are designated to contribute one-third of their inflows to the Rio Grande to the United States. Also are shown on the plot are the annual historical gaged flows for the 2001-2018 WAM extension period.

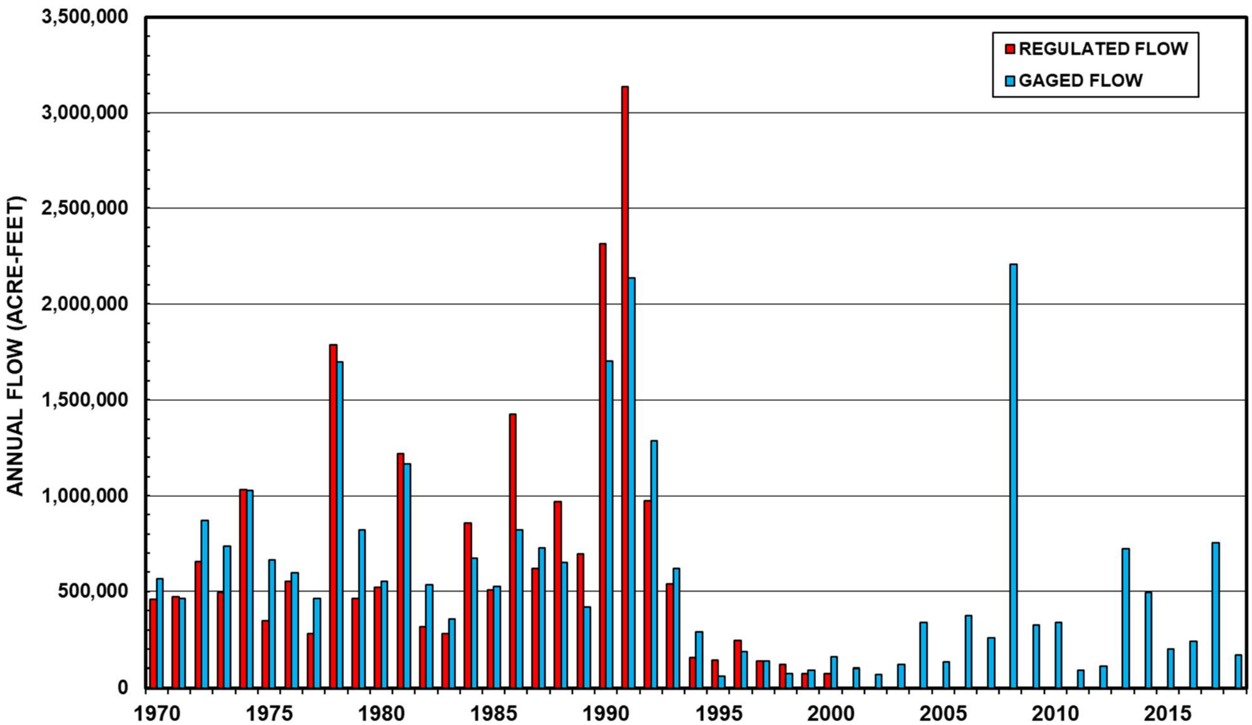


FIGURE 2 COMPARISON OF GAGED FLOWS WITH WAM REGULATED FLOWS FOR RIO CONCHOS AT OJINAGA

On the plot, the obvious major deviations of the 1970-2000 gaged flows from the corresponding regulated flows simulated with the WAM occur during high-flow years, with the simulated flows being considerably greater than the historical gaged flows. These large differences in annual flows occur because of floodwater storage in Luis L. Leon Reservoir, which is located on the Rio Conchos about 200 miles upstream from the Ojinaga gage and has a conservation storage capacity of 237,100 acre-feet with a large flood pool with approximately 400,000 acre-feet of storage capacity. This is the situation described above whereby floodwaters are stored in the flood pool and then gradually released during later periods either to minimize downstream flooding or to meet downstream Mexico water needs along the Rio Conchos, thus leaving significantly reduced tributary inflows to the Rio Grande. Mexico has always operated this reservoir, and others, in this manner, and the deviations between gaged flows and the simulated regulated flows are to be expected considering the way the WAM is structured to limit storage in Luis L. Leon Reservoir to its conservation storage capacity[4]. It is apparent that the higher tributary inflows simulated with the WAM without flood storage in Luis L. Leon Reservoir provide substantially more water to the United States based on the terms of the Treaty than actually was contributed under existing conditions with the floodwater inflows to the reservoir retained in its flood pool.

The historical gaged inflows shown on the plot in Figure 2 for the 2001-2018 period indicate that there is only one year, 2008, within the 2001-2018 WAM extension period where this deviation between the gaged and simulated (regulated) Rio Conchos flows could be significant. Examination of the historical 2008 storage data for Luis L. Leon Reservoir indicates that during month of September of 2008, storage in the reservoir was near its conservation storage capacity at the beginning of the month (237,100 acre-feet), but rapidly increased due to floodwater inflows to a maximum of approximately 650,000 acre-feet on September 15th. With floodwater releases, the reservoir storage was lowered down to about 470,000 acre-feet by the end of the month, but it was never reduced down to the conservation storage level during the remainder of the year. In a WAM simulation, with storage in the reservoir already at the conservation pool level at the beginning of September 2008, the entire volume of floodwater entering the reservoir during the month (~415,000 acre-feet) would be spilled downstream at the end of the September 2008 monthly time step. This simulated spill volume would, of course, contribute to the Rio Conchos inflows to the Rio Grande for the month of September 2008, and thus, to Rio Grande flows assigned to the United States under the provisions of the 1944 Treaty.

Considering the differences between the lower gaged historical flows for the Rio Conchos at Ojinaga and the higher simulated flows from the WAM, from a practical standpoint, the gaged flows likely provide a more realistic representation of inflows from the Rio Conchos to the Rio Grande, of which the United States would receive one-third in accordance with provisions in the 1944 Treaty. The fact is, most of the difference between the gaged and simulated flows represents flood flows that actually are stored in the flood pool of Luis L. Leon Reservoir and never reach the Rio Grande anyway, and consequently, do not produce inflows to the Rio Grande that could benefit the United States under the 1944 Treaty. For this reason, use of the 2001-2018 gaged flows as a representation of the regulated inflows to the Rio Grande from the Rio Conchos is considered to be more realistic and appropriate for purposes of extending the naturalized flow database for the Rio Grande WAM.

3.2 Other Mexico Tributaries Contributing Flows to United States

A comparison plot of the total annual gaged flows and the total annual simulated regulated flows for the other five Mexico tributaries named in the 1944 Treaty that contribute one-third of their

[4] Records reported in IBWC's Year-2006 Water Bulletin indicate that the monthly average storage in Luis L. Leon Reservoir for the 1968-2006 period exceeded the reservoir's conservation storage capacity in every month except for one, indicating that normally this reservoir has been operated with water stored in its flood pool.

inflows to the Rio Grande to the United States (Rio Conchos, Arroyo de las Vacas, Rio San Diego, Rio San Rodrigo, Rio Escondido, and Rio Salado) is presented in Figure 3. As shown, these gaged inflows compare favorably with the regulated inflows from the WAM. Only one of these tributaries has a significant reservoir. Venustiano Carranza Reservoir is located in the middle-upper portion of the Rio Salado basin, and it has significant storage capacity (1,121,870 acre-feet) for capturing inflows that are subsequently used to supply water to a major irrigation district with a water demand of about 300,000 acre-feet per year. With this significant storage capacity, it is likely that most of the inflows to the Rio Grande from the Rio Salado originate below Venustiano Carranza Reservoir. However, based on the general agreement between the annual gaged and simulated inflows to the Rio Grande from all five of the tributaries plotted in Figure 3, the use of the gaged inflows for each of these five Mexico tributaries as representations of the corresponding regulated inflows to the Rio Grande for purposes of the extension of the WAM database appears to be justified and appropriate.

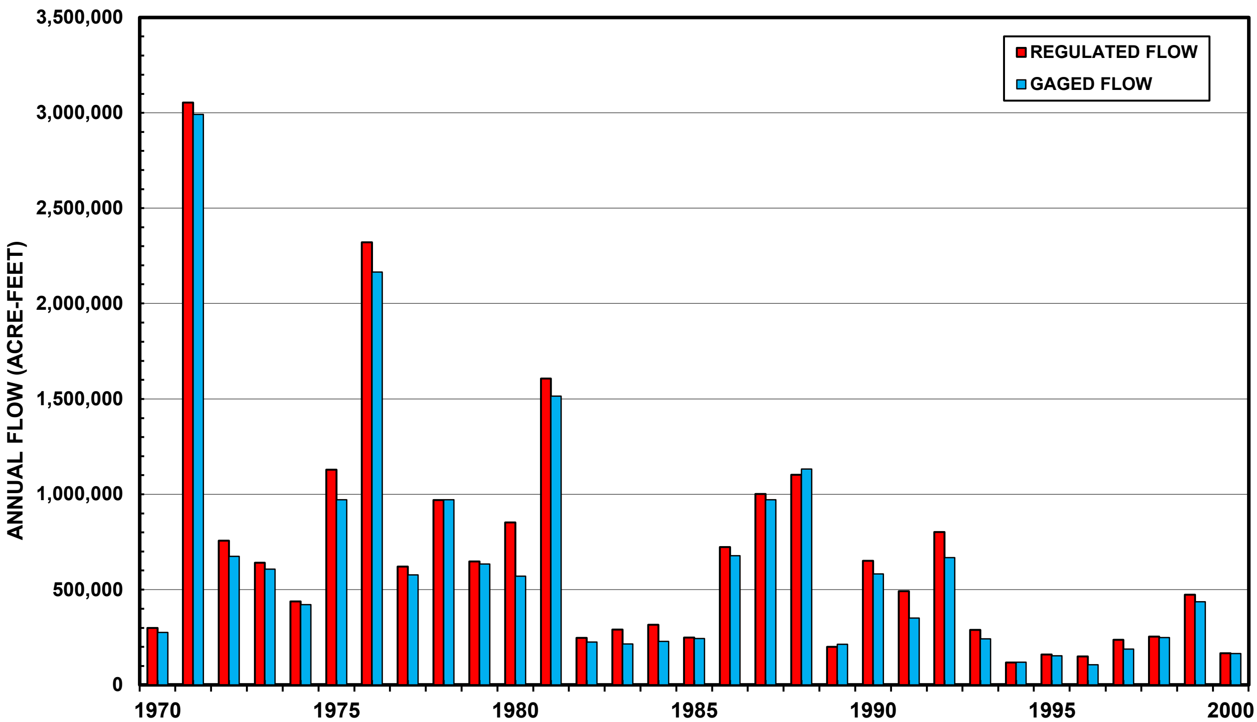


FIGURE 3 COMPARISON OF GAGED FLOWS WITH WAM REGULATED FLOWS FOR MEXICO TRIBUTARIES THAT CONTRIBUTE FLOWS TO THE UNITED STATES EXCEPT RIO CONCHOS

3.3 Rio Alamo and Rio San Juan

There are two other major tributaries, Rio Alamo and Rio San Juan, that provide inflows to the Rio Grande from Mexico. Both of these are located downstream of Falcon Reservoir, and in accordance with the Treaty, all of the inflows to the Rio Grande from these tributaries are owned by Mexico - none is assigned to the United States. Hence, from the perspective of Texas water users, accurately modeling these inflows to the Rio Grande with the WAM is not as critical as for the inflows from the six named Treaty tributaries of which the United States is designated to receive one-third.

A comparison plot of the gaged inflows to the Rio Grande and the WAM-simulated regulated inflows for Rio Alamo is presented in Figure 4.

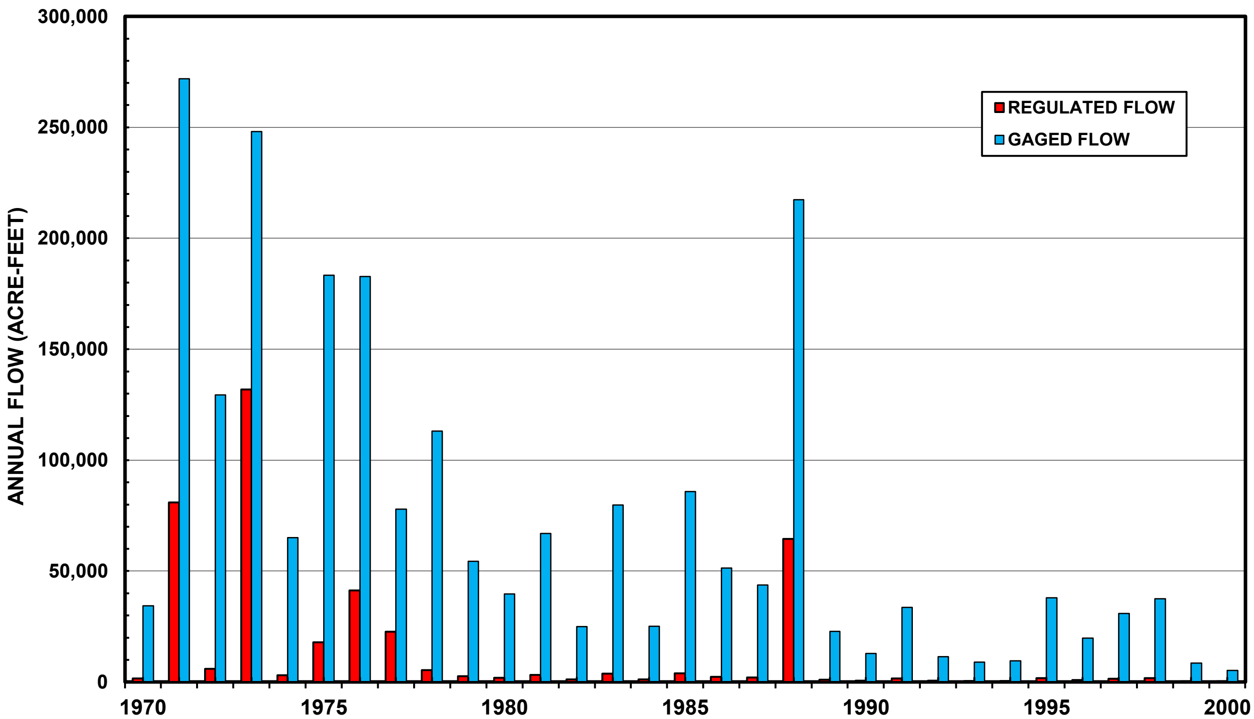


FIGURE 4 COMPARISON OF GAGED FLOWS WITH WAM REGULATED FLOWS FOR RIO ALAMO AT CD. MIER

As illustrated, this plot shows considerably more gaged inflows than regulated inflows in all years during the 1970-2000 period, which is just the opposite from the trend exhibited by the Rio Conchos inflows in Figure 2. However, this trend is consistent with the fact that the only major reservoir on the Rio Alamo, Las Blancas Lake, did not exist until the year 2000 and yet, by design, was included in the original Rio Grande WAM. Thus, in the WAM simulation for the 1940-2000 period, Rio Alamo flows are impounded in this reservoir, which significantly reduces the flows measured at the downstream gage. It is important to note that Rio Alamo inflows stored in Las Blanca Lake are conveyed to Marte R. Gomez Reservoir on the Rio San Juan to help meet water demands in that basin, which, in the WAM simulation, results in available storage capacity in Las Blanca Lake for impounding Rio Alamo flows. In reality, since Las Blancas Lake did not exist prior to 2000, these Rio Alamo flows passed uninhibited to the Rio Grande, thus the higher gaged flows. Considering that Las Blancas Lake on the Rio Alamo has been in operation since 2000 with diversions from this reservoir to the Rio San Juan basin, use of the Rio Alamo historical gaged flows to represent the Rio Alamo regulated inflows to the Rio Grande for the 2001-2018 period in the extended WAM is considered reasonable and appropriate.

The plot of annual gaged inflows versus annual regulated inflows for the Rio San Juan at Carmargo gage is presented in Figure 5. As shown, the regulated inflows are greater, to varying degrees, than the gaged inflows in almost all years. While this is similar to the trend exhibited in Figure 2 for the Rio Conchos, in this case the causes appear less obvious and more complex. First of all, the Rio San Juan has two large reservoirs located upstream of the Carmargo gage, El Cuchillo, constructed in 1993 with 910,304 acre-feet of conservation storage capacity and about 500,000 acre-feet of flood control storage, and Marte R. Gomez, constructed in 1943 with 889,228 acre-feet of conservation storage capacity and over one million acre-feet of flood control storage. Furthermore, as noted above, water from Las Blancas Lake on the Rio Alamo is diverted to Marte R. Gomez Reservoir to help meet water demands in the Rio San Juan basin.

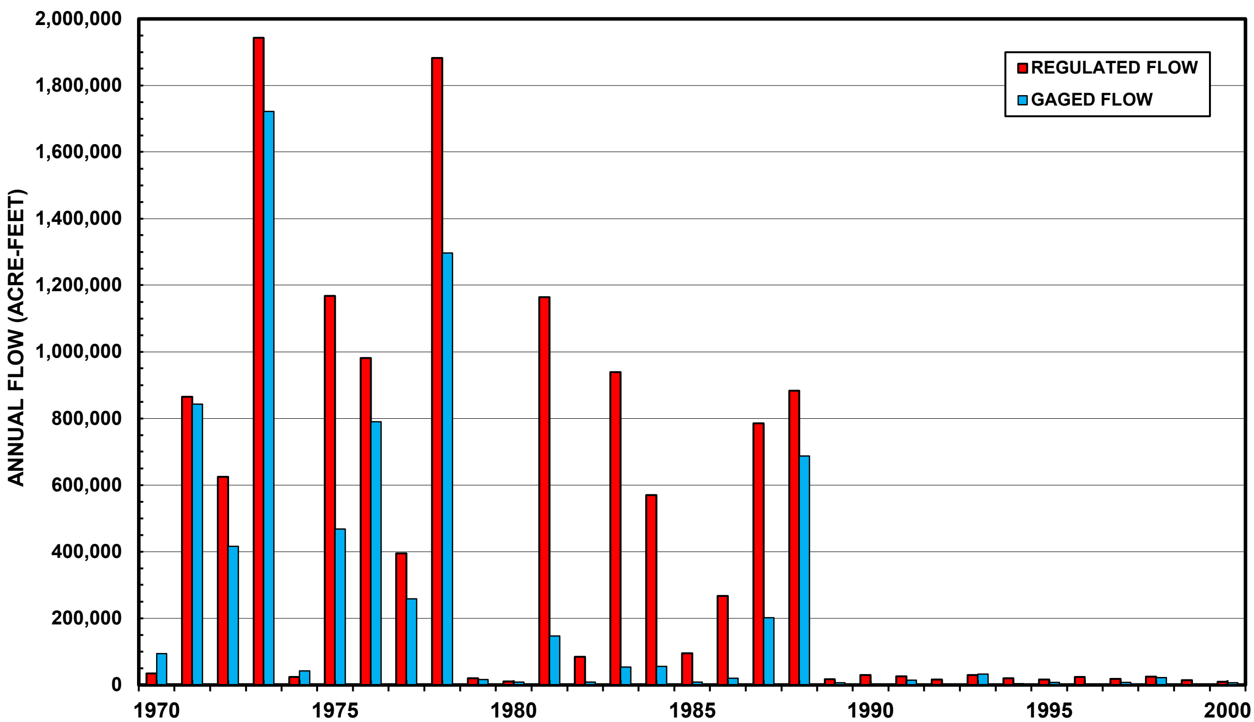


FIGURE 5 COMPARISON OF GAGED FLOWS WITH WAM REGULATED FLOWS FOR RIO SAN JUAN AT CARMARGO

How these reservoirs are operated relative to each other with regard to managing flood flows and meeting Mexico's interior water demands is complicated and not fully understandable based on available information. Also, it is possible that the actual historical demands for water by Mexico users in the Rio San Juan basin simply are much greater than the demands, referred to as "concessions", specified in the WAM. Major users of water from El Cuchillo Reservoir include the City of Monterrey and the Las Lajas Irrigation District, and the actual water demands of these entities may be substantially greater than what was determined when the original WAM was developed. As noted in the original Rio Grande WAM report, considerable data fill-in and estimation were required to derive Mexico's concession amounts, and these may have translated to projected concessions less than what water usage actually is today. In any event, as noted above, the need to accurately simulate the inflows from the Rio San Juan to the Rio Grande is not critical to Texas water users since none of these inflows are assigned to the United States under the 1944 Treaty, and the use of the gaged flows to represent the regulated inflows to the Rio Grande from the Rio San Juan is considered reasonable and appropriate.

3.4 Representation in WAM

To understand how this approach for representing Mexico tributary inflows to the Rio Grande has been incorporated into a WAM simulation, it is important to consider how the Rio Grande WAM is structured to simulate water use activities in Mexico and in the United States. Basically, in the WAM, the Rio Grande is divided into two different river systems, one representing Mexico and its tributaries and one representing the United States, or Texas, and its tributaries. Rio Grande mainstem flows are naturalized as a single total quantity with both countries' water combined, then these total naturalized flows are distributed to each country outside of and before being input to the WAM. Naturalized flows for all primary control points on tributaries in both countries are determined separately and specified separately in the WAM.

At each time step during the WAM simulation, the sequence of calculations proceeds such that Mexico's water use activities are processed first in upstream to downstream order, including tributary diversions and reservoir storage; this occurs before any of the Mexico simulated information is needed to support the simulation of United States water use activities. Thus, in accordance with the provisions of the 1944 Treaty that allocates one-third of the inflow to the Rio Grande from certain named Mexico tributaries to the United States, the simulated regulated inflows to the Rio Grande for each of these Mexico tributaries are available in advance of the assignment of these inflows to the separate Mexico and United States mainstem river systems.

It should be noted that use of the historical gaged Mexico tributary inflows to represent regulated inflows in the WAM simulation inherently includes Mexico's failure to comply with its obligation to deliver an annual average of 350,000 acre-feet of tributary inflows to the United States in five-year cycles during 2001-2005 of the 2001-2018 WAM extension period. However, this is considered appropriate and consistent with the way Mexico has operated its tributary reservoirs, which is not expected to change in the near future. What tributary flow Mexico has provided to the United States historically is likely to be reflective of future conditions.

With the alternative approach for representing Mexico's tributary inflows to the Rio Grande with gaged flows for the extended 2001-2018 period, naturalized flows for all of the interior Mexico primary control points are not needed, and, therefore, these are set equal to zero in the WAM input database. Consequently, the simulation of internal water use activities on the Mexico tributaries during each time step (diversions and reservoir storage) produces no change in the internal Mexico tributary flows - they remain equal to zero[5]. Then, with the regulated inflows to the Rio Grande for each of the Mexico tributaries set equal to the historical gaged inflows, with one-third allocated to the United States river system for the named tributaries in the 1944 Treaty, the normal simulation of all other water use activities proceeds from upstream to downstream, including for individual water rights on the Texas tributaries which are simulated in accordance with the prior appropriation doctrine.

In summary, the proposed approach for modeling Mexico's tributary inflows to the Rio Grande with the WAM for the 2001-2018 extension period assumes that the historical gaged tributary inflows are appropriate representations of the regulated inflows that would be simulated with the WAM after accounting for Mexico's interior water use activities, and as discussed above, they should be, considering the manner in which Mexico operates its interior reservoirs and uses its available tributary flows to fully meet its water demands and to fill its reservoirs. Hence, no naturalized flows have been calculated for any of Mexico's tributaries, and the historical gaged inflows to the Rio Grande for all of Mexico's tributaries, without modification, have been used to represent simulated regulated inflows to the Rio Grande in the WAM. It should be noted that using Mexico's gaged tributary inflows in the WAM reflects non-compliance with provisions of the 1944 Treaty by Mexico for the 2001-2005 period; however, this is consistent with how Mexico operates its interior water supply system and its tributary reservoirs.

For those Mexico tributaries that contribute inflows to the Rio Grande that are assigned to the United States under the 1944 Treaty, the negative consequences of using this alternative approach are not considered to be significant since Mexico already attempts to fully utilize its available water supplies from all of its tributaries, and this usage is reflected in the historical gaged flows. For those Mexico tributaries that do not contribute any flows to the United States under the Treaty (Rio Alamo and Rio San Juan), the representation of these gaged flows in the WAM is appropriate for the same reasons as described above for the Treaty tributaries. In addition, the flows from these tributaries are not critical to the available supply for Texas water users since these tributaries are located below Falcon Reservoir and do not contribute to the reservoir water supply. If at some point in the future Mexico should change how it operates its tributary reservoirs and how it utilizes its tributary water supplies pursuant to better compliance with the Treaty, then further modification of Mexico's tributary inflows as represented in the Rio Grande WAM may be warranted.

[5] It should be noted as discussed in Section 9.1, there is one unique situation where regulated flows are simulated for some of the interior control points within Mexico because Mexico's interior reservoirs contain simulated stored water at the end of December 2000, and this stored water is released from each reservoir over the subsequent months or years (until none remains) to meet the designated demands at downstream control points. As this released water passes intervening control points, regulated flows are simulated.

4.0 DATA COLLECTION, COMPILATION AND REVIEW

Data that have been required for developing monthly naturalized flows for the extended period of 2001-2018 for the Rio Grande WAM include the following:

- Monthly Gaged Streamflows
- Monthly Spring Discharges
- End-of-Month Reservoir Storage
- Reservoir Area-Capacity Relationships
- Monthly Reservoir Evaporation Rates
- Monthly Precipitation Amounts
- Monthly Diversions and Water Usage
- Monthly Municipal and Industrial Return Flows
- Monthly Irrigation Return Flows

Ideally, these data are needed for the entire 2001-2018 period; however, it is recognized that such complete data coverage generally is not likely to be available from existing records. Consequently, fill-in procedures have been employed to account for missing data. The available sources of the required data are identified and described in the following subsections. The procedures used to fill in and estimate missing data records are described in Section 5.0.

4.1 Monthly Gaged Streamflows

Certainly, the most important data needed for extending the naturalized flow dataset for the Rio Grande WAM are historical streamflows as measured at gages maintained by the IBWC, by the USGS, or by the Mexican government. With the exclusion of the Mexico tributary gages from the flow naturalization process, there are 23 streamflow gages for which naturalized flows have been developed for the extended 2001-2018 period, including 12 on the mainstem of the Rio Grande and 11 on tributaries in Texas.

Figure 6 shows the locations of the gages used for flow naturalization. Table 1 provides a listing of these gages with relevant descriptive information and available periods of record. As shown in the table, there are eight gages on the major Mexico tributaries near their confluence with the Rio Grande that have been used to provide the monthly Mexico tributary inflows to the Rio Grande in the WAM for the 2001-2018 period. As discussed in Section 3.0, the gaged flows for these eight Mexico tributaries for the 2001-2018 period have been substituted for naturalized flows in the WAM data input files and then used in the WAM simulation for the 2001-2018 period to represent simulated regulated tributary inflows to the Rio Grande from Mexico.

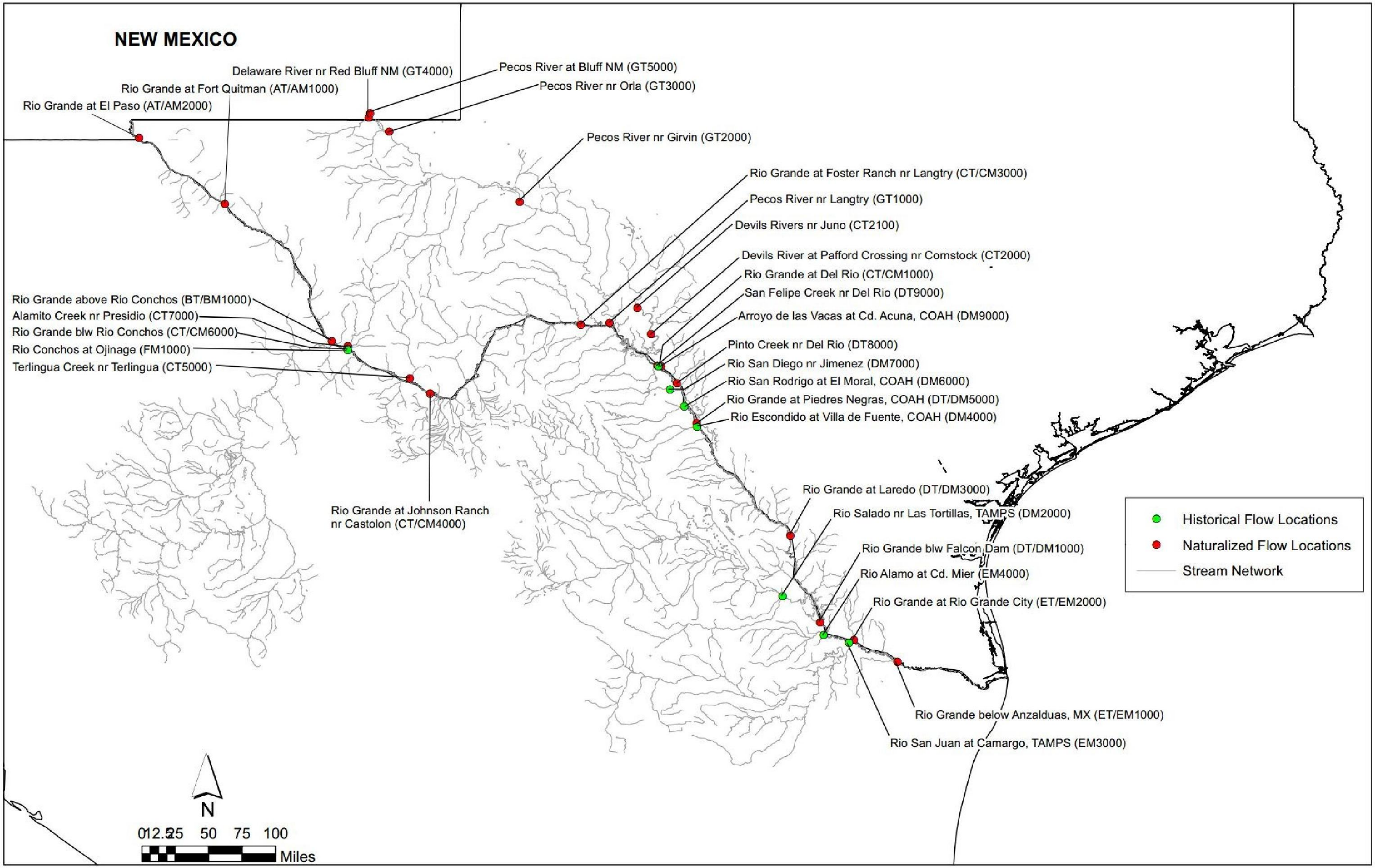


FIGURE 6 STREAMFLOW GAGES USED FOR DEVELOPING 2001-2018 NATURALIZED FLOWS

TABLE 1 STREAMFLOW GAGES USED IN 2001-2018 NATURALIZED FLOW PROCESS

WATER-SHED ID	NAME OF GAGE	IBWC/USGS GAGE NUMBER	DRAINAGE AREA SQ. MILES	PERIOD OF RECORD
MAINSTEM GAGES				
AT/AM	R Grande at El Paso, TX	08364000	29,267	1889 - Present
AT/AM	R Grande at Fort Quitman, TX [1]	08370500	31,944	1889 - Present
BT/BM	R Grande abv R Conchos, TX	08371500	35,000	1889 - Present
CT/CM	R Grande blw R Conchos, TX	08374200	66,339	1955 - Present
CT/CM	R Grande at Johnson Ranch nr Castolon, TX	08375000	67,760	1936 - Present
CT/CM	R Grande at Foster Ranch nr Langtry, TX	08377200	80,742	1961 - Present
DT/DM	R Grande at Del Rio, TX	08451800	123,302	1924 - Present
DT/DM	R Grande at Piedras Negras, COAH	08458000	127,311	1924 - Present
DT/DM	R Grande at Laredo, TX	08459000	132,577	1923 - Present
ET/EM	R Grande blw Falcon Dam	08461300	159,269	1953 - Present
ET/EM	R Grande at Rio Grande City, TX	08464700	174,362	1940 - Present
ET/EM	R Grande blw Anzalduas Dam, MX	08469200	176,112	1952 - Present
TEXAS TRIBUTARY GAGES				
CT	Alamito Ck nr Presidio, TX	08374000	1,504	1932 - Present
CT	Terlingua Ck nr Terlingua, TX	08374500	1,070	1932 - Present
G	Delaware R nr Red Bluff, NM	8408500	689	1937 - Present
G	Pecos R at Red Bluff, NM	08407500	19,540	1938 - Present
G	Pecos R nr Orla, TX [2]	08412500	21,210	1937 - Present
G	Pecos R nr Girvin, TX	08446500	29,562	1939 - Present
G	Pecos R nr Langtry, TX	08447410	35,179	1967 - Present
CT	Devils R nr Juno, TX [3]	08449000	2,730	1/1940 - 9/1949 10/1963 - 9/1973
CT	Devils R at Pafford Crossing nr Comstock, TX	08449400	3,960	1960 - Present
DT	San Felipe Ck nr Del Rio, TX	08453000	46	1931 - Present
DT	Pinto Ck nr Del Rio, TX	08455000	249	1929 - Present
MEXICO TRIBUTARY GAGES				
BM	R Conchos nr Ojinaga, CHIH	08373000	26,404	1924 - Present
DM	Arroyo de las Vacas at Cd. Acuna, COAH	08452000	350	1938 - Present
DM	R San Diego nr Jimenez, COAH	08455500	853	1932 - Present
DM	R San Rodrigo at El Maral, COAH	08457100	1,049	1962 - Present
DM	R Escondido at Villa de Fuente, COAH	08458150	1,459	1932 - Present
DM	R Salado nr Las Tortillas, TAMPS	08459700	20,463	1953 - Present
EM	R Alamo at Mier, TAMPS	08462000	1,675	1923 - Present
EM	R San Juan at Camargo, TAMPS	08464200	12,940	1954 - Present

Notes: [1] The Rio Grande at Fort Quitman gage has missing records for days during March 2012, August 2016 - April 2017, March 2018, and May - August 2018.
[2] The Pecos River near Orla gage has missing records for 11 days in 2017.
[3] The Devils River near Juno gage was discontinued beginning in October 1973.

Historical records of streamflows for the Rio Grande and the Texas and Mexico tributary gages listed in Table 1 for the 2001-2018 period have been obtained from the IBWC, with records for some of the Texas tributary gages obtained from the USGS. Except for three gages as indicated by the footnotes at the bottom of the table, complete records of streamflow are available for the entire 2001-2018 period. The fill-in procedures used for the three gages with missing records are discussed in Section 5.1.

4.2 Monthly Spring Discharges

When springflows are embedded in the naturalized streamflow records of a downstream gage along with runoff-generated flows, there is no logical way to distribute the naturalized gaged flows to upstream water rights, or any other secondary control point, using the standard drainage-area ratio proration procedure that is applied in WAM simulations. Ideally, the discharges from springs should be separated from the runoff-generated streamflows for each gage used in the streamflow naturalization process so that these two components of the total flow in a stream can be accounted for in the WAM separately and more realistically. With the springflows separated from the runoff-generated streamflows for a particular gage, the springflows can be specified in the WAM (using time series FA records) at the location upstream of the gage where the springflows are actually discharged into the stream. Then, the portion of the total streamflow that is generated by runoff from the watershed upstream of the gage can be distributed to water rights locations and other secondary points using the WAM's standard proration procedure. In this manner, each water right located downstream from a particular spring discharge point and upstream of a gage designated as a primary control point should have access to its appropriate share of the total available flow.

In the Rio Grande WAM, there is one series of springs located in the Toyah Creek watershed within the Pecos River basin that provides significant flows for local downstream water rights in the vicinity of the city of Balmorhea. These springs include primarily San Solomon and Giffin springs in Balmorhea State Park in Reeves County. All of the springs are associated with the Edwards-Trinity (Plateau) Aquifer. In the development of the original Rio Grande WAM, discharges from these springs were separated from streamflows at the downstream gage, and they were specified as a separate source of water for purposes of water availability simulations, and a similar procedure has been undertaken in this study for naturalizing the 2001-2018 flows.

Periodic measurements of monthly discharges for San Solomon and Giffin springs for the 2001-2018 period have been obtained from the San Angelo office of the USGS. While these data do not cover the entire 2001-2018 period for extending the naturalized flow dataset, there are sufficient data available to develop meaningful correlations and statistical relationships similar to what was done for the original naturalized flows so that a complete record for these springflows can be established. Fill-in procedures for these springflows are discussed in Section 5.2.

It should be noted that several springs appeared along the Rio Grande below Amistad Dam and along some tributaries, such as San Felipe Creek, after Amistad Reservoir was completed and began to fill in 1968. Discharges from these springs are attributable to seepage from the reservoir. Most of these springs are located upstream of the primary control point on the Rio Grande at Del Rio, and their discharges are accounted for in these gaged flows and their associated naturalized flows. Similarly, discharges from San Felipe springs enter San Felipe Creek just upstream of the streamflow gage on San Felipe Creek near Del Rio, and these spring flows are included in the measured gaged flows. There are no water rights between these springs and the gages; therefore, it was not necessary to separate the springflows from the gaged flows for purposes of simulating water availability with the WAM.

4.3 End-of-Month Reservoir Storage

As described in Section 2.0, the monthly changes in storage and evaporation losses for a given reservoir located upstream from a streamflow gage for which naturalized streamflows are being determined must be accounted for in the streamflow naturalization process. Also, if a particular reservoir is located in an area where gaged streamflow records are not available, then the monthly changes in the amounts of water stored in the reservoir can be used along with other parameters to calculate historical reservoir inflows, i.e., streamflows at that location.

Since streamflows for the Mexico tributaries have not been naturalized for the 2001-2018 period, the only reservoirs accounted for in the streamflow naturalization process are those on the mainstem of the Rio Grande and on Texas tributaries. For this purpose, only major reservoirs with a conservation storage capacity greater than 5,000 acre-feet have been considered. The major reservoirs that meet this criterion and that are accounted for in the naturalized flow process for the 2001-2018 period are shown on the map of the basin in Figure 7. These six reservoirs are listed along with pertinent descriptive information in Table 2. It should be noted that there are other reservoirs with storage capacities greater than 5,000 acre-feet that are located in Texas, namely San Esteban Lake on Alamito Creek and Imperial Reservoir, Valley Acres Reservoir and Delta Unit 2 Dam, all of which are off-channel reservoirs. San Esteban Lake is not included in the flow naturalization process because, according to a 1976 Inspection Report, the storage capacity of this impoundment at that time was reduced to 3,100 acre-feet due to sedimentation. The other off-channel reservoirs are not included in the flow naturalization process because their streamflow depletions are reflected in any associated streamflow diversions.

As indicated in the table, complete historical storage records for Amistad and Falcon Reservoirs are available from the IBWC, and these records have been obtained for the 2001-2018 period. The USGS has published daily records of historical reservoir stage for Red Bluff Reservoir, with only a few days with missing data during the 2001-2018 period. For the other two reservoirs, Lake Balmorhea and Lake Casa Blanca, there are no storage data available, and the historical storage changes for these reservoirs have been simulated for use in the naturalized flow process.

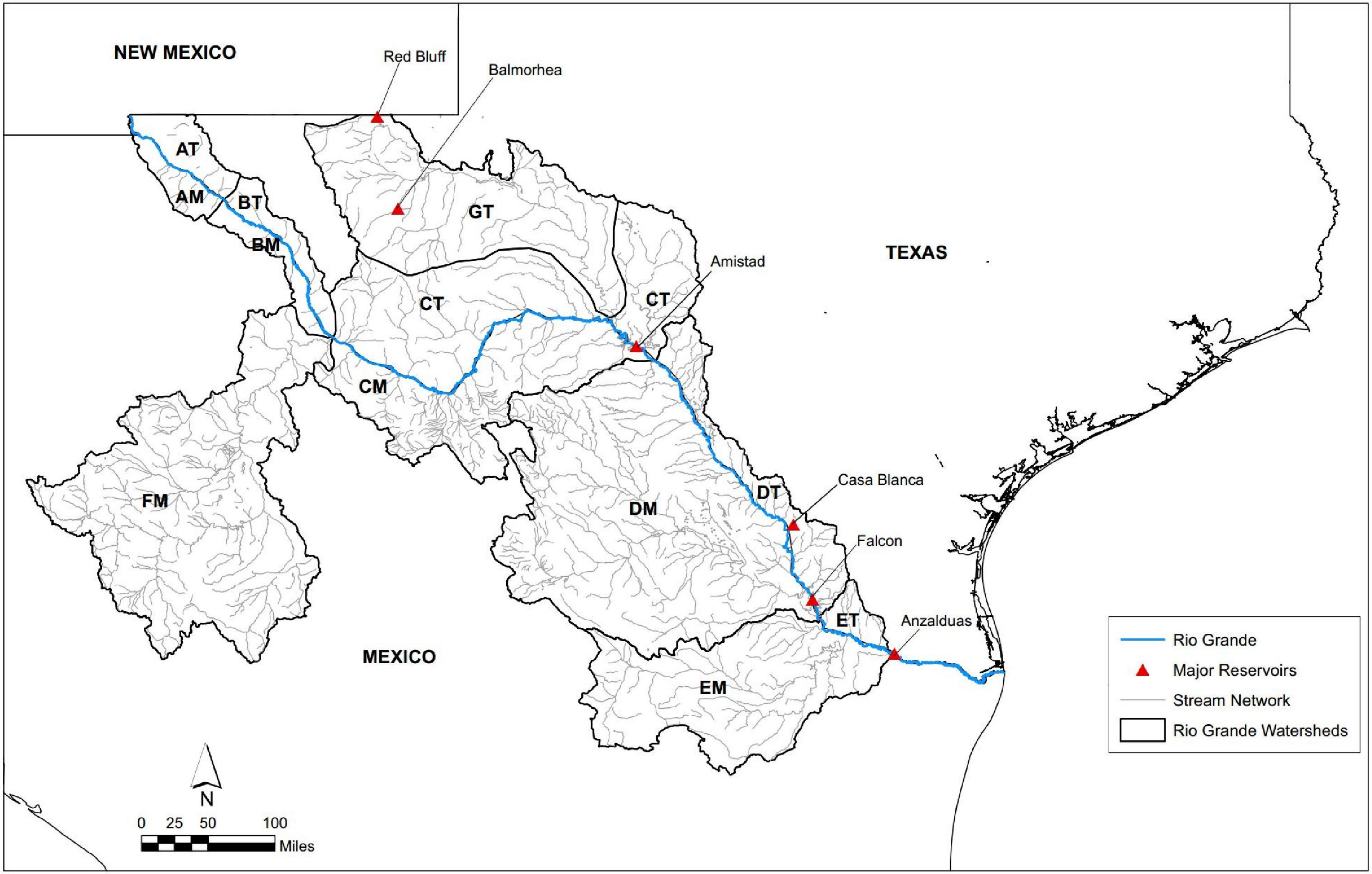


FIGURE 7 MAJOR RESERVOIRS ACCOUNTED FOR IN 2001-2018 FLOW NATURALIZATION PROCESS

TABLE 2 MAJOR RESERVOIRS IN TEXAS PORTION OF RIO GRANDE BASIN ACCOUNTED FOR IN NATURALIZED FLOW PROCESS

NAME OF RESERVOIR	DRAINAGE AREA SQ. MI.	STREAM NAME	DATE OF INITIAL IMPOUND-MENT	CONSERV. STORAGE CAPACITY AC-FT	HISTORICAL STORAGE DATA		DATE OF MOST RECENT AREA-CAPACITY DATA
					SOURCE OF DATA	PERIOD OF RECORD	
Red Bluff Reservoir	20,720	Pecos River	09/1936	300,000	Red Bluff WPCD	1940-2018	2011 Survey
Lake Balmorhea [1]	22	Sandia Creek	1917	6,350	Simulated	n/a	2000 (Run 8)
Amistad Reservoir [2]	126,423	Rio Grande	05/1968	3,276,000	IBWC	05/1968 - Present	2005 Survey
Amistad Reservoir [3]							2013 Region M
Casa Blanca Lake [1]	117	Chacon Creek	1949	20,000	Simulated	n/a	2000 (Run 8)
Falcon Reservoir [2]	164,482	Rio Grande	08/1953	2,647,000	IBWC	08/1953 - Present	2005 Survey
Falcon Reservoir [3]							2013 Region M
Anzalduas Reservoir [4]	176,112	Rio Grande	1960	13,900	IBWC	1960 - 2020	1989 Survey

[1] Storage changes and evaporation losses for these reservoirs have been simulated using an Excel reservoir operations program.
[2] The conservation storage capacities for Amistad and Falcon Reservoirs are current values reported by the IBWC as of April 10, 2021.
[3] In 2013, as part of the Region M Rio Grande Regional Water Planning Study, the 2005 area-capacity data for Amistad and Falcon Reservoirs were reanalyzed to represent 2013 storage conditions taking into account observed sedimentation rates from prior surveys.
[4] Storage changes in Anzalduas Reservoir have not been accounted for in the streamflow naturalization process because storage in the reservoir remains relatively full without significant fluctuations. However, evaporation losses have been accounted for in the naturalization flow process.

Anzalduas Reservoir serves primarily as a regulating reservoir for water released from Falcon Reservoir to downstream Texas and Mexico water users; therefore, under normal operating conditions, its storage is maintained relatively full and is not subject to significant fluctuations. For this reason, and the fact that the reservoir is relatively small and located at the lower end of the naturalized flow system, monthly storage changes for the reservoir have not been accounted for in the streamflow naturalization process for the 2001-2018 period, as was the case for the original 1940-2000 period. Consequently, historical storage data for Anzalduas Reservoir have not been required. However, adjustments have been made for evaporation losses.

4.4 Reservoir Area-Capacity Relationships

Relationships between the surface area of reservoirs and their storage capacity reflecting 2001-2018 conditions are required for those major reservoirs that are included in the development of the 2001-2018 extended naturalized flow dataset. For those reservoirs with available historical storage data but without corresponding surface area data, these relationships have been used to determine surface areas so that historical evaporation losses can be calculated. For those reservoirs without available historical storage data, area-capacity relationships have been used in the simulations of their historical monthly storage changes and evaporation losses for the 2001-2018 period.

The most recent years for which area-capacity data are known to have been developed and the sources of these data are indicated in Table 2. As shown, for the largest international reservoirs, Amistad and Falcon, the most recent measured area-capacity data are from 2005 when the last bathymetric surveys of these reservoirs were conducted. However, in 2013, as part of the Region M Rio Grande Water Planning Study for the lower and part of the middle Rio Grande, these area-capacity data were updated for both of the reservoirs to reflect storage loss due to sedimentation since the 2005 surveys. These 2013 area-capacity relationships are used in the existing Rio Grande WAM for Amistad and Falcon Reservoirs, and, as discussed below, they have been applied in this current study for estimating reservoir surface area as part of the flow naturalization process for part of the 2001-2018 period.

Prior to the 2005 survey of Amistad Reservoir, the next most recent survey of the reservoir was conducted by IBWC in 1992. However, after evaluating results from both the 1992 and the 2005 surveys, the IBWC determined that the 1992 survey may have understated the conservation storage capacity of the reservoir by over 150,000 acre-feet and could not be relied upon. Unfortunately, during the original development of the Rio Grande WAM, the 1992 area-capacity data for Amistad Reservoir were used in the determination of the storage changes and evaporation losses reflected in the downstream naturalized flows for the 1995-2000 period[6] for the Rio Grande; therefore, these naturalized flows may not be correct. Consequently, in this current study, the original naturalized

[6] Note that 1995 is the first year when the IBWC began using the 1992 area-capacity data for determining storage in Amistad Reservoir; therefore, 1995 also is the first year it was applied in the original naturalized flow process.

flows for the mainstem of the Rio Grande downstream of Amistad Reservoir have been recalculated for the 1995-2000 period using the 2005 area-capacity data for Amistad Reservoir. These 2005 area-capacity data also have been used in the calculation of the 2001-2009 naturalized flows, with the Region M 2013 area-capacity data used for the 2010-2018 period.

