Section 1
Introduction

1.1 Description of the Basin

The Guadalupe-San Antonio River Basin encompasses an area of over 10,100 square miles, extending from the headwaters on the Edwards Plateau north and west of San Antonio, through the Blackland Prairies, Post Oak Savannah, and the Gulf Coast Prairies and Marshes, to its outlet at San Antonio Bay south of Victoria. The basin is a highly complex hydrologic environment, with active surface water and groundwater interaction. The basin is crossed by at least five aquifer outcrops or recharge zones, including the Edwards, Carrizo-Wilcox, Queen City, Sparta, and Gulf Coast-Goliad Sand (Figure 1-1). The most significant of these is the Edwards, where an average of 318,310 acre-feet per year (acft/yr) entered the aquifer from the Guadalupe-San Antonio River Basin during the 1934 through 1996 historical period.[1] Although streamflow volumes entering the other aquifers are not as great as those entering the Edwards, interactions between surface water and groundwater at the outcrops of these aquifers can significantly affect channel loss rates and delivery of water from upstream to downstream locations.

Average annual rainfall in the basin ranges from approximately 28 inches in the northwest portion of the basin along the Edwards Plateau to approximately 40 inches near the coast (Figure 1-2). Rainfall in the upper portions of the basin is highly variable in magnitude and frequency, as most significant rainfall originates from localized convective thunderstorms. The sporadic nature of rainfall in the upper basin results in short periods of high flows in the smaller streams, preceded and followed by long periods of zero flows. Major streams, such as the Medina, Blanco, and Guadalupe Rivers, which originate in the most upstream portion of the basin, are sustained by flows discharging from the Edwards Plateau Aquifer. The intermittent, variable nature of streamflow in the upper basin significantly affects water availability to rights in that region. Rainfall in the middle and lower basin also is highly variable, and is caused by convective thunderstorms and coastal storm systems originating in the Gulf of Mexico. Base

[1] HDR Engineering, Inc. (HDR), et al., "Edwards Aquifer Recharge Analyses, Trans-Texas Water Program, West Central Study Area, Phase II," San Antonio River Authority, et al., March 1998.

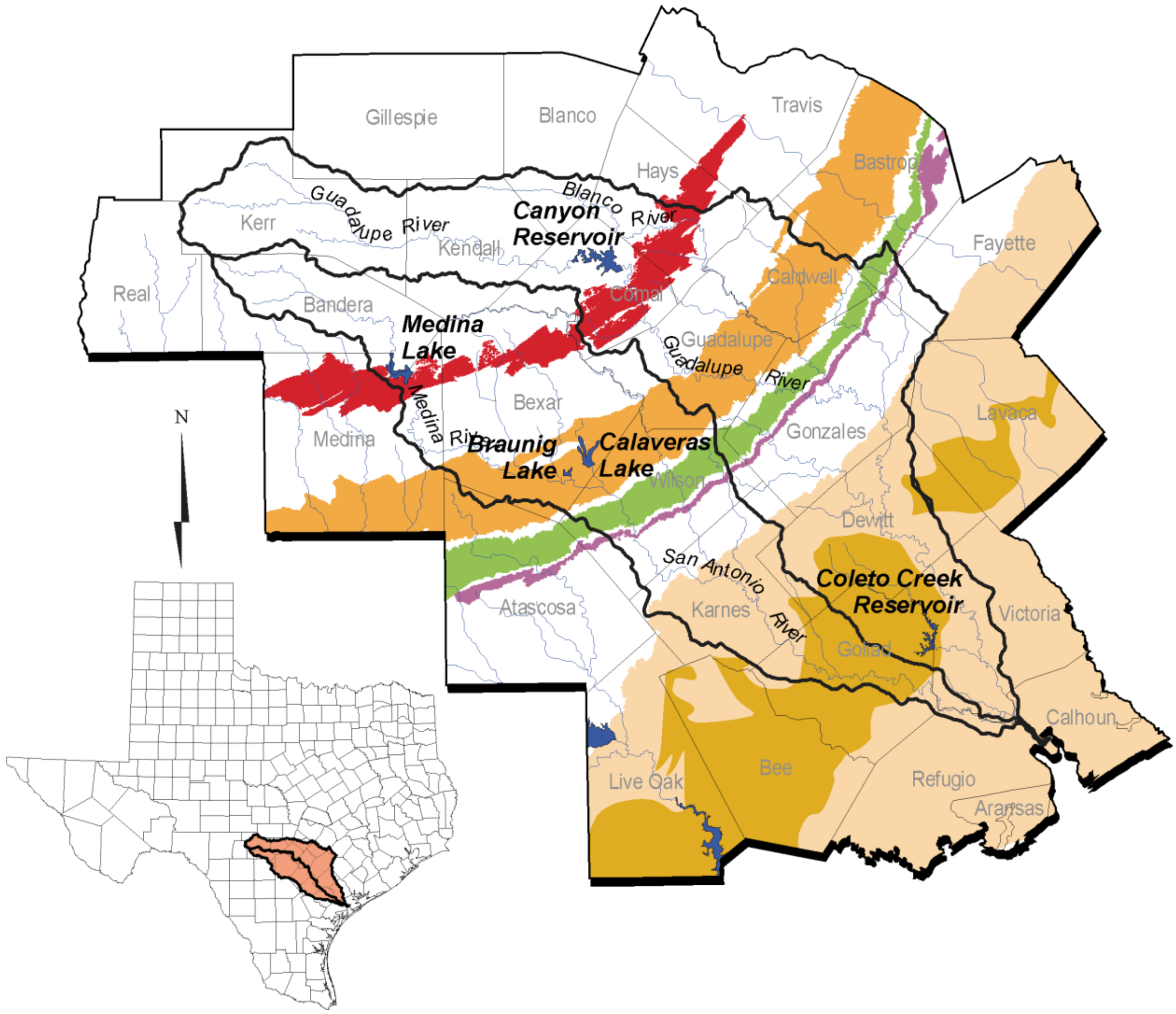


Figure 1-1. Guadalupe-San Antonio River Basin Map

flow in the middle and lower portions of the basin is sustained by several major and minor springs discharging from the Edwards Aquifer and by the discharge of treated municipal effluent in the San Antonio area. Major springs include Comal Springs (Comal River/Guadalupe River), San Marcos Springs (San Marcos River), San Antonio Springs (San Antonio River), San Pedro Springs (San Antonio River), and Hueco Springs (Guadalupe River).

Topography varies from steep slopes in the Hill Country upstream of and across the Edwards Aquifer recharge zone, to rolling hills in the middle basin, to generally mild or flat slopes in the Coastal Prairies approaching the Gulf of Mexico. The steep slopes and

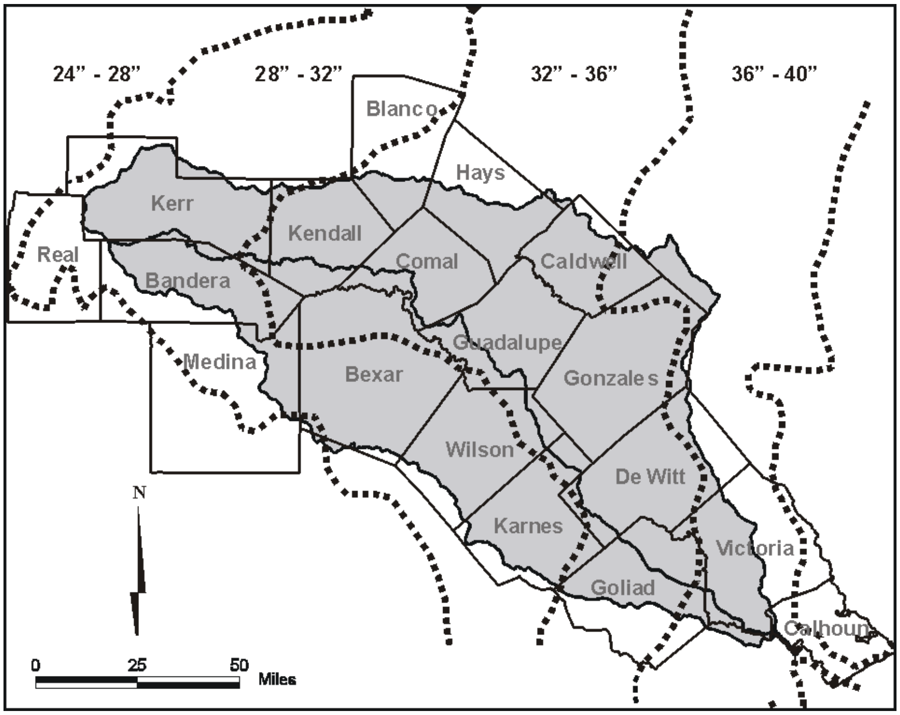


Figure 1-2. Average Annual Precipitation in the Guadalupe-San Antonio River Basin (1961 to 1990)

characteristically thin soils of the Hill Country and Edwards Plateau result in this area producing the greatest runoff per unit rainfall in the basin. In this portion of the basin, an annual average of about 11 to 15 percent of precipitation appears as runoff or gaged streamflow.[2] Downstream, annual runoff volumes average about 6 percent of annual precipitation. The Hill Country/Edwards Plateau area comprises roughly 35 to 40 percent of the land area in the Guadalupe-San Antonio River Basin.

Small streams in the upper Guadalupe River Basin drain to the Guadalupe and Blanco Rivers. Comal Springs discharges to the Comal River, which merges with the Guadalupe River some 2 miles downstream in the City of New Braunfels. San Marcos Springs discharges into the San Marcos River upstream of its confluence with the Blanco River. From that point, the San Marcos River flows to its confluence with the Guadalupe River near the City of Gonzales. Intermittent streams in the upper San Antonio River Basin drain to the Medina and San Antonio Rivers, which meet south of the City of San Antonio. Flow in the San Antonio River is sustained

[2] HDR, "Recharge Enhancement Study - Guadalupe-San Antonio River Basin," Edwards Underground Water District, September 1993.

by springflow from San Antonio Springs and San Pedro Springs, and by significant discharges of treated wastewater from multiple wastewater plants operated by the San Antonio Water System (SAWS). These discharges originate from groundwater pumped from the Edwards Aquifer and total in excess of 128,000 acft/yr (accounting for planned reuse of SAWS effluent), equal to nearly one-half of the mean annual naturalized flow of the San Antonio River at Elmendorf downstream of its confluence with the Medina River. The San Antonio River then continues downstream to its confluence with the Guadalupe River near the City of Tivoli. The Guadalupe River then flows over a saltwater barrier operated by the Guadalupe-Blanco River Authority (GBRA) and discharges into the Guadalupe Estuary downstream of Tivoli.

The Guadalupe River Basin and the San Antonio River Basin are generally considered two separate and distinct river basins. However, the San Antonio River is a tributary to the Guadalupe River, joining with the Guadalupe River upstream of its outfall to the Guadalupe Estuary. More than 30 percent of the total authorized consumptive diversions in the Guadalupe and San Antonio River Basins are located below the confluence of the two rivers. Hence, the basins are treated as a single river basin for water availability analyses presented herein.

Land use in the Guadalupe-San Antonio River Basin is predominately related to agriculture, with 37 percent classified as cropland or pastureland and 10.6 percent as rangeland. Urban land uses comprise only about 4 percent of the basin. The City of San Antonio, which is the largest municipality in the basin with a population of over 1 million, comprises about 50 percent of the total urban land use in the basin.

Groundwater resources currently supply about 88 percent of the water used for all purposes in the San Antonio River Basin and about 48 percent in the Guadalupe River Basin. Reliance on the Edwards Aquifer is expected to decrease in the future as limits on total pumpage from the Edwards Aquifer are implemented, pursuant to Senate Bill 1477 of the 73rd Texas Legislature and the creation of the Edwards Aquifer Authority. Increased reliance upon surface water supplies will be necessary.

The largest reservoir in the Guadalupe-San Antonio River Basin is Canyon Reservoir, which is located on the Guadalupe River above the City of Sattler. Canyon Reservoir has an authorized storage capacity of 740,900 acft, of which 386,200 acft is presently considered the conservation storage capacity for water supply purposes. Canyon Reservoir is owned and operated by the GBRA, which holds all of the authorized diversion rights in the reservoir. The conservation storage capacity of Canyon Reservoir is approximately equal to the total combined capacity of all other major reservoirs (capacity greater than 5,000 acft) in the Guadalupe-San Antonio River Basin. The Medina Lake System on the Medina River is comprised of Medina Lake (237,874 acft authorized impoundment) and the much smaller Diversion Lake (4,500 acft authorized impoundment) located a few miles downstream. Water supply releases are made from Medina Lake and diverted into the Medina Canal at Diversion Lake. The Medina Lake System is owned and operated by the Bexar-Medina-Atascosa Counties Water Control and Improvement District #1 (BMA).

1.2 Study Objectives

Pursuant to Senate Bill 1 of the 75th Texas Legislature, the Texas Natural Resource Conservation Commission (TNRCC) is developing new reservoir/river basin simulation models for 22 river basins in Texas in order to quantify available water in accordance with Chapter 11, Water Rights, Texas Water Code. The new models, commonly referred to as water availability models, are capable of assessing water available for diversion or impoundment under existing water rights and future permit applications subject to the doctrine of prior appropriation.

The objectives of this study are consistent with the direction provided in Senate Bill 1 and include:

- Develop an updated water availability model for the Guadalupe-San Antonio River Basin;
- Apply the model to provide water rights holders with information regarding long-term reliability and water availability during drought; and
- Apply the model to assess potential effects of reusing treated effluent and/or cancellation of unused water rights on water availability, instream flows, and freshwater inflows to bays and estuaries.

This report documents the methodologies employed and results obtained in the fulfillment of these objectives.

Cancellation and reuse scenarios are conducted per the Legislative requirement, §16.012(I) and (j) of the Water Code:

(I) Within 90 days of completing a water availability model for a river basin, the commission shall *provide to each regional water planning group created under Section 16.053 of this code in that river basin the projected amount of water that* *would be available if cancellation procedures were instigated* under the provisions of Subchapter E, Chapter 11, of this code.

(j) Within 90 days of completing a water availability model for a river basin, the commission, in coordination with the Parks and Wildlife Department, shall *determine the potential impact of reusing municipal and industrial effluent on existing water rights, instream uses, and freshwater inflows to bays and estuaries*. Within 30 days of making this determination, the commission shall *provide the projections to the board and each regional water planning group* created under Section 16.053 of this code in that river basin.

Section 2
Existing Water Availability Information

2.1 Water Rights

The TNRCC maintains records of all water rights in the Guadalupe-San Antonio River Basin. These water rights are comprised of certificates of adjudication based on claims filed during the adjudication process and of permits based on applications filed subsequent to the completion of the adjudication process in the early 1980s. In order to maintain consistency with current TNRCC practices, all rights conferred by certificates of adjudication will be referred to by their certificate of adjudication numbers and all permits by their permit application numbers. As a component of this study effort, all water rights have been reviewed and the electronic database provided by TNRCC has been revised to ensure that it accurately reflects priority date(s), authorized diversion(s), type(s) of use, special conditions, and other provisions associated with each water right.

There are 604 water rights in the Guadalupe-San Antonio River Basin having priority dates senior to August 1, 1998 and authorizing annual diversions of almost 6,400,000 acft and consumptive use of 558,430 acft. Summaries of these water rights, sorted by river basin, size of authorized annual diversion, type of use, and location, are provided in Tables 2-1 (Guadalupe) and 2-2 (San Antonio). Figure 2-1 identifies the locations of major water rights authorized to divert and/or consume approximately 2,000 acft/yr or more, along with any associated storage rights. In addition, Figure 2-1 identifies "segments" of the Guadalupe-San Antonio River Basin. These segments generally extend:

- From the headwaters to the downstream edge of the outcrop of the Edwards Aquifer (Segments 1 and 4);
- From Segments 1 and 4 through the Blackland Prairies and Post Oak Savannah to streamflow gaging stations near Victoria and Goliad (Segments 2 and 5); and
- From Segments 2 and 5 to the Guadalupe Estuary (Segments 3 and 6).

Annual authorized consumptive uses for the major water rights shown in Figure 2-1 comprise almost 86 percent of all authorized consumptive uses in the Guadalupe-San Antonio River Basin. Municipal and industrial diversion rights represent 68 percent of all authorized consumptive uses in the Guadalupe-San Antonio River Basin. Based in part on water stored in

Table 2-1.
Guadalupe River Basin Water Rights Summary

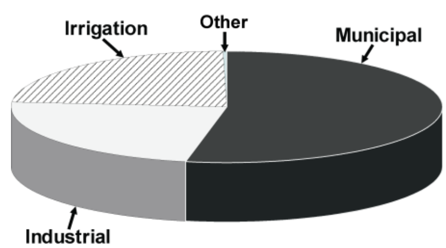
Sorted by Size of Authorized Annual Diversion

Range of Permitted Annual Diversions (acft)	*Number of Water Rights in Range Category*	*Total Authorized Annual Diversions (acft)*	*Total Authorized Annual Consumptive Use (acft)*
>50,000	12	6,020,746	251,462
10,000 – 49,999	4	77,500	53,000
2,000 – 9,999	11	58,873	38,993
1,000 – 1,999	7	9,621	8,161
200 – 999	42	18,023	18,023
<200	270	10,487	10,171
Total	346	6,195,250	379,810

Sorted by Type of Use

Type of Use	*Total Authorized Annual Diversions (acft)*	*Total Authorized Annual Consumptive Use (acft)*
Municipal/Domestic (1)	201,820	201,820
Industrial (2)	592,324	87,862
Irrigation (3)	89,121	89,121
Mining (4)	153	30
Hydroelectric (5)	5,303,585	0
Recreation (7)	6,648	8
Other (8)	1,600	970
Recharge (9)	0	0
Total	6,195,250	379,810

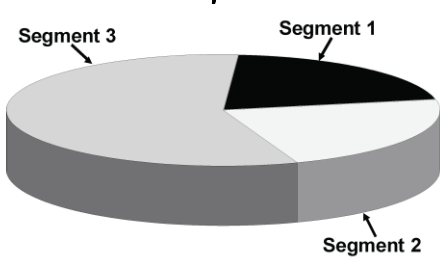
Consumptive Use



Sorted by Location

Basin Segments	*Total Authorized Annual Diversions (acft)*	*Total Authorized Annual Consumptive Use (acft)*
1	426,666	79,469
2	5,312,045	84,991
3	456,539	215,350
Total	6,195,250	379,810

Consumptive Use



* Summary based on water rights included in the TNRCC database table, WRDETAIL, dated January 7, 1999.

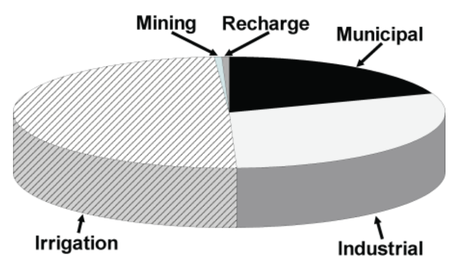
Table 2-2
*San Antonio River Basin Water Rights Summary**

Sorted by Size of Authorized Annual Diversion

Range of Permitted Annual Diversions (acft)	*Number of Water Rights in Range Category*	*Total Authorized Annual Diversions (acft)*	*Total Authorized Annual Consumptive Use (acft)*
>50,000	1	66,750	66,750
10,000 – 49,999	2	49,011	49,011
2,000 – 9,999	6	25,054	21,150
1,000 – 1,999	6	7,516	6,516
200 – 999	67	26,320	26,320
<200	176	9,063	8,873
Total	258	183,714	178,620

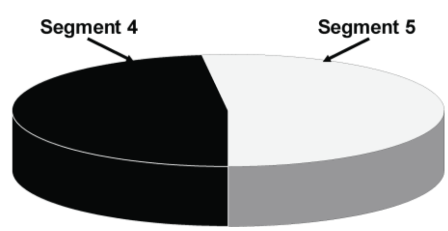
Sorted by Type of Use

Type of Use	*Total Authorized Annual Diversions (acft)*	*Total Authorized Annual Consumptive Use (acft)*
Municipal/Domestic (1)	34,967	34,967
Industrial (2)	53,436	53,436
Irrigation (3)	88,656	88,656
Mining (4)	4,504	600
Hydroelectric (5)	0	0
Recreation (7)	1,190	0
Other (8)	0	0
Recharge (9)	961	961
Total	183,714	178,620



Sorted by Location

Basin Segments	*Total Authorized Annual Diversions (acft)*	*Total Authorized Annual Consumptive Use (acft)*
4	89,752	85,658
5	93,962	92,962
6	0	0
Total	183,714	178,620



* Summary based on water rights included in the TNRCC database table, WRDETAIL, dated January 7, 1999.

Canyon Reservoir, the GBRA and Union Carbide hold almost 60 percent of these municipal and industrial rights. Authorized consumptive uses for irrigation and other purposes comprise almost 32 percent and less than 1 percent, respectively, of all authorized consumptive uses. In general terms, diversions for consumptive use are distributed throughout the Guadalupe-San Antonio River Basin, while large, non-consumptive hydropower rights are located only on the Guadalupe and Comal Rivers in Segment 2.

2.2 Historical Water Use

Records of surface water use as reported by individual water right owners were collected, tabulated, and maintained electronically by TNRCC staff for the 1915 to 1990 historical period. These records are generally comprised of annual totals for the 1915 to 1954 period and monthly totals for the 1955 to 1990 period. Since 1990, the TNRCC South Texas Watermaster has collected and maintained records of water use, as individual water right owners are no longer required to submit annual use reports. Historical surface water use in the Guadalupe-San Antonio River Basin has grown to marginally exceed 200,000 acft/yr. Figure 2-2 summarizes historical diversions by type of use. Historically, irrigation has been the type of use consuming the most water; however, increasing reported municipal and industrial use indicates that this will likely be changing in the future.

Review of Figure 2-2 reveals some potential concerns regarding actual water use with respect to consistency between that reported by individual owners prior to 1991 and that collected by the Watermaster in recent years. For example, Watermaster records for 1994 show uses totaling approximately 375,000 acft. This amount is questionable, as it reflects irrigation use more than twice typical amounts reported in the 1980s. Similarly, Watermaster records for irrigation use in 1991 through 1993 and for 1995 are questionable, as they are less than one-tenth the amounts reported in the 1980s. Clearly, reconciliation of Watermaster use records with those available from water right owners is desirable. Records of surface water use reported by individual water right owners for 1990 are available, though not in electronic format, at TNRCC.

