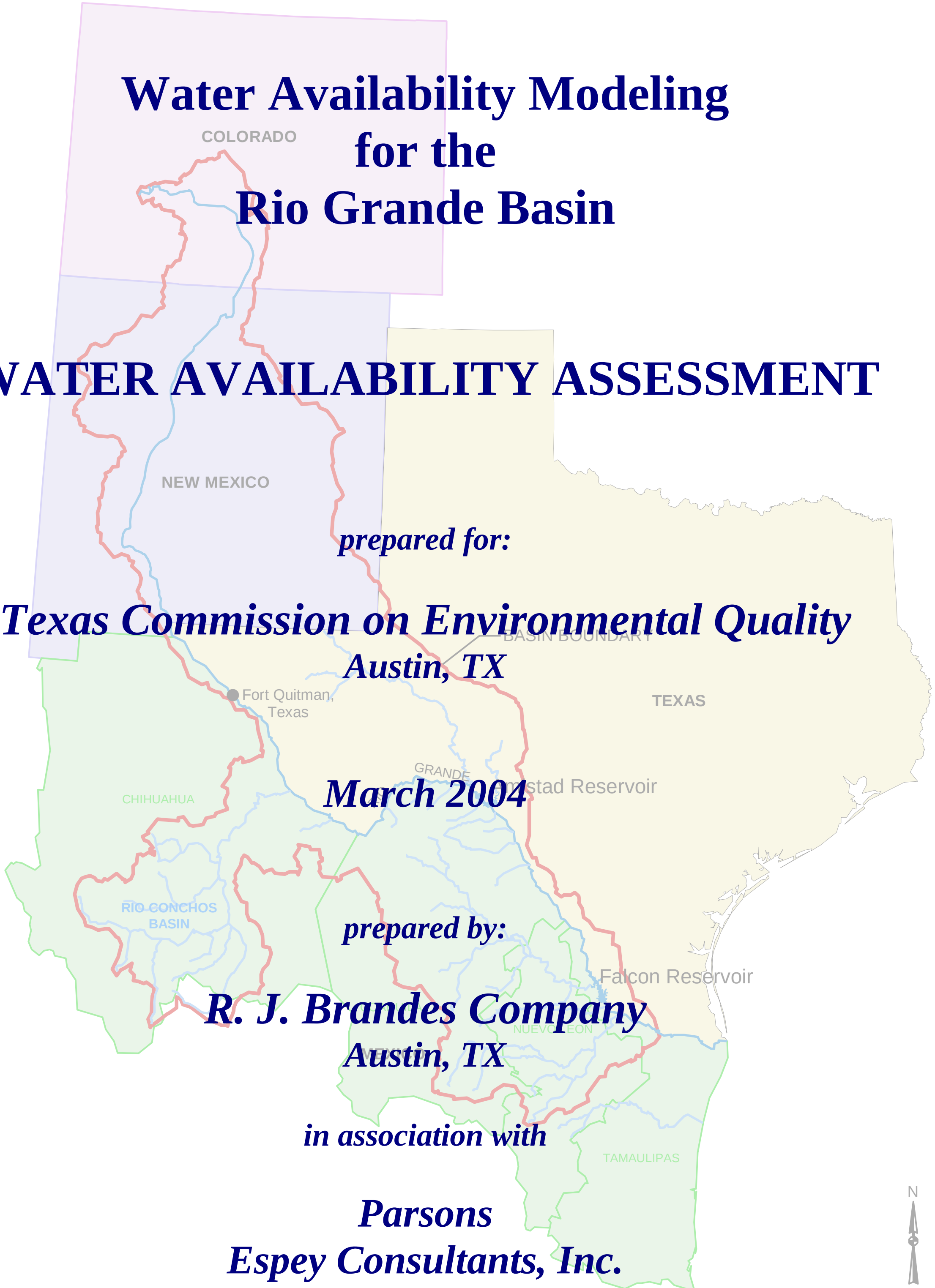
FINAL REPORT



Water Availability Modeling for the Rio Grande Basin

WATER AVAILABILITY ASSESSMENT

prepared for:

Texas Commission on Environmental Quality
Austin, TX

March 2004

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LIST OF ABBREVIATIONS

AC-FT	acre-feet
BANDAS	Banco Nacional de Datos de Aguas Superficiales (CNA database)
CLF	channel loss factor
CN	curve number
CNA	Comision Nacional del Agua
CRWR	University of Texas Center for Research in Water Resources
GIS	geographic information system
GRRB	Gerencia Regional del Río Bravo
IBT	inter-basin transfer
IBWC	International Boundary and Water Commission
MGD	million gallons per day
n/a	not applicable
NRCS	Natural Resources Conservation Service
RJBCO	R. J. Brandes Company
SB1	Senate Bill 1
SQ MI	square miles
TCEQ	Texas Commission on Environmental Quality
TPWD	Texas Parks and Wildlife Department
TWDB	Texas Water Development Board
USGS	U. S. Geological Survey
WAM	Water Availability Model
WRAP	Water Rights Analysis Package
WRDETAIL	TCEQ water rights database

EXECUTIVE SUMMARY

STUDY OBJECTIVES

This document presents the results of the Rio Grande Water Availability Modeling study (WAM). The objective of this effort has been to meet the requirements of Senate Bill 1 (SB1) of the 75th Texas Legislature and attendant House Bill 76 of the 76th Texas Legislature regarding the development of a new Rio Grande Basin simulation model for determining available water for individual water rights in accordance with Chapter 11, Water Rights, of the Texas Water Code. This model is capable of determining water availability in the basin under a range of policy and planning scenarios in accordance with the Prior Appropriation Doctrine and the Texas Commission on Environmental Quality (TCEQ) Rio Grande operating rules.

In accordance with the provisions of House Bill 76, the following specific information is to be developed by the TCEQ through the water availability analysis:

1. For all holders of existing permits, certified filings, and certificates of adjudication, the projected amount of water that would be available during extended droughts.

2. The projected amount of water that would be available if cancellation procedures were instigated under Subchapter E, Chapter 11 of the Texas Water Code.

3. The potential impact of reusing municipal and industrial effluent on existing water rights, instream uses, and freshwater inflows to bays and estuaries.

The basic procedure applied in analyzing water availability in a particular river basin involves developing naturalized streamflows throughout the basin from historical hydrologic and other data, then simulating on a monthly basis the ability of individual water rights to meet their authorized diversions or storage quantities in accordance with the Prior Appropriation Doctrine and, for the Rio Grande Basin, the TCEQ Rio Grande operating rules. For the Rio Grande WAM, the naturalized streamflow database that has been developed covers the 61-year period from January 1940 through December 2000. The simulations are performed using the Water Rights Analysis Package computer program (referred to as "WRAP") that was developed by Dr. Ralph A. Wurbs of Texas A&M University. The February 2004 version of WRAP has been used in developing the Rio Grande WAM.

RIO GRANDE BASIN DESCRIPTION

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 area is non-contributing, and the contributing drainage area is approximately 176,000 square miles, which is roughly split between the United States and Mexico. This report focuses on the portions of the basin in Texas and Mexico. The contributing drainage area within Texas is about 40,000 square miles, and within Mexico is about 87,000 square miles. The Rio Grande is 1,896 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 El Paso to the river’s mouth at the Gulf of Mexico near Brownsville. The basin comprises all or part of 31 counties.

The Rio Grande system through 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 the basin, eight in Texas and 18 in Mexico, including associated off-channel reservoirs. Of the eight in Texas, three are on the mainstem, four are on major tributaries, and one is off-channel. Major reservoirs are defined as those having a conservation storage capacity of 5,000 acre-feet or greater.

The climate varies widely throughout the Rio Grande Basin. The western portion of the basin in Texas is desert, with an annual precipitation of approximately 8 to 16 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 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 climactic 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 10,000-foot Sierra Madre Oriental mountain range 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 to 32 inches. However, lower elevations are desert with an annual precipitation of 8 to 12 inches.

WATER AVAILABILITY INFORMATION

There are 962 water rights in the Texas portion of the Rio Grande Basin as contained in the TCEQ water rights data base, WRDETAIL, as of March 7, 2003, with these water rights authorizing a total of 1,449 different diversions and/or impoundments. The most junior water right included in the WAM has priority date of June 9, 2000. The total amount of authorized diversions for these water rights is approximately five million acre-feet per year. As indicated in Table ES-1, approximately 12 percent of the total authorized diversion amount is for municipal supplies, 87 percent is for irrigation, and less than one percent is for mining, recreation, and other uses.

TABLE ES-1

WATER RIGHTS BY USE CATEGORY

USE CATEGORY	NUMBER OF RIGHTS BY USE TYPE	AUTHORIZED DIVERSION acre-feet/yr	PERCENT OF TOTAL*
TEXAS			
Municipal	142	366,414	12.4%
Irrigation	1,241	2,574,781	87.3%
Mining	36	7,598	0.3%
Hydroelectric	2	2,100,000	--
Recreation	8	72	0.0%
Other	20	50	0.0%
Texas Total	1,449**	2,984,915*	100.0%
MEXICO			
Municipal	12	378,480	12.3%
Irrigation	20	2,707,606	87.7%
Mexico Total	34	3,086,086	100.0%
GRAND TOTAL	1,483	6,071,001*	--

* Does not include hydroelectric. Hydropower may only be generated from spills or releases made for other uses.

** Many rights have multiple use categories. Total number of individual water rights is 962.

There are 32 water commitments, or “concessions” (as they have been referred to by Mexican officials), in the Mexico portion of the Rio Grande Basin that have been included in the WAM. The total amount of diversions for these concessions is approximately 3.1 million acre-feet per year. The distribution between municipal and irrigation uses is similar to Texas.

All municipal and industrial wastewater discharges (return flows) within the contributing drainage area of the Rio Grande Basin with a permitted flow greater than or equal to 0.5 million gallons per day (MGD), or approximately 560 acre-feet per year, were considered significant and were accounted for in the streamflow naturalization process. There are 31 such permitted dischargers in Texas, but only 15 of them actually discharge. There are 14 known significant wastewater discharges in Mexico.

HYDROLOGIC DATA REFINEMENT

All of the known U.S. Geological Survey (USGS) and International Boundary and Water Commission (IBWC) streamflow gages, both existing and discontinued, for which there are historical records within the Rio Grande Basin have been identified through research of USGS and IBWC reports, data from Mexico, and other documents. Forty-three gages (23 in Texas and 20 in Mexico) were selected as primary control points in the WAM, for which naturalized streamflows were developed.

Naturalized streamflows represent historical streamflow conditions without the influence of man's historical activities as they relate to water rights and water use. In essence, naturalized streamflows exclude the effects of historical diversions, return flows, and reservoir storage and evaporation. For the Rio Grande WAM, the naturalized streamflow database that has been developed covers the 61-year period from January 1940 through December 2000.

The difficulty in the streamflow naturalization process, of course, has been the development of reliable data regarding historical diversions, return flows, and reservoir storage and evaporation for the entire 1940-2000 period, particularly in Mexico. While the data that have been developed for this purpose very likely do not fully and accurately reflect actual historical diversions, return flows, and reservoir storage and evaporation, they are believed to represent reasonable estimates of these quantities that probably could not be significantly refined or improved upon without the availability of additional data records. Such records are not known to exist. The data that have been developed in this study for purposes of the streamflow naturalization process are believed to be adequate and satisfactory for purposes of developing and operating a meaningful WAM for the Rio Grande Basin.

Since the upper end of the Rio Grande WAM has been established essentially at the New Mexico stateline, an important aspect of the streamflow naturalization process dealt with determining the appropriate flows to be specified in the WAM for both the Rio Grande and the Pecos River at the New Mexico stateline. River flows delivered to Texas at both of these locations are subject to the provisions of existing compacts between the states. To derive the appropriate naturalized flows for the WAM, adjustments have been made to the historical streamflow records for the Rio Grande at El Paso to reflect the impact of the Rio Grande Compact, and for the Pecos River at Red Bluff, New Mexico to reflect the impact of the Pecos River Compact.

In Texas, monthly values of historical average reservoir evaporation amounts were obtained from the Texas Water Development Board (TWDB) based on available evaporation data provided at the center of each one-degree quadrangle covering the basin. In Mexico, evaporation and precipitation data are collected daily at each reservoir. These values were used directly.

Historical streamflow records for many of the gages located throughout the Rio Grande Basin are not available for the entire 1940-2000 period for which naturalized flows have been developed. Records from other gages have been used to fill in missing records. These streamflow fill-in procedures involved the development of correlations of flows between gages or the application of appropriate flow or drainage area ratios.

Naturalized streamflows developed for the primary control points were distributed to the other (ungaged, or secondary) control points throughout the basin using procedures provided in the WRAP program. The basic method used for distributing the naturalized flows from gaged to ungaged control points was by drainage area ratios, as directed by TCEQ.

WATER AVAILABILITY MODEL DEVELOPMENT

The computer program or code used to develop the water availability model (WAM) of the Rio Grande Basin is referred to as "WRAP." The basic WRAP program is described in the report titled "Water Rights Analysis Package (WRAP) Users and Reference Manual," published by the Texas Water Resources Institute at Texas A&M University, revised December 2003, by Ralph A. Wurbs (Wurbs, 2003). The version of the WRAP program dated February 2004 has been used for the Rio Grande WAM (Wurbs, 2004).

International WAM Structure

Because all of the Rio Grande Basin below the New Mexico stateline, including the Mexican portion of the basin, is included in the Rio Grande WAM, it has been necessary to incorporate into the WAM the essential provisions of existing international agreements between the United States and Mexico regarding the ownership of the water flowing in the Rio Grande. These agreements include the 1944 Treaty, which addresses the ownership of water downstream of Fort Quitman, and the 1906 Convention, which divides the water between the U.S. and Mexico above Fort Quitman.

To properly represent these agreements, it has been necessary to account for water owned by each of the two countries separately in the WAM. To facilitate this capability, as noted in the "Memo Regarding Special Conditions and Overall Model Construction" contained in Appendix I, the Rio Grande in the WAM is structured as two interconnected, parallel watercourses, one for U.S. flows and one for Mexican flows. With this structure, all of the tributaries of the Rio Grande in Texas are linked to the U.S. or Texas segment of the river, and all of the tributaries of the Rio Grande in Mexico are linked to the Mexican segment of the river.

The two different river segments of the WAM function essentially as separate models in that the water availability calculations for each country are performed separately. The relative order in which certain types of water use activities are simulated between the two model segments, however, is particularly important with regard to assuring that the proper sequencing of events occurs in accordance with the provisions of the international water agreements. This sequence of calculations is described in the memo in Appendix I.

Water Right Priorities

The Rio Grande Basin is unique among the basins in Texas as regards water rights priorities. Almost all of the prior appropriation water rights in the Rio Grande Basin are in the upper basin, i.e. upstream of Amistad Reservoir, or on tributaries. Representation of these water rights in the data input file for the WAM is relatively straightforward. Water rights on the middle and lower segments of the Rio Grande are dependent primarily on water stored in Amistad and Falcon Reservoirs. These water rights are not subject to the Prior Appropriation Doctrine and have a unique priority system based on type-of-use. The memorandum contained in Appendix I explains how these water rights have been modeled with respect to assigning priorities in the WAM.

Mexico does not have a water right system based on the Prior Appropriation Doctrine, but apparently does have some established levels of annual use that serve as targets for the allocation of annual supplies of water either stored in Mexico's reservoirs or anticipated to be available as a result of expected weather conditions and associated streamflows. For purposes of the WAM, the assumed general priority system that has been applied for satisfying demands and reservoir storage is based on river order (upstream to downstream) and type of use (municipal first, then irrigation).

The order in which the Mexican concessions were modeled in the WAM also reflects the procedure required for proper consideration of the provisions of the international agreements between the United States and Mexico. This is discussed in the memorandum of special conditions and overall model construction presented in Appendix I.

Amistad-Falcon Storage Accounting

Those Texas water rights that are located on the Rio Grande and are dependent on Amistad and Falcon Reservoirs for their primary water supply are subject to special rules adopted by the TCEQ and administered by the Rio Grande Watermaster. Relevant portions of these rules have been extracted from the Texas Administrative Code, Chapter 303, and included in Appendix O for reference purposes. In effect, these rules allocate the U.S. water stored in the Amistad-Falcon reservoir system among the different water rights on the middle and lower segments of the Rio Grande according to type of use, and they establish an associated system of monthly accounting for the water stored in the reservoirs. This accounting system provides reserves for domestic, municipal and industrial water users and reservoir operations, establishes individual storage accounts for all lower and middle Rio Grande irrigation and mining water rights, and provides a means for allocating available reservoir inflows to the irrigation and mining water rights on a monthly basis.

The fundamental features of the TCEQ's Rio Grande operating rules have been incorporated into the WAM in order to properly reflect the allocation of water stored in the U.S. pools of Amistad and Falcon Reservoirs. Because all of the municipal and industrial water rights are provided stored water from the reservoir system essentially with the same priority, there is no priority ranking among these rights.

WATER AVAILABILITY IN THE RIO GRANDE BASIN

Description of Scenarios Modeled

The TCEQ has defined eight specific scenarios that have been evaluated with respect to water availability in the Rio Grande Basin. These various scenarios are referred to as “Runs.” The output from these runs is intended to address directly the requirements for water availability information specified in House Bill 76 as described in the Study Objectives of this Executive Summary. Basically, the eight different runs are characterized by different combinations of input conditions for: (1) the diversion amounts specified for water rights; (2) the area-capacity relationships specified for reservoirs; (3) the quantities specified for return flows corresponding to assumed levels of reuse; and (4) diversions and/or storage associated with term water rights permits. The various combinations of these parameters for each of the eight runs are indicated in the matrix in Table ES-2.

As set forth in the “WAM Resolved Technical Issues No. 10 – Model Runs” document dated October 22, 1999, the firm annual yield for all major reservoirs in the Rio Grande Basin has also been determined using the WAM. The firm yield has been determined only for those reservoirs that experienced shortages in the Run 3 simulation. Diversions for the reservoirs exhibiting shortages were reduced until no shortages were experienced (the minimum volume remaining at the critical period was virtually zero), while maintaining all other water rights at their authorized amounts.

Water Availability Results

The simulated results from the WRAP model for the various input conditions corresponding to the eight runs provide an indication of water availability for each water right in the Rio Grande Basin. The basic results from the different runs with regard to water availability consist of monthly values of simulated diversions, simulated end-of-month reservoir storage, and reliability statistics for each of the water rights in the basin. Also of importance are the simulated quantities of monthly unappropriated streamflows and monthly regulated streamflows at various locations throughout the Rio Grande Basin. The unappropriated streamflows, of course, provide an indication of the water available for future water resource development projects, while the

TABLE ES-2

MATRIX DESCRIBING DIFFERENT WATER AVAILABILITY MODEL RUNS

PARAMETERS VARIED BY WAM RUN	RUN 1	RUN 2	RUN 3	RUN 4	RUN 5	RUN 6	RUN 7	RUN 8
AUTHORIZED DIVERSION AMOUNTS (ALL WATER RIGHTS)	X	X	X					
AUTHORIZED DIVERSION AMOUNTS WITH CANCELLATION				X		X		
MAXIMUM 10-YEAR DIVERSION AMOUNTS					X		X	X
AUTHORIZED RESERVOIR AREA-CAPACITY RELATIONSHIPS	X	X	X	X	X	X	X	
YEAR-2000 RESERVOIR AREA-CAPACITY RELATIONSHIPS								X
ASSUMED RETURN FLOWS WITH NO REUSE	X			X	X			X
ASSUMED RETURN FLOWS WITH 50% REUSE		X						
ASSUMED RETURN FLOWS WITH 100% REUSE (NO RETURN FLOWS)			X			X	X	
WITHOUT TERM WATER RIGHTS	X	X	X	X	X	X	X	
WITH TERM WATER RIGHTS								X

regulated streamflows reflect the actual levels of flow that can be expected in the streams under the various scenarios of diversions, reservoir storage, return flows, and term permits.

The results indicate that very little unappropriated water is available in the Rio Grande Basin. A summary of the results from the eight runs with regard to the amount and reliability of simulated diversions is presented in tables in Appendix P. Regulated and unappropriated flows at the primary control points are summarized in Appendices T, U, and V. The effects of the various assumptions associated with the different runs can generally be quantified by evaluating the average reliabilities of different groups of water rights. This type of information is provided in Table ES-3 for the eight runs and several different categories of water rights.

TABLE ES-3
SUMMARY OF AVERAGE VOLUME RELIABILITIES FOR WATER RIGHTS GROUPS

Run No.	Average Period Reliabilities, %			
	Prior Appropriation Water Rights	Amistad-Falcon Municipal Water Rights	Amistad-Falcon Class A Irrig. Water Rights	Amistad-Falcon Class B Irrig. Water Rights
1	63.4	100.0	70.4	45.1
2	63.4	100.0	69.3	44.5
3	63.4	100.0	68.2	43.8
4	63.9	100.0	70.7	45.3
5	71.5	100.0	91.5	73.2
6	63.9	100.0	68.6	44.1
7	71.5	100.0	91.5	73.2
8	67.0	100.0	91.2	73.0

Results of the reuse runs (Runs 1, 2 and 3) show that reuse of treated effluent has very little impact on water availability in the Rio Grande Basin. There is comparatively little water returned in the Rio Grande.

Because there is very little unappropriated water available throughout the Rio Grande Basin and because the only water rights subject to cancellation are some of the prior appropriation rights upstream of Amistad Reservoir and on some of the tributaries, the effects of cancellation on unappropriated water are not noticeable (Run 4 v. Run 1 and Run 6 v. Run 3).

The most significant factor affecting water availability in the basin is the use of maximum 10-year diversion amounts in Runs 5, 7, and 8 as opposed to fully authorized diversion amounts. Some increases in available water and reliability result from this assumption, because many water rights are under-utilized, or did not have sufficient water available during the 1991-2000 time period because of drought conditions. The inclusion of term permits in Run 8 has no impact because there are no term permits in the basin.

The firm annual yields have been determined only for those reservoirs that experienced shortages in the Run 3 simulation. Almost all reservoirs have demands that exceed the firm yield of the reservoir or reservoir system. The firm yield of the U.S. portion of the Amistad-Falcon reservoir system has been determined to be 1,055,250 acre-feet/year, based on the current TCEQ operating rules. The critical drought period for this yield is the current drought of record (1992-2000).

Factors Affecting Water Availability and Modeling Results

The single issue of most concern with regard to the water availability analyses performed for the Rio Grande Basin and the results from the WRAP model relates to the accuracy of the naturalized streamflows that have been used in the calculations. This includes inaccuracies in the USGS/IBWC streamflow gaging data, reservoir elevation or storage records and area-capacity data, estimation of drainage areas using GIS procedures, locations of control points on smaller tributaries, reported and estimated diversions and return flows, and channel losses. In addition, the quality of data obtained from sources in Mexico is poor in comparison to data obtained from other sources.

Another concern is the modeling of the Mexican portion of the basin, particularly with regard to the operating rules for Mexico’s internal reservoirs on tributaries and Mexico’s storage in Amistad and Falcon Reservoirs. The demands imposed on the Mexican system also may not accurately reflect actual demands under different hydrologic conditions since Mexico does not have an organized system of water rights in place for regulating the use of water. How Mexico may operate its water supply system in the future relative to the requirements of the 1944 Treaty and how much water the United States may receive from the Mexican tributaries in accordance with the provisions of the treaty also are uncertain. These operations directly affect the amount of water available for Texas users.

CONCLUSIONS

The primary conclusions from this water availability investigation and modeling effort for the Rio Grande Basin are as follows:

1) There are 962 water rights in the Texas portion of the Rio Grande Basin. The total amount of authorized diversions for these water rights is approximately 5 million acre-feet per year. There are 26 major reservoirs in the basin (eight in Texas and 18 in Mexico), defined as having a conservation storage capacity of 5,000 acre-feet or greater.

2) Shortages occur frequently for many water rights, particularly in the upper basin where precipitation is much lower. There are also frequent shortages for the Amistad-Falcon irrigation water rights. Amistad-Falcon municipal rights are fully satisfied all of the time because of their high priority status stipulated in the TCEQ Rio Grande operating rules.

3) The drought of record at many locations is the drought of the 1950s, but occurs at other times in some locations. In particular, the minimum storage condition for the U.S. portion of the Amistad-Falcon system occurs in September of 2000 for the period of record of the WAM. This drought extends beyond the period of record.

4) Comparison of the WRAP results from the different runs indicates that the effects of varying levels of municipal and industrial wastewater reuse have little impact on water availability for existing water rights and reservoir storage. There is comparatively little municipal and industrial water returned in the Rio Grande. Although not considered in these analyses, irrigation return flows are significant in some areas of the basin, particularly above Fort Quitman, and those water rights that are dependent on irrigation return flows are likely to exhibit reduced levels of available water supplies in the WAM.

5) The effects of water rights cancellations under fully authorized conditions are not significant. There are few water rights subject to cancellation, representing a relatively small quantity of water. However, when the use is limited to the maximum use in the last 10 years, there are some improvements in water availability. This is because the maximum usages in the last 10 years are generally significantly less than fully authorized amounts. The effects of reservoir sedimentation are most significant in Amistad Reservoir, which has lost approximately 300,000 acre-feet of storage since construction.

6) There is little or no unappropriated water available in the Rio Grande Basin under any of the runs, including the current conditions run.

7) The amount of regulated flows follows a pattern similar to unappropriated flows. There is little impact of the various runs on regulated flows. The regulated streamflows, of course, are somewhat greater than the unappropriated flows because they do not reflect all of the streamflow depletions associated with all water rights.

8) The firm yield analysis shows that almost all reservoirs have demands that exceed the firm yield of the reservoir or reservoir system. In particular, Red Bluff Reservoir has authorized annual diversions of about 290,000 acre-feet

and a firm yield of only about 56,000 acre-feet; the U.S. portion of the Amistad-Falcon system has authorized diversions of over 2 million acre-feet and a firm yield of about 1,055,000 acre-feet.

9. Because of the extreme spatial and temporal variation of streamflows in the upper portion of the Rio Grande Basin in response to rainfall events and limited data describing localized flow conditions, the amounts and locations of historical diversions and return flows (particularly related to irrigation), and variable channel losses, results from the WAM in terms of the available water supply for specific water rights in some locations may not be fully representative of actual conditions.

1.0 INTRODUCTION

1.1 Description of the 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 area is non-contributing, and the contributing drainage area is approximately 176,000 square miles, which is roughly split between the United States and Mexico. This report focuses on the portions of the basin in Texas and Mexico. The contributing drainage area within Texas is about 40,000 square miles, and within Mexico is about 87,000 square miles. The Rio Grande is 1,896 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 El Paso to the river's mouth at the Gulf of Mexico near Brownsville. The basin comprises all or part of 31 counties. Figure 1.1-1 presents a map of the basin. Figure 1.1-1 also shows the subwatersheds and primary control points (locations where naturalized flows were calculated) established for the purpose of the water availability modeling.

The Rio Grande system through 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 the basin, eight in Texas and on the mainstem 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.

The climate varies widely throughout the Rio Grande Basin. The western portion of the basin in Texas is desert, with an annual precipitation of approximately 8 to 16 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 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 climactic 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 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 5000 feet and an annual precipitation ranging between 20 to 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 evaporation rate of 59 inches. However, the large low-elevation reservoirs Luis Leon and Venustiano Carranza located within the arid regions of Chihuahua and Coahuila have measured evaporation rates of approximately 100 inches per year.

1.2 Study Objectives

This document presents the results of the Rio Grande water availability modeling study. The objective of this effort has been to meet the requirements of Senate Bill 1 (SB1) of the 75^{th} Texas Legislature and attendant House Bill 76 of the 76th Texas Legislature regarding the development of a new Rio Grande Basin simulation model for determining available water for individual water rights in accordance with Chapter 11, Water Rights, of the Texas Water Code. This model is capable of determining water availability in the basin under a range of policy and planning scenarios in accordance with the Prior Appropriation Doctrine and the Texas Commission on Environmental Quality (TCEQ) Rio Grande operating rules.

The TCEQ is responsible for developing water availability models for all basins in Texas. R. J. Brandes Company (RJBCO) of Austin, Texas, under contract with the TCEQ, has assisted the agency in the preparation, development, and application of a water availability model ("WAM") for the Rio Grande Basin (referred to as the "Rio Grande WAM"). Parsons Corporation of Austin, Texas; Riverside Technology, Inc. of Fort Collins, Colorado; Espey Consultants, Inc. of Austin, Texas; and Crespo Consulting Services, Inc. of Austin, Texas have served as subconsultants to RJBCO for this project.