It should be noted that while the changes in the naturalized flows for the Rio Grande that have resulted from using these different area-capacity data for Amistad Reservoir have affected, to varying degrees, simulated water availability downstream along the Rio Grande, there have been other revisions to the prior data and/or to the prior naturalized flow procedures that also have been required and made in this study. These revisions also have resulted in the need to recalculate the existing naturalized flows for the Rio Grande WAM. These changes are considered necessary to maintain the integrity of the Rio Grande WAM.

According to the IBWC, area-capacity data from the 2005 survey of Falcon Reservoir were considered to be consistent with expected changes in reservoir conditions since the 1992 survey; therefore, the use of the 1992 area-capacity data for Falcon Reservoir in the original WAM study was appropriate for calculating naturalized flows for the 1993-2000 period[7]. In this current study, the 2005 area-capacity data for Falcon Reservoir have been used in the naturalized flow calculations for the 2001-2009 period, and the Region M 2013 area-capacity data have been used for 2010-2018.

The most recent area-capacity data for Lake Balmorhea and Lake Casa Blanca are for the year 2000 when these relationships were developed to represent current conditions for the original Run 8 version of the Rio Grande WAM. These year-2000 area-capacity relationships were based on either extrapolation of existing area-capacity data representing different years or adjustments to previous area-capacity data to account for estimated sedimentation volumes since the last survey. In this current study, these existing year-2000 area-capacity data have been used for calculating the streamflow depletions used in naturalizing flows for the 2001-2018 period.

4.5 Monthly Evaporation Data

Monthly values of historical gross reservoir evaporation, expressed in inches, have been derived by the Texas Water Development Board (TWDB) for all of Texas based on available evaporation pan data. These gross reservoir evaporation values are available for each month of the entire 2001-2018 naturalized flow extension period. These data are provided at the center of each one-degree quadrangle covering the state. The relevant boundaries of these one-degree quadrangles are overlaid on the map of the Rio Grande basin in Figure 8.

[7] Note that 1993 is the first year when the IBWC began using the 1992 area-capacity data for determining storage in Falcon Reservoir; therefore, 1993 also is the first year it was applied in the original naturalized flow process.

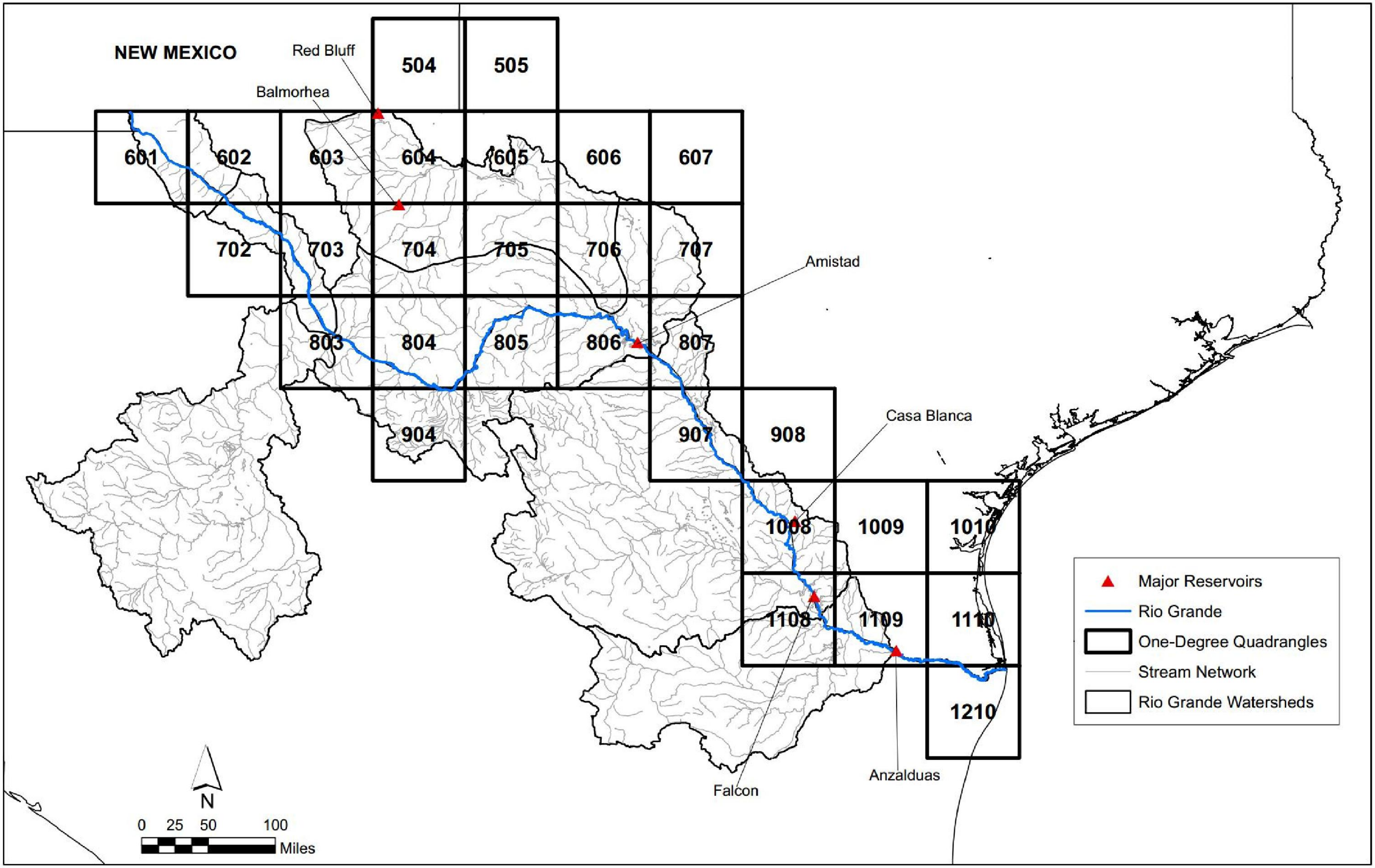


FIGURE 8 TWDB ONE-DEGREE QUADRANGLES FOR GROSS EVAPORATION DATA IN THE RIO GRANDE BASIN

For each major reservoir in the basin that is considered in the streamflow naturalization process and/or is included in the existing Rio Grande WAM, the distance-weighted factors determined during the original development of the Rio Grande WAM have been used for calculating the average reservoir evaporation value at the approximate centroid of each reservoir based on the reported reservoir evaporation values at the centers of the four nearest one-degree quadrangles. The equations applying these factors for all of the major reservoirs are listed in Table 3.

TABLE 3 EQUATIONS RELATING TWDB QUADRANGLE EVAPORATION DATA TO RESERVOIR LOCATIONS

WATER-SHED	RESERVOIR NAME	DISTANCE-WEIGHTED FACTORS AND QUADRANGLE ID NUMBERS *
CT	Red Bluff Reservoir	0.317(504) + 0.287(603) + 0.396(604)
CT	Lake Balmorhea	0.049(603) + 0.396(604) + 0.090(703) + 0.466(704)
CT/CM	Amistad International Reservoir	0.630(806) + 0.370(807)
DT	Lake Casa Blanca	0.046(908) + 0.887(1008) + 0.067(1009)
DT/DM	Falcon International Reservoir	0.120(1008) + 0.617(1108) + 0.263(1109)
ET/EM	Anzalduas International Reservoir	0.863(1109) + 0.137(1110)

* Quadrangle ID numbers are in parentheses. See Figure 8 for locations of quadrangles.

It should be noted that since the development of the original Rio Grande WAM, the TWDB, in an effort to improve the accuracy of reported monthly reservoir evaporation rates, has revised its procedures for determining monthly reservoir evaporation from available evaporation pan data. As a result, the TWDB has posted revised monthly values in some cases dating back to 1954 for many quadrangles across the state. These current revised reservoir evaporation data for the quadrangles associated with reservoirs in the Rio Grande basin have been compared to the original evaporation data used in the existing Rio Grande WAM. Graphical results from this analysis are presented in Appendix A for several of these quadrangles: 604 - Red Bluff Reservoir and Lake Balmorhea, 807 - Amistad Reservoir, 1008 - Casa Blanca Lake, 1108 - Falcon Reservoir, and 1109 - Anzalduas Reservoir. As shown on these graphs, the only deviations of the revised data from the original data occur in the years 1994, 1999 and 2000. These annual deviations generally range from less than 10 inches up to around 30 inches for a few quadrants, particularly for the years 1999 and 2000.

The potential effects of these changes in reservoir evaporation have been analyzed for the quadrants using the maximum annual deviations of the revised TWDB data from the original TWDB data. In each instance, these happen to be associated with quadrants that were used to establish net evaporation values for the three largest reservoirs, Amistad, Falcon, and Red Bluff. The maximum annual net evaporation deviations for these reservoirs are -35.4% for Falcon in 2000, +11.6% for Amistad in 1999, and -17.0% for Red Bluff in 1994. Using the annual average historical values of each reservoir's surface area for each of these years, the corresponding net evaporation loss for each of the reservoirs was calculated using the original net evaporation value and the revised evaporation value. These sets of net evaporation values then were compared to the corresponding naturalized flow at the next downstream primary control point. These comparisons at Rio Grande below Falcon for Falcon Reservoir, Rio Grande at Del Rio for Amistad Reservoir, and Pecos River at Orla for Red Bluff Reservoir indicate that the revisions of the evaporation data by the TWDB would result in the following maximum potential changes in the associated naturalized flows:

2000 Naturalized Rio Grande Flow below Falcon Reservoir	-2.3%
1999 Naturalized Rio Grande Flow at Del Rio	+1.0%
1999 Naturalized Pecos River Flow at Orla	+9.0%

These percentage changes represent maximum values and are relatively small quantities compared to other inaccuracies inherent to the naturalized flow process. Furthermore, the differences in the net evaporation values occur only in three years (1994, 1999 and 2000) of the entire 61-year WAM simulation period (1940-2000), and the resulting changes in the naturalized Rio Grande flows below Falcon and at Del Rio tend to be offsetting. However, since simulations with the existing Rio Grande WAM with its 1940-2000 database indicate that the critical drought period for the Amistad-Falcon reservoir system actually is in progress at the end of the simulation period in December of 2000 and because there are other data issues that have required recalculation of the original naturalized flows during the 1990s (revised area-capacity data for Amistad Reservoir), it was decided in consultation with TCEQ that the revised evaporation data for 1994, 1999 and 2000 should be used to recalculate the reservoir adjustments applied in the calculation of naturalized flows. To be consistent and to facilitate more accurate simulated reservoir evaporation losses, the net evaporation values in the existing WAM dataset for all reservoirs also have been corrected to reflect the current TWDB evaporation data for 1994, 1999 and 2000.

4.6 Monthly Precipitation Data

The TWDB also has compiled average monthly historical values of total precipitation for the 2001-2018 period for each of the one-degree quadrangles shown on the map in Figure 8. These data have been acquired and used to determine historical net evaporation values for reservoirs as required for naturalization of streamflows and for the WAM reservoir datasets for the 2001-2018 period. The same equations and distance-weighted factors presented in Table 3 have been applied for deriving average precipitation amounts at the locations of the major reservoirs.

4.7 Monthly Diversions and Water Use

Fundamental to the streamflow naturalization process is the adjustment of historical gaged streamflows for the historical amounts of water that were diverted by upstream water users. To make these adjustments, information describing these upstream diversions for the entire 2001-

2018 extended period, by month, has been compiled from existing diversion records or has been estimated from available data. The TCEQ provided electronic records of historical diversions for all Texas water rights in the Rio Grande basin, with most of this information coming from the Rio Grande Watermaster. The IBWC has also provided historical monthly diversion data for all water users (municipalities, industries, and irrigators) located along the mainstem of the Rio Grande below Fort Quitman for diverters in both the United States and Mexico.

Diversion and water use data from the TCEQ and IBWC for the 2001-2018 period, and for some years prior to this period, were examined for completeness and for consistency with the diversions accounted for in the previous flow naturalization process for the original Rio Grande WAM. Periods with missing data were identified and flagged for further analysis as to how best to estimate the missing records. These procedures are described in Section 5.0. In some cases, diverters that were included in the previous flow naturalization process did not appear in the current database for 2001-2018 and in other cases diverters in the current database were not considered for naturalizing the 1940-2000 flows. These types of issues have been researched to determine appropriate resolutions, with input from TCEQ staff and the Independent Peer Review team. A list of all Texas and Mexico diverters accounted for in the naturalized flow process for the 2001-2018 period is presented in Table 4 along with descriptive information.

For purposes of the streamflow naturalization process, historical diversions for irrigation use that could not be specifically quantified based on information from either the TCEQ or the IBWC databases were examined to assess whether meaningful estimates of missing records could be made. If so, procedures were undertaken to estimate these irrigation diversions based on data from adjacent years or correlations with other parameters; otherwise, these diversions were set equal to zero.

4.8 Monthly Municipal and Industrial Wastewater Discharges

As with diversions, discharges of municipal and industrial wastewater into the Rio Grande and its tributaries must be accounted for in the development of naturalized streamflows, i.e., deducted from gaged flows. In this study, permitted municipal and industrial wastewater treatment plants in Texas authorized to discharge greater than 0.5 million gallons per day ("mgd") have been accounted for in the streamflow naturalization process for the 2001-2018 period. This same criterion also has been applied to wastewater discharges into the Rio Grande from Mexico. Historical monthly discharge data for permitted municipal and industrial wastewater treatment facilities within Texas were acquired from the TCEQ and the U.S. Environmental Protection Agency ("EPA") for the 2001-2018 period. The IBWC also provided data for major discharges of municipal and industrial wastewater into the mainstem of the Rio Grande for Texas and Mexico.

TABLE 4 DIVERSIONS INCLUDED IN 2001-2018 NATURALIZED FLOW PROCESS

DOWN-STREAM CONTROL POINT ID	DOWNSTREAM STREAMFLOW GAGE NAME	TEXAS WATER RIGHT NUMBER	NAME OF DIVERTER	2001-2018 AVERAGE DIVERSION (Ac-Ft/Yr)
TEXAS MAINSTEM DIVERTERS				
RG-EP	Rio Grande at El Paso, TX	40	U S Federal Corrections Institute	174
RG-FQ	Rio Grande at Fort Quitman	192	Spence Farms Inc.	0
RG-FQ	Rio Grande at Fort Quitman	- -	American Canal	217,633
RG-FQ	Rio Grande at Fort Quitman	288	L R Allison	0
RG-FQ	Rio Grande at Fort Quitman	900	Fort Quitman Land Co.	0
RG-FQ	Rio Grande at Fort Quitman	901	William N roth et al	0
RG-FQ	Rio Grande at Fort Quitman	902	Sidney W Cowan	0
RG-FQ	Rio Grande at Fort Quitman	3215	Hudspeth County CRD No. 1	0
RG-FQ	Rio Grande at Fort Quitman	3216	Hudspeth County CRD No. 1	0
RG-FQ	Rio Grande at Fort Quitman	3217	Hudspeth County CRD No. 1	0
RG-FQ	Rio Grande at Fort Quitman	3218	Hudspeth County CRD No. 1	0
RG-FQ	Rio Grande at Fort Quitman	5406	Hudspeth County Comm. Court	0
RG-FQ	Rio Grande at Fort Quitman	5944	Hudspeth County CRD 1/United States	0
RG-FQ	Rio Grande at Fort Quitman	5943, 3544	Indian Cliffs Ranch Inc.	43
RG-FQ	Rio Grande at Fort Quitman	3219	Hudspeth County CRD No. 1	0
RG-AC	Rio Grande abv Rio Conchos	- -	IBWC Reach 1 U.S. Small Diverters	106
RG-BC	Rio Grande blw Rio Conchos	- -	IBWC Reach 2 U.S. Small Diverters	2,432
RG-JR	Rio Grande at Johnson Ranch	- -	IBWC Reach 3 U.S. Small Diverters	553
RG-FR	Rio Grande at Foster Ranch	- -	IBWC Reach 4 U.S. Small Diverters	82
RG-FR	Rio Grande at Foster Ranch	- -	IBWC BigBend Diversion	404
RG-DR	Rio Grande at Del Rio	- -	IBWC Reach 6 U.S. Small Diverters (10%)	12
RG-PN	Rio Grande at Piedras Negras	- -	IBWC Reach 6 U.S. Small Diverters (90%)	107
RG-PN	Rio Grande at Piedras Negras	- -	IBWC Reach 7 U.S. Small Diverters	641
RG-PN	Rio Grande at Piedras Negras	2671	Maverick County Irrig. Dist.	691,276
RG-PN	Rio Grande at Piedras Negras	0952, 3398	City of Eagle Pass Water Works	8,086
RG-PN	Rio Grande at Piedras Negras	952	Maverick County	361
RG-LA	Rio Grande at Laredo	- -	IBWC Reach 8 U.S. Small Diverters	5,517
RG-LA	Rio Grande at Laredo	952, 2698, 2774, 2777, 3997, A601, B601	City of Laredo	39,266
RG-BF	Rio Grande blw Falcon Dam	- -	IBWC Reach 9 & 9A U.S. Small Diverters	4,982
RG-BF	Rio Grande blw Falcon Dam	0072, 0582, 0603, 0646, 0673, 0675, 0699	Falcon Rural Water Supply Corp.	460

TABLE 4 (continued)

DOWN-STREAM CONTROL POINT ID	DOWNSTREAM STREAMFLOW GAGE NAME	TEXAS WATER RIGHT NUMBER	NAME OF DIVERTER	2001-2018 AVERAGE DIVERSION (Ac-Ft/Yr)
TEXAS MAINSTEM DIVERTERS				
RG-BF	Rio Grande blw Falcon Dam	2785, 2804, 2806, 0803	Zapata County Water Works, Zapata County WCID 16E	2,598
RG-BF	Rio Grande blw Falcon Dam	803	La Feria Irrig. Dist. CC No. 3	n/a
RG-RG	Rio Grande at Rio Grande City	- -	IBWC Reach 10 U.S. Small Diverters	7,180
RG-RG	Rio Grande at Rio Grande City	814	City of Roma	2,312
RG-RG	Rio Grande at Rio Grande City	851	City of Rio Grande City	3,176
RG-AN	Rio Grande blw Anzalduas D.	- -	IBWC Reach 11 U.S. Small Diverters	160,479
TEXAS TRIBUTARY DIVERTERS				
AC-PR	Alimito Creek near Presidio	969	John T. Macguire, et ux	0
AC-PR	Alimito Creek near Presidio	0970	Hayes Mitchell Jr.	0
AC-PR	Alimito Creek near Presidio	0971	Hayes Mitchell Jr.	0
AC-PR	Alimito Creek near Presidio	0972	Lucia H Russell Estate	0
AC-PR	Alimito Creek near Presidio	3392	Lucia H Russell Estate	0
TC-TE	Terlingua Creek nr Terlingua	3369	Elinor F. Green & Neville Ranch	0
TC-TE	Terlingua Creek nr Terlingua	3404	J Frank Woodward Jr	0
PR-OR	Pecos River near Orla	5438	Red Bluff Water Power Control Dist.	313
PR-GI	Pecos River near Girvin	1491	U S Bureau of Reclamation	0
PR-GI	Pecos River near Girvin	5439	City of Balmorhea	101
PR-GI	Pecos River near Girvin	5441	Spanish Trail Land & Cattle Co.	584
PR-GI	Pecos River near Girvin	5443	Spanish Trail Land & Cattle Co.	783
PR-GI	Pecos River near Girvin	5448	Joseph T Moore & J T Moore Inc	2,081
PR-GI	Pecos River near Girvin	5449	Crews Adams	22
PR-GI	Pecos River near Girvin	5450	John J Bush Estate	13
PR-GI	Pecos River near Girvin	5455	Wayne Moore & W H Gilmore	213
PR-GI	Pecos River near Girvin	5456	Pecos County WCID No. 1	0
PR-GI	Pecos River near Girvin	5457	La Escalera LP	586
PR-GI	Pecos River near Girvin	5458	La Escalera LP	586
PR-GI	Pecos River near Girvin	5459	Caramba Inc.	0
PR-GI	Pecos River near Girvin	1184	Hanging H Ranches Inc.	37
PR-GI	Pecos River near Girvin	5438	Red Bluff WPD (Pecos WID2)	1,470
PR-GI	Pecos River near Girvin	5438	Red Bluff WPD (Pecos WID3)	455
PR-GI	Pecos River near Girvin	5438	Red Bluff WPD (WARD WID1)	2,327
PR-GI	Pecos River near Girvin	5438	Red Bluff WPD (WARD WID2)	2,173
PR-GI	Pecos River near Girvin	5438	Red Bluff WPD (WARD WID3)	0
PR-GI	Pecos River near Girvin	5438	Red Bluff WPD (Reeves WID2)	129
PR-GI	Pecos River near Girvin	5438	Red Bluff WPD (Loving WID1)	23

TABLE 4 (continued)

DOWN-STREAM CONTROL POINT ID	DOWNSTREAM STREAMFLOW GAGE NAME	TEXAS WATER RIGHT NUMBER	NAME OF DIVERTER	2001-2018 AVERAGE DIVERSION (Ac-Ft/Yr)
TEXAS TRIBUTARY DIVERTERS				
PR-GI	Pecos River near Girvin	121	Clayton Williams	0
PR-GI	Pecos River near Girvin	5447	Don Weinacht	743
PR-GI	Pecos River near Girvin	1392	US Bureau of Reclamation	6
PR-GI	Pecos River near Girvin	1175	Cecilia Isabel Thompson	0
PR-GI	Pecos River near Girvin	1174	H E Sproul	0
PR-GI	Pecos River near Girvin	2474	Southwestern Portland Cement	0
PR-GI	Pecos River near Girvin	1178	Estelle Langham Sharp	0
PR-GI	Pecos River near Girvin	5445	RCS, Inc.	0
PR-GI	Pecos River near Girvin	1183	Margaret Hayter Newton	5
PR-GI	Pecos River near Girvin	1182	Margaret Hayter Newton	278
PR-GI	Pecos River near Girvin	645	Moore, Joseph T & J T Moore	0
PR-GI	Pecos River near Girvin	5446	Reeves Coounty WID No. 1	388
PR-GI	Pecos River near Girvin	1172	Scott Locke McIvor	0
PR-GI	Pecos River near Girvin	1181	Ned Maddox	0
PR-GI	Pecos River near Girvin	5454	Tassie Parker K Macuk	0
PR-GI	Pecos River near Girvin	5453	Tassie Parker K Macuk	0
PR-GI	Pecos River near Girvin	5442	R. E. Lyles	284
PR-GI	Pecos River near Girvin	1173	Ruth Johnson	12
PR-GI	Pecos River near Girvin	5444	Jack Hoffman/RCS Inc	0
PR-GI	Pecos River near Girvin	1177	George A Hoffman	2
PR-GI	Pecos River near Girvin	1176	Jimmy G Higgins	0
PR-GI	Pecos River near Girvin	5440	James P Espy Jr	45
PR-GI	Pecos River near Girvin	1180	Wanda Dean Trust	0
PR-GI	Pecos River near Girvin	1179	Wanda Dean Trust	0
PR-GI	Pecos River near Girvin	5452	BEAL, BARRY A	18
PR-GI	Pecos River near Girvin	375	U. S. Department of Interior	0
PR-GI	Pecos River near Girvin	1-57	Reeves County WID No. 1	10,425
PR-GI	Pecos River near Girvin	3-235	Reeves County WID No. 1	11,059
PR-GI	Pecos River near Girvin	3-236	Reeves County WID No. 1	0
PR-GI	Pecos River near Girvin	57, 235, 236	Reeves County WID No. 1 (2015-2018)	1,931
PR-LA	Pecos River near Langtry	5463	The Nature Conservancy	450
PR-LA	Pecos River near Langtry	5460	La Escalera LP	47
PR-LA	Pecos River near Langtry	5461	La Escalera LP	441
PR-LA	Pecos River near Langtry	5462	Estate of Joe B Chandler et al	52
PR-LA	Pecos River near Langtry	5464	Wilson Hardin "Cy" Banner	19
PR-LA	Pecos River near Langtry	5465	John Edward Robbins/John Clark	17
PR-LA	Pecos River near Langtry	5466	Mattie B. Bell/Wilson Hardin Banner	7

TABLE 4 (continued)

DOWN-STREAM CONTROL POINT ID	DOWNSTREAM STREAMFLOW GAGE NAME	TEXAS WATER RIGHT NUMBER	NAME OF DIVERTER	2001-2018 AVERAGE DIVERSION (Ac-Ft/Yr)
TEXAS TRIBUTARY DIVERTERS				
SF-DR	San Felipe Creek near Del Rio	2664	San Felipe AM&I Co.	3,048
SF-DR	San Felipe Creek near Del Rio	2665	Jose Oviedo Jr et ux	35
SF-DR	San Felipe Creek near Del Rio	2666	Petra Abrego Munoz	0
SF-DR	San Felipe Creek near Del Rio	2669	Rodolfo Mota	0
SF-DR	San Felipe Creek near Del Rio	2670	Victor D Bolner	2
SF-DR	San Felipe Creek near Del Rio	2672	CITY OF DEL RIO	5,894
SF-DR	San Felipe Creek near Del Rio	2912, 2913	Moody Ranches, Inc.	179
SF-DR	San Felipe Creek near Del Rio	5506	CITY OF DEL RIO	0
PC-DR	Pinto Creek near Del Rio	2676	Jewel Foreman Robinson	4
PC-DR	Pinto Creek near Del Rio	2678	Johnny E Rutherford	1

DOWNSTREAM CONTROL POINT ID	DOWNSTREAM STREAMFLOW GAGE NAME	NAME OF DIVERTER	AVERAGE DIVERSION (Ac-Ft/Yr)
MEXICO MAINSTEM DIVERTERS			
RG-FQ	Rio Grande at Fort Quitman	Mexico Acequia Madre	40,025
RG-AC	Rio Grande above Rio Conchos	IBWC Reach 1 MX Small Diverters	774
RG-BC	Rio Grande below Rio Conchos	IBWC Reach 2 MX Small Diverters	302
RG-JR	Rio Grande at Johnson Ranch	IBWC Reach 3 MX Small Diverters	10,732
RG-DR	Rio Grande at Del Rio	Ciudad Acuna	10,993
RG-PN	Rio Grande at Piedras Negras	IBWC Reach 6 MX Small Diverters	1,134
RG-PN	Rio Grande at Piedras Negras	IBWC Reach 7 MX Small Diverters (40%)	308
RG-PN	Rio Grande at Piedras Negras	Ciudad Piedras Negras	15,641
RG-LA	Rio Grande at Laredo	IBWC Reach 7 MX Small Diverters (60%)	403
RG-LA	Rio Grande at Laredo	IBWC Reach 8 MX Small Diverters	1,430
RG-LA	Rio Grande at Laredo	Rio Escondido Power Plant	25,213
RG-LA	Rio Grande at Laredo	Ciudad Nuevo Laredo	44,874
RG-BF	Rio Grande below Falcon Dam	IBWC Reach 9 and 9A MX Small Diverters	3,512
RG-BF	Rio Grande below Falcon Dam	Nueva Cuidad Guerrero	296
RG-RG	Rio Grande at Rio Grande City	IBWC Reach 10 MX Small Diverters	1,956
RG-RG	Rio Grande at Rio Grande City	Ciudad Mier	597
RG-RG	Rio Grande at Rio Grande City	Ciudad Miguel Aleman	2,802
RG-RG	Rio Grande at Rio Grande City	Ciudad Carmargo	87
RG-AN	Rio Grande below Anzalduas DAM	IBWC Reach 11 MX Small Diverters	15,683
RG-AN	Rio Grande below Anzalduas DAM	Anzalduas Canal	585,451
RG-AN	Rio Grande below Anzalduas DAM	Ciudad Diaz Ordaz	503
RG-AN	Rio Grande below Anzalduas DAM	Ciudad Reynosa	51,150

All of the wastewater discharge data have been compiled into a master database and then organized based on discharge amount and outfall location. Missing records were identified for subsequent fill-in as described in Section 5.4. Dischargers that were included in the 1940-2000 streamflow naturalization process but are not in the current TCEQ/EPA or IBWC databases have been investigated to determine if they ceased discharging since 2000 or if they are missing discharge records. Similarly, further research has been performed for dischargers that have data reported for the 2001-2018 period, but were not accounted for in the 1940-2000 streamflow naturalization process. Inconsistencies between data from the two periods have been investigated and addressed with assistance from TCEQ, IBWC and the El Paso Water Utilities department.

Outfalls for these wastewater discharges are located on the mainstem of the Rio Grande in Texas and in Mexico and on tributaries of the Rio Grande in Texas above Anzalduas Dam. The locations of the outfalls for these wastewater discharges were established from GIS data posted on the TCEQ web site and from information obtained from TCEQ, EPA and IBWC. The locations of the municipal and industrial wastewater discharges considered for use in the 2001-2018 naturalized flow process are shown on the map in Figure 9. Descriptive information for these wastewater discharges is listed in Table 5, including the primary control point downstream of each of the discharges where adjustments to gaged flows were made in the naturalized flow process. Also shown in the table are the historical periods when discharges to the Rio Grande and its tributaries were actually made, with "no discharge" indicated where the effluent was not discharged, but instead used for irrigation or some other purpose and therefore did not contribute to the flow at the downstream primary control point.

It should be noted that several of the City of El Paso's wastewater treatment plants listed in Table 5 either discharge only a part of their effluent to the Rio Grande or do not discharge to the river at all. How and when these discharges occurred historically are discussed in Section 6.3.1 with regard to changes that have been made in this study to properly represent these discharges in the development of naturalized flows for the 1940-2000 period and for the extended 2001-2018 period. Also, in Table 5, there is no listing for discharges to the Rio Grande from Ciudad Juarez. These discharges are made to interior ditches and canals within Mexico for subsequent reuse.

4.9 Monthly Irrigation Return Flows

Return flows from irrigated lands account for some of the historical streamflows that are reflected in gage records throughout the Rio Grande basin, and these have to be removed from the historical streamflows during the naturalization process. Major contributors of irrigation return flows to the Rio Grande and its tributaries in Texas include the Hudspeth County Conservation and Reclamation District No. 1 in the El Paso valley, the Red Bluff Water Power Control District in the Pecos River basin, and the Maverick County Water Control and Improvement District No. 1 in the middle Rio Grande. On the Mexico side, the Lower San Juan Irrigation District discharges return flows to the Rio Grande above and below the Rio Grande City streamflow gage.

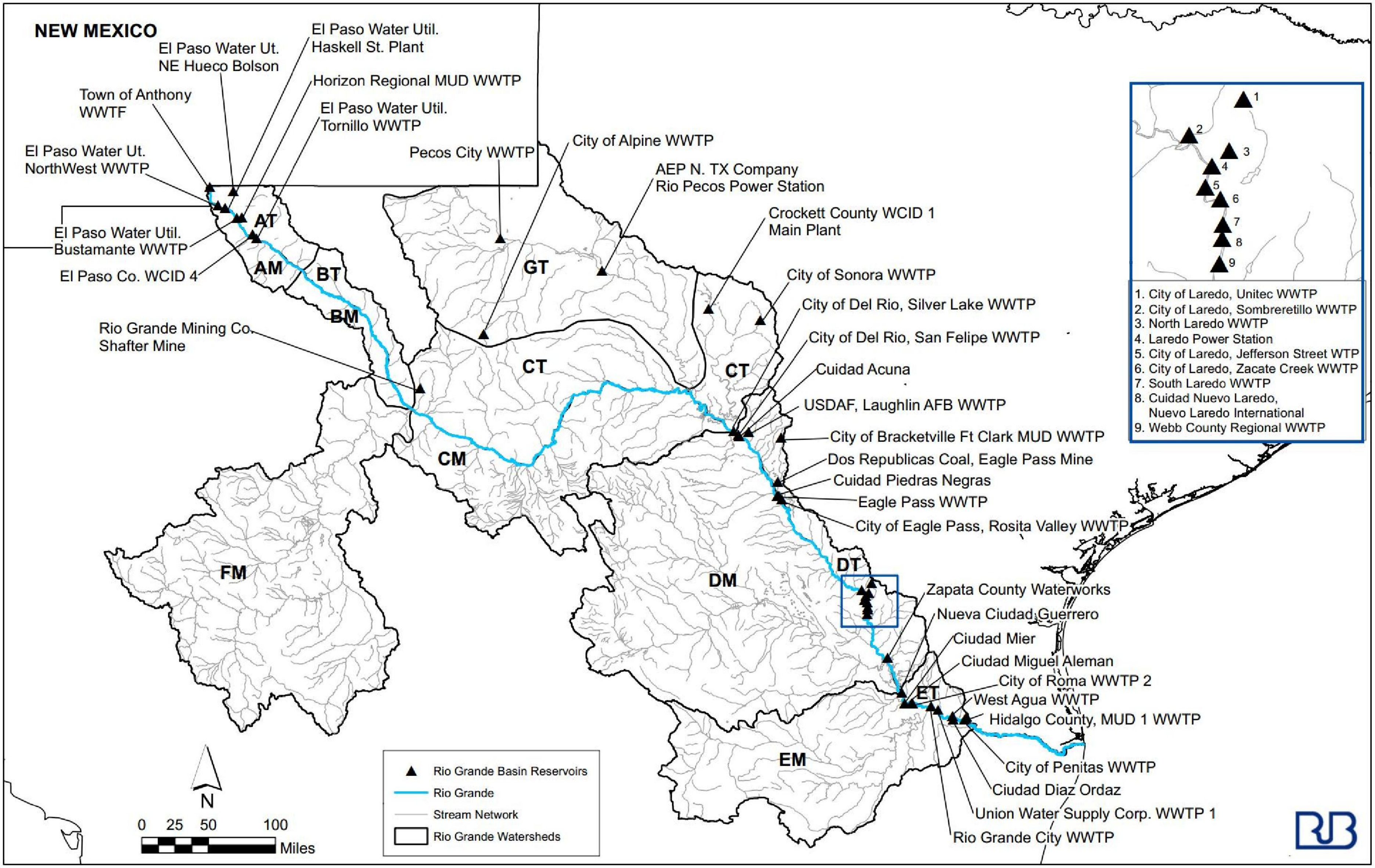


FIGURE 9 MUNICIPAL AND INDUSTRIAL WASTEWATER DISCHARGES ACCOUNTED FOR IN NATURALIZED FLOW PROCESS

TABLE 5 MUNICIPAL AND INDUSTRIAL WASTEWATER DISCHARGERS IN TEXAS AND IN MEXICO

	DOWN-STREAM CONTROL POINT	WATER-SHED	PERMIT NUMBER	FACILITY OWNER	FACILITY NAME	PERIOD OF DISCHARGE	PERMITTED OR MAX DAILY DISCHARGE (MGD)
	TEXAS WASTEWATER DISCHARGERS						
(1)	RG-EP	AT	15414-001	TOWN OF ANTHONY	TOWN OF ANTHONY WWTF	1/2007 - 12/2018	0.6
(2)	RG-EP	AT	10408-007	EL PASO WATER UTILITIES	FRED HERVEY WATER REC. PLT.	NO DISCHARGE	10.0
(3)	RG-FQ	AT	10166-001	EL PASO COUNTY WCID NO 4	EL PASO COUNTY WCID 4 WWTP	NO DISCHARGE	1.2
(4)	RG-FQ	AT	10408-004	EL PASO WATER UTILITIES	HASKELL R STREET WWTP	Pre-1940 - 12/1998	27.7
(5)	RG-FQ	AT	10408-010	EL PASO WATER UTILITIES	ROBERTO R BUSTAMANTE WWTP	NO DISCHARGE	39.0
(6)	RG-FQ	AT	10408-009	EL PASO WATER UTILITIES	JOHN T. HICKERSON WATER REC. FA	2/1987 - 12/2018	17.5
(7)	RG-FQ	AT	10795-001	HORIZON REGIONAL MUD	HORIZON REGIONAL MUD WWTP	5/2011 - 12/2018	3.0
(8)	RG-FQ	AT	14529-001	EL PASO CO. TORNILLO WID	TORNILLO WWTP	4/2009 - 12/2018	0.7
(9)	RG-BC	CT	04297-000	RIO GRANDE MINING CO	SHAFTER MINE	NO DISCHARGE	0.55
(10)	PR-GI	GT	10245-001	TOWN OF PECOS CITY	PECOS CITY WWTP	NO DISCHARGE	1.6
(11)	PR-GI	GT	14349-001	CITY OF ALPINE	CITY OF ALPINE WWTP	1/2000 - 12/2018	1.5
(12)	PR-LA	GT	961-001	AEP NORTH TEXAS COMPANY	RIO PECOS POWER STATION	6/1977 - 11/2003	0.9
(13)	DR-JU	CT	10545-001	CITY OF SONORA	CITY OF SONORA WWTP	6/1977 - 12/2018	0.9
(14)	DR-JU	CT	10059-001	CROCKETT COUNTY WCID 1	MAIN PLANT	7/1988 - 12/2018	0.5
(15)	RG-DR	CT	10159-003	CITY OF DEL RIO	SILVER LAKE WWTP	1/1973 - 12/2018	2.8
(16)	SF-DR	DT	10159-001	CITY OF DEL RIO	SAN FELIPE WWTP	6/1977 - 12/2018	3.8
(17)	PC-DR	DT	12651-001	US DEPT. OF THE AIR FORCE	LAUGHLIN AFB WWTP BLDG 1004	NO DISCHARGE	0.5
(18)	RG-PN	DT	10194-002	CITY OF BRACKETVILLE	BRACKETTVILLE/FT CLARK WWTP	8/1997 - 11/2018	0.5
(19)	RG-PN	DT	03511-000	DOS REPUBLICAS COAL	EAGLE PASS MINE	NO DISCHARGE	n/a
(20)	RG-LA	DT	10406-002	CITY OF EAGLE PASS	EAGLE PASS WWTP	Pre-1940 - 12/2018	6.0
(21)	RG-LA	DT	14688-001	CITY OF EAGLE PASS	ROSITA VALLEY WWTP	NO DISCHARGE	1.5
(22)	RG-LA	DT	01200-000	CENTRAL POWER & LIGHT CO.	LAREDO POWER STATION	1/1977 - 12/2000	1.3
(23)	RG-LA	DT	10681-001	CITY OF LAREDO	JEFFERSON STREET WTP	NO DISCHARGE	4.1
(24)	RG-LA	DT	10681-004	CITY OF LAREDO	NORTH LAREDO WWTP	9/1981 - 12/2018	2.9
(25)	RG-LA	DT	10681-008	CITY OF LAREDO	SOMBRERETILLO WWTP	NO DISCHARGE	1.8

TABLE 5 (continued)

	DOWN-STREAM CONTROL POINT	WATER-SHED	PERMIT NUMBER	FACILITY OWNER	FACILITY NAME	PERIOD OF DISCHARGE	PERMITTED OR MAX DAILY DISCHARGE (MGD)
	TEXAS WASTEWATER DISCHARGERS						
(26)	RG-BF	DT	10681-003	CITY OF LAREDO	SOUTH LAREDO WWTP	1/1981 - 12/2018	12.0
(27)	RG-BF	DT	10681-005	CITY OF LAREDO	UNITEC WWTP	NO DISCHARGE	0.18
(28)	RG-BF	DT	10681-002	CITY OF LAREDO	ZACATE CREEK WWTP	Pre-1940 - 12/2018	14.0
(29)	RG-BF	DT	13577-003	WEBB COUNTY	WEBB COUNTY REGIONAL WWTP	10/2002 - 12/2018	0.7
(30)	RG-BF	DT	10462-001	ZAPATA COUNTY	ZAPATA COUNTY WWTP	9/1981 - 12/2018	0.8
(31)	RG-RG	ET	10802-001	CITY OF RIO GRANDE CITY	RIO GRANDE CITY WWTP	1/1955 - 12/2018	1.5
(32)	RG-RG	ET	11212-002	CITY OF ROMA	CITY OF ROMA WWTP 2	8/2201 - 12/2018	2.0
(33)	RG-AN	ET	14415-001	AGUA SPECIAL UTILITY DIST.	WEST AGUA WWTP	8/2012 - 12/2018	1.4
(34)	RG-AN	ET	14884-001	CITY OF PENITAS	CITY OF PENITAS WWTP	5/2013 - 12/2018	0.8
(35)	RG-AN	ET	14950-001	HIDALGO COUNTY MUD 1	HIDALGO COUNTY MUD 1 WWTP	NO DISCHARGE	1.0
(36)	RG-AN	ET	14313.001	UNION WATER SUPPLY CORP.	WWTP 1	10/2005 - 12/2018	0.8
	MEXICO WASTEWATER DISCHARGERS						
(37)	RG-PN	DM	- -	CIUDAD ACUNA	- -	1/1990 - 12/2018	11.9
(38)	RG-LA	DM	- -	CIUDAD PIEDRAS NEGRAS	- -	1/1990 - 12/2018	18.8
(39)	RG-BF	DM	- -	CIUDAD NUEVO LAREDO	NUEVO LAREDO INTERNATIONAL	1/1978 - 12/2018	32.1
(40)	RG-RG	EM	- -	NUEVA CIUDAD GUERRERO	- -	1/1990 - 12/2018	0.6
(41)	RG-RG	EM	- -	CIUDAD MIGUEL ALEMAN	- -	1/1990 - 12/2018	2.2
(42)	RG-RG	EM	- -	CIUDAD MIER	- -	1/1990 - 12/2018	0.8
(43)	RG-AN	EM	- -	CIUDAD DIAZ ORDAZ	- -	1/1990 - 12/2018	0.9

Historical irrigation return flow records from IBWC are fairly complete for the Maverick County WCID No. 1 and the Lower San Juan Irrigation District because these inflows to the Rio Grande are measured pursuant to the requirements for water ownership accounting stipulated in the 1944 Treaty between the United States and Mexico, and these records have been provided by IBWC. Records for irrigation return flows into the Rio Grande in the El Paso valley are incomplete and less reliable; however, since return flows in this area are extensively rediverted and reused, assuming that the net quantity of return flows discharged into this reach of the river was essentially zero is considered to be justified for purposes of the naturalized streamflow analyses for the 2001-2018 period. Only very limited data regarding historical irrigation return flows to the Pecos River from the Red Bluff Water Power Control District are available, and estimates of these historical monthly quantities for portions of the 2001-2018 period have been made.

5.0 DATA ANALYSIS AND ESTIMATION OF MISSING 2001-2018 DATA

5.1 Monthly Gaged Streamflows

As noted in Section 4.1, three of the streamflow gages used in the naturalized flow process for the 2001-2018 period have missing records. One of these gages is on the Rio Grande at Fort Quitman, and for this gage, different fill-in procedures were applied depending on the nature of the missing data. For the several periods that had only a few consecutive days of missing data (maximum of four days), daily flows were calculated by linearly interpolating the observed daily flows for the days immediately before and after the period of missing records. There is also one period with missing flow data that extended over approximately nine consecutive months from August 2016 through April 2017. For this extended period, monthly observed flows reported for the Rio Grande above Rio Conchos gage, which is the next downstream gage approximately 200 miles from Fort Quitman, were adjusted to represent corresponding monthly flows at Fort Quitman using the 2001-2011 average monthly gaged flow ratios of the Rio Grande at Fort Quitman flow divided by the Rio Grande above Rio Conchos flow. Results from using this approach appear to be consistent with other monthly observed flows at the Fort Quitman gage.

The other two gages with missing records are for the Pecos River gage near Orla, which has only 11 days with missing flow data in 2017, and the Devils River gage near Juno, which was discontinued in 1973 but was used as a primary control point for the existing Rio Grande WAM and will continue to be used as a primary control point for the 2001-2018 period. For the Pecos River near Orla gage, available gaged flows for days immediately before and after the 11-day period of missing data, together with consideration of the gaged flows from the nearest gage upstream (Pecos River near Red Bluff), have been used to estimate the missing flow records. For the Devils River near Juno gage, no streamflow records for the 2001-2018 period are available as this gage was discontinued in 1973. As discussed in Section 7.7, naturalized flows for this gage site for 2001-2018 have been estimated based on monthly correlations with the naturalized flows at the next downstream gage, Devils River near Pafford Crossing near Comstock, that were developed during the original WAM study using common flows for the October 1963 through September 1973 period.

5.2 Monthly Spring Discharges

As discussed in Section 4.2, there is a series of springs located in the Toyah Creek watershed within the Pecos River basin that provides flows for local downstream water rights in the vicinity of the city of Balmorhea. These springs include primarily San Solomon and Giffin springs in Balmorhea State Park in Reeves County. Consistent with the procedures used in the original development of naturalized flows for the Rio Grande WAM, discharges from these springs have been separated from the streamflows at the nearest downstream gage for the 2001-2018 period.

Recent observed discharge information for these two springs indicates that, as was the case in the original naturalized flow effort, portions of the 2001-2018 records are missing. Techniques used to fill missing periods of springflow during the original Rio Grande WAM study have been reviewed for applicability to the 2001-2018 period. In the previous study, numerous fill procedures were utilized to estimate missing data for the largest spring, San Solomon spring near Toyahvale, and a correlation factor was applied to the San Solomon spring discharges to estimate flows for the smaller Giffin spring.

For the 2001-2018 period, observed springflow data are available from the USGS for Giffin spring for the period August 2002 through December 2018 and for San Soloman spring for the period June 2017 through December 2018. A review of these observed flow data indicates that the discharges from each of the springs did not vary much from month to month; thus, a simple monthly factor was developed from the common period of record for both springs (June 2017-December 2018), and this factor (7.650) was applied to the observed Giffin spring flows to estimate the discharges for San Soloman spring for the period of missing data (August 2002-May 2017). For the period from January 2001 through July 2002 when both springs were missing observed discharge data, the monthly average observed flow for each month for Giffin spring for the years 2003-2009 was used to fill in monthly Giffin spring discharges, and the estimated Giffin spring discharges then were multiplied by the 7.650 factor to fill in the San Solomon spring monthly flows for January 2001 through July 2002. The resulting estimated springflows were consistent with the observed values in the original 1940-2000 naturalized flow period.

5.3 Monthly Diversions and Water Use

5.3.1 American Canal

Current IBWC data for diversions into the American Canal during the 2001-2018 period include several months with missing values, all of which are in the non-irrigation season. Discussions with IBWC personnel indicated that during these months of minimal flow, the canal was not operational due to ongoing maintenance and construction activities, and, thus, the diversion values should be zero.

5.3.2 Rio Grande Watermaster End-of-Month Diversion Data

Some records of water use data provided by the Rio Grande Watermaster have missing daily data around the end of a month and/or the beginning of a month. Following discussions with TCEQ staff, it was determined that these missing records likely occurred because of overlapping periods of diversion covered by the Declarations of Intent for individual diverters. The Rio Grande Watermaster provided additional diversion data for many of the periods, and the remaining missing records were estimated based on available diversion data for the periods before and after the period with missing data.

5.3.3 Red Bluff District Diversions

Water use reports for the 2001-2018 period have been provided by the TCEQ for diversions from the Pecos River by the Red Bluff Water Power Control District ("RBWPCD"). These diversions are from multiple diversion points on the Pecos River upstream of the Girvin streamflow gage, most of which are for irrigation with a small amount for mining use. Diversion data for several continuous years during the 2001-2018 period are shown as blanks, and the diversions during these years were either confirmed to be zero by representatives of the Red Bluff District or were filled with supplemental diversion data provided by some of the member districts.