2.3 Treated Wastewater Discharge

The locations of major facilities discharging treated wastewater into receiving streams in the Guadalupe-San Antonio River Basin are shown in Figure 2-3. Considering discharge records

Map ID #	Permit #	Facility/Owner
1	1510.003	Capitol Aggregates, Inc.
2	2356.004	Kelly AFB
3	10137.003	Leon Creek, SAWS
4	10137.004	Mitchell Lake, SAWS
5	10137.008	Salado Creek Water Recycling Center, SAWS
6	10137.033	Dos Rios Water Recycling Center, SAWS
7	10137.040	Medio Creek Plant, SAWS
8	10749.001	Saltrillo Creek, SARA
9	10749.003	Upper Martinez Plant, SARA
10	11269.001	Odo J. Riedl, CCMA
11	335.001	Mission Valley Mills
12	476.001	Victoria Plant, Du Pont
13	10210.001	Lockhart, GBRA
14	10232.001	Kuehler Avenue Plant, New Braunfels
15	10273.002	San Marcos
16	10277.001	Walnut Branch, Seguin
17	10466.001	Victoria Willow Plant, GBRA
18	10488.001	Gonzales
19	10576.001	Kerrville
20	11078.001	Victoria Regional, GBRA

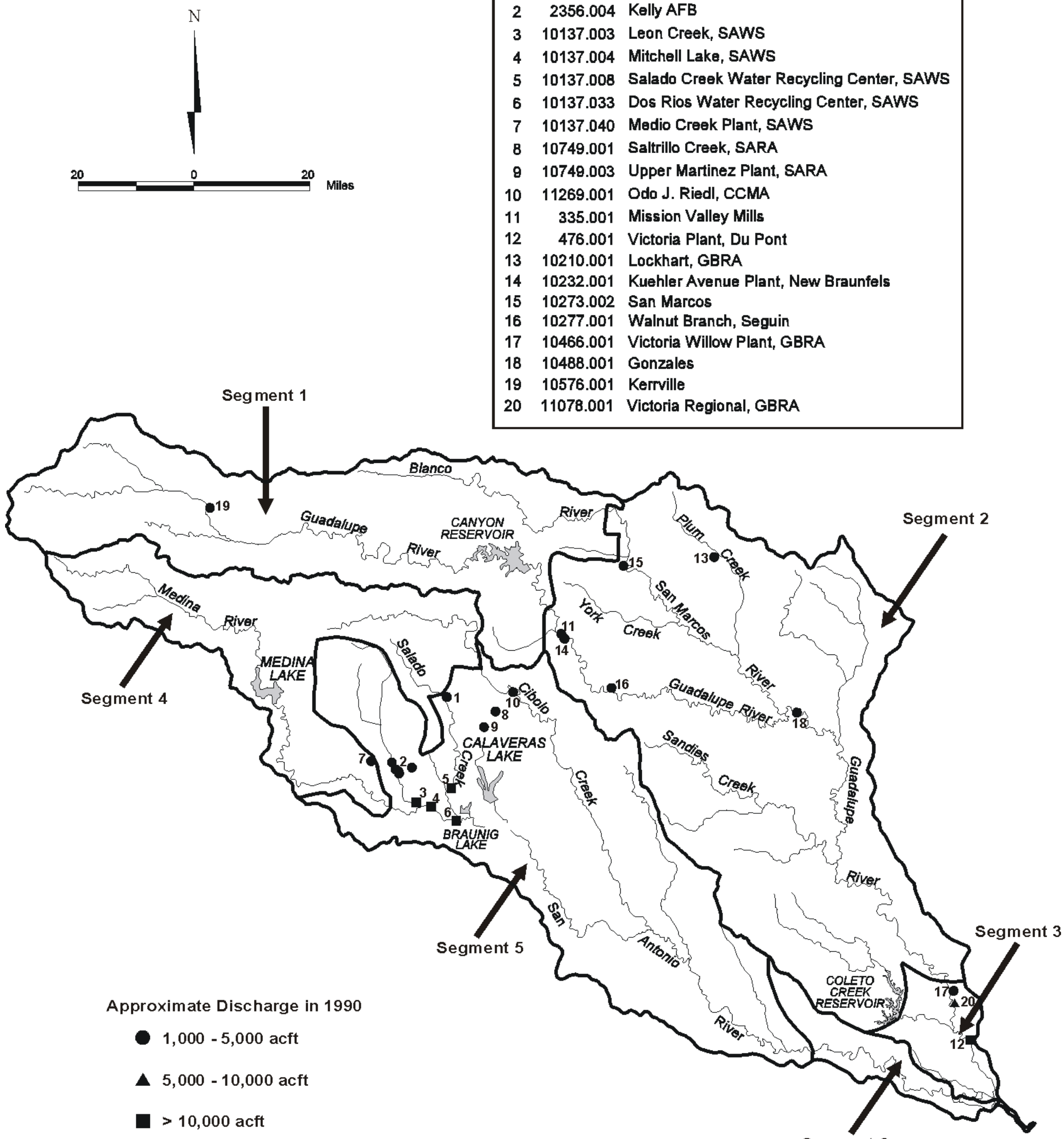


Figure 2-3. Major Treated Wastewater Discharges Location Map

for calendar year 1990 from the TNRCC self-reporting database, these major treated wastewater discharges were identified based on estimated annual discharge volume. The largest of these facilities are operated by SAWS and discharge an aggregate annual volume in excess of 128,000 acft (accounting for planned reuse of SAWS effluent). Facilities in the San Antonio and San Marcos areas in the upper portions of Segments 2 and 5 presently discharge water originating from the Edwards Aquifer. Other major facilities, with the exception of the Lockhart/GBRA facility on Plum Creek, discharge waters originating primarily from surface water sources. Major and relatively minor municipal and industrial treated wastewater discharges, for which current records are maintained by the TNRCC, are included at appropriate geographical locations in the water availability model. As municipal and industrial treated wastewater discharges in the Guadalupe-San Antonio River Basin are derived primarily from groundwater sources (or from surface water sources augmented by groundwater, as necessary), discharge volumes are generally not limited to simulated surface water availability under an associated diversion right. Return flows from irrigation operations are assumed negligible and are not included in the water availability model. The methodology used to incorporate these return flows is described in Section 4.2.3.3.

2.4 Previous Water Availability and Planning Studies

Due to the vital importance of surface water to future development in the Guadalupe-San Antonio River Basin, a number of water availability and water supply planning studies have been completed over the years. Key elements of some of these studies relevant to the development and application of the current water availability model are discussed in the following subsections.

2.4.1 TNRCC/TWC/TDWR Model Development and Application

The original water availability model (legacy model) of the Guadalupe-San Antonio River Basin was developed and applied by the staff of the former Texas Department of Water Resources (TDWR). Pertinent data and assumptions are presented, along with summaries of model application results in interim draft reports[3,4] that have never been formally published.

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[3] Texas Department of Water Resources (TDWR), "Revised Interim Report on Water Availability in the Guadalupe River Basin, Texas," Draft, March 1983.

[4] TDWR, "Revised Interim Report on Water Availability in the San Antonio River Basin, Texas," Draft, March 1983.

Development of the model included extensive hydrologic data collection and analysis resulting in the creation of complete databases of natural streamflow, water rights, net evaporation, and reservoir characteristics. The original computational algorithms used in the model are described by Murthy[5] and written in the Fortran programming language. Application(s) of the model focused primarily on the quantification of water available to large rights and unappropriated streamflow at locations throughout the river basin. Natural streamflows computed by the TDWR are compared to those used in the current water availability model in Section 3.1.5.

Features of the current (WRAP) model that differ from the existing (legacy) model are:

- The current model uses a hydrological database (1934 to 1989) some 40 percent longer than the original (1940 to 1979) and includes the most severe drought period on record, which occurred in the 1950s;
- The current model reflects completion of the adjudication process and changes in water rights between 1982 and early 1998, including the cancellation of large water rights associated with the proposed Applewhite Reservoir project;
- Simulations using the current model are continuous across the outcrop of the Edwards Aquifer and include the monthly estimation of recharge;
- Although the legacy model included Canyon Reservoir, the current model can more accurately simulate its operation subject to actual points of diversion and Federal Energy Regulatory Commission requirements for instream flows immediately below Canyon Dam;
- In the current model, storage in power plant reservoirs (Coleto Creek, Braunig, and Calaveras) is maintained at the full authorized conservation level to the extent that sufficient make-up supplies are available from the Guadalupe or San Antonio Rivers;
- Instream flow requirements for Canyon Reservoir, City of Victoria, and others are explicitly considered in the current model;
- Medina Lake System operations subject to recently authorized municipal and industrial diversions and updated equations for estimating recharge and leakage are reflected in the current model; and
- "Flange-to-flange" consumptive reuse of treated wastewater effluent in the San Antonio area (SAWS reuse project), in addition to that at Braunig and Calaveras Reservoirs, is accounted for in the current water availability model.
- Natural flows in the legacy model are differentiated into baseflows and runoff, whereas the WRAP model makes no distinction.

Many of these differences are discussed in greater detail in subsequent sections of this report.

[5] Murthy, V.R. Krishna, “Water Rights – Water Availability Models,” Presented to TDWR-TWCA Workshop on the Processing of Water Use Permit Applications, August 26, 1982.

2.4.2 Regional Water Planning Studies

A regional water supply planning study,[6] sponsored by the Edwards Underground Water District, which is now the Edwards Aquifer Authority, was initiated in 1992 with the primary objectives of computing natural recharge of the Edwards Aquifer and assessing the potential for development of Edwards Aquifer recharge enhancement projects. In order to accomplish these objectives, new natural streamflows and a river basin hydrologic simulation model were created to more realistically portray the effects of reservoir operations, springflow, natural recharge, and downstream channel losses on water available for enhancement of Edwards Aquifer recharge. In the course of this study, the Guadalupe-San Antonio River Basin Model (GSA Model) was developed with particular attention to simulation of unique operations policies for Canyon Reservoir, the Medina Lake System, and three reservoirs (Braunig, Calaveras, and Coleto Creek) providing cooling water for steam-electric power generation facilities.

The original natural streamflows developed in the Edwards Underground Water District planning study are used (with limited revisions, as described below) in the new TNRCC water availability model of the Guadalupe-San Antonio River Basin. Relatively minor revisions to the original natural streamflows were incorporated in subsequent studies to reflect improved estimates of streamflow passing the GBRA hydropower dam forming Lake Wood on the Guadalupe River and Texas Water Development Board (TWDB) estimates of ungaged runoff contributing freshwater inflows to the Guadalupe Estuary.[7] As shown in Section 3.1.5 and Appendix IV, the resulting natural streamflows are comparable to those developed by TDWR, with minor differences attributable to consideration of channel losses in flow naturalization and procedures employed for estimating unavailable records at some locations. These naturalized streamflows have not been updated to include the 1990 through 1996 historical period because the most severe drought of record for the Guadalupe-San Antonio River Basin clearly occurred in the 1950s.

Since its original development in 1993, the GSA Model has been refined and applied extensively in the course of the Trans-Texas Water Program and in other planning and research studies of regional interest. Applications of the GSA Model include:

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[6] HDR Engineering, Inc. (HDR) and Espey, Huston & Associates (EH&A), "Guadalupe-San Antonio River Basin Recharge Enhancement Study - Phase I," Vols. I, II, and III, Edwards Underground Water District, September 1993.
[7] HDR, "Guadalupe-San Antonio River Basin Model Modifications & Enhancements, Trans-Texas Water Program, West Central Study Area, Phase II," San Antonio River Authority, et al., March 1998.

- Computation of water availability for direct diversion and/or impoundment subject to senior water rights and environmental constraints;[8,9]
- Assessment of the feasibility of Edwards Aquifer recharge enhancement projects;[10]
- Evaluation of Canyon Reservoir's firm yield subject to a variety of hydropower subordination, Edwards Aquifer pumpage/springflow, and treated wastewater reuse scenarios;[11,12]
- Refinement and consideration of alternative environmental planning criteria for instream flows;[13,14]
- Detailed simulation of Coleto Creek Reservoir operations;[15] and
- Preliminary assessment of groundwater/surface water interactions involving the Carrizo-Wilcox Aquifer.[16]

Results from some of these applications of the GSA Model will be used for verification of various basin-specific modifications to WRAP necessary to accurately complete water availability analyses in the Guadalupe-San Antonio River Basin.

2.5 Significant Considerations Affecting Water Availability

2.5.1 Canyon Reservoir

Canyon Reservoir is a large water supply and flood control project located on the Guadalupe River in Comal County near Sattler as shown in Figure 2-4. It is owned and operated by the GBRA under certificate of adjudication C18-2074, as amended. Canyon Dam was completed in 1964, resulting in a total authorized impoundment of 740,900 acft. At present, 386,200 acft of this amount is considered the conservation storage capacity for water supply

[8] HDR, "Trans-Texas Water Program, West Central Study Area, Phase I Interim Report," Vols. 1 & 2, San Antonio River Authority, et al., May 1994.
[9] HDR, "Updated Evaluation of Potential Reservoirs in the Guadalupe River Basin, Trans-Texas Water Program, West Central Study Area, Phase II," San Antonio River Authority, et al., March 1998.
[10] HDR, "Edwards Aquifer Recharge Analyses, Trans-Texas Water Program, West Central Study Area, Phase II," San Antonio River Authority, et al., March 1998.
[11] HDR, "Trans-Texas Water Program, West Central Study Area, Phase I Interim Report," Vol. 3, San Antonio River Authority, et al., November 1994.
[12] HDR, "Letter of Intent Analysis, Trans-Texas Water Program, West Central Study Area, Phase II Report," San Antonio River Authority, et al., October 1996.
[13] HDR and Paul Price Associates, "Environmental Criteria Refinement, Trans-Texas Water Program, West Central Study Area, Phase II," San Antonio River Authority, et al., March 1998.
[14] HDR, "Evaluation of Alternative Instream and Bay & Estuary Flow Criteria for Run-of-the-River Diversions," Technical Memorandum, Texas Water Development Board (TWDB), et al., June 1995.
[15] HDR, "Coleto Creek Power Station Water Supply Operations Study," Central Power & Light Company and Guadalupe-Blanco River Authority, August 1998.
[16] LBG-Guyton Associates (LBG) and HDR, "Interaction Between Groundwater and Surface Water in the Carrizo-Wilcox Aquifer," TWDB, August 1998.

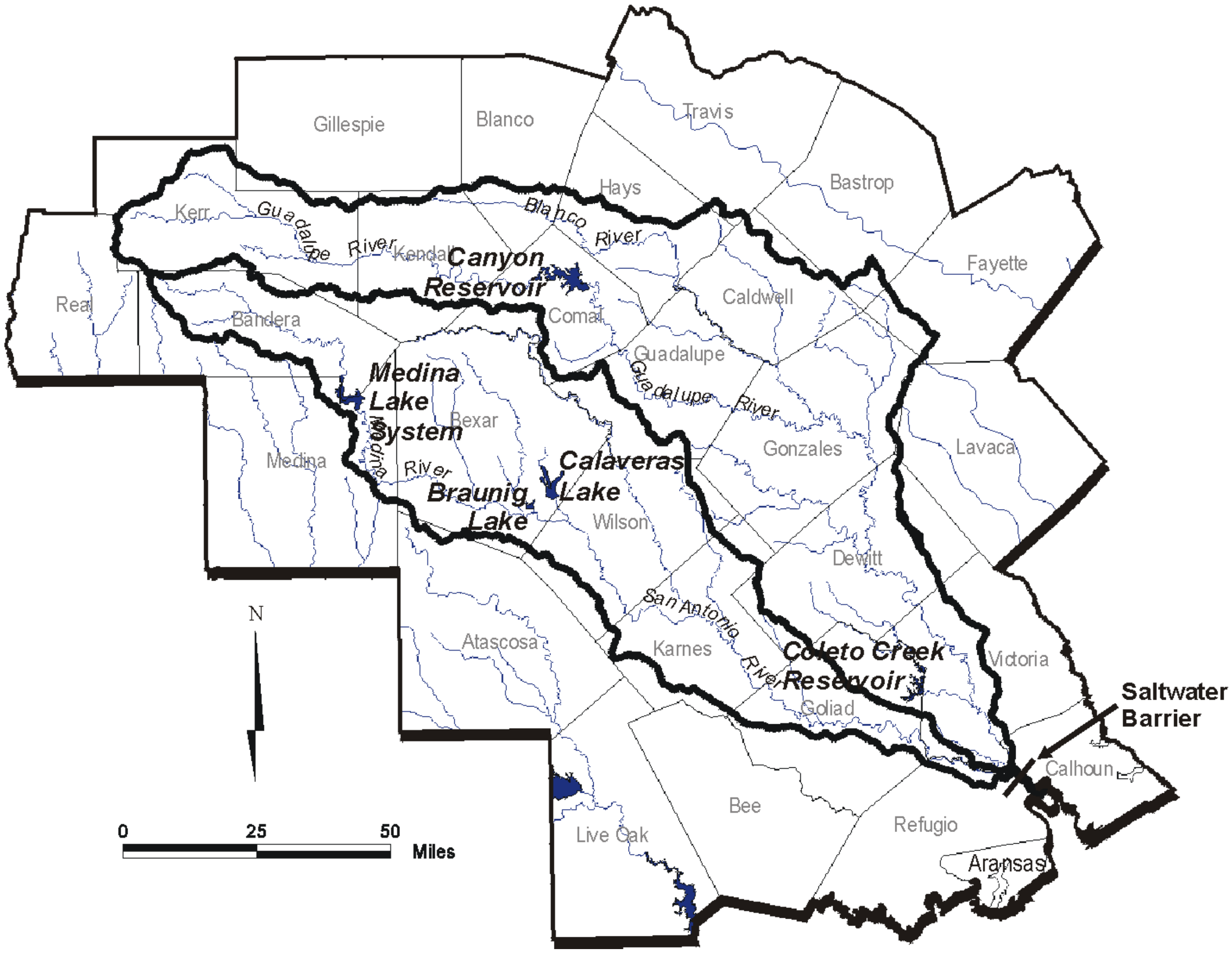

Figure 2-4. Major Reservoirs

purposes. The conservation storage capacity of Canyon Reservoir is approximately equal to the total combined capacity of all other major reservoirs in the Guadalupe-San Antonio River Basin; hence, accurate simulation of its operations is an essential component of the water availability modeling effort.

Operation of Canyon Reservoir is a complex function of many interrelated factors including inflow passage for senior water rights, authorized diversion amounts and contractual obligations, point(s) of diversion and channel losses incurred in delivery, subordination of downstream hydropower rights, and Edwards Aquifer pumpage and resultant springflow. In addition, the Federal Energy Regulatory Commission (FERC) license authorizing hydropower generation at Canyon Dam includes seasonally variable instream flow requirements below the dam. Calculation of the inflow passage requirements under the FERC license must be performed on a daily timestep in order to correctly simulate Canyon Reservoir operations and provide an accurate estimate of water available under certificate of adjudication C18-2074. Specific modifications to the WRAP necessary to simulate Canyon Reservoir operations are described in Section 4.1.2.1. For the purposes of assessing water availability in the Guadalupe-San Antonio River Basin, the following assumptions were made with respect to the significant factors affecting Canyon Reservoir operations identified above:

- Authorized annual diversions of stored water totaling 50,000 acft and comprised of multiple contractual obligations, types of use, and points of diversion are consolidated at one diversion point (Lake Dunlap below New Braunfels) and diverted under a seasonal pattern typical of municipal use;
- In this model, GBRA and City of Seguin hydropower water rights on the Guadalupe River are not subordinated to Canyon Reservoir and are included at their respective dates of priority assuming uniform diversion (and return) at annual authorized amounts; and
- Springflows resulting from fixed annual Edwards Aquifer pumpage of 400,000 acft with implementation of current Critical Period Management Rules, as described in Sections 2.5.7.1 and 4.1.2.6, are used.

2.5.2 Medina Lake System

The two-reservoir Medina Lake System was completed on the Medina River in 1913 and is presently owned and operated for irrigation, municipal, industrial, and other water supply purposes by the BMA. The Medina Lake System is located in Bandera and Medina Counties (Figure 2-4) and comprised of Medina Lake (237,874 acft authorized impoundment) and the much smaller Diversion Lake (4,500 acft authorized impoundment) located just a few miles downstream. Current reservoir storage capacities quantified through performance of volumetric surveys by the TWDB[17] are 254,823 acft for Medina Lake and 2,555 acft for Diversion Lake. In addition to diversions for water supply, surface water storage in each reservoir is continually depleted by direct percolation, which ultimately recharges the Edwards Aquifer, and by substantial leakage passing under, around, and through the dams. Recharge and leakage losses

[17] TWDB, "Volumetric Survey of Medina Lake and Diversion Lake," Bexar-Medina-Atascosa Counties Water Control and Improvement District #1 (BMA), August 29, 1996.

have been related to reservoir stage by Lowry[18] in the 1950s, Espey, Huston, & Associates (EH&A)[19] in 1989, and by the U.S. Geological Survey (USGS)[20] and Blackwell[21] in the 1990s. Historical Edwards Aquifer recharge attributable to the Medina Lake System for the 1934 to 1996 period has averaged 42,393 acft/yr,[22] which represents about 6.5 percent of total estimated Edwards Aquifer recharge. Recharge and leakage relationships developed by EH&A, with minor revisions for recent bathymetric and Diversion Lake leakage information obtained by the TWDB and Blackwell, respectively, have been included in the water availability model for the Medina Lake System. In order to simultaneously account for BMA's full authorized storage rights, unique stage-recharge and stage-leakage relationships, and operations to minimize leakage, the authorized storage in excess of the actual storage capacity for Diversion Lake has been reassigned to Medina Lake in the water availability model.

Authorized diversions associated with the Medina Lake System presently total 66,750 acft/yr. In accordance with certificate of adjudication C19-2130C, these water rights are allocated by type of use as 45,856 acft/yr for irrigation, 19,974 acft/yr for municipal and industrial, 750 acft/yr for domestic and livestock, and 170 acft/yr for local municipal use. All historical water use from the Medina Lake System has been diverted from Diversion Lake and delivered via the Medina Canal to irrigators in Bexar, Medina, and Atascosa Counties. BMA's current amended certificate also provides that diversions for municipal and industrial customers must be made from Diversion Lake. Hence, all simulated diversions from the Medina Lake System under BMA's rights (with the exception of 920 acft/yr for local municipal and domestic and livestock purposes) are assumed to be taken at Diversion Lake. In order to minimize losses of storage to recharge and leakage, a target water level some 5 feet below the full conservation storage pool is assumed for Diversion Lake. Basin-specific modifications to WRAP necessary to simulate Medina Lake System operations subject to aquifer recharge and leakage are described in Section 4.1.2.2 and are reflected in all estimates of water availability presented herein.

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[18] Lowry, R.L., "Recharge to the Edwards Groundwater Reservoir," San Antonio City Water Board, 1955.
[19] EH&A, "Medina Lake Hydrology Study," EUWD, March 1989.
[20] U.S. Geological Survey (USGS), "Assessment of Hydrogeology, Hydrologic Budget, and Water Chemistry of the Medina Lake Area, Medina and Bandera Counties, Texas," Draft, Water-Resources Investigations Report 98-__, U.S. Department of the Interior, August 1998.
[21] Blackwell & Associates, "Suggested Operational Criteria for Diversion Dam," BMA, March 1997.
[22] HDR, "Edwards Aquifer Recharge Analyses, Trans-Texas Water Program, West Central Study Area, Phase II," San Antonio River Authority, et al., March 1998.