In accordance with the provisions of House Bill 76, the following specific information is to be developed by the TCEQ through the water availability analysis:

1. For all holders of existing permits, certified filings, and certificates of adjudication, the projected amount of water that would be available during extended droughts.

2. The projected amount of water that would be available if cancellation procedures were instigated under Subchapter E, Chapter 11 of the Texas Water Code.

3. The potential impact of reusing municipal and industrial effluent on existing water rights, instream uses, and freshwater inflows to bays and estuaries.

1.3 Study Approach

The TCEQ, working with the Texas Water Development Board (TWDB) and the Texas Parks and Wildlife Department (TPWD), and with assistance from outside consultants, has developed specific procedures and criteria for development of the water availability models. The basic procedure applied in analyzing water availability in a particular river basin involves developing naturalized streamflows throughout the basin from historical hydrologic and other data, then

Figure 1.1-1 Location of Primary Control Points in Rio Grande Basin simulating on a monthly basis the ability of individual water rights to meet their authorized diversions or storage quantities in accordance with the Prior Appropriation Doctrine and, for the Rio Grande Basin, the TCEQ Rio Grande operating rules. The simulations are performed using the Water Rights Analysis Package computer program (referred to as "WRAP") that was developed by Dr. Ralph A. Wurbs of Texas A&M University. The February 2004 version of WRAP has been used in developing the Rio Grande WAM (Wurbs, 2004).

Naturalized streamflows represent historical streamflow conditions, including typical wet, dry, and normal flow periods, without the influence of man's historical activities as they relate to water rights and water use. In essence, naturalized streamflows exclude the effects of historical diversions, return flows, and reservoir storage and evaporation. For the Rio Grande WAM, the TCEQ has stipulated that the naturalized streamflow database must cover at least a 50-year period through calendar year 2000. The naturalized streamflow database that has been developed covers the 61-year period from January 1940 through December 2000. This longer period was selected because 1941 was a particularly wet year throughout the Rio Grande Basin. The WRAP model begins simulations assuming that all reservoirs are full. The inclusion of these above-normal streamflow conditions at the beginning of the WAM streamflow database increases the validity of this assumption. The 1940-2000 historical period also includes the droughts of the 1950s and 1990s, both of which represent extreme drought conditions for most of the Rio Grande Basin.

2.0 EXISTING WATER AVAILABILITY INFORMATION

2.1 Water Rights

2.1.1 Texas

There are 962 water rights in the Texas portion of the Rio Grande Basin as of March 7, 2003, with these water rights authorizing a total of 1,449 different diversions and/or impoundments. The most junior water right included in the WAM has priority date of June 9, 2000. The total amount of authorized diversions for these water rights is approximately five million acre-feet per year. As indicated in Table 2.1-1, approximately 12 percent of the total authorized diversion amount is for municipal supplies, 87 percent is for irrigation, and less than one percent is for mining, recreation, and other uses. Information on water rights was obtained from the TCEQ water rights database (WRDETAIL) and from hard copies of water rights permits and certificates of adjudication. Appendix A contains a copy of the TCEQ database sorted by water right number. Appendix B contains a memorandum with suggested corrections to the database. Figure 2.1-1 shows the location of all of the Texas water rights in the basin.

TABLE 2.1-1
WATER RIGHTS BY USE CATEGORY

USE CATEGORY	NUMBER OF RIGHTS BY USE TYPE	AUTHORIZED DIVERSION acre-feet/yr	PERCENT OF TOTAL*
TEXAS			
Municipal	142	366,414	12.4%
Irrigation	1,241	2,574,781	87.3%
Mining	36	7,598	0.3%
Hydroelectric	2	2,100,000	--
Recreation	8	72	0.0%
Other	20	50	0.0%
Texas Total	1,449**	2,984,915*	100.0%
MEXICO			
Municipal	12	378,480	12.3%
Irrigation	20	2,707,606	87.7%
Mexico Total	34	3,086,086	100.0%
GRAND TOTAL	1,483	6,071,001*	--

* Does not include hydroelectric. Hydropower may only be generated from spills or releases made for other uses.

** Many rights have multiple use categories. Total number of individual water rights is 962.

Figure 2.1-1 Location of Rio Grande Basin Water Rights

2.1.2 Mexico

There are 32 water commitments, or “concessions” (as they have been referred to by Mexican officials), in the Mexico portion of the Rio Grande Basin that have been included in the WAM. Mexico does not have a water right system based on the Prior Appropriation Doctrine, but apparently does have some established levels of annual use that serve as targets for the allocation of annual supplies of water either stored in Mexico’s reservoirs or anticipated to be available as a result of expected weather conditions and associated streamflows. The concessions that have been utilized for purposes of structuring the Mexico portion of the WAM have been obtained primarily from a water supply/allocation model, referred to as SIMBRAVO, that the Comision Nacional del Agua (CNA, Mexico’s National Water Commission) previously developed and used to examine the effects of various alternative strategies for operating the Mexican reservoirs within the Rio Grande Basin. Information from the SIMBRAVO model was obtained through discussions with CNA officials. Other information used to establish the Mexican water commitments included data published by the IBWC regarding historical diversions from the Rio Grande[1] and data obtained from the Gerencia Regional del Río Bravo (GRRB) in Monterrey. It should be noted that the concessions included in the WAM based on the SIMBRAVO model do not necessarily reflect the maximum historical use reported for some of these users. These are the concessions, however, that the Mexico CNA has used in its own planning with regard to the future water demands that will have to be satisfied in the Rio Bravo Basin.

The total amount of diversions for these concessions is approximately 3.1 million acre-feet per year. As indicated in Table 2.1-1 above, the distribution between municipal and irrigation uses is similar to Texas. Figure 2.1-1 also shows the locations of the diversion points associated with these concessions. A listing of the individual concessions that are included in the WAM is provided in Table 2.1-2. For each concession, the WAM ID number, the type of use, the annual diversion amount, the name of the stream on which the diversion(s) is located, and the name of the associated reservoir, if any, are indicated.

2.2 Historical Water Use

2.2.1 Texas

Information describing historical water use by month for the entire 1940-2000 analysis period has either been compiled from existing records or estimated from available data. Water use data were utilized in the naturalization process. The basic source of diversion information that has been relied upon has been the TCEQ and IBWC electronic records of historical monthly diversions by individual water rights holders (TCEQ) and aggregate diversions by river reach on

[1] International Boundary and Water Commission, United States and Mexico Sections; “Flow of the Rio Grande and Related Data, From Elephant Butte Dam, New Mexico to the Gulf of Mexico”; Water Bulletin Nos. 1-70; El Paso, Texas; 2000.

TABLE 2.1-2
MEXICO WATER USE CONCESSIONS INCLUDED IN WAM

WAM ID NUMBER	NAME OF CONCESSION	TYPE OF USE	DIVERSION AMOUNT acre-feet/year	STREAM NAME	ASSOCIATED RESERVOIR
FM5000MXP560	103 Rio Florido Irrigation District 1	Irrigation	10,343	Rio Florido	San Gabriel
FM5000MXP220	103 Rio Florido Irrigation District 2	Irrigation	74,849	Rio Florido	Pico del Aguila
FM3000MXP140	005 Delicias Irrigation District 1	Irrigation	837,042	Rio Conchos	La Boquilla
FM3000MXP150	005 Delicias Irrigation District 2	Irrigation	163,263	Rio Conchos	Francisco Madero
FM1000MXP200	090 Lower Conchos Irrigation District	Irrigation	130,223	Rio Conchos	Luis Leon
FM5000MXP230	006 Palestina Irrigation District 1	Irrigation	2,406	Rio Grande	Amistad
FM5000MXP500	006 Palestina Irrigation District 2	Irrigation	1,968	Rio Grande	Amistad
FM5000MXP500	006 Palestina Irrigation District 3	Irrigation	3,634	Arroyo de las Vacas	None
DM8000MXP570	006 Palestina Irrigation District 4	Irrigation	14,376	Rio San Diego	San Miguel
DM9000MXP260	006 Palestina Irrigation District 5	Irrigation	20,514	Rio San Diego	Centenario
DM6000PCP260	Local Irrigation	Irrigation	21,006	Rio San Rodrigo	LaFragua
DM4000PCP240	Local Irrigation	Irrigation	20,000	Rio Escondido	None
DM3000MXP190	050 Acuna Falcon Irrigation District	Irrigation	23,361	Rio Grande	Amistad
DM3000MXP580	004 Don Martin Irrigation District	Irrigation	285,337	Rio Salado	Venustiano Carranza
EM4000MXP160	058 Alto Rio San Juan Irrigation District	Irrigation	6,090	Rio San Juan	None
EM2000MXP180	031 Las Lajas Irrigation District	Irrigation	19,454	Rio San Juan	El Cuchillo
EM6000MXP440	026 Bajo Rio San Juan Irrigation District 1	Irrigation	342,755	Rio San Juan	Marte R. Gomez

TABLE 2.1-2, cont'd.

WAM ID NUMBER	NAME OF CONCESSION	TYPE OF USE	DIVERSION AMOUNT acre-feet/year	STREAM NAME	ASSOCIATED RESERVOIR
EM2000MXP310	026 Bajo Rio San Juan Irrigation District 2	Irrigation	6,016	Rio Grande	Falcon
EM1000MXP350	026 Bajo Rio San Juan Irrigation District 3	Irrigation	27,414	Rio Grande	Falcon
	025 Bajo Rio Bravo Irrigation District - Anz.	Irrigation	697,555	Rio Grande	Falcon
		TOTAL IRRIGATION:	2,707,606		
	Acequia Madre-Juarez	Mun./Irr.	60,000	Rio Grande	Elephant Butte
FM3000MXP380	La Colina - Downstream	Municipal	24,318	Rio Conchos	La Colina
CM1000MXP280	Ciudad Acuna	Municipal	2,496	Rio Grande	Amistad
DM5000PCP250	Piedras Negras	Municipal	10,425	Rio Grande	Amistad
DM3000PCP230	Nuevo Laredo	Municipal	29,263	Rio Grande	Amistad
DM2100MXP660	Ciudad Anahuac	Municipal	6,671	Salado	Venustiano Carranza
EM2000MXP310	Ciudad Miguel Aleman	Municipal	7,636	Rio Grande	Falcon
EM1000MXP550	Reynosa	Municipal	54,351	Rio Grande	Falcon
EM1000MXP240	Matamoros, et al	Municipal	38,990	Rio Grande	Falcon
	Monterrey - La Boca	Municipal	27,172	Rio San Juan	La Boca El Cuchillo
	Monterrey - El Cuchillo	Municipal	59,788	Rio San Juan	El Cuchillo
	Monterrey - Huasteca	Municipal	57,550	Rio San Juan	El Cuchillo La Boca
		TOTAL MUNICIPAL:	378,480		

the mainstem of the Rio Grande (IBWC). Some of these records date back to 1940 and most extend through 2000 (the end of the WAM analysis period). Many of the electronic records, however, did not appear to be complete, or they seemed to reflect erroneous data. Because of these problems, extensive effort was expended in obtaining and reviewing hard copies of the historical annual diversion reports from TCEQ's Central Records files, as well as contacting individual water rights holders to discuss their historical water usage.

Water right holders with incomplete records were contacted to obtain additional information to fill in the missing data. If no data were available, water use data were estimated on a per capita basis for municipal water rights. Per capita water use estimations were determined by dividing the water use in a given year by the population of the community using the water in that same year. Individual population data were obtained from the individual cities where water use was estimated. These per capita values were then multiplied by the population of the community during the period of missing data. Estimates for water use for industrial and irrigation water rights were based on historical use patterns of those water rights or rights with similar uses and diversion amounts. When a good estimate could not be formed, the historical use was estimated to be zero. This estimation provided a conservatively low estimate in the naturalized streamflow calculations.

The TCEQ Rio Grande Watermaster also provided a summary of the total amount of water used annually by the water rights on the lower and middle Rio Grande that are associated with Amistad and Falcon Reservoirs. These data, which are listed in Table 2.2-1, are grouped by water use category (municipal, irrigation, mining, etc.) for each year during the period from 1989 through 2002. As shown, the DMI uses have generally increased over the last ten years or so with approximately 260,000 acre-feet now being used from the Amistad-Falcon reservoir system. Irrigation use has fluctuated considerably since 1989 because of the extreme variations in weather and hydrologic conditions that have occurred. The late 1980s and early 1990s generally were wet years, whereas drought conditions generally have prevailed since then. As shown, the maximum amount of water used for irrigation and mining purposes was approximately 1.6 million acre-feet, which occurred in 1989 when water was plentiful, and the least amount of water used for these purposes was about 650,000 acre-feet, which occurred in 1997, 1999 and 2002, all relatively dry years with limited reservoir supplies available. The charged water use from the reservoirs in 1992 is zero because no releases were made for water supply purposes, only floodwater releases. Hence, no accounts were charged for reservoir water.

Records of monthly water use for different use types within the Rio Grande Basin also have been obtained from the Texas Water Development Board (TWDB) by county. These records begin around 1955 and extend to the present. In addition to the historical use, water use projections were also obtained from the TWDB. These water use projections were developed by the TWDB as part of the regional planning effort mandated by the Texas Legislature. Appendix C contains water use data for 1990 and 2000 and demand projections for the years 2030 and 2050.

TABLE 2.2-1
HISTORICAL ANNUAL WATER USE BY AMISTAD-FALCON TEXAS WATER RIGHTS

Use Type	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
WATER USAGE CHARGED TO ACCOUNTS														
Domestic	18,366	20,352	16,407	0	14,333	23,676	22,192	22,539	21,719	23,634	23,682	19,511	18,742	21,467
Municipal	152,591	180,753	153,484	0	131,871	186,829	188,594	196,978	192,747	212,927	211,260	228,764	224,594	237,327
Industrial	5,528	6,179	5,844	0	4,623	7,145	6,480	6,036	6,547	6,695	7,847	8,089	7,838	4,294
Subtotal	176,485	207,284	175,734	0	150,828	217,649	217,266	225,554	221,014	243,256	242,789	256,364	251,174	263,088
Irrigation	1,225,477	1,257,495	1,019,519	0	840,980	1,179,444	1,068,862	959,579	611,444	677,856	640,632	1,042,267	990,316	587,797
Mining	329	539	749		771	995	478	321	359	146	138	312	306	458
Recreation	95	96	92		96	96	77	39	28			87	62	123
Subtotal	1,225,902	1,258,130	1,020,361	0	841,846	1,180,534	1,069,417	959,938	611,831	678,002	640,771	1,042,666	990,684	588,378
Total	1,402,387	1,465,414	1,196,095	0	992,674	1,398,184	1,286,683	1,185,492	832,845	921,258	883,559	1,299,030	1,241,859	851,465
NO CHARGE WATER USAGE														
Domestic	4,935	150	3,103	20,833	6,593								0	0
Municipal	40,124	659	27,756	174,412	51,253		1,162	696	735	2,269	1,414	627	1,818	1,763
Industrial	1,340	0	614	6,189	1,768		0						0	0
Subtotal	46,399	809	31,473	201,434	59,614	0	1,162	696	735	2,269	1,414	627	1,818	1,763
Irrigation	377,707	15,857	103,158	727,879	313,063	834	13,973	13,946	31,235	51,802	29,572	12,130	42,773	78,449
Mining	55		74	486	132		6						0	0
Recreation	46		51	197	3								0	0
Subtotal	377,808	15,857	103,283	728,563	313,198	834	13,979	13,946	31,235	51,802	29,572	12,130	42,773	78,449
Total	424,208	16,666	134,756	929,996	372,813	834	15,140	14,642	31,970	54,072	30,986	12,757	44,591	80,211
TOTAL WATER USAGE														
Domestic	23,302	20,502	19,510	20,833	20,927	23,676	22,192	22,539	21,719	23,634	23,682	19,511	18,742	21,467
Municipal	192,715	181,412	181,240	174,412	183,124	186,829	189,755	197,674	193,482	215,196	212,673	229,391	226,412	239,089
Industrial	6,868	6,179	6,458	6,189	6,392	7,145	6,480	6,036	6,547	6,695	7,847	8,089	7,838	4,294
Subtotal	222,885	208,093	207,207	201,434	210,442	217,649	218,428	226,249	221,749	245,525	244,202	256,991	252,992	264,850
Irrigation	1,603,184	1,273,352	1,122,677	727,879	1,154,043	1,180,278	1,082,835	973,525	642,678	729,659	670,205	1,054,397	1,033,088	666,245
Mining	385	539	823	486	903	995	484	321	359	146	138	312	306	458
Recreation	141	96	143	197	99	96	77	39	28	0	0	87	62	123
Subtotal	1,603,710	1,273,987	1,123,644	728,563	1,155,045	1,181,369	1,083,396	973,884	643,066	729,805	670,343	1,054,796	1,033,457	666,826
Grand Total	1,826,595	1,482,081	1,330,851	929,996	1,365,487	1,399,018	1,301,824	1,200,134	864,815	975,330	914,545	1,311,787	1,286,450	931,676

2.2.2 Mexico

Historical annual municipal diversions for the City of Monterrey were obtained from Gerencia Regional del Río Bravo (GRRB) in Monterrey. These records detail the amount of water that was taken from a variety of sources, including groundwater aquifers, reservoirs, and trans-basin diversions. No other municipal diversion data from interior streams in Mexico were available; however, most of the interior Mexican municipalities in the Rio Grande Basin historically have used very little surface water. Most rely on groundwater for their supplies. For most other known municipal diversions in Mexico, correlations with estimates of population have been used to develop missing diversion data.

In Mexico, irrigation accounts for the vast majority of all diverted and consumptively used water. Unfortunately, CNA's historic database (BANDAS) for irrigation diversions is incomplete. Most major headgates have observations, but few have complete records for the 1940-2000 period. These data were supplemented with reservoir release data where it is understood that all reservoir releases below a certain threshold are for irrigation. In many cases there has been known irrigation but no flow records to support volumes (e.g., irrigation along Rio Escondido and Arroyo de las Vacas). These volumes have been estimated from records of historical acres under irrigation, cropping patterns, and records of annual volumes of irrigation water applied when available.

Eight irrigation districts served by rivers that are tributary to the Rio Grande were identified within Mexico. These are the Florido, Delicias, and Bajo Rio Conchos Districts in the Conchos Basin; the Palestina District located along some of the smaller tributaries between Amistad and Falcon Reservoirs; the Don Martin District in the Salado Basin; and Alto Rio San Juan, Las Lajas, and Bajo Rio San Juan Districts located in the San Juan Basin. Based upon data provided in CNA reports, the maximum water demand for irrigation has been about 3.2 million acre-feet per year for nearly 781,500 acres of irrigated land. Most of the districts rely upon upstream reservoir releases to meet their irrigation water requirements. The Delicias District in the Conchos Basin is by far the largest irrigation operation in the Rio Grande Basin.

Based upon map review and data obtained from IBWC, other smaller irrigation zones also were identified. Typically, only an estimated irrigated area or annual water demand was provided in reports and other sources. In such cases, cropping patterns and river diversions observed at other irrigation districts were translated to the irrigation zone in question. This process provided the means to develop monthly estimates for diversions that were sensitive to the available supplies within the associated river basin.

2.3 Historical Return Flows and Treated Wastewater Effluent Discharge

2.3.1 Texas

Available records for return flow of treated municipal and industrial wastewater effluent discharges were obtained from TCEQ for the time period of 1978 through 1996. Prior to 1978, return flow records were not required by the TCEQ and therefore generally not available. Also, reported return flows from IBWC were used to supplement the data obtained from the TCEQ. The following techniques were used to estimate return flows where records were not available:

- Return flow facilities were contacted to determine whether any records or estimates of flows existed for the time frame not covered by the TCEQ database.
- For cities where no additional information could be obtained, return flows were estimated based on conversations with city staff, prior water use, and/or a per capita value.
- For industries where no additional information could be obtained, return flows were estimated based on conversations with company employees, or based on water use in surrounding years.

Estimates of return flow were then calculated from the date in which discharge began through 1978.

All municipal and industrial wastewater discharges (return flows) within the contributing drainage area of the Rio Grande Basin with a permitted flow greater than or equal to 0.5 million gallons per day (MGD), or approximately 560 acre-feet per year, were considered significant and were accounted for in the streamflow naturalization process. There are 31 such permitted dischargers, but only 15 of them actually discharge, as shown in Table 2.3-1. Power plants utilizing once-through cooling were not included in the return flow adjustments since their return flows are essentially equal to their diversions. For the modeling process, return flows were located using latitude and longitude coordinates provided by TCEQ for all facilities greater than 0.5 MGD.

2.3.2 Mexico

For the interior Mexican portion of the Rio Grande Basin, few discharge records were available. Information on the capacity of treatment plants and the percent of capacity they are currently operating at for the major cities was obtained from CNA. Return flows were estimated based on historical population data as compared to current population as a fraction of the plant capacity data. Data and information regarding municipal return flows to the mainstem of the Rio Grande, primarily Nuevo Laredo, were obtained from the IBWC. Where historical data on return flows were missing, but the existence of return flows is known, return flows were assumed for the 1990-2000 period.

TABLE 2.3-1
SIGNIFICANT WASTEWATER DISCHARGERS
TEXAS

CONTROL POINT ID	COUNTY	PERMIT NUMBER	FACILITY OWNER	TYPE OF FACILITY	MAX DAILY FLOW MGD	DIS-CHARGE
AT2000	El Paso	00821	Newo Holdings, Inc.	Industrial	1.0	No
AT2000	El Paso	13341	U.S. Dept. of Justice	Municipal	0.6	No
AT1000	El Paso	10166	El Paso Co. WCID 4	Municipal	0.7	No
AT1280	El Paso	10408.004	El Paso Water Utilities	Municipal	27.7	Yes
AT1215	El Paso	10408.007	El Paso Water Utilities	Municipal	10.0	No
AT1320	El Paso	10408.009	El Paso Water Utilities	Municipal	17.5	Yes
AT1250	El Paso	10408.010	El Paso Water Utilities	Municipal	39.0	No
AT1210	El Paso	10795.001	El Paso Co. Water Auth.	Municipal	1.5	Yes
AT1000	El Paso	10795.002	El Paso Co. Water Auth.	Municipal	1.5	No
CT6000	Presidio	04297	Rio Grande Mining Co.	Industrial	0.6	No
CT2120	Sutton	10545	City of Sonora *	Municipal	0.9	Yes
CT2130	Crockett	10059	Crockett Co. WCID 1 *	Municipal	0.5	Yes
CT1030	Val Verde	10159.003	City of Del Rio	Municipal	2.8	Yes
DT9020	Val Verde	10159.001	City of Del Rio	Municipal	3.8	Yes
DT5000	Kinney	10194	City of Brackettville	Municipal	0.5	No
DT3122	Maverick	10406	City of Eagle Pass	Municipal	6	Yes
DT3024	Webb	1200	Central Power & Light Co.	Industrial	1.3	Yes
DT3000	Webb	10681.001	City of Laredo	Municipal	4.1	No
DT3004	Webb	10681.002	City of Laredo	Municipal	14.0	Yes
DT3000	Webb	10681.004	City of Laredo	Municipal	0.9	No
DT1056	Zapata	10462	Zapata Co.	Municipal	0.8	Yes
DT1226	Webb	10681.003	City of Laredo	Municipal	9.0	Yes
ET1176	Starr	10802	Starr Co. WCID 2	Municipal	1.5	Yes
ET1126	Starr	14313	Union Water Supply Corp.	Municipal	0.8	No
GT2000	Ward	556	TXU Generation Co. LP	Industrial	4.0	No
GT2000	Winkler	10200	City of Kermit	Municipal	1.0	No
GT2000	Ward	10224	City of Monahans	Municipal	1.1	No
GT2450	Reeves	10245	City of Pecos	Municipal	1.6	No
GT1170	Crockett	961	West Texas Utilities Co.*	Industrial	0.9	Yes
GT1000	Pecos	10708	City of Ft. Stockton	Municipal	1.4	No
none**	Cameron	10397	Brownsville PUB	Municipal	12.8	Yes

** Below ET1000 * Groundwater source

TABLE 2.3-1, continued
SIGNIFICANT WASTEWATER DISCHARGERS
MEXICO

CONTROL POINT ID	FACILITY OWNER	TYPE OF FACILITY	MAX DAILY FLOW MGD	DISCHARGE
CM1010	Ciudad Acuna	Municipal	4.1	Yes
DM1010	Nuevo Laredo	Municipal	30.9	Yes
DM3030	Piedras Negras	Municipal	5.7	Yes
EM3450	Pemex	Industrial	8.7	Yes
EM3460	Cadereyta	Municipal	1.6	Yes
EM3430	Montemorelos	Municipal	1.2	Yes
EM3200	Apodaca / Monterrey	Municipal	10.0	Yes
EM3200	Gral. Escobedo / Monterrey	Municipal	32.8	Yes
EM3210	Pesqueria / Monterrey	Municipal	89.0	Yes
EM2010	Miguel Aleman	Municipal	2.1	Yes
EM2000	Nueva Ciudad Guerrero	Municipal	0.6	Yes
EM2020	Mier	Municipal	0.8	Yes
EM1040	Diaz Ordaz	Municipal	0.9	Yes
EM1020	Reynosa	Municipal	17.6	Yes

2.4 Previous Water Availability and Planning Studies

The TCEQ and its predecessor agencies have not previously developed water availability models for the Texas portion of the Rio Grande Basin; hence, no legacy models are available with which to compare results from the current WAM. The TWDB, however, did sponsor the development of a computer model for the Amistad-Falcon reservoir system in 1998[2] that has been used to estimate the firm annual yield of the reservoirs and to investigate alternative strategies for establishing storage reserves in the reservoirs for Texas users. This model was structured using the TWDB's SIMYLD-II computer program for simulating reservoir system operations, and it consisted of separate nodes for municipal and irrigation demands and reservoir storage for Texas and for Mexico. Inflows to the model were based on historical flow records from the International Boundary and Water Commission (IBWC) developed specifically for this model, and separate inflows to the Rio Grande from the Texas side and from the Mexican side of the river were specified as inputs to the model. The TCEQ's rules regarding operation of the Amistad-Falcon system and the associated storage accounting, as well as IBWC's operating rules for the two international reservoirs were incorporated into the model.

The primary emphasis on water supply planning for the Rio Grande Basin in Texas has been through the Regional Planning Groups that have been established by the TWDB pursuant to the requirements of Senate Bill 1. There are five planning regions that cover various portions of the Rio Grande Basin. These are described below:

Region M (Rio Grande) - This region encompasses the entire Rio Grande Basin along the river from the mouth upstream to Maverick County (including Falcon Reservoir).

Region L (South Central Texas) - Only a small part of Dimmit County in the far western end of this region lies in the Rio Grande Basin.

Region J (Plateau) - This region includes portions of the Rio Grande Basin along the river in Kinney and Val Verde Counties (including Amistad Reservoir).

Region F - Most of the watersheds of the Devils and Pecos Rivers in west Texas are included in this region.

Region E (Far West Texas) - The western portion of the Rio Grande Basin, including the Big Bend area, is included in this region.

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[2] R. J. Brandes Company and Michael Sullivan & Associates, Inc.; "The International Reservoirs Operations and Drought contingency Planning Study for the Middle and Lower Rio Grande"; prepared for the Valley Water Policy and Management Council of the Lower Rio Grande Water Committee, Inc.; TWDB Research and Planning Grant, Contract No. 95-483-143; Austin, Texas; August, 1998.

All of these Regional Planning Groups completed Regional Water Plans in 2001 that included a variety of alternatives for meeting the future water demands within the Rio Grande Basin. Strategies for supplying future water needs include the development of groundwater, desalination of brackish groundwater, reservoir construction, aquifer-storage recovery projects, importation of water from outside the basin, conversion of surface water supplies from irrigation use to municipal use, wastewater reclamation and reuse, and municipal and agricultural water conservation measures. Each of the Planning Groups now is in the process of refining their initial plans through the second round of the TWDB-sponsored planning effort, with these Regional Water Plans to be finalized and provided to the TWDB on or before January 6, 2006. The TWDB is to produce a revised statewide Water Plan by January 6, 2007.

The Rio Grande WAM will be used in the regional planning effort, particularly with regard to investigating the yield of the Amistad-Falcon reservoir system under different operating plans and assumptions regarding future supplies of water available from Mexico.

2.5 Significant Considerations Affecting Water Availability in the Basin

Significant considerations that may affect water availability in the Rio Grande Basin include:

- Historical diversion data are not complete or sometimes are not reported correctly, and historical diversions had to be estimated or adjusted in some cases to provide meaningful data for use in the streamflow naturalization process.