5.3.4 Lake Balmorhea Diversions

TCEQ diversion records for the Reeves County Water Improvement District No. 1 ("RCWID1") from Lake Balmorhea are complete except for the last three years of the 2001-2018 period. Historical diversions by the RCWID1 have been used extensively for irrigation. To fill the three years of missing diversion records the average monthly diversions for 2014 and 2015 have been used to estimate the 2016-2018 monthly diversions.

5.3.5 Ciudad Camargo Diversions

Ciudad Camargo is a Mexican city located near the mouth of the Rio San Juan, just upstream from Rio Grande City on the Rio Grande. Diversion data reported by the IBWC for Ciudad Camargo end in December 2002. Through discussions with IBWC personnel, it was determined that Mexico has not reported any diversions for Ciudad Camargo since 2002 for purposes of Rio Grande water ownership accounting; therefore, the city must have developed an alternative water supply. For developing naturalized flows for the 2001-2018 period, diversions from the Rio Grande by Ciudad Camargo after 2002 have been set to zero.

5.4 Monthly Municipal and Industrial Wastewater Discharges

5.4.1 Texas Wastewater Discharges

Historical data for municipal and industrial wastewater discharges in Texas were fairly complete as obtained from the permitted discharge records of the TCEQ and EPA and from information provided by the IBWC. In the few cases where missing records had to be filled for relatively short periods (one or two months), the actual reported discharge data for months on each side of the periods with missing records were used to linearly estimate the missing data.

It should be noted that while the City of El Paso has several wastewater treatment plants ("WWTP") with relatively large capacities, including the Haskell R. Street WWTP, Roberto R. Bustamante WWTP, John T. Hickerson Water Reclamation Facility ("Northwest Plant"), and Fred Hervey Water Reclamation Plant, only a portion of the effluent from the Northwest plant is discharged into the Rio Grande. Instead, these plants either discharge their effluent into the canal system of the El Paso County Water Improvement District No. 1 for subsequent irrigation use or convey their effluent to golf courses, parks, schools and other public areas for landscape irrigation or use the treated effluent for aquifer recharge and subsequent reuse. Hence, only a portion of the discharges from these WWTPs needs to be accounted for in naturalizing Rio Grande flows at the Fort Quitman gage. Section 6.3.1 provides more detailed discussion.

5.4.2 Mexico Wastewater Discharges

Historical records of wastewater discharges from Mexico wastewater treatment plants with outfalls on the Rio Grande were provided by IBWC for the cities of Acuna, Piedras Negras, and Nuevo Laredo. Although it is a major city located on the Rio Grande, Ciudad Juarez does not discharge its wastewater effluent into the Rio Grande; instead, Ciudad Juarez discharges into interior ditches and canals within Mexico for subsequent reuse. No records of wastewater discharges for the cities of Nueva Guerrero, Miguel Aleman, Mier, and Diaz Ordaz were available, even though wastewater discharges for each of these cities were accounted for in the development of the original naturalized flows for the 1940-2000 period.

For the cities of Acuna, Piedras Negras and Nuevo Laredo, by far the largest Mexico dischargers to the Rio Grande, extended periods of years had missing data. For Acuna and Piedras Negras, no discharge records were available for 2001 and 2002 and for January-November of 2017, and for Nuevo Laredo, no discharge records were available for January-November of 2017. Monthly discharge values for these periods of missing data were filled by linearly interpolating monthly discharges from the years before and after the missing periods.

For the cities of Nueva Guerrero, Miguel Aleman, Mier, and Diaz Ordaz, all of which have relatively small discharges, estimates of annual discharges for years 2005, 2010 and 2020 were made based on correlations of year-2000 annual discharges with year-2000 population data obtained from the web site https://citypopulation.de/en/mexico/admin/. Annual discharges for intervening years between 2000, 2005, 2010 and 2020 were linearly interpolated, and then these annual values were distributed to monthly values based on the average monthly patterns for monthly discharges from the prior datasets.

6.0 CHANGES TO EXISTING 1940-2000 DATA AND WORKBOOKS

During the course of this investigation as data and the naturalized flow workbooks were being reviewed and analyzed for extending the naturalized flows for the 2001-2018 period, a number of issues were uncovered related to errors and inconsistencies in the existing 1940-2000 data and the associated naturalized flow workbooks. These issues have been addressed with appropriate revisions to these data and the workbooks as described in the following subsections.

6.1 Streamflow Records

Monthly historical streamflow data for the gage on the Pecos River near Orla apparently were not available during the development of the original 1940-2000 naturalized flows for the period from October 1997 through December 2000. Previously, the naturalized flows at this gage were estimated for the period of missing gaged data based on the naturalized flows for the Pecos River at Red Bluff gage. However, in this study, these missing gaged flow data for the Pecos River near Orla were available from USGS records. Consequently, as part of naturalizing the flows for the Pecos River near Orla gage for the 2001-2018 period, the original naturalized flows at this gage for October 1997 through December 2000 were recomputed using the historical flows at this gage.

A similar issue occurred with missing gaged flow records for the Pecos River near Girvin gage during the development of the original 1940-2000 naturalized flows. In this case, the monthly gaged flow data were missing for the October-December 2000 period, and as with the Pecos River near Orla gage, these missing flow records were available from the USGS in this current study. Again, as part of naturalizing the flows for the Pecos River near Girvin gage for the 2001-2018 period, the original naturalized flows at this gage for October-December 2000 were recomputed using the historical flows at this gage.

6.2 Diversions and Water Use

6.2.1 Rio Escondido Power Plant

In the original naturalized flow workbooks, the adjustments for the diversions from the Rio Grande for the Rio Escondido Power Plant in Mexico were included in both the Rio Grande at Piedras Negras workbook and the Rio Grande at Laredo workbook, when they belong only in the Rio Grande at Laredo workbook. This correction has been made, and now the naturalized flows are correctly calculated at Rio Grande at Laredo primary control point and at all downstream primary control points.

6.2.2 Ciudad Acuna

In the original WAM study, monthly diversion data from the Rio Grande for Ciudad Acuna were reported by IBWC in units of thousand cubic meters for the 1971-2000 period, but these values were not converted to units of acre-feet for the upstream diversion adjustments in the Rio Grande at Del Rio naturalized flow workbook. These diversion values have been converted to the correct units, and now the naturalized flows at the Rio Grande at Del Rio primary control point, and at all primary control points downstream, reflect these corrected diversion amounts.

6.2.3 Ciudad Diaz Ordaz

In the Rio Grande below Anzalduas Dam naturalized flow workbook, the adjustments for all upstream diversions reflect incorrect values for November and December of 2000 for the Rio Grande diversions by Ciudad Diaz Ordaz. These values have been corrected, and now the naturalized flows for these months are correctly calculated at this primary control point and at all primary control points downstream.

6.2.4 American Canal

Monthly diversion data for the American Canal accounted for in the original calculation of naturalized flows at the Rio Grande at Fort Quitman primary control point differ somewhat from the corresponding data acquired from IBWC during this current study. Annual values are different by about 40 acre-feet prior to 1991 and by about 1,200 acre-feet for 1991 through 2000. To be consistent with IBWC's current database, these monthly diversions have been revised in the Rio Grande at Fort Quitman naturalized flow workbook and now are reflected in the naturalized flows at the Rio Grande at Fort Quitman primary control point and at all primary control points downstream for the entire previous period of 1940-2000.

6.2.5 Acequia Madre

Comparison of the monthly diversion data for Mexico's Acequia Madre at Ciudad Juarez as used in the original calculation of naturalized flows at the Rio Grande at Fort Quitman primary control point with data obtained from IBWC during this study indicates differences on the order of about 250 acre-feet per year for 1994-2000, with smaller deviations for years prior. To be consistent with IBWC's current database, these monthly diversions have been revised and now are reflected in the naturalized flows at the Rio Grande at Fort Quitman primary control point and at all primary control points downstream for the entire previous period of 1940-2000.

6.3 Municipal and Industrial Wastewater Discharges

6.3.1 City of El Paso WWTPs

While reviewing wastewater discharge records for the City of El Paso in this study, it was determined that adjustments for some of these discharges in the previous development of naturalized flows for the original WAM were made incorrectly. Most of these issues relate to the timing as to when certain of the City's WWTPs came on line and how much of and when their effluent was actually discharged either to the Rio Grande or to the canal system of the El Paso County Water Improvement District No. 1 ("EPCWID") or was used directly for irrigation of golf courses, parks, schools and other public land areas or for sustaining wetlands. Information provided by the El Paso Water Utility has been used to establish the proper representation of El Paso's wastewater discharges in the naturalized flow process for both the original 1940-2000 period and the extended 2001-2018 period.

In the original WAM study, all of the discharges from the John T. Hickerson Water Reclamation Facility, also known as the Northwest Plant, were adjusted for in the calculation of naturalized flows at the downstream gage on the Rio Grande at Fort Quitman. However, only about 80% of these discharges contributed to the river flows at the Fort Quitman gage, with the remainder used primarily for landscape irrigation. The adjustments for these discharges in the Fort Quitman naturalized flow workbook now have been reduced to 80% of the total discharges for the 1987-2000 period when this WWTP was in operation. For the 2001-2018 extended period, 83% of the total discharges from this WWTP have been accounted for in the adjustments for naturalizing flows at the Fort Quitman gage.

While El Paso has other WWTPs, namely the Roberto R. Bustamante WWTP and the Fred Hervey Water Reclamation Plant, that produced effluent during the 1940-2000 period, these discharges were fully utilized for irrigation and industrial use and for wetlands maintenance, or they were treated to drinking water standards and injected into a local aquifer for subsequent withdrawal and reuse. Therefore, none of these discharges contributed to the flow in the Rio Grande at Fort Quitman, and no adjustments for these discharges were made for naturalizing flows at the Fort Quitman gage for the 1940-2000 period. The same is also true for the 2001-2018 period.

Also, the Haskell R. Street WWTP had discharges to the Rio Grande for 1940 through 1998 that were adjusted for in the original calculation of naturalized flows at the downstream gage on the Rio Grande at Fort Quitman. Beginning in 1999, all of the effluent from this plant was either discharged into the Riverside Canal and subsequently used by the EPCWID primarily for irrigation or used directly for landscape irrigation. Thus, since 1999, none of these discharges have contributed to the flow in the Rio Grande, and in the original WAM study, no adjustments to the Fort Quitman flows were made for 1999 and 2000. Similarly, none of these discharges have been considered in naturalizing flows for the 2001-2018 extended period.

6.3.2 Laredo Zacate Creek WWTP

In this current study, it has been determined that the outfall for the Laredo Zacate Creek WWTP is located downstream of the Laredo gage on the Rio Grande, and not upstream as these discharge adjustments were made in the development of the original naturalized flows. Therefore, in this study, all of the adjustments for the discharges from the Zacate Creek WWTP for the original 1940-2000 period have been moved from the naturalized flow workbook for the gage on the Rio Grande at Laredo to the workbook for the gage below Falcon Dam.

6.3.3 Rio Grande City and City of Roma WWTPs

In the previous development of naturalized flows for the 1940-2000 period, adjustments for the discharges from the Rio Grande City and Roma WWTPs were made to the Rio Grande flows at the gage below Anzalduas Dam; however, further investigation in this current study has determined that these WWTP outfalls actually are located upstream of the Rio Grande City gage. Therefore, in this study, all of the adjustments for the discharges from the Rio Grande City and Roma WWTPs for the original 1940-2000 period have been moved from the naturalized flow workbook for the gage below Anzalduas Dam to the workbook for the Rio Grande City gage.

6.3.4 Ciudad Reynosa WWTP

For the original 1940-2000 period, discharges from the Ciudad Reynosa WWTP to the Rio Grande were adjusted for in the naturalized flow process at the gage located on the Rio Grande below Anzalduas Reservoir. However, the outfall for this WWTP is downstream of this gage, so no adjustments should have been made. This has been corrected in this study, and the naturalized flows at the gage below Anzalduas Reservoir for 1940-2000 no longer reflect adjustments for these WWTP discharges.

6.4 Irrigation Return Flows

6.4.1 Maverick County Water Control and Improvement District No. 1

The Maverick County Water Control and Improvement District No. 1 ("Maverick District") diverts significant quantities of water from the Rio Grande into a canal system that extends along the Rio Grande above and below Eagle Pass, and a significant portion of these diversions are returned back to the Rio Grande. The diverted water is used for irrigation and for electric power generation at the Maverick Power Plant. Return flows are discharged at two locations upstream of Eagle Pass, one for discharges from the Maverick Power Plant and the other for discharges of irrigation return flows. A third return flow outfall is located below Eagle Pass. Data are available from the IBWC for diversions into the Maverick District canal beginning in July 1949 and for the return flows to the Rio Grande from the Maverick Power Plant beginning in January 1949, with both of these records extending through 2018. Records for irrigation return flows from the other two discharge locations are available from the IBWC beginning in April of 1959 and extend through 2018, except for 1996. For the period from 1960 through 2018 (excluding 1996), the diversions into the Maverick District canal averaged 849,186 acre-feet per year, and the total irrigation and power generation return flows discharged to the Rio Grande averaged 759,079 acre-feet per year.

In the development of the original 1940-2000 naturalized flows, the Maverick District diversions from the Rio Grande were accounted for in the calculation of the 1940-2000 naturalized flows at the Piedras Negras (Eagle Pass) gage on the Rio Grande beginning in June of 1949, and the return flows from the Maverick Power Plant were accounted for beginning in January of 1960 (for some reason the data available back to 1949 were not used). The irrigation return flows from the upstream outfall above Piedras Negras were accounted for in the Piedras Negras naturalized flow calculations beginning in January 1960, but excluded for 1996. Irrigation return flows from the downstream outfall below Piedras Negras also were accounted for beginning in January 1960 (excluding 1996) in the naturalized flows calculated at the downstream Laredo gage. Thus, there was about a 10-year gap in the naturalized flow calculations from 1949 when the Maverick District diversions were first accounted for to 1960 when all of the Maverick District return flows were first accounted for, which translates to incorrect naturalized flows for this period.

In this current study, missing records for monthly values of the Maverick District Rio Grande diversions for January-June of 1949 have been estimated based on monthly correlation factors relating the diversions to the Maverick Power Plant return flows as derived from January-June 1950 monthly data for each of these quantities. For the January 1949 through March 1959 missing monthly records of irrigation return flows at the upstream and downstream outfalls, monthly return flow factors derived from 1960-1969 monthly data for these return flows and the Maverick District diversions have been applied to 1949-1959 monthly values of the Maverick District diversions. The missing 1996 monthly values of these return flows also have been estimated based on 1995 and 1997 average monthly return flow factors derived using the 1960-1969 monthly Maverick District diversion data. Now, a complete accounting for all of the Maverick District diversions and return flows, both power and irrigation, beginning in January 1949 is included in the calculation of the 1940-2000 naturalized flows at the Piedras Negras and Laredo control points.

6.4.2 Lower Rio San Juan Irrigation District

The Lower Rio San Juan Irrigation District is located in Mexico generally along the Rio Grande upstream and downstream of the mouth of the Rio San Juan, which flows into the Rio Grande just upstream of the Rio Grande City gage. The water supply for this irrigation district is from the Marte R. Gomez Reservoir, which is about 12 miles upstream on the Rio San Juan. For the period from January 1946 through December 1976, the return flows from the Lower San Juan Irrigation

District as reported by the IBWC for the reach of the Rio Grande between Falcon Dam and the Rio Grande City gage included not only the actual irrigation return flows, but also the entire flow of the Rio San Juan as measured at the Camargo, Tamaulipas gage, which is located on the river about three miles upstream from the Rio Grande. With these Rio San Juan flows included, the reported return flows prior to 1976 were substantially overstated, which resulted in erroneous return flow adjustments in the calculation of naturalized flows for the Rio Grande at the Rio Grande City gage, as well as, at the Rio Grande below Anzalduas Dam gage.

In the current study, the return flows from the Lower San Juan Irrigation District for the reach of the Rio Grande between Falcon Dam and the Rio Grande City gage prior to 1976 have been corrected by: 1) removing the gaged flow of the Rio San Juan from the values reported by IBWC for the period back to January 1954, the earliest date the Rio San Juan gaged flow at Camargo was available from IBWC, and 2) estimating the return flows for the Lower San Juan Irrigation District for the 1946-1953 period based on average monthly corrected values for 1954-1964. These reduced return flows were then used as part of the adjustments applied to the river flows at Rio Grande City to derive corrected naturalized flows at the Rio Grande City gage and at the downstream gage below Anzalduas Dam for the period prior to 1976. The net effect of these corrected return flow adjustments was to increase the downstream naturalized flows.

6.5 1994, 1999 and 2000 Evaporation Data

As discussed in Section 4.5 of this report, the evaporation data used during the original development of the Rio Grande WAM was revised by the TWDB, and based on analysis of these earlier data and the current data reported by TWDB, it has been determined that the revised evaporation data for the years 1994, 1999 and 2000 should be used in deriving revised reservoir adjustments for the recalculation of naturalized flows. These changes have been made as necessary in the naturalized flow workbooks, and they are reflected in the recalculated naturalized flows.

6.6 United States Floodway System Discharges

During flood events, part of the flows in the Rio Grande are diverted from the Rio Grande channel just upstream from Anzalduas Dam into the United States floodway system to control downstream flooding along the lower Rio Grande. These flood discharges are measured at downstream gages on the floodway system and should be accounted for as part of the gaged flow at the downstream gage below Anzalduas Dam in the calculation of naturalized flows. During the original development of the 1940-2000 naturalized flows, however, these flow adjustments at the Anzalduas gage were not properly made. In this study, historical discharge data have been obtained: (1) from IBWC for the Banker Floodway, the current floodway inlet upstream of Anzalduas Dam, for the 1976-2018 available period of record, (2) from IBWC annual Water Bulletins for the Mission Floodway for selected years with high flows in the Rio Grande below

Anzalduas Dam for the period from 1958 to 1975, and (3) from IBWC annual Water Bulletins for the North Floodway South of McAllen for selected years with high flows in the Rio Grande for the period prior to 1958. All of these discharges now have been accounted for in the recalculation of naturalized flows at the gage below Anzalduas Dam for the entire 1940-2000 period.

7.0 DEVELOPMENT OF 2001-2018 NATURALIZED STREAMFLOWS

The primary control points for which naturalized streamflows have been developed for the 2001-2018 period include those located on the Rio Grande mainstem and on Texas tributaries. These primary control points are listed in Table 6 with their associated streamflow gage, and they are shown on the map of the Rio Grande basin in Figure 10. They include 12 gages located on the mainstem of the Rio Grande and 11 gages located on Texas tributaries. Other primary control points listed in the table and shown on the map are those for gages on the eight Mexico tributaries where historical gaged flows have been used to represent regulated flows in the WAM simulation for the extended 2001-2018 period. Naturalized flows have not been developed for these primary control points for the 2001-2018 period. Specific information regarding how certain data were used and incorporated into the naturalized flow workbooks is discussed in the following sections.

7.1 Historical Reservoir Depletions

For Amistad, Falcon and Red Bluff Reservoirs, adjustments for streamflow depletions in the naturalized flow process were based on: (1) measured monthly storage data for calculating monthly changes in storage and (2) monthly TWDB evaporation and precipitation data and historical reservoir surface area for calculating monthly evaporation losses. As discussed previously, Lakes Balmorhea and Casa Blanca do not have measured storage records for the 2001-2018 period; therefore, the monthly storage changes and monthly evaporation losses (depletions) for these reservoirs were derived through reservoir operation simulations for the 2001-2018 period using a water balance spreadsheet model. For each of these reservoirs, the spreadsheet water balance model was applied to perform a time-series simulation (using monthly time steps) of reservoir storage by adjusting the reservoir's previous month's content for the current month's inflows, diversions, return flows, and net evaporation losses, taking into account the area-capacity relationship and maximum available storage capacity for each reservoir.

Monthly inflows to the reservoirs were calculated by applying monthly runoff coefficients to monthly rainfall amounts extracted from the TWDB historical precipitation database. The runoff coefficients used for each reservoir were the same as those developed in the original WAM study that were based on corresponding rainfall data and gaged streamflows for the particular region proximate to each reservoir. For the reservoir simulations, monthly rainfall data for the appropriate TWDB one-degree quadrangles were determined for each reservoir, and then the specific monthly rainfall amounts for each reservoir's watershed were calculated using the distance-weighted factors in Table 3. Monthly evaporation rates for each reservoir also were determined using these same procedures. To complete the inflows for Balmorhea, historical springflows from upstream major springs were added to the simulated runoff volumes.

TABLE 6 PRIMARY CONTROL POINTS USED IN NATURALIZED FLOW PROCESS

CONTROL POINT ID	WORK BOOK ID	NAME OF GAGE	IBWC/USGS GAGE NUMBER
MAINSTEM GAGES			
AT/AM2000	RG-EP	R Grande at El Paso, TX	08364000
AT/AM1000	RG-FQ	R Grande at Fort Quitman, TX [1]	08370500
BT/BM1000	RG-AC	R Grande above R Conchos, TX	08371500
CT/CM6000	RG-BC	R Grande below R Conchos, TX	08374200
CT/CM4000	RG-JR	R Grande at Johnson Ranch nr Castolon, TX	08375000
CT/CM3000	RG-FR	R Grande at Foster Ranch nr Langtry, TX	08377200
CT/CM1000	RG-DR	R Grande at Del Rio, TX	08451800
DT/DM5000	RG-PN	R Grande at Piedras Negras, COAH	08458000
DT/DM3000	RG-LA	R Grande at Laredo, TX	08459000
DT/DM1000	RG-BF	R Grande below Falcon Dam	08461300
ET/EM2000	RG-RG	R Grande at Rio Grande City, TX	08464700
ET/EM1000	RG-AN	R Grande below Anzalduas Dam, MX	08469200
TEXAS TRIBUTARY GAGES			
CT7000	AC-PR	Alamito Ck near Presidio, TX	08374000
CT5000	TC-TE	Terlingua Ck near Terlingua, TX	08374500
GT4000	DR-RB	Delaware R near Red Bluff, NM	8408500
GT5000	PR-RB	Pecos R at Red Bluff, NM	08407500
GT3000	PR-OR	Pecos R near Orla, TX [2]	08412500
GT2000	PR-GI	Pecos R near Girvin, TX	08446500
GT1000	PR-LA	Pecos R near Langtry, TX	08447410
CT2100	DR-JU	Devils R near Juno, TX [3]	08449000
CT2000	DR-PC	Devils R at Pafford Crossing nr Comstock, TX	08449400
DT9000	SF-DR	San Felipe Ck near Del Rio, TX	08453000
DT8000	PC-DR	Pinto Ck near Del Rio, TX	08455000
MEXICO TRIBUTARY GAGES			
FM1000	RC-OJ	R Conchos near Ojinaga, CHIH	08373000
DM9000	AV-CA	Arroyo de las Vacas at Cd. Acuna, COAH	08452000
DM7000	SD-JI	R San Diego nr Jimenez, COAH	08455500
DM6000	SR-EM	R San Rodrigo at El Maral, COAH	08457100
DM4000	RE-VF	R Escondido at Villa de Fuente, COAH	08458150
DM2000	RS-LT	R Salado nr Las Tortillas, TAMPS	08459700
EM4000	RA-CM	R Alamo at Mier, TAMPS	08462000
EM3000	SJ-CA	R San Juan at Camargo, TAMPS	08464200

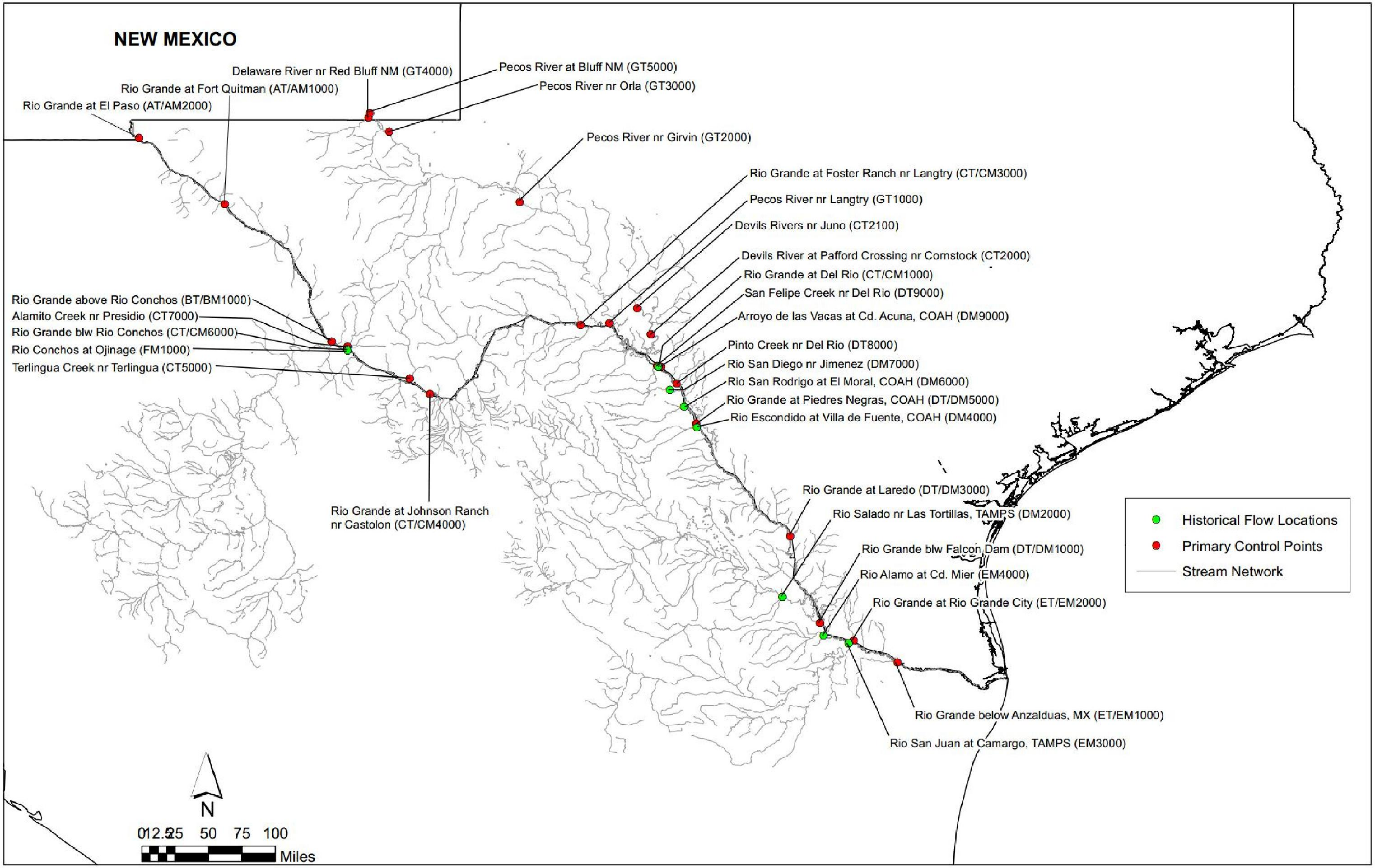


FIGURE 10 PRIMARY CONTROL POINTS USED IN 2001-2018 NATURALIZED FLOW PROCESS

7.2 Streamflow Channel Losses

Streamflow losses from the channel of a stream occur as a result of seepage, evaporation, plant uptake, and other factors such as unaccounted-for diversions and domestic and livestock use. While such losses are embedded in historical gaged flows to the extent that they actually occurred upstream of a gage, the corresponding losses associated with the various streamflow adjustments that are required to naturalize the gaged flows (to remove the effects of historical diversions, return flows, and reservoir storage and evaporation) must be accounted for separately. These additional streamflow losses have been factored into the 2001-2018 streamflow naturalization process for those stream reaches that were determined during the original Rio Grande WAM study to actually exhibit streamflow losses. The channel loss adjustments applied during the streamflow naturalization process for the 2001-2018 period are based on the same loss factors that were developed during the original Rio Grande WAM study. Use of the original loss factors is considered appropriate for the extended 2001-2018 period because there is no indication that channel conditions with regard to channel seepage, evaporation, and plant update have changed since 2000. The derivation of these channel losses is generally described in this section.

The channel loss adjustments applied during the streamflow naturalization process are made by applying a Channel Loss Factor, which represents the fraction (or percentage) of the streamflow that is lost over a particular stream reach. Therefore, the amount of flow that is delivered downstream after the loss adjustment is defined as:

$$\text{Downstream Flow} = \text{Upstream Flow} \times \text{Delivery Factor} \quad (1)$$

$$\text{where: Delivery Factor} = 1 - \text{Channel Loss Factor} \quad (2)$$

Channel losses along the streams within the Rio Grande basin originally were evaluated through a review of the geology, hydrogeology, and previous studies of the basin; an analysis of historical streamflows for selected stream reaches; and an analysis of evaporation and transpiration losses for selected stream reaches. Results from these analyses were used to establish the total Channel Loss Factor for the selected reaches as the sum of: (1) the fall-winter, dry period streamflow loss rate (as derived from historical streamflow records) reflecting channel seepage losses; (2) the average surface evaporation loss rate as derived from historical average annual gross evaporation data and stream surface areas; and (3) the average plant uptake loss rate based on estimated acreages of salt cedar and other phreatophytes along stream reaches and the average annual water consumption per acre of these plants.

For the streamflow naturalization process, values of the total loss per river mile reflecting the combined effects of channel seepage, evaporation, and salt cedar evapotranspiration for selected reaches in the basin were used to calculate streamflow loss rates for every stream reach between primary control points (or above the most upstream control point on a stream). These calculated streamflow loss rates were derived based on stream reach lengths relative to the selected stream reach lengths. The loss rates per river mile for the selected reaches associated with the various control point reaches are summarized in Table 7. These assignments were made taking into consideration the locations of the selected reaches for which total loss rates were determined relative to the locations of the control point reaches and general knowledge regarding the geologic and hydrogeologic characteristics of the specific areas. The resulting streamflow loss rates for the primary control point reaches represent the Channel Loss Factors referred to earlier, and they have been applied to all streamflow adjustments upstream of each primary control point (gage) in the flow naturalization process for the 2001-2018 period.

The Channel Loss Factor for a particular stream reach between two primary control points accounts for the total streamflow losses from the upstream end to the downstream end. However, flow adjustments in the naturalization process typically are required at various locations throughout the incremental drainage area, such as at the specific locations of diversions and return flows. Depending on their location within the incremental drainage area, these would have varying percentages of the total Channel Loss Factor applied to them, ranging from zero percent for an adjustment located at the downstream end to 100 percent for an adjustment located at the upstream end. Typically, there are numerous streamflow adjustments required within most incremental areas, and the procedure used in this study was to sum up these adjustments and apply a single weighted Channel Loss Factor to the sum. For simplicity considering the inherent uncertainties in the Channel Loss Factors, the sum of all adjustments for a particular incremental drainage area have been multiplied by 50 percent of the total Channel Loss Factor for the stream reach within the area. In effect this procedure results in the average Channel Loss Factor for the incremental drainage area being applied to all of the streamflow adjustments.

Where there are primary control points upstream of a stream reach subject to losses, the sum of all adjustments from all upstream watersheds has been routed through the downstream loss reach and reduced by the full Channel Loss Factor for the downstream loss reach. The use of this “routing” Channel Loss Factor is appropriate since all of the upstream adjustments would have to pass through the entire length of the downstream reach.

7.3 Non-Contributing Drainage Areas

Substantial portions of the upper Rio Grande basin do not drain to the Rio Grande or any of its tributaries. Instead, they have internal drainage systems that drain into a closed basin. Much of Texas west of the Pecos River comprises such non-contributing drainage areas. The occurrence of non-contributing drainage areas within the basin was considered in the streamflow naturalization process. Whenever streamflows from one gage have been transposed to another location using drainage area as an adjustment factor, the drainage areas used reflects only the

TABLE 7 CHANNEL LOSS FACTORS FOR RIO GRANDE MAINSTEM AND TEXAS TRIBUTARIES

CONTROL POINT ID	NAT FLOW WORKBOOK ID	CONTROL POINT LOCATION	UPSTREAM CONTROL POINTS	ASSOCIATED STREAM REACH FOR LOSS DETERMINATION	LOSS RATE %/Mile	REACH LENGTH Miles	CHANNEL LOSS FACTOR
AT/AM2000	RG-EP	R Grande at El Paso	n/a	n/a	n/a	n/a	n/a
AT/AM1000	RG-FQ	R Grande at Fort Quitman	AT/AM2000	R.G.-El Paso to Ft. Quitman	0.24	83	20%
BT/BM1000	RG-AC	R Grande abv R Conchos	AT/AM1000	R.G.-Ft. Quitman to abv R. Conchos	0.22	209	46%
CT7000	AC-PR	Alamito Ck nr Presidio	none	Pecos R.- Girvin to Langtry	0.19	82	9%
CT/CM6000	RG-BC	R Grande blw R Conchos	CT7000, AT/AM1000, FM1000	R.G.-Blw R.I Conchos to Johnson R.	0.11	14	2%
CT5000	TC-TE	Terlingua Ck nr Terlingua	none	Pecos R.- Girvin to Langtry	0.19	41	5%
CT/CM4000	RG-JR	R Grande at Johnson Ranch	CT5000, CT/CM6000	R.G.-Blw R.I Conchos to Johnson R.	0.11	88	10%
CT/CM3000	RG-FR	R Grande at Foster Ranch	CT/CM4000	R.G.- Johnson R. to Foster Ranch	0.01	205	2%
GT5000	PR-RB	Pecos R at Red Bluff	n/a	n/a	n/a	n/a	n/a
GT4000	DR-RB	Delaware R nr Red Bluff	none	Pecos R.- Orla to Girvin	0.35	25	9%
GT3000	PR-OR	Pecos R nr Orla	GT4000, GT5000	Pecos R.- Orla to Girvin	0.35	31	11%
GT2000	PR-GI	Pecos R nr Girvin	GT3000	Pecos R.- Orla to Girvin	0.35	136	48%
GT1000	PR-LA	Pecos R nr Langtry	GT2000	Pecos R.- Girvin to Langtry	0.19	160	30%
CT2100	DR-JU	Devils R nr Juno	none	Devils R.-Juno to Pafford Crossing	0.14	42	6%
CT2000	DR-PC	Devils R at Pafford Crossing	CT2100	Devils R.-Juno to Pafford Crossing	0.14	33	5%
CT/CM1000	RG-DR	R Grande at Del Rio	CT2000, GT1000, CT/CM3000	R.G.-Blw Amistad Dam to Del Rio	0.01	96	1%
DT9000	SF-DR	San Felipe Ck nr Del Rio	none	Devils R.-Juno to Pafford Crossing	0.14	5	1%
DT8000	PC-DR	Pinto Ck nr Del Rio	none	R.G.-Del Rio to Quemado	0.2	27	5%
DT/DM5000	RG-PN	R Grande at Piedras Negras	DT8000, DT9000, CT/CM1000, DM9500, DM7000, DM6000	R.G.-Del Rio to Quemado	0.2	64	13%
DT/DM3000	RG-LA	R Grande at Laredo	DT/DM5000, DM4000	R.G.-Eagle Pass to Laredo	0.1	137	14%
DT/DM1000	RG-BF	R Grande blw Falcon Dam	DT/DM3000, DM2000	R.G.-Blw Falcon Dam to R.G. City	0.18	86	9%
ET/EM2000	RG-RG	R Grande at Rio Grande City	DT/DM1000, EM4000, EM3000	R.G.-Blw Falcon Dam to R.G. City	0.18	40	4%
ET/EM1000	RG-AN	R Grande blw Anzalduas Dam	ET/EM2000	R.G.-Blw Falcon Dam to R.G. City	0.18	65	5%

runoff-contributing portions of the individual watersheds. Similarly, the drainage areas assigned to all control points for purposes of distributing naturalized streamflows in the WAM already reflect only contributing drainage areas. During the streamflow naturalization process, including data fill-in, non-contributing drainage areas were taken into account. Also, there are a few small water rights located in the closed basin in Texas. The current WAM addresses primary to secondary control point associations and has not been altered for the 2001-2018 extended period.

7.4 Texas-New Mexico State Line Flows

The Rio Grande and the Pecos River both enter Texas from New Mexico, and appropriate representations of the monthly flows for these rivers at or near the state line are required as inputs to the Rio Grande WAM. For the Rio Grande, these state line flows are specified at the gage at El Paso, which is the closest gage downstream from the state line and that is also located upstream of the first diversion at American Dam. For the Pecos River, the Red Bluff, New Mexico gage, which is located upstream of Red Bluff Reservoir, has been used for specifying these state line flows. In the WAM, each of these gages represents the most upstream primary control point on these rivers. Derivations of the monthly flows specified in the WAM for these state line locations for the 2001-2018 period are presented in the following sections.

7.4.1 Rio Grande at El Paso Gage

The Rio Grande Compact of 1938 includes specific procedures and requirements for how deliveries of Rio Grande water are to be made from Colorado to New Mexico at the state line and from New Mexico to Texas at Elephant Butte Reservoir. This reservoir is located on the Rio Grande about 130 river miles upstream from the New Mexico-Texas state line and is a key storage component of the Rio Grande Project. The Rio Grande Project was established in 1905 through federal legislation to provide water storage and delivery infrastructure and water management assistance primarily for irrigation water users in southern New Mexico, in the El Paso valley in western Texas, and in northern Mexico. Project water includes water stored in Elephant Butte Reservoir and Caballo Reservoir, which is located just downstream from Elephant Butte Reservoir, and inflows to the Rio Grande below Caballo Reservoir.

Allocations of Rio Grande Project water are made at the beginning of each year to irrigation districts in New Mexico and Texas in accordance with contracts between the districts and the federal government and to Mexico pursuant to provisions of the 1906 Convention between the United States and Mexico. The El Paso County Water Improvement District No. 1 ("EPCWID") is the owner of the Texas water right (Certificate of Adjudication No. 5940) that authorizes the diversion and use of 376,000 acre-feet per year of Rio Grande Project water in Texas. Annual allocations of Project water are made to the EPCWID, to the Elephant Butte Irrigation District ("EBID") in New Mexico, and to Mexico by the U. S. Bureau of Reclamation based on the quantity of water in storage in Elephant Butte Reservoir on or about December 1 of each year. Subsequent adjustments (primarily increases) to these allocations can be made during the course of an irrigation season primarily in response to inflows to the reservoir. Hence, as the amount of stored water and reservoir inflows vary, so do the annual allocations of Rio Grande Project water to the EBID, EPCWID and Mexico. Historically, there have been extended generally-wet periods when full allocations have been made available, such as from the early 1980s through 2002, and there have been other multi-year dry periods when very limited allocations have been made, such as during the 1950s drought and the recent drought that began in 2011.

One of the factors that has affected historical allocations of Rio Grande Project water is the fact that New Mexico has not met its obligations under the Rio Grande Compact to deliver Rio Grande water to Elephant Butte Reservoir. Beginning in the mid-1940s and extending until the early 1970s, New Mexico accrued significant shortages in its annual Compact deliveries, with the maximum negative balance exceeding 400,000 acre-feet from the mid-1950s through the mid-1960s. After that, New Mexico's annual Compact deliveries fluctuated above and below the Compact delivery requirements with significantly less accrued deficits. In the original study to develop the Rio Grande WAM, adjustments in the 1940-2000 gaged flows for the Rio Grande at El Paso were made to correct for the effects of the significant Compact under-deliveries by New Mexico, as well as their occasional over-deliveries. This was done so that the Rio Grande flows specified in the WAM at the state line (El Paso gage) for diversion by EPCWID and Mexico would reflect essentially full Compact compliance conditions with regard to New Mexico's deliveries to Elephant Butte Reservoir. Similar adjustments in the gaged flows for the Rio Grande at El Paso have not been necessary for the 2001-2018 period as New Mexico's compliance with its required Compact deliveries to Elephant Butte Reservoir has improved considerably. As shown in Table 8, over the 2001-2018 WAM extension period, there have been only a few years when New Mexico did not meet its obligation for Compact deliveries to Elephant Butte Reservoir. These annual under-deliveries were relatively small and generally were made up in the following few years such that allocations of water stored in Elephant Butte Reservoir to Rio Grande Project users, including EPCWID, were not appreciably affected.

For purposes of specifying naturalized flows for the Rio Grande at the Texas-New Mexico state line, the historical measured flows at the El Paso gage provide an approximation because these flows represent essentially the supply of Rio Grande Project water that was available historically for the EPCWID and Mexico, the only two entities that are entitled to Project water below the state line. However, there are two factors that require adjustments to the El Paso gaged flows in order to provide the correct Rio Grande inflows to the WAM. One relates to the fact that part of EPCWID's total diversion is made upstream of the El Paso gage in the Mesilla Valley. The EBID canal system is used to convey Rio Grande Project water across the stateline to EPCWID users in Texas. Therefore, for purposes of the WAM, in order to reflect the total EPCWID supply in the Rio Grande flows at the El Paso gage, these Mesilla Valley diversions must be added to the El Paso gaged flows. These calculations are summarized in Columns 2, 3 and 4 of Table 9 for annual flows for the 2001-2018 period.

TABLE 8 RIO GRANDE COMPACT DELIVERIES BY NEW MEXICO TO ELEPHANT BUTTE RESERVOIR DURING 2001-2018 PERIOD

YEAR	SCHEDULED DELIVERY UNDER COMPACT Ac-Ft	ACTUAL DELIVERY Ac-Ft	OVER (+) UNDER (-) DELIVERY Ac-Ft
2001	494,900	418,400	-76,500
2002	145,200	284,100	138,900
2003	270,300	222,800	-47,500
2004	371,500	407,000	35,500
2005	959,500	957,100	-2,400
2006	329,800	572,900	243,100
2007	513,500	546,300	32,800
2008	813,200	883,300	70,100
2009	540,000	622,900	82,900
2010	535,400	620,400	85,000
2011	328,400	281,300	-47,100
2012	268,400	239,800	-28,600
2013	249,800	310,100	60,300
2014	333,000	284,600	-48,400
2015	482,100	482,500	400
2016	433,000	412,400	-20,600
2017	853,000	871,700	18,700
2018	178,100	184,200	6,100

TABLE 9 2001-2018 NATURALIZED WAM INPUT FLOWS FOR RIO GRANDE AT EL PASO GAGE

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Year	Rio Grande Gaged Flow at El Paso	EPCWID Mesilla Valley Diversions	Sum of EP Gaged Flow and Mesilla Diversions	Rio Grande Project Allocations			WAM Input Flows	Distribution of Naturalized WAM Input Flows Specified at El Paso Gage	
				EPCWID	Mexico	Sum of EPCWID & Mexico	Maximum of Summed Flow (4) and Allocation (7)	EPCWID	Mexico
	ac-ft/yr	ac-ft/yr	ac-ft/yr	ac-ft/yr	ac-ft/yr	ac-ft/yr	ac-ft/yr	ac-ft/yr	ac-ft/yr
2001	453,491	31,645	485,136	376,862	60,000	436,862	485,136	425,136	60,000
2002	473,506	29,488	502,994	376,862	60,000	436,862	502,994	442,994	60,000
2003	172,330	11,040	183,369	125,735	26,616	152,351	183,369	151,334	32,035
2004	186,902	12,528	199,430	154,265	27,197	181,462	199,430	169,540	29,890
2005	329,796	23,177	352,973	376,862	60,000	436,862	436,862	376,862	60,000
2006	278,511	13,962	292,473	241,657	33,895	275,552	292,473	256,497	35,976
2007	337,852	19,425	357,277	403,491	58,769	462,260	462,260	403,491	58,769
2008	377,851	19,368	397,218	495,174	60,000	555,174	555,174	495,174	60,000
2009	382,039	19,104	401,142	552,997	53,386	606,383	606,383	552,997	53,386
2010	363,823	17,537	381,360	514,549	50,235	564,784	564,784	514,549	50,235
2011	230,397	6,861	237,258	267,814	25,649	293,463	293,463	267,814	25,649
2012	132,946	7,301	140,247	141,977	23,196	165,173	165,173	141,977	23,196
2013	57,452	3,243	60,695	47,061	3,665	50,726	60,695	56,310	4,385
2014	105,270	5,832	111,102	100,103	18,216	118,319	118,319	100,103	18,216
2015	170,508	8,389	178,897	188,117	35,355	223,472	223,472	188,117	35,355
2016	228,375	10,926	239,301	268,391	46,497	314,888	314,888	268,391	46,497
2017	270,499	16,021	286,520	438,371	60,000	498,371	498,371	438,371	60,000
2018	262,485	11,495	273,979	314,520	37,670	352,190	352,190	314,520	37,670

The other factor pertains to years in which the actual measured Rio Grande flow at the El Paso gage was less than the total amount of Rio Grande Project water that was allocated for both the EPCWID and Mexico (see Columns 5 and 6 in Table 9). This situation could have occurred for a variety of reasons, including when one or both of these entities simply did not request or need their full allocation of Project water, such as during wet periods, or when excessive groundwater pumping in New Mexico caused increased seepage losses of upstream river flows, thus reducing flows at the El Paso gage. For purposes of the WAM, in Table 9, the sum of annual Rio Grande flows at the El Paso gage and the EPCWID diversions at Mesilla Dam (Column 4) have been adjusted so that the annual flow specified in the WAM for the Rio Grande (Column 8) is always at least as much as the total annual allocation for the EPCWID and Mexico (Column 7).

With these adjustments, the full allocation of Project water for each of these entities at the El Paso gage is guaranteed to always be available for purposes of the WAM simulations. These adjusted annual flows have been prorated between the EPCWID and Mexico based on the historical allocations to these entities, with Mexico's annual amount calculated first and limited to 60,000 acre-feet per year in accordance with the 1906 Convention (Column 10 in Table 9). The balance of the annual flow has been assigned to EPCWID (Column 9). To accommodate the monthly time step used in the WAM, these annual flows in Columns 9 and 10 of Table 9 have been disaggregated to monthly values based on the average monthly diversion patterns derived from the 1940-2018 monthly diversion data for the EPCWID at the American Canal and for Mexico at the Acequia Madre.

7.4.2 Pecos River at Red Bluff Gage

The Pecos River Compact stipulates required annual deliveries of the waters of the Pecos River to Texas at the gage on the Pecos River at Red Bluff, New Mexico. Annual compact accounting reports summarize gaged river flows and deliveries to Texas, including annual overage and shortfall amounts. Similar to the approach used in the original WAM study, for purposes of providing Pecos River flows for input to the Rio Grande WAM for the 2001-2018 period, historical flows measured at the Pecos River at Red Bluff gage have been adjusted to account for the annual overage and shortfall amounts so that the flows at the stateline represent full Compact compliance conditions. The historical annual quantities of measured streamflow and the overage and shortfall amounts for the Pecos River at Red Bluff gage are summarized in Table 10.

Unlike the Rio Grande Compact, Texas' share of water apportioned under the Pecos River Compact is simply based on the flow measured at the streamflow gage on the Pecos River near Red Bluff, New Mexico (No. 08407500), adjusted to represent a 1947 condition. Therefore, to develop flows at this gage for input to the WAM for the 2001-2018 period that reflect full compliance with the Pecos River Compact, the historical flows at this gage (Column 2) have been adjusted to account for the reported annual quantities of overage and shortfall amounts (Column 3). These adjusted annual flows also are listed in Table 10 (Column 4). For purposes of the WAM simulations with a monthly time step, these annual flows have been disaggregated to monthly values based on the monthly distribution of the historical annual flows at the Red Bluff gage. It should be noted that while Article VI(b) of the Pecos River Compact stipulates that annual accounting shall be based on flows over successive three-year periods and that the annual overage and shortfall amounts in Table 10 (Column 3) represent three-year averages, the adjustments made in Table 10 to the annual Pecos River flows measured at the Red Bluff gage to reflect full-compliance conditions are considered to be sufficiently accurate for purposes of the updated Rio Grande WAM.