2.5.3 Discharge of Treated Wastewater Effluent from Groundwater Sources

As the majority of treated wastewater discharged in the Guadalupe-San Antonio River Basin originates from groundwater sources and is not dependent upon surface water supplies, effluent is generally simulated in the water availability model as imported water entering the stream system at the appropriate geographical locations. Similarly, it is assumed that municipal and industrial effluent discharges associated with surface water diversion rights that are backed up by groundwater supplies, or backed up by surface water imported from another basin, will continue uninterrupted during periods of surface water supply shortages. Only industrial wastewater discharges having surface water rights as their only source of supply are simulated with effluent discharge limited to a percentage of surface water available in any given month.

After authorized transfer (via the bed and banks of the Medina and San Antonio Rivers), a portion of the treated wastewater generated by SAWS is reused by the City Public Service Board of San Antonio for power plant operations at Calaveras and Braunig Lakes. Simulation procedures for power plant reservoirs, including those dependent upon treated wastewater for maintenance of desired storage levels, are discussed in Section 2.5.4. In addition, SAWS is presently constructing a water recycling system that will obtain treated wastewater directly from the Leon Creek and Salado Creek facilities (Figure 2-3) and deliver water supplies to industrial and irrigation customers via pipeline. Monthly effluent quantities associated with the Leon Creek and Salado Creek facilities are adjusted by a combined annual total of 24,941 acft[23] to reflect seasonal consumptive reuse by recycling system customers.

2.5.4 Cooling Reservoir Operations

Coleto Creek Reservoir, Calaveras Lake, and Braunig Lake serve as sources of circulating flow for the dissipation of heat resulting from the operations of three existing power generation facilities. Consumptive water use at these reservoirs, or cooling ponds, is the result of forced evaporation due to heat loading. Forced evaporation is a volume of water loss typically calculated from the megawatt hours of electricity generated and is accounted for separately from natural evaporation. Each of these reservoirs is located on a stream tributary to the Guadalupe or San Antonio River and has an authorized annual consumptive use rate that is supplemented by make-up diversions from the nearby river.

[23] San Antonio Water System, Personal Communication, June 10, 1998.

It is, in general, desirable to maintain power plant reservoirs at or near the conservation storage capacity because the efficiency of heat dissipation increases with the size of the available mixing volume and the areal extent of the free water surface. Therefore, the power plant reservoir operation policy in the water availability model solves for the desired monthly volume of make-up water in addition to local inflows necessary to maintain a full reservoir subject to forced and natural evaporation losses and any required instream flow releases. After satisfying any instream flow requirements at the source location specified for make-up diversions, flows available in the river are transferred to the reservoir, subject to instantaneous maximum diversion rates. Cumulative annual make-up diversions are recorded and river diversions are suspended for the remainder of the calendar year when the authorized annual maximum has been withdrawn. Information pertinent to the simulation of operations at each power plant reservoir is summarized in the following subsections.

2.5.4.1 Coleto Creek Reservoir

Coleto Creek Reservoir, located in Goliad and Victoria Counties (Figure 2-4), was completed by GBRA in 1980 with an authorized impoundment of 35,084 acft to provide cooling water supply for a coal-fired power plant owned and operated by Central Power & Light. The authorized annual water use of 12,500 acft at the reservoir (certificate of adjudication C18-5486) is simulated in accordance with an industrial seasonal water use pattern typical of this segment of the river basin. Run-of-river make-up diversions from the Guadalupe River above Victoria are authorized by certificate of adjudication C18-5486, up to 20,000 acft/yr with no specified instream flow requirements other than concurrent flow past the Saltwater Barrier near Tivoli. For logical clarity in reservoir storage and make-up diversion simulations, consumptive use at the reservoir has been assigned a priority date immediately senior to that for make-up diversions from the Guadalupe River. Central Power & Light has a rather complex contractual agreement with GBRA for periodic delivery of supplementary make-up water from Canyon Reservoir. As mentioned in Section 2.5.1, this contract has been consolidated with other rights and contracts associated with Canyon Reservoir for the water availability analyses reported herein and is not included in estimates of water available to Coleto Creek Reservoir. Inflows up to 5 cfs are passed through Coleto Creek Reservoir for maintenance of instream flows in accordance with special conditions in certificate of adjudication C18-5486.

2.5.4.2 Calaveras and Braunig Lakes

Calaveras and Braunig Lakes were completed in the 1960s, with respective authorized impoundments of 63,200 acft and 26,500 acft, to provide cooling water supply for power plants owned and operated by the City Public Service Board. Authorized consumptive water uses of 37,000 acft/yr and 12,000 acft/yr for Calaveras and Braunig Lakes, respectively, are simulated in accordance with a seasonal water use pattern typical of industrial use in this segment of the river basin. Make-up diversions for both reservoirs are obtained from the San Antonio River above the streamflow gaging station near Elmendorf (USGS #08181800), subject to a 10 cfs minimum instream flow requirement and to specified instantaneous maximum diversion rates. Certificate of adjudication C19-2162 authorizes make-up diversions for Calaveras Lake of up to 60,000 acft/yr, contingent upon the discharge and delivery of an equivalent volume of treated wastewater from SAWS facilities to the point of diversion from the San Antonio River. Make-up diversions for Braunig Lake under certificate of adjudication C19-2161 are limited to 12,000 acft/yr, subject to senior and superior water rights only. Pursuant to certificate of adjudication C19-2161A, a portion of this 12,000 acft/yr maximum make-up diversion may be used at Calaveras Lake for consumptive industrial purposes.

2.5.5 Hydropower and Other Subordination Agreements

As indicated in Figure 2-1, there are several water rights for the generation of hydropower located on the Guadalupe River downstream of Canyon Reservoir, each having authorized annual non-consumptive diversions well in excess of 200,000 acft. The GBRA and the City of Seguin have an agreement that stipulates that both entities' senior hydroelectric water rights downstream of Canyon reservoir will not make priority calls on inflows to Canyon Reservoir. However, since this stipulation is not specifically authorized by the involved water rights and there is a pending water right amendment requesting such authorization, the TNRCC has directed that all water rights (Canyon Reservoir and downstream hydroelectric rights) be included in the water availability model at the full extent and priority in which they are currently authorized.

On a smaller scale, a number of entities located upstream of Canyon Reservoir and holding junior water rights have entered into hydropower subordination agreements with GBRA.

The provisions of these agreements are not included in the water availability model. Hence, estimates of water available to these junior rights are based simply upon their own priority dates and honoring senior water rights. It is noted that many of these rights are also junior in priority to Canyon Reservoir and would not have access to water (even with a hydropower subordination agreement) unless Canyon Reservoir were full and spilling.

2.5.6 Freshwater Inflows to the Guadalupe Estuary

Water available for future appropriation and for some current water rights may be limited by requirements for the maintenance of freshwater inflows to the Guadalupe Estuary. The TNRCC, TWDB, and Texas Parks & Wildlife Department (TPWD) have been studying freshwater inflow needs of Texas' major estuarine systems for more than 30 years. The scope of these studies has been quite broad, ranging from basic hydrology and data collection, to the application of multi-objective optimization techniques using quantitative relationships between inflow, salinity, and reported fisheries harvest to calculate freshwater inflow needs based on defined management objectives. Perhaps the most comprehensive summary of pertinent findings with respect to the Guadalupe Estuary may be found in a report completed by the TWDB and TPWD[24] in 1994. A recent report prepared by the TPWD and TWDB[25] indicates that the desired freshwater inflow to the Guadalupe Estuary for optimization of fisheries harvest is about 1.15 million acft/yr, as compared to an average historical inflow of 2.34 million acft/yr for the 1941 through 1987 historical period.

Freshwater inflow requirements for the Guadalupe Estuary have no direct effect on the assessments of water availability to existing rights and of unappropriated streamflow presented herein. Such requirements will, however, have significant effects on the evaluation of future applications for water rights. In order to facilitate future considerations of freshwater inflow requirements, estimates of natural, ungaged runoff contributing to the Guadalupe Estuary and originating below the Guadalupe River at Victoria (USGS #08176500), Coleto Creek Reservoir (USGS #08177400), and the San Antonio River at Goliad (USGS #08188500) have been

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[24] TPWD and TWDB, "Freshwater Inflow Recommendation for the Guadalupe Estuary of Texas," December 1998.
[25] TWDB, TPWD, and TNRCC, "Texas Bays and Estuaries Program, Determination of Freshwater Inflow Needs," September 1998.

included in the water availability model. Original derivation of these ungaged runoff estimates was accomplished by the TDWR,[26] with periodic updates completed by the TWDB and HDR.[27]

2.5.7 Groundwater/Surface Water Interactions

The Guadalupe-San Antonio River Basin is traversed by the outcrops of five major aquifers including the Edwards, Carrizo-Wilcox, Queen City, Sparta, and Gulf Coast-Goliad Sand. Figure 2-5 shows the location and extent of these major aquifer outcrops. Interactions between groundwater and surface water in the Guadalupe-San Antonio River Basin occur as artesian springflow and as recharge in outcrop areas where surface waters may percolate directly into the aquifer. Comal and San Marcos Springs are the two largest in Texas and emerge from the Edwards Aquifer in the Guadalupe River Basin at New Braunfels and San Marcos, respectively. Other notable springs include Hueco Springs on the Guadalupe River and San Antonio, San Pedro, and Sutherland Springs in the San Antonio River Basin. Recharge, on the other hand, is most apparent at the outcrop of the Edwards Aquifer, where substantial quantities of streamflow and stored water enter the aquifer each year. When this recharge occurs in a defined stream, it becomes one component of a more generalized depletion of surface water flows referenced herein as "channel losses." Channel losses may include aquifer recharge, over-bank flooding, evaporation, and transpiration by riparian vegetation. Channel losses can be quite significant and become most evident between streamflow gaging stations during drought when intervening runoff is minimal. Consideration of channel losses and aquifer recharge are essential components of accurate natural streamflow development and water availability modeling in the Guadalupe-San Antonio River Basin.

2.5.7.1 Edwards Aquifer Recharge and Springflow

The Edwards Aquifer is a highly porous, fractured limestone formation outcropping in Kinney, Uvalde, Medina, Bexar, Comal, and Hays Counties. In fact, the numerous cracks and fissures typical of the Edwards formation are so efficient in recharging the aquifer that only the Guadalupe and Blanco Rivers typically sustain a base flow across the outcrop. Other streams in

[26] TDWR, "Guadalupe Estuary: A Study of the Influence of Freshwater Inflows," LP-107, August 1980.
[27] HDR, "Guadalupe-San Antonio River Basin Model Modifications & Enhancements, Trans-Texas Water Program, West Central Study Area, Phase II," San Antonio River Authority, et al., March 1998.

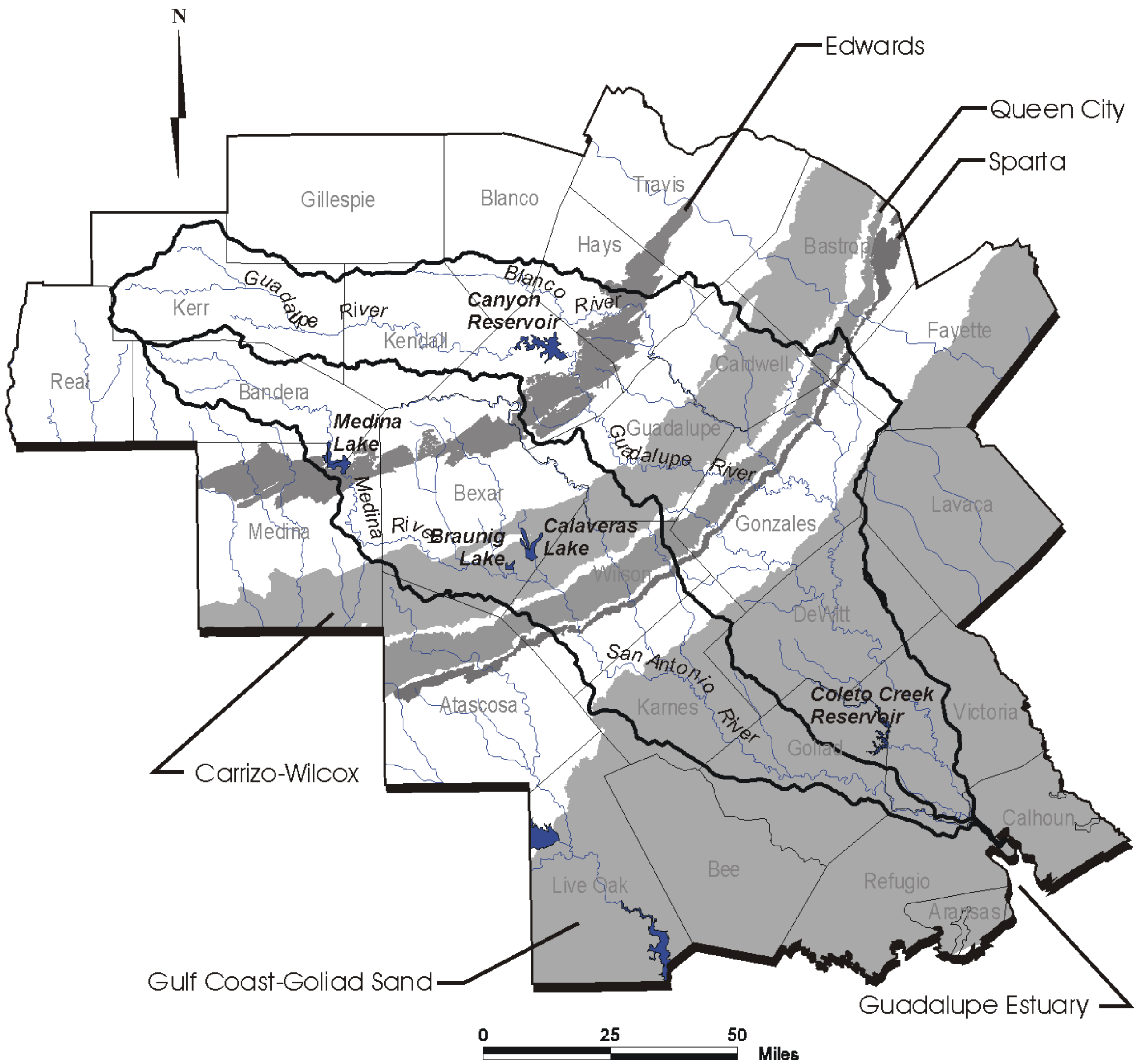

Figure 2-5. Major Aquifers

the Guadalupe-San Antonio River Basin, such as San Geronimo, Leon, Salado, Cibolo, Dry Comal, York, Purgatory, and Sink Creeks, are often dry at the downstream edge of the outcrop. Computational procedures for estimation of recharge were first established by the USGS[28] and subsequently modified by HDR in the development of natural streamflows. Recharge of the

[28] USGS, "Method of Estimating Natural Recharge to the Edwards Aquifer in the San Antonio Area, Texas," Water Resources Investigations 78-10, April 1978.

Edwards Aquifer in the Guadalupe-San Antonio River Basin averaged an estimated 318,310 acft/yr[29] during the 1934 to 1996 historical period.

The Edwards Aquifer Authority (EAA) has constructed one recharge enhancement project in the Guadalupe-San Antonio River Basin. Authorized diversions for this project, located on San Geronimo Creek, are 961 acft/yr. Although not specifically permitted through the TNRCC, there are numerous other manmade facilities that enhance recharge of the Edwards Aquifer in addition to their primary functions. These facilities include the Medina Lake System and programs of flood-retardation structures constructed in the Salado Creek, Dry Comal Creek, and upper San Marcos River watersheds. Recharge enhancement associated with these projects is estimated on a monthly timestep using a basin-specific modification in WRAP.

Springflow contributions explicitly simulated in the Guadalupe-San Antonio River Basin occur at Comal, San Marcos, Hueco, San Antonio, and San Pedro Springs. Flows at each of these springs originate in the Edwards Aquifer and are correlated (to varying degrees) with water levels in the Bexar County monitoring well (J-17). In order to obtain aquifer levels for estimation of spring discharge subject to regulated (rather than historical) pumpage, the TWDB has completed modifications to and application of its Edwards Aquifer model (GWSIM4).[30,31,32]

The most recent application of the GWSIM4 model is based on the following key assumptions:

1) Fixed annual pumpage of 400,000 acft using geographical and seasonal distributions generally based on proposed permits issued by the EAA and some voluntary reductions in irrigation pumpage;
2) Implementation of current EAA Critical Period Management Rules, which were intended to place limits on municipal pumpage during periods when aquifer levels are low; and
3) Estimates of recharge developed by HDR, which reflect long-term recharge enhancement associated with existing projects.

[29] HDR, "Edwards Aquifer Recharge Analyses, Trans-Texas Water Program, West Central Study Area, Phase II," San Antonio River Authority, et al., March 1998.
[30] TDWR, "Ground-Water Resources and Model Applications for the Edwards (Balcones Fault Zone) Aquifer in the San Antonio Region, Texas," Report 239, October 1979.
[31] TWDB, "Model Refinement and Applications for the Edwards (Balcones Fault Zone) Aquifer in the San Antonio Region, Texas," Report 340, July 1992.
[32] TWDB, "Summary of a GWSIM-IV Model Run Simulating the Effects of the Edwards Aquifer Authority Critical Period Management Plan for the Regional Water Planning Process," July 1999.

The maximum annual pumpage of 400,000 acft is consistent with legislation (Senate Bill 1477) creating the EAA, which requires that permitted withdrawals may not exceed this amount after December 31, 2007. As current proposed permits total about 484,000 acft/yr, it is assumed that voluntary reduction in permitted withdrawals are most likely to come from the irrigation sector. Unfortunately, the current EAA Critical Period Management Rules would not effectively limit pumpage during drought. Hence, the TWDB included program logic in GWSIM4 to limit monthly pumpage during drought to no more than that in more moderate times. Should alternative Edwards Aquifer pumpage limitations, management policies, or recharge estimates be adopted in the future, the associated effects on surface water streamflows may be readily incorporated. Specific modifications to WRAP necessary to simulate Edwards Aquifer recharge, changes in springflow, and recharge enhancement are described in Section 4.1.2 of this report.

2.5.7.2 Channel Losses

The effects of channel losses were included in the downstream translation of changes in streamflow associated with historical diversions in the development of natural streamflows for the Guadalupe-San Antonio River Basin. Similarly, channel losses apply in the downstream translation of changes in flow associated with water rights diversions, authorized impoundments, treated wastewater discharges, and modified springflows in the assessments of water availability using WRAP. Methodologies employed for the estimation of reasonable channel loss or water delivery rates by HDR were primarily based on studies conducted by the USGS[33,34] and are described in greater detail in Section 3.1.3 of this report.

2.5.7.3 Carrizo-Wilcox Aquifer

Upon review of Figure 2-5, it is clear that a significant component of observed channel losses can be attributed to recharge of aquifers downstream of the outcrop of the Edwards Aquifer. The TWDB sponsored a recent research study[35] with the primary objectives of

[33] USGS, "Conveyance Characteristics of the Nueces River, Cotulla to Simmons, Texas," Water-Resources Investigations Report 83-4004, Austin, Texas, 1983.
[34] USGS, "Hydrologic Effects of Floodwater-Retarding Structures on Garza-Little Elm Reservoir, Texas," Water-Supply Paper 1984, 1970.
[35] LBG and HDR, "Interaction Between Groundwater and Surface Water in the Carrizo-Wilcox Aquifer," Texas Water Development Board, August 1998.

developing an improved model of the Carrizo-Wilcox Aquifer and assessing potential effects of present and future pumpage levels on streamflows and surface water rights. Results of this study indicate that long-term pumpage at 1994 levels may reduce freshwater inflows to the Guadalupe Estuary on the order of only 1 to 2 percent. Based on these relatively small simulated impacts, no additional consideration of groundwater/surface water interactions beyond that reflected in the channel loss rates has been included at this time. Should significantly increased pumpage of the Carrizo-Wilcox Aquifer occur in the Guadalupe-San Antonio River Basin, however, consideration should be given to modification of the channel loss rates and/or more explicit simulation of groundwater/surface water interactions in future updates of the TNRCC water availability models.

2.5.7.4 Gulf Coast Aquifer

The presence of the Gulf Coast Aquifer, including the Goliad Sand formation, contributes to observed channel losses in the San Antonio River below Falls City and the Guadalupe River below Gonzales. These losses are reflected in the gaged streamflow records used to derive natural streamflows and channel loss rates in the lower Guadalupe-San Antonio River Basin. Loss rates are consistent with those found by HDR[36] and the USGS[37] in the lower Nueces River Basin.

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[36] HDR, "Nueces River Basin Regional Water Supply Planning Study – Phase I," Nueces River Authority, et al., May 1991.

[37] USGS, "Water-Delivery Study, Lower Nueces River Valley, Texas," TWDB Report 75, May 1968.

Section 3
Hydrologic Data Refinement

3.1 Natural Streamflow at Gaged Locations

The compilation of accurate estimates of historical natural streamflow is a key prerequisite to the development of a useful model of the Guadalupe-San Antonio River Basin. Natural streamflow is defined as that which would have occurred historically, exclusive of human influences. Natural streamflows used in the Guadalupe-San Antonio River Basin water availability model were developed in a study sponsored by the Edwards Underground Water District (EUWD).[38] The following subsections summarize the development of natural streamflows for the primary control points (locations where water availability information is desired) at gaged locations in the Guadalupe-San Antonio Basin.

3.1.1 Streamflow Naturalization Methodology

Monthly natural streamflows for the 1934 to 1989 period were developed by adjusting gaged streamflows and calculated reservoir inflows for the effects of historical water supply diversions, municipal and industrial return flows, and reservoir operations. Translation of the effects of upstream diversions and return flows to downstream locations was accomplished with the use of delivery equations representative of typical channel loss rates in each intervening reach. Derivation of delivery equations is described in Section 3.1.3.

The streamflow naturalization methodology applied in this study is summarized in schematic and equation form in Figure 3-1. Historical monthly diversions of all use types, as well as return flows, were grouped by subwatershed as delineated by control point. The natural flow at the downstream end of an headwater subwatershed, such as Subwatershed 1 shown in Figure 3-1, is calculated by simply adding the historical diversions to and subtracting the historical return flows from the gaged streamflow at Control Point 1 (CP1). Natural flow at the downstream end of Subwatershed 2 (CP2) is equal to the gaged streamflow adjusted for local diversions and return flows that occurred in Subwatershed 2 plus the portion of the change in

[38] HDR Engineering, Inc. (HDR), "Guadalupe-San Antonio River Basin Recharge Enhancement Study," Vols. I, II and III, Edwards Underground Water District (EUWD), September 1993.