- Historical return flow data are not complete or sometimes are not reported correctly, or reported at all (irrigation return flows), and historical return flows had to be estimated or adjusted in many cases to provide useful data for application in the streamflow naturalization process.

- Historical reservoir data, including storage and releases, are not complete or sometimes not available at all, and this information had to be estimated, or simulated, for purposes of the streamflow naturalization process.

- Negative incremental monthly flows occur as a result of the streamflow naturalization process. While some of these streamflow reductions are attributable to natural losses along stream reaches, particularly in the western portion of the basin, they also are likely the result of timing errors between upstream and downstream gages and/or errors in gage flows, reservoir storage volumes, and/or reported diversion and return flow amounts. While efforts have been made to examine the potential causes of these negative incremental flows and, in some cases, adjustments in data have been made when warranted and considered logical in order to reduce the negative incremental flows, none of the negative incremental flows have been arbitrarily eliminated.

- Area-capacity curves for most reservoirs smaller than 5,000 acre-feet have been estimated using regression equations based on data from the few reservoirs for which curves are available.

- Channel losses have been determined for all major river and stream reaches based on available streamflow records and estimates of natural losses due to surface evaporation and uptake of streamflows by phreatophytes. The loss factors derived from these analyses provide best estimates of total channel losses, but actual losses are known to vary considerably and certainly can deviate from the estimates incorporated into the streamflow naturalization process and the WAM.

- The use of specific watershed parameters to distribute naturalized flows from streamflow gages to ungaged locations may not accurately reflect actual hydrologic and climatic conditions as they occurred historically in localized areas.

- The extreme spatial and temporal variation of streamflows in the upper portion of the Rio Grande Basin in response to rainfall events and limited data describing localized flow conditions, the amounts and locations of historical diversions and return flows (particularly related to irrigation), and variable channel losses may cause results from the WAM in terms of the available water supply for specific water rights in some locations to not be fully representative of actual conditions.

- The assumed demands for Mexico water users included in the WAM reflect recent modeling performed by the Mexican CNA for water planning purposes, but in some cases, these demands are less than the maximum historical quantities of surface water used as reported by the IBWC and Mexico.

- Future appropriations are subject to environmental flow restrictions pursuant to Chapter 11 of the Texas Water Code. Environmental flow needs, including instream flows and freshwater inflows, will be considered when granting new water rights or amending existing water rights, thereby affecting the amount of water available for appropriation.

3.0 HYDROLOGIC DATA REFINEMENT

3.1 Natural Streamflow at Gaged Locations

The development of naturalized flows for specific gages in the Rio Grande Basin for purposes of providing the hydrologic inputs to the WAM is described in a separate report[3]. This report provides details regarding the procedures used and the results from the naturalization process. Summaries of the more important aspects of the streamflow naturalization process are summarized in the following sections.

3.1.1 Streamflow Naturalization Methodology

The process of removing the effects of various man-related influences from historical streamflow records is referred to as "streamflow naturalization." These influences include primarily historical diversions of surface water for different uses, historical discharges of municipal or industrial wastewater and irrigation return flows, and the historical quantities of streamflow that may have been stored in or evaporated from reservoirs (reservoir depletions). The following general equation has been used to derive the corresponding naturalized streamflows:

Naturalized Streamflow	=	Historical Streamflow
	+	Historical Upstream Diversions
	–	Historical Upstream Return Flows
	+	Historical Changes in Upstream Reservoir Storage
	+	Historical Upstream Reservoir Evaporation Loss
	–	Historical Upstream Miscellaneous Adjustments (e.g. spring flows)

This equation can be simplified as:

Naturalized Streamflow	=	Gaged Flow
	+	Upstream Cumulative Historical Adjustments

The streamflow naturalization process was conducted in an upstream-to-downstream mode. In other words, naturalized flows were calculated for an upstream gage (primary control point), incremental adjustments were calculated for the intervening drainage area between the upstream control point and the next downstream control point, and then the incremental adjustments were added to the upstream cumulative adjustments and the gaged flow.

3 R. J. Brandes Company, et al; "Final Report, Water Availability Modeling for the Rio Grande Basin, Naturalized Streamflow Data"; prepared for Texas Commission on Environmental Quality; October, 2003; Austin, Texas.

In deriving the naturalized streamflows for certain gages located downstream of major springs, the historical spring discharges have been removed from the measured streamflows at a downstream gage location in order to derive flow values at the gage that only represent historical watershed runoff. These watershed runoff flow values then have been naturalized using the above equation. For modeling purposes, the corresponding spring discharges have been specified separately in WRAP (using time series FA records) as a single water source at the actual location of the spring. For the Rio Grande WAM, only one set of springs, comprising San Solomon and Giffin Springs in the vicinity of Lake Balmorhea, was specified separately using FA records.

The difficulty in the streamflow naturalization process, of course, has been the development of reliable data regarding historical diversions, return flows, and reservoir storage and evaporation for the entire 1940-2000 period, particularly in Mexico. While the data that have been developed for this purpose very likely do not fully and accurately reflect actual historical diversions, return flows, and reservoir storage and evaporation, they are believed to represent reasonable estimates of these quantities that probably could not be significantly refined or improved upon without the availability of additional data records. Such records are not known to exist. Furthermore, such refinements or improvements in these data would require a substantial amount of additional effort and time. The data that have been developed in this study for purposes of the streamflow naturalization process are believed to be adequate and satisfactory for purposes of developing and operating a meaningful WAM for the Rio Grande Basin.

It is important to recognize that the adjustments included in the above streamflow naturalization equation could result in negative naturalized streamflow values, or negative incremental naturalized streamflow values (between two gages on the same stream) for certain months, even after the streamflow losses associated with the adjustments have been accounted for. This could be caused by unreported diversions, inaccurate measured data such as streamflows or reservoir contents, errors in estimated data such as filled missing streamflows, or inaccurate hydrologic parameters or streamflow loss estimates. Also, the travel time along a stream between gages or from the points where diversions or return flows occur or from where reservoirs are located to a downstream gage site could cause inconsistencies in reported monthly flows, thus resulting in negative incremental or total naturalized streamflows.

Negative incremental flows have not been adjusted or eliminated in the flow naturalization process, and have been handled by one of the options available in the WRAP program for purposes of modeling. Since negative total flows cannot physically occur, they have been eliminated from the sequences of naturalized streamflows by setting a negative flow value for a particular month to zero. In cases where negative flows appeared to be attributed to travel time, corresponding decreases have been made in the naturalized streamflows for adjacent months to preserve the total flow quantity. Adjustments made for negative flows have been accumulated along with the other historical adjustments and become part of the “Upstream Cumulative Historical Adjustments” at downstream gages, as described above.

3.1.2 Streamflow Data Sources

All of the known U.S. Geological Survey (USGS) streamflow gages, both existing and discontinued, for which there are historical records within the Rio Grande Basin for all or part of the 1940-2000 period have been identified through research of USGS reports, data from Mexico, and other documents. There are over 123 gages in the basin in both Texas and Mexico; of these, 44 gages have been identified as containing records useful for the streamflow naturalization process. Forty-three gages (23 in Texas and 20 in Mexico) were selected as primary control points (see Figure 1.1-1).

3.1.3 Naturalized Flows at New Mexico Stateline

Since the upper end of the Rio Grande WAM has been established essentially at the New Mexico stateline, an important aspect of the streamflow naturalization process dealt with determining the appropriate flows to be specified in the WAM for both the Rio Grande and the Pecos River at the New Mexico stateline. River flows delivered to Texas at both of these locations are subject to the provisions of existing compacts between the states, i.e., New Mexico and Colorado for the Rio Grande and New Mexico for the Pecos River. Furthermore, Texas' share of the water flowing in the Rio Grande at the stateline with New Mexico also is dependent upon the available supply and allocation provisions of the Rio Grande Project, which includes the water stored in Elephant Butte Reservoir in New Mexico and the facilities for delivery of this water to irrigation and municipal users in southern New Mexico and far west Texas upstream of Fort Quitman.

To derive the appropriate naturalized flows at the New Mexico stateline for the WAM, adjustments have been made to the historical streamflow records for the Rio Grande at the El Paso gage to reflect the impact of historical under-deliveries and over-deliveries by the State of New Mexico pursuant to the Rio Grande Compact and the potential over-allocations of Rio Grande Project water that may have been made historically because all of the Project water allocated in one year may not have been actually released from Elephant Butte Reservoir in that year (and was subsequently included in the allocation for the following year). Adjustments also have been made for the Pecos River flows as measured at the Red Bluff, New Mexico gage to reflect the impact of historical under-deliveries and over-deliveries by the State of New Mexico pursuant to the Pecos River Compact. Both of these gages are located near the Texas-New Mexico stateline and are used as the most upstream control points in the WAM. The details of how these various adjustments were derived have been previously described in the Rio Grande Naturalized Streamflow Data report, and this discussion is included in Appendix Y of this report for reference purposes. The annual over/under compact deliveries and potential unreleased Rio Grande Project water in Elephant Butte Reservoir and the resulting final historical flow adjustments for the Rio Grande and the Pecos River at the stateline gages required for naturalization are listed in Table 3.1-1.

3.1.4 Delivery Factors and Channel Loss Rates

For purposes of the Rio Grande WAM, channel losses along the streams within the Rio Grande Basin have been evaluated through the following activities:

- Review of the geology and hydrogeology and previous studies in the basin.
- Analysis of historical gaged streamflows for selected reaches.
- Examination of potential evapotranspiration losses from both free water surfaces and plant uptake.
- Review of modeling performed by the Comision Nacional del Agua (CNA), the National Water Commission in Mexico City.

Appendix G contains a technical memorandum detailing the procedures used.

Tables 3.1-2 and 3.1-3 present the overall channel loss factors used for all primary control point reaches in Texas and in Mexico, respectively.

3.1.5 Completion of Streamflow Records

Historical streamflow records for many of the gages located throughout the Rio Grande Basin are not available for the entire 1940-2000 period for which naturalized flows have been developed. Records from other gages have been used to fill in missing records. These streamflow fill-in procedures involved the development of correlations of flows between gages or the application of appropriate flow or drainage area ratios.

All of the gages designated as primary control points were examined to determine periods of missing records, and an appropriate means for filling in missing monthly streamflow values was identified based on an analysis of the existing data. This information is summarized in the table in Appendix E. To obtain better correlations and minimize other variables, regression analyses were done for each month of the year, rather than performing a single regression for all months at a gage. For each month of the year, data from several different gages on the same or nearby streams were evaluated to determine the degree of fit with the gage where data were missing. The best-fit method was selected for each month at each gage. The type of analysis used for the majority of the fills was a scatter plot of monthly flows for each month of the year using a linear regression correlation.

TABLE 3.1-1
SUMMARY OF HISTORICAL OVER/UNDER COMPACT DELIVERIES AND ALLOCATIONS OF UNRELEASED RIO GRANDE PROJECT WATER AND STREAMFLOW ADJUSTMENTS REQUIRED FOR NATURALIZATION

YEAR	RIO GRANDE				PECOS RIVER	
	NM Compact Over/Under Delivery Balance Acre-Feet	Annual NM Compact Over/Under Delivery Acre-Feet	Potential Allocated Unreleased Proj. Water Acre-Feet	El Paso Gage Flow Adjustment Acre-Feet	Annual NM Compact Over/Under Delivery Acre-Feet	Red Bluff Gage Flow Adjustment Acre-Feet
1940	-58,900	-58,900	0	60,981	0	0
1941	49,400	108,300	31,958	56,794	0	0
1942	0	-49,400	59,609	43,887	0	0
1943	-59,200	-59,200	0	64,291	0	0
1944	-136,600	-77,400	0	62,650	0	0
1945	-150,400	-13,800	0	66,512	0	0
1946	-105,400	45,000	0	50,862	0	0
1947	-176,800	-71,400	0	59,920	0	0
1948	-286,400	-109,600	38,945	56,806	0	0
1949	-280,400	6,000	22,018	58,114	0	0
1950	-263,100	17,300	51,632	53,500	0	0
1951	-331,800	-68,700	44,527	58,404	0	0
1952	-453,200	-121,400	24,860	144,242	-13,200	+13,200
1953	-478,900	-25,700	109,177	38,030	8,100	-8,100
1954	-497,700	-18,800	0	24,953	-15,400	+15,400
1955	-477,300	20,400	0	21,802	-19,600	+19,600
1956	-529,400	-52,100	0	60,315	-15,800	+15,800
1957	-473,900	55,500	0	49,527	7,500	-7,500
1958	-468,700	5,200	0	44,123	13,700	-13,700
1959	-497,900	-29,200	26,740	51,111	11,300	-11,300
1960	-448,100	49,800	76,402	58,829	15,900	-15,900
1961	-400,600	47,500	58,706	59,399	14,900	-14,900
1962	-345,400	55,200	80,693	60,772	27,900	-27,900
1963	-351,800	-6,400	111,927	38,991	29,300	-29,300
1964	-417,700	-65,900	29,970	35,217	25,600	-25,600
1965	-445,600	-27,900	0	95,236	19,500	-19,500
1966	-424,200	21,400	9,781	58,131	-14,800	+14,800
1967	-382,400	41,800	42,633	32,881	-2,900	+2,900
1968	-296,900	85,500	0	39,454	-300	+300
1969	-182,400	114,500	41,466	71,568	35,900	-35,900
1970	-150,500	31,900	96,209	76,266	33,000	-33,000

TABLE 3.1-1, cont'd.

YEAR	RIO GRANDE				PECOS RIVER	
	NM Compact Over/Under Delivery Balance Acre-Feet	Annual NM Compact Over/Under Delivery Acre-Feet	Potential Unreleased Proj. Water Allocation Acre-Feet	El Paso Gage Flow Adjustment Acre-Feet	Annual NM Compact Over/Under Delivery Acre-Feet	Red Bluff Gage Flow Adjustment Acre-Feet
1971	-107,200	43,300	102,645	42,296	30,400	-30,400
1972	41,700	148,900	0	33,417	26,500	-26,500
1973	-37,200	-78,900	32,251	135,175	30,500	-30,500
1974	13,000	50,200	146,618	54,058	21,100	-21,100
1975	74,000	61,000	122,952	75,982	3,900	-3,900
1976	46,100	-27,900	183,196	48,665	-6,600	+6,600
1977	32,000	-14,100	84,275	21,292	10,300	-10,300
1978	-28,200	-60,200	0	22,443	8,600	-8,600
1979	-129,100	-100,900	0	124,384	10,400	-10,400
1980	-148,000	-18,900	195,178	82,940	9,800	-9,800
1981	-195,700	-47,700	105,187	103,608	5,500	-5,500
1982	-168,200	27,500	155,865	110,345	9,800	-9,800
1983	-120,200	48,000	119,990	104,999	19,300	-19,300
1984	-96,900	23,300	115,533	77,593	26,500	-26,500
1985	0	96,900	110,819	77,029	26,300	-26,300
1986	0	0	86,220	40,436	-4,900	+4,900
1987	0	0	0	40,890	-15,400	+15,400
1988	0	0	0	44,844	-23,600	+23,600
1989	-21,500	-21,500	0	49,238	-2,700	+2,700
1990	-51,100	-29,600	27,862	49,754	14,100	-14,100
1991	54,000	105,100	83,872	64,872	16,500	-16,500
1992	165,700	111,700	137,860	50,026	-10,900	+10,900
1993	164,900	-800	29,001	44,344	-6,600	+6,600
1994	106,900	-58,000	0	47,957	-5,900	+5,900
1995	0	-106,900	0	39,743	14,100	-14,100
1996	0	0	0	48,328	6,700	-6,700
1997	43,300	43,300	0	48,928	-6,100	+6,100
1998	153,100	109,800	0	47,754	-1,700	+1,700
1999	170,700	17,600	0	50,030	-1,400	+1,400
2000	270,800	100,100	28,925	47,689	12,300	-12,300
Avg	-152,284	4,439	46,320	58,732	6,187	-6,187
Max	270,800	148,900	195,178	144,242	35,900	+23,600
Min	-529,400	-121,400	0	21,292	-23,600	-35,900

TABLE 3.1-2
CHANNEL LOSS FACTORS FOR TEXAS AND MAINSTEM CONTROL POINTS

CONTROL POINT NO.	C.P. ID	CONTROL POINT LOCATION	UPSTREAM CONTROL POINTS	LOSS RATE %/Mile	REACH LENGTH Miles [a]	CHANNEL LOSS FACTOR, %
AT/AM2000	RG-EP	R Grande at El Paso	n/a	n/a	n/a	n/a
AT/AM1000	RG-FQ	R Grande at Fort Quitman	AT/AM2000	0.24	83	20
BT/BM1000	RG-AC	R Grande abv R Conchos	AT/AM1000	0.22	209	46
CT7000	AC-PR	Alamito Ck nr Presidio	none	0.19	82	9
CT/CM6000	RG-BC	R Grande blw R Conchos	CT7000, AT/AM1000, FM1000	0.11	14	2
CT5000	TC-TE	Terlingua Ck nr Terlingua	none	0.19	41	5
CT/CM4000	RG-JR	R Grande at Johnson Ranch	CT5000, CT/CM6000	0.11	88	10
CT/CM3000	RG-FR	R Grande at Foster Ranch	CT/CM4000	0.01	205	2
GT5000	PR-RB	Pecos R at Red Bluff	n/a	n/a	n/a	n/a
GT4000	DR-RB	Delaware R nr Red Bluff	none	0.35	25	9
GT3000	PR-OR	Pecos R nr Orla	GT4000, GT5000	0.35	31	11
GT2000	PR-GI	Pecos R nr Girvin	GT3000	0.35	136	48 [b]
GT1000	PR-LA	Pecos R nr Langtry	GT2000	0.19	160	30
CT2100	DR-JU	Devils R nr Juno	none	0.14	42	6
CT2000	DR-PC	Devils R at Pafford Crossing	CT2100	0.14	33	5
CT/CM1000	RG-DR	R Grande at Del Rio	CT2000, GT1000, CT/CM3000	0.01	96	1
DT9000	SF-DR	San Felipe Ck nr Del Rio	none	0.14	5	1
DT8000	PC-DR	Pinto Ck nr Del Rio	none	0.20	27	5
DT/DM5000	RG-PN	R Grande at Piedras Negras	DT8000, DT9000, CT/CM1000, DM9500, DM7000, DM6000	0.20	64	13
DT/DM3000	RG-LA	R Grande at Laredo	DT/DM5000, DM4000	0.10	137	14
DT/DM1000	RG-BF	R Grande blw Falcon Dam	DT/DM3000, DM2000	0.10	86	9
ET/EM2000	RG-RG	R Grande at Rio Grande City	DT/DM1000, EM4000, EM3000	0.10	40	4 [c]
ET/EM1000	RG-AN	R Grande blw Anzalduas Dam	ET/EM2000	0.08	65	5 [c]
ET/EM0100	RG-BR	R Grande blw Brownsville	ET/EM1000	0.10	121	5 [c]
ET/EM0000	RG-MO	R Grande at Mouth	ET/EM0100	0.10	49	5 [c]

[a] Stream miles from upstream

CP on same stream or headwaters to CP of interest
[b] 85% CLF used for Toyah Creek (Balmorhea area)
[c] R. J. Brandes Co.; "Evaluation of Amistad-Falcon Water Supply Under Current and Extended Drought Conditions"; Lower Rio Grande Valley Development Council and Valley Water Policy and Management Council of the Lower Rio Grande Water Committee, Inc.; March, 1999.

TABLE 3.1-3
CHANNEL LOSS FACTORS FOR MEXICO CONTROL POINTS

CONTROL POINT NO.	C.P. ID	CONTROL POINT LOCATION	UPSTREAM CONTROL POINT(S)	LOSS RATE %/Mile	REACH LENGTH Miles	CHANNEL LOSS FACTOR %
FM5000	RF-CJ	R Florido at Cd. Jimenez, CHIH	none	0.15	117	18
FM6000	RC-BO	R Conchos at Presa La Boquilla, CHIH	none	n/a*	n/a*	n/a*
FM4000	SP-VI	R San Pedro at Villalba, CHIH	none	n/a*	n/a*	n/a*
FM3000	RC-LB	R Conchos at Las Burras, CHIH	FM4000, FM5000, FM6000	0.15	131	20
FM2000	RC-EG	R Conchos at El Granero, CHIH	FM3000	0.20	50	10
FM1000	RC-OJ	R Conchos nr Ojinaga, CHIH	FM2000	0.16	109	17
DM9500	AV-CA	Arroyo de las Vacas at Cd. Acuna, COAH	none	0.20	50	10
DM7000	SD-JI	R San Diego nr Jimenez, COAH	none	0.20	50	10
DM6000	SR-EM	R San Rodrigo at El Moral, COAH	none	0.20	45	9
DM4000	RE-VF	R Escondido at Villa de Fuente, COAH	none	0.20	45	9
DM2300	RS-SA	R Sabinas at Sabinas, COAH	none	0.09	15	1
DM2200	RN-PR	R Nadadores at Progreso, COAH	none	0.09	20	2
DM2100	RS-RO	R Salado at Rodriguez, NL	DM2200, DM2300	0.09	69	6
DM2000	RS-LT	R Salado nr Las Tortillas, TAMPS	DM2100	0.09	71	6
EM4000	RA-CM	R Alamo at Cd. Mier, TAMPS	none	0.09	34	3
EM3400	SJ-EC	R San Juan at El Cuchillo, NL	none	0.09	142	13
EM3300	RS-CF	R Salinas at Cienega de Flores, NL	none	0.09	75	7
EM3200	RP-LH	R Pesqueria at Los Herrera, NL	EM3300	0.09	120	11
EM3100	SJ-LA	R San Juan at Los Aldamas, NL	EM3200, EM3400	0.09	30	3
EM3000	SJ-CA	R San Juan at Camargo, TAMPS	EM3100	0.09	34	3

* n/a = not applicable. There are no streamflow adjustments within the upstream watershed; therefore, no loss factor is required.

A flow ratio method ("Flow Factors") was also used for filling in data in some cases where a nearby downstream gage existed during both the period when fill-in was required and the period when the upstream gage of interest was operational. These factors were calculated by determining the percentage of incremental flow at the downstream gage that was attributable to the upstream gage during their common period of record. To fill in when the upstream gage was not operational, this percentage was multiplied by the incremental flow at the downstream gage. That product was used as the incremental naturalized flow at the upstream gage of interest, which was added to the naturalized flow at the next upstream gage to produce the total naturalized flows at the gage of interest.

For Mexico gages, because of the numerous missing records at many gages, a software program developed by Riverside Technology, Inc., known as TSTool, was used to develop fill-in relationships. TSTool is a program that manipulates time series data (e.g. gage records) using regression analysis and finds the best fits with other gages on a monthly basis. The results were evaluated and the best available fit was selected for the time periods needed. This resulted in different equations for various time periods at each given gage. Filling was done on a monthly basis rather by ranges of years. Because of the erratic nature of missing records in Mexico (scattered missing individual months in addition to longer missing blocks of records), various relationships from other gages were used for filling a given month during different years. For example, a gage used to fill missing records for the month of interest may have been missing data from that month during one or more years that needed to be filled, and a different gage had to be used. As with the United States gages, the type of analysis used for the fills was a linear regression or rarely a log-log regression of monthly flows for each month of the year. Log regressions were used to fill selected missing data values when the normal regression gave a negative fill value. This happened occasionally if there was an observed value of zero or near zero at the selected station.

The resulting monthly and annual naturalized flows for the primary control points for the entire study record (1940-2000) are tabulated in Appendix F.

3.1.6 Comparison With Other Naturalized and Historical Streamflows

There is no TCEQ Legacy Water Availability Model for the Rio Grande Basin, and no other source of naturalized flows for the basin is known to exist. Consequently, there are no naturalized flows available to use for comparison with the set of naturalized flows developed at gages throughout the basin in this study.

Comparisons of the annual naturalized streamflows developed in this study with the historical gaged streamflows at all of the primary control points are presented on plots in Appendix H. The annual historical flow values in the plots correspond to the periods of record for the individual gages. As expected, most of the plots indicate some level of difference between the historical gaged flows and the naturalized streamflows developed in this study, with the naturalized streamflows typically being greater than the gaged flows. These differences occur, of course, because of the adjustments made in deriving the naturalized streamflows to account for the historical effects of diversions, return flows, and reservoir depletions, with the diversions and reservoir depletions being the most dominant. Gages located at or immediately downstream of major reservoirs, such as Pecos River near Orla (Red Bluff Reservoir) and Rio Conchos at Presa La Boquilla (La Boquilla Reservoir), occasionally have greater gaged flows as compared to naturalized flows, reflecting times when releases were made from the reservoirs, but natural inflows were low.

3.1.7 Statistical Assessment of Trends in Streamflow

A statistical analysis of the monthly gaged flows and corresponding periods of naturalized flows is presented in Table 3.1-4. The table shows minimum and maximum flows, and flows corresponding to selected exceedence percentages (flow frequencies) at all primary control points. In general, the trends exhibited by these flow values are consistent with those expected for natural flow systems. Typically, flows increase in the downstream direction. In some cases, channel losses cause noticeable reductions in downstream flows.

3.1.8 International Treaty Flow Distribution

The naturalized streamflows developed in this study for the mainstem of the Rio Grande represent total flows in the river, without regard to ownership between the United States and Mexico pursuant to the terms of the 1944 Treaty and the 1906 Convention between the two countries. The Rio Grande WAM does incorporate the essential provisions of these international agreements with regard to the ownership of the water flowing in the Rio Grande, and these procedures are described in the “Memo Regarding Special Conditions and Overall Model Construction” contained in Appendix I.

As noted in this memo, the Rio Grande in the WAM is structured as two interconnected, parallel watercourses, one for United States flows and one for Mexican flows. With this structure, all of the tributaries of the Rio Grande in Texas are linked to the U.S. or Texas segment of the river, and all of the tributaries of the Rio Grande in Mexico are linked to the Mexican segment of the river. This modeling approach requires that the naturalized flows for the entire basin be divided between the two river systems at the outset of a model simulation, 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 a mass balance on the naturalized flows in the Rio Grande for each side of the river, beginning with the flows at the El Paso gage, i.e., at the upper end of the river system modeled with the WAM. The complete spreadsheet program is included in Appendix Z.