TABLE 10 PECOS RIVER COMPACT DELIVERIES BY NEW MEXICO AND WAM INPUT FLOWS FOR 2001-2018 PERIOD

(1)	(2)	(3)	(4)
Year	Pecos River Flow at Red Bluff ac-ft/yr	Annual Overage(+) and Shortfall(-) Pecos River Compact Deliveries ac-ft	WAM Input Flows Adjusted For Full Compact Deliveries ac-ft/yr
2001	43,710	-700	44,410
2002	39,668	-3,000	42,668
2003	22,439	2,000	20,439
2004	125,249	8,300	116,949
2005	106,505	24,000	82,505
2006	66,855	26,100	40,755
2007	67,469	25,200	42,269
2008	57,996	6,000	51,996
2009	44,018	1,600	42,418
2010	60,627	-500	61,127
2011	24,560	500	24,060
2012	17,756	1,900	15,856
2013	51,025	-6,300	57,325
2014	146,613	700	145,913
2015	101,063	27,300	73,763
2016	75,430	27,200	48,230
2017	46,925	19,900	27,025
2018	42,646	5,300	37,346

7.5 Streamflow Naturalization Procedure

As described in Section 2.0, the basic equation for naturalizing the flows at a particular location involves applying adjustments to the historical gaged flows at that location to remove the effects of all upstream water-related activities. These adjustments to the historical gaged flows include adding the total upstream diversions, subtracting the total upstream wastewater discharges and irrigation return flows, and adjusting for changes in storage and net evaporation losses associated with all upstream major reservoirs.

In this study, application of this procedure for the 2001-2018 period has proceeded from upstream to downstream, just as was done during the original development of the naturalized flows for the existing Rio Grande WAM. This process begins with the most upstream primary control point on the mainstem of the Rio Grande at El Paso and continues in the downstream direction along the mainstem of the Rio Grande, including Texas tributaries as they enter the Rio Grande, from one primary control point to the next primary control point all the way to the most downstream primary control point below Anzalduas Dam. At each primary control point, the historical gaged flows have been adjusted for the combined effects of all upstream diversions, wastewater discharges and return flows, compact flow adjustments, reservoir depletions, and springflows. Channel losses and any required springflow adjustments also have been accounted for using the same procedures and factors applied during the original development of the 1940-2000 naturalized flows.

Gaged flows for tributaries in Texas that have primary control points also have been naturalized from upstream to downstream, with these tributary adjustments for diversions, discharges and return flows, and reservoir depletions included as part of the total upstream adjustment values used in the naturalization of river flows at all downstream mainstem primary control points. In accordance with the alternative approach for representing 2001-2018 inflows to the Rio Grande from the Mexico tributaries in the WAM, gaged flows for the Mexico tributaries have not been naturalized. Thus, in the WAM, all water use activities on Mexico tributaries for the 2001-2018 period have been set equal to zero, which, in effect, has resulted in the gaged inflows to the Rio Grande from the Mexico tributaries being reflected in the simulations as regulated flows.

7.6 Fill-In Procedures for Naturalized Flows

7.6.1 1940-2000 Period

As described in previous sections of this report, a number of revisions have been made to the data and to the naturalized flow procedures used in the original development of the 1940-2000 naturalized flows. These revisions have resulted in changes to the original naturalized flows at numerous primary control points both on the mainstem of the Rio Grande and on tributaries in Texas. Because the 1940-2000 naturalized flows at some of the primary control points originally had to be filled using relationships with naturalized flows at other primary control points with common periods of record, the naturalized flows at these same primary control points also were filled in this current study based on the updated 1940-2018 naturalized flows.

The statistical procedures used for filling the missing naturalized flows in this current study were the same as those applied in the original WAM study, except that the correlation coefficients and flow factors were recalculated using updated naturalized flows for the entire 1940-2018 period. Table 11 summarizes these revised equations and the periods when they have been applied to fill in naturalized flows at primary control points.

7.6.2 2001-2018 Period

For the 2001-2018 period, naturalized flows had to be estimated for only one primary control point, the Devils River near Juno gage site. In the original WAM study, monthly linear regression equations were derived relating the naturalized flows at this gage site when gaged flows were available (October 1963 through September 1973) to the corresponding naturalized flows at the next downstream gage, Devils River near Pafford Crossing near Comstock. Since no further records of measured flows for the Juno gage are available (after September 1973), the same monthly regression equations derived in the original WAM study have been used to estimate naturalized flows at the Juno primary control point for the extended 2001-2018 period based on the complete set of 2001-2018 naturalized flows at the Devils River near Pafford Crossing gage. These linear regression equations are presented in Table 12.

Use of these regression equations is considered appropriate based on an analysis of the cumulative Devils River near Pafford Crossing naturalized flows for the 1940-2018 period. The time-series single-mass graph of these flows indicated no appreciable deviations, suggesting that there have been no significant changes in the watershed conditions for the Devils River near Pafford Crossing gage over this period; therefore, the original relationships between monthly naturalized flows at this gage and at the Devils River near Juno gage are considered to be appropriate for application to the 2001-2018 period.

7.7 Adjustments for Negative Naturalized Flows

In the naturalized flow process, after the adjustments to gaged streamflows have been made at a primary control point to remove the effects of upstream reservoirs, diversions, return flows and other water-related activities, negative monthly values of total naturalized streamflows or incremental naturalized streamflows between upstream gages and the next downstream gage can occur, even after the streamflow losses associated with the adjustments have been accounted for. These negative naturalized flows can be caused by a number of factors, including natural channel losses, inaccurate measured data such as streamflows or diversions, errors in estimated data,

TABLE 11 PROCEDURES USED FOR FILLING NATURALIZED FLOWS FOR THE 1940-2000 PERIOD

PRIMARY CONTROL POINT WORKBOOK ID AND NAME	MONTHS/YEARS WITH FILLED FLOWS	PROCEDURE USED	LINEAR REGRESSION AND FLOW FACTOR EQUATIONS USED IN CURRENT STUDY	NOTES
RG-FR - Rio Grande at Foster Ranch	1/1940 thru 8/1961	Linear Reg. Eq.	January: 0.89 x RGJR + 22,461	1, 2
	1/1940 thru 8/1961	Linear Reg. Eq.	February: 1.06 x RGJR + 10,195	1, 2
	1/1940 thru 8/1961	Linear Reg. Eq.	March: 1.03 x RGJR + 13,471	1, 2
	1/1940 thru 8/1961	Linear Reg. Eq.	April: 1.02 x RGJR + 15,907	1, 2
	1/1940 thru 8/1961	Linear Reg. Eq.	May: 1.04 x RGJR + 17,703	1, 2
	1/1940 thru 8/1961	Linear Reg. Eq.	June: 0.98 x RGJR + 28,616	1, 2
	1/1940 thru 8/1961	Linear Reg. Eq.	July: 0.97 x RGJR + 25,277	1, 2
	1/1940 thru 8/1961	Linear Reg. Eq.	August: 0.98 x RGJR + 21,761	1, 2
	1/1940 thru 8/1961	Linear Reg. Eq.	September: 0.95 x RGJR + 40,073	1, 2
	1/1940 thru 8/1961	Linear Reg. Eq.	October: 1.14 x RGJR + 7,098	1, 2
	1/1940 thru 8/1961	Linear Reg. Eq.	November: 1.41 x RGJR – 7,445	1, 2
	1/1940 thru 8/1961	Linear Reg. Eq.	December: 0.97 x RGJR + 18,055	1, 2
OR-LA - Pecos River near Langtry	1/1940 thru 9/1949	Flow Factor	(0.1747 x (RGDR-RGJR-PRGI-DRJU)) + PRGI	1, 3, 5
	10/1949 thru 12/1959	Flow Factor	(0.1496 x (RGDR-RGJR-PRGI)) + PRGI	1, 3, 5
	1/1960 thru 12/1961	Flow Factor	(0.1986 x (RGDR-RGJR-PRGI-DRPC)) + PRGI	1, 3, 5
	1/1962 thru 6/1967	Flow Factor	(0.2854 x (RGDR-RGFR-PRGI-DRPC)) + PRGI	1, 3, 5
DR-JU - Devils River near Juno	01/1960 thru 09/1963 & 10/1973 thru 12/2018	Linear Reg. Eq.	January: 0.3224 x DRPC + 0	1, 4
	01/1960 thru 09/1963 & 10/1973 thru 12/2018	Linear Reg. Eq.	February: 0.3313 x DRPC + 0	1, 4
	01/1960 thru 09/1963 & 10/1973 thru 12/2018	Linear Reg. Eq.	March: 0.3478 x DRPC + 0	1, 4
	01/1960 thru 09/1963 & 10/1973 thru 12/2018	Linear Reg. Eq.	April: 0.0203 x DRPC + 2,757	1, 4

TABLE 11 (continued)

PRIMARY CONTROL POINT	MONTHS/YEARS WITH FILLED FLOWS	PROCEDURE USED	LINEAR REGRESSION AND FLOW FACTOR EQUATIONS USED IN CURRENT STUDY	NOTES
DR-JU - Devils River near Juno, continued	01/1960 thru 09/1963 & 10/1973 thru 12/2018	Linear Reg. Eq.	May: 0.6678 x DRPC - 1,846	1, 4
	01/1960 thru 09/1963 & 10/1973 thru 12/2018	Linear Reg. Eq.	June: 0.1792 x DRPC + 1,011	1, 4
	01/1960 thru 09/1963 & 10/1973 thru 12/2018	Linear Reg. Eq.	July: 0.7579 x DRPC - 2,998	1, 4
	01/1960 thru 09/1963 & 10/1973 thru 12/2018	Linear Reg. Eq.	August: 0.7221 x DRPC + 0	1, 4
	01/1960 thru 09/1963 & 10/1973 thru 12/2018	Linear Reg. Eq.	September: 0.8834 x DRPC + 0	1, 4
	01/1960 thru 09/1963 & 10/1973 thru 12/2018	Linear Reg. Eq.	October: 0.1934 x DRPC + 1,889	1, 4
	01/1960 thru 09/1963 & 10/1973 thru 12/2018	Linear Reg. Eq.	November: 0.3029 x DRPC + 269	1, 4
	01/1960 thru 09/1963 & 10/1973 thru 12/2018	Linear Reg. Eq.	December: 0.3065 x DRPC + 239	1, 4
	10/1949 thru 12/1959	Flow Factor	0.1208 x (RGDR-PRGI-RGJR)	1, 3
DR-PC - Devils River at Pafford Crossing	1/1940 THRU 9/1949	Flow Factor	(0.1302 x (RGDR-PRGI-DRJU-RGJR)) + DRJU	1, 3, 5
	10/1949 thru 12/1959	Flow Factor	0.2367 x (RGDR-PRGI-RGJR)	1, 3
RG-BF - Rio Grande below Falcon Dam	1/1940 thru 12/1951	Linear Reg. Eq.	January: 0.9786 x RGLA + 8,598	1, 4
	1/1940 thru 12/1951	Linear Reg. Eq.	February: 1.0023 x RGLA + 10,718	1, 4
	1/1940 thru 12/1951	Linear Reg. Eq.	March: 0.8231 x RGRG + 15,545	1, 4
	1/1940 thru 12/1951	Linear Reg. Eq.	April: 0.7259 x RGRG + 30,286	1, 4
	1/1940 thru 12/1951	Linear Reg. Eq.	May: 0.7815 x RGRG + 3,504	1, 4
	1/1940 thru 12/1951	Linear Reg. Eq.	June: 0.7025 x RGRG + 27,288	1, 4

TABLE 11 (continued)

PRIMARY CONTROL POINT	MONTHS/YEARS WITH FILLED FLOWS	PROCEDURE USED	LINEAR REGRESSION AND FLOW FACTOR EQUATIONS USED IN CURRENT STUDY	NOTES
RG-BF - Rio Grande below Falcon Dam, continued	1/1940 thru 12/1951	Linear Reg. Eq.	July: 0.8060 x RGRG + 20,129	1, 4
	1/1940 thru 12/1951	Linear Reg. Eq.	August: 1.0672 x RGLA - 326	1, 4
	1/1940 thru 12/1951	Linear Reg. Eq.	September: 0.5944 x RGRG + 103,884	1, 4
	1/1940 thru 12/1951	Linear Reg. Eq.	October: 0.6957 x RGRG + 29,492	1, 4
	1/1940 thru 12/1951	Linear Reg. Eq.	November: 0.6783 x RGRG + 24,517	1, 4
	1/1940 thru 12/1951	Linear Reg. Eq.	December: 1.1697 x RGLA - 22,539	1, 4
	1952	Linear Reg. Eq.	January: 0.9786 x RGLA + 8,598	1, 4
	1952	Linear Reg. Eq.	February: 1.0023 x RGLA + 10,718	1, 4
	1952	Linear Reg. Eq.	March: 0.8231 x RGRG + 15,545	1, 4
	1952	Linear Reg. Eq.	April: 0.7413 x RGAN + 32,311	1, 4
	1952	Linear Reg. Eq.	May: 0.7815 x RGRG + 3,504	1, 4
	1952	Linear Reg. Eq.	June: 0.7025 x RGRG + 27,288	1, 4
	1952	Linear Reg. Eq.	July: 0.8060 x RGRG + 20,129	1, 4
	1952	Linear Reg. Eq.	August: 1.0672 x RGLA - 326	1, 4
	1952	Linear Reg. Eq.	September: 0.6184 x RGAN + 102,917	1, 4
	1952	Linear Reg. Eq.	October: 0.6957 x RGRG + 29,492	1, 4
	1952	Linear Reg. Eq.	November: 0.6783 x RGRG + 24,517	1, 4
	1952	Linear Reg. Eq.	December: 0.6075 x RGAN + 44,958	1, 4
RG-AN - Rio Grande below Anzalduas Dam	1/1940 thru 12/1951	Linear Reg. Eq.	January: 1.0007 RGRG - 5,120	1, 4
	1/1940 thru 12/1951	Linear Reg. Eq.	February: 1.0062 x RGRG - 718	1, 4
	1/1940 thru 12/1951	Linear Reg. Eq.	March: 1.0314 x RGRG - 13,689	1, 4
	1/1940 thru 12/1951	Linear Reg. Eq.	April: 0.9797 x RGRG - 2,905	1, 4

TABLE 11 (continued)

PRIMARY CONTROL POINT	MONTHS/YEARS WITH FILLED FLOWS	PROCEDURE USED	LINEAR REGRESSION AND FLOW FACTOR EQUATIONS USED IN CURRENT STUDY	NOTES
RG-AN - Rio Grande below Anzalduas Dam, continued	1/1940 thru 12/1951	Linear Reg. Eq.	May: 0.9865 x RGRG +12,304	1, 4
	1/1940 thru 12/1951	Linear Reg. Eq.	June: 0.9647 x RGRG + 14,598	1, 4
	1/1940 thru 12/1951	Linear Reg. Eq.	July: 0.9273 x RGRG + 20,080	1, 4
	1/1940 thru 12/1951	Linear Reg. Eq.	August: 0.9926 x RGRG - 6,967	1, 4
	1/1940 thru 12/1951	Linear Reg. Eq.	September: 0.9525 x RGRG + 8,074	1, 4
	1/1940 thru 12/1951	Linear Reg. Eq.	October: 0.9744 x RGRG + 7594	1, 4
	1/1940 thru 12/1951	Linear Reg. Eq.	November: 1.0706 x RGRG - 18,958	1, 4
	1/1940 thru 12/1951	Linear Reg. Eq.	December: 1.0377 x RGRG - 13,158	1, 4

Notes:

1) Abbreviations: RGJR - Rio Grande at Johnson Ranch, RGFR - Rio Grande at Foster Ranch, PRGI - Pecos River at Girvin, PRLA - Pecos River at Langtry, DRJU - Devils River at Juno, DRPC - Devils River at Pafford Crossing, RGDR - Rio Grande at Del Rio, Rio Grande at Laredo, RGBF - Rio Grande below Falcon Dam, RGRG - Rio Grande at Rio Grande City, RGAN - Rio Grande below Anzalduas Dam
2) Naturalized flows for Rio Grande at Johnson Ranch for 1940-2000 did not change appreciably, therefore, original equations have been used for fills.
3) Revised flow factors have been developed based on common period 1940-2018 updated naturalized flows and used for fills in original period.
4) Revised linear regression equations have been developed based on common period 1940-2018 updated naturalized flows and used for fills in original period.
5) The upstream naturalized flow that was added to the filled incremental flow was adjusted for channel losses occuring in the incremental reach.

TABLE 12 NATURALIZED FLOW FILL-IN EQUATIONS FOR DEVILS RIVER NEAR JUNO

MONTH	CORRELATION EQUATION
January	DR-JU = 0.3224 x DR-PC
February	DR-JU = 0.3313 x DR-PC
March	DR-JU = 0.3478 x DR-PC
April	DR-JU = 0.0203 x DR-PC + 2,757
May	DR-JU = 0.6678 x DR-PC - 1,846
June	DR-JU = 0.1792 x DR-PC + 1,011
July	DR-JU = 0.7579 x DR-PC - 2,998
August	DR-JU = 0.7221 x DR-PC
September	DR-JU = 0.8834 x DR-PC
October	DR-JU = 0.1934 x DR-PC + 1889
November	DR-JU = 0.3029 x DR-PC + 269
December	DR-JU = 0.3065 x DR-PC + 239

DR-JU = Naturalized flow for Devils River near Juno
DR-PC = Naturalized flow for Devils River near Pafford Crossing

unreported or unaccounted for diversions or return flows, and/or inaccurate hydrologic parameters or streamflow loss estimates. Also, the travel time along a stream reach between gages or from the points where diversions or return flows occur or from where reservoirs are located to a downstream gage site can cause inconsistencies in reported monthly flows, resulting in negative total or incremental naturalized streamflows. However, in basins like the Rio Grande where significant natural channel losses are known to exist and where loss factors have been calculated between gaged flow locations (primary control points), negative incremental naturalized flows are to be expected since in the naturalized flow process, only man's historical water-related activities and the channel losses associated with these activities are adjusted for. Natural channel losses that occurred historically between control points remain embedded in the naturalized flows.

Negative values of <u>total</u> naturalized flows typically do not occur in a river system because natural inflows are always contributing to the total flow along the length of the river; however, in the rare instances where they may have been calculated in this study, they have been eliminated by setting a negative total flow value for a particular month to zero. This has been done for all cases during the entire 1940-2018 period. For negative <u>incremental</u> naturalized flows, no adjustments have been made to eliminate these negative flow values in the streamflow naturalization process because: 1) as part of the WAM simulation process, the method used to prorate flow to ungaged locations taking into account channel losses largely addresses the negative incremental flow issue for the Rio Grande basin, and 2) to the extent this method does not, the remaining negative incremental naturalized flows have been taken into account by using Option 5 in the WRAP program, which is one of several options available for dealing with negative incremental flows. A more in-depth discussion of negative total and incremental naturalized flows in the Rio Grande basin and justification for not adjusting the negative incremental flows is provided in Appendix B.

It should be noted that negative incremental naturalized flows between primary control points located on the Rio Grande mainstem and on intervening tributaries are accounted for in the distribution of naturalized flows between the United States and Mexico river systems as represented in the Rio Grande WAM. These distributions, which are discussed in Section 7.10, are made in accordance with water ownership accounting procedures that are performed weekly and monthly by the IBWC for flows in the Rio Grande. Consistent with language in the 1944 Treaty, to determine each country's naturalized flow at a downstream primary control point, positive incremental naturalized flows are divided equally and added to each country's total naturalized flow at the upstream mainstem control point plus any assigned naturalized tributary inflows. Negative incremental flows are proportionally distributed to each country based on the calculated amount of known naturalized flow each country has in the Rio Grande at the downstream control point (based on the sum of the naturalized flows at the upstream primary control points plus any assigned tributary inflows). As with the positive incremental naturalized flows, each country's total naturalized flow at a downstream primary control point is calculated by adding each country's portion of the negative incremental flow to each country's total naturalized flow at the upstream mainstem control point and any assigned naturalized tributary inflows. The result of this flow distribution process does not eliminate any negative incremental naturalized flows; it only distributes them to each country's total naturalized flow.

7.8 Updated Naturalized Flows, Evaporation and Flow Adjustment Datasets

Final values of the updated naturalized flows for the entire 1940-2018 period are tabulated in the updated naturalized flow workbooks for all primary control points on the Rio Grande mainstem and on Texas tributaries. Each workbook for a primary control point includes individual worksheets that contain the gaged flow at the primary control point and the incremental and total gaged flow adjustments for diversions, return flows, reservoir depletions, and miscellaneous adjustments such as for springflows and Compact flows. Also included in the workbooks are tabulations of the updated net evaporation data for every reservoir included in the WAM and the flow adjustment datasets required for input to the WAM. The 1940-2018 updated naturalized flows, updated net reservoir evaporation, and updated flow adjustment datasets also have all been incorporated into the Rio Grande WAM input files to produce an updated WAM representative of 1940-2018 hydrologic and climatic conditions.

7.9 Comparison of Original and Updated Naturalized Flows

As discussed in Section 6.0, several adjustments have been made in this study to correct for errors or inconsistencies that have been observed in the original 1940-2000 data and the associated naturalized flow workbooks. These include adjustments of streamflow records, diversion and water use data, municipal wastewater discharges, irrigation and power plant return flows, and evaporation data for 1994, 1999 and 2000. Also, the diversions for the Rio Escondido Power Plant on the Rio Grande were included in both the Piedras Negras and Laredo naturalized flow workbooks, when they belong only in the Laredo workbook. Major corrections and adjustments were made for the Maverick District diversions from the Rio Grande and the associated return flows near Eagle Pass and for return flows to the Rio Grande from the Lower San Juan Irrigation District in Mexico near Rio Grande City. Combined, these adjustments and revisions of the 1940-2000 WAM datasets have resulted in changes to the original naturalized flows varying from a few acre-feet per year up to several hundred thousand acre-feet per year.

To demonstrate the significance of these adjustments and revisions, the naturalized flows as originally developed for the existing WAM and as updated in this current study for selected primary control points considered representative of overall flow conditions have been statistically analyzed: (1) for the original 1940-2000 period, (2) for the updated 1940-2000 period, and (3) for the updated 2001-2018 period. These results are summarized in Table 13, Sub-tables a, b, c and d. As shown, the statistical results are presented in four sub-tables, one each for the average, median, maximum and minimum values of the annual naturalized flows, with the changes in these quantities from the 1940-2000 original flows to the 1940-2000 updated flows (Column 5) and from the 1940-2000 updated flows to the 2001-2018 updated flows (Column 7) included in each sub-table.

Table 13a shows the results for average annual values and provides an overview of how the naturalized flows have changed with the revisions made in this study. As shown in Column 5, changes from the original 1940-2000 naturalized flows to the updated 1940-2000 naturalized flows are relatively small above the Piedras Negras primary control point, with most of these changes due to relatively minor corrections of the data used for adjusting the upstream gaged flows in the naturalized flow calculation process, including corrections to the reservoir evaporation for 1994, 1999 and 2000. Significant changes in the annual average flows begin at the Piedras Negras control point and are apparent all the way downstream to the primary control point below Anzalduas Dam (Column 5). These changes result from: (1) major corrections to the Maverick District diversions from the Rio Grande and the associated return flows for 1949 through 1960, (2) proper location of the Rio Escondido Power Plant diversion to below Piedras Negras, (3) adjustments to the locations of WWTP outfalls for Ciudad Acuna and Laredo and cities below Falcon Dam, (4) major corrections to the amounts and locations of return flows to the Rio Grande from the Lower Rio San Juan Irrigation District in Mexico above and below the Rio Grande City

TABLE 13a AVERAGE VALUES OF ORIGINAL AND UPDATED NATURALIZED FLOWS

(1)	(2)	(3)	(4)	(5)	(6)	(7)
CONTROL POINT ID	NAME OF GAGE / WORK BOOK ID	AVERAGE ANNUAL NATURALIZED FLOW VALUES				
		1940-2000 Original	1940-2000 Updated	Change [1]	2001-2018 Updated	Change [2]
AT/AM1000	Rio Grande at Fort Quitman/RG-FQ	475,633	476,052	419	370,712	-105,340
CT/CM6000	Rio Grande below Rio Conchos/RG-BC	1,804,966	1,805,201	236	600,896	-1,204,306
GT1000	Pecos River near Langtry/PR-LA	266,819	259,725	-7,095	183,575	-76,149
CT2000	Devils River at Pafford Crossing/DR-PC	262,320	262,949	628	224,849	-38,099
CT/CM1000	Rio Grande at Del Rio/RG-DR	2,967,705	2,968,320	615	1,786,933	-1,181,388
DT/DM5000	Rio Grande at Piedras Negras/RG-PN	3,409,544	3,307,953	-101,591	2,133,122	-1,174,831
DT/DM3000	Rio Grande at Laredo/RG-LA	3,514,852	3,418,331	-96,521	2,232,899	-1,185,432
DT/DM1000	Rio Grande below Falcon Dam/RG-BF	3,930,259	3,827,657	-102,602	2,462,416	-1,365,242
ET/EM2000	Rio Grande at Rio Grande City/RG-RG	4,864,030	4,935,875	71,846	2,868,778	-2,067,097
ET/EM1000	Rio Grande below Anzalduas Dam/RG-AN	4,667,049	4,848,320	181,272	2,814,277	-2,034,043

Notes: [1] Change from 1940-2000 Original Flows to 1940-2000 Updated Flows
[2] Change from 1940-2000 Updated Flows to 2001-2018 Updated Flows

TABLE 13b MEDIAN VALUES OF ORIGINAL AND UPDATED NATURALIZED FLOWS

(1)	(2)	(3)	(4)	(5)	(6)	(7)
CONTROL POINT ID	NAME OF GAGE / WORK BOOK ID	MEDIAN ANNUAL NATURALIZED FLOW VALUES				
		1940-2000 Original	1940-2000 Updated	Change [1]	2001-2018 Updated	Change [2]
AT/AM1000	Rio Grande at Fort Quitman/RG-FQ	453,622	453,655	33	347,690	-105,966
CT/CM6000	Rio Grande below Rio Conchos/RG-BC	1,612,146	1,612,166	20	453,473	-1,158,693
GT1000	Pecos River near Langtry/PR-LA	217,544	217,544	0	153,669	-63,876
CT2000	Devils River at Pafford Crossing/DR-PC	207,943	209,960	2,017	193,688	-16,273
CT/CM1000	Rio Grande at Del Rio/RG-DR	2,657,133	2,656,557	-576	1,560,836	-1,095,722
DT/DM5000	Rio Grande at Piedras Negras/RG-PN	3,074,464	2,905,957	-168,507	1,789,311	-1,116,647
DT/DM3000	Rio Grande at Laredo/RG-LA	3,202,670	3,019,470	-183,200	1,855,229	-1,164,241
DT/DM1000	Rio Grande below Falcon Dam/RG-BF	3,514,464	3,487,555	-26,909	1,954,710	-1,532,845
ET/EM2000	Rio Grande at Rio Grande City/RG-RG	4,478,245	4,528,904	50,659	2,296,044	-2,232,861
ET/EM1000	Rio Grande below Anzalduas Dam/RG-AN	4,231,630	4,347,143	115,513	2,288,415	-2,058,729

Notes: [1] Change from 1940-2000 Original Flows to 1940-2000 Updated Flows
[2] Change from 1940-2000 Updated Flows to 2001-2018 Updated Flows

TABLE 13c MAXIMUM VALUES OF ORIGINAL AND UPDATED NATURALIZED FLOWS

(1)	(2)	(3)	(4)	(5)	(6)	(7)
CONTROL POINT ID	NAME OF GAGE / WORK BOOK ID	MAXIMUM ANNUAL NATURALIZED FLOW VALUES				
		1940-2000 Original	1940-2000 Updated	Change [1]	2001-2018 Updated	Change [2]
AT/AM1000	Rio Grande at Fort Quitman/RG-FQ	1,793,727	1,793,787	60	631,195	-1,162,592
CT/CM6000	Rio Grande below Rio Conchos/RG-BC	4,657,408	4,658,442	1,034	2,497,590	-2,160,852
GT1000	Pecos River near Langtry/PR-LA	1,530,916	1,516,292	-14,624	366,218	-1,150,074
CT2000	Devils River at Pafford Crossing/DR-PC	946,067	950,953	4,886	505,472	-445,481
CT/CM1000	Rio Grande at Del Rio/RG-DR	6,143,837	6,144,237	400	3,979,345	-2,164,892
DT/DM5000	Rio Grande at Piedras Negras/RG-PN	6,881,370	6,325,171	-556,199	4,911,665	-1,413,506
DT/DM3000	Rio Grande at Laredo/RG-LA	6,735,122	6,386,513	-348,609	5,023,752	-1,362,761
DT/DM1000	Rio Grande below Falcon Dam/RG-BF	9,307,873	8,747,902	-559,971	7,785,468	-962,434
ET/EM2000	Rio Grande at Rio Grande City/RG-RG	10,614,375	11,197,277	582,902	10,783,136	-414,141
ET/EM1000	Rio Grande below Anzalduas Dam/RG-AN	9,557,558	10,737,462	1,179,904	10,556,661	-180,801

Notes: [1] Change from 1940-2000 Original Flows to 1940-2000 Updated Flows
[2] Change from 1940-2000 Updated Flows to 2001-2018 Updated Flows

TABLE 13d MINIMUM VALUES OF ORIGINAL AND UPDATED NATURALIZED FLOWS

(1)	(2)	(3)	(4)	(5)	(6)	(7)
CONTROL POINT ID	NAME OF GAGE / WORK BOOK ID	MINIMUM ANNUAL NATURALIZED FLOW VALUES				
		1940-2000 Original	1940-2000 Updated	Change [1]	2001-2018 Updated	Change [2]
AT/AM1000	Rio Grande at Fort Quitman/RG-FQ	68,845	68,853	8	57,426	-11,427
CT/CM6000	Rio Grande below Rio Conchos/RG-BC	456,436	456,439	3	190,276	-266,163
GT1000	Pecos River near Langtry/PR-LA	91,072	89,894	-1,178	80,923	-8,971
CT2000	Devils River at Pafford Crossing/DR-PC	72,492	72,492	0	93,457	20,965
CT/CM1000	Rio Grande at Del Rio/RG-DR	1,111,987	1,112,363	376	1,111,904	-459
DT/DM5000	Rio Grande at Piedras Negras/RG-PN	1,564,408	1,206,870	-357,538	1,169,563	-37,307
DT/DM3000	Rio Grande at Laredo/RG-LA	1,655,188	1,268,137	-387,051	1,292,137	24,000
DT/DM1000	Rio Grande below Falcon Dam/RG-BF	1,771,435	1,414,509	-356,926	1,480,986	66,477
ET/EM2000	Rio Grande at Rio Grande City/RG-RG	1,923,925	1,597,669	-326,256	1,603,608	5,939
ET/EM1000	Rio Grande below Anzalduas Dam/RG-AN	1,699,012	1,389,531	-309,481	1,509,543	120,012

Notes: [1] Change from 1940-2000 Original Flows to 1940-2000 Updated Flows
[2] Change from 1940-2000 Updated Flows to 2001-2018 Updated Flows

gage, (5) corrections of reservoir evaporation for 1994, 1999 and 2000, and (6) proper accounting for the flood discharges through the Banker Floodway just upstream of Anzalduas Dam. As shown in Column 5 of Table 13a, the annual average of these changes varies by approximately ±100,000 acre-feet per year, and the maximum annual values of these changes (Table 13c, Column 5) range from a negative 559,971 acre-feet per year at the gage below Falcon Dam up to 1,179,904 acre-feet per year at the gage below Anzalduas Dam. The large changes in the naturalized flows at the Rio Grande City gage and the gage below Anzalduas Dam are attributable primarily to the corrections made to the return flows from the Rio San Juan Irrigation District, with some of the changes at the gage below Anzalduas due to the corrections that were made for the Banker Floodway discharges.

Another point regarding to the changes in Column 7 of Table 13a from the updated 1940-2000 naturalized flows (Column 4) to the updated 2001-2018 naturalized flows (Column 6) is that this latter period, on average, was considerably drier with significantly lower flows by approximately 2,000,000 acre-feet per year at several of the primary control points. These lower flows for the 2001-2018 period are consistent with simulated results from the existing Rio Grande WAM that show significantly declining storage levels for Amistad and Falcon Reservoirs in the latter 1990s and 2000. These storage levels are lower than those simulated for the 1950s drought, suggesting that the critical drought for the reservoirs in terms of their firm yield is likely not the 1950s drought, but sometime after the late 1990s. This condition is confirmed with the firm yield results presented in Section 9.3.

Time-series plots of annual values of the 1940-2000 original naturalized flows and the 1940-2018 updated naturalized flows for the same primary control points included in Table 13 are presented in Appendix C in Figures C-1 through C-10. These graphs illustrate the extreme variations in the annual naturalized flows over the period of record at each primary control point, as well as the years in which the naturalized flows have changed significantly due to the revisions that have been made in the underlying data and procedures used to recalculate the naturalized flows for the 1940-2000 period. The differences in the curves in specific years due to these revisions are consistent with the statistical changes in the naturalized flows summarized in Table 13 between the original and the updated values. The curves for the updated naturalized flows in Appendix C also again show that the naturalized flows for the 2001-2018 period are generally lower than those for the 1940-2000 period, which is consistent with the statistical results summarized in Table 13.

Double-mass curves are presented in Appendix D relating the original naturalized flows to the updated naturalized flows for the 1940-2000 period for the same primary control points used for the comparative naturalized flow plots in Appendix C. These curves provide insight to the consistency between the original naturalized flows and the updated naturalized flows for the existing period and whether they appear to be compatible for purposes of the WAM. The straight-line curves on these graphs indicate that the updated naturalized flows are generally consistent with the original naturalized flows, and that they have a fairly uniform relationship with the original naturalized flows throughout the 1940-2000 period. The minor deviations that characterize the plots in Figures D-6, D-7 and D-8 for the Piedras Negras, Laredo and below Falcon primary control points result primarily from the corrections made to the Maverick County District historical diversions and return flows. The plots in Figures D-9 and D-10 for the Rio Grande City and below Anzalduas primary control points exhibit similar minor deviations, and these are related to the major revisions made with regard to the return flows for the Lower San Juan Irrigation District in Mexico. Overall, these curves suggest that while the updated naturalized flows vary somewhat from the original naturalized flows, the deviations are explainable and are not significant enough to warrant further analysis. The differences between the total cumulative naturalized flows at the end of 2000 are all less than a few percent.

7.10 Distribution of Naturalized Flows to United States and Mexico

In the WAM, the Rio Grande mainstem is structured as two parallel watercourses, one for United States flows and one for Mexico flows. With this structure, all of the tributaries of the Rio Grande in Texas are linked to the United States or Texas segment of the river, and all of the tributaries of the Rio Grande in Mexico are linked to the Mexico segment of the river. This modeling approach requires that the naturalized flows for the entire basin be divided between the two river systems before actually running the model, including the flows in the Rio Grande itself. This has been accomplished with an Excel spreadsheet program developed specifically for this purpose. In effect, this program performs accounting of the naturalized flows in the Rio Grande for each side of the river, beginning with the Rio Grande flows at the El Paso gage, i.e., at the upper end of the river system modeled with the WAM.

At the El Paso gage, the Mexico portion of the total annual Rio Grande flow is assigned the value of the available Mexico allocation from the Rio Grande Project as described in Section 7.4.1 above (which is the only Rio Grande water available to Mexico above Fort Quitman under the 1906 Convention). The annual amounts of these Mexico allocations have been distributed to monthly values based on the 1940-2018 historical monthly use (diversion) pattern for Mexico's Acequia Madre at Juarez. The balance of the monthly naturalized flows at El Paso then has been assigned to the United States (Texas). These monthly naturalized flows for the Rio Grande for Mexico and the United States at the El Paso gage are plotted on the graph in Figure 11.

With the Rio Grande naturalized flows distributed between Mexico and the United States at the El Paso gage, the process of determining each country's share of the naturalized flow in the river at each downstream primary control point then involves a systematic accounting process whereby each country's tributary and ungaged incremental inflows to the Rio Grande are added to their respective share of the Rio Grande mainstem flow at each primary control point, proceeding from upstream to downstream. For ungaged areas between primary control points (exclusive of the gaged tributary areas), the incremental monthly inflows to the Rio Grande are calculated as the

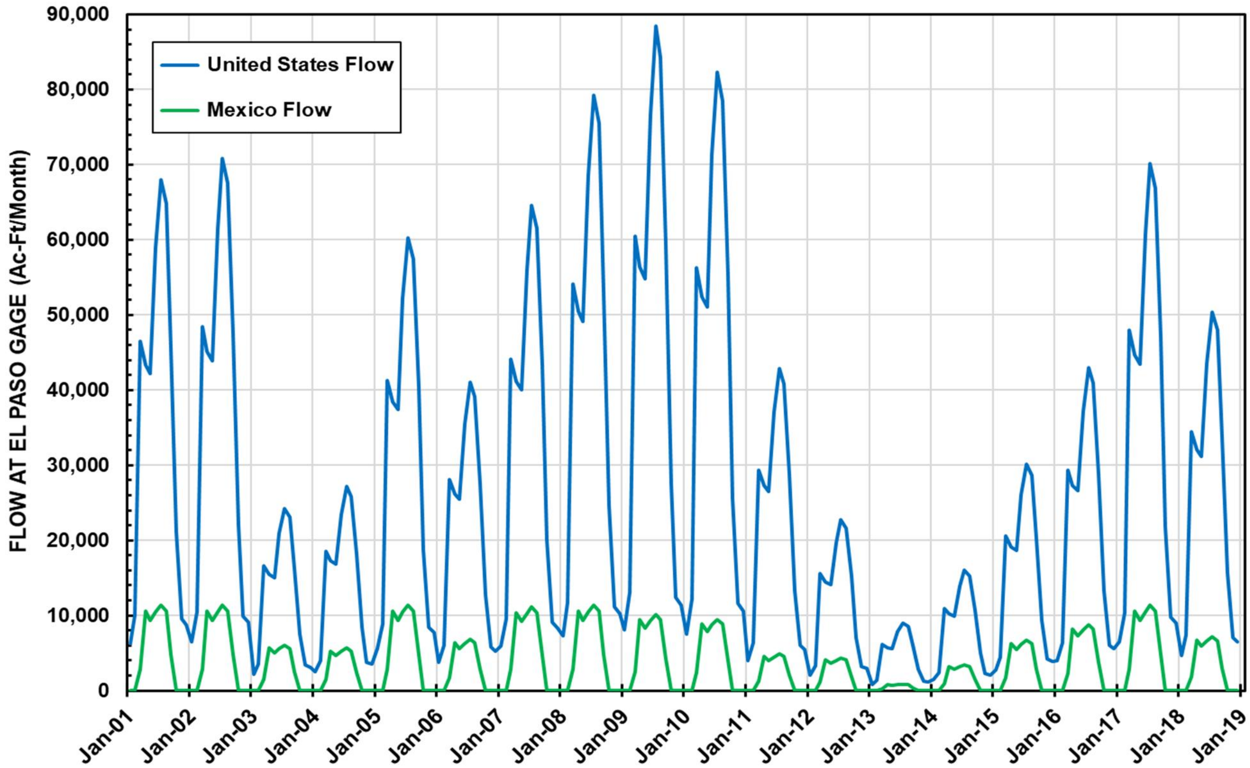


FIGURE 11 UNITED STATES AND MEXICO RIO GRANDE FLOWS AT EL PASO GAGE

difference between the total naturalized flows at the upstream and downstream primary control points, reduced by any United States or Mexico naturalized tributary inflows. If this incremental inflow for a particular month is positive, it represents a gain in river flow, and it is split equally between the two countries in accordance with the provisions of the 1944 Treaty, with each country's portion added to their calculated Rio Grande naturalized flow at the downstream primary control point. If the incremental flow is negative, then it represents a loss and, again in accordance with the 1944 Treaty, it is distributed to each country proportional to the amount of water each country has flowing in the subject reach of the Rio Grande, which is calculated as the sum of each country's naturalized flow at the upstream primary control point plus each country's naturalized tributary inflows between the upstream and downstream primary control points. The result of this monthly calculation process is the naturalized flow for each country at the downstream primary control point. This flow distribution procedure whereby negative incremental flows are maintained and assigned to each country rather than being eliminated through flow manipulations is consistent with the procedures used in the naturalized flow process and in the WAM simulation where negative incremental flows remaining after adjustments for channel losses are taken into account using WRAP's Option 5 to compute available flow.

This flow distribution process has been applied in downstream order along the entire length of the Rio Grande to the lowest primary control point included in the WAM for each country at the below Anzalduas gage. The final result then is a complete set of naturalized monthly streamflows for each country at each of the primary control points on the mainstem of the Rio Grande. It should be noted that because of the adjustments and revisions that have been made in this study to some of the original 1940-2000 data and naturalized flow procedures, the process of distributing the naturalized flows between the United States and Mexico was performed using the revised naturalized flows for the entire 1940-2018 period.

As described above, an important aspect of the naturalized flow distribution process involves the calculation and distribution to the United States and to Mexico of the ungaged inflows to the Rio Grande between primary control points both on the mainstem and on tributaries. Calculation of these ungaged inflows is accomplished through a mass balance procedure applied between mainstem primary control points each month, with all other mainstem and tributary flows for each country being known quantities, including the gaged inflows for the Mexico tributaries. Thus, the naturalized flow distribution process as described above is fully applicable for determining Mexico's portion of the naturalized flows for the Rio Grande mainstem even though historical gaged inflows to the Rio Grande for the Mexico tributaries are used in place of naturalized flows for the 2001-2018 period.

8.0 CHANGES TO EXISTING WAM DATASETS

In addition to the extended naturalized flows and net evaporation data for the 2001-2018 period, other changes and revisions to the existing datasets used in the Rio Grande WAM have been made to correct errors or inconsistencies identified during the study. These are discussed in the following sections.

8.1 Revised and Extended Naturalized Flows

The existing naturalized flow dataset for the Rio Grande WAM has been modified to include both revised values for the original 1940-2000 period and updated values for the extended 2001-2018 period. The revised values for the original 1940-2000 period reflect changes made to correct for errors and/or inconsistencies as discussed in Section 6.0. With this complete dataset, the Rio Grande WAM now simulates 79 years of monthly hydrologic variations.

8.2 Revised and Extended Net Evaporation Data

The existing net evaporation dataset for the Rio Grande WAM has been modified to include both revised values for the original 1940-2000 period and updated values for the extended 2001-2018 period. The revised values for the original 1940-2000 period reflect changes made by the TWDB to monthly evaporation data for 1994, 1999 and 2000 as discussed in Section 4.5.

8.3 Amistad and Falcon Reservoirs Conservation Storage

Amistad and Falcon Reservoirs are unique in that they are international reservoirs with conservation storage capacity available for storing water by both the United States and Mexico. The IBWC administers ownership of flows in the Rio Grande for each country in accordance with the 1944 Treaty and also performs accounting to determine ownership of stored water in these reservoirs. There are no water rights owned by Texas water users or by Mexico water interests that authorize either storage of water in these international reservoirs or the use of stored water from these reservoirs. These authorizations are dictated by provisions in the 1944 Treaty between the United States and Mexico. Consequently, there are no authorized conservation storage capacities designated for these international reservoirs. However, the IBWC periodically does establish current conservation storage capacities based on previous bathymetric surveys of the reservoirs and consideration of subsequent sediment accumulation. These conservation storage capacities are used by IBWC for water ownership accounting between the two countries, and in the original WAM study, through consultation with TCEQ, it was decided to use IBWC's current storage capacities at that time as the authorized values for purposes of the Rio Grande WAM. Currently, as of April 10, 2021, the conservation storage capacities for Amistad and Falcon

Reservoirs as reported by IBWC for the United States, Mexico and in total are as follows, expressed in acre-feet:

	United States	Mexico	Total
Amistad Reservoir	1,841,000	1,435,000	3,276,000
Falcon Reservoir	1,551,000	1,096,000	2,647,000

These are slightly higher than the conservation storage capacities used in the existing Rio Grande WAM, which has 3,241,106 acre-feet for the total conservation storage capacity for Amistad and 2,642,730 acre-feet for Falcon. These existing total conservation storage values were established in 2013 as part of the Region M Rio Grande Water Planning Study for the lower and middle parts of the Rio Grande basin in Texas based on analyses of results from the 2005 surveys of the reservoirs, with adjustments for sediment accumulations in the reservoirs over the eight-year period. Apparently, IBWC performed similar analyses and arrived at somewhat different values for the current conservation storage capacities. For this update of the Rio Grande WAM, the existing conservation storage capacities specified in the WAM data input files have been replaced with IBWC's current conservation storage capacities as listed above. The area-capacity data corresponding to 2013 sedimentation conditions for these reservoirs have not been changed and remain in the updated WAM datasets. However, it has been noted that the data input for the existing version of Rio Grande WAM does not properly accommodate the total number of existing area and capacity values specified for Amistad and Falcon Reservoirs, and appropriate changes have been made to the JD record to resolve this issue.

8.4 Acequia Madre Monthly Diversion Pattern

In the existing Rio Grande WAM the monthly pattern for diversions into Mexico's Acequia Madre is based on the monthly diversion pattern for the Rio Florido Irrigation District, when there is a specific monthly diversion pattern included in the WAM data files for the Acequia Madre. This has been corrected, and now the annual diversion for the Acequia Madre (60,000 acre-feet/year) is distributed to monthly values in accordance with the historical 1940-2018 monthly average diversion data for the Acequia Madre. These average monthly diversion distribution factors are listed in Table 14.

8.5 EPCWID Monthly Diversion Pattern

In the existing Rio Grande WAM, the monthly diversion pattern for EPCWID conforms to a general irrigation use pattern that is specified in the WAM data files. Analyses have been undertaken to develop a unique monthly diversion pattern applicable only to EPCWID based on historical monthly diversions by the District. For this purpose, monthly diversion data for the Franklin Canal and the Riverside Canal as available from various records from the U. S. Bureau of Reclamation have been compiled for 1980-2017. Based on the monthly sums of these canal diversions for this period, average monthly percentages of these diversions have been calculated, and these values are listed in Table 14. These monthly distribution factors have been incorporated into the WAM data files and used to distribute the authorized annual diversion amount for the EPCWID (376,000 acre-feet/year).

TABLE 14 MONTHLY DISTRIBUTION FACTORS FOR EPCWID AND ACEQUIA MADRE ANNUAL DIVERSIONS

Month	EPCWID Based on Franklin & Riverside Canals 1980-2017 Diversion Data	Acequia Madre Based on Acequia Madre 1940-2018 Diversion Data
January	1.8%	0.0%
February	3.3%	0.0%
March	12.1%	4.8%
April	9.7%	17.7%
May	10.1%	15.6%
June	14.4%	17.4%
July	15.8%	18.9%
August	14.4%	17.6%
September	10.8%	8.0%
October	5.1%	0.0%
November	1.6%	0.0%
December	0.9%	0.0%

9.0 RESULTS FROM UPDATED RIO GRANDE WAM

9.1 Regulated Streamflows

Both the current version of the existing Rio Grande WAM and the updated Rio Grande WAM have been operated so that the effects of the changes in the updated naturalized flows and net evaporation values can be examined. Results from statistical analyses of the two sets of simulated regulated flows for the same control points considered in evaluating naturalized flows in Section 7.8 are summarized in Table 15, Sub-tables a, b, c and d. The changes and trends exhibited between the regulated flows for 1940-2000 from the existing WAM, for 1940-2000 from the updated WAM, and for 2001-2018 from the updated WAM are similar to those that characterize the naturalized flows as summarized by the statistics in Table 13. Upstream of the Piedras Negras primary control point, the changes in the average regulated flows for 1940-2000 from the existing WAM and from the updated WAM are fairly small (Table 15a, Column 5), while from the Piedras Negras primary control point downstream, the average changes are fairly significant, ranging from -92,318 acre-feet per year up to 127,331 acre-feet per year. The causes of these various changes are the same as those discussed regarding similar changes exhibited by the corresponding naturalized flows. Also, examining the changes in the average regulated flows simulated with the updated WAM for the 1940-2000 period and for the 2001-2018 period (Table 15a, Column 7) shows lower regulated flows for the latter period, similar to the naturalized flows, again because of overall drier 2001-2018 conditions.