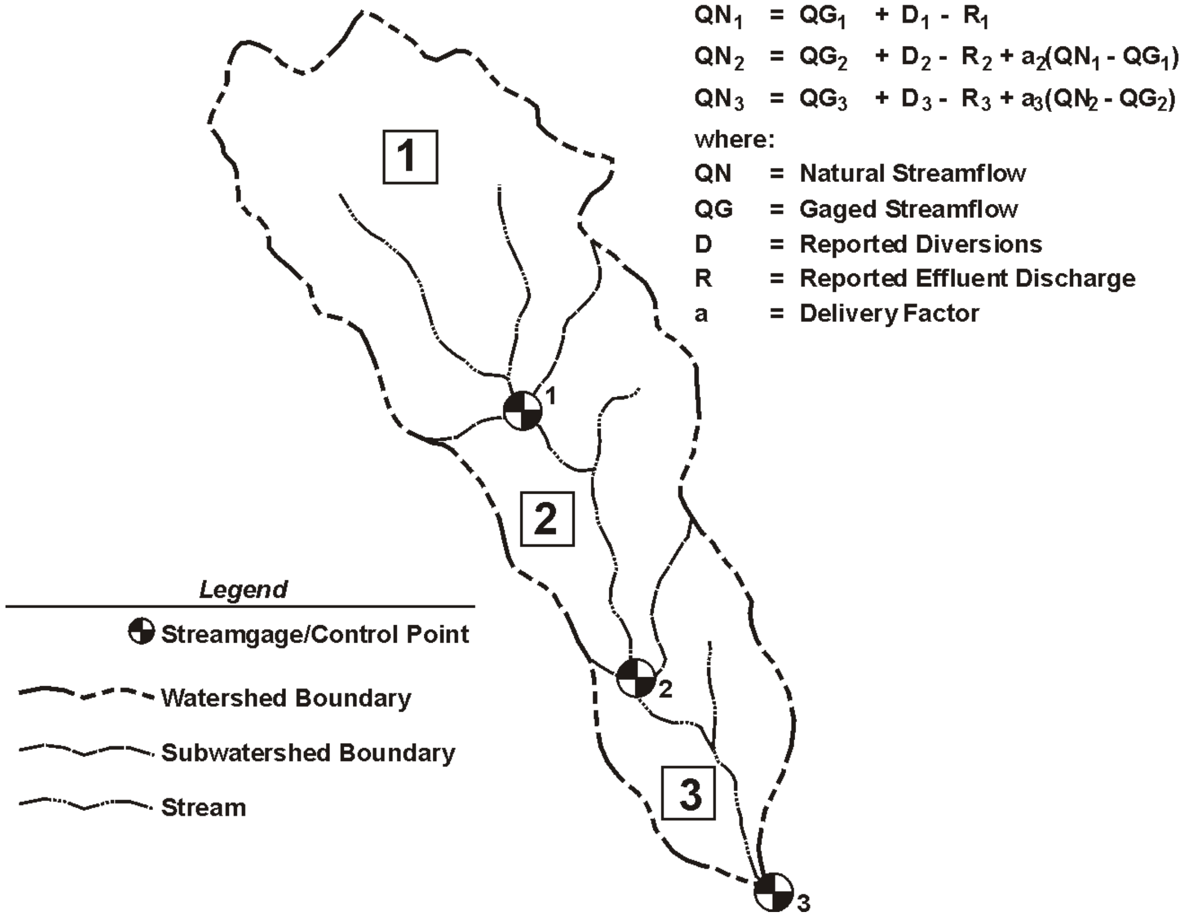

Figure 3-1. Streamflow Naturalization Methodology

flow (from gaged to natural) at CP1 that arrives at CP2. In like manner, streamflows were naturalized at consecutive control points moving from upstream to downstream through the entire river basin.

The streamflow naturalization methodology applied in this study was originally developed by HDR in the performance of a regional water supply planning study of the Nueces River Basin[39] and is different from the more traditional methodology incorporated in previous natural streamflow databases and river basin models.[40,41] Traditionally, successive downstream gaged streamflows were adjusted for historical upstream diversions and return flows on a one-to-one basis to obtain natural streamflows, thereby neglecting that fact that channel losses reduce

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[39] HDR, "Nueces River Basin Regional Water Supply Planning Study – Phase I," Vols. I, II, and III, Nueces River Authority, et al., May 1991.
[40] Texas Department of Water Resources (TDWR), "Revised Interim Report of Water Availability in the Guadalupe River Basin, Texas," March 1983.

the effects of diversions as diversions are translated downstream. Simply stated, diversion of 1 acft of streamflow in the headwaters of the basin does not reduce inflow to the Guadalupe Estuary by 1 acft. Application of traditional methodology generally results in higher estimates of natural flow. Potential errors resulting from this traditional technique were mitigated, in part, by the one-to-one adjustment of natural flows to account for full water rights diversions and applicable return flows in the evaluation of water available for appropriation. However, if full water rights use significantly exceeds historical water use (which is often the case), application of the traditional methodology can significantly underestimate both water availability and remaining downstream flows. Accounting for channel losses, as modeled in this study, more accurately reflects the natural physical processes that affect streamflows throughout the basin.

3.1.2 Streamflow Data Sources

3.1.2.1 Streamflows

Records of streamflow in the Guadalupe-San Antonio River Basin have been collected at numerous streamflow gaging stations maintained by the USGS. Figure 3-2 indicates the location of each streamflow gaging station used to develop naturalized flows, including those selected as primary control points. Several additional streamflow gaging stations were used to extend records at selected primary control points. Summary data for all primary control points and those streamgages not utilized as primary control points are summarized in Table 3-1. Additional primary control points for ungaged watersheds were adopted to facilitate calculation of Edwards Aquifer recharge and are also shown in Figure 3-2. Section 3.2 gives a description of how these flows were developed. The drainage areas used in the streamflow naturalization at the primary control points are those reported by the USGS and in previous studies.[42,43] The differences between the drainage areas presented in Table 3-1 and those provided by the TNRCC through the University of Texas Center for Research in Water Resources (CRWR) are minimal. The streamflow naturalization processes at the secondary control points, however, utilize the CRWR data as described in

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[41] TDWR, "Revised Interim Report of Water Availability in the San Antonio River Basin, Texas," March 1983.
[42] USGS, "Water Resources Data, Texas," Annual.
[43] HDR, Op. Cit., September 1993.

Table 3-1.
Primary Control Points in the Guadalupe-San Antonio River Basin

Control Point	Gage Reference Number	Stream Name, Location	Drainage Area (sq. mi.)	Period of Record
Primary Control Points at Gaged Locations				
CP01	1670	Guadalupe River, Comfort	839.00	06/39 to 12/89
CP02	1675	Guadalupe River, Spring Branch	1,315.00	07/22 to 12/89
CP03	1677	Guadalupe River, Canyon Lake	1,432.00	07/62 to 12/89
CP04	1685	Guadalupe River, above Comal River at New Braunfels	1,518.00	01/28 to 12/89
CP05	1690	Comal River, New Braunfels	130.00	01/28 to 12/89
CP08	1710	Blanco River, Wimberley	355.00	07/28 to 12/89
CP09	1713	Blanco River, Kyle	412.00	06/56 to 12/89
CP10	1720	San Marcos River, Luling	838.00	05/39 to 12/89
CP11	1730	Plum Creek, Luling	309.00	04/30 to 12/89
CP12	1746	Peach Creek, Dilworth	460.00	08/59 to 09/79
CP13	1750	Sandies Creek, Westhoff	549.00	08/59 to 12/89
CP14	1758	Guadalupe River, Cuero	4,934.00	09/20 to 11/35 01/64 to 12/89
CP15	1765	Guadalupe River, Victoria	5,198.00	12/34 to 12/89
CP16	1774	Coleto Creek Reservoir, Victoria	494.00	02/80 to 12/89
CP18	1780	San Antonio River, San Antonio	41.80	03/39 to 12/89
CP19	1787	Salado Creek, San Antonio Upper Station	137.00	10/60 to 12/89
CP20	1788	Salado Creek, San Antonio Lower Station	189.00	10/60 to 12/89
CP21	1795	Medina Lake	634.00	04/13 to 12/89
CP27	1808	Medina River, Somerset	967.00	10/70 to 12/89
CP28	1815	Medina River, San Antonio	1,317.00	08/39 to 12/89
CP29	1818	San Antonio River, Elmendorf	1,743.00	10/62 to 12/89
CP32	1835	San Antonio River, Falls City	2,113.00	05/25 to 12/89
CP33	1839	Cibolo Creek, Boerne	68.40	03/62 to 12/89
CP34	1850	Cibolo Creek, Selma	274.00	04/46 to 12/89
CP35	1860	Cibolo Creek, Falls City	827.00	10/30 to 12/89
CP36	1865	Ecleto Creek, Runge	239.00	04/62 to 12/89
CP37	1885	San Antonio River, Goliad	3,921.00	03/39 to 12/89
CP38	1888	Guadalupe River, Tivoli	10,128.00	09/65 to 12/89

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Table 3-1 (continued)

Control Point	Gage Reference Number	Stream Name, Location	Drainage Area (sq. mi.)	Period of Record
Primary Control Points at Ungaged Locations				
CP06	N/A	Guadalupe River, Lake Wood (H-5)	2,103.00	01/80 to 12/89
CP17	N/A	Olmos Creek	8.30	N/A
CP22	N/A	Tributaries to Diversion Lake	15.60	N/A
CP241, CP242	N/A	Deep Creek, Edwards	13.10	N/A
CP25	N/A	San Geronimo Creek	58.30	N/A
CP261	N/A	Leon Creek	59.76	N/A
CP262	N/A	Helotes Creek	28.06	N/A
CP263	N/A	Government Creek	11.78	N/A
CP30	N/A	Braunig Lake	9.40	02/63 to 12/89
CP31	N/A	Calaveras Lake	65.40	01/71 to 12/89
CP71	N/A	Sink Creek	43.27	N/A
CP72	N/A	Purgatory Creek	33.98	N/A
CP73	N/A	York Creek	12.38	N/A
CP74	N/A	Alligator Creek	4.22	N/A
CP241	N/A	West Tributaries downstream of Diversion Lake	4.45	N/A
CP242	N/A	East Tributaries downstream of Diversion Lake	7.20	N/A
CPDUN	N/A	Lake Dunlap, Guadalupe River	1,661.00	N/A
CPEST	N/A	Guadalupe Estuary	10,250.00	N/A
Streamgages Not Used for Primary Control Points				
N/A	1678	Guadalupe River, Sattler	1,436	03/60 to 12/89
N/A	1769	Coleto Creek, Schroeder	357	10/78 to 12/89
N/A	1770	Coleto Creek, Schroeder	369	10/52 to 09/79
N/A	1775	Coleto Creek, Victoria	514	07/39 to 09/54 06/78 to 12/89
N/A	1788.8	Medina River, Bandera	427	10/82 to 12/89
N/A	1790	Medina River, Pipe Creek	474	10/22 to 06/35 10/52 to 09/82
N/A	1791	Red Bluff Creek, Pipe Creek	56.3	04/56 to 11/81
N/A	1800	Medina Canal	N/A	04/22 to 04/34 07/57 to 12/89
N/A	1805	Medina River, Riomedina	650	02/53 to 09/73
N/A	1814	Helotes Creek, Helotes	15	06/68 to 12/89
N/A	1825	Calaveras Creek, Elmendorf	77.2	10/54 to 09/71

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Section 3.2.2. Summaries of monthly streamflow records were obtained from the Texas Water Commission (TWC) and directly from the USGS. Records from these gaging stations, with few exceptions, are classified by the USGS[44] as "good," which means that 95 percent of the published daily discharges are within 10 percent of their true values.

An additional primary control point (CP06) was established at Lake Wood (H-5) because of its key location on the Guadalupe River just upstream of the San Marcos River confluence. Streamflow records at this location were estimated for the 1980 to 1989 period using microfilmed hydropower and spill logs maintained by the GBRA for hydroelectric power generation. These logs contain detailed records of governor and gate settings and headwater and tailwater depths during normal operations and during flood events that exceeded the turbine capacity and resulted in flow over the gates. Monthly spill volumes were calculated using a spillway rating table provided by GBRA, with appropriate adjustments for tailwater levels[45] and leakage. Combining these computed spill volumes with calculated flows through the turbines, estimated gaged flows were obtained for the Guadalupe River at Lake Wood (H-5).

In order to facilitate basin-specific modifications related to Canyon Reservoir hydropower pass-through computations, control point CPDUN was added as a primary control point. Flows of CPDUN are the sum of the flows at CP04 (Guadalupe River at New Braunfels) and CP05 (Comal River at New Braunfels). A total of 45 primary control points are included in the GSA Model.

Senate Bill 1 requires that estimates be made of total inflow to the Guadalupe Estuary. Control point CPEST was added in order to facilitate this requirement. Flows for this control point represent flow passing CP38 (Guadalupe River at Tivoli) plus all ungaged runoff to the Guadalupe Estuary below Tivoli.

3.1.2.2 Reservoir Inflows

Historical reservoir inflows were computed for Canyon Lake (July 1962 through December 1989) and Calaveras Lake (February 1971 through December 1989) to supplement gaged streamflow records for the Guadalupe River and Calaveras Creek, respectively.

[44] USGS, Op. Cit., Annual.
[45] U.S. Bureau of Reclamation (USBR), "Design of Small Dams," Water Resources Technical Publication, U.S. Department of the Interior, Revised Reprint, 1977.

Computation of historical inflow was based on the principle of continuity, as formulated in the following simplified equation:

$$I_t = (Z_{t+1} - Z_t) + E_t + D_t + S_t - P_t \qquad \textbf{(3-1)}$$

where: I_t = ***Inflow;***
Z_{t+1} = ***End-of-month storage;***
Z_t = ***Beginning-of-month storage;***
E_t = ***Net evaporation;***
D_t = ***Direct diversion;***
S_t = ***Spill and/or release; and***
P_t = ***Imported inflow.***

This equation was solved for monthly inflow assuming the monthly storage change due to net evaporation is based on the surface area associated with the average storage volume for the month. Computed monthly inflow estimates less than zero were set equal to zero. The resultant historical reservoir inflows are comparable to gaged streamflows and were naturalized in the same manner.

Basic data for reservoir inflow computations was obtained from a variety of sources. Reservoir storage records for Canyon and Calaveras Lakes were obtained from USGS publications[46,47,48] and summary tables provided by the City Public Service Board,[49] respectively. Elevation-area-capacity tables from original reservoir mapping in 1947 and from a bathymetric survey conducted by the U.S. Army Corps of Engineers in 1972 were used for Canyon Lake, while an elevation-area-capacity table dated 1970[50] was used for Calaveras Lake. Gross monthly water surface evaporation rates derived from TWDB data, as described in Section 3.3, were adjusted using records from nearby National Weather Service or TWDB precipitation stations to obtain applicable monthly net evaporation rates. The City Public Service Board provided monthly estimates of imported inflows (make-up water from the San Antonio River), releases,

[46] U.S. Geological Survey (USGS), "Surface Water Supply of the United States, 1961-65, Part 8, Western Gulf of Mexico Basins, Volume 2, Basins from Lavaca River to Rio Grande," Water Supply Paper 1923, 1970.
[47] USGS, "Surface Water Supply of the United States, 1966-70, Part 8, Western Gulf of Mexico Basins, Volume 2, Basins from Lavaca River to Rio Grande," Water Supply Paper 2123, 1975.
[48] USGS, "Water Resources Data, Texas, Water Year 19__," Annual.
[49] City Public Service Board, Written Communication, San Antonio, Texas, June 23, 1992.
[50] Texas Water Development Board (TWDB), "Engineering Data on Dams and Reservoirs in Texas, Part III," Report 126, February 1971.

spills, and direct diversions (consumptive use in the form of forced evaporation) for Calaveras Lake. Gaged streamflow records for the Guadalupe River at Sattler (ID# 1678) were assumed to approximate the sum of all inflows passed through, releases from storage, and spills at Canyon Lake during the 1971 to 1989 period.

3.1.3 Delivery Factors and Channel Loss Rates

Channel losses occur as water is lost from the stream via evapotranspiration, evaporation, and recharge. These losses occur naturally and are reflected in the gaged records upon which the naturalized flows are based. **The channel losses developed herein represent long-term average losses and are applied only to changes in flow caused by impoundments, diversions, changes in springflows from historical conditions, and effluent discharges.** These losses are applied during both the streamflow naturalization and the simulation processes. The channel loss factors are applied in the form of delivery factors, related by the equation:

Delivery Factor = 1 – Channel Loss

In its application, a delivery factor represents the decimal fraction of a change in flow that is translated downstream.

A streamflow delivery equation was developed for each stream reach linking control points in the Guadalupe-San Antonio River Basin in order to estimate the typical percentage of water passing an upstream control point that arrives at the next downstream control point. The equations were derived using gaged streamflow records at the upstream and downstream control points, along with calibrated estimates of runoff from the intervening area, and include adjustments for intervening diversions and return flows. Previous streamflow studies conducted by the USGS[51] have shown a direct logarithmic relationship between channel loss and streamflow. This type of relationship was utilized to describe the channel loss characteristics in each stream segment in the Guadalupe-San Antonio River Basin. The channel loss equations derived for each segment illustrate that as streamflow increases, the *volume* of channel loss increases while the *percentage* of upstream flow lost decreases.

Channel loss relationships were developed for selected stream segments by performing long-term comparisons of concurrent upstream and downstream gaged streamflow records using

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[51] USGS, "Hydrologic Effects of Floodwater Retarding Structures on Garza – Little Elm Reservoir, Texas," Water Supply Paper 1984, 1970.

a modified Soil Conservation Service (SCS), which is now the Natural Resources Conservation Service (NRCS), curve number procedure and monthly areal precipitation to estimate intervening runoff arriving at the downstream gage.

The first step in the derivation of the channel loss relationships was the estimation of appropriate SCS "map" curve numbers for each subwatershed. This was accomplished by detailed review of county soil surveys. Areas of map curve number were delineated on the county soil survey maps and the areas were measured using planimeters. The resulting map curve numbers (AMC II) and intervening drainage areas for each of the subwatersheds are summarized in Table 3-2.

Using the modified SCS procedure, monthly intervening runoff was computed from areal precipitation using the following general equation:

$$QI = \left(\frac{640}{12}\right) A \frac{\left(P - \frac{200}{CN} + 2\right)^2}{\left(P + \frac{800}{CN} - 8\right)} \qquad \textbf{(3-2)}$$

where: ***QI = Intervening runoff (acft/month);***
A = Watershed area (square miles);
P = Areal precipitation (inches/month); and
CN = Calibrated SCS curve number.

The amount of channel loss in a given stream segment was computed for each month of concurrent record for the upstream and downstream gaging stations. Channel loss for each month was computed as:

$$Q_{LOSS} = QG_1 + QI - QNH_2 \qquad \textbf{3-3}$$

where: ***Q_{Loss} = Channel loss;***
QG_1 = Upstream gaged flow;
QI = Intervening runoff; and
QNH_2 = Downstream flow adjusted for intervening diversions and return flows.

Table 3-2.
Summary of SCS Map Runoff Curve Numbers Utilized to Estimate Intervening Runoff

Control Point	ID Number	Stream Name, Location	Intervening Drainage Area (sq. mi.)	SCS Map Runoff Curve Number (AMCII)
CP01	1670	Guadalupe River, Comfort	839	84.3
CP02	1675	Guadalupe River, Spring Branch	476	82.4
CP03	1677	Guadalupe River, Canyon Lake	117	82.7
CP04	1685	Guadalupe River, above Comal River at New Braunfels	86	83.7
CP05	1690	Comal River, New Braunfels	130	86.5
CP08	1710	Blanco River, Wimberley	355	82.6
CP09	1713	Blanco River, Kyle	57	84.3
CP10	1720	San Marcos River, Luling	332[1]	83.4
CP11	1730	Plum Creek, Luling	309	83.7
CP12	1746	Peach Creek, Dilworth	460	76.4
CP13	1750	Sandies Creek, Westhoff	549	79.4
CP14	1758	Guadalupe River, Cuero	675	74.7
CP15	1765	Guadalupe River, Victoria	264	74.8
CP16	1774	Coleto Creek Reservoir, Victoria	494	73.8
CP18	1780	San Antonio River, San Antonio	41.8	83.0
CP19	1787	Salado Creek, San Antonio Upper Station	137	85.4
CP20	1788	Salado Creek, San Antonio Lower Station	52	78.0
CP21	1795	Medina Lake	634	83.6
CP27	1808	Medina River, Somerset	246[1]	80.7
CP28	1815	Medina River, San Antonio	242[1]	80.8
CP29	1818	San Antonio River, Elmendorf	195.2[2]	75.1
CP32	1835	San Antonio River, Falls City	305[3]	75.9
CP33	1839	Cibolo Creek, Boerne	68.4	82.9
CP34	1850	Cibolo Creek, Selma	205.6	83.1
CP35	1860	Cibolo Creek, Falls City	553	79.4
CP36	1865	Ecleto Creek, Runge	239	77.8
CP37	1885	San Antonio River, Goliad	742	76.4
CP38	1888	Guadalupe River, Tivoli	515	78.2

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Table 3-2 (continued)

Control Point	*ID Number*	*Stream Name, Location*	*Intervening Drainage Area (sq. mi.)*	*SCS Map Runoff Curve Number (AMCII)*
CP06	6	Guadalupe River, Lake Wood (H-5)	455	80.2
CP17	17	Olmos Creek	8.3	85.6
CP22	22	Tributaries to Diversion Lake[4]	15.6	85.6
CP241, CP242	24	Deep Creek, Edwards	13.1	85.6
CP25	25	San Geronimo Creek	58.3	86.7
CP261, CP262	26	Leon, Helotes, and Government Creeks[4]	99.7	86.4
CP263, CP31	31	Calaveras Lake	65.0	81.5
CP71, CP72 CP73, CP74	G	Sink, Purgatory, York, Alligator Creeks[4]	94.0	86.4

[1] Intervening area below the downstream edge of the recharge zone.
[2] Includes Braunig Lake (CP30) drainage area.
[3] Excludes Calaveras Lake drainage area
[4] Drainage Area and Curve Number represent combined values for control points listed.

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Channel loss equations for each of the stream segments were derived based on the monthly estimates of channel loss as a function of monthly upstream flow. Months when losses were calculated to be less than zero or greater than the upstream flow were not included in the derivations. Calculated losses in these months represent extreme or impossible conditions, which generally result from inaccuracies in estimating runoff for large intervening watersheds using monthly areal precipitation. The channel loss equations were derived using linear regression techniques for a log-log relationship of channel loss as a function of upstream flow. The standard form of the channel loss equation is expressed as:

$$\mathrm{Log}_{10}(Q_{LOSS}) = b\,\mathrm{Log}_{10}(QG_1) + \mathrm{Log}_{10}(a) \qquad \textbf{(3-4)}$$

or

$$Q_{LOSS} = a(QG_1)^b \qquad \textbf{(3-5)}$$

where: Q_{LOSS} = ***Channel loss (acft/month);***
QG_1 = ***Upstream gaged flow (acft/month); and***
a,b = Regression coefficients.