At the El Paso gage, the Mexican portion of the total river flow has been assigned the value of the available Mexico allocation from the Rio Grande Project (which is the only Rio Grande

TABLE 3.1-4
NATURALIZED FLOW STATISTICS FOR PRIMARY CONTROL POINTS - UNITED STATES AND MAINSTEM
(Acre-Feet/Month)

PRIMARY CONTROL POINT NO.	CONTROL POINT LOCATION	PERCENT OF TIME FLOW WAS EQUALED OR EXCEEDED													
		MAXIMUM		**10%**		**25%**		**MEDIAN**		**75%**		**90%**		**MINIMUM**	
		NAT FLOWS	GAGED FLOWS	NAT FLOWS	GAGED FLOWS	NAT FLOWS	GAGED FLOWS	NAT FLOWS	GAGED FLOWS	NAT FLOWS	GAGED FLOWS	NAT FLOWS	GAGED FLOWS	NAT FLOWS	GAGED FLOWS
AT/AM2000	R Grande at El Paso	366,567	356,532	76,579	67,426	58,885	50,892	35,377	29,428	10,698	8,798	4,635	3,703	182	134
AT/AM1000	R Grande at Fort Quitman	382,248	309,392	78,122	27,293	58,407	14,555	34,289	5,697	13,114	892	2,541	67	0	0
BT/BM1000	R Grande abv R Conchos	279,081	239,535	48,196	24,753	34,088	12,972	21,422	3,404	8,834	284	1,440	0	0	0
CT7000	Alamito Ck nr Presidio	59,362	59,362	2,963	2,938	711	711	135	131	78	76	53	51	12	12
CT/CM6000	R Grande blw R Conchos	1,592,267	1,324,213	338,754	157,491	152,640	74,893	82,928	37,523	54,161	20,219	37,184	11,682	8,857	218
CT5000	Terlingua Ck nr Terlingua	68,402	68,402	8,939	8,939	2,973	2,973	295	295	144	144	109	109	20	20
CT/CM4000	R Grande at Johnson Ranch	1,513,190	1,403,574	333,061	164,082	149,203	80,125	80,817	40,278	52,844	22,488	36,314	12,091	7,557	0
CT/CM3000	R Grande at Foster Ranch	1,243,490	929,996	394,954	193,998	182,055	104,242	107,739	57,676	74,372	40,129	57,143	30,043	31,179	13,027
GT5000	Pecos R at Red Bluff	427,555	427,555	14,836	14,362	7,269	6,617	4,229	3,631	2,517	2,118	1,349	1,134	149	157
GT4000	Delaware R nr Red Bluff	45,939	45,939	1,107	1,107	334	334	165	165	94	94	37	37	0	0
GT3000	Pecos R nr Orla	429,255	167,067	14,964	17,008	8,538	9,421	4,662	3,258	2,863	858	1,573	484	0	26
GT2000	Pecos R nr Girvin	522,174	523,001	12,218	5,183	6,431	2,648	3,615	1,765	1,669	1,200	0	803	0	169
GT1000	Pecos R nr Langtry	836,987	804,537	28,110	26,205	16,406	14,986	11,854	10,671	8,881	8,027	7,144	6,450	2,771	3,323
CT2100	Devils R nr Juno	289,478	289,478	9,092	9,092	5,580	5,580	4,499	4,499	2,626	2,626	1,706	1,706	1,093	1,093
CT2000	Devils R at Pafford Crossing	503,018	503,018	29,003	29,034	21,280	21,297	14,907	14,937	10,366	10,384	7,065	7,090	3,955	3,955
CT/CM1000	R Grande at Del Rio	2,976,874	2,959,706	488,941	283,540	262,352	183,070	162,033	116,420	123,201	79,738	99,544	58,630	50,975	11,582
DT9000	San Felipe Ck nr Del Rio	39,909	38,723	8,416	7,584	7,631	6,736	6,163	5,344	3,994	3,349	2,208	1,699	863	286
DT8000	Pinto Ck nr Del Rio	56,767	56,767	2,068	2,068	875	875	319	319	90	90	1	0	0	0
DT/DM5000	R Grande at Piedras Negras	2,898,766	2,793,777	556,938	335,939	313,123	205,143	198,009	125,648	144,373	86,198	117,760	56,891	55,091	4,529
DT/DM3000	R Grande at Laredo	2,327,017	1,994,472	552,464	366,682	338,244	238,603	211,642	143,390	150,290	94,968	121,305	64,386	51,165	338
DT/DM1000	R Grande blw Falcon Dam	2,958,854	1,998,051	599,644	402,132	348,174	257,088	226,135	135,853	156,455	66,543	121,288	40,640	52,110	461
ET/EM2000	R Grande at Rio Grande City	3,257,901	3,048,386	771,988	465,593	471,541	311,276	271,107	163,311	185,002	94,008	143,268	55,622	58,916	72
ET/EM1000	R Grande blw Anzalduas Dam	2,585,407	2,325,935	697,305	230,219	429,062	136,071	254,768	78,899	173,419	47,796	126,822	27,066	58,901	339

TABLE 3.1-4, continued
NATURALIZED FLOW STATISTICS FOR PRIMARY CONTROL POINTS - MEXICO
(Acre-Feet/Month)

PRIMARY CONTROL POINT NO.	CONTROL POINT LOCATION	PERCENT OF TIME FLOW WAS EQUALED OR EXCEEDED													
		MAXIMUM		10%		25%		MEDIAN		75%		90%		MINIMUM	
		NAT FLOWS	GAGED FLOWS	NAT FLOWS	GAGED FLOWS	NAT FLOWS	GAGED FLOWS	NAT FLOWS	GAGED FLOWS	NAT FLOWS	GAGED FLOWS	NAT FLOWS	GAGED FLOWS	NAT FLOWS	GAGED FLOWS
FM6000	R Conchos at La Boquilla Res.	1,251,727	215,620	221,225	132,217	75,116	102,025	32,836	73,366	17,306	33,313	7,627	7,995	0	546
FM5000	R Florido at Cd. Jimenez	454,193	454,193	26,655	16,289	3,628	1,347	353	18	0	0	0	0	0	0
FM4000	R San Pedro at Villalba	390,950	390,950	66,487	66,487	13,526	13,526	4,539	4,539	2,550	2,550	1,443	1,443	476	476
FM3000	R Conchos at Las Burras	1,909,090	987,469	332,048	71,649	130,216	45,277	69,110	32,308	42,469	21,679	25,924	8,370	3,239	525
FM2000	R Conchos at El Granero	1,913,910	763,569	380,757	107,814	143,392	62,200	81,195	33,348	54,211	20,432	36,164	12,713	7,390	0
FM1000	R Conchos nr Ojinaga	1,690,153	1,042,202	297,905	115,252	124,096	62,999	67,839	28,183	42,804	15,109	26,157	5,793	77	280
DM9500	Arroyo de las Vacas at Cd. Acuna	63,301	62,538	2,577	2,297	1,144	729	725	395	393	187	235	95	67	21
DM7000	R San Diego nr Jimenez	156,587	136,243	36,085	27,051	19,741	14,304	10,542	5,558	5,798	3,076	3,600	2,025	788	145
DM6000	R San Rodrigo at El Moral	459,498	454,948	23,720	20,702	9,561	6,595	3,603	1,809	1,487	418	413	0	0	0
DM4000	R Escondido at Villa de Fuente	55,213	49,209	14,510	8,990	9,109	3,152	5,359	1,305	2,218	464	1,078	195	0	0
DM2300	R Sabinas at Sabinas	626,572	625,343	75,023	74,409	21,872	21,399	4,288	3,154	1,545	399	812	37	331	0
DM2200	R Nadadores at Progreso	125,711	123,516	7,086	2,822	5,387	1,157	3,660	252	2,263	31	1,506	0	987	0
DM2100	R Salado at Rodriguez	800,468	710,155	90,599	20,355	36,127	6,891	14,974	2,929	6,328	980	2,879	159	542	0
DM2000	R Salado nr Las Tortillas	1,051,633	807,836	106,957	42,782	49,150	14,001	19,628	4,749	7,960	1,082	3,438	0	0	0
EM4000	R Alamo at Cd. Mier	434,565	434,565	17,628	17,628	6,888	6,888	1,571	1,571	203	203	0	0	0	0
EM3400	R San Juan at El Cuchillo	967,923	965,174	109,024	95,638	46,435	38,193	19,566	14,343	7,905	3,957	3,455	887	0	0
EM3300	R Salinas at Cienega de Flores	267,188	267,188	10,466	10,466	4,134	4,134	1,284	1,284	252	252	47	47	0	0
EM3200	R Pesqueria at Los Herrera	273,066	269,579	29,018	24,522	15,081	10,579	7,746	3,805	3,669	660	2,264	0	0	0
EM3100	R San Juan at Los Aldamas	1,780,742	1,773,070	187,982	170,240	80,248	64,297	37,254	25,058	18,522	6,532	11,497	2,539	0	215
EM3000	R San Juan at Camargo	1,860,153	1,881,032	205,799	32,703	83,375	3,593	37,159	526	18,133	226	9,334	11	0	0

water available to Mexico above Fort Quitman under the 1906 Convention) as determined during the streamflow naturalization process for the New Mexico stateline gages as described in the Rio Grande Naturalized Streamflow Report and as summarized in Section 3.1.3 above. The annual amounts of these Mexican allocations were distributed to monthly values based on the historical monthly use (diversion) pattern for Mexico's Acequia Madre canal at Juarez, which is the only reported Rio Grande diversion for Mexico above Fort Quitman. The balance of the monthly naturalized flow at El Paso then was assigned to the United States (Texas). These monthly naturalized flows for the Rio Grande for Mexico and for the U.S. at the El Paso gage are presented in Tables 3.1-5 and 3.1-6, respectively.

With the Rio Grande naturalized flows distributed between Mexico and the U.S. 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 simply involved a systematic process of adding each country's tributary inflows to the Rio Grande (naturalized) to their respective share of the flow at each control point, proceeding from upstream to downstream. Between gaged tributaries, the incremental naturalized flows, provided they represented gains in river flow, were split equally between the two countries in accordance with the provisions of the 1944 Treaty. If the incremental flows indicated streamflow losses, then, again in accordance with the provisions of the 1944 Treaty, the losses were distributed to the river flows of each country proportional to the amount of water each country had flowing in the subject reach of the river. This flow distribution process was continued downstream along the entire length of the Rio Grande to the lowest primary control points included in the WAM for each country. The final result was a complete set of monthly naturalized streamflows for the 1940-2000 period for each country at each of the primary control points on the mainstem of the Rio Grande as presented in Appendix Z.

3.2 Natural Streamflow at Ungaged Locations

3.2.1 Distribution of Natural Flows Considering Channel Losses

There are 951 control points in the Rio Grande WAM, 863 in the U.S. and 88 in Mexico. Naturalized streamflows were developed for the primary control points as discussed above. These naturalized streamflows then were distributed to the other (ungaged, or secondary) control points throughout the basin using procedures provided in the WRAP program. The basic method used for distributing the naturalized flows from gaged to ungaged control points was the drainage area ratio method, as directed by TCEQ. With this method, flows at gaged points are multiplied by the ratio of drainage areas between the ungaged and gaged points to obtain the flows at the ungaged point.

The WRAP model has an option that uses the U.S. Natural Resources Conservation Service (NRCS) Curve Number (CN) method, which is documented and described in detail in the WRAP users manual. This method uses total drainage areas, curve numbers, and mean annual

TABLE 3.1-5
NATURALIZED RIO GRANDE FLOWS FOR MEXICO AT EL PASO GAGE

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC	ANNUAL
1940	0	0	2,400	10,200	10,200	10,800	10,800	10,800	4,800	0	0	0	60,000
1941	0	0	2,400	10,200	10,200	10,800	10,800	10,800	4,800	0	0	0	60,000
1942	0	0	2,400	10,200	10,200	10,800	10,800	10,800	4,800	0	0	0	60,000
1943	0	0	2,400	10,200	10,200	10,800	10,800	10,800	4,800	0	0	0	60,000
1944	0	0	2,400	10,200	10,200	10,800	10,800	10,800	4,800	0	0	0	60,000
1945	0	0	2,400	10,200	10,200	10,800	10,800	10,800	4,800	0	0	0	60,000
1946	0	0	1,983	8,426	8,426	8,921	8,921	8,921	3,965	0	0	0	49,563
1947	0	0	2,400	10,200	10,200	10,800	10,800	10,800	4,800	0	0	0	60,000
1948	0	0	2,400	10,200	10,200	10,800	10,800	10,800	4,800	0	0	0	60,000
1949	0	0	2,400	10,200	10,200	10,800	10,800	10,800	4,800	0	0	0	60,000
1950	0	0	2,400	10,200	10,200	10,800	10,800	10,800	4,800	0	0	0	60,000
1951	0	0	1,649	7,007	7,007	7,419	7,419	7,419	3,297	0	0	0	41,217
1952	0	0	2,346	9,971	9,971	10,558	10,558	10,558	4,692	0	0	0	58,653
1953	0	0	1,508	6,409	6,409	6,786	6,786	6,786	3,016	0	0	0	37,698
1954	0	0	467	1,986	1,986	2,103	2,103	2,103	935	0	0	0	11,683
1955	0	0	333	1,417	1,417	1,500	1,500	1,500	667	0	0	0	8,333
1956	0	0	505	2,146	2,146	2,272	2,272	2,272	1,010	0	0	0	12,622
1957	0	0	929	3,946	732	7,393	4,179	4,179	1,857	0	0	0	23,214
1958	0	0	2,400	10,200	10,200	10,800	10,800	10,800	4,800	0	0	0	60,000
1959	0	0	2,400	10,200	10,200	10,800	10,800	10,800	4,800	0	0	0	60,000
1960	0	0	2,400	10,200	10,200	10,800	10,800	10,800	4,800	0	0	0	60,000
1961	0	0	1,944	8,264	8,264	8,750	8,750	8,750	3,889	0	0	0	48,611
1962	0	0	2,400	10,200	10,200	10,800	10,800	10,800	4,800	0	0	0	60,000
1963	0	0	1,587	6,746	6,746	7,143	7,143	7,143	3,175	0	0	0	39,683
1964	0	0	397	1,686	1,686	1,785	1,785	1,785	793	0	0	0	9,916
1965	0	0	1,573	6,685	767	10,800	9,274	7,078	3,146	0	0	0	39,322
1966	0	0	1,984	8,433	8,433	8,929	8,929	8,929	3,968	0	0	0	49,603
1967	0	0	1,190	5,060	5,060	5,357	5,357	5,357	2,381	0	0	0	29,762
1968	0	0	1,587	6,746	6,746	7,143	7,143	7,143	3,175	0	0	0	39,683
1969	0	0	2,400	10,200	10,200	10,800	10,800	10,800	4,800	0	0	0	60,000
1970	0	0	2,400	10,200	10,200	10,800	10,800	10,800	4,800	0	0	0	60,000
1971	0	0	1,389	5,903	5,903	6,250	6,250	6,250	2,778	0	0	0	34,722
1972	0	0	261	1,107	1,107	1,173	1,173	1,173	521	0	0	0	6,514
1973	0	0	2,400	10,200	10,200	10,800	10,800	10,800	4,800	0	0	0	60,000
1974	0	0	2,400	10,200	10,200	10,800	10,800	10,800	4,800	0	0	0	60,000
1975	0	0	2,400	10,200	10,200	10,800	10,800	10,800	4,800	0	0	0	60,000
1976	0	0	2,400	10,200	10,200	10,800	10,800	10,800	4,800	0	0	0	60,000
1977	0	0	924	3,927	3,927	4,158	4,158	4,158	1,848	0	0	0	23,103
1978	0	0	821	3,489	2,968	4,215	3,694	3,694	1,642	0	0	0	20,525

TABLE 3.1-5, cont'd.

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC	ANNUAL
1979	0	0	2,400	10,200	10,200	10,800	10,800	10,800	4,800	0	0	0	60,000
1980	0	0	2,400	10,200	10,200	10,800	10,800	10,800	4,800	0	0	0	60,000
1981	0	0	2,400	10,200	10,200	10,800	10,800	10,800	4,800	0	0	0	60,000
1982	0	0	2,400	10,200	10,200	10,800	10,800	10,800	4,800	0	0	0	60,000
1983	0	0	2,400	10,200	10,200	10,800	10,800	10,800	4,800	0	0	0	60,000
1984	0	0	2,400	10,200	10,200	10,800	10,800	10,800	4,800	0	0	0	60,000
1985	0	0	2,400	10,200	10,200	10,800	10,800	10,800	4,800	0	0	0	60,000
1986	0	0	2,400	10,200	10,200	10,800	10,800	10,800	4,800	0	0	0	60,000
1987	0	0	2,400	10,200	10,200	10,800	10,800	10,800	4,800	0	0	0	60,000
1988	0	0	2,400	10,200	10,200	10,800	10,800	10,800	4,800	0	0	0	60,000
1989	0	0	2,400	10,200	10,200	10,800	10,800	10,800	4,800	0	0	0	60,000
1990	0	0	2,400	10,200	10,200	10,800	10,800	10,800	4,800	0	0	0	60,000
1991	0	0	2,400	10,200	10,200	10,800	10,800	10,800	4,800	0	0	0	60,000
1992	0	0	2,400	10,200	10,200	10,800	10,800	10,800	4,800	0	0	0	60,000
1993	0	0	2,400	10,200	10,200	10,800	10,800	10,800	4,800	0	0	0	60,000
1994	0	0	2,400	10,200	10,200	10,800	10,800	10,800	4,800	0	0	0	60,000
1995	0	0	2,400	10,200	10,200	10,800	10,800	10,800	4,800	0	0	0	60,000
1996	0	0	2,400	10,200	10,200	10,800	10,800	10,800	4,800	0	0	0	60,000
1997	0	0	2,400	10,200	10,200	10,800	10,800	10,800	4,800	0	0	0	60,000
1998	0	0	2,400	10,200	10,200	10,800	10,800	10,800	4,800	0	0	0	60,000
1999	0	0	2,400	10,200	10,200	10,800	10,800	10,800	4,800	0	0	0	60,000
2000	0	0	2,400	10,200	10,200	10,800	10,800	10,800	4,800	0	0	0	60,000

TABLE 3.1-6
NATURALIZED RIO GRANDE FLOWS FOR TEXAS AT EL PASO GAGE

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC	ANNUAL
1940	12,191	14,440	41,472	55,321	48,981	66,624	67,316	58,400	42,470	21,594	13,489	12,478	454,776
1941	9,437	8,036	26,999	58,006	54,917	57,679	71,617	80,824	74,769	28,659	18,501	18,683	508,127
1942	13,380	53,672	61,904	132,776	356,367	302,186	192,655	151,260	171,483	59,555	21,609	26,327	1,543,175
1943	16,679	24,060	55,295	76,358	80,703	79,678	83,529	82,750	65,119	29,885	23,448	18,579	636,082
1944	13,161	17,109	48,471	71,944	68,832	68,286	81,714	92,826	82,571	32,538	18,405	18,703	614,558
1945	12,720	18,604	52,350	66,057	64,320	59,621	74,329	80,314	62,820	39,513	20,530	24,133	575,310
1946	13,269	16,799	40,387	59,240	61,525	56,235	69,451	76,677	45,721	27,790	16,772	15,443	499,309
1947	11,151	10,329	39,720	63,269	48,389	60,674	67,991	77,146	41,052	16,478	11,755	10,693	458,647
1948	8,798	7,362	22,817	48,210	46,070	56,908	73,784	70,415	42,548	21,355	15,135	15,002	428,404
1949	12,152	9,163	36,380	54,194	53,035	55,643	71,866	62,887	53,209	22,593	16,762	13,784	461,667
1950	10,943	11,327	51,098	54,004	52,897	55,494	76,469	65,779	44,761	20,390	12,179	10,801	466,141
1951	10,413	8,095	28,698	32,772	15,047	34,362	48,602	51,389	17,795	8,538	6,946	6,530	269,188
1952	6,465	4,816	11,171	29,399	41,893	60,469	67,025	76,894	44,625	11,186	7,723	7,540	369,207
1953	4,946	3,290	38,449	31,329	21,794	33,511	41,715	46,746	27,692	6,327	4,900	4,235	264,934
1954	4,127	2,538	6,453	26,739	14,158	13,706	18,376	12,699	2,138	4,797	682	568	106,979
1955	708	370	5,741	12,548	1,398	6,472	18,337	14,493	17,624	1,964	512	368	80,535
1956	478	432	22,042	34,302	343	12,771	18,058	7,708	7,812	306	465	421	105,137
1957	297	182	1,491	5,293	0	12,314	45,937	60,171	35,658	3,212	752	600	165,907
1958	450	397	30,584	28,718	37,569	50,393	64,955	62,532	66,865	21,590	7,291	5,611	376,953
1959	4,544	3,785	55,012	33,579	40,480	58,165	59,616	64,392	33,407	9,595	6,930	7,438	376,945
1960	6,605	4,419	56,206	34,473	37,848	50,191	59,532	60,576	37,512	12,702	8,552	8,336	376,951
1961	6,961	4,753	43,331	31,418	27,427	39,890	55,885	48,999	28,384	8,962	6,987	8,612	311,610
1962	5,819	4,291	51,600	31,465	30,115	49,757	63,369	62,368	43,039	15,457	10,259	9,410	376,950
1963	6,964	4,891	54,013	30,831	18,710	40,134	48,021	26,636	15,790	6,989	5,238	4,806	263,022
1964	5,437	3,596	11,805	16,968	177	7,989	13,151	14,340	13,802	825	749	775	89,614
1965	726	663	3,723	15,735	0	47,359	74,738	68,240	40,708	3,079	1,752	1,583	258,305
1966	1,171	889	51,197	35,191	25,776	52,281	55,693	56,084	20,116	7,822	5,642	5,438	317,302
1967	4,251	2,744	51,381	23,871	22,571	23,512	30,786	35,853	28,980	5,812	2,877	3,206	235,842
1968	3,193	2,156	43,876	24,584	20,224	40,440	46,398	39,638	24,281	7,616	5,746	6,008	264,159
1969	5,605	3,075	48,194	30,108	26,808	52,351	70,168	71,994	38,971	12,968	8,124	8,584	376,949
1970	6,783	6,755	53,784	36,123	39,229	45,859	70,671	54,872	33,657	14,338	8,161	6,716	376,949
1971	5,877	3,738	49,260	30,289	33,486	37,265	40,215	26,695	12,640	5,656	3,344	3,255	251,721
1972	3,119	2,177	42,051	19,282	10,017	7,785	29,672	25,265	12,531	6,415	1,145	1,010	160,469
1973	672	505	33,679	33,822	35,036	53,329	66,339	74,057	50,450	14,492	7,980	6,579	376,941
1974	4,870	4,263	53,733	30,687	31,406	51,997	59,127	57,416	36,083	25,265	13,859	8,246	376,952
1975	10,972	8,115	36,529	36,307	39,996	49,511	48,672	56,481	52,145	16,281	10,950	10,990	376,949
1976	17,465	15,880	42,555	45,847	57,019	45,930	43,653	53,514	30,577	16,072	11,741	11,206	391,461

TABLE 3.1-6, cont'd.

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC	ANNUAL
1977	8,388	4,912	33,001	20,984	16,640	30,209	33,761	41,331	14,594	3,602	2,491	2,854	212,766
1978	2,400	1,579	15,124	8,813	0	31,001	32,983	43,417	13,359	3,348	4,045	1,834	157,902
1979	2,037	1,451	41,687	26,601	28,960	60,031	72,511	67,057	52,286	12,143	7,074	5,105	376,942
1980	10,867	9,208	38,494	37,057	40,221	57,414	62,991	56,152	32,427	13,667	9,472	8,978	376,948
1981	4,635	14,399	33,443	37,637	43,623	53,316	60,129	52,334	47,969	14,679	8,465	6,309	376,938
1982	5,685	11,112	46,789	39,195	43,403	41,144	52,737	60,805	39,568	15,820	9,891	10,786	376,937
1983	6,984	12,093	42,585	30,274	38,842	40,732	60,398	60,168	44,076	23,151	11,092	6,548	376,944
1984	5,105	13,095	38,506	32,811	43,466	44,578	56,255	55,871	39,778	25,755	10,698	11,023	376,941
1985	8,228	5,753	35,559	30,839	38,041	44,457	55,256	53,845	43,985	37,973	13,374	9,639	376,948
1986	24,140	53,119	67,625	46,462	61,746	87,407	133,870	87,050	59,151	137,832	104,805	166,173	1,029,379
1987	126,263	102,939	115,763	106,088	155,245	119,382	154,281	73,751	45,019	30,436	16,238	11,696	1,057,100
1988	11,613	14,795	91,064	76,229	58,859	67,628	71,489	70,484	43,534	26,999	12,085	10,023	554,800
1989	8,304	11,328	58,339	35,403	44,580	61,139	69,613	56,742	37,078	18,026	9,289	7,555	417,395
1990	5,906	8,358	54,633	30,580	33,042	58,263	64,886	37,418	44,584	23,325	11,940	8,720	381,655
1991	6,569	6,301	50,954	28,486	32,477	48,085	61,784	52,638	42,478	22,782	12,651	12,883	378,089
1992	19,084	19,354	61,939	41,067	46,686	51,506	59,602	55,145	46,694	35,858	14,111	10,683	461,732
1993	12,007	22,723	62,758	55,627	53,533	57,074	68,195	65,046	46,250	28,716	12,707	8,663	493,298
1994	12,280	18,766	53,290	36,732	36,056	99,163	63,648	59,063	44,473	48,068	14,558	13,012	499,109
1995	13,071	16,081	58,247	40,426	69,166	106,933	162,487	81,785	65,170	45,022	14,715	10,793	683,896
1996	17,103	22,518	59,635	40,316	39,152	57,445	58,081	53,665	44,567	25,855	10,322	6,504	435,163
1997	9,111	15,934	63,724	37,596	33,345	61,210	74,362	64,296	52,708	34,654	14,678	10,402	472,020
1998	13,643	18,926	51,729	35,380	33,566	55,747	72,738	64,862	45,641	30,637	13,535	9,368	445,773
1999	7,595	17,866	53,615	35,072	35,453	59,486	70,754	69,192	47,342	30,761	11,409	8,858	447,403
2000	12,573	11,222	51,216	29,920	35,369	67,904	61,732	61,145	41,462	28,419	13,236	8,817	423,014

precipitation to distribute the flows from gaged to ungaged control points. Drainage areas, mean annual precipitation values, and curve numbers for the gaged watersheds and ungaged subwatersheds associated with the control points used in the WAM were provided by the University of Texas Center for Research in Water Resources (CRWR) using a geographic information system (GIS) data base. These data have been included in the WRAP input file for possible later use, but were not used in this analysis.

For control points representing off-channel reservoirs with no significant contributing drainage area, zero watershed inflows have been assumed, and no naturalized flows were distributed to these points. However, direct precipitation on these impoundments has been accounted for in the water availability analyses.

Channel losses were defined for each reach between primary control points and were applied in developing the naturalized flows as discussed in Section 3.1.4. These channel loss factors (CLFs) were also used in the WRAP model to distribute naturalized flows to secondary control points. CLFs are also applied by WRAP to diversions, return flows, springs, and reservoir depletions and releases. For these purposes, the loss rates determined for each loss reach discussed in Section 3.1.4 were prorated to the secondary control points within each losing reach proportional to the stream channel length between a control point and the next downstream control point within the incremental drainage area that included the relevant reach, and adjusted to preserve the overall defined CLF for the primary reach.

3.2.2 Ungaged Freshwater Inflows to the Estuary

The Rio Grande estuary is limited to a portion of the river channel below Brownsville, a distance of up to approximately 35 miles. This area receives insignificant inflows from ungaged drainage areas. Flood control levees along the river below Anzalduas Dam and the naturally sloping of the land away from the river as a result of historical sedimentation substantially limit runoff to the river. Consequently, the river flows at the Anzalduas primary control point (ET/EM-1000) represent virtually all natural flows in the river from there to the mouth. Nonetheless, an additional control point has been established at the mouth of the Rio Grande to account for all additional inflows (ET/EM-0000). Naturalized flows have been distributed to this point using the same procedure utilized for all secondary control points.

3.3 Adjusted Net Reservoir Evaporation

3.3.1 Evaporation and Precipitation Data Sources

In Texas, monthly values of historical average reservoir gross evaporation amounts have been derived by the Texas Water Development Board (TWDB) for all of Texas based on available evaporation data. These gross evaporation rates are available for each month of the entire 1940-2000 analysis period for the Rio Grande Basin, and they are provided at the center of each one-degree quadrangle covering the basin. Similarly, historical monthly average precipitation amounts have been determined at the same locations. The relevant boundaries of these one-degree quadrangles as well as the locations of the major reservoirs (see Section 3.4) are overlaid on the map of the Rio Grande Basin in Figure 3.3-1.

In Mexico, evaporation and precipitation data are collected daily at each reservoir. These values were used directly.

3.3.2 Procedures for Estimation of Adjusted Net Evaporation

For each major reservoir in Texas and on the mainstem of the Rio Grande, distance-weighted factors have been determined and used to calculate average gross evaporation and precipitation values at the approximate centroid of the reservoir based on the reported gross evaporation rates and precipitation amounts at the centers of the nearest TWDB one-degree quadrangles. The weighting given to each quadrangle was inversely proportional to the distance from the reservoir to the center of the quadrangle. The equations incorporating these factors and used to calculate the historical monthly gross evaporation and precipitation rates for each of the major reservoirs in the basin are listed in Table 3.3-1.

As stated above, the actual evaporation data collected at each reservoir in Mexico were used for these reservoirs.

Adjusted net reservoir evaporation is defined by the following relationship:

Adjusted Net Reservoir Evaporation = Gross Reservoir Evaporation

– Precipitation on the Reservoir Surface

+ Runoff from Reservoir Area in Absence

The calculation of runoff for a given amount of precipitation at a major reservoir site was done by applying a runoff coefficient to the historical rainfall. Historical monthly streamflows for selected streamflow gages throughout the basin have been used, in conjunction with the corresponding historical monthly rainfall amounts, to calculate representative monthly runoff coefficients for the various regions of the Rio Grande Basin.

There are comparatively few minor reservoirs in the Rio Grande Basin. Adjusted net reservoir evaporation from the nearest major reservoir was used for these reservoirs.