Time-series plots of annual values of regulated flows from the existing Rio Grande WAM and from the updated Rio Grande WAM are presented in Appendix E for selected control points where noticeable differences are apparent in some years. At the Del Rio primary control point in Figure E-1, the regulated flows from the updated WAM deviate from those simulated with the existing WAM during the 1956-1959 period. This appears to be the result of a change in the releases from Amistad Reservoir during this period to meet downstream demands in response to the reductions in the updated naturalized flows at the Piedras Negras control point downstream caused by significant corrections to the Maverick District diversions and return flows. These reductions also are reflected in the regulated flows from the updated WAM at the Piedras Negras control point as shown on the graph in Figure E-2 and at the Laredo control point in Figure E-3. The regulated flows below Falcon Dam are shown on the graph in Figure E-4, with a noticeable reduction in the 1958 value of the regulated flow from the updated WAM. This reduction in releases from Falcon Reservoir appears to be the result of increased updated naturalized flows downstream at the Rio Grande City control point (Figure C-9) and at the control point below Anzalduas Dam (Figure C-10). Other differences in the regulated flows at the Rio Grande City control point shown in Figure E-5 and at the control point below Anzalduas Dam in Figure E-6 are much smaller and reflect the changes made in developing the updated naturalized flows.

TABLE 15a AVERAGE VALUES OF EXISTING AND UPDATED WAM REGULATED FLOWS

(1)	(2)	(3)	(4)	(5)	(6)	(7)
CONTROL POINT ID	NAME OF GAGE / WORK BOOK ID	AVERAGE ANNUAL REGULATED FLOW VALUES				
		1940-2000 Original	1940-2000 Updated	Change [1]	2001-2018 Updated	Change [2]
AT/AM1000	Rio Grande at Fort Quitman/RG-FQ	166,018	161,620	-4,397	97,082	-64,538
CT/CM6000	Rio Grande below Rio Conchos/RG-BC	542,408	542,952	544	341,811	-201,142
GT1000	Pecos River near Langtry/PR-LA	216,251	209,250	-7,001	153,454	-55,796
CT2000	Devils River at Pafford Crossing/DR-PC	262,320	262,949	628	224,849	-38,099
CT/CM1000	Rio Grande at Del Rio/RG-DR	1,796,378	1,805,642	9,264	1,464,689	-340,953
DT/DM5000	Rio Grande at Piedras Negras/RG-PN	2,336,936	2,244,618	-92,318	1,846,135	-398,482
DT/DM3000	Rio Grande at Laredo/RG-LA	2,374,543	2,288,409	-86,134	1,799,765	-488,644
DT/DM1000	Rio Grande below Falcon Dam/RG-BF	2,601,724	2,531,232	-70,492	2,043,227	-488,005
ET/EM2000	Rio Grande at Rio Grande City/RG-RG	3,007,340	3,028,881	21,542	2,491,266	-537,615
ET/EM1000	Rio Grande below Anzalduas Dam/RG-AN	2,225,929	2,353,261	127,331	1,815,173	-538,087

Notes: [1] Change from 1940-2000 Original Flows to 1940-2000 Updated Flows
[2] Change from 1940-2000 Updated Flows to 2001-2018 Updated Flows

TABLE 15b MEDIAN VALUES OF EXISTING AND UPDATED WAM REGULATED FLOWS

(1)	(2)	(3)	(4)	(5)	(6)	(7)
CONTROL POINT ID	NAME OF GAGE / WORK BOOK ID	MEDIAN ANNUAL REGULATED FLOW VALUES				
		1940-2000 Original	1940-2000 Updated	Change [1]	2001-2018 Updated	Change [2]
AT/AM1000	Rio Grande at Fort Quitman/RG-FQ	114,480	104,767	-9,713	84,349	-20,418
CT/CM6000	Rio Grande below Rio Conchos/RG-BC	320,793	327,290	6,497	251,781	-75,510
GT1000	Pecos River near Langtry/PR-LA	171,626	166,846	-4,780	125,971	-40,876
CT2000	Devils River at Pafford Crossing/DR-PC	207,943	209,960	2,017	193,688	-16,273
CT/CM1000	Rio Grande at Del Rio/RG-DR	1,748,337	1,779,585	31,248	1,477,905	-301,680
DT/DM5000	Rio Grande at Piedras Negras/RG-PN	2,117,734	2,152,721	34,987	1,784,331	-368,391
DT/DM3000	Rio Grande at Laredo/RG-LA	2,164,745	2,102,360	-62,385	1,610,399	-491,961
DT/DM1000	Rio Grande below Falcon Dam/RG-BF	2,525,252	2,506,324	-18,928	1,979,582	-526,743
ET/EM2000	Rio Grande at Rio Grande City/RG-RG	2,756,643	2,643,007	-113,636	2,149,628	-493,379
ET/EM1000	Rio Grande below Anzalduas Dam/RG-AN	1,923,769	2,036,091	112,322	1,475,963	-560,129

Notes: [1] Change from 1940-2000 Original Flows to 1940-2000 Updated Flows
[2] Change from 1940-2000 Updated Flows to 2001-2018 Updated Flows

TABLE 15c MAXIMUM VALUES OF EXISTING AND UPDATED WAM REGULATED FLOWS

(1)	(2)	(3)	(4)	(5)	(6)	(7)
CONTROL POINT ID	NAME OF GAGE / WORK BOOK ID	MAXIMUM ANNUAL REGULATED FLOW VALUES				
		1940-2000 Original	1940-2000 Updated	Change [1]	2001-2018 Updated	Change [2]
AT/AM1000	Rio Grande at Fort Quitman/RG-FQ	1,389,719	1,379,856	-9,863	222,936	-1,156,920
CT/CM6000	Rio Grande below Rio Conchos/RG-BC	2,478,312	2,482,569	4,257	1,592,617	-889,952
GT1000	Pecos River near Langtry/PR-LA	1,295,379	1,280,308	-15,071	331,188	-949,120
CT2000	Devils River at Pafford Crossing/DR-PC	946,067	950,953	4,886	505,472	-445,481
CT/CM1000	Rio Grande at Del Rio/RG-DR	4,302,707	4,303,951	1,244	2,115,990	-2,187,961
DT/DM5000	Rio Grande at Piedras Negras/RG-PN	4,829,959	4,788,172	-41,787	3,576,593	-1,211,579
DT/DM3000	Rio Grande at Laredo/RG-LA	4,795,610	4,757,650	-37,960	3,745,439	-1,012,211
DT/DM1000	Rio Grande below Falcon Dam/RG-BF	5,441,514	4,476,908	-964,606	4,537,672	60,764
ET/EM2000	Rio Grande at Rio Grande City/RG-RG	6,114,372	6,151,682	37,310	7,811,311	1,659,629
ET/EM1000	Rio Grande below Anzalduas Dam/RG-AN	4,848,517	5,550,496	701,979	7,126,534	1,576,038

Notes: [1] Change from 1940-2000 Original Flows to 1940-2000 Updated Flows
[2] Change from 1940-2000 Updated Flows to 2001-2018 Updated Flows

TABLE 15d MINIMUM VALUES OF EXISTING AND UPDATED WAM REGULATED FLOWS

(1)	(2)	(3)	(4)	(5)	(6)	(7)
CONTROL POINT ID	NAME OF GAGE / WORK BOOK ID	MINIMUM ANNUAL REGULATED FLOW VALUES				
		1940-2000 Original	1940-2000 Updated	Change [1]	2001-2018 Updated	Change [2]
AT/AM1000	Rio Grande at Fort Quitman/RG-FQ	30	29	-1	6,934	6,905
CT/CM6000	Rio Grande below Rio Conchos/RG-BC	33,972	33,974	2	82,636	48,662
GT1000	Pecos River near Langtry/PR-LA	64,544	64,540	-4	67,426	2,886
CT2000	Devils River at Pafford Crossing/DR-PC	72,492	72,492	0	93,457	20,965
CT/CM1000	Rio Grande at Del Rio/RG-DR	589,729	837,883	248,154	875,718	37,835
DT/DM5000	Rio Grande at Piedras Negras/RG-PN	1,027,189	1,052,012	24,823	1,042,179	-9,833
DT/DM3000	Rio Grande at Laredo/RG-LA	1,019,197	984,535	-34,662	879,238	-105,297
DT/DM1000	Rio Grande below Falcon Dam/RG-BF	1,516,133	1,405,539	-110,594	1,176,261	-229,278
ET/EM2000	Rio Grande at Rio Grande City/RG-RG	1,551,485	1,420,770	-130,715	1,239,663	-181,107
ET/EM1000	Rio Grande below Anzalduas Dam/RG-AN	668,635	538,403	-130,232	859,850	321,447

Notes: [1] Change from 1940-2000 Original Flows to 1940-2000 Updated Flows
[2] Change from 1940-2000 Updated Flows to 2001-2018 Updated Flows

It should be noted that in the updated WAM simulation for the 1940-2018 period, regulated flows are simulated for some of the interior control points within Mexico for the period immediately after December 2000. This occurs at control points immediately downstream from Mexico reservoirs that have simulated storage remaining at the end of December 2000, the end of the original WAM simulation period during which water activities at all of the Mexico interior control points were simulated in response to specified interior naturalized flows. Beginning in January 2001 of the extended 2001-2018 period when naturalized flows at all interior Mexico control points are set to zero, the water stored in the interior reservoirs at the end of December 2000 can still be released in subsequent months during 2001 and later to meet the demands at one or more downstream control points located below intervening control points. Thus, regulated flows can occur at the intervening control points as the released water passes downstream. This has no effect, however, on the flows at the mouth of the Mexico tributaries or the Mexico regulated flows in the Rio Grande because these waters are fully consumed by the downstream Mexican users for which the releases were made. Therefore, since gaged flows are specified at the most downstream gage for all Mexico tributaries as a representation of regulated flows for the extended 2001-2018 period, these regulated flows are uninfluenced by the release and consumption of water at some interior Mexico control points.

9.2 Storage in Amistad and Falcon Reservoirs

Time-series graphs of simulated monthly storage for Amistad and Falcon Reservoirs from the existing Rio Grande WAM and from the updated WAM are presented in Appendix F. Generally, for the 1940-2000 period, these curves track each other for both reservoirs except during the late 1950s. This is the same period when the regulated flows at Del Rio also deviate, which, as explained above, is the result of changes in the releases from Amistad Reservoir during this period to meet downstream demands in response to reductions in the updated naturalized flows at the Piedras Negras primary control point. These reductions in the updated naturalized flows at the Piedras Negras primary control point are attributable to the significant changes in naturalized flows at this location associated with corrections to the Maverick District diversions and return flows during this same period.

The significance of the drought that began in the mid-1990s and extended through 2010 is readily apparent on the graphs, particularly when compared to the drought of the 1950s. The relevance of this drought to the firm annual yield of the Amistad-Falcon reservoir system is discussed below.

9.3 Firm Yield of Water Supply Reservoirs

The firm annual yield for all major reservoirs, or reservoir systems, in the Texas portion of the Rio Grande basin that are used for water supply has been determined with the updated Rio Grande WAM. These reservoirs include Red Bluff Reservoir, Lake Balmorhea, and the Amistad-Falcon international reservoir system. Table 16 summarizes the results from the firm yield analyses, with yield values reported for both the United States (Texas) and Mexico for the Amistad-Falcon reservoir system. Also included in Table 16 are the corresponding firm yield values for these reservoirs as determined with the existing Rio Grande WAM.

When operating the WAM to calculate the firm annual yield for any one of the reservoirs, or the reservoir system, the specified water demand(s) on the reservoir or reservoir system was reduced from the authorized amount until no demand shortages occurred. This amount of specified demand then has been taken to represent the firm annual yield of the reservoir or reservoir system. With this amount of demand, only a minimal amount of storage remains in the reservoir or reservoir system at the end of one month during the critical drought period. The year during which this minimum storage condition occurs for each reservoir or reservoir system, when operated at the firm yield demand condition, is indicated in Table 16.

The determination of the firm yield for the Amistad-Falcon reservoir system was complicated because of the separate independently-operated pools in each reservoir for the United States and for Mexico and because of different reservoir operating rules for each country. While the operating rules for both countries favor storing water to the extent possible in the upstream Amistad Reservoir as a fundamental objective, their rules for allocating reservoir storage and making releases to supply water users are considerably different. For Mexico, releases are simply made to meet the demands of downstream users with no rules for allocating stored water to individual users. For the United States, however, the TCEQ's reservoir storage accounting rules and the existing type-of-use priority system for Texas water rights associated with the Amistad-Falcon reservoir system complicate the yield determinations.

As the first step in the yield determination process for the Amistad-Falcon reservoir system, the yield for the Mexico pools was determined by reducing Mexico's concessions (demands) that utilize stored water from the Amistad-Falcon system through successive WAM simulations until no shortages occurred. For these simulations, no changes were made to the Texas demands on the reservoir system. Next, a series of simulations were made to determine an initial estimate of the yield of the United States pools with the Mexico demands maintained at their respective firm yield values. A proportional adjustment scheme was employed to alter the Texas demands on the United States pools in the reservoirs whereby the authorized diversion amounts for the different sets of Class A and Class B water rights (see Section 1.5) were adjusted, as necessary, to arrive at an appropriate system yield value with no demand shortages for any of the Texas water rights.

A unique aspect of the yield determination for the United States pools in the Amistad-Falcon reservoir system relates to the minimum amount of water remaining in storage in the pools during the critical drought period. Because of the requirements in the TCEQ Rules, Chapter 303 - Operation of the Rio Grande, to always maintain the Domestic-Municipal-Industrial reserve in

TABLE 16 SUMMARY OF RESERVOIR FIRM ANNUAL YIELD ANALYSES

RESERVOIR NAME	EXTENDED AND UPDATED WAM					TCEQ EXISTING WAM		
	AUTHORIZED CONSERVATION STORAGE ac-ft	AUTHORIZED DIVERSION AMOUNT ac-ft/year	FIRM ANNUAL YIELD ac-ft/year	MINIMUM STORAGE ac-ft	YEAR OF MINIMUM STORAGE	FIRM ANNUAL YIELD ac-ft/year	MINIMUM STORAGE ac-ft	YEAR OF MINIMUM STORAGE
Amistad-Falcon System - US	1,841,000 A* 1,551,000 F	2,077,222	1,002,058	430,333	2003	1,076,710	411,824	2000
Amistad-Falcon System - MX	1,435,000 A* 1,096,000 F	901,701	756,736	1,249	2003	888,106	3,690	2000
Red Bluff Reservoir	300,000	292,500	38,930	17	2013	65,860	32	1984
Lake Balmorhea**	6,350	32,120	0	- -	- -	0	- -	- -

* The conservation storage values for Amistad and Falcon Reservoirs are current storage capacities reported by IBWC on April 10, 2021.

** Most of the inflows to Lake Balmorhea are passed downstream to senior water rights.

the reservoirs at 225,000 acre-feet and to provide for a fluctuating operating reserve up to 75,000 acre-feet, there always is some minimum amount of water remaining in the reservoirs during the lowest-storage condition of the critical drought period. This is unavoidable with the TCEQ rules regarding these minimum storage reserves. For the yield values reported in Table 16, the minimum combined volume of United States storage remaining in both of the reservoirs was approximately 430,000 acre-feet as simulated with the updated WAM and 412,000 acre-feet as simulated with the existing WAM. Part of these minimum storage amounts also is attributable to the fact that the firm yield demands specified in the WAM for all of the different sets of Texas water rights cannot be finely adjusted so that the simulated storage exactly matches the minimum storage reserves.

As shown in Table 16, the firm yield value for the United States portion of the Amistad-Falcon reservoir system has been determined to be 1,002,058 acre-feet per year with the updated WAM and 1,076,710 acre-feet per year with the TCEQ existing WAM, a reduction of about 75,000 acre-feet per year. This is not surprising considering the severity of the critical drought that determines the firm yield of the reservoir system. A time-series graph of the total United States storage in Amistad and Falcon Reservoirs as simulated with the updated Rio Grande WAM under firm yield conditions for both the United States and Mexico is presented in Figure 12.

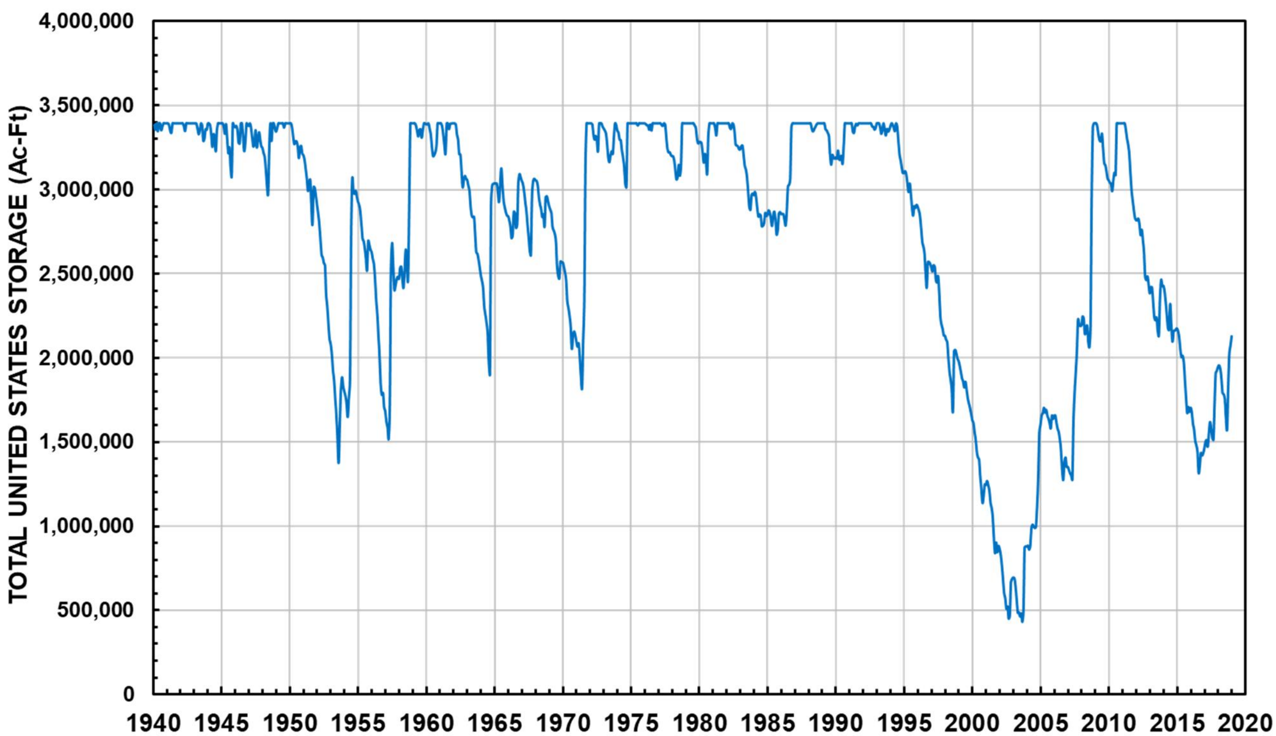


FIGURE 12 UNITED STATES STORAGE IN AMISTAD-FALCON RESERVOIR SYSTEM UNDER FIRM YIELD CONDITIONS FOR TEXAS AND MEXICO USERS

This plot clearly shows that the period from 1995 to 2009 is the critical drought period that determines the firm yield demand, with the minimum storage level occurring in August of 2003. This validates the observation during the development of the original Rio Grande WAM that the critical drought for the reservoir system was not the 1950s drought, but instead the drought that began in the 1990s and was still ongoing at the time the original WAM was completed. It should also be noted that another drought began later in 2011 but appears to have reached its minimum storage level in 2016 with the storage rising above the minimum critical drought storage level.

As shown in Table 16, the firm annual yield of Red Bluff Reservoir decreased from 65,860 acre-feet per year with the TCEQ existing WAM to 38,930 acre-feet per year with the updated WAM. This is understandable since the critical drought period as indicated by the year of minimum storage shifted from 1984 with the existing WAM to 2013 with the updated WAM. The firm annual yield of Lake Balmorhea is zero as determined by both the existing WAM and the updated WAM. This apparently occurs because there are a number of senior water rights located downstream of Lake Balmorhea that have priority calls on inflows to the reservoir, which reduces the ability of the reservoir to retain storage.

10.0 INDEPENDENT PEER REVIEW

As discussed in Section 1.3, an Independent Peer Review ("IPR") team reviewed and critiqued the detailed work plan at the start of this study to validate the proposed technical approach and the proposed methods and procedures for compiling, organizing, analyzing, and estimating data for use in the naturalized flow process. The IPR team also has examined the updated naturalized flow workbooks for both the 1940-2000 period and the 2001-2018 period and has reviewed and commented on the draft final report to ensure that the technical approach and procedures were correctly applied and that the resulting 2001-2018 updated naturalized flows were reasonable and consistent with those for the 1940-2000 period. Major and significant comments from the IPR team regarding the draft final report and the naturalized flow workbooks are included in a memo dated July 15, 2021, which is included in Appendix G. The IPR team also produced an Excel document containing a review checklist for each primary control point in the naturalized flow workbooks, and this document was reviewed and taken into consideration as part of IPR process.

Significant issues identified by and comments made by the IPR team during review of the detailed work plan, the naturalized flow workbooks, and the draft final report are addressed with responses in the following sections. Other minor issues identified by or comments made by the IPR team during review of these documents pertaining to clarification and editing are noted with track changes and comments in the documents received from the IPR team, and these have been addressed as appropriate in revisions to these documents.

10.1 Detailed Work Plan

Section 1.2.4 - Subtask 2.4 – Development of Naturalized Streamflow Workbooks

- Comment - With regard to analysis of updated naturalized flows, should control point to control point comparisons also be done to assess changes in relationships between control points?
- Response - Yes, these comparisons will be performed.

Section 6.1 - Historical Monthly Gaged Streamflows

- Comment - With less than 20 years of actual record available, does it make sense to keep the Juno gage as a control point?
- Response - The Juno gage is going to continue to be used as a primary control point only because it was one in the original WAM and eliminating it would require revising the WAM dat file.

Section 6.2 - Historical Monthly Spring Discharges

- Comment - For Region F we noticed that some of the water rights associated with the springs in the Toyah Creek watershed were modeled upstream of where the FA flows come in, so they had no access to the flows. Not sure if this was communicated back to TCEQ.

- Response - This issue will be investigated and the WAM dat file will be changed, if necessary,

Section 6.2 - Historical Monthly Spring Discharges

- Comment - Should we say what is done with Phantom Lake Springs? Are we leaving them out because data are not available?
- Response - As noted in the original WAM study, Phantom Lake Springs had ceased flowing, so it was not considered, and reference to it here has been removed.

Section 6.3 - Historical End-of-Month Reservoir Storage

- Comment - For other reservoirs and WAMs, authorized storage is usually initial storage and does not change over time with sedimentation. All things considered, is it better to take account of sedimentation for Falcon and Amistad?
- Response - This has been an issue from Day 1 for Amistad and Falcon. It was decided in the original WAM to use the current storage at that time since there are no water rights specifying authorized storage for these reservoirs. So, the 1992 surveys were used. Now it appears that the most recent surveys should be used, i.e. 2005. However, as part of the Region M Rio Grande Water Planning Study in 2013, these 2005 area-capacity relationships were revised to represent 2013 reservoir sedimentation conditions, and these revised relationships will be used for updating the WAM.

Section 6.5 - Historical Monthly Reservoir Evaporation

- Comment - This analysis of changes in the TWDB's historical evaporation data does not address errors, if any, introduced in the previous naturalization of Mexico flows by incorrect evaporation figures.
- Response - Evaporation data for all of Mexico's reservoirs in the WAM originally were obtained from site-specific measurements provided by IBWC, not from the TWDB evaporation database. Therefore, these data were not affected by any changes made to the TWDB's historical lake evaporation data.

Section 6.7 - Historical Monthly Diversions and Water Usage

- Comment - With regard to missing irrigation return flow records, might it be better to estimate diversions in some specific cases? We could insert "or estimated with acceptable reliability" between users. Still leaves us able to set all to zero if we don't find a decent way to estimate.
- Response - Agree, will make that change.

Section 6.8 - Historical Monthly Municipal and Industrial Return Flows

- Comment - El Paso's Haskell plant appears to still be around, but their Web site indicates preferred discharge is to the American Canal rather than Rio Grande. https://www.epwater.org/our_water/plants/haskell_r__street_w_w_t_p

  I believe all the EPWU plants go into the canal first where they can be used for downstream irrigation. Is that taken into account in the naturalization process (or does it need to be taken into account)?
- Response - Checked with the City on these return flows. Except for the Northwest WWTP just upstream from American Dam that discharges part of its effluent into the Rio Grande, all of the City of El Paso's effluent is discharged into EPCWID canals

except for a portion that is used for aquifer recharge. Practically all of EPCWID irrigation return flows go to the Hudspeth County District. All return flows from Hudspeth County District are discharged back to the Rio Grande via Arroyo Balluco near Fort Quitman. And yes, the discharges from EPWU's WWTPs are properly accounted for in the naturalization process.

Section 6.8 - Historical Monthly Municipal and Industrial Return Flows

- Comment - If I remember correctly, Mexico keeps ownership of these return flows. Do we need to say something about that here?
- Response - Yes, Mexico owns its return flows to the Rio Grande.

Section 6.9 - Historical Monthly Irrigation Return Flows

- Comment - I assume El Paso County District has no irrigation return flows to the RG?
- Response - Essentially correct. EPCWID's return flows go to Hudspeth with limited amounts discharged to the Rio Grande.

Section 7.0 - Estimation of Missing Data and Statistical Techniques

- Comment - In section 6.9 only Hudspeth County District is mentioned in this area. Is it all there is? Perhaps if so, use the name here also.
- Response - Yes, Hudspeth County District has been added to paragraph.

10.2 Updated Naturalized Flow Workbooks

RG-EP Workbook

- Comment - There seems to be a discrepancy between the assumed annual pattern that was used to adjust flows from the Rio Grande Project (file NM 2001-2018 Stateline Flow Adjustments_2021.xlsx) and the historical flows used at the Acequia Madre. Seems to me these two patterns should be the same.
- Response - Revised monthly distribution factors based on 1940-2018 diversion data have been calculated for distributing the annual diversions for the Acequia Madre, and these factors have been incorporated into the flow distribution program, the RG-EP workbook, and into the WAM so that the same factors are used everywhere.

RG-FQ Workbook

- Comment - Diversions only summed through WR 3219. Only 5493 has diversions and they are small.
- Response - Agreed, the formula has been corrected to now include the water rights that were previously excluded.

RG-FQ Workbook

- Comment - Not sure why using 2001 to 2011 for fill using downstream.
- Response - See response to similar comment made under Section 5.1 - Monthly Gaged Streamflows in Section 10.2 below.

RG-AC Workbook

- Comment - Mexico diversions for 3/03, 4/03 and 7/16 look suspicious.

- Response - Agreed, but since this information was officially reported for Mexico by IBWC it is considered to be reliable.

RG-JR Workbook

- Comment - Some negative cumulative diversions. Not sure what that means. Might be good to add note as to why Castolon and Mulato are added to the IBWC cumulative.
- Response - With regard to the negative diversion quantities, these values were included in the information provided by IBWC. Through discussions with IBWC personnel, it has been explained that these small negative diversions result from certain calculations performed regarding ownership of water in the Rio Grande. They thought setting these values to zero would be appropriate, and that change has been made in this workbook. With regard to Castolon and Mulato being summarized differently between the existing and extended period, as provided by IBWC, Castolon's diversions were combined into a single table of values with all other diversions for IBWC's Reach 3 for the original 1940-2000 period, but for the 2001-2018 period, Castolon's diversions were provided separately. These different reporting formats are documented and explained in the diversion workbook for Rio Grande near Johnson Ranch gage.

RG-FR Workbook

- Comment - US cumulative diversion for 4/16 looks suspicious. Would be helpful to add a note about why Big Bend diversion is included in the extension but not in the previous.
- Response - With regard to the 4/16 diversion, the value is relatively large compared to adjacent months, but the fact that other years had monthly diversions significantly greater than the 4/16 value and also because this information was officially reported by IBWC, it is considered to be reliable. With regard to the Big Bend diversions, similar to the reported diversions for Castolon, the Big Bend diversions were combined into a single table of values with all other diversions for IBWC's Reach 4 for the original 1940-2000 period, but for the 2001-2018 period, the Big Bend diversions were provided separately. These different reporting formats are documented and explained in the diversion workbook for Rio Grande near Foster Ranch gage.

PR-GI Workbook

- Comment - Many diversions look suspicious, particularly 5441, 5443, 5447, 5446, 5442, 5440, 236 (Jan 1992). Might want to include some notes in the nat flow books about where A and B are located. Where does the data for return flows from irrigation rights come from? If it is reported not sure I would use it.
- Response - For the question related to suspicious diversions for the water rights listed, these diversions were verified and are clearly the reported quantities in the TCEQ's water use database indicating the water right owners actually filed water use reports for the amounts reported. Even though the reported values are often the same monthly and annual volumes for several of the years or are fairly large values in a single month, the reported values are not unprecedented, and it is believed the information can be relied upon. With regard to the return flows reported by some water rights, this information

is from the original 1940-2000 period with very little available documentation. However, it is noted that the return flows were nearly zero in all cases except one, which did report about 2,700 acre-feet of return flow in one year. Since this water right was Red Bluff's Pecos #2 member district, one of the member districts that operate the Imperial off-channel reservoir, we believe the quantities are reasonable. With regard to which water rights are in group A versus group B, this information is described at the top of the diversion tab in the naturalized flow workbook (Group A – Pecos River, excluding Toyah Creek; Group B – Balmorhea area - Toyah Creek drainage).

PR-LA Workbook

- Comment - Diversions for 5463, 5462, 5464, 5465, 5466 look suspicious.
- Response - Agreed, but since this information was officially reported in TCEQ's water use database, it was considered to be reliable and within what could be expected.

PR-LA Workbook

- Comment - Shouldn't incremental flow calculations include losses?
- Response - It is understood that this comment relates to the fill approach used to estimate naturalized flows for the period before the Pecos River near Langtry (PR-LA) gage was in place (1/1940- 6/1967). In the fill approach, flow factors are computed relating the completed incremental naturalized flows for PR-LA to the sum of the completed incremental and total naturalized flows for several nearby control points. Note that the periods of record used to develop the flow factors were constrained to the periods when completed naturalized flows were available for PR-LA (7/1967-12/2018) and the upstream primary control point at the Pecos River near Girvin gage (PR-GI), and further constrained to the periods when the source control points had completed naturalized flow available during the 7/1967-12/2018 period. Also note that the source control points were only selected if they also had coverage for some portion of the period of record PR-LA was missing (1/40-6/1967). Different flow factors were computed for several discrete periods within these constraints for the period after the PR-LA gage was operational (7/1967-12/2018), again depending on the available periods of record for the source gages. The various flow factors and their associated incremental flow equations were then applied to discrete periods with missing PR-LA gaged flow data resulting in estimates of the incremental naturalized flows for PR-LA for these periods. These estimated incremental naturalized flows then were added to the total naturalized flows at the PR-GI control point upstream of PR-LA to arrive at total naturalized flows for PR-LA. The different discrete periods when these procedures were applied are listed below, along with the equations (flow factors and source total naturalized flows) used to calculate the PR-LA incremental naturalized flow:

1/40 - 9/49:	PR-LA Inc. = (0.17467431 x (RGDR-RGJR-PRGI-DRJU)) + PRGI
10/49 - 12/59:	PR-LA Inc. = (0.14962941 x (RGDR-RGJR-PRGI)) + PRGI
1/60 - 8/61:	PR-LA Inc. = (0.19860464 x (RGDR-RGJR-PRGI-DRPC)) + PRGI
9/61 - 6/67:	PR-LA Inc. = (0.28537739 x (RGDR-RGFR-PRGI-DRPC)) + PRGI

The above logic culminates in estimates of the PR-LA incremental naturalized flow at the PR-LA gage site with losses fully accounted for since the incremental flow equations were derived using completed naturalized flows at the PR-LA gage that included adjustments already corrected for upstream losses. However, when adding these incremental flows to the total naturalized flows at the Pecos River Girvin primary control point to arrive at estimates of the total naturalized flows at the downstream PR-LA location, it is correct that losses along the Pecos River from Girvin to Langtry should have been accounted for. The channel loss rate for this reach of the river is 30 percent (see Table 7). This correction has been made in the naturalized flow workbook for the Pecos River at Langtry primary control point, and revised naturalized flows for the entire Rio Grande basin have been calculated and incorporated into the updated WAM datasets.

It should be noted, however, that this change has only affected the total naturalized flows for the Pecos River at Langtry primary control point since the total naturalized flows at the next downstream control point on the Rio Grande at Del Rio were calculated by simply adjusting the gaged flows at Del Rio for all upstream changes associated with diversions, return flows and reservoir depletions, meaning that the naturalized flows for the Pecos River at Langtry primary control point were not used; only the flow adjustments upstream of this location were used. Therefore, the only changes that the revised total naturalized flows at the Pecos River at Langtry primary control point have caused relate to the distribution of Rio Grande mainstem and tributary naturalized flows between the United States and Mexico, calculations that are made external to the Rio Grande WAM. However, analyses of the magnitude of these changes have been investigated, and they are miniscule compared to the downstream total naturalized flows. Furthermore, an analysis of the few water rights located on the Pecos River upstream of the Langtry primary control point has indicated that the correction for channel losses at this location has very little effect, if any, on their reliabilities. For these reasons, even though the naturalized flow workbooks and the naturalized flows used in the updated Rio Grande WAM have been revised to correct for the loss issue at the Pecos River at Langtry primary control point, no changes have been made in the tables and figures presented in this report because the resulting differences are infinitesimally small and indiscernible.

DR-JU Workbook

- Comment - Would be nice to have support graphs or regression calcs for fills.
- Response - The information used to calculate naturalized flow fills for this primary control point is associated by a link to this naturalized flow workbook, which is the procedure used for all of the naturalized flow workbooks involving filled naturalized flow values. The regression calculations are in this documentation file, as well as in the report. Graphs were not created for many of these results; instead, either the same flow

factor logic that was used for the original 1940-2000 naturalized flows was applied in this study for the 2001-2018 period or multiple regression analyses were performed with the result having the highest R-squared value generally selected. Documentation of these procedures and the associated calculations are included in the file named *FILLS 2,3,4.xlsx*.

DR-PC Workbook

- Comment - I don't think you should be adding filled DR-JU from 10/49-12/59.
- Response - Agreed, this was the result of repeating the approach that was used in the original development of naturalized flows for the 1940-2000 period, which was in error for this primary control point. The flow factor has now been correctly calculated for the 10/49-12/59 period without using the DR-JU filled naturalized flows, and the revised equation has been used to fill naturalized flows for the DR-PC control point.

RG-BF Workbook

- Comment - Area from 2010-2018 not consistent with content (using different EAC curves). Difference seems small.
- Response - The IBWC provided end-of-month storage for Amistad and Falcon Reservoirs for the 2000-2018 period, but did not provide the elevation-area-capacity (EAC) data that they used to determine storage volumes. Therefore, it was not possible to calculate water surface areas using the exact EAC data that IBWC used to determine storage. For the reservoir evaporation loss calculations in the naturalized flow workbooks, the most appropriate EAC curves (either 2005 or 2013) were used to calculate water surface area from the storage volumes provided by IBWC. For the change in storage calculations in the naturalized flow workbooks, the end-of-month storage volumes provided by IBWC were used. As noted in the reviewer's comment, the differences between periods where different EAC data were used to calculate water surface area were small, and thus, the approach used is considered to be reasonable.

RG-BF Workbook

- Comment - Not sure that the 2013 storage estimate for Amistad and Falcon was applied correctly. Hard for me to tell. You might want to check that. If IBWC used it then you are good except for the month where the survey changes from 2005 to 2013, which does not appear to be accounted for (like was done in the previous work).
- Response – The use of the 2013 EAC data was approved in the Work Plan, and the 2013 EAC data also is what is used in the existing TCEQ Rio Grande WAM and in Region M's planning models for both Amistad and Falcon Reservoirs. The 2013 EAC data are considered to be the most reasonable and up to date for use in the naturalized flow process.

10.3 Draft Final Report

Section 1.5 - Texas Water Rights in Existing Rio Grande WAM

- Comment - With regard to water rights authorized to use stored water the from Amistad-Falcon reservoir system, do all of the water rights have the same priority, at least as far as the model is concerned?
- Response - No, their priorities are different depending on their use classifications. DMI water rights have the highest priority for allocations of stored water from Amistad-Falcon reservoir system. Class A irrigation and mining water rights have the next highest priority for allocations of stored water, followed by the Class B irrigation and mining water rights. Within each of these three groups of water rights, allocation priorities are the same among individual water rights.

Section 1.5 - Texas Water Rights in Existing Rio Grande WAM

- Comment - With regard to the general equation for calculating naturalized flows, are losses applied to adjustments?
- Response - Yes, and clarifying language has been added to the text.

Section 3.0 - Alternative Approach for Mexico Tributary Inflows

- Comment - The discussion above does not say whether Mexico has met its treaty obligations historically 2001-2018, and therefore whether we are assuming Mexican compliance or non-compliance. Should we address that?
- Response - Text has been added to the introduction of Section 3.0 noting that Mexico was not in compliance with the 1944 Treaty during 2001-2005 of the 2001-2018 WAM extension period, and additional text has been added to Section 3.4 stating that including these non-compliant tributary flows is consistent with Mexico's operation of its interior water system and its tributary reservoirs.

Section 3.1 - Texas Water Rights in Existing Rio Grande WAM

- Comment - What about modifying the reservoir storage rules in the WAM to allow use of the flood pool in Luis L. Leon Reservoir on the Rio Conchos instead of the using adopted alternative approach where gaged flows are used to represent regulated flows for the Rio Conchos inflows to the Rio Grande in the WAM?
- Response - This was considered, but it would have introduced extensive complexities regarding rules for how the flood pools in all of Mexico's tributary reservoirs should be operated, requiring information from Mexico that would not have been readily available. Also, part of the reason for using the adopted alternative approach was that it eliminated the need for data for all of Mexico's interior water activities (diversions, return flows and reservoir depletions) in the naturalization flow process since none of these activities had to be accounted for.

Section 3.4 - Representation in WAM

- Comment - With regard to stating that simulation of all water use activities in the WAM proceeds upstream to downstream, what about the prior allocation water rights?
- Response - This has been addressed with additional text in Section 3.4.

Section 3.4 - Representation in WAM

- Comment - We mention 1/3 of inflow frequently without the 350,000 af/y minimum average. At some point, we should probably discuss whether Mexico has historically met the 350,000 (and therefore whether Mexico is assumed to meet it in the WAM).
- Response - Text has been added to this section to address this issue.

Section 4.3 - End-of-Month Reservoir Storage

- Comment - TWDB mentions two more reservoirs, Imperial and San Esteban Lake. Might want to add a sentence or two saying why not included in naturalization (or refer to previous report if it is in there).
- Response - Text has been added to this section explaining why these reservoirs have not been included in the flow naturalization process.

Section 4.8 - Monthly Municipal and Industrial Wastewater Discharges

- Comment - I notice that Ciudad Juarez is not mentioned. Does it discharge outside of the Rio Grande watershed? Or is it non-permitted discharge to the RG? Should probably mention and discuss it, anyway.
- Response - This has been addressed with additional text at the end of Section 4.8.

Section 5.1 - Monthly Gaged Streamflows

- Comment - The description of how missing Fort Quitman gaged flows were filled in doesn't sound right unless the average monthly gaged flow ratios were developed after correction for losses. If this was done, the description should be clearer.
- Response - The procedure for estimating missing Fort Quitman gaged flows has been changed whereby 2001-2011 average monthly gaged flow ratios of the Rio Grande at Fort Quitman flow divided by the Rio Grande above Rio Conchos flow are used to estimate the missing Fort Quitman flows based on known Rio Grande above Rio Conchos flows.

Section 5.1 - Monthly Gaged Streamflows

- Comment - Why did we not use relationship to naturalized flows? To rephrase, normally longer periods of missing historical data are filled in using naturalized flows rather than observed flows. Why were the observed flows used in this particular case?
- Response - It is correct this fill could have been accomplished using monthly relationships between naturalized flows at the Fort Quitman gage and at the above Rio Conchos gage for the common period of record. However, considering that flows at the Fort Quitman gage normally are relatively small because almost all of the flow passing the upstream El Paso gage is consumed by diversions into the American Canal and Mexico's Acequia Madre, any errors in filling the gaged flows at Fort Quitman using monthly relationships with the above Rio Conchos gaged flows were considered to be insignificant and not likely to appreciably affect the development of naturalized flows at Fort Quitman.

Section 5.3.5 - Ciudad Camargo Diversions

- Comment - Do we know that they had other sources of supply (groundwater, other surface water)?

- Response - IBWC has no information regarding whether this city has alternative sources of supply; however, with no reported diversions from the Rio Grande, no adjustments are required in the naturalization flow process.

Section 5.4.1 - Texas Wastewater Discharges

- Comment - With regard to use of the City of El Paso WWTP discharges, pretty sure they use wastewater for aquifer recharge.
- Response - Made revisions to the text to address this and other details regarding how WWTP discharges are used.

Section 5.4.2 - Mexico Wastewater Discharges

- Comment - It would be good to discuss Ciudad Juarez, like El Paso above.
- Response - Text was added describing how Ciudad Juarez handles wastewater discharges.

Section 7.2 - Streamflow Channel Losses

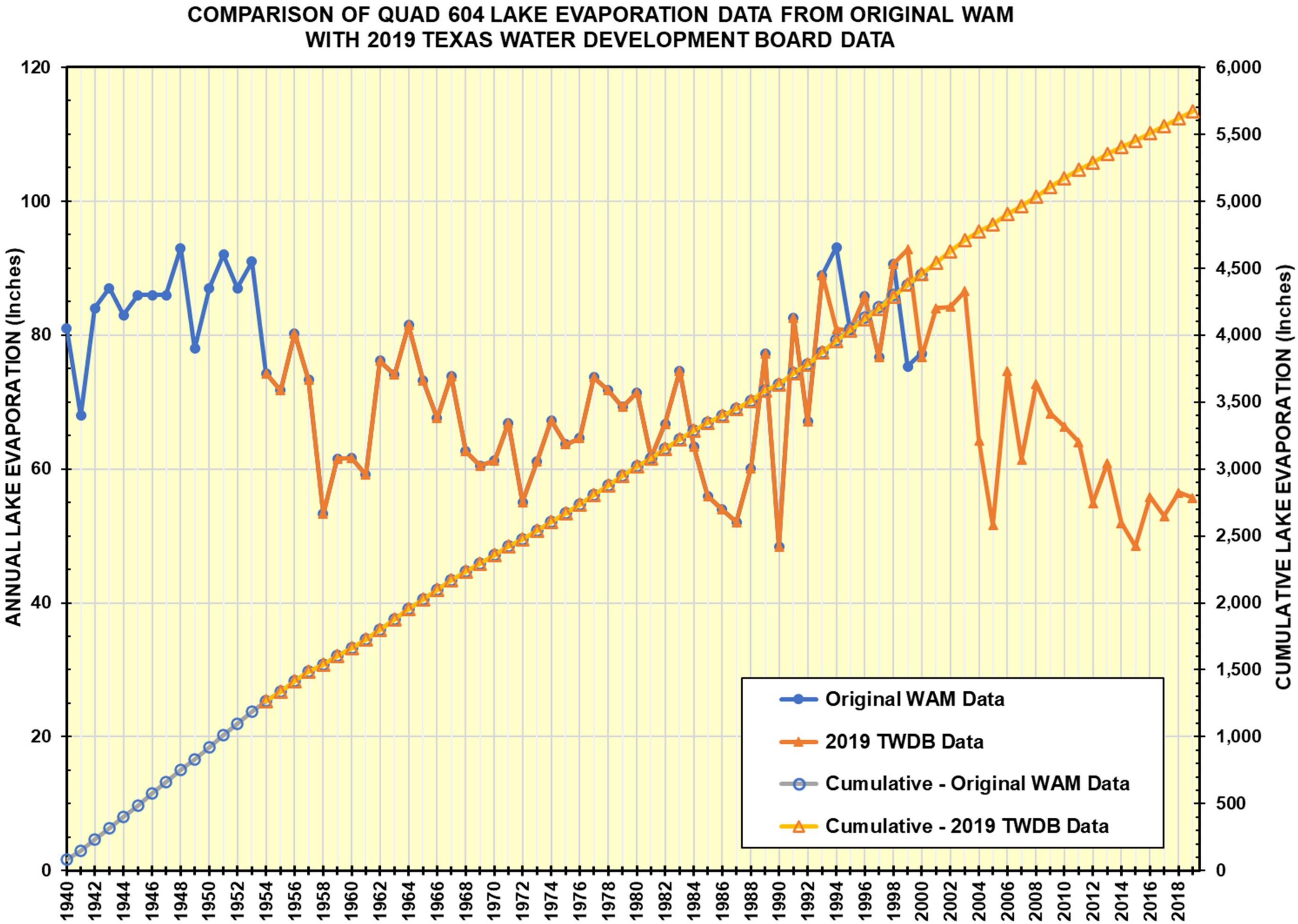
- Comment - I would think that for specific major adjustments located near the upstream or downstream end of the reach, we should set specific individual adjustment factors.
- While this could possibly provide a more accurate accounting of channel losses for the adjustments applied during flow naturalization, considering the inherent uncertainties in the derivation of the Channel Loss Factors, it is questionable whether this refinement is warranted, and such changes have not been made for channel losses.

Section 9.3 - Firm Yield of Water Supply Reservoirs

- Comment - Would it be useful to determine what the US firm yield would be if there were no reserve required for municipal? That would give a value more like firm yield as generally understood.
- Response - It may be an interesting exercise and, in fact, has been done in earlier Region M studies, but for purposes of this study, the value in having a firm yield value for the Amistad-Falcon reservoir system that cannot be achieved under existing allocation and operating rules is questionable and considered unnecessary.