For purposes of this study, the regression coefficients in the channel loss equation were retained only if they were significantly different from zero at the 90 percent confidence level based on the Students t Test.[52] The resulting regression equations for selected stream segments had coefficients of determination (r^2) ranging from 0.16 for the Blanco River at Wimberley to 0.37 for the San Antonio River at Goliad. For stream reaches where insufficient gaged data were available to compute meaningful channel loss equations, equations developed for nearby stream reaches were utilized with adjustments for median upstream flow.

Table 3-3 summarizes the channel loss equations applied for all stream segments in the Guadalupe-San Antonio River Basin. The channel loss equations developed for stream segments in the Guadalupe-San Antonio River Basin, to a large extent, fall within the range of channel loss relationships found in USGS studies.[53] Generally, channel loss rates were found to be in the lower range for those stream segments upstream of the Edwards Aquifer recharge zone and in the plains and coastal prairies, while higher channel loss rates were found to occur in those segments crossing aquifer outcrops.

Figure 3-3 presents a summary of typical channel loss rates in percent per mile, based on average flow conditions for all stream segments where losses were calculated from gaged records. Channel loss rates outside of the Edwards Aquifer recharge zone ranged from 0.15 percent per mile to 1.44 percent per mile, with the highest for the Medina River segment, which crosses the Carrizo-Wilcox Aquifer outcrop. Generally, the lower channel loss rates were found to occur in those stream segments that do not traverse major aquifer outcrops or have short travel distances across these outcrop areas. Overall, channel loss rates downstream of the Edwards Aquifer recharge zone averaged 0.22 percent per mile in the Guadalupe-San Antonio River Basin.[54]

WRAP considers channel losses as simple factors multiplied by changes in flow to translate the effects of diversions, return flows, and stored water to downstream control points. The original channel loss equations developed previously were based on total flows and, therefore, vary with the magnitude of regulated flows. For inclusion in WRAP, the original channel loss equations for each reach were converted to constant loss factors based on the loss

[52] Haan, C.T., "Statistical Methods in Hydrology," Iowa State University Press, 1977.
[53] USGS, Op. Cit., 1970.
[54] HDR, Op. Cit., May 1991.

Table 3-3.
Summary of Channel Loss Equations

Stream Segment Description	Upstream Control Point(s) ID (gage #)	Downstream Control Point ID (gage #)	Channel Loss Equation Coefficients a	Channel Loss Equation Coefficients b	Channel Loss Factor Based on Median Flow
Guadalupe River Basin					
Guadalupe River Comfort to Spring Branch	CP01 (1670)	CP02 (1675)	1.0000	0.7979	0.164
Guadalupe River Spring Branch to Canyon Lake	CP02 (1675)	CP03 (1677)	1.0000	0.7150	0.0625
Guadalupe River Canyon Lake to New Braunfels	CP03 (1677)	CP04 (1685)	0.0000	0.0000	0.000
Guadalupe River New Braunfels to Lake Wood	CP05 (1690) CP04 (1685)	CP06	0.0221	1.1462	0.1006
Guadalupe River Lake Wood to Cuero	CP06 CP10 (1720) CP11 (1730) CP12 (1746) CP13 (1750)	CP14 (1758)	1.3088	0.7801	0.1211
Guadalupe River Cuero to Victoria	CP14 (1758)	CP15 (1765)	1.0000	0.7801	0.0839
Guadalupe River Victoria to Tivoli	CP15 (1765) CP16 (1774)	CP38 (1888)	0.7194	0.7801	0.0617
Blanco River Wimberley to Kyle	CP08 (1710)	CP09 (1713)	92.4272	0.3314	0.2350
San Marcos River San Marcos to Luling	CP07 (1700) CP09 (1713)	CP10 (1720)	0.0057	1.3161	0.1144
San Antonio River Basin					
Medina River Diversion Lake to Somerset	CP21 (1795) CP23 CP24 CP25	CP27 (1808)	1.3502	0.7980	0.2098
Medina River Somerset to San Antonio	CP27 (1808) CP26	CP28 (1815)	1.0000	0.7980	0.1767
San Antonio River San Antonio to Elmendorf	CP18 (1780) CP20 (1788) CP28 (1815) CP30	CP29 (1818)	1.0023	0.7980	0.1584
San Antonio River Elmendorf to Falls City	CP29 (1818) CP31 (1825)	CP32 (1835)	0.1727	0.9278	0.0835
San Antonio River Falls City to Goliad	CP32 (1835) CP35 (1860) CP36 (1865)	CP37 (1885)	0.0490	1.0880	0.1216
San Antonio River Goliad to Tivoli	CP37 (1885)	CP38 (1888)	0.0379	1.0880	0.0914
Cibolo Creek Boerne to Selma	CP33 (1839)	CP34 (1850)	1.0000	1.0000	1.0000
Cibolo Creek Selma to Falls City	CP34 (1850)	CP35 (1860)	0.5509	1.0000	0.5510
Salado Creek Upper Sta. to Lower Sta.	CP19 (1787)	CP20 (1788)	0.2944	1.0000	0.2944

[1] Coefficients "a" and "b" for Channel Loss Equation expressed as $Q_{LOSS} = a(QG_1)^b$, where Q_{LOSS} is the monthly channel loss in acft and QG_1 is the total monthly flow at the upstream control points in acft.

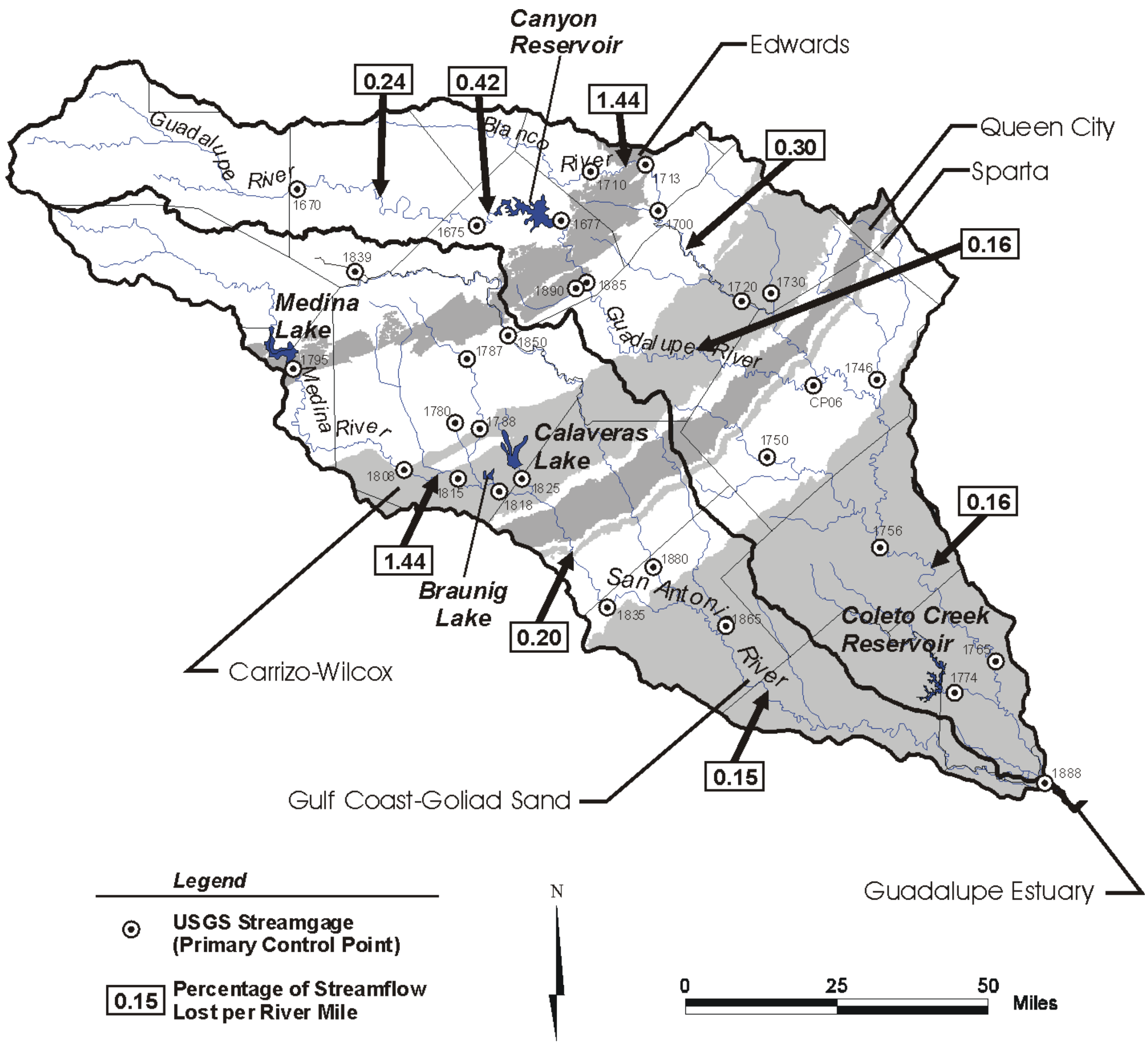

Figure 3-3. Average Channel Loss Rates in the Guadalupe-San Antonio River Basin

associated with the downstream translation of the sum of median naturalized streamflows at the upper end of each stream reach. In other words, the original channel loss equation applicable to each stream reach was simplified to an average channel loss factor. These factors, shown in Table 3-3, were prorated to secondary control points as described in Section 4.2.1.

3.1.4 Completion of Streamflow Records

Streamflow records missing during the 1934 to 1989 historical period were estimated for 24 streamflow gaging stations located throughout the Guadalupe-San Antonio River Basin. Records were completed using multiple linear regression techniques based on available streamflow records, calibrated estimates of local runoff based on areal precipitation and curve number, or drainage area ratio based on available streamflow records in the same or an adjacent watershed. The equations used to estimate these missing monthly streamflow records are summarized in Table 3-4.

Table 3-4.
Estimation of Missing Streamflow Records

Control Point	***Reference Number of Control Point /Streamgage with Missing Records***	***Period of Missing Records***	***Regression Equation***	***Length of Concurrent Records (Years)***	***Coefficient of Determination (r^2)***
CP01	1670	01/34 to 05/39	QG_{1670} = (QNH_{1675} - 0.8851 QI_{1675})/1.0829	50	.93
CP03	1677[1]	01/34 to 06/62	QNH_{1677} = 0.9274 QG_{1675} + 0.8980 QI_{1677} + 1225.5800	27	.99
CP06	H-5	01/34 to 12/59	QNH_{H-5} = 0.79967 QG_{1685} + 1.24622 QG_{1690}	10	.96
CP06	H-5	01/60 to 12/79	QNH_{H-5} = 0.76308 QG_{1685} + 1.18412 QG_{1690} + 0.26594 QI_{H-5}	10	.97
CP09	1713	01/34 to 05/56	QNH_{1713} = 1.0289 QG_{1710} + 0.3844 QI_{1713} + 1360.1090	33	.98
CP10	1720	01/34 to 04/39	QNH_{1720} = 1.1776 QG_{1710} + 0.7441 QG_{1730} + 1.1762 QG_{1700} – 2673.7705	50	.94
CP12	1746	01/34 to 07/59 10/79 to 12/89	QN_{1746} = QI_{1746} , ptnr=1730 (no regression)	---	---
CP13	1750	11/34 to 07/59	QN_{1750} = 0.9596 QN_{1860}	31	.52
CP14	1758	12/35 to 12/63	QG_{1758} = (QNH_{1765} - 1239.8739)/1.0461	26	.99
CP15	1765	01/34 to 11/34	QNH_{1765} = 1.0461 QG_{1758} + 1239.8739	26	.99
CP16	1774	01/34 to 06/39	QN_{1774} = 770.9900 $PREC^2_{1774}$ - 2657.9253 $PREC_{1774}$ + 3424.5904	50	.78
CP16	1774	07/39 to 09/54	QN_{1774} = QN_{1775} $(494/514)_{\text{D.A.R. w/ gage 1775}}$ (no regression)	---	---
CP16	1774	10/54 to 09/78	QN_{1774} = QN_{1770} $(494/369)_{\text{D.A.R. w/ gage 1770}}$ (no regression)	---	---
CP16	1774	10/78 to 12/89	QN_{1774} = QN_{1769} $(494/357)_{\text{D.A.R. w/ gage 1769}}$ (no regression)	---	---
CP18	1780	01/34 to 02/39	QN_{1780} = 1.0910 $QG_{\text{S.A.SPRING}}$ + 6.6831 $QG_{\text{RUNOFF RCHZ}}$ + 0.3556 QI_{1780} + 1206.3234	51	.87
CP19	1787	01/34 to 09/60	QN_{1787} = QI_{1787} - RN_{1787} (no regression)	---	---
CP20	1788	01/34 to 02/39	QN_{1788} = 1.6024 QN_{1787} + 0.1319 QI_{1788} + 1479.5876	29	.84
CP20	1788	03/39 to 09/60	QNH_{1788} = 0.7510 QN_{1780}	29	.52
N/A	1790	07/35 to 09/42	QN_{1790} = 0.4325 QN_{1675}	30	.75
N/A	1790	10/42 to 09/52	QN_{1790} = 0.4443 QN_{1690} + 1.1155 QN_{1980}	30	.87
CP21	1795	01/34 to 03/56 12/81 to 09/82	QN_{1795} = QN_{1790} $(634/474)_{\text{D.A.R. w/ gage 1790}}$ (no regression)	---	---
CP21	1795	04/56 to 11/81	QN_{1795} = (QN_{1790} + QN_{1791}) $(634/(474+56.3))_{\text{D.A.R.}}$ (no regression)	---	---
CP21	1795	10/82 to 12/89	QN_{1795} = QN_{17888} $(634/427)_{\text{D.A.R. w/ gage 17888}}$ (no regression)	---	---

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Table 3-4 (continued)

Control Point	***Reference Number of Control Point /Streamgage with Missing Records***	***Period of Missing Records***	***Regression Equation***	***Length of Concurrent Records (Years)***	***Coefficient of Determination (r^2)***
N/A	1805	01/34 to 12/89	$QN_{1805} = QN_{1795} + QI_{1805} – RN_{1805}$ -10^(0.3314 logQN_{1795} + 1.9658)	---	---
CP27	1808	01/34 to 07/39	$QNH_{1808} = 1.1787\ QG_{1805} + 0.2179\ QI_{1808} + 2787.7344$	19	.90
CP27	1808	08/39 to 09/70	$QG_{1808} = (QNH_{1815} - 959.2566 - 0.1303\ QI_{1815})/1.0833$	19	.99
CP28	1815	01/34 to 07/39	$QNH_{1815} = 1.3496\ QG_{1805} + 4650.5164$	50	.83
CP29	1818	01/34 to 09/54	$QG_{1818} = QNH_{1835}/1.0942$	27	.97
CP29	1818	10/54 to 09/62	$QG_{1818} = (QNH_{1835} - 5.3685\ QG_{CL} - 1839.0573)/0.9960$	27	.98
CP30	Braunig Lake	01/34 to 12/89	$QN_{BL} = QN_{CL}\ (9.4/65)$ D.A.R. w/ Calaveras Lake (no regression)		
CP31[2]	1825	01/34 to 09/54 01/69 to 12/70	$QG_{CL} = 0.0527\ QNH_{1835} – 555.0354$	14	.61
CP31[3]	1825	10/54 to 12/68	$QN_{CL} = QN_{1825}\ (65/77.2)$ D.A.R. w/ gage 1825 (no regression)	---	---
CP31[4]	1825	01/71 to 12/89	QN_{CL} = MASS BALANCE (no regression)	---	---
CP33	1839	01/34 to 06/35 10/52 to 02/62	$QN_{1839} = 0.1772\ QI_{1765} + 0.0122\ QN_{1790} - 367.9174$	21	.80
CP33	1839	07/35 to 09/52	$QN_{1839} = 0.1466\ QI_{1765}$	28	.76
CP34	1850	01/34 to 03/46	$QNH_{1850} = 0.3768\ QG_{1839} + 0.4070\ QI_{1850} - 1701.6080$	28	.64
CP36	1865	01/34 to 02/39	$QN_{1865} = 0.2875\ QN_{1860}$	27	.42
CP36	1865	03/39 to 03/62 10/89 to 12/89	$QG_{1865} = (QNH_{1885} - 1.0815\ QG_{1835} - 0.3649\ GQ_{1860})/4.0338$	27	.93
CP37	1885	01/34 to 02/39	$QNH_{1885} = 0.9962\ QG_{1835} + 1.7361\ QG_{1860} + 2622.1322$	51	.83

Definition of Terms: QG = Gaged Flow QN = Natural Flow P = Areal Precipitation
QNH = Gaged Flow Adjusted for Local Diversion and Return Flows
QI = Intervening or Potential Runoff Calculated Using Modified SCS Procedure
D.A.R. = Drainage Area Ratio RN = Natural Recharge
Units: Acre-feet/month: QG, QN, QNH, QI, RN Inches/Month: P

[1] QNH_{1677} used to develop regression equation is Canyon inflows developed for 1962 to 1989 using mass balance computations and hence, flows calculated using this equation represent flows computed using mass balance techniques for purposes of the effective precipitation adjustment described in Section 3.3.2.

[2] Flows computed using this drainage area ratio for specific time periods represent either drainage area ratio flow or mass balance flow according to the method used to develop flows for Calaveras Lake during the concurrent period.

[3] Flows computed during these time periods represent mass balance inflows.

[4] Flows computed during this timer period represent drainage area ratio flows.

Generally, regression equations were developed to calculate missing flows from available upstream or downstream flows and estimates of intervening runoff. When suitable upstream or downstream flow records were not available, however, regression equations were developed from available natural flows in one or more adjacent watersheds or by other means. Table 3-4 indicates the length of concurrent record on which each regression equation was based, which averaged 2.2 times the length of missing records. Coefficients of determination (r^2) for the regression equations ranged from 0.42 to 0.99, with the average, weighted by dependent mean, being about 0.94.

3.1.5 Comparison with Legacy Model Naturalized Streamflow

Natural streamflows used in the performance of this study were compared to those used by the TDWR (now TNRCC) in the legacy computer model. Figure 3-4 presents both HDR and TDWR natural streamflows for the Guadalupe River at Victoria for the 1940 to 1978 historical period selected by the TDWR. As is apparent in Figure 3-4, agreement between the two data sets is quite good, with the TDWR flows always being slightly greater than those used by HDR. Differences between the TDWR and HDR flows average only 2.6 percent of the mean annual streamflow.

The differences in natural streamflow are due to differences in the streamflow naturalization methodologies applied. The exact differences are not known, because the exact procedures used to develop the legacy model naturalized flows are not known. It is believed that the most significant difference is that TDWR adjusted gaged streamflows for historical diversions, effluent discharge, and reservoir storage on a one-to-one basis throughout the basin,

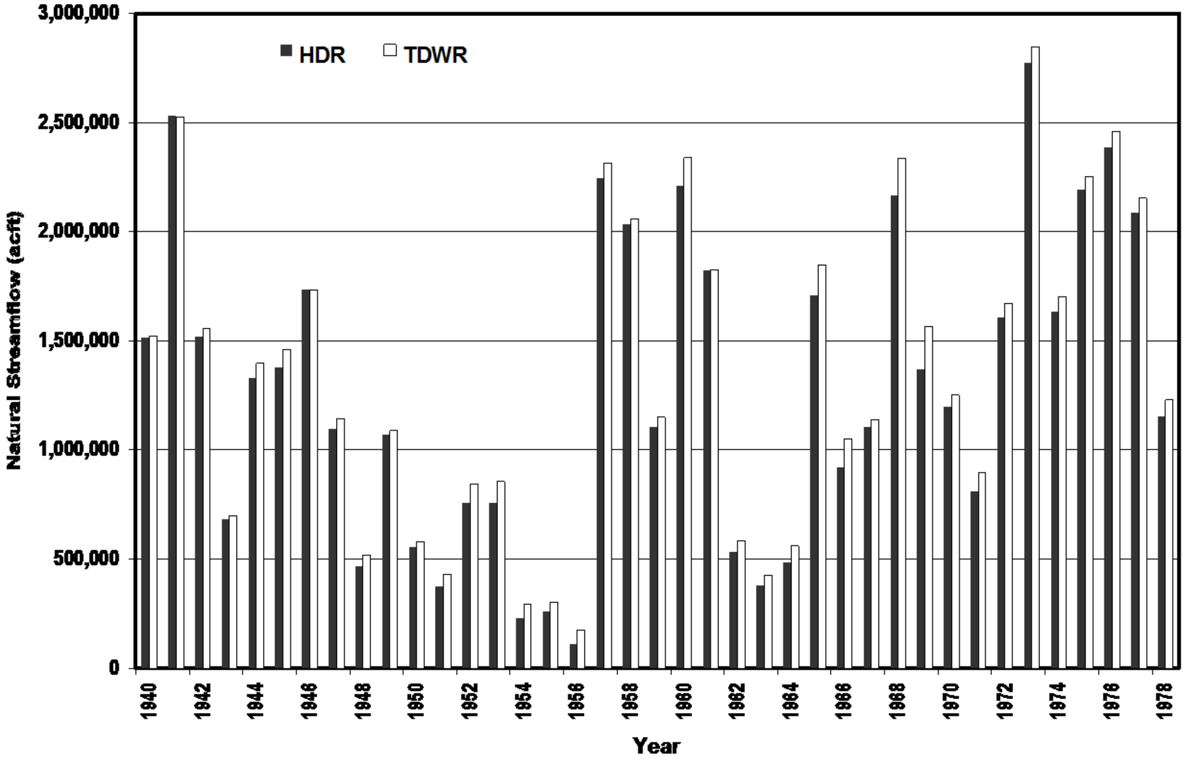

Figure 3-4. Comparison of Annual HDR and TDWR Naturalized Streamflows for the Guadalupe River at Victoria

while HDR considered channel losses and applied delivery factors to translate the effects of historical streamflow changes to downstream gages. The other differences may include alternative procedures for estimating missing flow records and/or historical diversions, as well as historical adjustments by the TDWR to account for minor reservoirs, and other factors.