Figure 3.3-1 Evaporation Quadrangles and Reservoir Locations

TABLE 3.3-1
RESERVOIR EVAPORATION-PRECIPITATION EQUATIONS
TEXAS AND MAINSTEM RESERVOIRS

WATER-SHED	RESERVOIR NAME	DISTANCE-WEIGHTED FACTORS AND TWDB QUADRANGLE ID NUMBERS *
BT1000	San Esteban	0.377(703) + 0.333(704) + 0.161(803) + 0.129(804)
GT3000	Red Bluff Reservoir	0.317(504) + 0.287(603) + 0.396(604)
GT2000	Lake Balmorhea	0.049(603) + 0.396(604) + 0.090(703) + 0.466(704)
GT2000	Imperial Reservoir	0.297(604)+0.556(605)+0.147(705)
CT/CM1000	Amistad International Reservoir	0.630(806) + 0.370(807)
DT3000	Lake Casa Blanca	0.046(908) + 0.887(1008) + 0.067(1009)
DT/DM1000	Falcon International Reservoir	0.120(1008) + 0.617(1108) + 0.263(1109)
ET1000	Delta Unit 1	0.470(1109) + 0.530(1110)
ET1000	Delta Unit 2	0.440(1109) + 0.560(1110)
ET1000	Valley Acres Reservoir	0.310(1109) + 0.532(1110) + 0.157(1210)
ET/EM1000	Anzalduas Channel Reservoir	0.863(1109) + 0.137(1110)

* Quadrangle ID numbers are in parentheses. See Figure 3.3-1 for locations of quadrangles.

3.3.3 Comparison of Evaporation Data Sets

The average annual values from the adjusted net evaporation data for the 1940-2000 analysis period for the major Texas and mainstem reservoirs are plotted on Figure 3.3-2. These data sets have been separated into two groups for comparison purposes, representing the reservoirs in the upper (above Amistad Dam) and lower parts of the basin. As expected, the trend is for higher net evaporation in the upper part of the basin. In general, the highest net evaporation rates were observed during the droughts of the 1950s and 1990s.

3.4 Reservoir Elevation-Area-Capacity Relationships

Historical relationships between the surface area of reservoirs and their storage capacity are needed to properly account for the storage capabilities and net evaporation losses in the WAM. The elevation-area-capacity relationship (also referred to as an area-capacity curve) for a reservoir is generally developed during the reservoir design phase. This relationship is based on the topographic characteristics of the land to be inundated by the reservoir. During the life of the reservoir, sediment deposition within the reservoir typically alters that relationship and reduces the capacity of the reservoir. Sediment deposition is distributed in various zones of a reservoir at differing rates, dependent on the shape of the reservoir and other factors.

Area-capacity curves have been specified assuming that stored water would be available down to the bottom of the channel, ignoring dead storage. It is presumed that during an extreme drought a means would be devised to gain access to all stored water.

3.4.1 Major Reservoirs

As requested by TCEQ, two different elevation-area-capacity relationships have been considered for the reservoirs in the Texas and mainstem portion of the Rio Grande Basin for purposes of the water availability analyses. The first is referred to as the “authorized” area-capacity relationship, and it corresponds to the original area-capacity curve that was adopted at the time each impoundment was permitted. The other area-capacity relationship corresponds to reservoir sedimentation conditions for the year-2000, and it is to be used only for major reservoirs. The year-2000 area-capacity relationships for off-channel reservoirs with no watershed inflows have not been considered in the water availability analyses since sedimentation effects on such reservoirs would be relatively insignificant.

The major reservoirs in the Rio Grande Basin are listed along with pertinent descriptive information in Table 3.4-1. There are eight major reservoirs in Texas and 18 in Mexico. Also indicated are the years in which area-capacity relationships are known to have been developed from pre-reservoir topographic maps and/or post-reservoir sedimentation surveys of the actual impoundments, along with the estimated year-2000 capacities.

FIGURE 3.3-2
COMPARISON OF ANNUAL ADJUSTED NET EVAPORATION
(Texas and Mainstem Reservoirs)

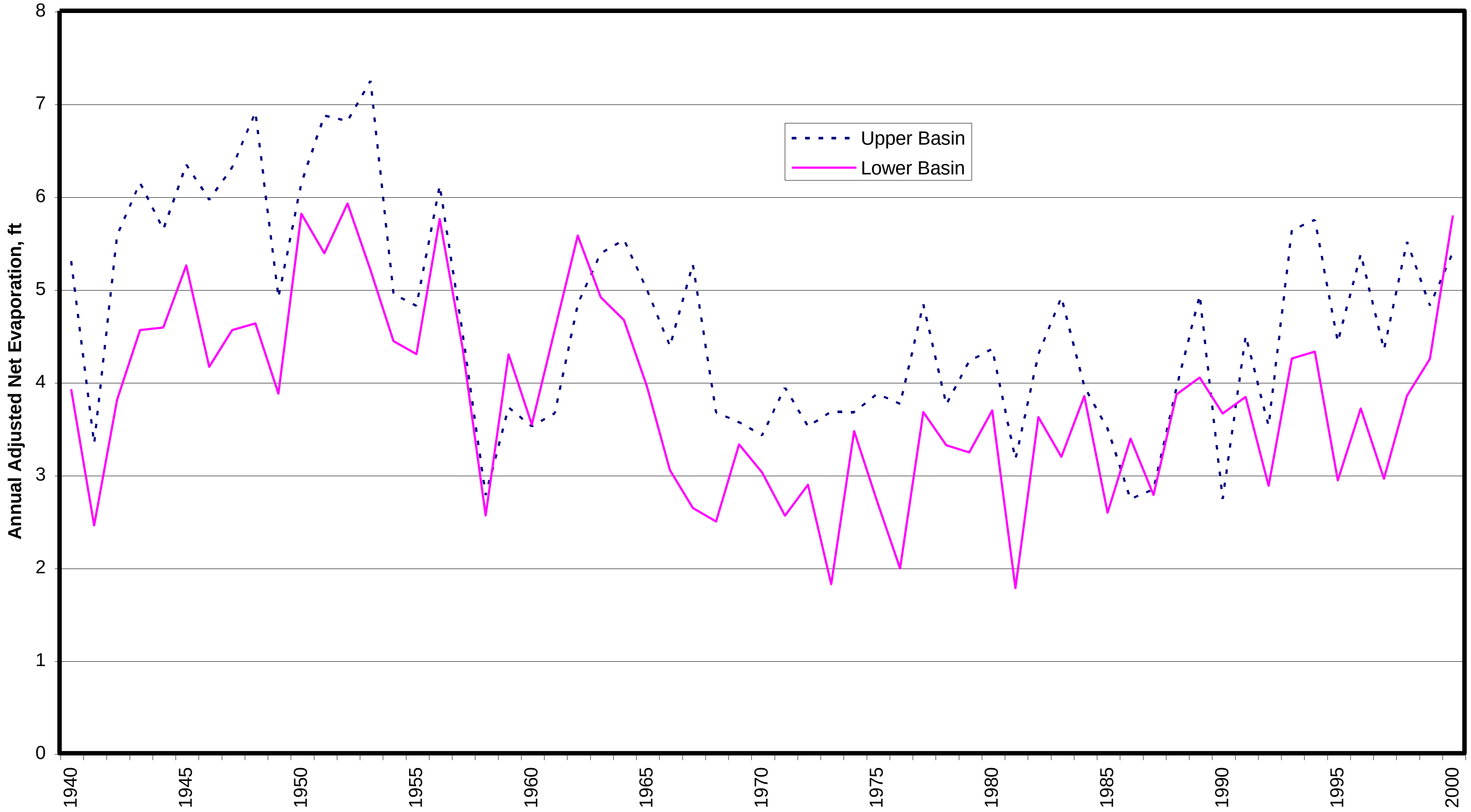


TABLE 3.4-1
MAJOR RESERVOIRS IN THE RIO GRANDE BASIN
TEXAS AND MAINSTEM RESERVOIRS

NAME OF RESERVOIR	ORIGINAL STORAGE CAPACITY AC-FT	DATE OF IMPOUND-MENT	SURVEYED STORAGE CAPACITY AC-FT	DATE OF SURVEY	PERIOD YEARS	CONTRIB. DRAINAGE AREA SQ. MI.	SEDIMENTATION RATE	
							CALCULATED AC-FT/MI^2/YR	TWDB REPORT 268 AC-FT/MI^2/YR
San Esteban Lake	18,770	1911	3,100	1986 [a]	75	500	0.42	n/a
Red Bluff Dam	310,000	1936	289,000	1962/1986 [b]	24	20,720	0.04	0.18
Lake Balmorhea	6,350	1917	n/a	n/a	n/a	22	n/a	0.13
Imperial Reservoir *	6,000	1914	n/a	n/a	n/a	48	n/a	n/a
Amistad Reservoir	3,505,238	1968	3,151,306	1992 [c]	24	126,423	0.12	0.08
Casa Blanca Lake	20,000	1949	19,000	1963 [d]	14	117	0.61	0.16
Falcon Reservoir	2,371,221	1953	2,653,793	1992 [e]	39	164,482	-0.04	0.15
Anzalduas Dam	13,900	1960	n/a	n/a	n/a	176,112	n/a	n/a

* Off-channel reservoir

[a] TWRC, 1976

[b] RBWPCD, 1987

[c] IBWC, 1994

[d] TWDB, 1971

[e] IBWC, 1992

TABLE 3.4-1, continued
MAJOR RESERVOIRS IN THE RIO GRANDE BASIN
MEXICAN RESERVOIRS

NAME OF RESERVOIR	ORIGINAL STORAGE CAPACITY AC-FT	DATE OF IMPOUND-MENT	SURVEYED STORAGE CAPACITY AC-FT	DATE OF SURVEY	PERIOD YEARS	DRAINAGE AREA SQ. MI.	SEDIMENTATION RATE CALCULATED AC-FT/MI^2/YR
El Parral	8,187	1952	n/a	n/a	n/a	147	n/a
Pico del Aguila	40,520	1992	n/a	n/a	n/a	1,151	n/a
San Gabriel	207,027	1979	n/a	n/a	n/a	1,056	n/a
La Boquilla	2,353,728	1916	2,111,573	1977	62	8,113	0.48
La Colina	19,535	1927	n/a	n/a	n/a	8,175	n/a
Francisco I. Madero	282,126	1949	225,167	1977	29	4,163	0.47
Chihuahua	20,913	1960	n/a	n/a	n/a	152	n/a
El Rejon	7,676	1968	n/a	n/a	n/a	63	n/a
Luis L. Leon	288,574	1968	n/a	n/a	n/a	22,536	n/a
Centenario	21,322	1985	n/a	n/a	n/a	n/a	n/a
San Miguel	16,212	1936	n/a	n/a	n/a	n/a	n/a
La Fragua	36,477	1993	n/a	n/a	n/a	680	n/a
Las Blancas	100,514	2000	n/a	n/a	n/a	4,000	n/a
Venustiano Carranza	1,122,182	1930	1,072,037	2001	72	16,158	0.04
Laguna de Salinillas	15,401	1957	n/a	n/a	n/a	25	n/a
La Boca	33,235	1957	n/a	n/a	n/a	107	n/a
El Cuchillo	910,304	1993	n/a	n/a	n/a	3,447	n/a
Marte R. Gomez	889,228	1943	750,842	1959	17	12,563	0.65

The general methodology used for developing the year-2000 area-capacity relationship for each of the large reservoirs has involved the following steps:

1) Obtain the authorized and any subsequent area-capacity curves.
2) Estimate annual sediment delivery to the impoundments.
3) Distribute the sediment throughout the impoundment using the SEDDIS2 program.
4) Prepare the year-2000 curve using the SEDDIS2 output.

The authorized area-capacity curves have been obtained primarily from TWDB Report 126, “Dams and Reservoirs in Texas” (1971). Some authorized curves and more recent curves have also been obtained from TCEQ Dam Safety files, IBWC, directly from other lake owners or operators, and from volumetric surveys performed by the TWDB.

Estimates of historical sediment delivery to the different reservoirs have been obtained primarily from Texas Department of Water Resources Report 268, “Erosion and Sedimentation by Water in Texas” (1982). Where volumetric surveys have been performed since construction, sediment accumulation rates were calculated based on the capacity lost as determined by the re-survey. Sedimentation rates are presented as part of Table 3.4-1.

The estimated sediment loadings have been distributed within the reservoirs using an unpublished computer program called SEDDIS2. This program distributes sediment throughout the elevations of a reservoir between the bottom of the original streambed at the dam and the maximum normal water surface. Computations are based on the U. S. Bureau of Reclamation's Empirical Area-Reduction Method (Borland and Miller, 1958). Distribution of the sediment is based primarily on the reservoir type: lake, floodplain-foothill, hill, or gorge. The program determines the type based on the original elevation-area-capacity data. Distribution of the sediment in the reservoirs in the Rio Grande Basin has been limited to the area below the elevation of the top of the conservation pool.

The authorized and year-2000 area-capacity curves for the major reservoirs modeled are presented in Appendix J.

For the Mexico portion of the Rio Grande Basin only the original area-capacity curves were utilized in the model. The area-capacity curves have been derived primarily from information from the Comision Nacional del Agua (CNA).

3.4.2 Small Reservoirs

Elevation-area-capacity relationships have been used in the water availability analyses for the small reservoirs with less than 5,000 acre-feet of storage capacity and the off-channel reservoirs. The elevation-area-capacity relationships as originally permitted for these reservoirs have been used, where known. All permitted impoundments located in the contributing drainage area have been included in the WRAP model regardless of size.

For those impoundments where only the maximum storage capacity could be obtained, standardized area-capacity curves have been generated using an equation of the form:

$$\text{Area} = a(\text{Capacity})^{b} + c$$

This form of equation, known as a power function, is the only equation form available to represent area-capacity relationships in the WRAP model. To obtain the coefficients a, b, and c, regression analyses of available area-capacity data for existing small reservoirs have been performed. All available area-capacity curves for reservoirs with a conservation capacity less than 5,000 acre-feet in the Rio Grande Basin were plotted, and power function regression analyses were performed to obtain the best-fit equation.

The data for the lower Rio Grande were analyzed separately from the upper Rio Grande Basin data, with Amistad Dam acting as the divide between the upper and lower basin. The lower analysis was based on two reservoirs in Starr County. The upper was based on 15 reservoirs in Hudspeth, Crockett, and Sutton counties. This data from the areas below Amistad exhibited a somewhat higher area-to-capacity ratio than the upper Rio Grande data. The flat topography of the area below Amistad Dam typically results in higher reservoir surface areas compared to reservoirs in the upper portions of the basin, where there is greater relief.

For the lower Rio Grande, the best-fit equation for all the data resulted in the following equation:

$$\text{Area} = 1.7304(\text{Capacity})^{0.6545} + 0 \qquad r^2 = 0.9138$$

For the upper Rio Grande, the best-fit equation for all the data resulted in the following equation:

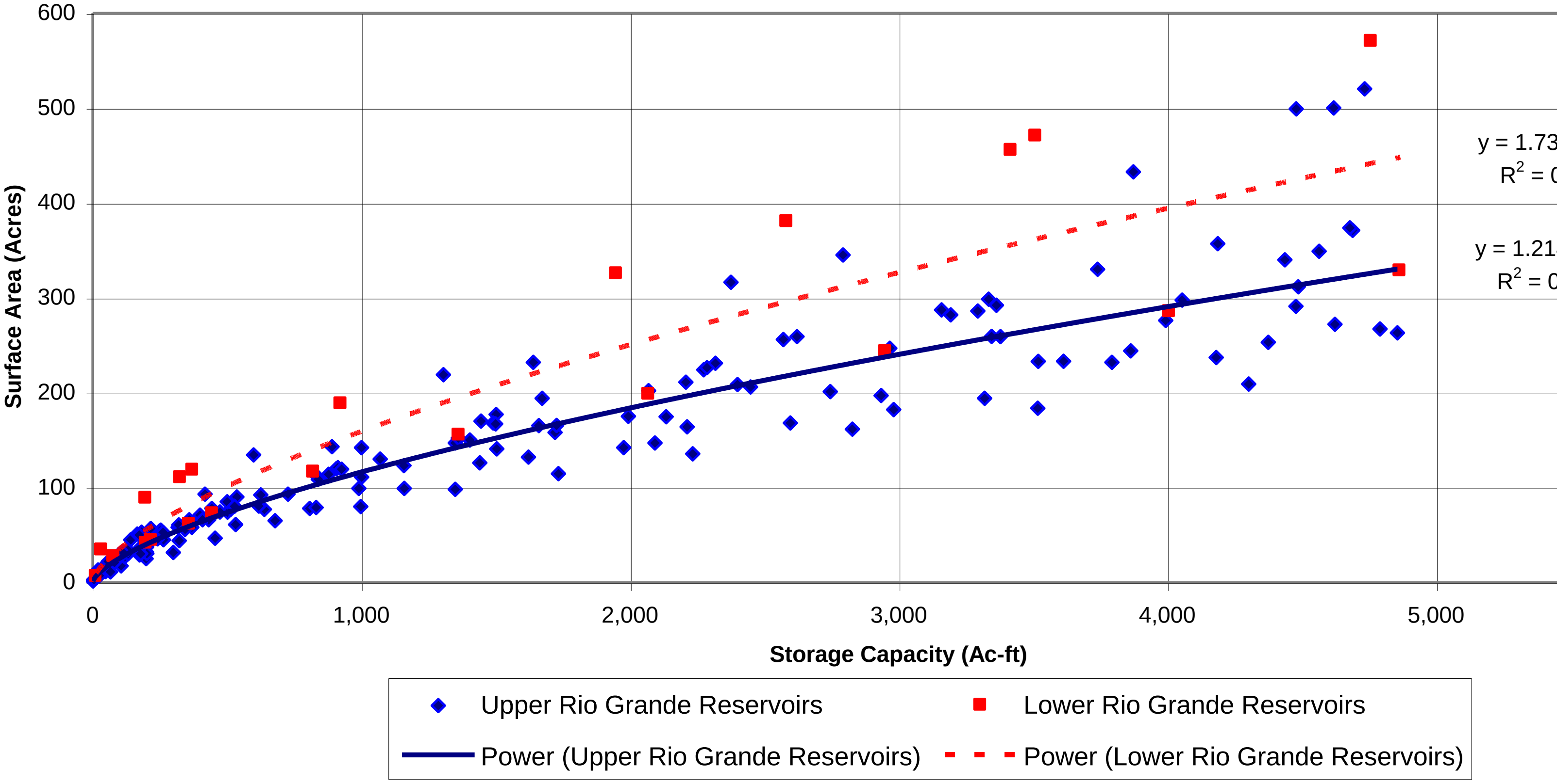
$$\text{Area} = 1.2141(\text{Capacity})^{0.6604} + 0 \qquad r^2 = 0.9581$$

The graphs for the above equations and the original data points are shown in Figure 3.4-1.

3.5 Aquifer Recharge

Aquifer recharge with respect to water availability is not a consideration in the Rio Grande Basin.

FIGURE 3.4-1
AREA-CAPACITY CURVES FOR SMALL RESERVOIRS



Reservoirs in the Upper Rio Grande are those located upstream of Amistad Dam.

4.0 WATER AVAILABILITY MODEL OF THE BASIN

4.1 DESCRIPTION OF *WRAP* MODEL

4.1.1 Base *WRAP* Model

The computer program or code used to develop the water availability model (WAM) of the Rio Grande Basin is referred to as “WRAP.” The basic WRAP program is described in the report titled “Water Rights Analysis Package (WRAP) Users and Reference Manual,” published by the Texas Water Resources Institute at Texas A&M University, revised December 2003, by Ralph A. Wurbs (Wurbs, 2004). The version of the WRAP program dated February 2004 has been used for the Rio Grande WAM.

Dr. Ralph Wurbs of Texas A&M is the primary author of the WRAP program. The WRAP program is coded in FORTRAN and is operational on desktop personal computers. The WRAP program is in the public domain and is available upon request from the Texas Water Resources Institute at Texas A&M. The TCEQ is responsible for distributing versions of the WRAP program, including data files, as used in this study for the Rio Grande Basin.

The WRAP program, which is referred to as a “model” with appropriately structured data input files, simulates the allocation of prescribed amounts of water within a river basin to individual water rights, i.e. diversions and storage, subject to the Prior Appropriation Doctrine (“first in time, first in right”) as it is applied for water rights administration in Texas. The priority dates have been adjusted for the Rio Grande Basin to reflect the type-of-use-based priority system for water rights dependent on storage in Amistad and Falcon Reservoirs, international treaty obligations, and for water rights in Mexico, known as “concessions.” WRAP utilizes a network of control points with interconnected links to describe flow paths and the locations of inflows, diversions, reservoirs, and return flows. Computations within the model are performed on a monthly basis using monthly time series values of specified inflows, reservoir net evaporation rates, and water demands subject to prescribed water rights conditions and reservoir system operating rules. Results from the WRAP model include monthly diversion and storage amounts for each water right and remaining unappropriated water at selected locations throughout the basin. These results are displayed and stored in tabular form. Because of the model's general capabilities for describing hydrologic and water resource system features in Texas and its representation of the Prior Appropriation Doctrine, the TCEQ adopted the WRAP program as the basic water rights simulation tool for performing the water availability analyses required by Senate Bill 1.

While the basic WRAP program in its original form does provide the fundamental framework for structuring water availability models of Texas river basins, numerous additional features and routines have been incorporated into the WRAP program that have enhanced its capabilities for performing the required water availability analyses. These program modifications have been made, for the most part, by Dr. Ralph Wurbs under contract to the TCEQ. As noted above, the February 2004 version of the revised WRAP program has been used for developing the Rio Grande WAM.

4.1.2 Basin-Specific *WRAP* Model

No basin-specific modifications have been made to the WRAP program for purposes of developing and structuring the Rio Grande WAM. There were, however, several modifications made to the WRAP program to facilitate the representation of certain water use activities in the Rio Grande Basin. These included: (1) a special flag for certain diversions and return flows that resulted in no losses being associated with the diversions or return flows in the WAM so that transfers of water from Mexico to the U.S. and vice versa pursuant to treaty obligations could be properly represented in the model; (2) expanded mathematical functions for the TO card to include multiplication and division to facilitate the curtailment of Class A and B irrigation rights based on the amount of water remaining in storage in the irrigation accounts pool in Amistad and Falcon Reservoirs; and (3) refined formatting for displaying the diversion amounts and diversion reliabilities for certain water rights with extremely small authorized diversions. All of these modifications are included in the February 2004 version of the WRAP program.

4.1.3 International WAM Structure

Because all of the Rio Grande Basin below the New Mexico stateline, including the Mexican portion of the basin, is included in the Rio Grande WAM, it has been necessary to incorporate into the WAM the essential provisions of existing international agreements between the United States and Mexico regarding the ownership of the water flowing in the Rio Grande. These agreements include the 1944 Treaty, which addresses the ownership of water downstream of Fort Quitman, and the 1906 Convention, which divides the water between the U.S. and Mexico above Fort Quitman.

To properly represent these agreements, it has been necessary to account for water owned by each of the two countries separately in the WAM. To facilitate this capability, as noted in the "Memo Regarding Special Conditions and Overall Model Construction" contained in Appendix I, the Rio Grande is structured in the WAM as two interconnected, parallel watercourses, one for U.S. flows and one for Mexican flows. With this structure, all of the tributaries of the Rio Grande in Texas are linked to the U.S. or Texas segment of the river, and all of the tributaries of the Rio Grande in Mexico are linked to the Mexican segment of the river.

The two different river segments of the WAM function essentially as separate models in that the water availability calculations for each country are performed separately. The relative order in which certain types of water use activities are simulated between the two model segments, however, is particularly important with regard to assuring that the proper sequencing of events occurs in accordance with the provisions of the international water agreements. This sequence of calculations is described in the memo in Appendix I.

One of the most important aspects of this process involves the transfer of Mexican water from certain Mexican tributaries of the Rio Grande to the U.S. segment of the WAM. This requirement stems from a provision of the 1944 Treaty which states that one-third of the flow reaching the Rio Grande from Mexico through the Rio Conchos, Arroyo de las Vacas, Rio San Diego, Rio Rodrigo, Rio Escondido and Rio Salado must be transferred to U.S. ownership in the river. This is accomplished in the WAM after all of Mexico's demands and reservoirs on these tributaries have been simulated. One-third of the remaining flow at the mouths of each of these six tributaries then is diverted and subsequently discharged as a return flow to the U.S. segment of the river. Demands for water along the Rio Grande by both U.S. and Mexican water users downstream of these Mexican tributaries then are simulated in the model.

Another international aspect of the WAM relates to the equal split of the flows in the Rio Grande at Fort Quitman. Implementation of this procedure in the WAM has required that all water use activities above Fort Quitman in both the U.S. and Mexico be simulated first, which has required some restructuring of priority dates for those upstream water rights in Texas. These priority date changes also are described in the memo in Appendix I. It should be pointed out that the equal split of the Fort Quitman flows is the procedure currently used by the IBWC in its accounting of U.S. and Mexican ownership of water flowing in the Rio Grande. This procedure does not seem to be consistent, however, with language adopted by the 1906 Convention, which states that except for the delivery of Rio Grande Project water to Mexico at the Acequia Madre, all water flowing in the Rio Grande above Fort Quitman is owned by the United States. This would suggest that the U.S. owns all of the river water passing Fort Quitman, but this is not how the current accounting is performed by IBWC.

4.2 DEVELOPMENT OF *WRAP* WATER RIGHTS INPUT FILES

4.2.1 Control Points

Control points used with the WRAP program provide a mechanism to describe the geographical configuration of a river basin. Control points are specified in the input data to indicate the locations of streamflow information, reservoirs, water rights diversions, return flows, imports, and other system features. The computations performed by the WRAP program are based on knowing for every control point the specific control point that is located downstream. Essentially any configuration of stream tributaries, reservoirs, and within-basin or inter-basin conveyance facilities can be represented. Each water right can be assigned a separate control point, or multiple water rights can be assigned to a given control point. Multiple water rights at the same control point all have access, in priority order, to the streamflow available at the control point.

Certain control points, typically those located at streamflow gaging stations, are referred to as "primary" control points and are assigned (through data input) time series of monthly values of naturalized streamflows for the duration of the selected simulation period. The WRAP program distributes these naturalized streamflows at the primary control points to all other control points included in the model network. These other control points are referred to as "secondary" control points. For the entire network of control points, the WRAP program simulates unappropriated and regulated streamflows and other quantities for each control point. Through the simulation process, the WRAP program limits the amount of water available to a water right at a control point to the lesser of the currently-simulated unappropriated flow at the control point or at any downstream control point.

For the WRAP model of the Rio Grande Basin, control points have been assigned at the locations of all existing water rights. In some cases, multiple water rights have been specified at a single control point, such as multiple water rights out of the same reservoir, and in some cases, multiple control points have been required to represent a single water right. Where a water right has multiple diversion points, a single control point was used at the most downstream diversion point. Additional control points have been assigned at locations where naturalized flows were determined (primary control points), other stream gage locations, the end points of classified stream (water quality) segments defined by the TCEQ, significant spring discharges, the locations where significant return flows are discharged into the basin, the mouth of the Rio Grande, and other special locations required to facilitate the modeling process.

The locations of all of the control points specified in the Rio Grande WAM are shown on the map of the stream network of the basin in Figure 4.2-1. Detailed maps of each subwatershed showing the location and ID of every control point are contained in the map pockets. A summary of the number of different types of control points used in structuring the network for the Rio Grande WAM is presented in Table 4.2-1.

TABLE 4.2-1
SUMMARY OF CONTROL POINT TYPES

TYPE OF CONTROL POINT	NUMBER OF POINTS-U.S. [a]	NUMBER OF POINTS-MEXICO [a]
Primary Control Points	26 [b]	32 [b]
Water Rights	1,535 [c]	56
Other Stream Gages	10	74
Water Quality Segment Terminus	14	0
Springs	18	0
Wastewater Discharge Outfalls	20	0
Other Miscellaneous Locations	13	21
Rio Grande Watermaster Pump Locations Not Used for Diversions	392	0

[a] Some points represent more than one type or are spatially coincident with other points.
[b] Includes 12 mainstem control points duplicated in the model segments for both countries.
[c] 390 Prior Appropriation; 1,145 Type-of-Use (Amistad-Falcon System)

FIGURE 4.2-1 Location of Control Points in Rio Grande Basin
(11x17 drawing of the basin showing control points without ID numbers)

A correlation table listing all of the WRAP control points that are associated with water rights and the associated water right identification number is contained in Appendix N.

It should be noted that as part of developing the Rio Grande WAM, a series of ArcView GIS coverages has been prepared for the entire basin that provides descriptive information and attributes for each of the control points, including their locations on the basin stream network, their connectivity relative to each other, and their associated water rights specifications, if any. These ArcView coverages are available from the TCEQ.