APPENDIX A

ANALYSIS OF TWDB ORIGINAL AND REVISED ANNUAL EVAPORATION DATA FOR RIO GRANDE QUADRANGLES


COMPARISON OF QUAD 604 LAKE EVAPORATION DATA FROM ORIGINAL WAM
WITH 2019 TEXAS WATER DEVELOPMENT BOARD DATA
ANNUAL LAKE EVAPORATION (Inches)
CUMULATIVE LAKE EVAPORATION (Inches)
Original WAM Data
2019 TWDB Data
Cumulative - Original WAM Data
Cumulative - 2019 TWDB Data
0
20
40
60
80
100
120
0
500
1,000
1,500
2,000
2,500
3,000
3,500
4,000
4,500
5,000
5,500
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1940
1942
1944
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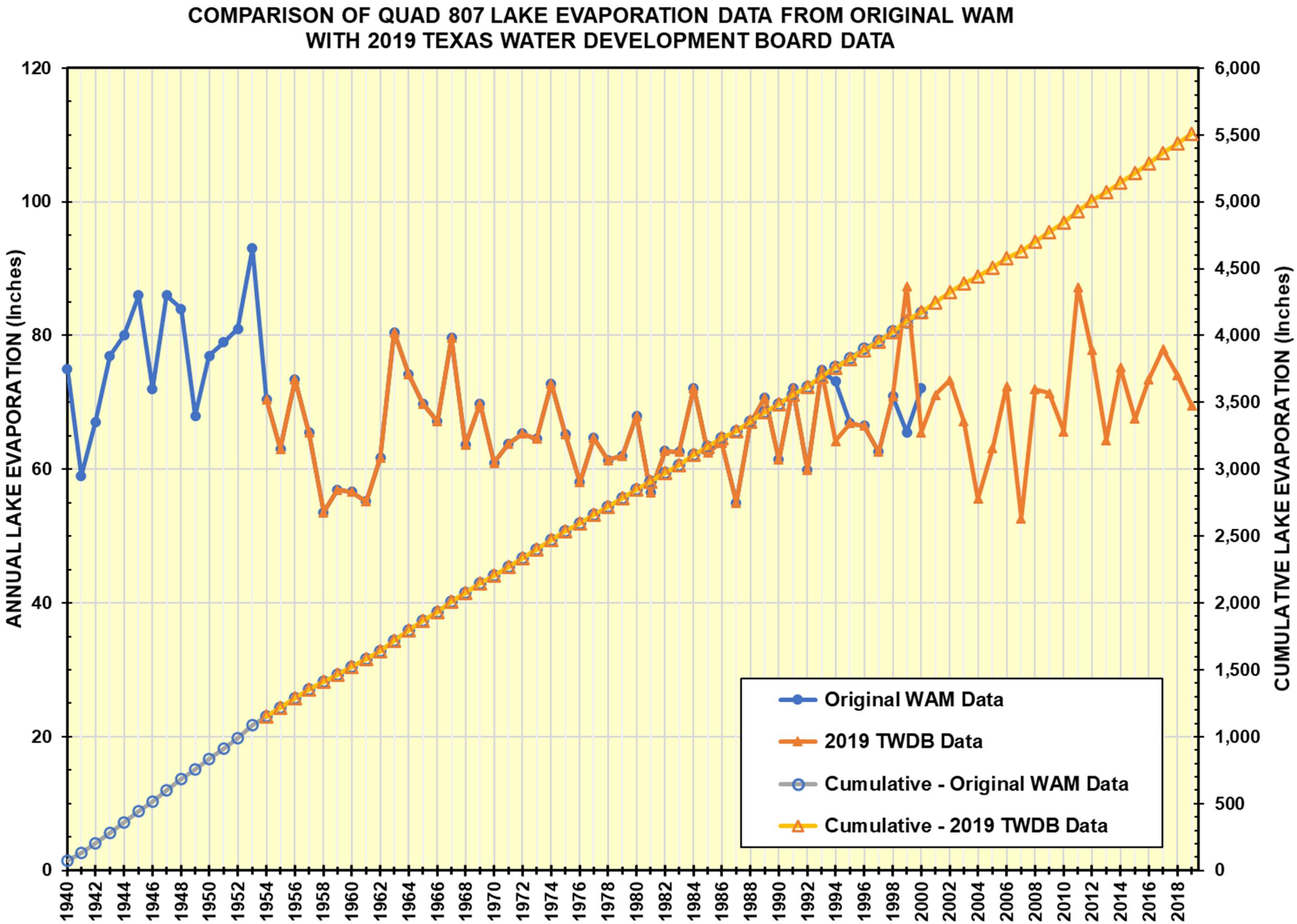
COMPARISON OF QUAD 807 LAKE EVAPORATION DATA FROM ORIGINAL WAM
WITH 2019 TEXAS WATER DEVELOPMENT BOARD DATA
ANNUAL LAKE EVAPORATION (Inches)
CUMULATIVE LAKE EVAPORATION (Inches)
Original WAM Data
2019 TWDB Data
Cumulative - Original WAM Data
Cumulative - 2019 TWDB Data
0
20
40
60
80
100
120
0
500
1,000
1,500
2,000
2,500
3,000
3,500
4,000
4,500
5,000
5,500
6,000
1940
1942
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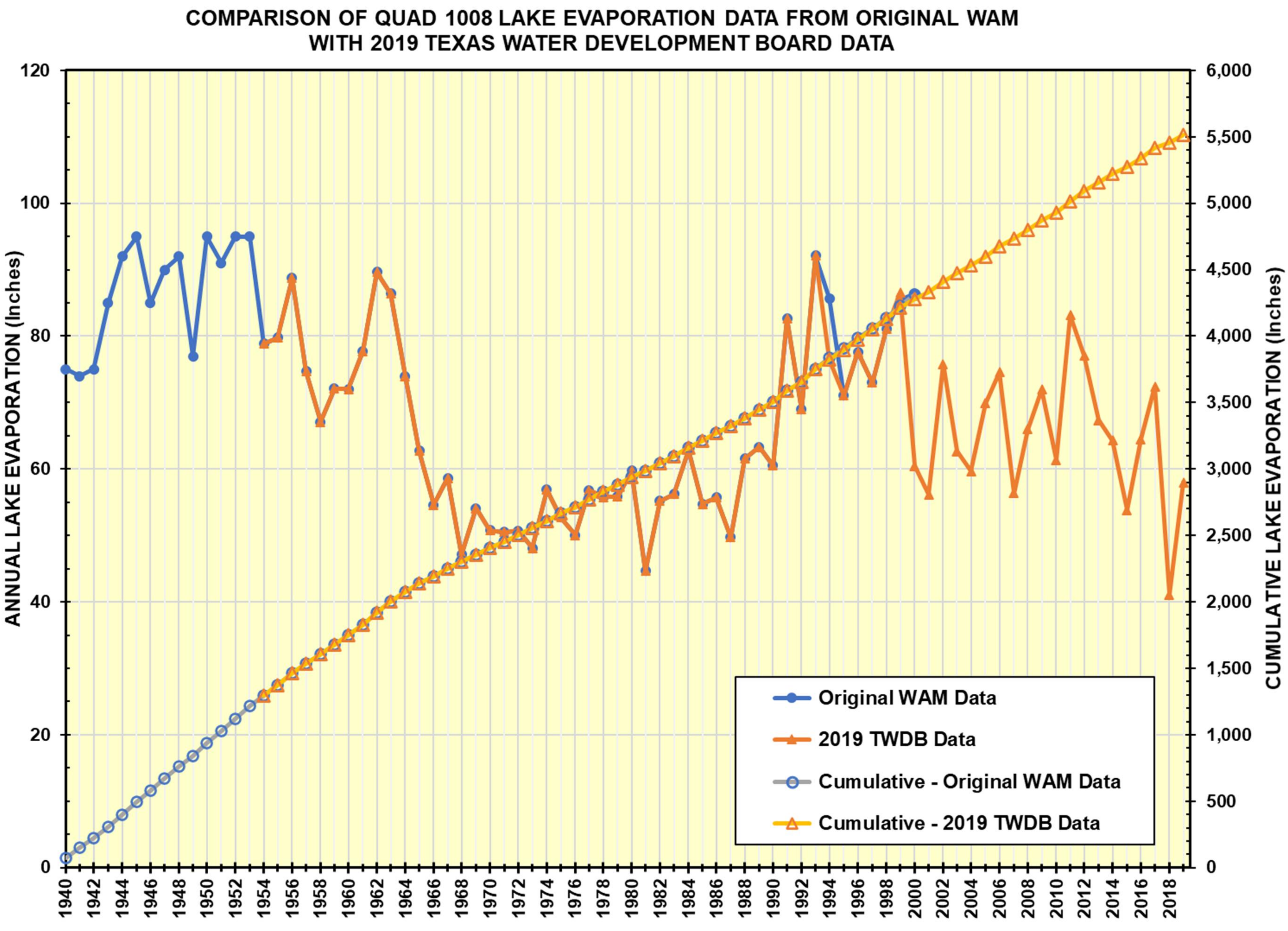
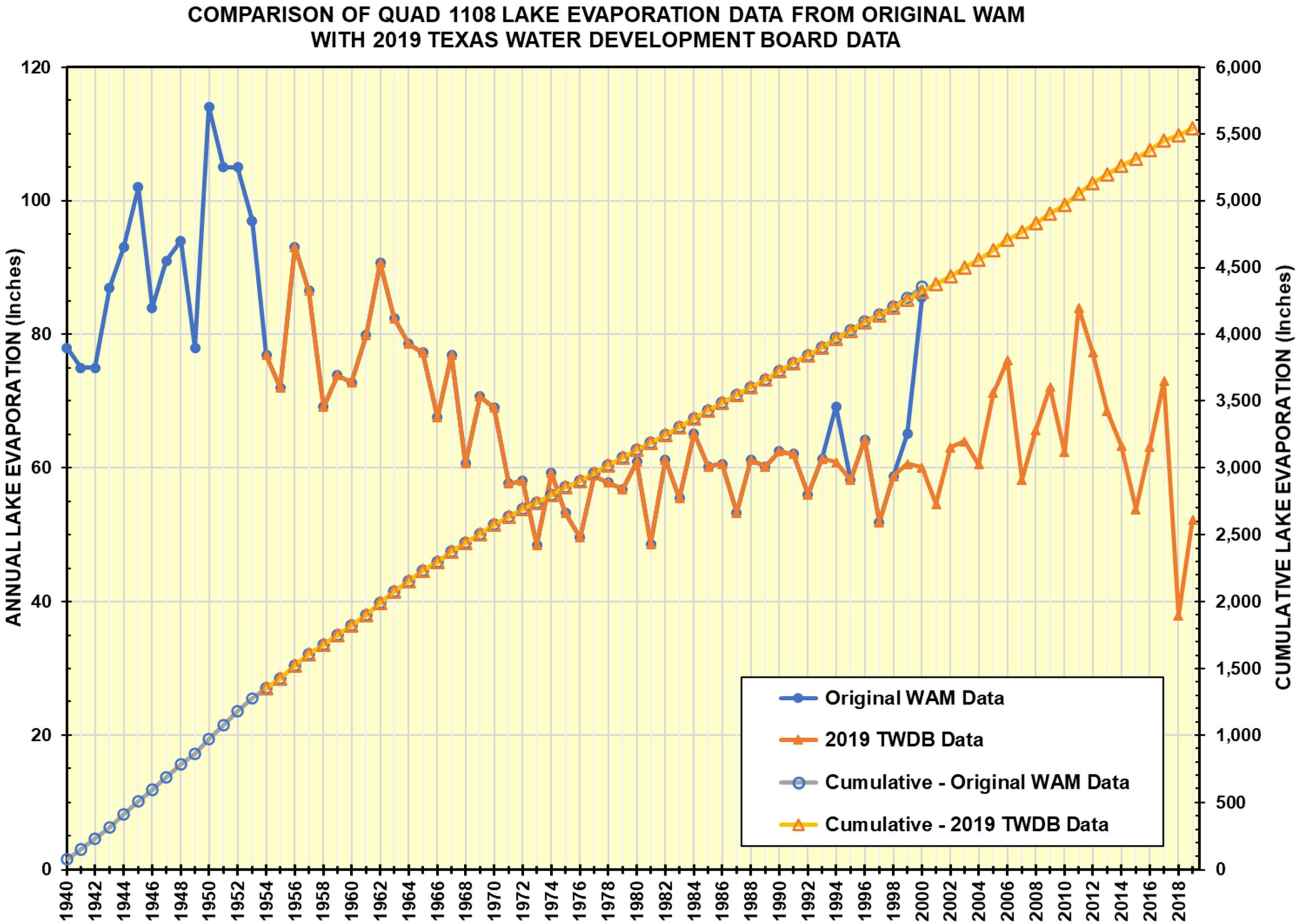
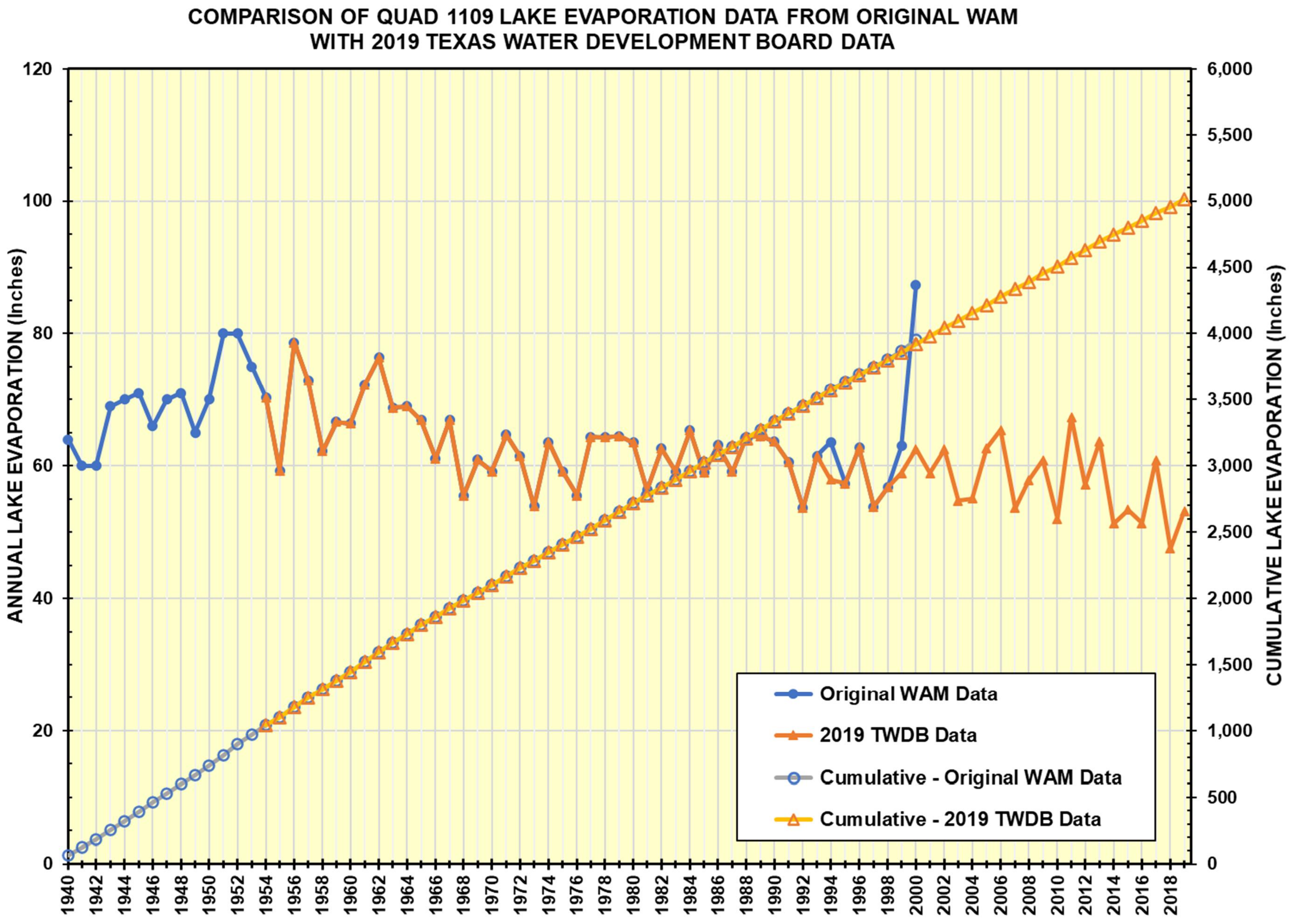

COMPARISON OF QUAD 1008 LAKE EVAPORATION DATA FROM ORIGINAL WAM
WITH 2019 TEXAS WATER DEVELOPMENT BOARD DATA
ANNUAL LAKE EVAPORATION (Inches)
CUMULATIVE LAKE EVAPORATION (Inches)
Original WAM Data
2019 TWDB Data
Cumulative - Original WAM Data
Cumulative - 2019 TWDB Data


COMPARISON OF QUAD 1108 LAKE EVAPORATION DATA FROM ORIGINAL WAM WITH 2019 TEXAS WATER DEVELOPMENT BOARD DATA
ANNUAL LAKE EVAPORATION (Inches)
CUMULATIVE LAKE EVAPORATION (Inches)
Original WAM Data
2019 TWDB Data
Cumulative - Original WAM Data
Cumulative - 2019 TWDB Data


COMPARISON OF QUAD 1109 LAKE EVAPORATION DATA FROM ORIGINAL WAM WITH 2019 TEXAS WATER DEVELOPMENT BOARD DATA
ANNUAL LAKE EVAPORATION (Inches)
CUMULATIVE LAKE EVAPORATION (Inches)
0
20
40
60
80
100
120
0
500
1,000
1,500
2,000
2,500
3,000
3,500
4,000
4,500
5,000
5,500
6,000
1940
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2008
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2012
2014
2016
2018
Original WAM Data
2019 TWDB Data
Cumulative - Original WAM Data
Cumulative - 2019 TWDB Data

APPENDIX B

ASSESSMENT OF NEGATIVE TOTAL AND INCREMENTAL NATURALIZED FLOWS

APPENDIX B
ASSESSMENT OF NEGATIVE TOTAL AND INCREMENTAL NATURALIZED FLOWS

To better understand the negative total and negative incremental naturalized flow issue, all final naturalized flows at each primary control point have been reviewed to gain insight to: (1) the number of months the total naturalized flows are negative, requiring an adjustment to zero, and (2) the extent and magnitude to which negative incremental flows occur between primary control points. This information has also been reviewed with respect to the methods the Water Rights Analysis Package ("WRAP") uses when naturalized flows at primary control points (gaged locations) are used to estimate the naturalized flows at a secondary control point (ungaged location). Discussions of these topics are presented in the following sections.

WRAP Method for Prorating Naturalized Flows from Primary to Secondary Control Points

WRAP has several options for prorating naturalized flows from primary control points (gaged) to a secondary (ungaged) control point, and because there are channel losses between all primary control points in the Rio Grande WAM, the method used necessarily takes into account channel losses. Although in the naturalized flow process, channel loss factors are used to account for channel losses associated with the adjustments applied to gaged flows (diversions, return flows, reservoir depletions, etc.) to arrive at naturalized flows, channel losses that may be inherent in gaged flows are not altered and remain embedded in the final naturalized flows. Therefore, if the incremental flow is calculated by simply subtracting the upstream naturalized flows from the downstream naturalized flow, negative values, referred to as apparent negative incremental naturalized flows, very likely can result.

In the WAM, however, when calculating incremental flows, channel losses are applied to the upstream naturalized flows to translate them to the downstream primary control point location, which results in many of the apparent negative incremental flows being reduced or eliminated altogether. To better demonstrate this, Table B-1 summarizes the simulated incremental flow results for 2018 from the updated Rio Grande WAM for a mainstem secondary control point on the Pecos River between the upstream Orla (GT3000) and the downstream Girvin (GT2000) primary control points and for a tributary secondary control point between these two primary control points[8]. As noted in the table, the apparent negative incremental flows shown in Column 4 are significantly reduced or eliminated in the final negative incremental flow values in Column 6 because of WRAP's consideration of channel losses between the two primary control points when it computes the incremental flows needed to calculate the naturalized flows at the two

[8] It should be noted that the version of the WAM used to create the example in Table B-1 was modified to remove all flow adjustment records so that the precise proration of flows from primary control points to the secondary control point locations could be more clearly demonstrated.

TABLE B-1 EXAMPLE OF WRAP LOGIC TO PRORATE NATURALIZED FLOWS TO SECONDARY CONTROL POINTS BASED ON INCREMENTAL FLOWS BETWEEN UPSTREAM AND DOWNSTREAM PRIMARY CONTROL POINTS

BASIC INPUTS TO WRAP	
Total Drainage Area at Upstream Primary Control Point (GT3000) - Pecos River at Orla (sq. mi.):	21,128
Total Drainage Area at Downstream Primary Control Point (GT2000) - Pecos River at Girvin (sq. mi.):	32,900
Total Drainage Area at Mainstem Secondary Control Point (GT2120) Between Orla and Girvin (sq. mi.):	26,396
Total Drainage Area at Tributary Secondary Control Point (GT2040) Between Orla and Girvin (sq. mi.):	1,264
Channel Loss from Orla Primary Control Point (GT3000) Downsteam to Girvin Primary Control Point (GT2000):	47.95%
Channel Loss from Mainstem Secondary Control Point (GT2120) Downstream to Girvin Primary Control Point (GT2000):	29.20%
Channel Loss from Tributary Secondary Control Point (GT2040) Downstream to Girvin Primary Control Point (GT2000):	30.80%
Channel Loss from Mainstem Secondary Control Point (GT2120) Upstream to Orla Primary Control Point (GT3000):	26.47%

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1)	FINAL OUTPUT FROM WRAP							
(2) (3) (4)	Month-Year	Upstream Pecos River Naturalized Flow at Orla (GT3000)	Downstream Pecos River Naturalized Flow at Girvin (GT2000)	Apparent Incremental Naturalized Flow Without Channel Losses Considered	Pecos River Naturalized Flow at Orla After Channel Losses from Orla to Girvin	Actual Incremental Naturalized Flow With Channel Losses Considered	Pecos River Naturalized Flow at Mainstem Secondary Control Point (GT2120)	Tributary Naturalized Flow at Tributary Secondary Control Point (GT2040)
(5)	Jan-18	3,289	2,500	-789	1,712	788	2,824	88
(6)	Feb-18	2,596	1,419	-1,177	1,351	68	1,944	8
(7)	Mar-18	2,554	1,602	-952	1,329	273	2,018	30
(8)	Apr-18	1,982	1,538	-444	1,032	506	1,718	56
(9)	May-18	3,110	0	-3,110	1,619	-1,619	1,453	0
(10)	Jun-18	3,225	2,162	-1,063	1,679	483	2,620	54
(11)	Jul-18	2,115	608	-1,507	1,101	-493	1,301	0
(12)	Aug-18	1,246	639	-607	649	-10	911	0
(13)	Sep-18	3,583	5,217	1,634	1,865	3,352	4,360	372
(14)	Oct-18	7,389	5,499	-1,890	3,846	1,653	6,284	184
(15)	Nov-18	3,655	3,650	-5	1,903	1,747	3,587	194
(16)	Dec-18	3,300	2,892	-408	1,718	1,174	3,031	130

example secondary control point locations in Columns 7 and 8. Note that the prorated naturalized flows at these two locations have values even though the apparent incremental naturalized flows in Column 4 are negative, and they are set to zero only when the actual incremental naturalized flows in Column 6 are negative.

Effects of Channel Loss Adjustments on Incremental Naturalized Flows

To further demonstrate how channel loss adjustments in WRAP affect negative incremental naturalized flows, the following Table B-2 presents total and incremental naturalized flow information from the updated 1940-2018 workbooks for all mainstem and Texas tributary primary control points that have primary control points located immediately upstream (headwater primary control points are excluded since they do not have any upstream primary control points). Information pertaining to each primary control point is presented in Columns 1 through 4, including the upstream channel loss rate, the number of monthly negative values of total naturalized flow that were set equal to zero, and the average annual naturalized flow. As shown, only two of the primary control points on the Rio Grande mainstem have negative total naturalized flows, and these are both in the upper end of the river in Texas where the channel loss rates are the highest and where external adjustments for diversions and return flows may not be accurately documented due to data issues. The other primary control points with negative total naturalized flows are in the upper end of the Pecos River, again likely due to the same factors noted for the upper Rio Grande primary control points. Variations in the average annual naturalized flows along the Rio Grande are consistent with significant inflows from Mexico tributaries and major diversions and return flows by both Texas and Mexico water users.

Columns 5 through 14 present statistics for monthly negative incremental naturalized flows for each primary control point, with values listed under each category <u>before</u> channel loss adjustments and <u>after</u> channel loss adjustments. The "before channel loss adjustments" phrase pertains to negative incremental flow statistics that are based on calculations using the basic total naturalized flows as they are input to the WAM, whereas the "after channel loss adjustments" phrase means that in the calculation of incremental flows for a particular primary control point, the total naturalized flows at all upstream primary control points have been adjusted for downstream channel losses within the incremental area. In the 1940-2018 simulation period for the updated Rio Grande WAM, there are 948 simulation months, so the significance of the "before" and "after" loss adjustments on the number of months with negative incremental naturalized flows at each primary control point is clearly evident in Columns 5 and 6. The same is true for each pair of "before" and "after" negative incremental flow statistics in Columns 7 through 12. The last two columns indicate how the channel loss adjustments affect the values of the average annual negative incremental naturalized flows expressed as a percent of the average annual naturalized flows. Several of the primary control points show significant reductions due to the channel loss adjustments.

TABLE B-2 SUMMARY OF TOTAL NATURALIZED FLOW ADJUSTMENTS AND NEGATIVE INCREMENTAL NATURALIZED FLOWS BEFORE AND AFTER CHANNEL LOSS ADJUSTMENTS

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
	PRIMARY CONTROL POINT AND TOTAL NATURALIZED FLOW INFORMATION				NEGATIVE INCREMENTAL FLOW INFORMATION									
	NAT FLOW WORKBOOK PRIMARY CONTROL POINT ID [Note 1]	UPSTREAM REACH CHANNEL LOSS	NO. OF MONTHS ADJUSTED FOR TOTAL NEGATIVE NAT FLOW	AVERAGE ANNUAL NAT FLOW (Ac-Ft/Yr)	NO. OF MONTHS WITH NEGATIVE INCREMENTAL NAT FLOWS		MAXIMUM MONTHLY NEGATIVE INCREMENTAL NATURALIZED FLOW		MAXIMUM ANNUAL NEGATIVE INCREMENTAL NATURALIZED FLOW		AVERAGE ANNUAL NEGATIVE INCREMENTAL NATURALIZED FLOW		AVERAGE ANNUAL NEG INCREMENTAL NAT FLOW AS % OF AVERAGE ANNUAL NAT FLOW	
					BEFORE LOSS ADJUST.	AFTER LOSS ADJUST.	BEFORE LOSS ADJUST.	AFTER LOSS ADJUST.	BEFORE LOSS ADJUST.	AFTER LOSS ADJUST.	BEFORE LOSS ADJUST.	AFTER LOSS ADJUST.	BEFORE LOSS ADJUST.	AFTER LOSS ADJUST.
	Rio Grande Mainstem													
(1)	RGFQ	20.0%	35	452,051	539	150	-53,950	-40,137	-216,111	-147,402	-32,417	-4,939	-7.2%	-1.1%
(2)	RGAC	46.0%	13	293,394	844	271	-105,328	-16,831	-363,129	-30,168	-165,760	-4,951	-56.5%	-1.7%
(3)	RGBC	2.0%	0	1,553,436	503	315	-193,394	-183,675	-647,840	-606,886	-70,376	-55,477	-4.5%	-3.6%
(4)	RGJR	10.0%	0	1,534,640	663	126	-206,642	-61,237	-391,684	-64,215	-85,359	-7,144	-5.6%	-0.5%
(5)	RGFR	2.0%	0	1,774,305	37	26	-152,868	-127,241	-188,254	-150,182	-10,415	-6,113	-0.6%	-0.3%
(6)	RGDR	1.0%	0	2,699,144	51	37	-327,459	-309,849	-327,459	-309,849	-10,964	-8,579	-0.4%	-0.3%
(7)	RGPN	13.0%	0	3,307,953	635	57	-408,645	-243,516	-539,841	-243,516	-160,454	-8,715	-4.9%	-0.3%
(8)	RGLA	14.0%	0	3,148,232	479	32	-814,968	-415,675	-844,575	-415,675	-132,501	-7,788	-4.2%	-0.2%
(9)	RGBF	9.0%	0	3,516,590	636	277	-975,833	-790,437	-1,266,606	-945,903	-264,624	-78,718	-7.5%	-2.2%
(10)	RGRG	4.0%	0	4,464,891	522	171	-176,832	-127,668	-389,154	-253,063	-102,592	-31,867	-2.3%	-0.7%
(11)	RGAN	5.0%	0	4,384,867	639	237	-424,060	-171,405	-639,384	-257,370	-141,091	-32,215	-3.2%	-0.7%
	Pecos River													
(12)	PROR	11.0%	15	109,152	525	311	-48,042	-18,786	-65,994	-33,313	-9,226	-3,993	-8.5%	-3.7%
(13)	PRGI	48.0%	112	76,677	626	277	-321,422	-130,186	-659,530	-201,360	-41,878	-9,191	-54.6%	-12.0%
(14)	PRLA	30.0%	0	242,375	7	0	-6,217	0	-6,217	0	-342	0	-0.1%	0.0%
	Devils River													
(15)	DRPC	5.0%	0	254,268	0	0	0	0	0	0	0	0	0.0%	0.0%

Note 1 - Only primary control points with upstream primary control points are included. Headwater primary control points are excluded from table.

The results of this exercise clearly show that the primary control points that have the highest percentage of negative incremental flow "before" the channel loss adjustments (Column 13) are also the control points that have the higher channel loss rates (Column 2), and that these percentages are significantly reduced "after" the channel loss adjustments are applied to the upstream naturalized flows at each primary control point. This information is important to understand how negative incremental naturalized flows are calculated and addressed in the WAM and whether further external adjustments to eliminate negative incremental naturalized flows are even necessary or required.

WAM Method to Address Negative Incremental Naturalized Flows

In the existing Rio Grande WAM, Option 5 in the WRAP code is used to address negative incremental naturalized flows. Unlike other negative incremental flow options available in WRAP, this option does not make any flow adjustments to offset negative incremental flows. Instead, a different approach for calculating available flow at certain control points is used in the WRAP algorithm. Normally, WRAP determines the available flow at a location as the minimum of the remaining available flow at that location and at all control points downstream. Once the amount of available flow is calculated and a depletion occurs at the subject location, the amount of the depletion is adjusted for (subtracted away) from the available flow at the subject location and all control points downstream, with channel losses taken into account as these downstream adjustments are made.

With the use of Option 5, the only downstream control points that are considered in the determination of available flow at the subject location are downstream control points that have water right activities senior in priority to the water right activity at the subject location, i.e., they have already been processed in the simulation loop. In addition, after the depletion is made at the subject location, the adjustment (flow reduction) that is normally made to the available flow at the subject location and all control points downstream is limited to only the downstream control points that have senior-priority water right activities. As a result, the Option 5 approach does not constrain water availability at the subject location based on the available flow downstream unless a downstream senior water right activity has previously utilized the available flow. Because of the way the overall priorities for performing water availability simulations are structured in the Rio Grande WAM (upstream activities are generally processed as senior to downstream activities), few, if any, of the downstream water rights have been processed when most of the upstream water rights are being simulated. Therefore, Option 5 is particularly suited to these conditions.

Based on the above discussion of WRAP's procedure for considering channel losses when computing naturalized flows at secondary control point locations and the appropriateness of using WRAP's Option 5 to compute available flow in the simulation process, it has been concluded that the best approach is to not make any external adjustments to the final naturalized flows for the purpose of eliminating negative incremental naturalized flows.