It is believed that use of the HDR natural streamflows and delivery factors accurately represents the response of the basin to authorized diversions and potential implementation of new water supply projects. Use of the TDWR procedures neglecting channel losses is reasonable in basins where authorized diversion rights approximate historical diversions, because the losses inherent in the gaged streamflow records would more closely match those modeled under full utilization of water rights. This is not the case where historical diversions are significantly less than authorized. In the Guadalupe-San Antonio River Basin, underestimation of lower basin streamflows and freshwater inflows to the Guadalupe Estuary would result because authorized diversion rights significantly exceed historical diversions. Additional information regarding comparisons between TDWR and HDR natural streamflows and gaged streamflows was presented in the form of a technical memorandum submitted to TNRCC.[55]

3.1.6 Trends in Annual Streamflow

It is not uncommon for streamflows to be influenced over time by various changes occurring within a river basin that are not directly considered in the streamflow naturalization process. Examples of these changes potentially applicable to the Guadalupe-San Antonio River Basin include:

1) Increased groundwater use from the Edwards Aquifer, which, in turn, may reduce the discharge of certain springs;
2) Increased groundwater use from other aquifers that outcrop within the basin which, in turn, may reduce the baseflow of streams and increase aquifer recharge and channel losses;
3) Urbanization which may increase surface runoff;
4) Changes in farming techniques intended to reduce runoff such as furrow diking, contour plowing, and terracing;
5) Increased prevalence of certain types of vegetation which enhance evapotranspiration losses; and
6) Construction of farm ponds and other water control structures.

While changes in springflow from the Edwards Aquifer are considered in the application of WRAP, reduced baseflow originating from other aquifers is not. Reduced baseflow and other changes in flow due to urbanization and other land use changes are generally assumed to be of insufficient magnitude on a basin-wide scale to warrant similar consideration. Climatic changes such as global warming may also affect the frequency and intensity of precipitation events and other factors that may influence streamflows. Recent analysis of potential trends in declining runoff per unit rainfall in the Guadalupe-San Antonio River Basin have ranged from purely statistical assessments[56] to computer modeling of groundwater/surface water interactions.[57] This

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[55] HDR and Crespo Consulting Services, Inc., “Comparison of Naturalized and Gaged Flows, Water Availability Modeling Project, Guadalupe-San Antonio and Nueces River Basins,” Technical Memorandum, TNRCC, August 27, 1998.
[56] HDR, Op. Cit., September 1993.
[57] LBG-Guyton (LBG) and HDR, “Interaction Between Groundwater and Surface Water in the Carrizo-Wilcox Aquifer,” TWDB, August 1998.

section describes previous studies addressing potential runoff trends in the basin and summarizes analyses of long-term rainfall and natural streamflow data to ascertain the presence of significant trends.

In the 1993 Guadalupe-San Antonio River Basin Recharge Enhancement Study,[58] historical trends in runoff as a percentage of rainfall were evaluated for three locations selected to be somewhat representative of inflows to Canyon Reservoir (Guadalupe River near Spring Branch, CP02), Guadalupe River Basin runoff (Guadalupe River at Victoria, CP15), and San Antonio River Basin runoff (San Antonio River at Goliad, CP37). Only the Guadalupe River near Spring Branch exhibited a statistically significant (increasing) trend at the 90 percent confidence level. No significant trends were detected for the Guadalupe River at Victoria or the San Antonio River at Goliad in spite of dramatically increased pumpage and urbanization in the San Antonio area.

In the 1998 study by LGB and HDR,[59] a calibrated groundwater model of the Carrizo-Wilcox Aquifer in the Nueces and Guadalupe-San Antonio River Basins was developed. This model simulated historical pumpage from the aquifer for the period from 1934 to 1994 and interactions between the aquifer and streams that cross its outcrop area. During the early portion of the simulation period, all streams in the Guadalupe-San Antonio River Basin indicate gains from the Carrizo-Wilcox Aquifer in those areas crossing the aquifer outcrop. In later periods, however, the San Antonio River and Cibolo Creek indicate losses to the aquifer due to reduced aquifer levels caused by increased pumpage in the 1960's. While the completion of this research study represents a very significant step, definition of the interactions between surface water and groundwater remains a developing science.

Without a full understanding of the physical causes for the apparent increase in unit runoff in the Guadalupe River above Canyon Reservoir and deeper understanding of the complex relationship between surface water and groundwater in the Guadalupe-San Antonio River Basin, adjustment of naturalized streamflows for apparent trends is not warranted.

[58] HDR, Op. Cit., September 1993.
[59] LBG and HDR, Op. Cit., August 1998.

3.2 Natural Streamflow at Ungaged Locations

3.2.1 Development of Natural Flows for Ungaged Watersheds Adjacent to the Edwards Aquifer Recharge Zone

Monthly natural streamflow and potential runoff data sets were developed for selected ungaged watersheds originating upstream of or atop the Edwards Aquifer outcrop in previous studies, cited in Section 2.4. These flow sets were developed in order to estimate recharge into the Edwards Aquifer, as described in Section 3.5. In this study, these data sets are also used to estimate water available to rights located on those streams whose headwaters are predominately within the Edwards Aquifer outcrop. Estimates of potential runoff at these locations were computed using a modified SCS method (Sections 3.5.1.5 through 3.5.1.9) and reduced by monthly estimates of natural flow to obtain natural recharge. These estimates of natural flow were utilized to distribute flows to ungaged water right diversion locations (secondary control points) as described in the following section.

3.2.2 Distribution of Natural Flows Considering Channel Losses

Many locations in a river basin where water availability calculations are needed are not located near streamflow gaging stations or other primary control points where naturalized flows are typically computed. Hence, naturalized flows at these "secondary" control points must be estimated. Secondary control points may include reservoir locations, diversion points, and the ends of classified stream segments. Figure 3-5 shows the locations of all primary and secondary control points utilized in the Guadalupe-San Antonio River Basin.

Several alternative algorithms are coded into the WRAP Model to distribute naturalized flows from primary ("known-flow") control points to secondary control points using watershed characteristics such as drainage area, runoff curve number, and mean annual precipitation. The method used can vary by control point. Only two of the methods available in WRAP can correctly account for channel losses when distributing flows, INMETHOD3 and INMETHOD6. INMETHOD3 utilizes a regression-type equation that can incorporate channel losses into the formulation. INMETHOD6 utilizes drainage area ratios adjusted for channel losses. The theoretical basis for INMETHOD6 is described in detail in the form of a technical memorandum.[60] The application of INMETHOD3 and INMETHOD6 is described in the WRAP Users Manual. Because channel losses play a significant role in the Guadalupe-San Antonio River Basin, and INMETHOD6 is designed specifically to account for channel losses, INMETHOD6 was used for all secondary control points except for instances where INMETHOD2 was used to set flows at a secondary control point equal to those at a primary control point.

3.2.3 Ungaged Freshwater Inflows to the Guadalupe Estuary

Runoff estimates for the ungaged coastal area in the Guadalupe-San Antonio River Basin were required to develop a natural flow record at the Saltwater Barrier near Tivoli (CP38). The ungaged area includes the intervening area upstream of the Saltwater Barrier, and downstream of the following locations: San Antonio River at Goliad (CP37), Coleto Creek at Coleto Creek Reservoir near Victoria (CP16), and the Guadalupe River at Victoria (CP15). Ungaged runoff estimates for the coastal area were available from past studies by EH&A,[61] TDWR,[62] and TWDB.[63] In order to ensure consistency with the fisheries harvest and salinity equations developed by the TWDB and TPWD, TWDB estimates of ungaged runoff were adapted for use in the water availability model. The TWDB provided composite estimates of ungaged runoff above and below the Saltwater Barrier for the 1941 to 1989 historical period, which, after minor adjustments for drainage area, were used to develop regression equations for estimation of ungaged runoff for the 1934 to 1940 period based on HDR estimates monthly areal precipitation. Annual ungaged runoff above and below the Saltwater Barrier averaged 263,926 acft/yr and 86,330 acft/yr, respectively, for the 1934 to 1989 historical period. Control point CPEST was added and represents flows at CP38 (Guadalupe River at Tivoli) plus the ungaged runoff below the Saltwater Barrier. As such, the CPEST control point does not represent a discrete point, but rather, all of the watershed area contributing flow to the Guadalupe Estuary.

[60] HDR, "Distribution of Naturalized Streamflows from Gaged to Ungaged Control Points Accounting for Aquifer Recharge and Channel Losses," Technical Memorandum, TNRCC, December 1998.
[61] Espey, Huston & Associates, Inc. (EH&A), "Engineering Analyses and Hydrologic Modeling to Determine the Effects of Subordination of Hydropower Water Rights," Guadalupe-Blanco River Authority, March 1993.
[62] TDWR, "Guadalupe Estuary: A Study of the Influence of Freshwater Inflows," LP-107, August 1980.
[63] TWDB and TPWD, "Freshwater Inflows to Texas Bays and Estuaries: Ecological Relationships and Methods for Determination of Needs," Joint Estuarine Research Study, 1994.

3.3 Net Reservoir Evaporation

3.3.1 Evaporation and Precipitation Data Sources

Since the turn of the century, evaporation pans have been maintained at various locations throughout the state by numerous federal and state agencies, municipalities, and local interests. The TWDB compiled much of the available historical pan evaporation data[64] and developed monthly reservoir gross evaporation rates for the entire state by one-degree quadrangles of latitude and longitude[65] for the 1940 to 1990 period. The TWDB also published monthly "net" reservoir evaporation rates in the same fashion. Net reservoir evaporation is typically defined as the gross evaporation rate minus rainfall occurring over the reservoir surface area.

The net reservoir evaporation rates formerly published by the TWDB were actually "adjusted net" evaporation rates. The precipitation subtracted from the gross evaporation rates was "effective" precipitation, representing "rainfall over the reservoir site less the amount that has run off and is already reflected in the runoff records. The part of the rainfall that appears as runoff must be deducted to prevent duplication of this amount of water in planning studies."[66] These adjusted net evaporation rates are applicable for evaluating new reservoirs, and for evaluating existing reservoirs for which the naturalized inflows are developed using drainage area ratios and/or gaged streamflows. This effective precipitation adjustment is not appropriate for existing reservoirs for which naturalized inflows were developed using reservoir mass balance techniques. The gross and adjusted net evaporation rates are referred to herein as the "pre-1996" data set.

In 1998, the TWDB recomputed gross evaporation rates for all quadrangles and issued updated data for the 1954 to 1996 historical period[67] in response to recent work by the National Weather Service regarding geographical variability in evaporation pan coefficients.[68] The gross evaporation rates recently published by the TWDB are referred to herein as the "new" data set. The net effect of these adjustments in the TWDB's data is a general reduction in estimated annual evaporation rates across the state, including a reduction in the annual pan coefficients

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[64] TWDB, "Evaporation Data in Texas, Compilation Report, January 1907 - December 1970," Report 192, June 1975.
[65] TWDB, "Monthly Reservoir Evaporation Rates for Texas, 1940 through 1965," Report 64, October 1967.
[66] Ibid.
[67] TWDB, "Monthly Reservoir Evaporation Rates for Texas Using GIS," March 1998.
[68] Farnsworth, R.K., et al., "Evaporation Atlas for the Contiguous 48 United States," NOAA Technical Report NWS33, Washington, D.C.: National Weather Service Office of Hydrology, 1982.

from 0.78 to 0.70 for the quadrangles that overlay the Guadalupe-San Antonio River Basin. Use of the new data would result in greater estimates of available water due to smaller computed evaporation. Net evaporation rates (adjusted and unadjusted for effective precipitation) have not been provided by the TWDB.

Naturalized flows for Canyon Reservoir, Calaveras Lake, and Braunig Lake were based, in part, on reservoir mass balance techniques using the pre-1996 TWDB gross evaporation data, adjusted by local precipitation. Preliminary mass balance analyses were conducted to evaluate the relative performance of the original and the new TWDB gross evaporation data in replicating the historical content fluctuations at Canyon Reservoir. The results of these analyses indicate that the original TWDB gross evaporation data sets provide more accurate simulations of Canyon Reservoir storage fluctuations. Similar mass balance analyses could not be performed for other reservoirs in the Guadalupe-San Antonio River Basin because of the influences of Edwards Aquifer recharge and forced evaporation due to power plant operations. As the mass balance analyses tend to support the original TWDB evaporation data and use of the new data could result in overestimation of water availability, the pre-1996 TWDB gross evaporation data sets are used in the current study for all reservoirs in the Guadalupe-San Antonio River Basin.

3.3.2 Procedures for Estimation of Net Evaporation

Based on a TNRCC technical memorandum issued in 1998,[69] this document defines effective precipitation as "the quantity of precipitation that does not contribute to the surface water flows in a subject watershed because of natural depletions (e.g., infiltration, consumptive use, or interception). Effective precipitation is usually calculated by reducing observed precipitation by an estimate of precipitation that is expected to runoff and contribute to streamflow based on rainfall/runoff relationships in the subject watershed."

WRAP includes a procedure to "adjust" net evaporation rates for effective precipitation on a control point-by-control point basis, depending upon how the naturalized inflows at each control point were developed. For control points at which reservoirs with authorized storage capacities less than 4,000 acft are located, naturalized flows were developed using the flow distribution algorithms within WRAP, and the effective precipitation adjustment within WRAP was utilized. Net evaporation for these control points was computed on a quadrangle basis by

[69] HDR and Crespo Consulting Services, Inc., Op. Cit., August 27, 1998

adjusting the gross evaporation associated with a quadrangle with precipitation data from nearby rain gages. Representative precipitation for each quadrangle was computed using data from each nearby rain gage, weighted by the ratios of the inverse distance from the rain gage to the centroid of the quadrangle. Net evaporation rates for each quadrangle for the 1934 to 1939 period were computed from available pan evaporation records adjusted by pan coefficients recommended by the TWDB[70] and by precipitation calculated from nearby rain gages. Evaporation and precipitation were weighted using ratios of the inverse distances from the gages to the quadrangle centroids.

For each reservoir shown in Table 3-5, the naturalized inflows were determined using either mass balance computations or a combination of mass balance and gaged inflows (with drainage area adjustments), depending upon the availability of gaged records and the time of construction of the reservoir. For these reservoirs, the WRAP net evaporation adjustment feature was not utilized, and the input data sets include both adjusted and unadjusted net evaporation data, as appropriate for each time period of naturalized flows. Table 3-5 notes the method for naturalized flow determination and whether the evaporation data represent net or adjusted net evaporation rates. Unadjusted net evaporation data were developed for the reservoirs in Table 3-5 from pre-1996 TWDB gross evaporation data, adjusted for local precipitation or for precipitation levels gathered from surrounding rain gages, as appropriate. Naturalized inflows for Canyon Reservoir, Calaveras Lake, and Braunig Lake were determined in part using the equations presented in Table 3-4. Footnotes included in Table 3-4 indicate time periods during which the naturalized flows computed using the equations represent mass balance flows. The adjusted net evaporation data for those reservoirs noted in Table 3-5 are the pre-1996 adjusted net evaporation data published by the TWDB.

[70] TWDB, "Monthly Reservoir Evaporation Rates for Texas, 1940 through 1965," Report 64, October 1967.

3.4 Reservoir Elevation-Area-Capacity Relationships

3.4.1 Large Reservoirs

Table 3-6 lists the five major reservoirs (capacity greater than 5,000 acft) in the Guadalupe-San Antonio River Basin and Boerne Lake (capacity 4,043 acft). For the reservoirs listed in Table 3-6, the most recent elevation-area-capacity relationship was obtained and utilized

Table 3-5.
Reservoirs for Which the WRAP
Net Evaporation Adjustment Was Not Applied

Reservoir (Control Point)	***Dates***	***Method to Determine Naturalized Inflows***	***Evaporation Data Used***
Canyon Reservoir (CP03)	Jan. 1934 to Dec. 1989	Mass Balance	Net
Coleto Creek Reservoir (CP16)	Jan. 1934 to Dec. 1989	Drainage Area Ratio	Adjusted Net
Medina Lake (CP21)	Jan. 1934 to Dec. 1989	Drainage Area Ratio	Adjusted Net
Braunig Lake (CP30)	Jan. 1934 to Sep. 1954	Mass Balance	Net
	Oct. 1954 to Dec. 1968	Drainage Area	Adjusted Net
	Jan. 1969 to Dec. 1989	Mass Balance	Net
Calaveras Lake (CP31)	Jan. 1934 to Sep. 1954	Mass Balance	Net
	Oct. 1954 to Dec. 1968	Drainage Area	Adjusted Net
	Jan. 1969 to Dec. 1989	Mass Balance	Net

Table 3-6.
Large Reservoirs in the Guadalupe-San Antonio River Basin

Reservoir	Authorized Impoundment (acft/yr)	Surveyed Capacity (acft)	Source	Year	Accumulation Rate (acft/yr)	Year 2000 Capacity (acft)
Canyon Reservoir	386,200	382,000	USCE[1]	1972	358	371,976
Coleto Creek Reservoir	35,084	35,084	Forrest & Cotton[2]	1980	138	32,318
Medina Lake[3]	237,874	254,823	TWDB[4]	1995	222	253,713
Calaveras Lake	63,200	62,800	TWDB[5]	1969	66.7	60,732
Braunig Lake	26,500	26,500	TWDB[5]	1963	9.6	26,145
Boerne Lake	4,046	4,043	SAWS[6]	1997	6.8	4,022

1 Bathymetric survey by the U.S. Army Corps of Engineers.
2 URS/Forrest and Cotton Consulting Engineers, "Coleto Creek Project, Coleto Creek, Guadalupe River Basin, Victoria and Goliad Counties, Texas," December 1976.
3 The authorized storage for Diversion Lake (4,500 acft) is much greater than the actual capacity of 2,555 acft. The authorized storage for Medina Lake included for all model runs is the authorized annual *plus* the difference between the authorized and actual storage amounts for Diversion Lake (237,874 + (4,500 – 2,555) = 239,819.
4 Bathymetric survey by the TWDB.
5 TWDB, "Engineering Data on Dams and Reservoirs in Texas," Report 126, February 1971..
6 Simpson Group, "Draft Report — Boerne Water Supply Feasibility Study, City of Boerne, Kendall County, Texas," December 1997.

for Runs 1 through 7, limited by the authorized storage for each reservoir. For Run 8 (Current Conditions Run), sediment accumulation rates were estimated for these reservoirs[71] and used to estimate year 2000 elevation-area-capacity relationships using the USBR "Empirical Area-Reduction Method" for sediment deposition computations.[72,73]

The current and year 2000 storage capacities of Medina Lake (254,823 acft) are much greater than its authorized amount (237,874 acft), while the current storage capacity of Diversion Lake (2,555 acft) is much less than its authorized amount (4,500 acft). The leakage and recharge functions for these two reservoirs utilized in the basin-specific modifications completed by HDR (Section 4.1.2.2) require the current elevation-area-capacity relationships. In order to account for recharge and leakage, these relationships and the current capacity of Diversion Lake were used in all runs. The amount by which the current capacity of Diversion Lake is less than its authorized amount was added to the authorized capacity of Medina Lake for Runs 1 through 9.

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71 TDWR, "Erosion and Sedimentation by Water in Texas," Report 268, 1982.
72 Borland, W.M. and Miller, C.R., "Distribution of Sediment in Large Reservoirs," Journal of the Hydraulic Engineering Division, ASCE, April 1958.

For Runs 8 and 9, the area-capacity relationship for Medina Lake was adjusted to reflect the year 2000 sedimentation condition, but the authorized capacity was not increased above that utilized in Runs 1 through 7.

3.4.2 Small Reservoirs

Reliable area-capacity relationships for small reservoirs (less than 5,000 acft) generally are not available in the Guadalupe-San Antonio River Basin. For these reservoirs, the generalized relationship[74] developed by Ralph Wurbs at Texas A&M University was utilized. This relationship defines reservoir surface area with the following power function of reservoir storage:

$$\text{Area} = 1.000 * (\text{Storage})^{0.727}$$

This relationship is similar to the relationship developed by the R.J. Brandes Company for small reservoirs in the Sulphur River Basin:[75]

$$\text{Area} = 0.8136 * (\text{Storage})^{0.7505}$$

Reservoir surface areas produced by the two equations differ by about 0.6 percent at a storage of 5,000 acft. This percentage difference increases at smaller storages, to about 9.3 percent for a 100 acft reservoir. These relationships were not adjusted to year 2000 sedimentation conditions for Run 8.

3.5 Aquifer Recharge

3.5.1 Historical Recharge

The WRAP Model has been modified to estimate recharge into the Edwards Aquifer for the five major recharge basins within the Guadalupe and San Antonio River Basins. The methodology implemented in the WRAP Model is virtually identical to that which was used and accepted in previous studies of the Guadalupe-San Antonio River Basin.[76] Estimates of recharge to the Edwards Aquifer for the five major recharge basins in the Guadalupe-San Antonio River

[73] USBR, "Revision of the Procedure to Compute Sediment Distribution in Large Reservoirs," Sedimentation Section, Hydrology Branch, U.S. Dept. of the Interior, May 1962.
[74] Wurbs, R.A., et al., "Hydrologic and Institutional Water Availability in the Brazos River Basin," TR-144, Texas Water Resources Institute, Texas A&M University, August 1988.
[75] R.J. Brandes Company, "Water Availability Modeling for the Sulphur River Basin, Draft Report," January 1999.

Basin were calculated for the 56-year period from 1934 through 1989. The boundaries of the five recharge basins are shown in Figure 3-6. These recharge basin boundaries are the same as those utilized by the USGS in recharge computations prepared annually in cooperation with the EAA (formerly EUWD). Drainage areas and corresponding percentages of the total drainage area included in each recharge basin are summarized in Table 3-7. Gaged areas total about 2,838 square miles above and within the recharge zone, and partially gaged and ungaged areas total about 554 square miles. Procedures applied in the calculation of recharge in gaged and partially gaged and ungaged areas are detailed in the following sections.

3.5.1.1 Recharge in Gaged Areas

In the Guadalupe-San Antonio River Basin, there are three streams that recharge the Edwards Aquifer that are gaged both upstream and immediately downstream of the recharge

Table 3-7.
Recharge Basin Drainage Areas

Recharge Basin[1]	***Drainage Area (sq. mi.)***	***Percent of Total***
Medina River (5)	634	18%
Area between Medina River and Cibolo Creek (6)	330	10%
Cibolo Creek and Dry Comal Creek (7)	404	12%
Guadalupe River (8)	1,518	45%
Blanco River and Upper San Marcos River (9)	506	15%
Total	3,392	100%

[1] Recharge Basins 1 through 4 are located in the Nueces River Basin (Refs. 39 and 45).

zone. As shown in Figure 3-6, these streams are the Blanco River, Cibolo Creek, and the Guadalupe River.

Historical recharge in gaged areas was calculated on a monthly timestep in accordance with the following equation:

$$R_k = Qreg_{us} + QI - [Qreg_k + Qwr] \qquad \textbf{(3-6)}$$

[76] HDR and EH&A, "Recharge Enhancement Study Guadalupe-San Antonio River Basin," Volume II-Technical Report, EUWD, September 1993.

where: R_k = ***Recharge above control point k;***

$Qreg_{us}$ = ***Summation of regulated flow at upstream boundary of recharge zone;***

QI = ***Potential runoff over recharge zone;***

$Qreg_k$ = ***Regulated flow at control point k; and***

Qwr = ***Summation of streamflow depletions made by water rights over recharge zone located upstream of control point k.***

Potential runoff is the most difficult parameter to quantify in the above equation because it cannot be measured directly and must be estimated from available data, such as gaged streamflow, precipitation, and watershed characteristics. In the calculation of recharge, potential runoff may also be called intervening runoff, as it represents the volume of runoff that would have arrived at the downstream gage if the intervening area were not over the recharge zone.