For each control point location, a unique identification number has been defined which identifies the point with respect to its general location within the Rio Grande Basin. This number is referred to as the "WRAP_CP_ID" in the GIS shape file, and the structure of this number is as follows:

"X01111"

The "X0" denotes the first two characters of the WRAP CP ID number of the downstream primary control point ("X" denotes the subwatershed) above which the particular control point lies. The "1111" denotes a unique sequential number assigned to each control point. These numbers have been incremented by 10 to allow room to insert intermediate-numbered control points in the future. Note that if a particular control point is a primary control point, then the "1111" of the identification number for this control point is assigned "0000," and the "X0" does not represent the next downstream control point number, but rather the actual primary control point number at its own location. Primary control points have also been assigned alpha IDs representing abbreviations of the USGS gage name. Table 4.2-2 lists the primary control points in the Rio Grande Basin along with their associated streamflow gages.

4.2.2 Monthly Demand Distribution Factors

In the WAM, the monthly variations of individual water demands associated with water rights are described by specifying the annual diversion amount in acre-feet for each individual diversion and a set of 12 monthly demand distribution factors in percent per month. The monthly demand distribution factors are multiplied by the annual diversion amount to determine the diversion amounts, or demands, for the different months of the year.

To establish appropriate demand distribution factors for each of the water rights, historical monthly water use data as reported by water rights holders to the TCEQ, and in Mexico the CNA, have been compiled and analyzed. Diversion data for the Rio Grande from the IBWC also have been analyzed for purposes of establishing specific monthly demand distributions. These are the same data that have been used in the streamflow naturalization process. For water rights with authorized diversions, the average reported water use has been determined by month for the last ten years, and the fractions of the total annual water use represented by the average monthly water use values have been calculated.

TABLE 4.2-2

PRIMARY CONTROL POINTS USED IN WAM
UNITED STATES AND MAINSTEM GAGES

PRIMARY CONTROL POINT		CONTROL POINT LOCATION	IBWC/USGS GAGE NUMBER	DRAINAGE AREA Sq. Mi.
NO.	I.D.			
AT/AM2000	RG-EP	R Grande at El Paso, TX	08364000	29,270
AT/AM1000	RG-FQ	R Grande at Fort Quitman, TX	08370500	31,944
BT/BM1000	RG-AC	R Grande abv R Conchos, TX	08371500	35,000
CT7000	AC-PR	Alamito Ck nr Presidio, TX	08374000	1,504
CT/CM6000	RG-BC	R Grande blw R Conchos, TX	08374200	63,339
CT5000	TC-TE	Terlingua Ck nr Terlingua, TX	08374500	1,070
CT/CM4000	RG-JR	R Grande at Johnson Ranch nr Castolon, TX	08375000	67,760
CT/CM3000	RG-FR	R Grande at Foster Ranch nr Langtry, TX	08377200	80,742
GT5000	PR-RB	Pecos R at Red Bluff, NM	08407500	19,540
GT4000	DR-RB	Delaware R nr Red Bluff, NM	08408500	689
GT3000	PR-OR	Pecos R nr Orla, TX	08412500	21,210
GT2000	PR-GI	Pecos R nr Girvin, TX	08446500	29,562
GT1000	PR-LA	Pecos R nr Langtry, TX	08447410	35,179
CT2100	DR-JU	Devils R nr Juno, TX	08449000	2,730
CT2000	DR-PC	Devils R at Pafford Crossing nr Comstock, TX	08449400	3,960
CT/CM1000	RG-DR	R Grande at Del Rio, TX	08451800	123,302
DT9000	SF-DR	San Felipe Ck nr Del Rio, TX	08453000	46
DT8000	PC-DR	Pinto Ck nr Del Rio, TX	08455000	249
DT/DM5000	RG-PN	R Grande at Piedras Negras, COAH	08458000	127,311
DT/DM3000	RG-LA	R Grande at Laredo, TX	08459000	132,577
DT/DM1000	RG-BF	R Grande blw Falcon Dam	08461300	159,269
ET/EM2000	RG-RG	R Grande at Rio Grande City, TX	08464700	174,362
ET/EM1000	RG-AN	R Grande blw Anzalduas Dam, TX	08469200	176,112

TABLE 4.2-2, continued
PRIMARY CONTROL POINTS USED IN WAM

MEXICO GAGES

PRIMARY CONTROL POINT			IBWC/CNA GAGE	DRAINAGE AREA
NO.	I.D.	CONTROL POINT LOCATION	NUMBER	Sq. Mi.
FM6000	RC-BO	R Conchos at La Boquilla Reservoir, CHIH	24077	8,109
FM5000	RF-CJ	R Florido at Cd. Jimenez, CHIH	24225	2,857
FM4000	SP-VI	R San Pedro at Villalba, CHIH	24181	3,633
FM3000	RC-LB	R Conchos at Las Burras, CHIH	24226	19,815
FM2000	RC-EG	R Conchos at El Granero, CHIH	24339	22,526
FM1000	RC-OJ	R Conchos nr Ojinaga, CHIH	08373000	26,404
DM9500	AV-CA	Arroyo de las Vacas at Cd. Acuna, COAH	08452000	350
DM7000	SD-JI	R San Diego nr Jimenez, COAH	08455500	853
DM6000	SR-EM	R San Rodrigo at El Moral, COAH	08457100	1,049
DM4000	RE-VF	R Escondido at Villa de Fuente, COAH	08458150	1,459
DM2300	RS-SA	R Sabinas at Sabinas, COAH	24026	4,887
DM2200	RN-PR	R Nadadores at Progreso, COAH	24150	8,918
DM2100	RS-RO	R Salado at Rodriguez, NL	24038	18,329
DM2000	RS-LT	R Salado nr Las Tortillas, TAMPS	08459700	23,154
EM4000	RA-CM	R Alamo at Cd. Mier, TAMPS	08462000	1,675
EM3400	SJ-EC	R San Juan at El Cuchillo, NL	24088	3,397
EM3300	RS-CF	R Salinas at Cienega de Flores, NL	24087	5,660
EM3200	RP-LH	R Pesqueria at Los Herrera, NL	24196	7,734
EM3100	SJ-LA	R San Juan at Los Aldamas, NL	24351	11,627
EM3000	SJ-CA	R San Juan at Camargo, TAMPS	08464200	12,940

In Texas, for municipal and industrial water rights, an analysis of the data generally revealed no significant seasonal differences within the basin, except for the City of El Paso. Therefore, the same sets of monthly demand distribution factors were used for describing these demand patterns throughout the entire basin, with a separate set for El Paso. These monthly demand patterns are represented by the demand distribution factors listed in Table 4.2-3 and are identified as “MUN” and “IND,” respectively. Mining and other uses were given a flat distribution, and are identified as “MIN” and “OTH,” respectively. For output purposes, different names were given to sets for the upper, middle, and lower portions of the basin; these are identified as “UP,” “M” or “MID,” and “L” or “LWR,” respectively. The distribution of power plant water usage was determined for both Texas and Mexico and is identified as “TPOWER” and “MPOWER.”

The historical diversion data for irrigation water use do exhibit significant seasonal differences between the various portions of the Rio Grande Basin. Consequently, a unique set of monthly demand distribution factors has been developed to represent the average irrigation demand patterns for the upper, middle, and lower portions of the basin. These are identified as “XY-IRR,” where “X” is either “A” or “B,” representing Class A or Class B irrigation water rights. “Y” is either “M” or “L,” representing the middle or lower portions of the basin. “UP” represents the prior appropriation water rights, which are in the upper basin or on tributaries.

For Mexico, demand distribution factors were determined for each of the major irrigation districts. The districts have abbreviations, which are identified in the WRAP input file. Municipal diversions excluding Juarez, and municipal diversions into Acequia Madre in Juarez, are identified as “MUNCPL” and “MNACEQ,” respectively.

4.2.3 Texas Water Rights

The general features and characteristics of the existing water rights in the Rio Grande Basin have been previously identified and described in Section 2.1. Specific information regarding each water right is contained in the TCEQ database contained in Appendix A, with previously identified corrections in Appendix B. The map of the basin presented in Figure 2.1-1 shows the locations of the water rights with respect to the stream network. Detailed maps of each subwatershed showing the location and ID of every control point are contained in the map pockets inside the back cover of this report and are also available in ArcView or .pdf format from the TCEQ. A correlation table showing the water right(s) associated with each control point is contained in Appendix N.

Note that the following labeling scheme was used in the WRAP input files to identify water rights on the WR records:

Water Right ID (WRID) - TCEQ_ID
Second WRID (Group ID #1) - TCEQ_ID less the last 3 numbers of the TCEQ_ID
Third WRID (Group ID #2) - TCEQ_ID less basin ID and 0 preceding water right number

TABLE 4.2-3
MONTHLY DEMAND DISTRIBUTION FACTORS

TYPE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
TEXAS												
AM-IRR	7.4	7.9	9.1	9.3	9.5	8.8	8.5	8.3	7.6	7.9	7.8	7.7
AM-MIN	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3
AM-MUN	6.8	6.5	7.7	8.3	9.1	9.4	11.0	10.6	8.7	8.1	7.0	6.8
AM-OTH	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3
AL-IRR	5.9	7.7	10.1	10.2	10.0	8.7	10.4	10.6	6.5	7.5	7.0	5.3
AL-MIN	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3
AL-MUN	6.8	6.5	7.7	8.3	9.1	9.4	11.0	10.6	8.7	8.1	7.0	6.8
AL-OTH	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3
BM-IRR	7.4	7.9	9.1	9.3	9.5	8.8	8.5	8.3	7.6	7.9	7.8	7.7
BM-MIN	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3
BM-MUN	6.8	6.5	7.7	8.3	9.1	9.4	11.0	10.6	8.7	8.1	7.0	6.8
BM-OTH	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3
BL-IRR	5.9	7.7	10.1	10.2	10.0	8.7	10.4	10.6	6.5	7.5	7.0	5.3
BL-MIN	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3
BL-MUN	6.8	6.5	7.7	8.3	9.1	9.4	11.0	10.6	8.7	8.1	7.0	6.8
BL-OTH	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3
UP-IRR	2.2	3.5	11.8	8.8	10.2	13.4	14.6	13.6	11.0	6.8	2.5	1.6
TPOWER	4.6	5.3	6.4	8.1	9.6	10.7	13.2	13.0	10.7	8.0	5.4	5.0
MUNLWR	6.8	6.5	7.7	8.3	9.1	9.4	11.0	10.6	8.7	8.1	7.0	6.8
MUNMID	6.8	6.5	7.7	8.3	9.1	9.4	11.0	10.6	8.7	8.1	7.0	6.8
TEXIND	6.8	6.5	7.7	8.3	9.1	9.4	11.0	10.6	8.7	8.1	7.0	6.8
OTHER	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3
TEXMIN	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3
TEXMUN	6.8	6.5	7.7	8.3	9.1	9.4	11.0	10.6	8.7	8.1	7.0	6.8
ELPASO	0.2	1.5	9.9	13.8	13.7	15.2	15.3	15.2	13.7	1.5	0.0	0.0
MEXICO												
MPOWER	5.3	7.2	8.7	8.8	7.1	8.9	10.9	10.7	9.1	9.5	7.5	6.3
RFLRDO	1.8	3.5	7.4	10.2	17.2	10.7	11.4	18.9	13.1	4.9	0.9	0.1
DELCAS	5.0	8.0	11.3	13.2	13.0	11.7	10.4	9.7	9.2	5.5	1.4	1.7
PALSTA	7.5	8.1	9.2	7.1	9.1	9.9	8.1	10.1	11.0	6.8	6.2	6.8
DONMTN	6.5	13.1	16.0	15.1	19.6	17.0	2.7	1.3	0.6	1.1	1.1	5.8
ASANJN	14.5	11.0	3.1	19.4	23.9	12.2	2.7	5.5	2.8	3.0	0.5	1.3
BSANJN	18.5	7.7	8.1	33.5	21.9	1.3	0.3	1.0	0.0	1.1	0.7	5.8
MUNCPL	7.7	7.3	8.2	7.6	8.4	8.5	9.3	9.0	8.6	8.1	8.4	8.7
MNACEQ	0.0	0.0	4.0	17.0	17.0	18.0	18.0	18.0	8.0	0.0	0.0	0.0

Values in percent per month.

There were some exceptions/additions to the above scheme. Specifically, additional identifiers were added to the end of some of the Water Right ID's to represent run-of-river (RR) or back up (BU) portions of a water right, different priority dates for the same water right (A,B,C, etc.), or different types of use being simulated for the same water right (A,B,C, etc.). In addition, some water rights that were modeled by refilling storage with one WR record and making a diversion on another WR record were differentiated by associating the words FILLONLY to the WR record that only fills the reservoir. In addition, the water rights associated with Amistad and Falcon Reservoirs have a more detailed naming convention in order to keep track of the type of each water right to facilitate the use of the accounting system for these rights. The Water Right ID for these rights is the TCEQ_ID followed by two integers for use in cases of multiple owners (00 for one owner, 01 and 02 for two owners, etc.). The integers are followed by a letter identifying the type of use (and thus the priority) of the water right (M for municipal; A for irrigation, Class A; and B for irrigation, Class B).

Specific features of the water rights that have required special attention in developing the WRAP input data are discussed in the following sections.

4.2.3.1 Priority Dates

Most prior appropriation water rights in the Rio Grande Basin have a single priority date for diversions and/or reservoir storage. Representation of these water rights in the data input file for the WAM is relatively straightforward.

Other water rights have multiple dates establishing their time priorities for diverting and/or impounding water. This occurs for a variety of reasons, including amendments to the original permit increasing the diversion amount, increasing the storage capacity of a reservoir, adding additional reservoirs, incorporating different operating procedures, or providing for minimum environmental flows. Each priority date for use and/or impoundment of water, with its associated authorized amount, has been accounted for separately in the Rio Grande WAM. The WRAP program readily accommodates these types of water rights with multiple priority dates.

Water rights on the middle and lower segments of the Rio Grande are dependent primarily on water stored in Amistad and Falcon Reservoirs. These water rights are not subject to the Prior Appropriation Doctrine and have a unique priority system based on type-of-use. The memorandum contained in Appendix I explains how these water rights have been modeled with respect to assigning priorities in the WAM.

4.2.3.2 Amistad-Falcon Storage Accounting

Those Texas water rights that are located on the Rio Grande and are dependent on Amistad and Falcon Reservoirs for their primary water supply are subject to special rules adopted by the TCEQ and administered by the Rio Grande Watermaster. Relevant portions of these rules have been extracted from the Texas Administrative Code, Chapter 303, and included in Appendix O for reference purposes. In effect, these rules allocate the U.S. water stored in the Amistad-Falcon reservoir system among the different water rights on the middle and lower segments of the Rio Grande according to type of use, and they establish an associated system of monthly accounting for the water stored in the reservoirs. This accounting system provides reserves for domestic, municipal and industrial water users and reservoir operations, establishes individual storage accounts for all lower and middle Rio Grande irrigation and mining water rights, and provides a means for allocating available reservoir inflows to the irrigation and mining water rights on a monthly basis.

The underlying basis and authority for the TCEQ's Rio Grande operating and accounting rules is the decision of the Thirteenth Court of Civil Appeals in the landmark case styled "State of Texas, et al. vs. Hidalgo County Water Control and Improvement District No. 18, et al.", which is commonly referred to as the Valley Water Case. The original suit was filed by the State of Texas in 1956 to restrain the diversion of water from the Rio Grande for irrigation when the share of water due the United States from water impounded in Falcon Reservoir was 50,000 acre-feet or less. The volume of 50,000 acre-feet was the amount of water that the Texas Board of Water Engineers (predecessor agency to the TCEQ) had determined to be necessary to meet municipal, domestic and livestock demands for a three-month period without additional inflows into Falcon Reservoir. Earlier efforts to apply voluntary restrictions on diversions of water had collapsed due to severe drought conditions and the consequent shortage of water supplies.

The original trial of the Valley Water Case lasted from January, 1964 to August, 1966, and the final judgment of the Appellate Court was entered in 1969. In 1971, the Texas Water Rights Commission (predecessor agency to the TCEQ) adopted rules and regulations implementing the court decision. Based on the judgment rendered in the case, a storage reserve in Falcon Reservoir equal to 60,000 acre-feet was established to meet municipal and industrial demands, and a total of approximately 155,000 acre-feet of water per year was allocated for municipal, industrial and domestic uses. Irrigation water from the Rio Grande was allocated for 742,808.6 acres of agricultural use below Falcon Dam. Of this amount, 641,221 acres were assigned Class A irrigation rights, and the remaining acreage was awarded Class B irrigation rights. These different classifications were intended to reflect the nature of a water right claim as filed with the Court and the extent to which the historical usage under a particular water right could be documented and verified during the adjudication.

Whereas the result of the Valley Water Case was to grant the highest water supply priority to municipal and industrial uses, the remaining Class A and B irrigation and mining water rights were subject to an allocation system dependent on the amount of storage remaining in Amistad and Falcon Reservoirs after water first was reserved for the municipal and industrial users and certain reservoir operating requirements. The Class A and Class B water rights provided a means for differentiating the rates at which water would be credited to the individual Amistad-Falcon storage accounts of the irrigation and mining water rights. Under the current system, a Class A water right accrues water at a rate 1.7 times higher than a Class B water right. Although this weighted priority system for irrigation and mining water users generally has little significance during years of plentiful water, its effect in water-short years is to distribute the shortage among all users, with the greater shortages occurring on lands with the Class B water rights.

The current TCEQ rules and regulations provide a reserve of 225,000 acre-feet of storage in Amistad and Falcon Reservoirs for domestic, municipal, and industrial uses, which is referred to as the “municipal pool” or the “DMI” reserve. An operating reserve of 75,000 acre-feet also is established to provide for: (1) loss of water by seepage, evaporation and conveyance; (2) emergency requirements; and (3) adjustments of amounts in storage, as may be necessary by finalization of IBWC provisional United States-Mexico water ownership computations. Under certain low-inflow conditions, the operating reserve can fall below 75,000 acre-feet, but it cannot be reduced to less than zero.

The TCEQ rules specify procedures for allocating United States water in storage in Amistad and Falcon to the DMI reserve, the operating reserve, and the Class A and B irrigation and mining accounts. Such allocations are based on the amount of United States water considered to be “usable storage” in Falcon and Amistad Reservoirs, as reported by the IBWC on the last Saturday of each month. Usable storage is defined as the amount of United States water stored in the conservation pools of the reservoirs less dead storage, which currently is assumed to be 4,500 acre-feet by the Rio Grande Watermaster. To determine the amounts of United States water to be allocated to the specified reserves and accounts each month, the following computations are made:

1. From the amount of water in usable storage, 225,000 acre-feet are deducted to reestablish the reserve for domestic, municipal and industrial uses, i.e. the municipal pool; hence, storage for these uses is given the highest priority;

2. From the remaining storage, the total end-of-month account balances for all Lower and Middle Rio Grande irrigation and mining allottees are deducted; and

3. From the remaining storage, the operating reserve is deducted.

If there is water remaining in the United States usable storage after the above three sets of allocations are made, the remaining storage amount is further allocated to the individual irrigation and mining water rights accounts. The allotment of the remaining storage amount for irrigation and mining uses is divided and allotted in accordance with the Class A and Class B (allottees) allocation rates. Class A water rights receive 1.7 times as much water as that allotted to Class B rights. Under the rules, an irrigation allottee cannot accumulate in storage more than 1.41 times its annual authorized diversion amount, and, if an allottee does not use water for two consecutive years, its account is reduced to zero.

The fundamental features of the TCEQ’s Rio Grande operating rules have been incorporated into the WAM in order to properly reflect the allocation of water stored in the U.S. pools of Amistad and Falcon Reservoirs. Because all of the municipal and industrial water rights are provided stored water from the reservoir system essentially with the same priority, there is no priority ranking among these rights. In the WAM, should a shortage condition occur, the demands of these water rights would be satisfied in the order in which they are listed in the WRAP data input files. In this regard, the middle basin municipal and industrial water rights (between Amistad and Falcon) are simulated first in order of ascending water right number, followed by the lower basin water rights also in order of ascending water right number.

The same simulation order also is used first for all of the Class A irrigation and mining water rights, and then for all of the Class B irrigation and mining water rights. For these water rights, however, there should never be unequal shares of stored water available for each of the individual Class A water rights or for each of the Class B water rights because, during water shortage periods, their respective total (as a class) water demands are automatically curtailed under the rules at the beginning of each month of the simulation period to match the available supply of stored water in the Amistad-Falcon system.

The TCEQ Rio Grande accounting process is accomplished in the WAM using dummy control points and dummy reservoirs to represent the various accounting features, CI (constant inflow) cards to produce computational water and represent future demands, and DI (drought index) cards to constrain Class A and Class B irrigation water rights consistent with the TCEQ Rio Grande operating rules. DI cards are associated with the WR record of each Class A and Class B water right, and the following three dummy reservoirs are established:

(1) First Dummy Reservoir (FDR) - established with a capacity equal the total U.S. storage available in Amistad and Falcon Reservoirs, but has zero water in storage at the beginning of a simulation and the beginning of each time step.

(2) Class A Dummy Reservoir (A Pool) - established with a capacity equal to 1.41 times the total authorized diversion amount of all Class A water rights. This reservoir is full at the beginning of a simulation. Deductions are made from this reservoir equal to the quantity of water actually diverted by all Class A water rights during each time step of a simulation. Deductions also are made when the accounting process determines that water is required to protect the DMI water rights or to re-establish the system operating reserve. Additions are made to this reservoir when the accounting process indicates there is stored water in Amistad and Falcon Reservoirs available for allocation.

(3) Class B Dummy Reservoir (B Pool) - established with a capacity equal to 1.41 times the total authorized diversion amount of all Class B water rights. This reservoir is full at the beginning of a simulation. Deductions are made from this reservoir equal to the quantity of water actually diverted by all Class B water rights during each time step of a simulation. Deductions also are made when the accounting process determines that water is required to protect the DMI water rights or to re-establish the system operating reserve. Additions are made to this reservoir when the accounting process indicates there is stored water in Amistad and Falcon Reservoirs available for allocation.

After all water rights are simulated in a time step, computational water is used to set the storage in the FDR equal to the sum of the simulated storage in the U.S. Amistad pool (TEXAMI) and the U.S. Falcon pool (TEXFAL). A series of deductions from this amount of storage in the FDR are then made determine how much, if any, of the water stored in Amistad and Falcon Reservoirs can be allocated to the Class A and Class B water rights accounts in the Class A Dummy Reservoir and the Class B Dummy Reservoir, respectively. These deductions are made in the following order and amounts:

(1)	Dead Storage of Amistad and Falcon Reservoirs	4,600 Acre-Feet
(2)	DMI Reserve	225,000 Acre-Feet
(3)	Current Content of Class A Dummy Reservoir (A Pool) (reflects previous diversions and allocations)	Varies
(4)	Current Content of Class B Dummy Reservoir (B Pool) (reflects previous diversions and allocations)	Varies
(5)	Operating Reservoir	75,000 Acre-Feet

If there is any water remaining in the FDR after these deductions, the amount remaining is allocated to the Class A and Class B pools. Each of the Class A water rights gets 1.7 times the quantity that each Class B water right gets, based on the authorized annual diversion amounts of the water rights.

If there is not enough available storage in the FDR to provide the full 75,000 acre-feet for the operating reserve, what ever amount is available is assigned to the operating reserve, and no water is allocated into the A and B Pools. If there is not enough water in the FDR to provide any water for the operating reserve, then the TCEQ rules dictate that a negative allocation must be made from the A and B Pools in order to restore the operating reserve to 48,000 acre-feet. This is accomplished in the WAM by adding 48,000 acre-feet to the amount of the shortage encountered after Step (4) above and deducting this total quantity from the A and B Pools on a pro-rata basis based on the actual quantity of water contained in the A and B Pools.

After the above accounting process is performed in the WAM, the quantity of computational water finally stored in the A Pool is divided by the total demand of all Class A water rights for the next time step (month), and this value (as a quantity of water) is placed in a separate dummy Class A control reservoir (Control A). Likewise, the quantity of computational water finally stored in the B Pool is divided by the total demand of all Class B water rights for the next time step, and this value (as a quantity of water) is placed in a separate dummy Class B control reservoir (Control B). At the beginning of each time step, DI factors are computed based on the quantity of water stored in each of the control reservoirs (Control A and Control B). These DI factors then are utilized in the WAM to produce demand factors, which are applied to the coded diversion amount on the WR card for each water right to establish the appropriate amount to be diverted during the time step consistent with the outcome of the accounting process. The Control A, Control B and FDR reservoirs then are emptied and prepared for the next accounting process at the end of the time step. Before the next accounting process begins and after all Class A and Class B water rights have made their actual diversions from the Amistad-Falcon reservoir system, duplicate storage reductions are made from the A and B Pools using TO cards, and the accounting process is then repeated at the end of the time step.

It should be noted that all water rights in the Rio Grande Basin, including the Class A and Class B irrigation and mining rights, are simulated individually in the WAM, but the Amistad-Falcon storage accounting process is performed with all water rights of a single class grouped and accounted for as a single account or pool. With the different classes of water rights grouped in this manner for purposes of accounting, all Class A water rights generally have the same diversion reliability within the WAM. Likewise, all Class B water rights generally have the same diversion reliability in WAM.

4.2.3.3 Treatment of Reservoir Storage

Generally, the maximum conservation storage for each reservoir has been specified in the WRAP model of the Rio Grande Basin in accordance with the maximum authorized storage amounts listed in the TCEQ water rights data base in Appendix A, with the previously identified corrections in Appendix B.

When simulating storage in a particular reservoir with multiple priority dates for specific storage amounts, such as Red Bluff Reservoir, the WRAP program uses the priority dates to determine when water can be stored in the reservoir up to the associated authorized amounts, after accounting for the demands of upstream and downstream senior water rights. Once water is stored in the reservoir under any one of its multiple priority dates, the WRAP program performs no further accounting of the water within the reservoir with respect to the different priority dates. Hence, the total quantity of water in storage is available to satisfy any and all specified diversions associated with the reservoir, subject to their specified priority dates.

The United States pools in Amistad and Falcon Reservoirs are operated as a reservoir system. In the WAM, OR cards are used to enable demands (releases) to be met from the two reservoirs in a specified order down to specific trigger capacities of each reservoir based on assumed operational rules. The objective of these rules is to primarily store water in Amistad Reservoir (the uppermost international impoundment) pursuant to the provisions of the 1944 Treaty between the U.S. and Mexico, while maintaining a lower operating pool in Falcon Reservoir to facilitate day-to-day releases to the water users in the Lower Rio Grande Valley.

Anzalduas Reservoir has been represented in both the U.S. and Mexican portions of the WAM with each country's pool having a capacity equal to one-half of the total conservation storage capacity of the reservoir, which is 6,027 acre-feet between 100.0 feet and 104.5 feet above mean sea level. Appropriate evaporation data have been associated with each country's pool. Since Anzalduas is used primarily to provide temporary storage as part of the flow regulation procedure for delivering water to downstream users and to create sufficient head for Mexico's diversions into the Anzalduas Canal, the operation of Anzalduas Reservoir for both countries has been modeled to maintain the reservoir full, first from river flows and then with water released from the Amistad-Falcon reservoir system. Neither country is allowed to deplete storage in Anzalduas Reservoir.

4.2.3.4 Return Flows

All municipal and industrial wastewater discharges (return flows) with a permitted flow greater than or equal to 0.5 million gallons per day (MGD), or approximately 560 acre-feet per year, were considered significant and were included in the naturalized flow calculations and the WRAP model (see Table 2.3-1).

Return flows in the Rio Grande WAM have been specified either as prescribed fractions of their associated diversion amounts, or as constant monthly amounts. Historical return flow data from the TCEQ for all of the entities that have discharges into the Rio Grande Basin have been compiled and analyzed. Based on the last five years of available records, average minimum monthly dry-weather return flow quantities have been established, and corresponding monthly return flow factors have been determined where possible. These return flow factors have been used to calculate the monthly return flow amounts for each of the water rights holders with diversions, i.e., the annual diversion amounts have been multiplied by the monthly return flow factors to establish the corresponding return flow amounts. For those return flow dischargers not associated with water rights diversions, the five-year average minimum monthly dry-weather return flow values have been used directly to specify return flows in the WRAP data input file.