APPENDIX C

GRAPHS COMPARING UPDATED NATURALIZED FLOWS WITH ORIGINAL NATURALIZED FLOWS

FIGURE C-1 NATURALIZED FLOWS FOR RIO GRANDE AT FORT QUITMAN GAGE

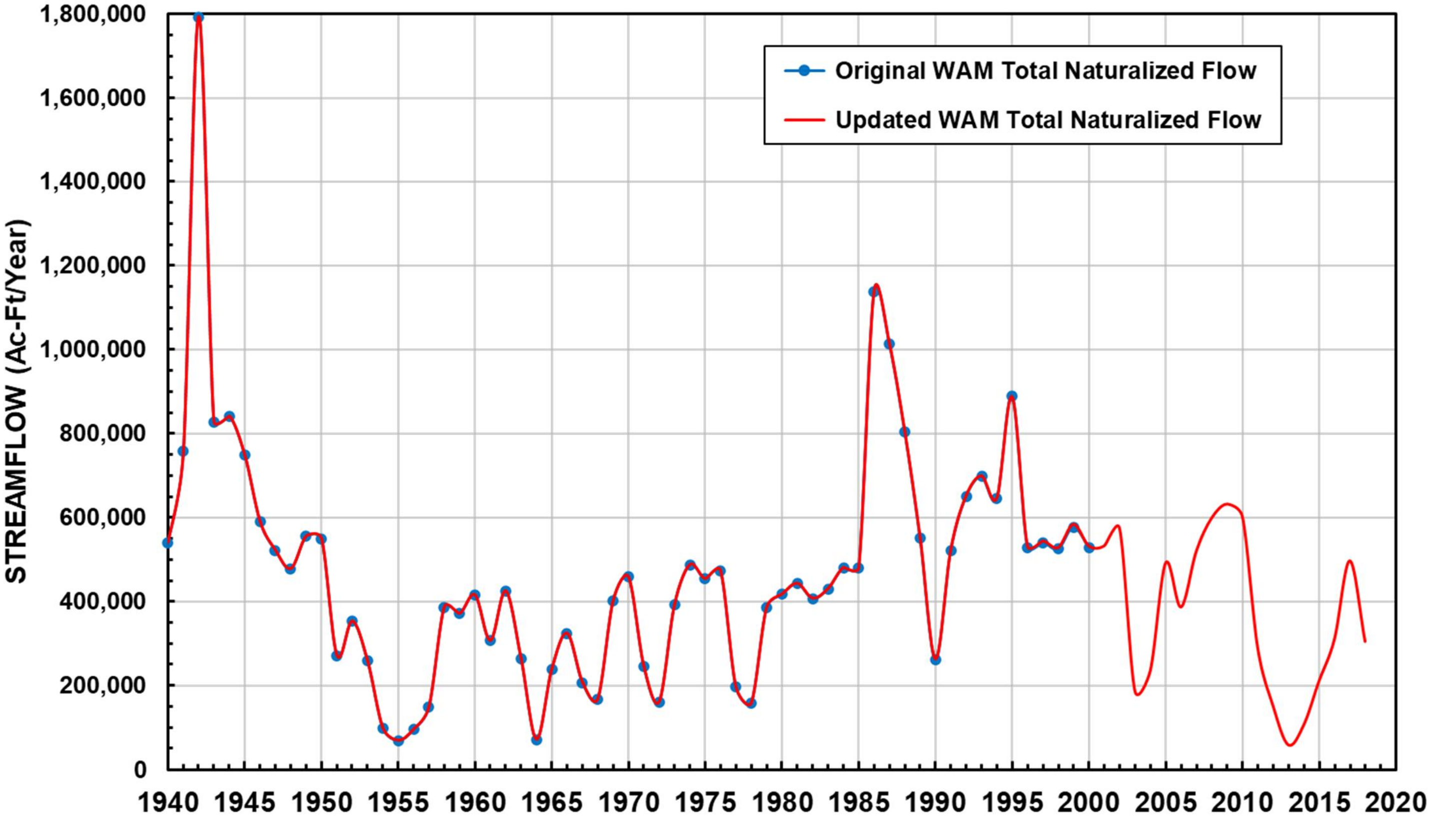


FIGURE C-2 NATURALIZED FLOWS FOR RIO GRANDE BELOW RIO CONCHOS GAGE

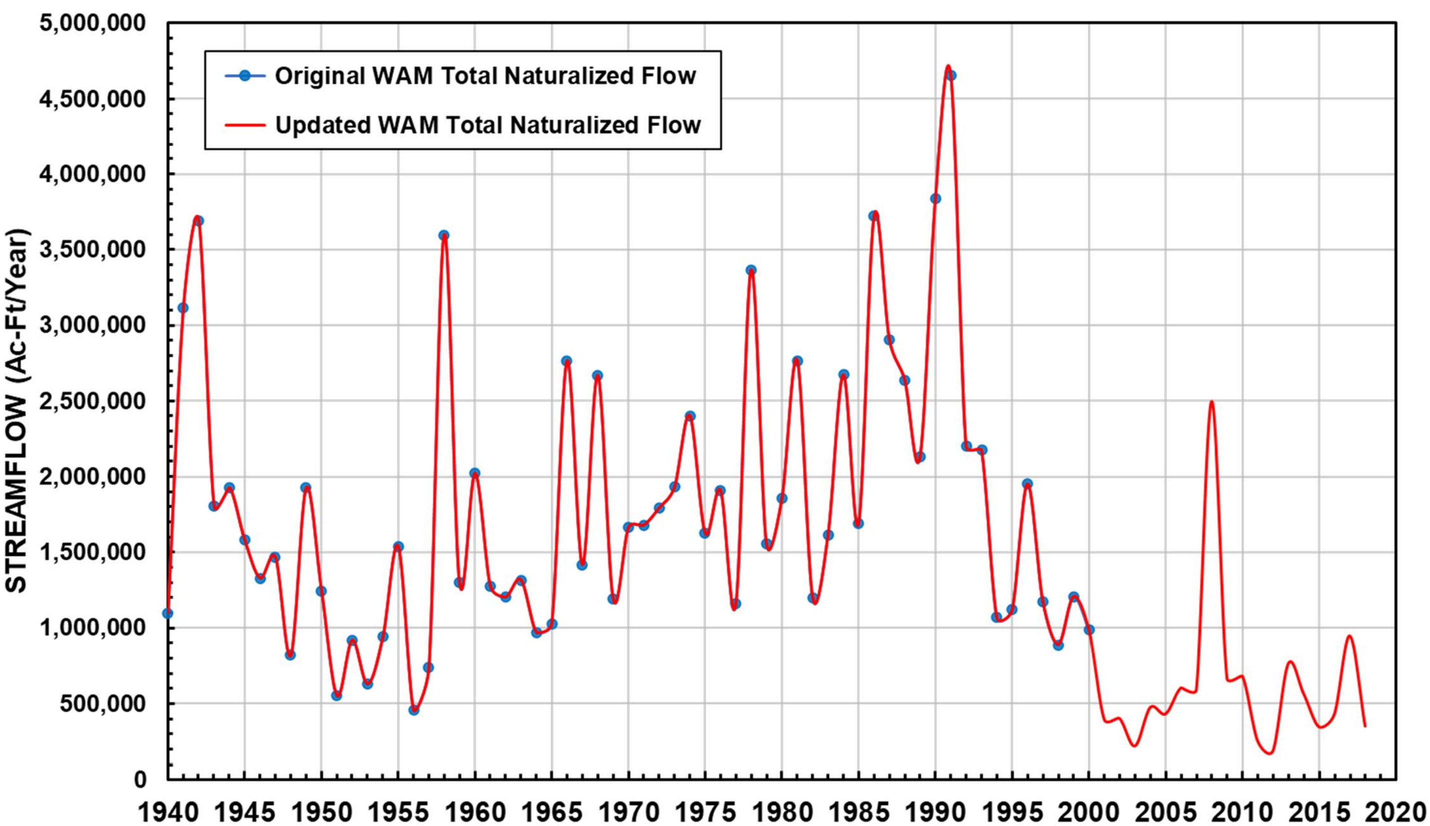


FIGURE C-3 NATURALIZED FLOWS FOR PECOS RIVER NEAR LANGTRY GAGE

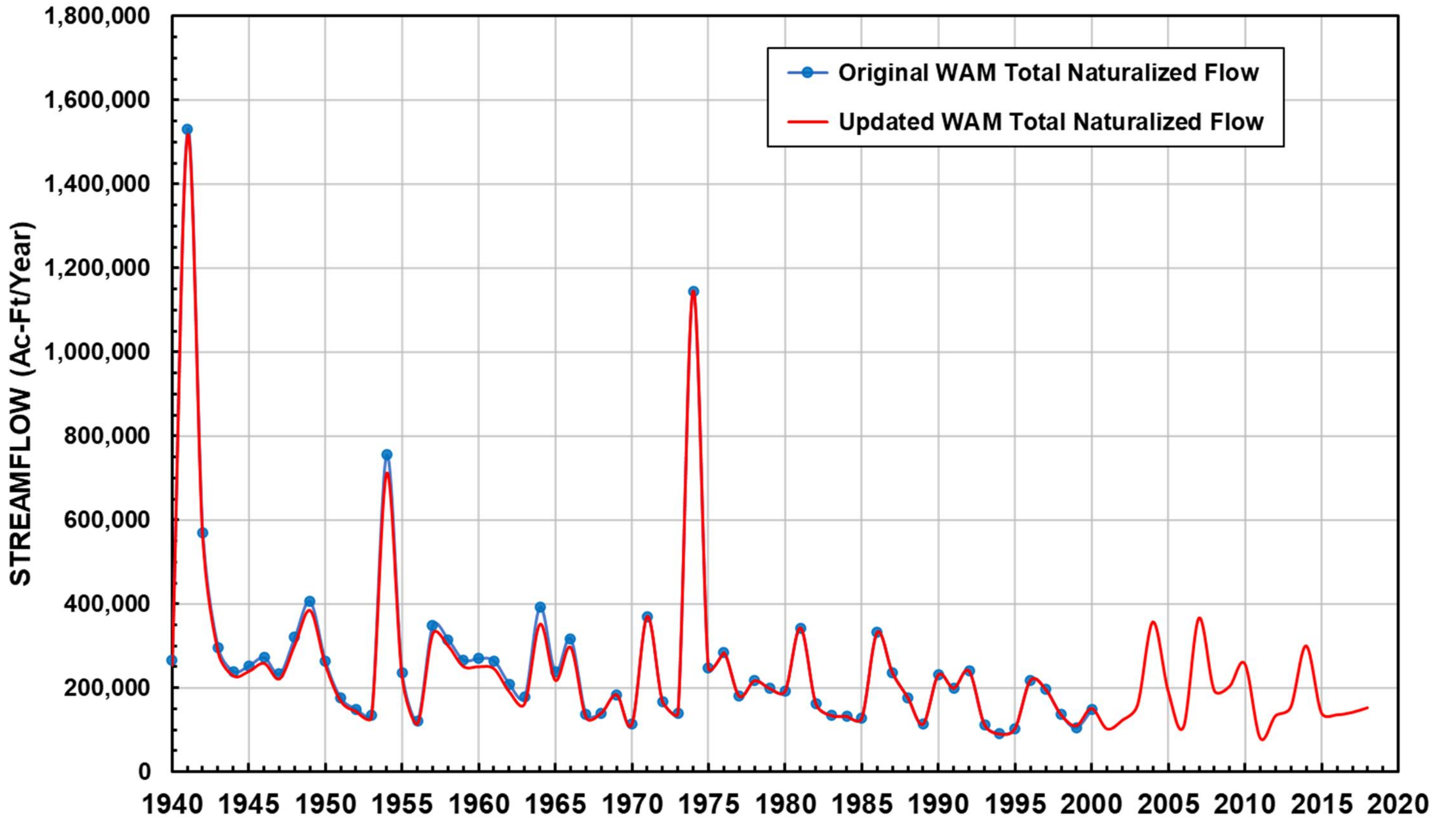


FIGURE C-4 NATURALIZED FLOWS FOR DEVILS RIVER AT PAFFORD CROSSING GAGE

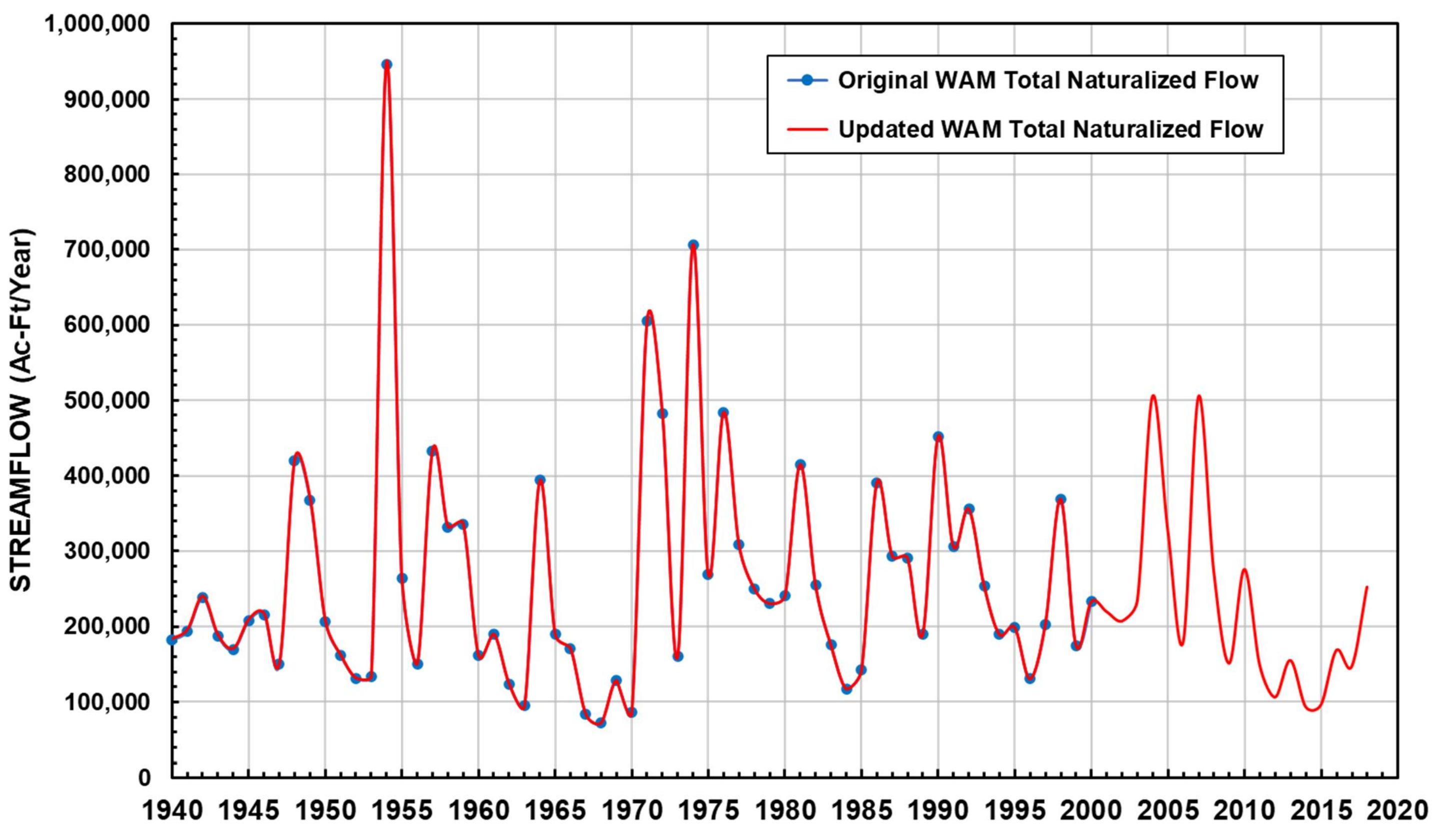


FIGURE C-5 NATURALIZED FLOWS FOR RIO GRANDE AT DEL RIO GAGE

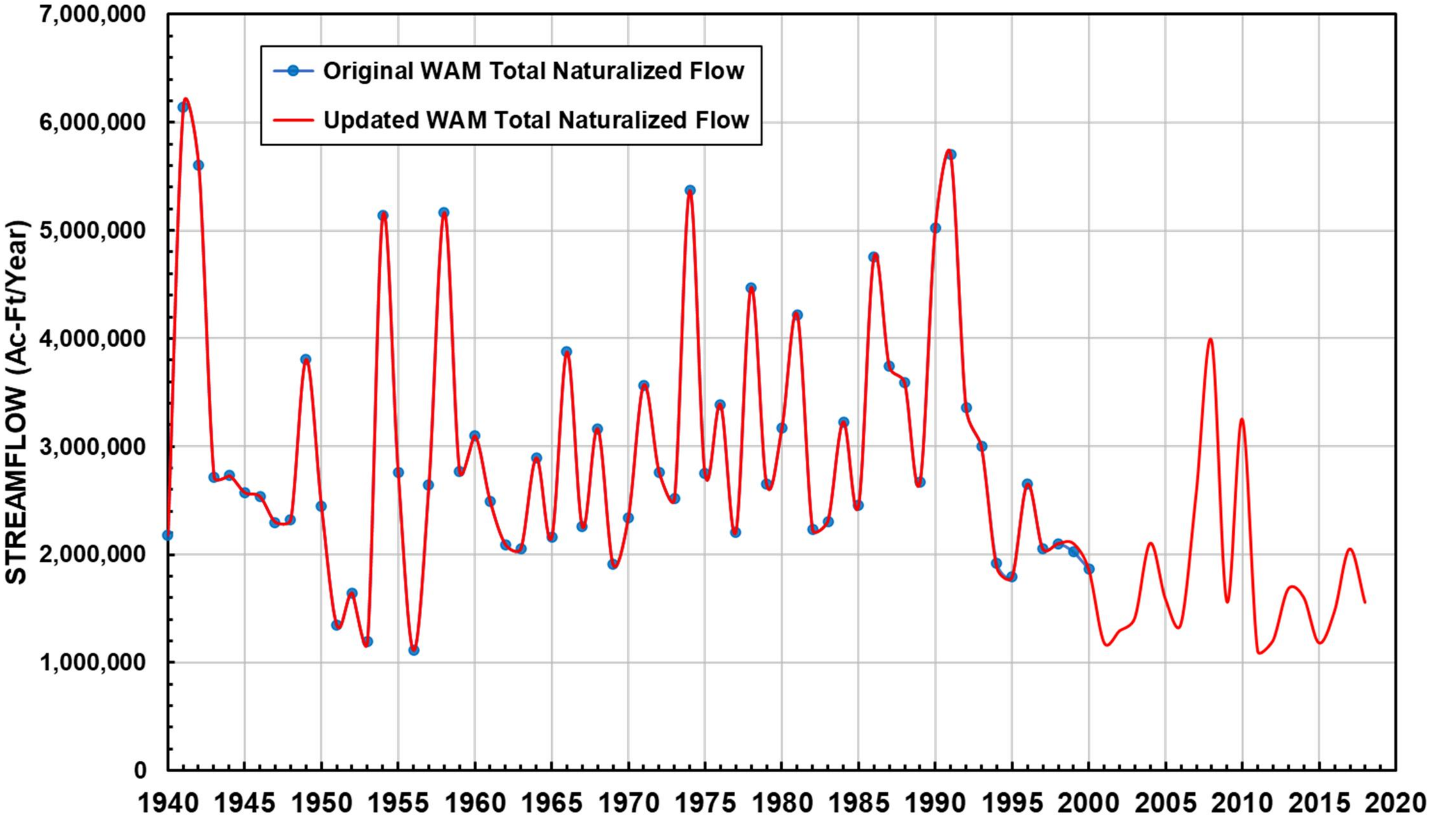


FIGURE C-6 NATURALIZED FLOWS FOR RIO GRANDE AT PIEDRAS NEGRAS GAGE

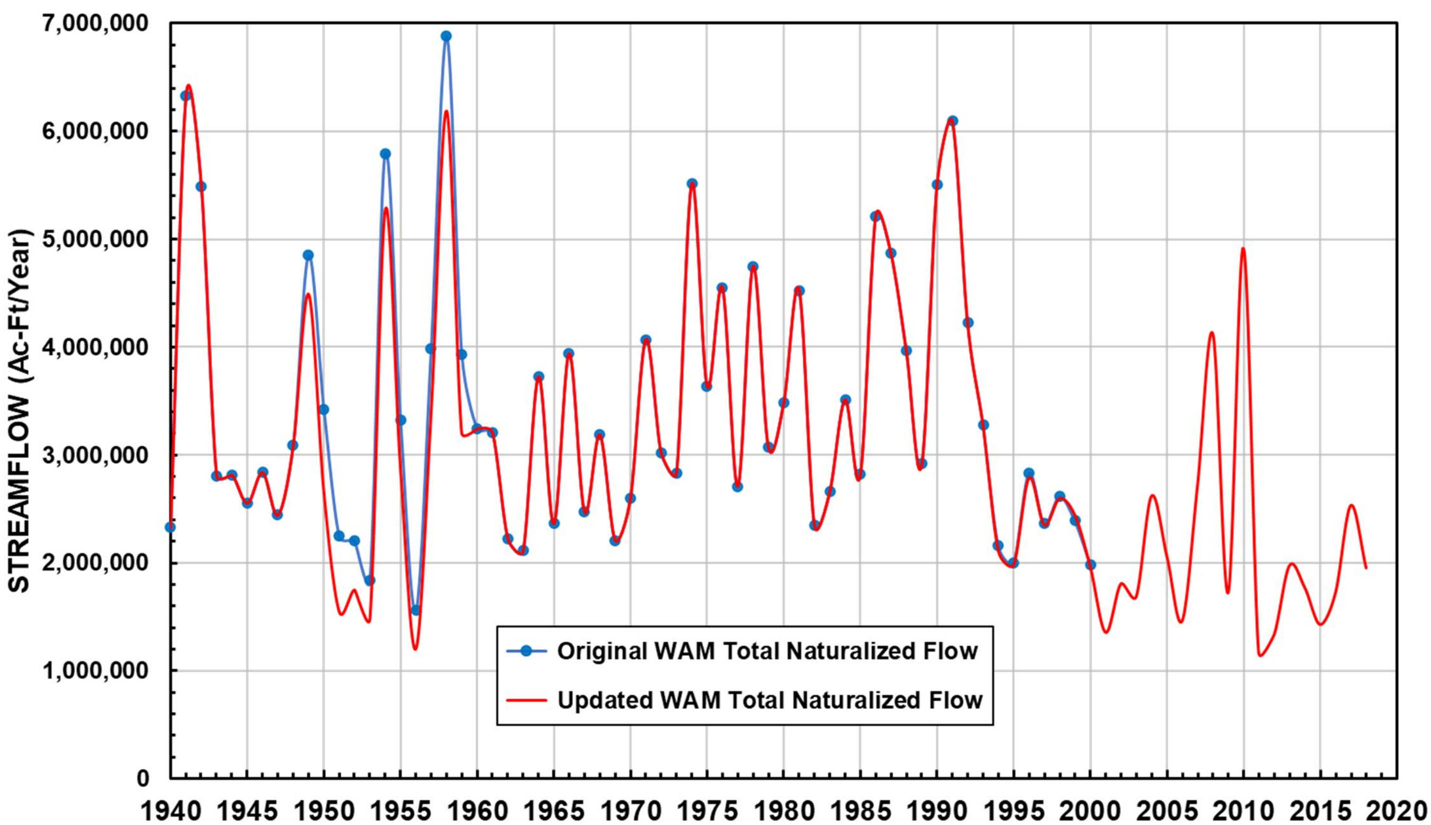


FIGURE C-7 NATURALIZED FLOWS FOR RIO GRANDE AT LAREDO GAGE

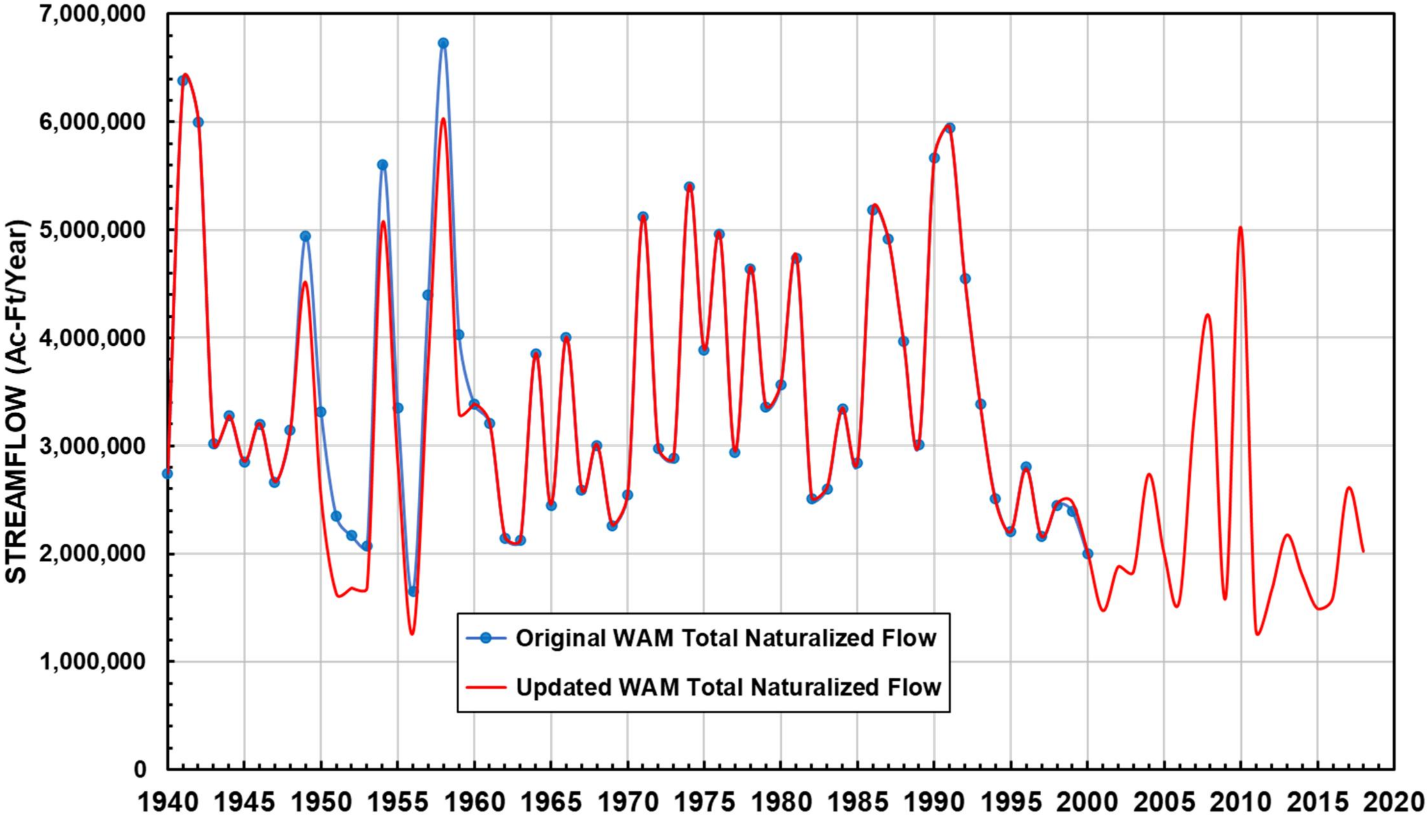


FIGURE C-8 NATURALIZED FLOWS FOR RIO GRANDE BELOW FALCON DAM GAGE

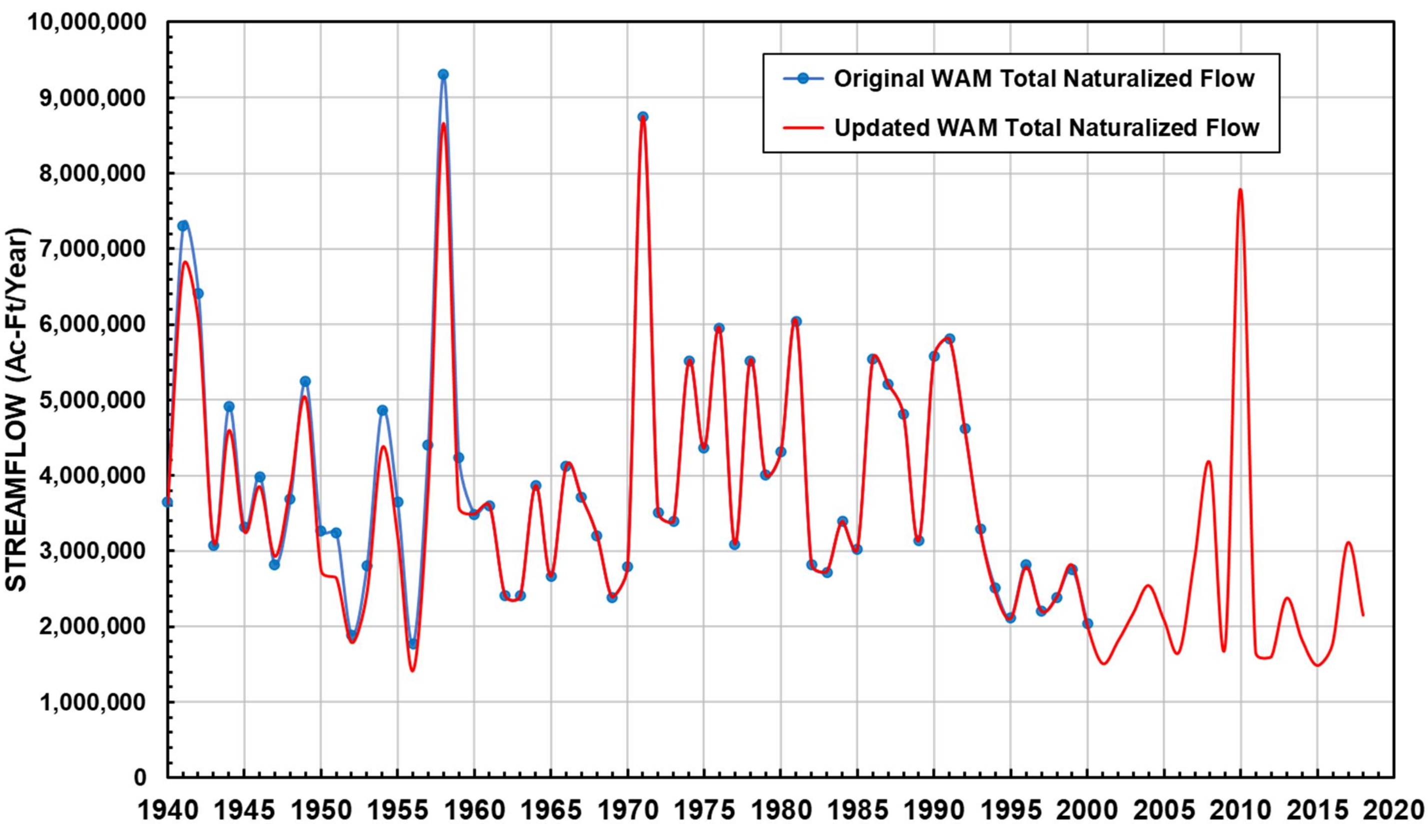


FIGURE C-9 NATURALIZED FLOWS FOR RIO GRANDE AT RIO GRANDE CITY

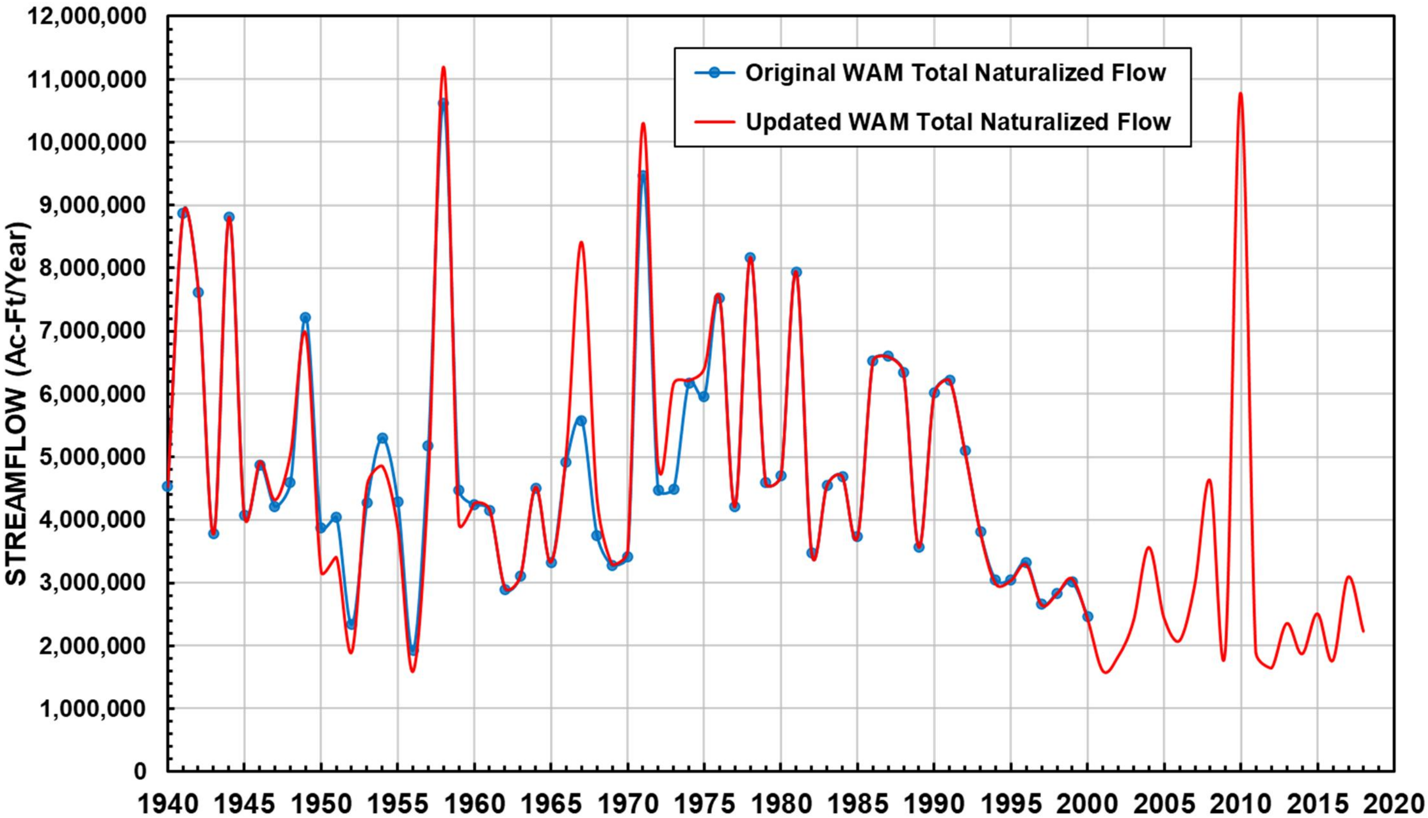
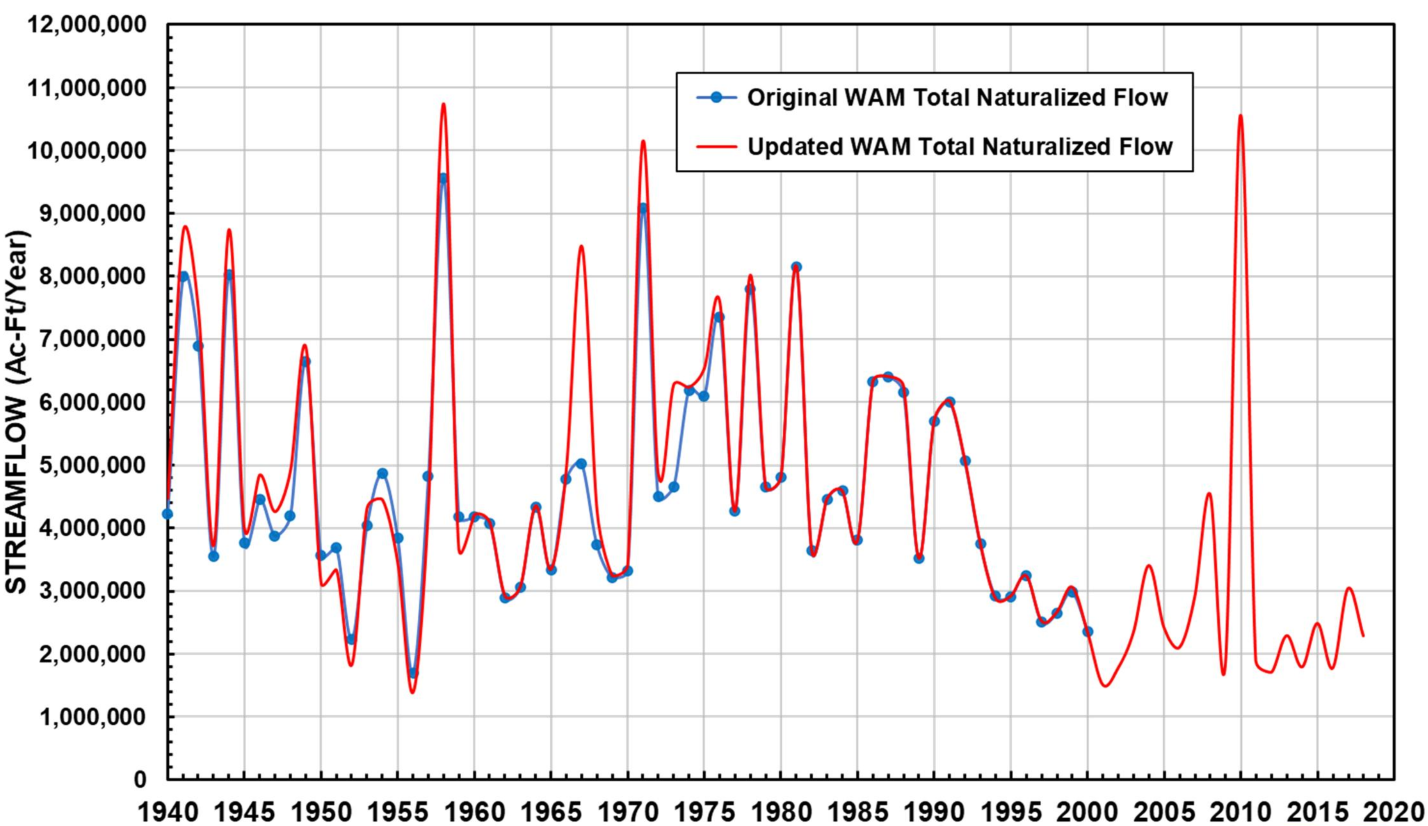