The method employed to estimate potential runoff for the intervening area is a variation of the SCS runoff curve number procedure[77,78] developed by HDR for the calculation of recharge in the Nueces River Basin. This procedure takes into account differences in soil-cover complex, as well as differences in precipitation between upstream or partner gaged areas and intervening areas. Partner gaged areas are areas from adjacent or nearby basins with similar runoff characteristics.

The first step in the application of the modified SCS runoff curve number procedure is the selection of a runoff curve number (CN) for each major soil-cover complex in a watershed. The curve numbers are then weighted by area to arrive at a composite average CN for each watershed. Under the SCS procedure, the curve number also varies with antecedent moisture conditions (AMC). The curve number increases with wet antecedent moisture conditions and decreases with dry conditions. The higher the curve number, the more runoff is produced for a given rainfall amount.

In calculating potential runoff for the intervening areas, an average curve number is calculated for all gaged and ungaged watersheds using the SCS soils reports. The CN is adjusted each month based on antecedent moisture conditions as reflected in the corresponding upstream gage flow. This calculation is based on the relationship of monthly rainfall and precipitation excess expressed in inches of runoff for the upstream drainage area. In those instances when

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[77] Soil Conservation Service (SCS), "Engineering-Hydrology Memorandum TX-1 (Rev. 1) (Supplement 3," U.S. Dept. of Agriculture, May 5, 1978.
[78] SCS, "Section 4, Hydrology, SCS National Engineering Handbook," USDA, 1972.

more runoff than rainfall occurred as a result of storms occurring near the end of the previous month or high base flow conditions, a CN based on average antecedent moisture conditions is used for the intervening area.

After the curve number for the intervening area is adjusted to reflect antecedent moisture conditions for a given month, runoff is calculated based on applying the curve number to the monthly rainfall for the intervening area. Using this modified SCS procedure automatically adjusts for differences in precipitation and soil cover complex between the upstream and intervening drainage areas.

3.5.1.2 Blanco River Basin

Recharge in the Blanco River Basin was computed utilizing the streamflow gaging stations located upstream of the recharge zone near Wimberley (ID# 1710) and downstream of the recharge zone near Kyle (ID# 1713). The upstream gaging station was in service for the entire 1934 to 1989 period, while the downstream gaging station was in service only during the 1956 to 1989 period. Streamflow at the downstream gaging station prior to 1956 was estimated by standard multiple linear regression techniques utilizing the upstream gaged flow and the estimated intervening runoff. Estimates of potential runoff for the 57 square mile intervening area over the recharge zone were made using the Blanco River watershed above Wimberley as a partner area.

3.5.1.3 Cibolo Creek Basin

Recharge in the Cibolo Creek Basin was computed utilizing the streamflow gaging stations located upstream of the recharge zone near Boerne (ID# 1839) and downstream of the recharge zone near Selma (ID# 1850). The upstream gaging station was in service for the 1962 to 1989 period and the downstream gaging station was in service for the 1946 to 1989 period. Streamflow at the upstream gaging station for the period prior to 1962 was estimated using relationships based on the intervening runoff for the Guadalupe River at Spring Branch (ID# 1765) and streamflow as measured on the Medina River near Pipe Creek (ID# 1790). Streamflow data at the downstream gaging station for the period prior to 1946 was estimated using estimated upstream gaged flow (ID# 1839) and potential runoff for the Cibolo Creek intervening area. Estimates of potential runoff for the 205.6 square mile intervening area over the recharge zone were made using the Cibolo Creek watershed above Boerne as a partner area.

Accuracy of recharge estimates prior to 1962 may be limited by the accuracy of estimated flows at the upstream and downstream gaging stations. The large difference in drainage area between the upstream partner area (68.4 square miles) and the intervening area over the recharge zone (205.6 square miles) may also affect the accuracy of recharge estimates for the Cibolo Creek Basin.

3.5.1.4 Guadalupe River Basin

Recharge in the Guadalupe River Basin was computed using the streamflow gaging stations located upstream of the recharge zone near Sattler (ID# 1678) and downstream of the recharge zone at New Braunfels (ID# 1685). Streamflow records are available for the downstream gaging station for the 1934 to 1989 period; however, records for the upstream gaging station exist only for the 1962 to 1989 period. Streamflow at the upstream gaging station prior to 1962 was estimated using a relationship with the Guadalupe River at Spring Branch (ID# 1675) and the intervening runoff between the Spring Branch and Sattler gages (Table 3-4). Intervening runoff estimates for the area over the recharge zone between the Sattler and New Braunfels gaging stations were developed utilizing the Blanco River watershed above Wimberley (ID# 1710) as a partner area.

In addition to upstream and downstream gaged flows and potential intervening runoff, there is an exchange of water or flux between the Edwards Aquifer and the Guadalupe River occurring in this reach which affects the calculation of recharge. Initially, it was theorized that Hueco Springs was the primary component of this flux, but literature review[79,80] and preliminary regression analyses using periodic discharge measurements indicate that flows from Hueco Springs are probably influenced by a combination of local recharge, regional Edwards Aquifer levels, and possible underflow from the Guadalupe River.

In order to obtain an estimate of historical and/or simulated recharge occurring in this reach, it was necessary to isolate the steady component of flux driven by regional Edwards Aquifer levels from the transient components associated with local recharge and underflow from the Guadalupe River. It is expected that the regional Edwards Aquifer level flux component would be affected by changes from historical pumpage rates to a greater degree than would the

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[79] Brune, Gunnar, "Springs of Texas," Volume 1, Branch-Smith, Inc., Fort Worth, Texas, 1981.
[80] TDWR, "Geohydrology of Comal, San Marcos, and Hueco Springs," Report 234, William F. Guyton & Associates, June 1979.

transient, local components. Hence, estimates of Edwards Aquifer flux in this reach of the Guadalupe River were developed by subtracting downstream flow from upstream flow during each of the 94 months when intervening runoff was insignificant and flows in the previous month were below average. These estimates of flux were then correlated to the corresponding monthly average well level at the Bexar County Monitoring Well (J-17), resulting in a linear relationship of flux as a function of well level. A linear relationship was assumed based on similar linear relationships found for San Antonio, San Pedro, and Comal springflow as a function of J-17 level. The resulting relationship is expressed as:

$$Q_E = 36.31(H_{J\text{-}17}) - 23{,}486 \qquad \textbf{(3-7)}$$

where: Q_E = ***Edwards Aquifer flux (acft/month); and***
$H_{J\text{-}17}$ = ***Average monthly J-17 well level (ft-msl).***

Statistical significance of the regression equation and coefficients was confirmed by F and t tests,[81] respectively. The coefficient of determination (r^2), however, was 0.16, which indicates that only 16 percent of the variation in flux is explained by the regression equation.

Streamflow surveys performed by the USGS[82,83] for the reach between the Sattler and New Braunfels gaging stations were completed during January 1955 and March 1962. The average monthly J-17 well levels for these two periods were 637.8 feet-mean sea level (ft-msl) and 671.7 ft-msl, respectively. The January 1955 streamflow survey showed a net loss of about 120 acft/month (2 cubic feet per second, or cfs) in the reach, while the March 1962 streamflow survey showed a net gain of 1,200 acft/month (20 cfs). These two surveys, in general, appear to support the derived relationship of J-17 well level versus Edwards Aquifer flux. The regression equation indicates that this segment of the Guadalupe River changes from a gaining to a losing reach, with respect to water in the Edwards Aquifer when the J-17 well level falls below about 647 ft-msl.

Using the derived relationship, Edwards Aquifer flux was computed for each month during the 1934 to 1989 period based on average monthly J-17 well levels. Recharge for the Guadalupe River Basin was then calculated using the following equation:

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[81] Haan, C.T., "Statistical Methods in Hydrology," Iowa State University Press, 1977.
[82] USGS, "Base Flow Studies, Guadalupe River, Comal County, Texas," Bulletin 6503, Texas Water Commission, March 1965.
[83] USGS, "Guadalupe and Blanco Rivers, Texas, Seepage Investigations, 1955," GSA file Report 52, Texas State Board of Water Engineers, October 1955.

$$R_{CP04} = QG_{1677} + QI - (QNH_{1685} - Q_E) \quad \textbf{(3-8)}$$

where: R_{CP04} = ***Recharge for Guadalupe River Basin;***

QG_{1677} = ***Upstream gaged flow for Guadalupe River at Sattler (ID# 1678);***

QI = ***Potential intervening runoff for area between Sattler (ID# 1678) and New Braunfels (ID# 1685);***

QNH_{1685} = ***Downstream flow for Guadalupe River at New Braunfels (ID# 1685) adjusted for intervening diversions and return flows; and***

Q_E = ***Edwards Aquifer flux ($Q_E \geq 0$).***

Accuracy of the Edwards Aquifer flux and recharge estimates for the Guadalupe River Basin may be somewhat limited by the accuracy of the flow estimates at Sattler during dry periods prior to 1962.

3.5.1.5 Recharge in Partially Gaged and Ungaged Basins

Partially gaged and ungaged areas that contribute to Edwards Aquifer recharge in the Guadalupe-San Antonio River Basin include portions of the Dry Comal, Salado, Olmos, Leon, Helotes, Government, San Geronimo, Sink, Purgatory, York, and Alligator Creek watersheds. The last four of these areas are referenced herein as the Upper San Marcos River. All of these areas are headwater watersheds which lie primarily on the Edwards Aquifer recharge zone and have no gages located upstream of the recharge zone. Dry Comal and Salado Creeks are gaged at locations just below the downstream limits of the recharge zone, Helotes Creek has been gaged within the recharge zone in recent years, and the remaining watersheds listed above are ungaged in or near the recharge zone. Without upstream gage records, the calculation of recharge is highly dependent on estimates of potential runoff, which reflect the soil types, slopes, and land use characteristics of each area. Hence, potential runoff in each of these areas was computed using the modified SCS procedure described in Section 3.5.1, which includes monthly calibration to an adjacent gaged watershed. Calculation of recharge in each of these partially gaged and ungaged watersheds is described in the following subsections.

3.5.1.6 Dry Comal Creek Basin

The Dry Comal Creek Basin is an area of about 130 square miles upstream of the USGS streamflow gaging station on the Comal River at New Braunfels (ID# 1690), the majority of which is located on the Edwards Aquifer recharge zone. Published records for this gaging station include the discharge of Comal Springs; however, the USGS has performed hydrograph separations on a daily basis throughout the entire 1934 to 1989 study period to obtain estimates of surface runoff exclusive of springflow and provided these estimates to HDR. The surface runoff estimates were then adjusted by HDR to account for reported historical diversions and return flows. Potential runoff for the Dry Comal Creek Basin was estimated using the Blanco River watershed above Wimberley (ID# 1710) as a partner area and historical recharge was calculated in accordance with the following equation:

$$R_{CP05} = QI_{CP05} - QNH_{CP05} \qquad \textbf{(3-9)}$$

where: R_{CP05} = ***Recharge for Dry Comal Creek Basin;***
QI_{CP05} = ***Potential runoff for Dry Comal Creek Basin; and***
QNH_{CP05} = ***Surface runoff for Comal River at New Braunfels (ID# 1690) adjusted for upstream diversions and return flows.***

There are a total of five SCS flood-retarding structures (FRS) located in the Dry Comal Creek Basin controlling runoff from 57.4 percent of the watershed with aggregate normal pool capacity of 709 acft and active pool capacity of 18,265 acft. SCS records indicate that these SCS/FRS were completed between June 1956 and April 1981. Clearly, the SCS/FRS have the effect of enhancing recharge through both direct percolation and steady release of impounded waters while performing their primary flood control function. The Dry Comal Creek Basin is the primary source of gaged surface runoff data for watersheds located directly over the Edwards Aquifer recharge zone in the Guadalupe-San Antonio River Basin and is an important partner area. For this reason, it was necessary to remove the SCS/FRS effects from the gaged data and obtain estimates of natural recharge that could be used to estimate recharge in ungaged basins. Furthermore, it was necessary to simulate the effects of these structures as if they were in place throughout the study period in order to obtain recharge and streamflow baselines for the consideration of potential recharge enhancement projects.

In order to assess the recharge characteristics of the SCS/FRS, it was postulated that historical recharge (R) is comprised of natural recharge (R_N) and additional components associated with the normal pool (R_{NP}) and active pool (R_{AP}), as defined in the following equations (in which, for clarity, the control point ID# 1690 is not shown):

$$R = R_N + R_{NP} + R_{AP} \quad (3\text{-}10)$$

$$R_{NP} = c_{NP}(A_c/A)(QI - R_N) \leq c_{NP}\ (NP) \quad (3\text{-}11)$$

$$R_{AP} = c_{AP}[(A_c/A)(QI - R_N) - R_{NP}] \leq c_{AP}\ (AP) \quad (3\text{-}12)$$

where:

R = *Historical recharge;*
R_N = *Natural recharge;*
R_{NP} = *SCS/FRS normal pool recharge;*
R_{AP} = *SCS/FRS active pool recharge;*
QI = *Potential runoff;*
A_c = *Watershed area controlled;*
A = *Total watershed area;*
c_{NP} = *Normal pool recharge coefficient;*
c_{AP} = *Active pool recharge coefficient;*
NP = *Aggregate normal pool storage; and*
AP = *Aggregate active pool storage.*

Assuming that potential runoff, historical recharge, area controlled, and SCS/FRS physical characteristics were known for the 1956 to 1989 period, reasonable estimates for natural recharge and the recharge coefficients were sought in the following manner. First, an approximation of natural monthly recharge for the 1956 to 1989 period was obtained from a linear regression relationship between natural and potential runoff based on available data prior to SCS/FRS construction. The normal pool recharge coefficient was assumed equal to 1.0, which implies that 100 percent of water impounded within the normal pools of the SCS/FRS will contribute to recharge neglecting evaporation. Historical monthly recharge was then computed based on the postulated equations using various assumed values for the active pool recharge coefficient. An assumed active pool recharge coefficient of 0.70 resulted in the least error in estimating historical recharge during the 1981 to 1989 period when all structures were in place. This result indicates that approximately 70 percent of the runoff temporarily impounded by the SCS/FRS ultimately contributes to recharge neglecting evaporation. For that reason, normal and active pool recharge coefficients of 1.00 and 0.70, respectively, were adopted for the Dry Comal Creek

Basin SCS/FRS, and consistent monthly estimates of natural recharge and runoff were computed using Equations 3-3 through 3-6.

3.5.1.7 Salado Creek Basin

The Salado Creek Basin is an area of about 137 square miles upstream of the USGS streamflow gaging station on Salado Creek (Upper Station) at San Antonio (ID# 1787) the majority of which is located on the Edwards Aquifer recharge zone. Available gaged streamflows for the 1960 to 1989 period were adjusted for reported upstream diversions and return flows and potential runoff was estimated using the Blanco River watershed above Wimberley (ID# 1710) as a partner area. The curve number used in the estimation of potential runoff for the Salado Creek was increased with respect to time to reflect the gradual urbanization of the watershed. Historical recharge for the 1960 to 1989 period was computed in accordance with the following equation:

$$R_{CP19} = QI_{CP19} - QNH_{CP19} \qquad (3\text{-}13)$$

where: R_{CP19} = ***Recharge for Salado Creek Basin;***
QI_{CP19} = ***Potential runoff for Salado Creek Basin; and***
QNH_{CP19} = ***Surface runoff for Salado Creek at San Antonio (ID# 1787) adjusted for upstream diversions and return flows.***

Historical recharge for the 1934 to 1959 period when gaged streamflow records on Salado Creek are unavailable was computed using the following equation:

$$R_{CP19} = QI_{CP19}\,(RN_{CP05}/QI_{CP05}) \qquad (3\text{-}14)$$

where: RN_{CP05} = ***Natural recharge for Dry Comal Creek Basin; and***
QI_{CP05} = ***Potential runoff for Dry Comal Creek Basin.***

As of 1999, there are a total of 13 SCS/FRS located in the Salado Creek Basin controlling runoff from 62.2 percent of the watershed with aggregate normal pool capacity of 1,906 acft and active pool capacity of 30,701 acft. These structures have the effect of enhancing recharge through both direct percolation and steady release of impounded waters while performing their primary flood control function. For reasons identical to those stated with respect to Dry Comal Creek (Section 3.5.1.6), it was necessary to quantify and remove the SCS/FRS effects and obtain monthly estimates of natural streamflow and recharge. Employing the methodology described for the Dry Comal Creek Basin, an active pool coefficient of 0.70 and a normal pool coefficient of 1.00 were adopted for the Salado Creek Basin SCS/FRS.

3.5.1.8 Upper San Marcos River Basin

The Upper San Marcos River recharge basin includes Sink and Purgatory Creeks, which feed the headwaters of the San Marcos River near San Marcos Springs, as well as the portion of York and Alligator Creek watersheds over the recharge zone. No gaged streamflow data has been published for the basin, therefore, natural recharge that occurred in this basin was estimated using the relationship of natural recharge to potential runoff in the nearby Dry Comal Creek Basin. Potential runoff estimates for the Upper San Marcos River Basin were developed by application of modified SCS procedures using the Blanco River watershed above Wimberley (ID# 1710) as a partner area. Natural recharge in the Upper San Marcos River Basin was computed using the following equation:

$$R_{N1700} = QI_{1700}\left(\frac{R_{N\,CP05}}{QI_{CP05}}\right) \qquad \textbf{(3-15)}$$

where: $R_{N\,1700}$ = ***Natural recharge for Upper San Marcos River Basin;***
QI_{1700} = ***Potential runoff for Upper San Marcos River Basin;***
$R_{N\,CP05}$ = ***Natural recharge for Dry Comal Creek Basin; and***
QI_{CP05} = ***Potential runoff for Dry Comal Creek Basin.***

Using natural recharge and potential runoff for the Upper San Marcos Basin, drainage ratios were applied to calculate natural recharge and potential runoff for Sink, Purgatory, and York Creeks.

Seven SCS/FRS have been constructed on Sink, Purgatory, and York Creeks on the recharge zone, which provide a total of 1,158 acft of normal pool storage and 21,530 acft of active pool storage. Historical recharge enhancement due to SCS/FRS in the Upper San Marcos River Basin was estimated by application of techniques developed for assessment of SCS/FRS in the Dry Comal and Salado Creek watersheds. Normal and active pool coefficients of 1.00 and 0.70, respectively, were used. Natural recharge was combined with estimated recharge enhancement due to the SCS/FRS to obtain the total historical recharge for Sink, Purgatory, and York Creeks.

3.5.1.9 Leon, Helotes, Government, and San Geronimo Creeks

Recharge estimates for the portions of the Leon, Helotes, Government, and San Geronimo Creek watersheds upstream of and over the recharge zone were developed for the 1934 to 1989 period. These watersheds were ungaged during the study period, with the exception of Helotes Creek which was gaged (ID# 1814) during the 1968 to 1989 period. Recharge estimates were developed by considering the basins as a group and included the intervening area over the recharge zone between Medina Lake and Diversion Lake and the subwatersheds over the recharge zone adjacent to the Diversion Lake watershed. The combined area totals 193 square miles, of which 106 square miles is upstream of the recharge zone and 87 square miles is on the recharge zone. Composite curve numbers were computed for the areas upstream of and on the recharge zone and monthly potential runoff estimates were developed for both of these areas using the Cibolo Creek watershed near Boerne (ID# 1839) as a partner area.

For the area on the recharge zone, recharge was computed using the ratio of natural recharge to potential runoff for the Salado Creek Basin expressed as follows:

$$R_{NZ} = QI_Z \left(\frac{R_{N\ CP19}}{QI_{CP19}} \right) \tag{3-16}$$

where: R_{NZ} = ***Natural recharge for area on recharge zone;***
QI_Z = ***Potential runoff for area on recharge zone;***
$R_{N\ CP19}$ = ***Natural recharge for Salado Creek Basin; and***
QI_{CP19} = ***Potential runoff for Salado Creek Basin.***

For the area upstream of the recharge zone, recharge during the 1968 to 1989 period was computed utilizing measured data from the Helotes Creek gaging station (ID# 1814). The Helotes Creek gaging station measures runoff from an area that is predominantly upstream of the recharge zone, but overlies the recharge zone in the vicinity of the gage. Using the Cibolo Creek watershed near Boerne (ID# 1839) as a partner area, monthly potential runoff estimates were developed for the Helotes Creek watershed. Recharge for the Helotes Creek Basin was computed as the difference between potential and measured runoff at the gaging station. The monthly ratio of recharge to potential runoff for the Helotes Creek Basin was then used to compute recharge for the entire 106 square mile area upstream of the recharge zone in accordance with the following equation:

$$R_U = QI_U \left(\frac{R_{1814}}{QI_{1814}} \right) \tag{3-17}$$

where: R_U = ***Recharge for area upstream of recharge zone;***
QI_U = ***Potential runoff for area upstream of recharge zone;***
R_{1814} = ***Recharge for Helotes Creek Basin; and***
QI_{1814} = ***Potential runoff for Helotes Creek Basin.***

For the period prior to 1968, when the Helotes Creek gaging station was not in service, recharge estimates for the area upstream of the recharge zone were based on respective averages developed for the Helotes and Salado Creek Basins. For the 1968 to 1989 period, recharge in the Helotes Creek Basin averaged about 61 percent of potential runoff while natural recharge averaged about 85 percent of potential runoff in the adjacent Salado Creek Basin. Therefore, the ratio of recharge to potential runoff for the area upstream of the recharge zone (including the Helotes Creek Basin) averaged about 71 percent (61/85) of that for the Salado Creek Basin. This percentage was used to compute monthly recharge estimates for the area upstream of the recharge zone for the 1934 to 1967 period based on natural recharge and potential runoff in the adjacent Salado Creek Basin in accordance with the following equation:

$$R_U = 0.71 QI_U \left(\frac{R_{N\ CP19}}{QI_{CP19}} \right) \tag{3-18}$$

where: R_U = ***Recharge for area upstream of recharge zone;***
QI_U = ***Potential runoff for area upstream of recharge zone;***
$R_{N\ 1787}$ = ***Natural recharge for Salado Creek Basin; and***
QI_{1787} = ***Potential runoff for Salado Creek Basin.***

San Geronimo Creek Dam was constructed at the downstream edge of the recharge zone by the EUWD for the purpose of enhancing recharge to the Edwards Aquifer. Incremental recharge provided by this structure was obtained from TWC monthly water use reports prepared by the EUWD and added to the recharge estimates computed for the areas upstream of and on the recharge zone.