All return flows associated with groundwater supplies or inter-basin transfers for municipal water supplies have been set equal to constant monthly values for each model run. This approach provides for continuous and constant return flows throughout an entire simulation period. The underlying assumption is that such municipal water use will be continuous, even during drought periods when municipal surface water rights diversions may be significantly reduced because of limited streamflows or available reservoir storage. The specification of the constant monthly return flows in the WRAP data file is accomplished with CI (Constant Inflow) records.

Power plant return flows have been handled in two different ways. If the water right is for once-through cooling, or merely authorizes a consumptive use, as is typical with most plants, then that consumptive amount has been used as the diversion amount for the water right with no return flow. If the water right authorizes a large diversion amount and a smaller consumptive use, then the full diversion has been modeled with an appropriate return flow factor.

All irrigation return flows have been assumed to be zero.

For purposes of the water availability analyses for the Rio Grande Basin, five different sets of return flow data have been developed as required for the different simulation conditions specified by the TCEQ (Runs 1 through 8). These are listed below:

Return Flow Data Set 1	Return flows corresponding to fully authorized water rights diversions with no reuse beyond current levels based on return flow data for the last five years (Run 1)
Return Flow Data Set 2	Return flows corresponding to fully authorized water rights diversions with 50-percent reuse (Run 2)
Return Flow Data Set 3	Return flows corresponding to fully authorized water rights diversions with 100-percent reuse, zero return flows (Run 3 and also Runs 6 and 7)
Return Flow Data Set 4	Return flows corresponding to fully authorized water rights diversions with no reuse beyond current levels as reflected in return flow data for the last five years, with all water rights with no reported use during the last ten years assumed to be cancelled and discharging zero return flows (Run 4)
Return Flow Data Set 5	Return flows corresponding to maximum reported water rights diversions during the last 10 years with no reuse beyond current levels as reflected in return flow data for the last five years (Runs 5 and 8, Section 5.1)

The reuse assumptions for Return Flow Data Sets 2 and 3 were not applied to power plant return flows, which remained the same for all runs.

4.2.3.5 Multiple Diversion Locations

There are numerous water rights in the Rio Grande Basin with multiple diversion or impoundment points. Multiple diversion points, in this context, include only those water rights with diversion points on different streams or different locations on the same stream where drainage areas, and thus streamflows, are significantly different. This excludes water rights with multiple diversion points on the same reservoir, or water rights with multiple diversion points on a short reach of a stream. In general, the authorized diversion for a particular water right with multiple diversion points on the same stream has been assigned to the most downstream diversion location. For those water rights with multiple diversion points on different streams, the “BACKUP” feature in WRAP has been used to allow diversions from secondary streams to supplement the available supply from a designated primary stream. For water rights with multiple diversions authorized from storage in different reservoirs, the diversions and the reservoirs have been modeled using the system operation capability of WRAP.

4.2.3.6 Closed Basin Water Rights

There are four water rights that are located within the Closed Basin of the Rio Grande Basin in far West Texas. Control points for these water rights have been included in the WAM at their respective locations, and appropriate watershed parameters (drainage area, curve number and mean annual rainfall) have been determined for each of the control points. These control points and their associated Closed Basin water rights are listed below:

Control Point No.	Certificate of Adjudication No.
XCB001	5469, 5406
XCB002	5468, 5406
XCB003	5467, 5406

The naturalized flows for these control points have been established using their respective watershed parameters and the watershed parameters and naturalized flows for the primary control point identified as Delaware River near Red Bluff (GT4000). During the WAM simulation, any excess flow occurring at any of these Closed Basin control points is routed to OUT, which effectively removes this water from the system.

4.2.3.7 Water Rights Requiring Special Consideration

A number of water rights in the Rio Grande Basin have special conditions or special operating procedures that affect water availability. Appendix B contains a memorandum to TCEQ related to corrections to the Water Rights Database and includes brief descriptions of special conditions associated with specific water rights.

Appendix I contains a memorandum describing special conditions and overall model construction. In particular, water rights above Fort Quitman and water rights dependent on storage in Amistad and Falcon Reservoirs have unique priority systems that have been represented in the WAM with special priority “dates.” The modeling of these water rights has been previously described and discussed in this report.

Appendix L contains a memorandum related to inter-basin transfers (IBT) affecting the Rio Grande Basin. There are no IBTs to be considered in the Rio Grande WAM.

Appendix M contains a memorandum related to saline water rights in areas tidally influenced. There are no such water rights in the Rio Grande Basin.

The only water rights in the entire Rio Grande Basin with instream flow restrictions are Permit Nos. 1838 and 5259 owned by the City of Brownsville Public Utilities Board (PUB). These water rights authorize the impoundment (Permit No. 5259) and the diversion (Permit No. 1838) of excess flows in the Rio Grande near Brownsville, provided a minimum flow of 25 cfs is passed downstream. As modeled in the WAM, these water rights are simulated with a priority date that allows them to be processed immediately after Amistad and Falcon Reservoirs are filled, but immediately before the processing of all of the lower and middle Rio Grande water rights that are backed up with stored water in the Amistad-Falcon reservoir system. In this way, the PUB excess flow rights have access to whatever U.S. flows may occur in the river downstream of Falcon before the reservoir-dependent water rights. Otherwise, all of the U.S. flows in the lower Rio Grande would be diverted first by the reservoir-dependent water rights, and the PUB water rights would never have any water available for impoundment or diversion.

Water rights associated with the Red Bluff Water Power Control District (Red Bluff Reservoir) are modeled in the WAM such that it could be argued that the member districts are allowed to deplete more water than they are specifically authorized to use. This is because one of the "whereas" clauses contained in the Certificate of Adjudication (No. 23-5438) states that each of the member districts have "authorized" the master district (Red Bluff Water Power Control District) to impound in Red Bluff Reservoir the water each member district is authorized to divert and then to release this water to the member districts when they need it. However, the certificate fails to authorize each member district any priority storage rights for impounding water in Red Bluff Reservoir, and the actual priority date for impounding water in Red Bluff Reservoir is junior to the diversion rights of all of the downstream member districts. This relationship was represented in the WAM by allowing all of the member districts to impound their authorized diversion amounts in Red Bluff Reservoir at their respective priority dates (senior to the Red Bluff Reservoir priority date). Each member district then tries to meet its demand from available streamflows at its downstream diversion location in priority order, with any shortage backed up with releases of stored water from Red Bluff Reservoir limited to the member district's authorized diversion amount. This approach seems to reasonably represent the way the Red Bluff system is actually operated; however, in some years, an individual district can store its authorized diversion amount in Red Bluff Reservoir and divert additional water that is available at its diversion location downstream of Red Bluff Reservoir.

4.2.4 Mexico Water Rights

4.2.4.1 Priority System

Mexico does not have a water right system based on the Prior Appropriation Doctrine, but apparently does have some established levels of annual use that serve as targets for the allocation of annual supplies of water either stored in Mexico's reservoirs or anticipated to be available as a result of expected weather conditions and associated streamflows. For purposes of the WAM, the assumed general priority system that has been applied for satisfying demands and reservoir storage is based on river order (upstream to downstream) and type of use (municipal first, then irrigation). The application of this priority approach for Mexico in the WAM is explained in the memorandum of special conditions and overall model construction presented in Appendix I.

4.2.4.2 Treatment of Reservoir Storage

Reservoir storage in Mexico has been treated similarly to Texas as described in Section 4.2.3.2. There are no Mexican reservoirs with multiple priority dates for different storage amounts.

It has been assumed that the Mexican pools in Amistad and Falcon Reservoirs are operated as a reservoir system using procedures similar to those used for the United States pools. In the WAM, OR cards are used to enable demands (releases) to be met from the two reservoirs in a specified order down to specific trigger capacities of each reservoir based on assumed operational rules. Releases are made from Amistad Reservoir first until it reaches a capacity of 1,666,202 acre-feet (85 percent of conservation storage capacity), then releases are made from Falcon Reservoir until it reaches a capacity of 150,000 acre-feet, then releases are again made from Amistad Reservoir until it is depleted, and then from Falcon until it is depleted.

4.2.4.3 Return Flows

Return flows in Mexico were treated similarly to Texas as described in Section 4.2.3.3. Return flows are listed in Table 2.3-1. Only one return flow factor data set was used, and no reuse or cancellation of return flows was considered for Mexico.

4.2.4.4 Multiple Diversion Locations

Multiple diversion locations were not considered in Mexico. A single diversion location was used for each concession.

4.2.4.5 Water Rights Requiring Special Consideration

Many of the Mexican concessions are associated with reservoirs. These concessions were modeled in the WAM with backup supplies from specified reservoirs.

The order in which the Mexican concessions were modeled in the WAM also reflects the procedure required for proper consideration of the provisions of the international agreements between the United States and Mexico. This is discussed in the memorandum of special conditions and overall model construction presented in Appendix I.

4.2.5 Data for Basin-Specific Features Added to WRAP

No basin-specific modifications have been made to the WRAP program as part of this water availability modeling study for the Rio Grande Basin. Consequently, no special data are required for basin-specific features. Special procedures available in the WRAP program were used to simulate the water rights dependent on Amistad and Falcon Reservoirs and to handle the international treaty provisions. While certain modifications in the WRAP program were made to facilitate the representation of some of the water rights conditions in the Rio Grande Basin, these modifications are an integral of the most recent version of the WRAP program that now is used for simulating water availability in all Texas basins.

4.3 SIGNIFICANT ASSUMPTIONS AFFECTING WATER AVAILABILITY MODELING

The following significant assumptions could affect results from the water availability modeling:

- In preparing naturalized flows, complete data were not available for describing historical diversion amounts and the associated quantities of return flows for all water rights in the Rio Grande Basin, particularly in the upper Rio Grande basin above Amistad Reservoir and on some tributaries. In general, zero values have been assumed where there are no data. In some cases, various fill-in and estimation procedures have been employed to develop as complete and accurate data as possible for use in the streamflow naturalization process. Because of the lack of diversion data in the TCEQ database prior to approximately 1990, diversions on the mainstem of the Rio Grande were estimated by reach rather than individual water rights, based on data from IBWC. Prior to the early 1950s, there are no data, so early historical data averages were used. In Mexico, data were sporadic, and some diversions were estimated based on reservoir drawdowns and knowledge of diversion amounts in other years.

- Compliance with the Pecos and Rio Grande Compacts was assumed in preparing the naturalized flows. Historical gage flows at the New Mexico stateline were changed to adjust for historical under-deliveries and over-deliveries under the compacts. Future compliance may be uncertain.

- Allocation of Texas' appropriate share of Rio Grande Project water has been assumed, and adjustments in the historical allocations have been made to correct for over-allocations that appears to have occurred in some years because allocated storage from previous years was not fully utilized and carried over to subsequent years. Allocations to Texas and diversions of Project water by Texas and New Mexico users are not likely to always be precise in the future.

- The international treaties between the United States and Mexico regarding the ownership of Rio Grande water have been incorporated into the WAM to the extent possible, but future Rio Grande water management practices by Mexico could affect how much water the United States receives from the Mexican tributaries. It has been assumed that Mexico will continue to impound all upstream inflows to its reservoirs on tributaries of the Rio Grande and that none of this water will be deliberately released for the purpose of complying with the provision of the 1944 Treaty that requires an average of 350,000 acre-feet per year be delivered to the United States from six named Mexican tributaries.

- In accordance with the 1944 Treaty, incremental inflows to the Rio Grande from ungaged tributaries and drainage areas have been divided equally (50/50) between the United States and Mexico in the WAM based on a mass balance procedure applied to the set of naturalized flows for all primary control points outside of the WAM. This approach is necessary to represent the international ownership of Rio Grande water in the WAM as accurately as possible within the limits of the WRAP program and the prior appropriation WAM modeling procedure; however, this division of incremental inflows to the two countries normally is performed on a monthly basis as part of IBWC's normal accounting process, taking into account current runoff, demands, channel losses, and unidentified inflows and outflows. Performing the incremental inflow distribution outside of the WAM before any simulations are performed may introduce some small errors in the water availability results, but considering all of the other assumptions that have been made regarding the structure of the model, these are believed to be insignificant.

- Channel losses were estimated where sufficient data were available, but in many cases, there were little data. In particular, channel losses in the upper Pecos River watershed, including Toyah Creek, may be different from what has been assumed. Also, losses in the Pecos River are known to be higher when the first releases of the season are made from Red Bluff Reservoir. A single channel loss rate for each reach of the river was assumed because of limitations in the WRAP program.

- Some negative incremental flows exist in the naturalized streamflow database where significant natural streamflow losses occur and because of unknown or under-reported diversions and variability of filled naturalized flow values. The lack of diversion and/or return flow data and the assumption in many cases of zero values where none are reported can have a significant impact on this.

- The WRAP program provides several options for dealing with negative incremental flows, but there is no clear direction as to the best approach to use. For all of the WAM simulations of the Rio Grande Basin that have been made to produce the results reported herein, the “-4” option in the WRAP program has been used. It is possible that significantly different results would be obtained by assuming a different option.

- The manner in which water is released from Amistad Reservoir and transferred downstream either to satisfy demands along the middle Rio Grande or to supplement the storage in Falcon Reservoir is important with respect to evaluating water availability for users in both Texas and Mexico. There are no precise rules regarding this reservoir system operation, other than the 1944 Treaty provision that requires water to be stored in the upper most international reservoir to minimize evaporation losses and to conserve the water of the basin. For purposes of the WAM, system operation rules have been devised in this regard, but they may not reflect how the reservoirs are operated all of the time.

- Storage accounting procedures for the Amistad-Falcon reservoir system have been incorporated into the WAM pursuant to the TCEQ Rio Grande operating rules; however, storage accounts for individual irrigation and mining water rights that are dependent on the Amistad-Falcon reservoir system are not modeled. Instead, storage accounts are simulated for all Class A water rights as a group and all Class B water rights as a group. This approach greatly simplifies the structure of the WAM, but in some cases, it could limit the ability to simulate water availability for an individual water right, even though in the WAM the demand for all Amistad-Falcon water rights are modeled individually.

5.0 WATER AVAILABILITY IN THE BASIN

5.1 DESCRIPTIONS OF SCENARIOS MODELED

The TCEQ has defined eight specific scenarios that have been evaluated with respect to water availability in the Rio Grande Basin. These various scenarios, referred to as “Runs,” are described in the following sections. The output from these runs is intended to address directly the requirements for water availability information specified in House Bill 76 as described in Section 1.2 of this report. Basically, the eight different runs are characterized by different combinations of input conditions for: (1) the diversion amounts specified for individual water rights; (2) the storage capacities and area-capacity relationships specified for reservoirs; (3) the quantities specified for return flows corresponding to assumed levels of reuse; and (4) diversions and/or storage associated with term permits. The various combinations of these parameters for each of the eight runs are indicated in the matrix in Table 5.1-1.

It should be noted that the simulated water availability results from the WAM for each of these runs are described and summarized only in general terms in this report. Results for specific water rights and specific locations are presented as examples to demonstrate the general condition of the Rio Grande Basin with regard to overall water availability and to illustrate the types of water rights output that has been generated with the WAM. More detailed results from the WAM water availability analyses for individual water rights, including tables and plots of diversions and reservoir storage, can be extracted from the WAM output.

5.1.1 Reuse Runs

Three different simulations of water availability with the WAM have been made to address the effects of different levels of reuse of return flows in the Rio Grande Basin. The first of these, Run 1, is the simulation used as the basis of comparison for water availability in the Rio Grande Basin for all other runs. It includes fully authorized diversions by all water rights, authorized area-capacity relationships for all reservoirs as they were originally permitted, no term water right permits, and current levels of return flows, i.e., no reuse beyond what is reflected in historical return flows as reported for the last five years. For Mexico, no reuse of return flows has been assumed for all runs.

Although for the purposes of this study the results from Run 1 provide the basis of comparison against which the results from the other seven runs have been compared, it should be noted that this run is not the run used by TCEQ to assess water availability for permit applications. For permitting purposes, TCEQ uses Runs 3 and 8 (see below).

Runs 2 and 3 incorporate exactly the same input conditions as Run 1, except that Run 2 assumes that 50 percent of the current return flows are reused and Run 3 assumes that all of the current return flows are reused (zero return flow condition). Hence, in general, the results from Run 1

TABLE 5.1-1

MATRIX DESCRIBING DIFFERENT WATER AVAILABILITY MODEL RUNS

PARAMETERS VARIED BY WAM RUN	RUN 1	RUN 2	RUN 3	RUN 4	RUN 5	RUN 6	RUN 7	RUN 8
AUTHORIZED DIVERSION AMOUNTS (ALL WATER RIGHTS)	X	X	X					
AUTHORIZED DIVERSION AMOUNTS WITH CANCELLATION				X		X		
MAXIMUM 10-YEAR DIVERSION AMOUNTS					X		X	X
AUTHORIZED RESERVOIR AREA-CAPACITY RELATIONSHIPS	X	X	X	X	X	X	X	
YEAR-2000 RESERVOIR AREA-CAPACITY RELATIONSHIPS								X
ASSUMED RETURN FLOWS WITH NO REUSE	X			X	X			X
ASSUMED RETURN FLOWS WITH 50% REUSE		X						
ASSUMED RETURN FLOWS WITH 100% REUSE (NO RETURN FLOWS)			X			X	X	
WITHOUT TERM WATER RIGHTS	X	X	X	X	X	X	X	
WITH TERM WATER RIGHTS								X

should reflect more water available than those from either Run 2 or Run 3, and the results from Run 2 should reflect more water available than those from Run 3. For Run 3, all return flow amounts have been set equal to zero, excluding power plant return flows and those return flow amounts specifically listed in certificates or permits, which remained the same for all runs.

5.1.2 Cancellation Runs

Various simulations have been made with the WAM to provide information regarding the potential water availability impacts of canceling water rights in the Rio Grande Basin pursuant to the provisions of Subchapter E, Chapter 11 of the Texas Water Code. Under this section of the Water Code, the TCEQ has the authority to cancel a permit, certified filing, or certificate of adjudication if the water authorized to be appropriated has not been beneficially used during the last ten years. This excludes municipal water rights, which cannot be cancelled even if there has been no use. Hence, those non-municipal water rights in the Rio Grande Basin that have not been used in the last ten years according to TCEQ records have been identified and assumed to be cancelled for purposes of these analyses.

The determination of water rights subject to cancellation in the Rio Grande Basin has been simplified somewhat because cancellation proceedings were actually undertaken during the past year for water rights dependent upon the Amistad-Falcon reservoir system for their water supplies. Consequently, according to the Rio Grande Watermaster, there are no remaining water rights on the Rio Grande in the middle and lower basins that qualify for cancellation. The water rights that are subject to cancellation are the prior appropriation water rights on the mainstem of the Rio Grande upstream of Amistad Reservoir and on tributaries of the Rio Grande. Of this group, those with no reported usage in the last ten years are identified in Table 5.1-2. None of the Mexican water concessions was assumed to be cancelled for any of the runs.

Four different runs have been made for purposes of investigating water rights cancellation in the Texas portion of the Rio Grande Basin. For current reuse conditions, two runs have been made. One, Run 4, incorporates fully authorized diversions in the WAM except for those water rights that qualify for cancellation (diversions for these have been set equal to zero). The other, Run 5, has all diversions set equal to the maximum annual use reported during the last ten years, which, by definition, also includes zero diversions for those water rights that qualify for cancellation, and includes municipal water rights with no use during the last ten years. Runs 6 and 7 correspond to Runs 4 and 5 directly, except that 100-percent reuse of all return flows is assumed (zero return flow amounts). For all four of these runs, the authorized area-capacity relationships for all reservoirs have been used, and all term permits have been excluded.

For determining the maximum annual use reported during the last ten years for water rights in the Rio Grande Basin, historical use records from the TCEQ and the IBWC have been used. For the Amistad-Falcon water rights in the lower and middle basins, the summary of the total amount of water used from the reservoirs annually by water use category as provided by the Rio Grande

TABLE 5.1-2

WATER RIGHTS WITH ZERO REPORTED USE DURING LAST TEN YEARS

(TCEQ Water Right IDs)

TCEQ ID	WATER RIGHT OWNER	ANNUAL AUTHORIZED AMOUNT (acre-feet)
12300192001	G B SPENCE FARMS INC	2,220.0
12300270001	L R ALLISON	6,000.0
22303217001	HUDSPETH CO CONS & REC DIST 1	200.0
22303219001	HUDSPETH CO CONS & REC DIST 1	200.0
22303218001	HUDSPETH CO CONS & REC DIST 1	1,032.0
22303216001	HUDSPETH CO CONS & REC DIST 1	200.0
22303215001	HUDSPETH CO CONS & REC DIST 1	200.0
62302680001	ANN A LEGG & ERNESTINE A LOPE	15.0
62300915001	JOHN B MEADOWS TRUSTEE	1,944.0
62301184001	HANGING H RANCHES INC	3,600.0
62300987002	U S NATL PARK SERVICE	1,000.0
62300991001	EDGAR A BASSE JR	7,600.0
62300916001	TEXAS PARKS & WILDLIFE DEPT	714.0
62300957001	EVA MARIA NIETO ET AL	536.0
62302666001	PETRA ABREGO MUNOZ	23.6
62300982001	JAIME REDE MADRID ET AL	80.0
62300973001	JOSE A HERNANDEZ	96.0
62300980001	ALVARO PENA ET UX	52.0
62302676001	JEWEL FOREMAN ROBINSON	252.0
62305449001	CREWS ADAMS	1,920.0
12303005001	DANIEL T ESTRADA	108.0
12303006001	LAJITAS RESORT LTD	132.0
12303041001	TEXAS PARKS & WILDLIFE DEPT	1,017.0
12303133002	ELINOR FRANCES GREEN	162.0
12303112001	JEANNE NORSWORTHY	156.0
12303133001	NEVILLE RANCH	18.0

Watermaster for the period 1989 through 2002 were used. These data were previously presented in Table 2.2-1. For municipal use, these data indicate that the maximum use during the last ten years was on the order of 265,000 acre-feet per year. Based on the irrigation water use data summarized in Table 2.2-1, a value of approximately 1,270,000 acre-feet has been selected as the maximum annual use for irrigation in the last ten years. This quantity is generally consistent with the actual irrigation diversions of reservoir water, and it is considered to reasonably reflect maximum usage under current agricultural practices along the lower and middle Rio Grande, taking into account the general trend of converting irrigation water rights to municipal use as urbanization of the region continues.

For purposes of the cancellation runs, the maximum ten-year Amistad-Falcon demands of 265,000 acre-feet per year for DMI water rights and 1,270,000 acre-feet per year for irrigation and mining water rights have been used to calculate demand reduction factors based on the total authorized diversion amounts for these categories of water rights. The resulting demand reduction factors are 87.1 percent for the DMI water rights and 70.0 percent for the irrigation and mining water rights. Since all of the water rights in these specific categories are represented in a similar manner in the WAM and are subject to the provisions of the TCEQ Rio Grande operating rules, the maximum ten-year demand for each of the water rights in these categories has been calculated by multiplying the authorized annual diversion amount of each water right times the appropriate demand reduction factor. These reduced diversion amounts then were incorporated into the WAM data input files, along with the maximum use in the last ten years for all of the prior appropriation water rights, for purposes of the model simulations.

5.1.3 Current Conditions Runs

Run 8 is intended to reflect current conditions with respect to water rights in the Rio Grande Basin. This means that the annual diversion amounts for all water rights have been set equal to the maximum annual use reported during the last ten years (calculated as described in Section 5.1.2), the area-capacity relationships for all major reservoirs have been assumed to correspond to year-2000 sedimentation conditions, all return flows have been based on current conditions without any additional reuse, and all unexpired term water rights permits have been fully accounted for.

5.1.4 Firm Yield Analysis

As set forth in the “WAM Resolved Technical Issues No. 10 – Model Runs” document dated October 22, 1999, the firm annual yield for all major reservoirs, or reservoir systems, in the Rio Grande Basin has also been determined using the WAM. The firm yield has been determined only for those reservoirs that experienced shortages in the Run 3 simulation. Diversions for the reservoirs exhibiting shortages were reduced until no shortages were experienced, while maintaining all other water rights at their authorized amounts. The minimum volume remaining in the reservoirs during the critical period was virtually zero for the firm yield demands, except for the Amistad-Falcon system, which had water left in storage because of the required reserves.

5.2 RESULTS OF WATER AVAILABILITY MODEL RUNS

The simulated results from the WAM for the various input conditions corresponding to the eight runs provide an indication of water availability for each water right in the Rio Grande Basin. All of these simulations have encompassed monthly hydrologic conditions for the 1940 through 2000 period. The basic results from the different runs with regard to water availability consist of monthly values of simulated diversions and simulated end-of-month reservoir storage for each of the water rights in the basin. Also of importance are the simulated quantities of monthly unappropriated streamflows and monthly regulated streamflows at various locations throughout the Rio Grande Basin. The unappropriated streamflows, of course, provide an indication of the water available for future water resource development projects, while the regulated streamflows reflect the actual levels of flow that can be expected in the streams under the various scenarios of diversions, reservoir storage, return flows, and term permits.

To illustrate the variations in water availability among major water rights in the Rio Grande Basin for the different simulation runs, results for selected individual water rights (reservoirs) and primary control points are graphically displayed. These graphs include comparisons of monthly reservoir storage and regulated flows at locations throughout the basin for Runs 1, 2 and 3 (Reuse) in Appendix Q, Runs 1, 4 and 5 (Cancellation) in Appendix R, and Runs 1 and 8 (Current Conditions) in Appendix S. In accordance with the TCEQ Scope of Work for the Rio Grande WAM, results from the modeling for each of the primary control points used in the model are presented as in the following appendices:

Appendix	Description
T	Regulated Flows, Runs 1, 3, 8 (graphs)
U	Unappropriated Flows, Runs 1, 3, 8 (graphs)
V	Unappropriated Flows, Run 3 (tables)

A summary of the results from the eight runs with regard to the amount and reliability of simulated diversions is presented in tables in Appendix W. These tables list the Texas water rights with authorized diversions in the Rio Grande Basin, and indicate their respective water right numbers and types of use, i.e., municipal, industrial, irrigation, or other. For each of the eight runs, the authorized annual diversion amount for each water right and type of use is listed, along with the simulated mean annual shortage amount, the percent of the total months analyzed (61 years x 12 = 732 months) for which the authorized diversion was satisfied (referred to as the “period reliability”), and the percent of the total authorized diversion amount over the entire 1940-2000 analysis period that was actually diverted (referred to as the "volume reliability"). Although these results do not provide a complete picture of when and how much water is available for each water right, the two percentage quantities in the table do provide an indication of the reliability with which water can be diverted. At 100 percent, the fully authorized annual diversion of a particular water right is satisfied in every month. A zero value means water is never available.

The reliability results summarized in Appendix P indicate a wide variability in the reliability of the individual prior appropriation water rights that are located on the mainstem of the Rio Grande upstream of Amistad Reservoir and on tributaries of the river. Obviously the location of these water rights within their respective watersheds and the basin as a whole dictate how much water is available for diversion, as well as the magnitude of the individual authorized diversion amounts.

The effects of the various assumptions associated with the different runs can generally be quantified by evaluating the average reliabilities of different groups of water rights. This type of information is provided below for the eight runs and several different categories of water rights.

TABLE 5.2-1
SUMMARY OF AVERAGE VOLUME RELIABILITIES FOR WATER RIGHTS GROUPS

Run No.	Average Period Reliabilities, %			
	Prior Appropriation Water Rights	Amistad-Falcon Municipal Water Rights	Amistad-Falcon Class A Irrig. Water Rights	Amistad-Falcon Class B Irrig. Water Rights
1	63.4	100.0	70.4	45.1
2	63.4	100.0	69.3	44.5
3	63.4	100.0	68.2	43.8
4	63.9	100.0	70.7	45.3
5	71.5	100.0	91.5	73.2
6	63.9	100.0	68.6	44.1
7	71.5	100.0	91.5	73.2
8	67.0	100.0	91.2	73.0

It is obvious that the Amistad-Falcon municipal (DMI) water rights are fully satisfied all of the time because of their high priority status stipulated in the TCEQ Rio Grande operating rules. Similarly, the Class A irrigation/mining rights are somewhat more reliable than the Class B rights because of the higher allocation rate afforded the Class A rights. The effect of decreased return flows in the basin is evident by the slightly decreasing reliabilities of the irrigation rights from Run 1 to Run 3, but the prior appropriation rights generally are unaffected. The reliabilities of the Run 4 diversions are lower than those of the Run 5 diversions because of the fully authorized demands used for Run 4 as opposed to current demands for Run 5. The same trend is also indicated for the Run 6 and Run 7 results. As expected, the effect of return flows on the cancellation runs (Runs 4 and 6) is not significant.