FIGURE C-10 NATURALIZED FLOWS FOR RIO GRANDE BELOW ANZALDUAS DAM GAGE



APPENDIX D

DOUBLE-MASS GRAPHS OF UPDATED NATURALIZED FLOWS AND EXISTING NATURALIZED FLOWS

FIGURE D-1 DOUBLE-MASS CURVE FOR RIO GRANDE AT FORT QUITMAN NATURALIZED FLOWS

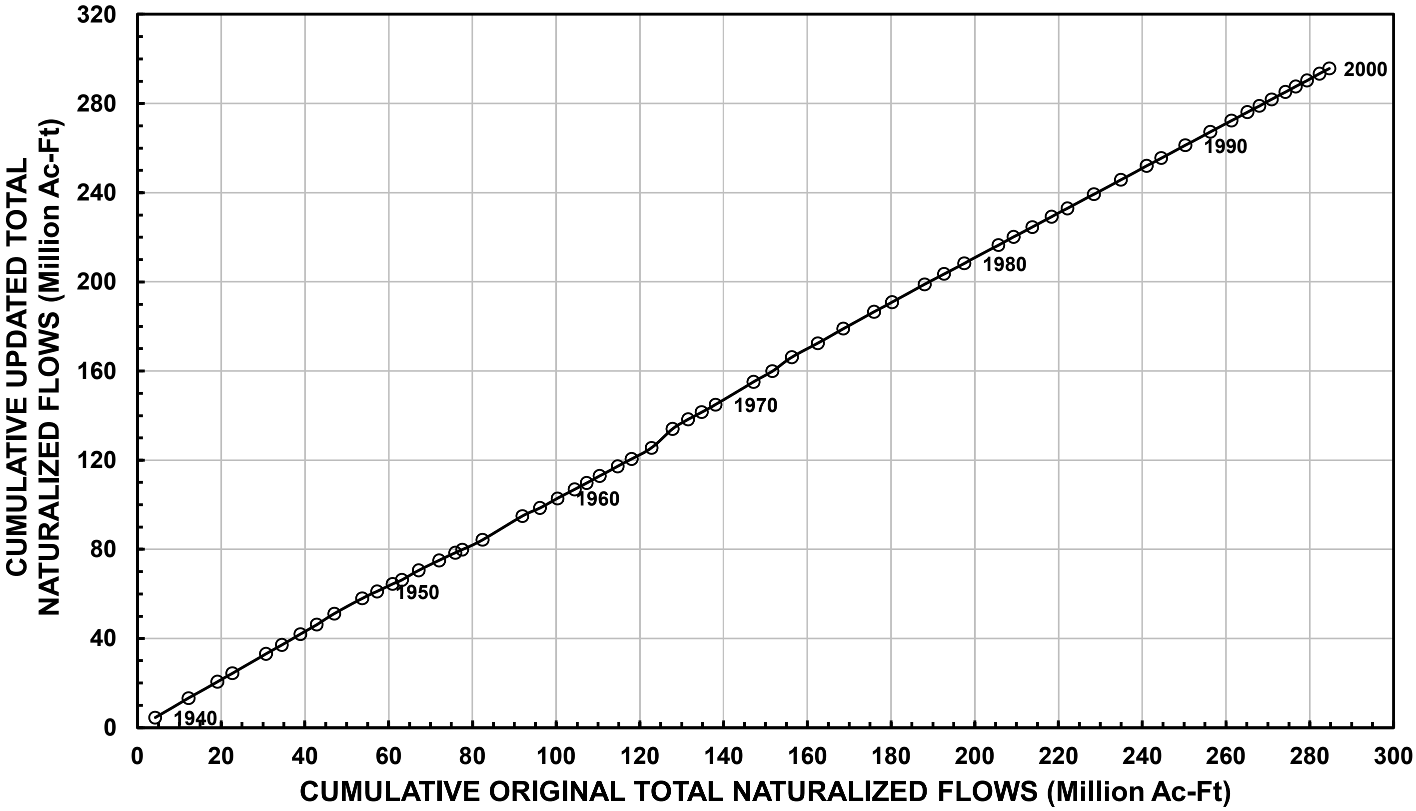


FIGURE D-2 DOUBLE-MASS CURVE FOR RIO GRANDE BELOW RIO CONCHOS NATURALZIED FLOWS

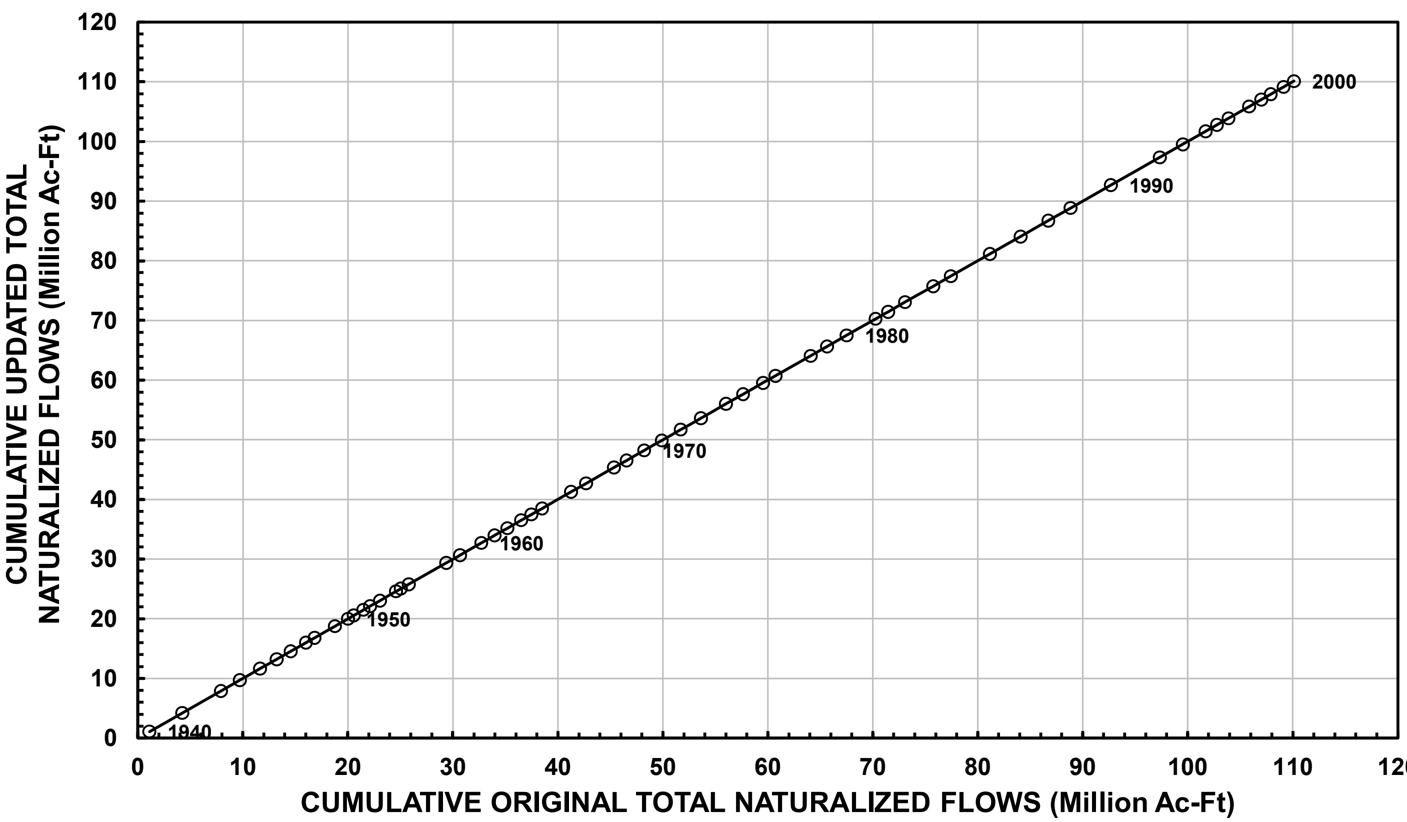


FIGURE D-3 DOUBLE-MASS CURVE FOR PECOS RIVER NEAR LANGTRY NATURALIZED FLOWS

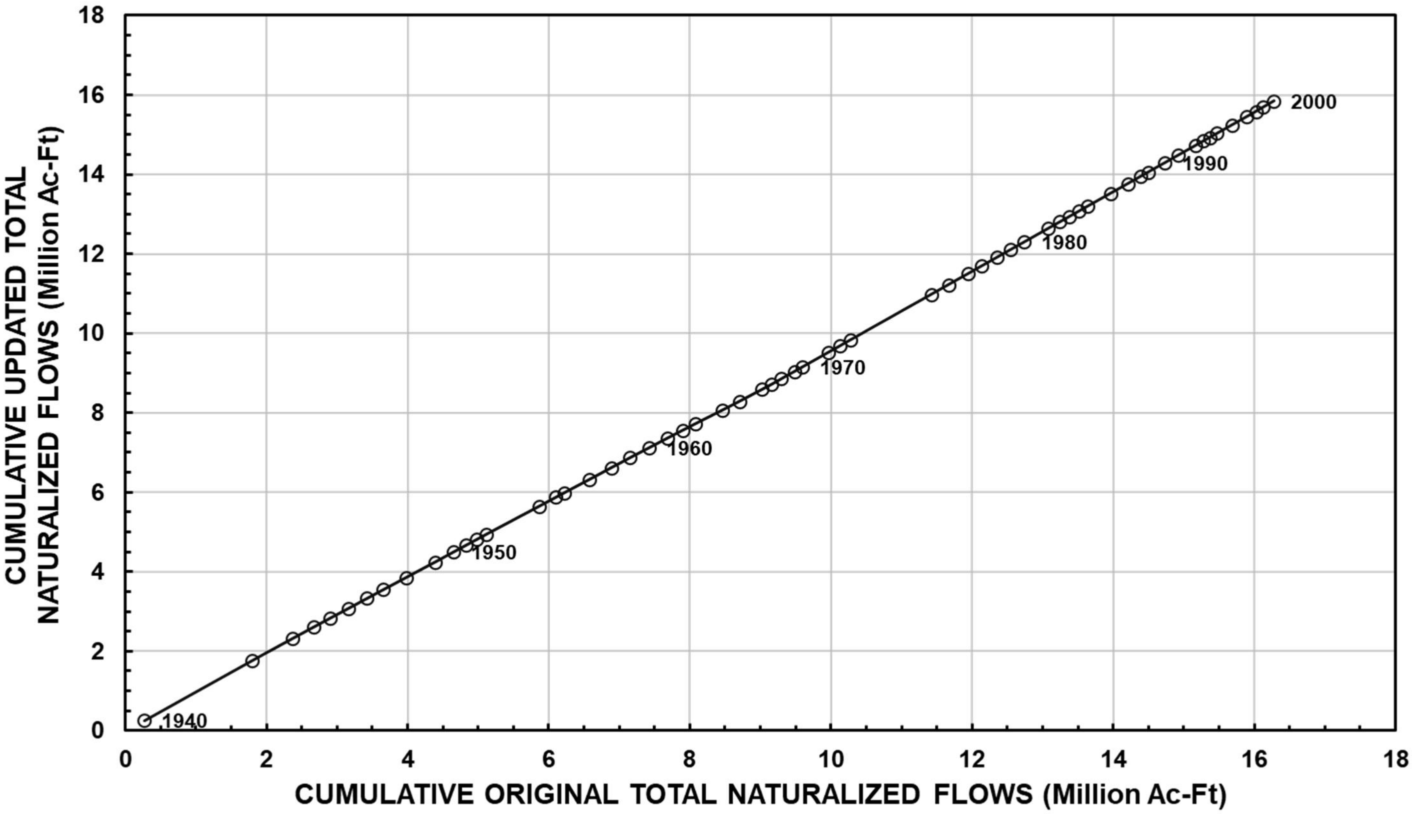


FIGURE D-4 DOUBLE-MASS CURVE FOR DEVILS RIVER AT PAFFORD CROSSING NATURALIZED FLOWS

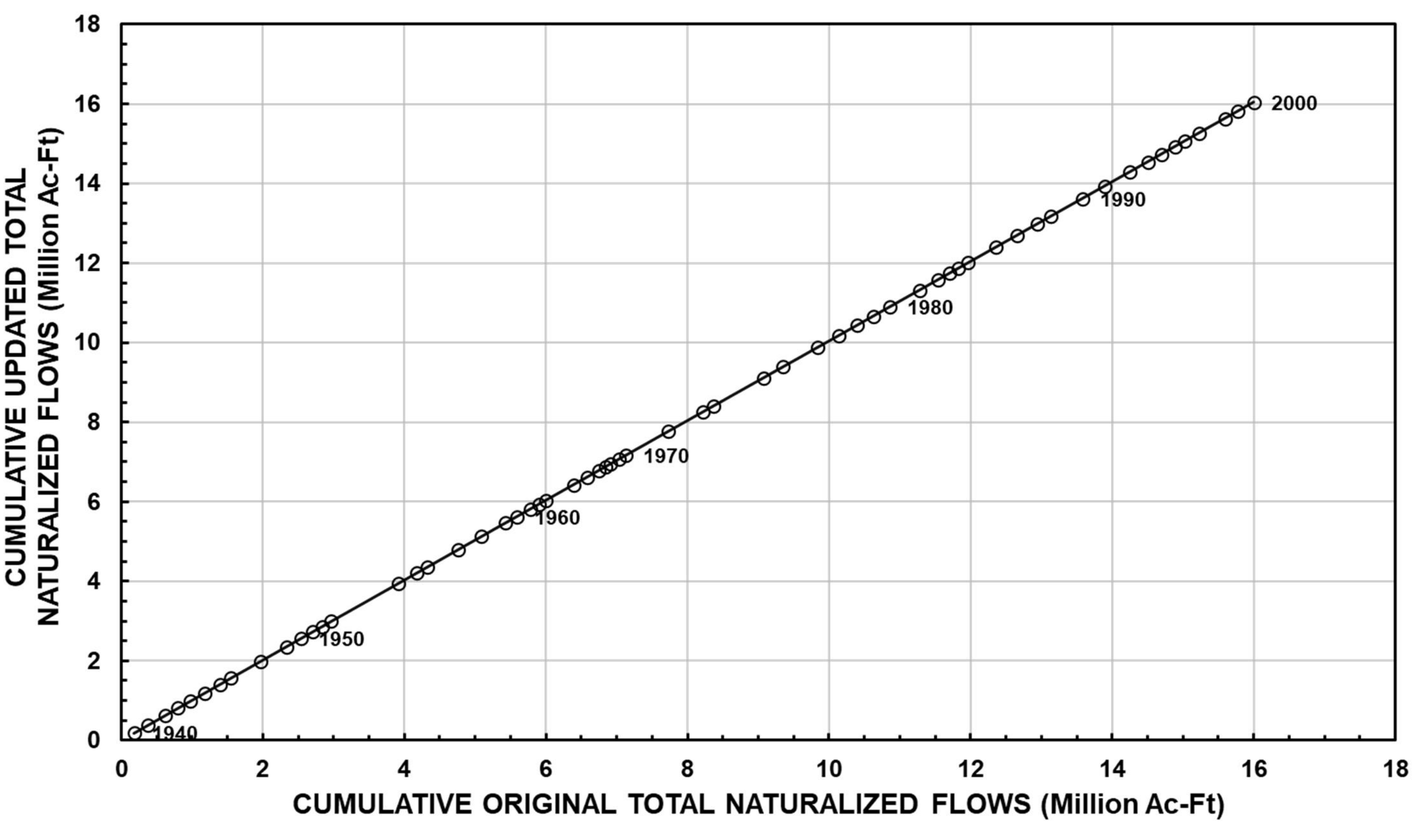


FIGURE D-5 DOUBLE-MASS CURVE FOR RIO GRANDE AT DEL RIO NATURALIZED FLOWS

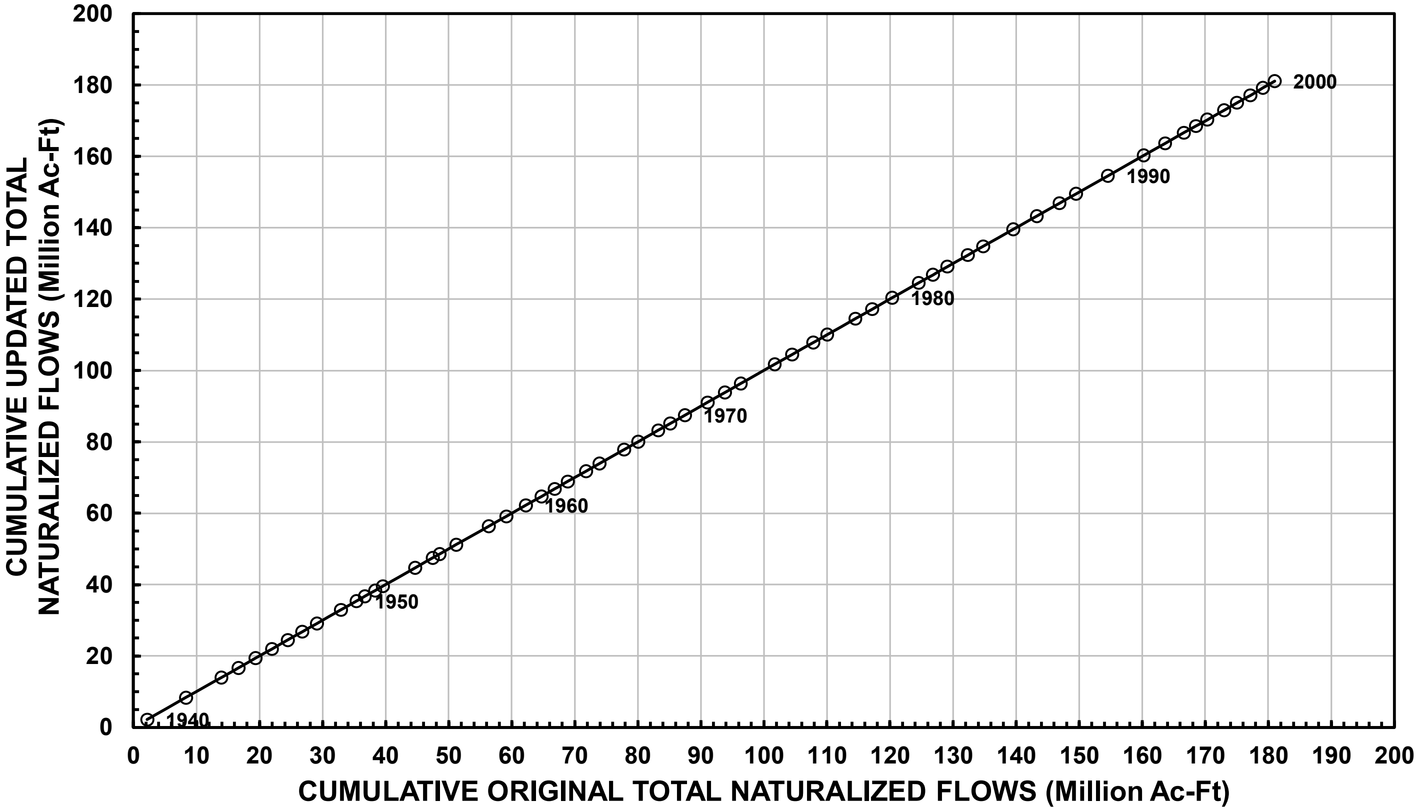


FIGURE D-6 DOUBLE-MASS CURVE FOR RIO GRANDE AT PIEGRAS NEGRAS NATURALIZED FLOWS

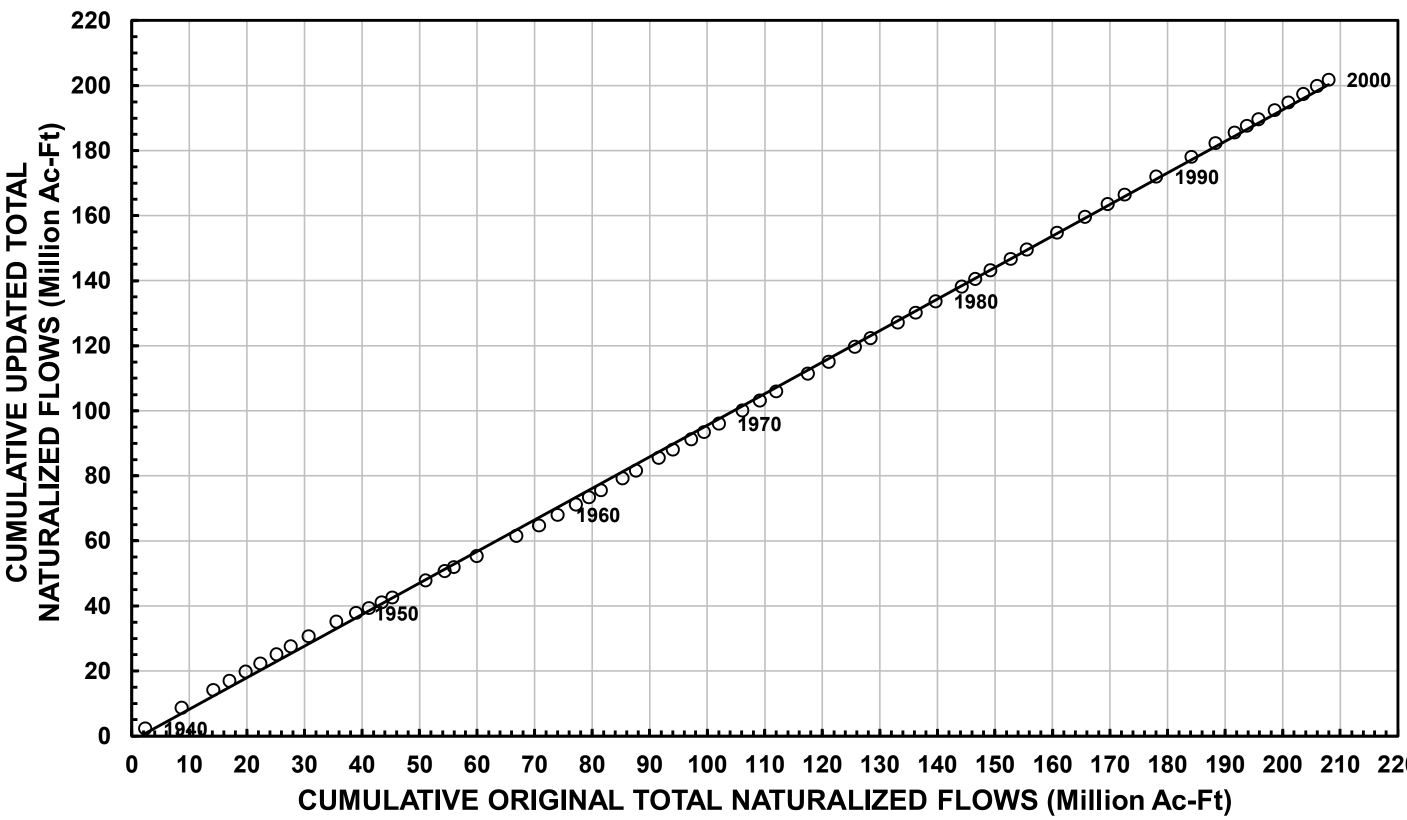


FIGURE D-7 DOUBLE-MASS CURVE FOR RIO GRANDE AT LAREDO NATURALIZED FLOWS

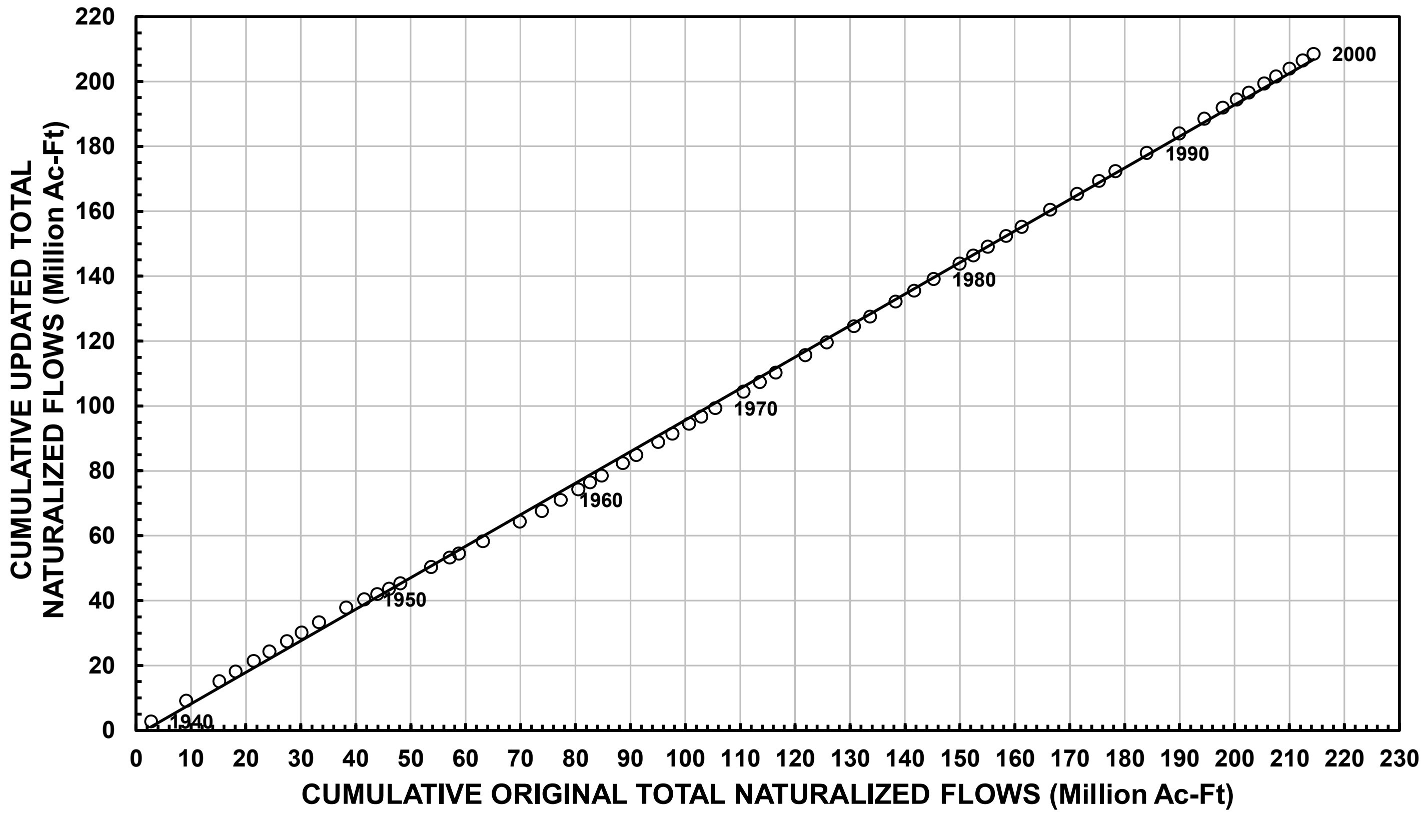


FIGURE D-8 DOUBLE-MASS CURVE FOR RIO GRANDE BELOW FALCON DAM NATURALIZED FLOWS

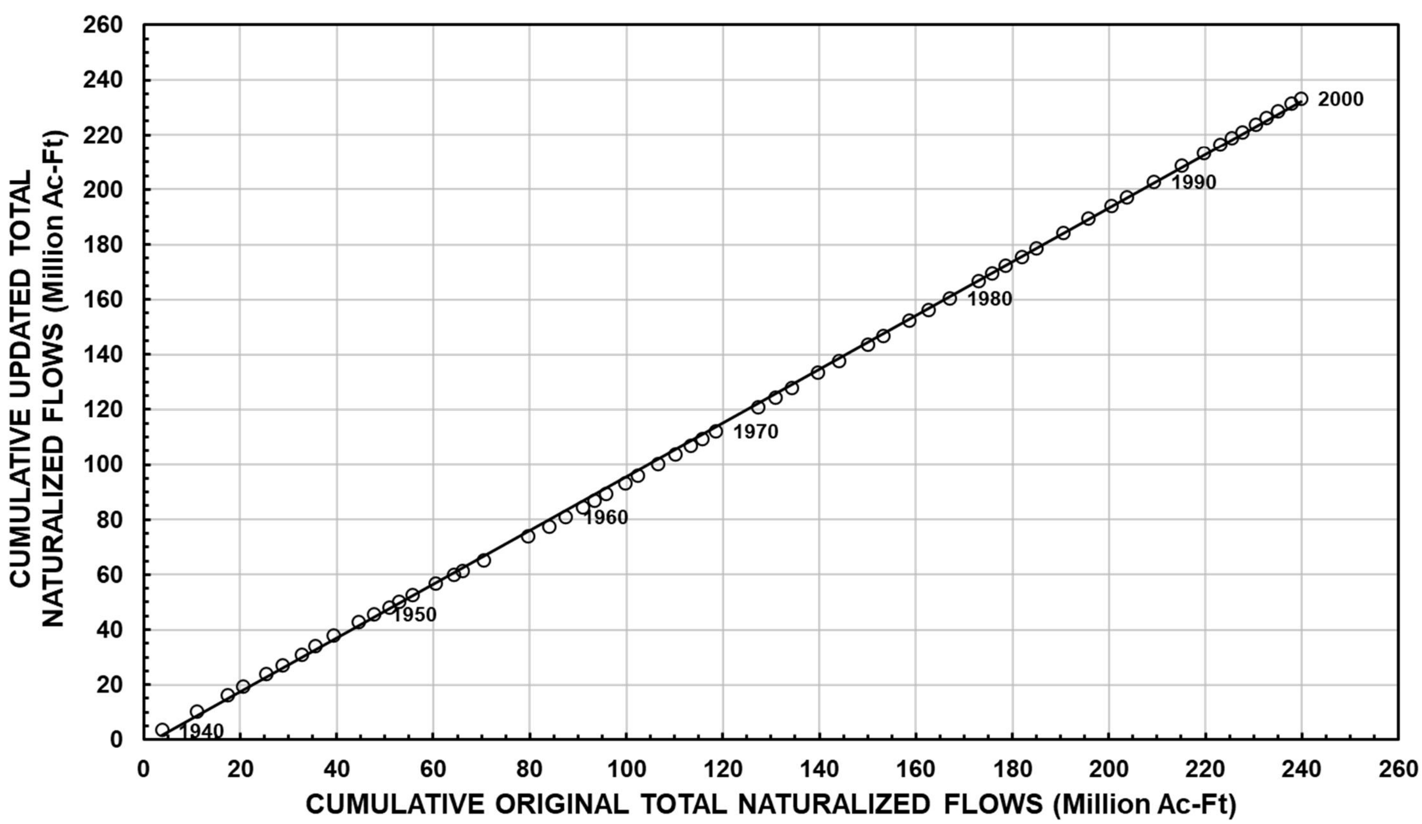


FIGURE D-9 DOUBLE-MASS CURVE FOR RIO GRANDE AT RIO GRANDE CITY NATURALIZED FLOWS

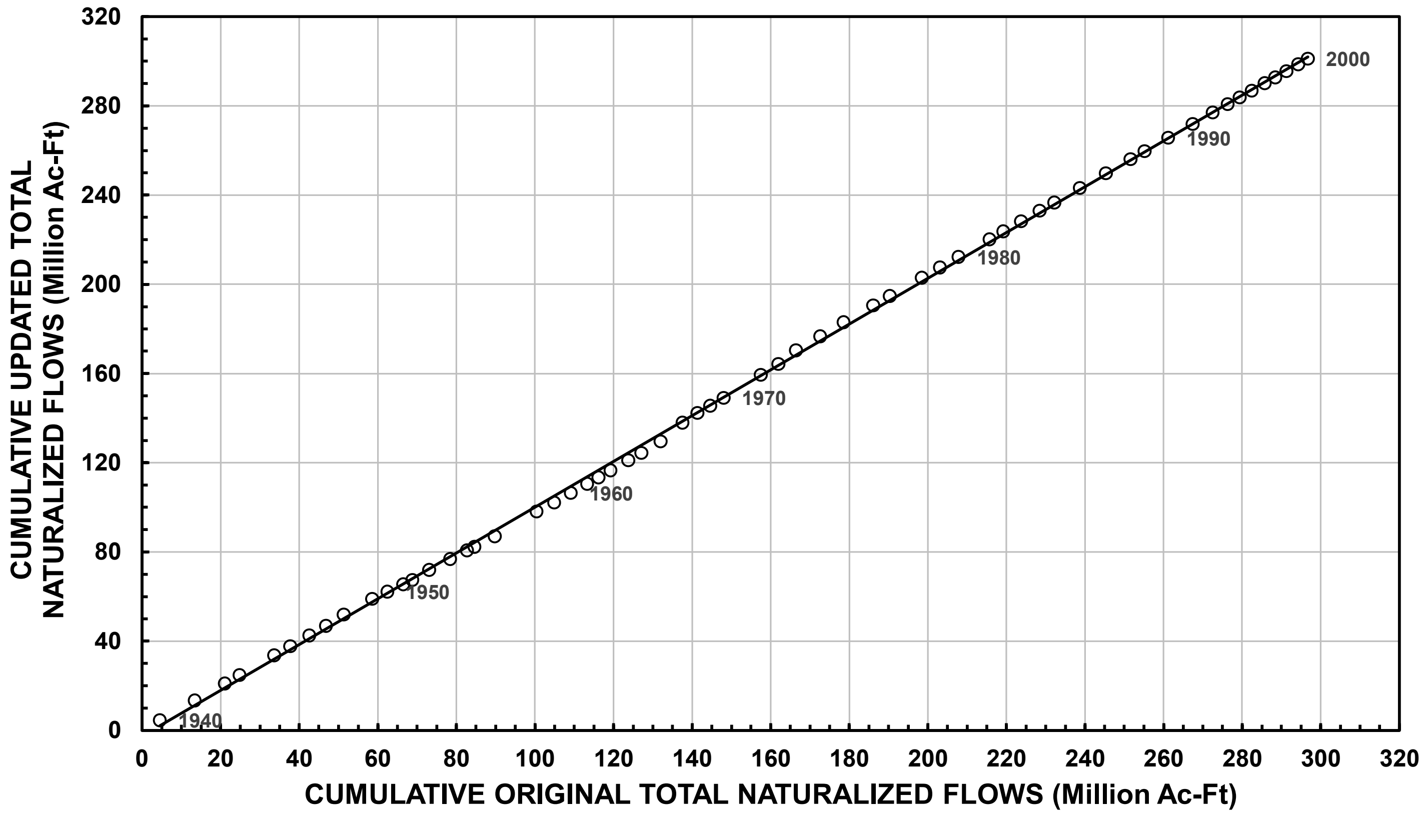
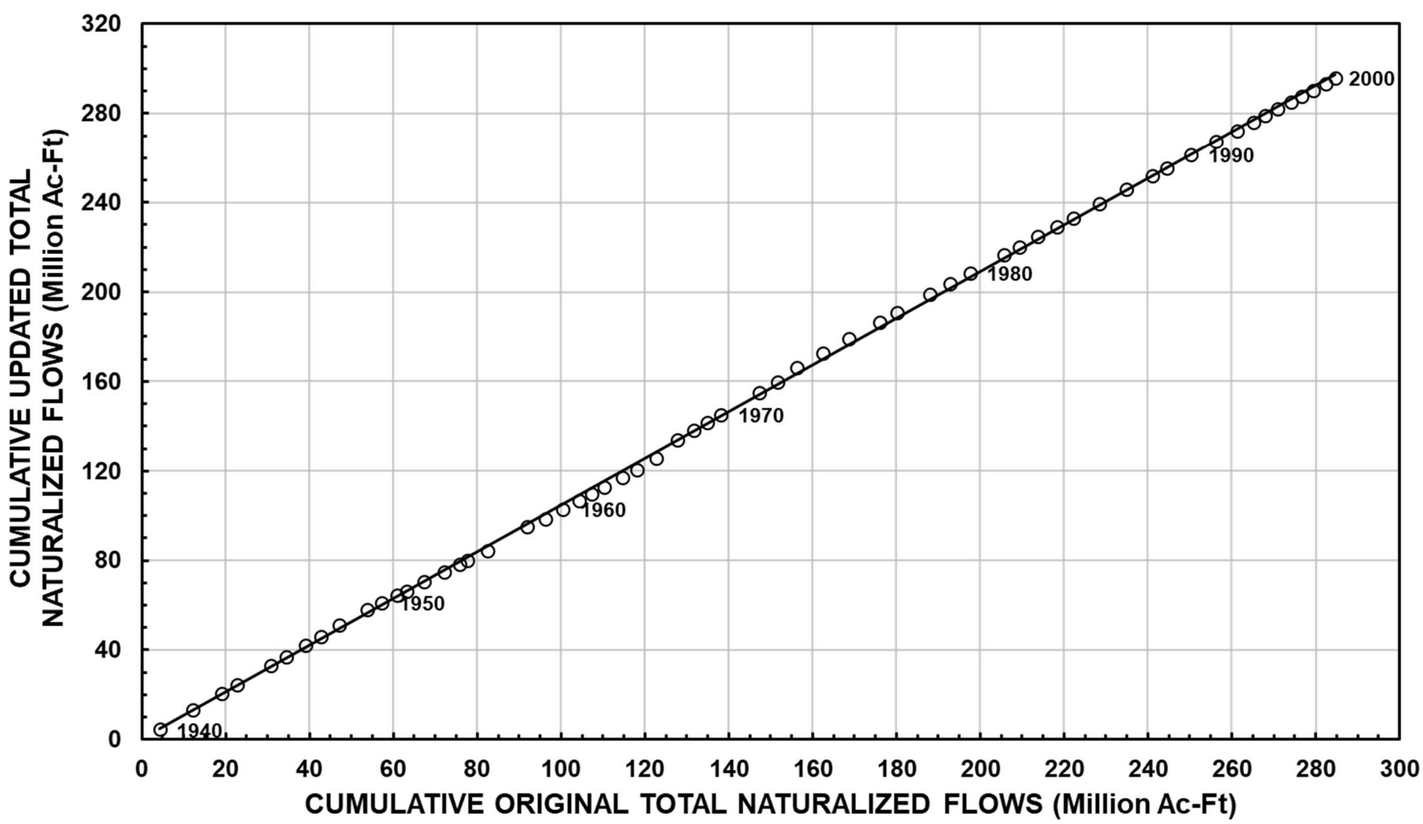


FIGURE D-10 DOUBLE-MASS CURVE FOR RIO GRANDE BELOW ANZALDUAS NATURALIZED FLOWS



APPENDIX E

GRAPHS COMPARING UPDATED WAM REGULATED FLOWS WITH EXISTING WAM REGULATED FLOWS

FIGURE E-1 REGULATED FLOWS FOR RIO GRANDE AT DEL RIO GAGE

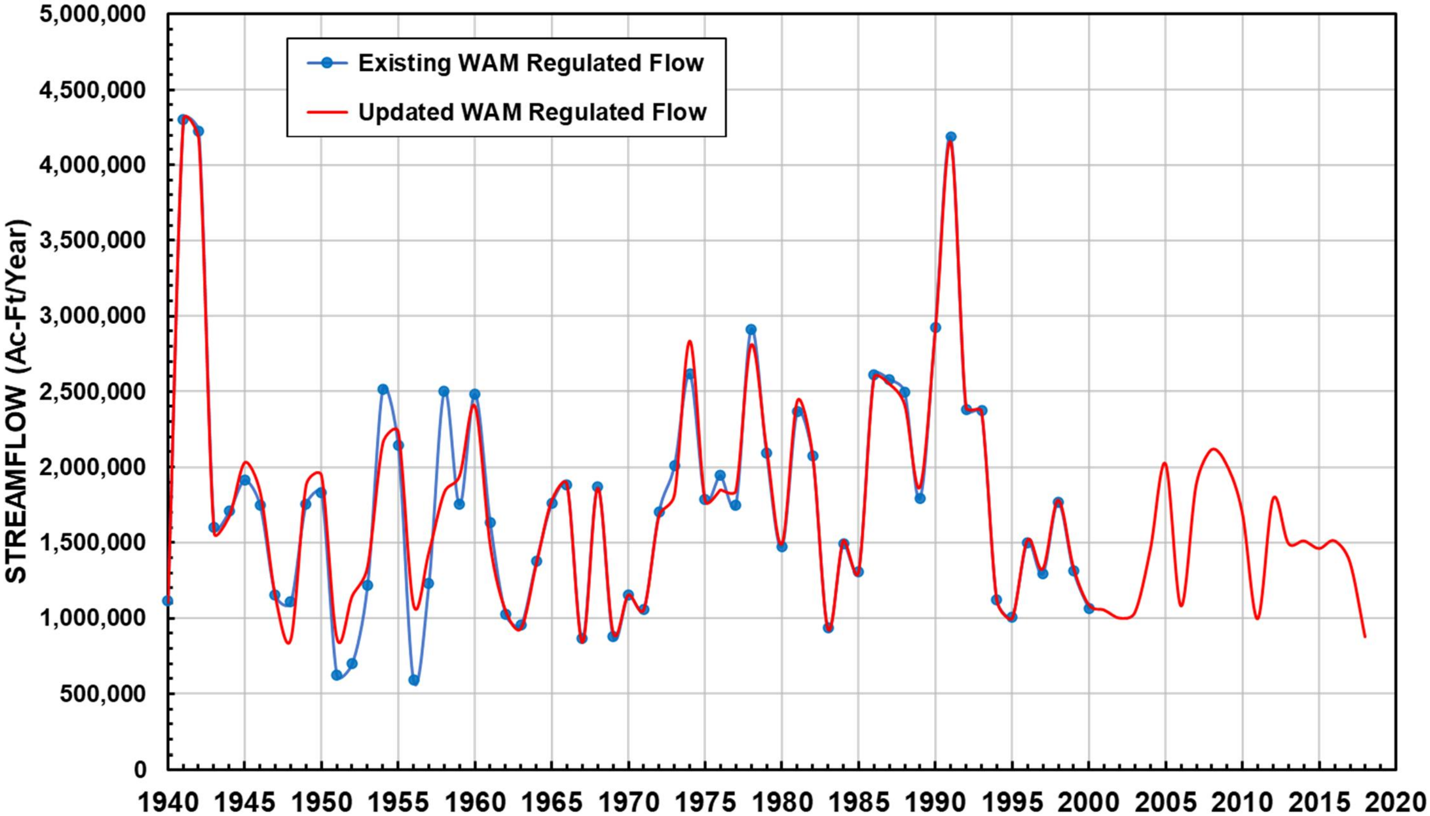


FIGURE E-2 REGULATED FLOWS FOR RIO GRANDE AT PIEGRAS NEGRAS GAGE

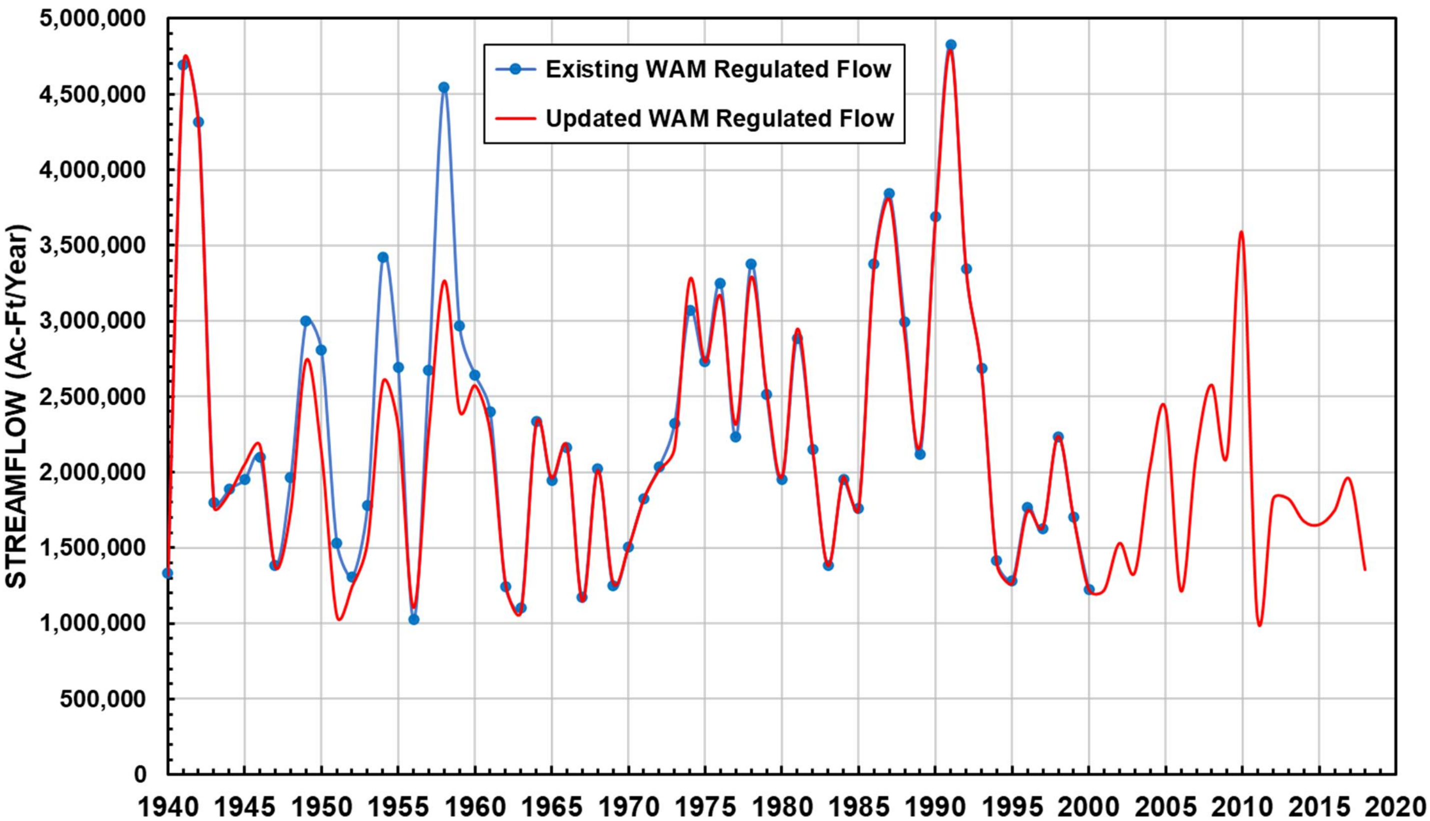


FIGURE E-3 REGULATED FLOWS FOR RIO GRANDE AT LAREDO

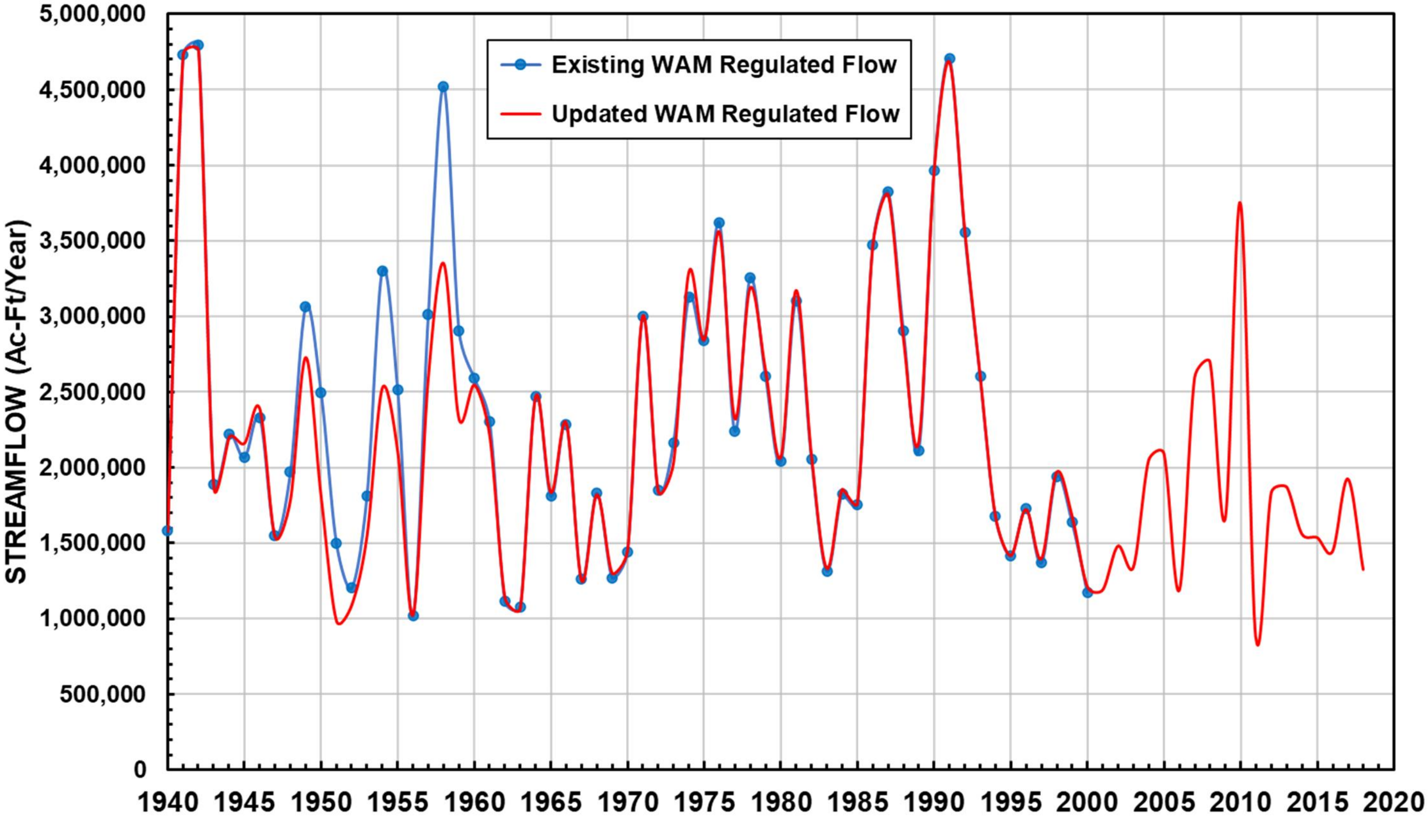


FIGURE E-4 REGULATED FLOWS FOR RIO GRANDE AT GAGE BELOW FALCON DAM

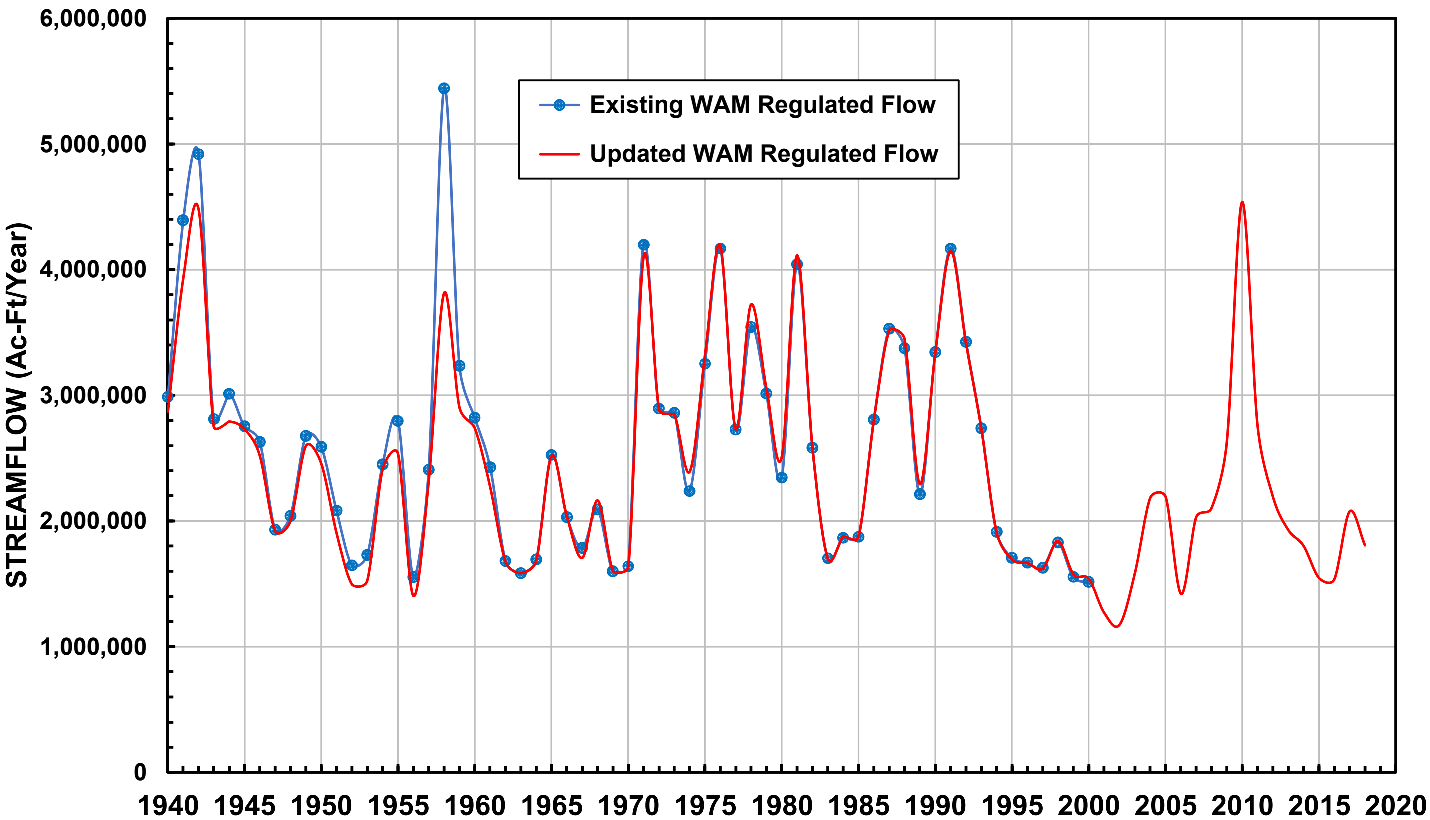


FIGURE E-5 REGULATED FLOWS FOR RIO GRANDE AT RIO GRANDE CITY GAGE

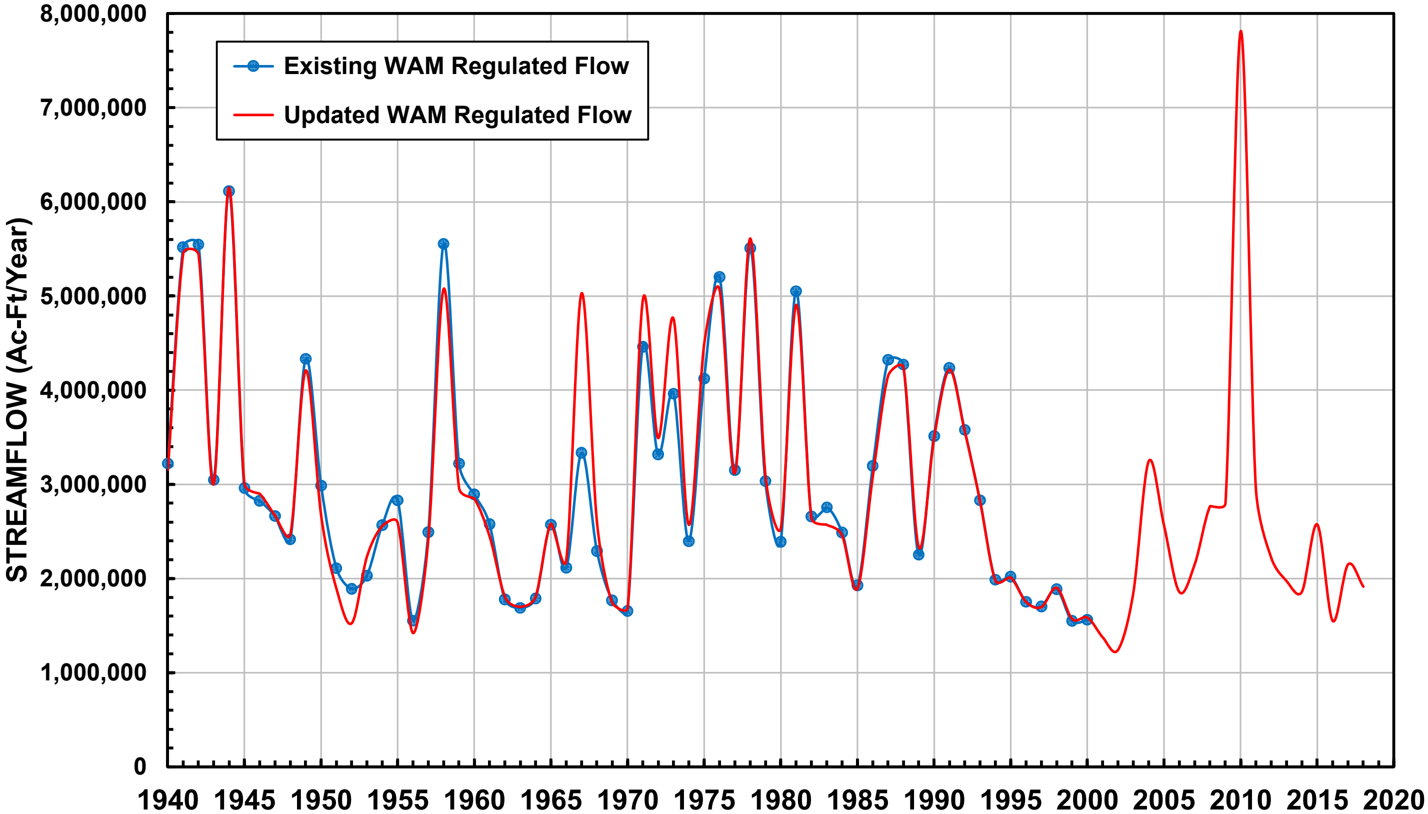
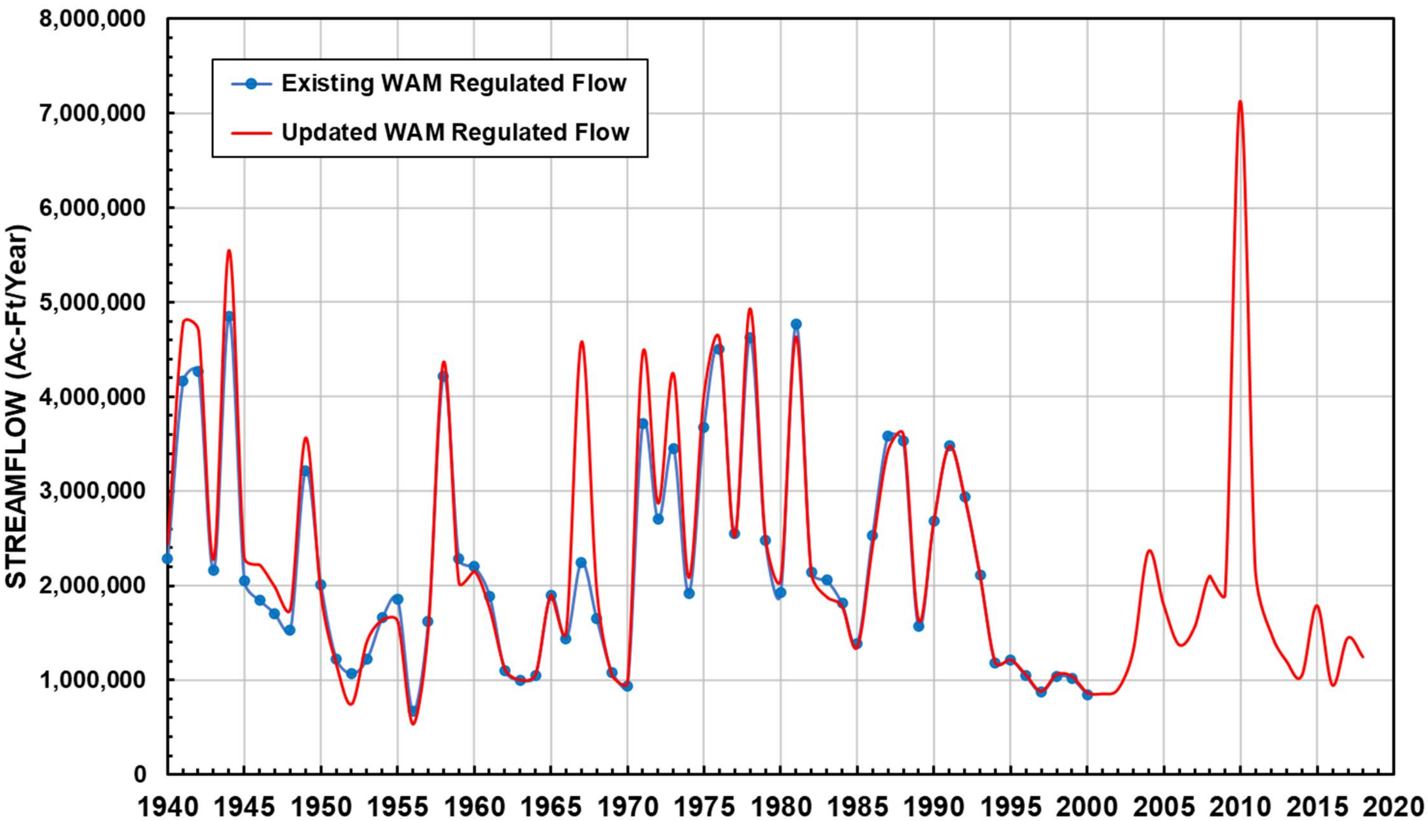


FIGURE E-6 REGULATED FLOWS FOR RIO GRANDE AT GAGE BELOW ANZALDUAS DAM



APPENDIX F

GRAPHS COMPARING UPDATED WAM RESERVOIR STORAGE WITH EXISTING WAM RESERVOIR STORAGE

FIGURE F-1 MONTHLY TOTAL STORAGE IN AMISTAD RESERVOIR

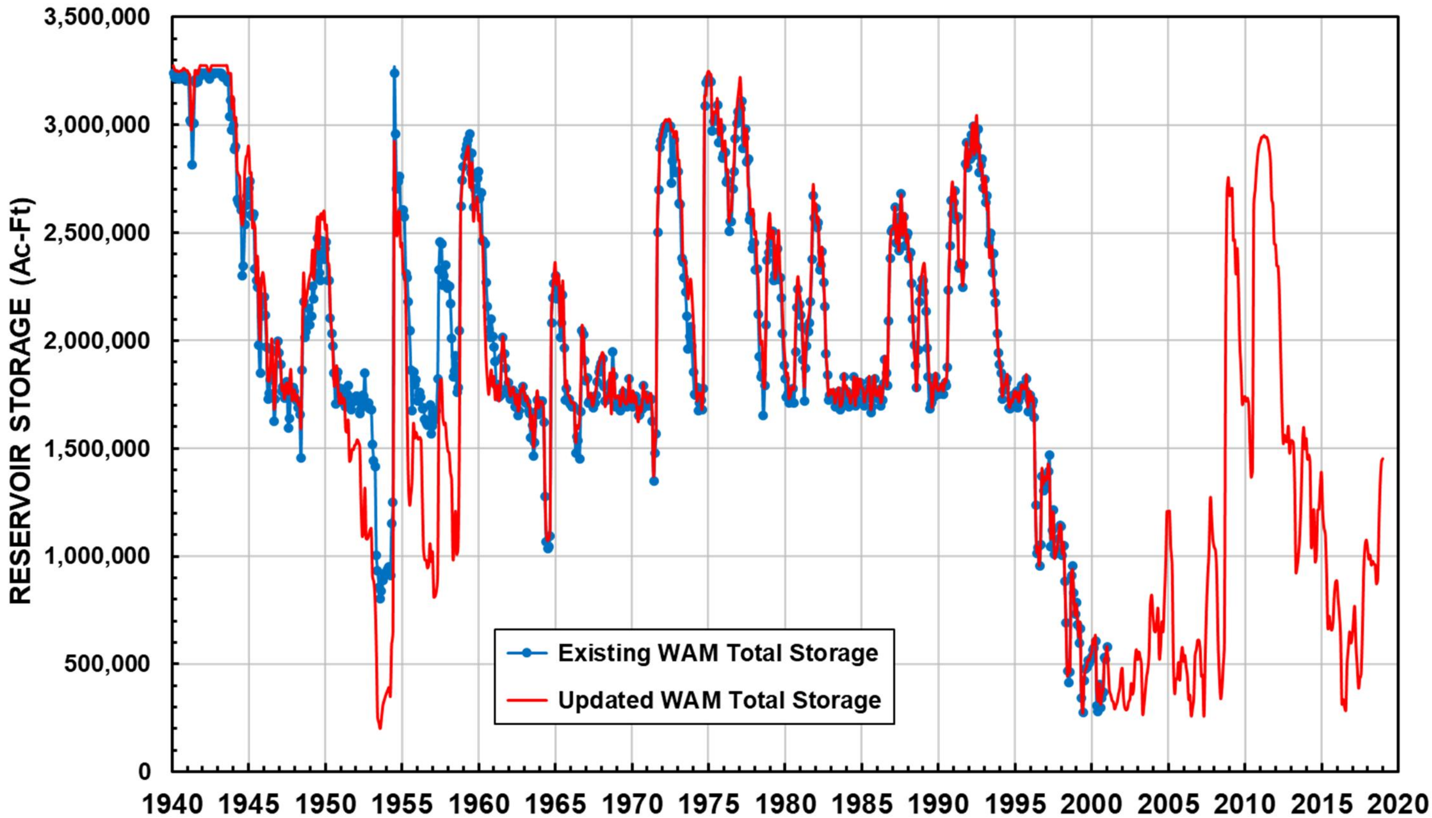
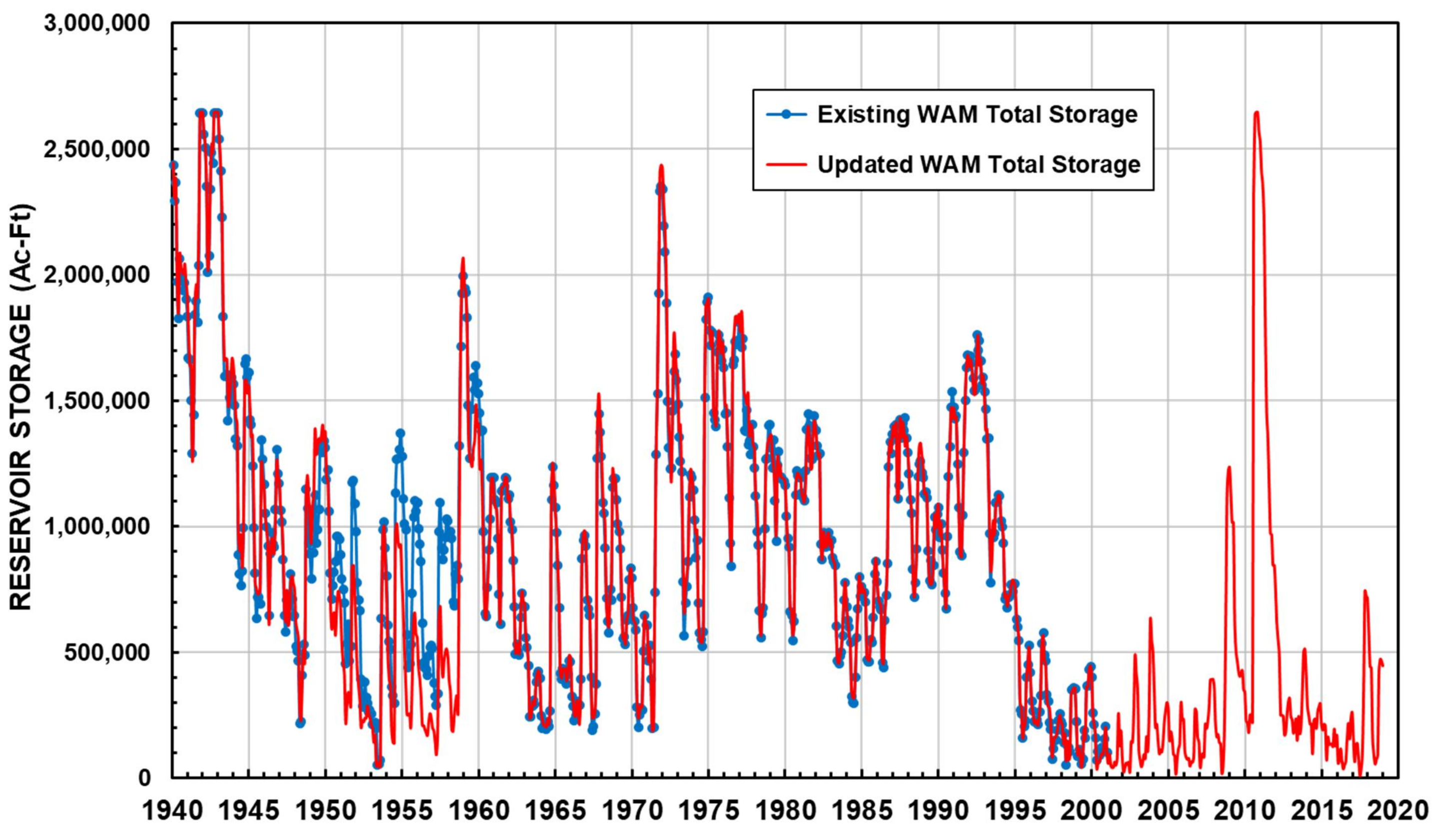


FIGURE F-2 MONTHLY TOTAL STORAGE IN FALCON RESERVOIR



APPENDIX G

FREESE AND NICHOLS INDEPENDENT PEER REVIEW MEMO

MEMORANDUM

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TO: Bob Brandes

CC:

FROM: Jon Albright and Tom Gooch

SUBJECT: Comments on Rio Grande WAM Naturalized Flow Report and Naturalized Flows

DATE: 7/15/2021

PROJECT: RJB20371 TCEQ Contract No. 582-20-13331

Tom Gooch and Jon Albright of Freese and Nichols (FNI) reviewed the *Draft Final Report Water Availability Model (WAM) Update Phase I - Rio Grande Basin* and the associated naturalized flow workbooks between July 1 and July 15, 2021. We found this work to be well organized and clearly presented, with only a few items that needed to be addressed. The approach was technically sound. This memorandum summarizes the major comments on the report and the naturalized flows.

Comments on Report

This section contains the major comments on the report text. These comments are also included as Word comments in the report file. Editorial comments were included as tracked changes in the document and are not discussed in this memorandum. These comments are optional suggestions meant to clarify or otherwise enhance the text or graphics.

Section 1.4 page 5 – discussion on lake evaporation should identify if the reported figures are based on gross, net or adjusted net evaporation.

Section 3.0 pages 11-13 - The discussion in this section does not say whether Mexico has met its treaty obligations historically 2001-2018, and therefore whether we are assuming Mexican compliance or non-compliance. Should we address that?

Section 3.2 page 15 first paragraph – it would be helpful if the five Mexican tributaries being discussed were named in the report.

Section 3.4 page 19 - We mention the one third of the inflow from certain Mexican tributaries allocated to the U.S. frequently without the 350,000 acre-feet per year minimum average. At some point, we should probably discuss whether Mexico has historically met the 350,000 acre-feet (and therefore whether Mexico is assumed to meet it in the WAM).

Section 4.2 last paragraph page 25 - It sounds like the springflows downstream of Amistad were not separated from other flows. We should say so specifically and say why, particularly for San Felipe Springs.

Section 4.3 – the Texas Water Development Board lists San Estaban Lake and Imperial Reservoir as major reservoirs in the Rio Grande Basin. Although we concur with leaving these out of the naturalization, the report should explain why they were excluded.

Section 4.4 page 29 – the discussion regarding use of the 2013 Region M estimated area-capacity data does not quite match what was done in the naturalized flow workbooks. In the naturalized flow workbooks, IBWC storage was used to calculate surface area using the 2013 area-capacity data, but it is not clear that IBWC used the 2013 Region M data.

Section 4.5 page 30 – clarify if evaporation refers to gross, net, or adjusted net evaporation.

Section 5.1 page 45 – explain why historical flows were used to fill in data for the nine months of missing data at the Fort Quitman gage, which were then subsequently naturalized. Typically longer periods of missing data are filled using naturalized flows.

Section 7.2 page 60 – The discussion regarding application of loss factors implies that all adjustments within a reach use half of the channel loss factors. For specific major adjustments located near the upstream or downstream end of the reach, we should set specific individual adjustment factors. (We note that the workbooks are set up to apply different loss factors. Some discussion here that this was applied should be added as a clarification.)

Section 9.3 page 88 – The discussion regarding reserves in Amistad/Falcon could use a little more explanation regarding what is meant by DMI reserve and fluctuating operating reserve. It might be useful to determine what the US firm yield would be if there were no reserve required for municipal. That would give a value more like firm yield as generally understood.

Comments on Naturalized Flow Workbooks

The comments in this section are the significant comments on the naturalized flow workbooks. A checklist with review notes has been previously provided to the Rio Grande WAM team.

Control point RG-EP. The monthly pattern used to distribute Rio Grande Project water to Mexico does not match historical diversions at the Acequia Madre. Specifically, there has never been any supply to Mexico from the project for October through February. It appears that the pattern is from the Rio Florido Irrigation District. This pattern is also used for Acequia Madre diversions in the WAM setup.

Control point RG-FQ. Diversions for water right 5493 are not included in the diversion summary. These diversions are very small.

Control point DR-PC. Fills from 10/49 to 12/59 should not have flows from DR-JU added (these are also filled flows).

General comment – some of the diversion data does not appear to be consistent with other data reported by the same diverter. Some of the IBWC's aggregated diversions are actually a very small negative number. These potential inconsistencies have been noted in the review checklist. Changing these data is a judgement call. Since most of these data are from the IBWC and have been through that agency's approval process, we may want to leave them as they are.