5.2.1 Reuse Runs

5.2.1.1 Simulated Storage for Major Reservoirs

The effects on reservoir storage of the varying levels of reuse specified in the WAM for Runs 1, 2, and 3 for the major U.S. reservoirs in the Rio Grande Basin are illustrated in Figures Q-1 through Q-6 in Appendix Q. Because of the limited amount of municipal and industrial return flow that is discharged into the streams within the basin, the storage levels in the reservoirs exhibit very little change with the different levels of assumed reuse. Furthermore, with the substantial demands on the system because of the large volume of authorized diversions, most of the reservoirs, including the U.S. pools of Amistad and Falcon on the mainstem, only have significant amounts of water in storage during and immediately following high runoff periods. Otherwise, most of the reservoirs are relatively empty.

5.2.1.2 Unappropriated Flow at Selected Locations

Eight control points were chosen to illustrate the WAM simulated results with respect to U.S. unappropriated water. Table 5.2-2 lists the control points and their location. Annual quantities of the simulated unappropriated U.S. streamflows for the analysis period 1940-2000 for each of the three reuse conditions specified in Runs 1, 2, and 3 are plotted in Figures Q-7 through Q-14 at locations corresponding to the control points listed in Table 5.2-2.

TABLE 5.2-2

SELECTED CONTROL POINTS FOR WAM FLOW RESULTS PRESENTATION

CONTROL POINT		CONTROL POINT LOCATION
NO.	ID	
AT1000	**RG-FQ**	Rio Grande at Fort Quitman, TX
CT6000	RG-BC	Rio Grande below Rio Conchos, TX
CT1000	RG-DR	Rio Grande at Del Rio, TX

DT3000	RG-LA	Rio Grande at Laredo, TX
DT1000	RG-BF	Rio Grande below Falcon Dam, TX
GT1000	PR-LA	Pecos River near Langtry, TX
ET1000	RG-AN	Rio Grande below Anzalduas Dam, TX
ET0000	RG-MO	Rio Grande at Mouth, TX

As expected, these results indicate that very little unappropriated water is available in the Rio Grande Basin, and, therefore, very little difference is noted between the unappropriated flow values for the different reuse runs.

5.2.1.3 Regulated Flow at Selected Locations

Annual quantities of the simulated regulated streamflows for the analysis period 1940-2000 for each of the three reuse conditions specified in Runs 1, 2, and 3 are plotted in Figures Q-15 through Q-22 for the same locations used for presenting the unappropriated streamflows. The effects of the different levels of return flows associated with the three reuse conditions on the regulated streamflows are essentially the same as those indicated for the unappropriated flows.

5.2.2 Cancellation Runs

5.2.2.1 Simulated Storage for Major Reservoirs

The plots in Figures R-1 through R-12 in Appendix R illustrate the effects of water rights cancellation on storage in the major reservoirs. These plots present simulated monthly storage variations for selected reservoirs over the period 1940 through 2000 for the fully authorized water availability case (Run 1) and the different cancellation conditions (Runs 4, 5, 6, and 7). In general, the major deviations in the simulated reservoir storage levels from the fully authorized case (Run 1) result from the maximum 10-year use simulations (Runs 5 and 7). The diversion amounts specified in the model for these simulations are somewhat less than the fully authorized diversions; consequently, more water generally is stored in the reservoirs. The greatest increase in storage levels occurs at Red Bluff Reservoir on the Pecos River and at Imperial Reservoir, an off-channel reservoir dependent on flows diverted from the Pecos River. Amistad and Falcon Reservoirs exhibit some storage increase as a result of the reduced maximum 10-year demands.

5.2.2.2 Unappropriated Flow at Selected Locations

Annual quantities of the simulated unappropriated streamflows for the analysis period 1940-2000 for each of the four cancellation scenarios, i.e., Runs 4, 5, 6, and 7, are plotted in Figures R-13 through R-28. Again, because there is very little unappropriated water available throughout the Rio Grande Basin and because the only water rights subject to cancellation are some of the prior appropriation rights upstream of Amistad Reservoir and on some of the tributaries, the effects of cancellation on unappropriated water are not noticeable. It is interesting to note, however, that the high flows that occurred on the Rio Grande during the early 1940s translate to unappropriated water at all of the mainstem gages for the maximum 10-year use simulations. This is likely the result of starting all of the reservoirs full at the beginning of the simulation in 1940. Higher levels of naturalized flows also occurred on the Rio Grande in other years but did not result in unappropriated water because of available unused capacity in the major reservoirs.

5.2.2.3 Regulated Flow at Selected Locations

Annual quantities of the simulated regulated streamflows for the analysis period 1940-2000 for the fully authorized case (Run 1), the two cancellation conditions (Runs 4 and 6), and the two 10-year maximum use scenarios (Runs 5 and 7) are plotted in Figures R-29 through R-44 for the same locations used for presenting the unappropriated streamflows. The effects of the different cancellation and maximum water use scenarios on the regulated streamflows are essentially the same as those indicated for the unappropriated flows. The regulated streamflows, of course, are somewhat greater than the unappropriated flows because they do not reflect all of the streamflow depletions associated with all water rights.

5.2.3 Current Conditions Run

5.2.3.1 Simulated Storage for Major Reservoirs

The differences in the simulated reservoir storage attributable to the changes in area-capacity curves between the authorized storage conditions and year-2000 storage conditions and the use of current demands for all Texas water rights (maximum uses in the last 10 years) are reflected on the reservoir storage plots in Figures S-1 through S-6 in Appendix S. These plots present simulated monthly storage variations for selected reservoirs over the period 1940 through 2000 for the fully authorized water availability case (Run 1) and the current conditions case (Run 8). In general, the major deviations in the Run 8 simulated reservoir storage levels from the Run 1 case occur because the diversion amounts specified in the model for these current conditions simulations are somewhat less than the fully authorized diversions; consequently, more water is stored in the reservoirs. Only the mainstem reservoirs, Amistad and Falcon, exhibit any significant change in storage from the baseline Run 1 case.

One obvious difference between the two sets of storage results for Amistad Reservoir relates to the maximum available storage capacities that have been used for the two conditions. Because of sedimentation, the year-2000 maximum reservoir storage capacity for the United States is approximately 300,000 acre-feet less than the original conservation storage capacity.

5.2.3.2 Unappropriated Flows at Selected Locations

Under current conditions, many water rights do not utilize their fully authorized diversion amounts. Although there are currently unused flows in the Rio Grande, all of this water is technically not "unappropriated," since some of it is subject to lawful claim by existing water rights holders. While these flows may not be available on a perpetual basis, they could possibly be available on a temporary basis and subject to temporary appropriation. Annual quantities of the simulated unappropriated streamflows for the analysis period 1940-1998 for Run 1 and the current conditions scenario (Run 8) are plotted in Figures S-7 through S-14.

These curves are similar to those presented for other runs for unappropriated water. Very little unappropriated water, if any, is shown to be available for either case. Again, the high flows that occurred on the Rio Grande during the early 1940s do produce unappropriated water at all of the mainstem gages for the maximum 10-year use simulation, and this is likely the result of starting all of the reservoirs full at the beginning of the simulation in 1940, thereby causing spills.

5.2.3.3 Regulated Flow at Selected Locations

Annual quantities of the simulated regulated streamflows for the analysis period 1940-2000 for the fully authorized case (Run 1) and the current conditions scenario (Run 8) are plotted in Figures S-15 through S-22 for the same locations used for presenting the unappropriated streamflows. As shown, on the mainstem and tributaries of the Rio Grande above Amistad, the two sets of regulated flows are essentially the same, which is to be expected because the demands on the system upstream of Amistad are not appreciably different. Below Amistad Reservoir, the Run 1 regulated flows with fully authorized diversion amounts sometimes are lower than the current conditions regulated flows, but most of the time they appear to be higher. This occurs because the current-conditions demands on the system downstream of Amistad are somewhat lower than the authorized diversions; hence, less water is released from both Amistad and Falcon Reservoirs to meet these demands, thereby resulting in lower river flows.

5.2.4 Flow-Duration Curves

When a time series of hydrologic events, in this case annual streamflows at a location, are arranged in order of their magnitude, the percent of time that each annual streamflow value is equaled or exceeded can be computed. A plot of the annual streamflows versus the corresponding percentages of time is known as a flow-duration curve. Flow-duration curves have been computed for the control points listed in Table 5.2-2. These results are presented in Appendix W in Figures W-1 through W-8. Curves are shown for naturalized flows and for regulated flows as simulated with the WAM for Run 1 (fully authorized diversions with full return flows), Run 3 (fully authorized diversions with no return flows, i.e. 100% reuse), and Run 8 (maximum use for the last 10 years and existing return flows, i.e. current conditions).

Comparison of these curves can be used to assess the cumulative impact of appropriations on streamflows. Generally, these curves indicate that there is very little difference in the simulated streamflows for Runs 1, 3 and 8, except for the flows at the mouth of the Rio Grande. This is because return flows throughout the basin generally are not significant compared to streamflow levels (Run 1 versus Run 3) and because current diversions are not significantly less than authorized amounts (Run 8 versus Runs 1 and 3). At the mouth of the river, the effects of the return flows from the City of Brownsville (the only major city on the lower Rio Grande that discharges treated wastewater into the river) are apparent, i.e., Run 1 flows are higher than Run 3 flows. Of course, all of the curves illustrate the reductions in the naturalized flows caused by the appropriations of water associated with existing water rights.

5.2.5 Reservoir Firm Yield Analyses

5.2.5.1 Major Reservoirs

The firm annual yield for all major reservoirs, or reservoir systems, in the Rio Grande Basin has been determined consistent with the guidelines set forth in the "WAM Resolved Technical Issues No. 10 – Model Runs". As directed, the firm yield has been determined only for those reservoirs that experienced shortages in the Run 3 simulation. For the reservoirs that do not exhibit shortages, the firm annual yield has been identified as the "permitted firm yield." Table 5.2-3 summarizes the results from the firm yield analyses for all major reservoirs, or reservoir systems, in the Rio Grande Basin.

When operating the WAM to calculate the firm annual yield of any one of the reservoirs, or reservoir systems, the specified demand(s) on the reservoir, or reservoir system, was reduced from its authorized amount until no shortages occurred. This amount of specified demand has been taken to represent the firm annual yield of the reservoir, or reservoir system. With this amount of demand, virtually no 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, is indicated in Table 5.2-3.

The determination of the firm yield of the Amistad-Falcon reservoir system was complicated by the TCEQ's reservoir storage accounting rules and the type-of-use priority system in place for the Texas water rights that are associated with Amistad and Falcon Reservoirs. A proportional adjustment scheme was employed to alter the Texas demands on the U.S. pools of the reservoir system whereby the authorized diversion amount of each individual water right was adjusted by the same factor, as necessary, to arrive at an appropriate system yield value. As noted above, total demands on the system were considered to be at the firm yield condition when no shortages occurred.

Another unique aspect of the yield determination for the Amistad-Falcon system relates to the amount of water remaining in storage during the critical drought period with the yield demand imposed on the system. Because of the requirements in the TCEQ rules to maintain the DMI reserve (225,000 acre-feet) and to provide for a fluctuating operating reserve (up to 75,000 acre-feet), there is some amount of water still in the reservoir during the lowest-storage condition of the critical drought period. This is unavoidable as long as the rules regarding the reserves are in effect. For the yield value reported in Table 5.2-3, the minimum combined volume of storage remaining in both of the reservoirs was approximately 340,500 acre-feet.

TABLE 5.2-3
SUMMARY OF RESERVOIR FIRM YIELD ANALYSES

RESERVOIR	AUTHORIZED CONSERVATION STORAGE acre-feet	AUTHORIZED DIVERSION AMOUNT acre-feet/year	FIRM YIELD DIVERSION AMOUNT acre-feet/year	YEAR OF MINIMUM STORAGE	NOTE REF.
San Esteban Lake	18,770	0	n.a.	n.a.	1
Red Bluff Reservoir	310,000	292,500	56,350	1984	2
Lake Balmorhea	6,350	32,120	0	n.a.	3
Imperial Reservoir	6,000	n.a.	n.a.	n.a.	4
Amistad-Falcon System	1,673,055 A 1,551,897 F	2,147,279	1,055,250	2000	5,6
Casa Blanca Lake	20,000	600	600	n.a.	7
Anzalduas Reservoir	13,900	n.a.	n.a.	n.a.	8

NOTES:
1 Recreational reservoir, no authorized diversion.
2 Based on irrigation demand distribution as per authorizing water right.
3 Authorized for irrigation use only.
4 Off-channel reservoir authorized for irrigation use only.
5 Conservation storage capacities reflect currently recognized United States available storage capacity in each reservoir based on 2000 survey.
6 Yield reflects the system yield of both reservoirs.
7 Authorized diversion amount is firm without shortages; therefore, the Firm Annual Yield is the "Permitted Firm Yield".
8 Used for regulation of river flows downstream of Falcon Reservoir.

The WAM also has been operated to determine the firm yield of the Amistad-Falcon system without the TCEQ rules in effect regarding reserves and storage accounting. For this analysis, a single municipal demand has been specified immediately downstream of Falcon Reservoir, and this demand has been adjusted to arrive at the firm yield of the reservoir system. Using this procedure, the firm yield of the United States portion of the Amistad-Falcon system has been determined to be approximately 1,099,700 acre-feet per year, with essentially no water remaining in storage during the critical drought period. As a separate exercise, the yield demand was moved from immediately downstream of Falcon Reservoir to near Brownsville, a distance of about 200 river miles. For this case, the firm yield of the United States portion of the Amistad-Falcon system was determined to be approximately 977,000 acre-feet per year. This lower yield amount reflects the losses that occur along the lower Rio Grande below Falcon Reservoir as stipulated in the WAM. These values of system yield for Amistad and Falcon Reservoirs might be considered to represent the ultimate yield of the system in the event that some day none of the water in the reservoirs would be used for irrigation and mining purposes and the storage accounting system would be abandoned.

5.2.5.2 Yield Comparisons With Other Studies

The only other source of yield information for the major reservoirs in the Rio Grande Basin is the SIMYLD-II model of the Amistad-Falcon reservoir system that was previously developed as part of a planning study undertaken by the Valley Water Policy and Management Council of the Lower Rio Grande Water Committee, Inc. with funding support from the TWDB and subsequently used in the Senate Bill 1 Region M Rio Grande Regional Planning Study. This model did not include full utilization by all water rights in the basin, and it utilized historical inflows to the reservoirs as developed by IBWC. The model also did not account for channel losses along the Rio Grande between Amistad and Falcon or downstream of Falcon.

The total system yield for the United States as determined with this model was 1,166,939 acre-feet per year. This is only about 11 percent greater than the system yield derived with the WAM in this study. This difference in yield is not surprising considering the numerous differences and assumptions in the two models and the ability of the WAM to better describe the more complex aspects of water management and utilization in the basin.

5.2.6 WAM Results for Mexico

Selected results from the WAM for water use activities in Mexico are presented in Appendix X. Figures X-1 through X-9 present time series plots of reservoir storage for all of the major reservoirs in the Mexican portion of the Rio Grande Basin. As shown, reservoir levels vary considerably in response to hydrologic conditions, with droughts apparent during the 1950s, 1970s and 1990s.

The combined flow of annual Mexican and United States water in the Rio Grande at Fort Quitman is plotted on the graph in Figure X-10 for the period from 1940 through 2000. The portion allocated to the U.S. (50 percent) is indicated. The 1944 Treaty stipulates that ownership of one-third of the inflows to the Rio Grande from six named tributaries in Mexico is to be transferred to the United States. These inflows as simulated with the WAM are plotted in Figures X-11 through X-16 for the Rio Conchos, Arroyo de la Vacas, Rio San Diego, Rio San Rodrigo, Rio Escondido and Rio Salado. The U.S. one-third share of these flows also is indicated on the plots. For the period from 1954 through 2000, the historical average amount of water delivered to the United States from all six of the Mexican tributaries was 411,205 acre-feet per year. Based on the WAM results, the average amount delivered to the United States for this same period is 409,406 acre-feet per year. These results may reflect increased historical demands within Mexico that actually exceed the concessions that are specified in the WAM.

Graphs of the inflows to the Rio Grande from the Rio San Juan and the Rio Alamo below Falcon Reservoir are presented in Figures X-17 and X-18, respectively. These flows are considered to be entirely Mexican water under the provisions of the 1944 Treaty.

5.3 COMPARISON TO EXISTING RIVER BASIN MODEL

There is no TCEQ Legacy model or any other water rights model for the Rio Grande Basin that is known to exist within the public domain. Consequently, no comparisons can be effectively made using the results generated with the WAM.

5.4 FACTORS AFFECTING WATER AVAILABILITY AND MODELING RESULTS

One of the most significant issues with regard to the water availability analyses performed for the Rio Grande Basin and the results from the WAM relates to the accuracy of the naturalized streamflows that have been used in the calculations. Results from the WAM may be affected by potential inaccuracies in the USGS/IBWC streamflow gaging data, reservoir elevation or storage records and area-capacity data, estimation of drainage areas using GIS procedures, locations of control points on smaller tributaries, reported and estimated diversions and return flows, and channel losses. In addition, the quality of data obtained from sources in Mexico is poor in comparison to data obtained from other sources.

Another concern is the modeling of the Mexican portion of the basin, particularly with regard to the operating rules for Mexico's internal reservoirs on tributaries and Mexico's storage in Amistad and Falcon Reservoirs. The demands imposed on the Mexican system also may not accurately reflect actual demands under different hydrologic conditions since Mexico does not have an organized system of water rights in place for regulating the use of water. How Mexico may operate its water supply system in the future relative to the requirements of the 1944 Treaty and how much water the United States may receive from the Mexican tributaries in accordance with the provisions of the treaty also are uncertain. These operations directly affect the amount of water available for Texas users.

Water rights with multiple diversion points generally have been represented in the model either by using the most downstream diversion point for all diversions or by grouping some of the diversions at a single point and assigning a portion of the annual authorized diversion amount for a given water right to this group of diversions. The allocation of different fractions of the annual authorized diversion amount to individual diversion points can only be estimated considering such factors as drainage area size and historical water use patterns. Because of these uncertainties, there may be some unnecessary limitations on water availability as simulated with the WRAP model for those water rights with multiple diversion points.

Other factors that may have an effect on the water availability results for the Rio Grande Basin include the significant considerations listed in Section 2.5 and the various assumptions that are inherent in the WAM as listed and described in Section 4.3.

5.5 REQUIREMENTS FOR MODEL RE-RUN AND/OR MODEL UPDATE

Included in this section are general instructions regarding changes and modifications required to be made in the WAM data input files in order to incorporate additional water rights or to change conditions for existing water rights, such as the location of the diversion point. It is assumed that the modeler has a general understanding of WAM/WRAP issues and concepts. It is recommended that all model users obtain a copy of the document entitled "Water Rights Analysis Package (WRAP) Modeling System Reference Manual, August 2003 (Revised December 2003)", which is available at "http://ceprofs.tamu.edu/rwurbs/wrap.htm".

5.5.1 Rio Grande WAM Data Specifications

The following input records have been used in the Rio Grande WAM, and depending upon the type of change or modification being made, these may or may not require updating:

<u>Records for Defining Control Point Connectivity and Other Related Information</u>

CP - Control Point connectivity and references naturalized flows and evaporation data
FD - Flow Distribution specifications transferring flows from gaged to ungaged control points
WP - Watershed Parameters used in flow distribution
CI, FA-Constant Inflows or outflows and Flow Adjustments, entering or leaving system
RF - Return Flow factors

<u>Records Used for Characterizing Water Rights Information in the WAM</u>

WR - Water Rights basic information
UC - Use Coefficients specifying monthly water use distribution
SO - Supplemental Options for water rights
IF - Instream Flow requirements
TO - Target Options

Records for Defining Reservoir-Related Information

WS -	Water Storage for a reservoir associated with a water right
SV, SA -	Storage Volume, Surface Area characteristics of reservoirs
OR -	Operating Rules for multiple reservoir operations
DI -	Drought Index

The purpose of this section is to assist the modeler in modifying or updating the WAM data input files to incorporate future changes to the Rio Grande Basin WAM. This requires that all future changes be made consistent with the priority logic specified in the modeling memo contained in Appendix I. This will ensure the proper representation of the different types of Texas water rights in the basin, as well as the proper interaction between waters in the Rio Grande owned by the United States and Mexico pursuant to the 1944 Treaty. Following is a summary of specific guidelines for specific priority groups:

> Prior Appropriation Water Rights on Rio Grande above Fort Quitman - All water rights in this reach are assigned priority dates consistent with the date associated with their water right permit or certificate of adjudication, less 200 years.
>
> All Other Prior Appropriation Water Rights - These water rights are assigned priority dates consistent with the date associated with their water right permit or certificate of adjudication. All Texas tributary water rights are simulated before any Texas Rio Grande mainstem water rights below Amistad Dam.
>
> Texas Amistad-Falcon Water Rights (Middle and Lower Rio Grande only) - These water rights are assigned priority codes consistent with the type of use authorized: domestic, municipal and industrial first; Class A irrigation and mining second; and Class B irrigation and mining third.
>
> Mexican Water Rights - These water rights are assigned priority codes to accomplish upstream-to-downstream simulation, with municipal water uses given highest priority in the event both municipal and non-municipal diversions are at the same location. All Mexican tributary water rights are simulated before any Mexican mainstem water rights on the Rio Grande.

It should also be noted that changes made to Amistad-Falcon water rights on the middle and lower Rio Grande which result in different quantities of water being authorized for Class A or Class B irrigation water rights will require changes to the Rio Grande WAM .dat file to enable the allocation logic to be properly represented. This is accomplished by making normal additions and/or changes to this portion of the .dat file using the exact same logic that is already specified for the different types of Amistad-Falcon water rights. However, special effort must be made to associate the new or changed activity with the current set of UC cards that is coded in the WAM data file for Class A and Class B irrigation and mining water rights (AM-IRR, AM-MIN, AM-MUN, AL-IRR, AL-MIN, BM-IRR, BM-MIN, BL-IRR, BL-MIN). Once the model changes are made, the revised WAM must be operated, with the TABLES 1SUM record executed to determine the total authorized diversion amount for all Class A and Class B water rights using the UC code. Once the total amounts are obtained for the above UC codes, the totals then must be distributed by the factors on their respective UC cards so that monthly quantities can be obtained for each UC code. Monthly totals then must be summed for all four of the Class B water right UC codes and all five of the Class A water right UC codes. Once this information has been calculated, the CI cards with CP's named "APW" (A Pool) and "BPW" (B Pool) Must be changed to reflect the new amounts for the Class A and Class B totals. The model then can be re-run. It should also be noted that future changes to the total authorized diversion amounts of Class A and Class B water rights requires that the accounting pools that represent each class of water right also need to be changed so that both accounting reservoirs (CLASSA and CLASSB) are sized to be 1.41 times the total authorized diversion amount.

After any changes are made to the WR/WS portion of the .dat file, it is recommended that the TABLES 1SRT record be used to produce a list of all water rights in priority order to ensure that the new activity is being considered by WRAP in the proper order with respect to all of the other water right activities in the Rio Grande WAM.

5.5.2 Updating the Hydrology Data

WRAP develops the hydrology records for secondary control points from naturalized flow records at primary control points as necessary to run the model simulation. All hydrology parameters are stored in the following files: RG1.DAT contains control point connectivity data and channel loss information on CP cards; RG1.DIS contains watershed parameters (WP records) and other data for distributing flow from gaged to ungaged control points (FD records); RG1.INF contains the naturalized streamflows for primary control points (IN records); RG1.EVA contains the evaporation data for selected control points (EV records); and RG1.FAD constrains flow adjustment information to represent spring discharges.

If a new control point is required, the following changes must be made:

1. New watershed parameters must be determined for the new location and coded with a WP record in the file RG1.dis.

2. New flow distribution instructions must be determined and coded with an FD record in the file RG1.dis.

3. The connectivity, with respect to existing control points, must be established and coded with a CP record in the file RG1.dat.

4. The distance the new control point is from the existing upstream control point (if applicable) and the existing downstream control point must be determined and the previous channel loss factor that represented the previous reach must be divided (based on distance) into two parts and associated to the new upstream and downstream reaches. This information then must be coded on the new CP record and the next upstream CP record in the file RG1.dat.

5.5.3 Updating the Water Rights Data

The WAM, through the WRAP program, performs the water rights simulation for the river basin configuration, and the water rights descriptions and data files are stored in the RG1.DAT file. The following changes are required to be made to the RG1.DAT file in order to model a new water use activity:

1. Add a new set of UC records for the monthly use factors, to be referenced in the WR card. If an existing set of UC records is representative of the new water use activity, a new set of UC records is not required.

2. Add a new set of RF records to represent the monthly return flow factors to be referenced in the WR card. If the new water use activity has a constant return flow factor, or if an existing set of return flow factors is representative, no new RF records are required.

3. Add a new set of CI records to represent any new constant inflows.

4. Add a new WR record to represent a new water right. See the above section for specific details related to priority date and other unique coding requirements of the Rio Grande WAM.

5. Add a new WS record if the new water right activity requires. The reservoir storage-area relationship may be described using coefficients in the WS record, or using a set of SA and SV records.

6.0 SUMMARY AND CONCLUSIONS

The Texas A&M WRAP model has been applied to the Rio Grande Basin in Texas and Mexico to determine water availability. All water rights in the basin have been modeled for a 61-year period of naturalized streamflows from 1940 through 2000 under eight different scenarios (referred to as “Runs”). The runs consist of three basic sets of conditions: (1) fully authorized diversion amounts and varied return flow amounts (Reuse Runs), (2) varied diversion amounts and varied return flow assumptions (Cancellation Runs), and (3) approximate current diversion and return flow conditions with year-2000 area-capacity relationships for reservoirs (Current Conditions Run). Special conditions reflecting environmental flow requirements have been included in all model runs where applicable.

The primary conclusions from this water availability investigation and modeling effort for the Rio Grande Basin are as follows:

1) There are 962 water rights in the Texas portion of the Rio Grande Basin. The total amount of authorized diversions for these water rights is approximately 5 million acre-feet per year. There are 26 major reservoirs in the basin (eight in Texas and 18 in Mexico), defined as having a conservation storage capacity of 5,000 acre-feet or greater.

2) Shortages occur frequently for many water rights, particularly in the upper basin where precipitation is much lower. There are also frequent shortages for the Amistad-Falcon irrigation water rights. Amistad-Falcon municipal rights are fully satisfied all of the time because of their high priority status stipulated in the TCEQ Rio Grande operating rules.

3) The drought of record at most locations is the drought of the 1950s, but occurs at other times in some locations. In particular, the minimum storage condition for the U.S. portion of the Amistad-Falcon system occurs in September of 2000 for the period of record of the WAM. This drought extends beyond the period of record.

4) Comparison of the WRAP results from the different runs indicates that the effects of varying levels of reuse have little impact on existing water rights and reservoir storage. There is comparatively little water returned in the Rio Grande.

5) The effects of water rights cancellations under fully authorized conditions are not significant. There are few water rights subject to cancellation, representing a relatively small quantity of water. However, when the use is limited to the maximum use in the last 10

years, there are some improvements in water availability. This is because the maximum usages in the last 10 years are generally significantly less than fully authorized amounts. The effects of reservoir sedimentation are most significant in Amistad Reservoir, which has lost approximately 300,000 acre-feet of storage since construction.

6) There is little or no unappropriated water available in the Rio Grande Basin under any of the runs, including the current conditions run.

7) The amount of regulated flows follows a similar pattern to unappropriated flows. There is little impact of the various runs on regulated flows. The regulated streamflows, of course, are somewhat greater than the unappropriated flows because they do not reflect all of the streamflow depletions associated with all water rights.

8) The firm yield analysis shows that almost all reservoirs have demands that exceed the firm yield of the reservoir or reservoir system. In particular, Red Bluff Reservoir has authorized annual diversions of about 290,000 acre-feet and a firm yield of only about 56,000 acre-feet; the U.S. portion of the Amistad-Falcon system has authorized diversions of over 2 million acre-feet and a firm yield of about 1,055,000 acre-feet.

9. Because of the extreme spatial and temporal variation of streamflows in the upper portion of the Rio Grande Basin in response to rainfall events and limited data describing localized flow conditions, the amounts and locations of historical diversions and return flows (particularly related to irrigation), and variable channel losses, results from the WAM in terms of the available water supply for specific water rights in some locations may not be fully representative of actual conditions.