3.5.2 Enhanced Recharge

Edwards Aquifer recharge, in addition to the estimates of natural recharge, occurs at Medina and Diversion Lakes, the San Geronimo Creek Recharge structure, and the SCS/FRS. Section 3.5.1 explains the estimation of additional recharge at the SCS/FRS. The following sections detail the recharge estimates at Medina Lake, Diversion Lake, and the San Geronimo Creek structure.

3.5.2.1 Medina and Diversion Lakes

Estimation of monthly Edwards Aquifer recharge occurring at Medina and Diversion Lakes (Medina Lake System) is very different from the procedures used in other watersheds as it is based on relationships with reservoir stages. The Medina Lake System has been in place throughout the 1934 to 1989 study period and has been operated primarily to supply water for irrigation through a distribution canal beginning at Diversion Lake. In addition to diversions for water supply and net evaporation losses, storage in these reservoirs is affected by percolation into the Edwards Aquifer or recharge, as well as leakage through the dams. It is assumed that reasonable estimates of recharge, leakage, and net evaporation could be based on the elevation or water surface area associated with the average reservoir storage in each month.

Key records used in the calculation of historical recharge include Medina Lake storage (1913 to 1989) and gaged flows for the Medina River at Riomedina (ID# 1805) (1953 to 1973) and for the Medina Canal (1922 to 1935 and 1957 to 1989). Additional diversion records for the Medina Canal were obtained from an EH&A report[84] for the 1940 to 1956 period and estimated by HDR for the 1935 to 1939 period. Elevation-area-capacity tables for Medina and Diversion Lakes were obtained from published reports.[85,86]

Calculation of historical monthly recharge at Medina Lake and leakage at Medina Dam was accomplished using the reservoir stage associated with average monthly storage and recharge and leakage curves developed by EH&A.[87] Historical recharge at Diversion Lake, however, was somewhat more difficult to calculate in the absence of storage records. When gaged streamflow records were available for the Medina River at Riomedina (ID# 1805), they

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[84] EH&A, "Medina Lake Hydrology Study," EUWD, March 1989.
[85] TDWR, "Phase I Inspection Report, National Dam Safety Program, Medina Diversion Dam, Medina County, Texas," January 31, 1979.
[86] USBR, "Storage and Irrigation Facilities, Technical Report," BMA, August 1992.
[87] EH&A, Op. Cit., March 1989.

were assumed equal to the sum of leakage and spills from Diversion Lake. During these periods, average monthly lake level was estimated from the EH&A leakage curve, and recharge was calculated from the EH&A recharge curve using the average lake level. When gaged streamflows were not available below Diversion Dam, average monthly lake level was estimated by iterative mass balance calculations considering runoff below Medina Dam, leakage and releases from Medina Lake, Medina Canal diversions, and net evaporation losses. Releases from Medina to Diversion Lake were based on the operational objective of maintaining Diversion Lake at a level about 5 feet below the spillway during irrigation season to minimize losses and maintain diversion efficiency.

Average annual recharge at Medina and Diversion Lakes for the 1934 to 1989 period was 41,833 acft, which represents 6.5 percent of the total average annual recharge of the Edwards Aquifer. Approximately 64 percent of the historical average recharge is attributable to Medina Lake. The minimum annual recharge estimate was 10,256 acft in 1951 and the maximum annual recharge estimate was 53,275 acft in 1936.

3.5.2.2 Permitted Recharge Structures

Recharge structures with permitted water rights are modeled in WRAP such that they cannot recharge more the their annual permitted amounts. Therefore, the projects will recharge all available water until their annual limits are reached, and thereafter pass flows that, in reality, would have recharged. This causes the recharge at the projects to be underestimated in the later months of some years. The San Geronimo Creek project is owned by the EAA and is the only recharge structure in the Guadalupe-San Antonio Basins with a permitted water right. The right includes a 200-acft authorized impoundment and a maximum annual use of 961 acft.

3.5.2.3 SCS Flood Retarding Structures

Enhanced recharge due to the SCS/FRS is based on the aggregated normal pool and active pool volumes associated with the structures in each recharge area, as explained in Sections 2.5.1.6, 3.5.1.7, and 3.5.1.8. The 25 SCS/FRS structures in the Guadalupe-San Antonio River Basin that enhance Edwards Aquifer recharge (in addition to performance of their flood control function) are located in the Dry Comal and Salado Creek basins and in the upper San Marcos River watershed. Estimated recharge enhancement attributable to these structures is expected to average about 12,700 acft/yr.

Section 4
Water Availability Model of the Guadalupe-San Antonio River Basin

4.1 Description of the WRAP Model

The Texas A&M University Water Rights Analysis Program (TAMUWRAP) was developed and initially documented in 1988[88] as a single simulation program written in the Fortran programming language. The initial application of the model to the Brazos River Basin was documented by Wurbs, et al.,[89] and by Walls.[90] In 1993, numerous enhancements were added to the simulation model, resulting in two simulation programs, WRAP2 and WRAP3. WRAP2 included essentially the same capabilities of the original TAMUWRAP, but with enhanced input and output capabilities. WRAP3 included several additional capabilities focused on multiple-reservoir system operations. A post-processor program, TABLES, was included in the package to provide summary output and statistics. Development of the 1993 version of the model is documented by Wurbs and Dunn[91] and by Dunn.[92]

In August 1998, the TNRCC contracted with Texas A&M University to add several additional capabilities to the WRAP model pursuant to the requirements of the Water Availability Modeling (WAM) project authorized by SB1 in the 75th Legislature. The December 1999 version of the package (WRAP) includes the simulation program, WRAP-SIM, which is an enhanced version of WRAP3; the post-processor program, TABLES; and an input processor used to facilitate development of hydrologic input, WRAP-HYD. The December 1999 version of WRAP is documented in a user's manual.[93] All of these programs are written in the FORTRAN programming language. This package of programs comprises the WRAP Model. For clarity, the package of programs will be referred to simply as WRAP.

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[88] Walls, W.B. and Wurbs, R.A., "Water Rights Analysis Program (TAMUWRAP), Program Description and Users Manual," TR-146, Texas Water Resources Institute, Texas A&M University, 1988.
[89] Wurbs, R.A., et al., "Hydrologic and Institutional Water Availability in the Brazos River Basin," TR-144, Texas Water Resources Institute, Texas A&M University, August 1988.
[90] Walls, W.B. "Application of a Water Rights Analysis Program to Reservoir System Yield Calculations," Master of Science Thesis, Texas A&M University, August 1988.
[91] Wurbs, R.A. and Dunn, D.D., "Water Rights Analysis Package (WRAP) Model Description and Users Manual," TR-146, Texas Water Resources Institute, Texas A&M University, October 1996.
[92] Dunn, D.D., "Incorporation of System Operation Strategies in Water Rights Modeling and Analysis," Master of Science Thesis, Texas A&M University, December 1993.

The fundamental purpose of WRAP is to determine the availability of water to individual rights or groups of rights under the Prior Appropriation Doctrine. Under the Prior Appropriation Doctrine, the right to divert water from a stream or reservoir is based on date of priority. Under a strict interpretation of the doctrine, a right cannot divert water and a reservoir cannot impound water until rights with senior priority are satisfied (i.e., "first in time, first in right"). WRAP makes the determination of availability to each right in priority order, on a monthly basis. In many instances, multiple rights and reservoirs may be owned by single entities. WRAP is designed to simulate the management of complex surface water resources, and determine water availability to rights within the constraints of the Prior Appropriation Doctrine.

4.1.1 Base WRAP Simulation Program

A WRAP simulation requires several input data files. Data within these files describe the locations of water rights (control points--CP records); inflows (naturalized flows, return flows, and gains/losses) and evaporation at those control points (IN, FD, WP, CI, SP, and EV records); information describing individual rights and groups of rights (date(s) of priority, permitted diversion amount, type of use, and reservoir storage--WR, WS, OR, SV, and SA records); and instream flow requirements (IF records).

During a WRAP simulation, data describing various model options and the data describing control points and water rights are read from an input file, sorted, and stored in various arrays. The model then begins a set of three nested loops: annual (outer), monthly (middle), and priority (inner). Within the annual loop, monthly naturalized flows at each primary control point are read from an input file, these flows are distributed to secondary control points using the flow distribution algorithms, and the monthly loop starts. Within the monthly loop, array values are initialized from previous months, the priority loop operates, and summary data for control points and reservoirs are written to the WRAP output file.

The bulk of the WRAP computations occur within the priority loop. Water availability computations begin with the first right listed in priority order. For each right in priority order, flows at the location of the right and at all downstream control points are checked, and the availability of water to that right is determined. The model then calculates the target "streamflow depletion" needed to satisfy the right. This target includes the monthly diversion

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[93] Wurbs, R.A., "Reference and Users Manual for the Water Rights Analysis Package (WRAP)," TR-180, Texas Water

requirement, and the amount needed to refill storage and meet evaporation if reservoir storage is associated with the right. The lesser of the available flow and the target streamflow depletion are removed at the water right location, and this change in flow is translated downstream and removed from other control points, accounting for channel losses where necessary. If the right has authorized storage, reservoir evaporation calculations are performed. Once calculations are complete for a right, data summarizing the right for that month are written to the WRAP output file and the next right in priority order is analyzed.

Rights with multiple types of use, dates of priority, or diversion locations may be represented as multiple "rights" in the WRAP simulation (i.e., different portions of a certificate of adjudication or permit can be represented as separate rights (WR, WS, and OR records) within the WRAP input file). These individual "rights" can then be summarized as a group by the TABLES program to show the availability of water to the overall water right.

Options in WRAP allow the target streamflow depletion to be met from multiple reservoirs, as defined by additional WS and OR records following a WR record. The user defines reservoir system operating rules that are used by WRAP to make release decisions to individual rights. The capability of WRAP to model different aspects of water rights individually and to specify reservoir system operations allows most water rights to be modeled accurately using the basic capabilities within WRAP.

The base WRAP simulation program used for this study is the December 1999 version, modified to correct known problems with the flow adjustment algorithm (*root*.FAD file option). These corrections will be included in future versions of the model[94].

4.1.2 Basin-Specific WRAP Model

Certain aspects of some rights, and certain water management and/or hydrologic complexities within some river basins, cannot be accurately simulated using the basic capabilities of WRAP. In these cases, the rights and hydrologic complexities must be modeled in an approximate fashion or code must be added to the base WRAP simulation program. Several such hydrologic and water management complexities in the Guadalupe-San Antonio River Basin required additional capabilities to be added to the base WRAP simulation program. These additional capabilities, referred to as "basin-specific modifications," are described

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Resources Institute, Texas A&M University, August 1999.

generally in the following sections, and more specifically in the WRAP User's Manual Addendum found in Appendix X (separately bound).

4.1.2.1 Canyon Reservoir, Certificate of Adjudication C2074

Operation of Canyon Reservoir, owned by the GBRA under certificate of adjudication C2074 (as amended), is governed by passage of inflows to meet downstream senior rights; releases or diversions from storage for contractual water supply obligations; and instream flow guidelines established by the Federal Energy Regulatory Commission (FERC). The base WRAP simulation program performs the calculations necessary for passage of inflows on a monthly basis to meet downstream senior rights including hydropower generation requirements. Inflows to Canyon Reservoir are quite variable, however, and in many months the majority of the reservoir inflow volume occurs during a storm event only a few days in duration. The FERC guidelines establish daily instream flow targets immediately below Canyon Dam, which cannot readily be converted to monthly volumes due to the highly variable nature of inflows to Canyon Reservoir. Similarly, the pass-through requirements for downstream hydropower generation are best determined on a daily basis for accurate water supply planning since the run-of-the-river facilities can only pass through their turbines daily flows less than about 1,300 cfs. Any flows in excess of about 1,300 cfs bypass the turbines and are not available for power generation.

Under the FERC guidelines, Canyon Reservoir is required to maintain instream flow minima of 100 cfs (June through January) and 120 cfs (February through May) during "non-drought" periods, to the extent inflows as measured at the USGS streamflow gage on the Guadalupe River near Spring Branch (CP02, gage reference number 1675) are available. In the event of 45 days of inflows less than 90 cfs, drought conditions apply and the instream flow requirement is limited to passage of inflows up to 90 cfs until the reservoir level exceeds 909.0 ft-msl.

The GBRA has traditionally operated Canyon Reservoir to honor senior downstream hydropower rights on a daily timestep by passing inflows sufficient to meet a specified flow rate (ranging from 0 cfs to 1,300 cfs) at Lake Dunlap. Lake Dunlap is the location of the most upstream hydropower facility having a priority date senior to Canyon Reservoir.

[94] Wurbs, R.A., telephone conversation, December 1999.

The capability to simulate daily operation of Canyon Reservoir to meet FERC instream flow guidelines and honor downstream senior hydropower rights required a basin-specific modification to the base WRAP simulation program. During the priority loop, when the Canyon Reservoir right is simulated in priority order, a basin-specific routine is utilized to perform a daily analysis of Canyon Reservoir inflows and releases. For each month in the simulation, daily gaged flows as measured at Spring Branch are read from a separate input file and used as a pattern to distribute the monthly inflow volumes for the Spring Branch control point (CP02) and the Canyon Reservoir inflow control point (CP03) to daily inflows. The daily flows computed for the Spring Branch control point are utilized to determine pass-through requirements under the FERC guidelines. For consistency regarding water rights, total inflows to Canyon Reservoir (CP03) are used to determine other pass-through requirements. The monthly volume passed to honor downstream senior rights is determined and distributed to a constant daily value. The monthly diversion targets for the downstream diversions associated with Canyon Reservoir are also distributed to a constant daily target.

For each day in the month, the FERC pass-through flow requirement is determined based upon the criteria described previously. Additional pass-through flows for hydroelectric power are determined so as to meet the user-defined daily hydropower target for the Lake Dunlap facility at control point CPDUN. A composite daily pass-through flow is then determined, comprised of that flow necessary to honor the downstream senior rights, meet the diversion target for the Canyon Reservoir diversion right, meet the FERC pass-through requirement, and honor the daily hydropower requirement at Lake Dunlap. The resulting daily flow targets are summed to a combined monthly total, and Canyon Reservoir is then operated on a monthly basis to pass the combined flow targets. The resulting streamflow depletions made by Canyon Reservoir to refill storage and meet the diversion portion of the Canyon Reservoir water right are computed, and the model simulation analyzes the remaining rights in the basin in priority order on a monthly basis.

The subroutine requires that the FERC instream flow requirement and the hydropower requirement be entered on IF records with zero annual values. The basin-specific modification sets these instream flow requirements on a month-by-month basis to ensure that upstream junior rights do not impair the ability of Canyon Reservoir to honor these FERC and hydropower requirements. All upstream rights junior to Canyon Reservoir are subject to those instream flow requirements. It is important to note that the hydropower target at Lake Dunlap acts as an additional pass-through requirement for Canyon Reservoir. Also note that downstream senior

Table 4-1.
Monthly Demand Distribution Patterns[1]

Segment	Use	January	February	March	April	May	June	July	August	September	October	November	December
1	MUN	6.3	6.3	7.2	8.1	8.7	9.6	12.1	12.3	8.9	7.2	7	6.3
	IND	6	7	8	9	8	9	10	10	10	8	7	8
	IRR	1.9	2.5	5.3	7.8	9.6	15.9	19.7	17.8	10.3	5.1	2.1	2
2	MUN	6.3	6.3	7.2	8.1	8.7	9.6	12.1	12.3	8.9	7.2	7	6.3
	IND	6	7	8	9	8	9	10	10	10	8	7	8
	IRR	3	3.5	7.1	8.6	9.9	13.9	15.4	14.7	8.8	6.8	4.4	3.9
3	MUN	6.4	5.7	6.8	7.6	8.5	10.2	12.4	12.5	8.9	7.8	6.6	6.6
	IND	6	7	8	9	8	9	10	10	10	8	7	8
	IRR	2.7	3.1	7	10.8	12	15.7	16.2	15.1	8	4	3.2	2.2
4	MUN	6.4	5.7	6.8	7.6	8.5	10.2	12.4	12.5	8.9	7.8	6.6	6.6
	IND	6	7	8	9	8	9	10	10	10	8	7	8
	IRR	2.8	3.9	8	10.8	14.3	16.6	13.8	11.7	8	4.3	3.5	2.3
5	MUN	8.4	7.3	7.4	7.9	7.8	9.1	9.7	9.2	8.4	8.6	7.9	8.3
	IND	6	7	8	9	8	9	10	10	10	8	7	8
	IRR	0	0.6	1.6	9.7	14	19.1	20.6	16.7	12.5	5	0.2	0
6	MUN	8.4	7.3	7.4	7.9	7.8	9.1	9.7	9.2	8.4	8.6	7.9	8.3
	IND	6	7	8	9	8	9	10	10	10	8	7	8
	IRR	0	0.6	1.6	9.7	14	19.1	20.6	16.7	12.5	5	0.2	0

[1] Values are monthly percentages of annual total.

hydropower rights should not be included as WR records with priority senior to Canyon Reservoir if they are already included an IF record as described above.

The portion of the basin-specific modification to WRAP regarding passage of daily flows to meet the hydroelectric target at Lake Dunlap was not utilized in this study. Rather, the senior hydropower rights are included in the model at their individual dates of priority as standard water rights with 100 percent return flow factors (zero percent consumptive use). The annual authorized diversions are distributed to monthly using a uniform demand distribution.

4.1.2.2 Medina Lake System, Certificate of Adjudication C2130

Operation of Medina and Diversion Lakes is complicated by significant recharge to the Edwards Aquifer through the reservoir bottoms, as well as significant leakage through the dams. Recharge from the Medina Lake System represents about 6.5 percent of the total average annual recharge to the Edwards Aquifer. This complication necessitated a basin-specific modification to the base WRAP simulation program in order to account for recharge and leakage from Medina and Diversion Lakes and conjunctive operation of the two reservoirs.

The recharge and leakage curves developed by Espey Huston and Associates,[95] with minor revisions for recent bathymetric and Diversion Lake leakage information obtained by the TWDB[96] and Blackwell,[97] respectively, were incorporated into a subroutine to perform operations of the Medina Lake System within the priority loop of WRAP. Except for a small diversion from Medina Lake for local municipal, domestic, and livestock use, water developed by the Medina Lake System is released from Medina Lake and diverted at Diversion Lake into the Medina Canal. In order to minimize leakage losses from Diversion Lake, the operations were coded so as to maintain a target water level in Diversion Lake about 5 feet below the spillway. The subroutine operates Medina and Diversion Lakes conjunctively to meet the diversion requirement into the Medina Canal. Inflows from tributaries (control point CP22) to Diversion Lake are included in the computations. Storage is maintained above the target level in Diversion Lake only if sufficient flows are available to maintain this storage level and refill storage

completely in Medina Lake. Recharge to the Edwards Aquifer computed by the subroutine is stored and included in the recharge estimates calculated for the overall Guadalupe-San Antonio River Basin (Section 4.1.2.5).

4.1.2.3 Special Conditions Associated with City of Victoria Permit P5466

Special Conditions stated in the permit held by the City of Victoria to divert water from the Guadalupe River for municipal and industrial uses cannot be modeled within the capabilities of the base WRAP simulation program. These Special Conditions specify monthly normal and

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95 Espey, Huston, and Associates (EH&A), "Medina Lake Hydrology Study," Edwards Underground Water District (EUWD), March 1989.

96 TWDB, "Volumetric Survey of Medina Lake and Diversion Lake," BMA, August 1996.

97 Blackwell & Associates, "Suggested Operational Criteria for Diversion Dam," Bexar-Medina-Atascosa Counties Water Control and Improvement District #1, March 1997.

low flow conditions, as measured at the Victoria streamgage (control point CP15), that limit diversions under the permit. When flows are greater than the normal flow value in a given month, the right is authorized to divert that amount in excess of the normal flow plus 10 percent of the remaining normal flow, not to exceed the authorized diversion rate of 150 cfs. When flows are below normal, but greater than the monthly low flow condition, up to 10 percent of the remaining flow at the diversion location may be diverted, limited to maintaining at least the low flow at the Victoria gage. When flows are below the low flow condition at the Victoria gage, no diversions are allowed. These special conditions necessitate a basin-specific modification to WRAP.

When permit P4566 is analyzed during the priority loop, a basin-specific subroutine is called to determine water available to the right under the provisions of these Special Conditions. Because diversions under this permit are contingent on flow remaining in the Guadalupe River at Victoria, the subroutine sets an instream flow requirement (IF record) at the Victoria gage (CP15) equal to the flow to which the Victoria gage can be further decreased without causing the Victoria diversion to violate the Special Conditions stated in the right. This ensures that junior rights analyzed later in the priority loop do not cause permit P5466 to violate the Special Conditions.

4.1.2.4 Make-up Diversions Associated with CPS's Certificate of Adjudication C2162 (Calaveras Lake)

Make-up diversions from the San Antonio River into Calaveras Lake are authorized under certificate of adjudication C2162. Special Conditions in the certificate state that only effluent discharge from the City of San Antonio wastewater treatment plants may be diverted into Calaveras Lake, and that a minimum 10 cfs instream flow remain in the San Antonio River after the diversion. An algorithm was added to the base WRAP simulation program to track return flows from user-specified locations (entered on CI records) to the diversion point on the San Antonio River, and limit the diversion into Calaveras Lake to those return flows, accounting for channel losses and senior upstream diversions between the discharge locations and the diversion point. Under direction from the TNRCC, these return flows are considered "state water," and the availability of return flows for diversion into Calaveras Lake is subject to upstream and downstream senior rights.

4.1.2.5 Edwards Aquifer Recharge

The WRAP simulation program has been modified to estimate recharge of the Edwards Aquifer in the Guadalupe-San Antonio River Basin. The methodology encoded is identical to that used and accepted in previous studies[98,99] of the Guadalupe-San Antonio River Basin and is described in detail in Section 3.5.

Estimated natural recharge is calculated at the end of the monthly loop and does not directly affect water availability because it is reflected in the natural streamflows throughout the basin. Enhanced recharge associated with the right for an existing recharge structure on San Geronimo Creek is included in the calculation of recharge. This recharge right is modeled as a Type 2 water right with a maximum annual diversion amount. Water right types are described fully in the WRAP User's Manual. The monthly streamflow depletions calculated for this recharge right in the priority loop are passed to the recharge routines and added to the natural recharge estimates for the appropriate control point. Recharge estimation is limited to the Edwards Aquifer in areas between the primary control points designated as recharge points in the basin-specific model input files.

4.2 Development of WRAP Water Rights Input File

4.2.1 Control Points

Data in the water rights input file include information concerning primary and secondary control points, their locational relationships, and channel losses between control points. Data sources for naturalized inflows and net evaporation at control points are also specified.

The TNRCC, through the University of Texas Center for Research in Water Resources (CRWR), provided a database of water right and other locations and watershed parameters in a geographic information system (GIS). Water right locations include diversion locations and the locations of on- and off-channel reservoirs. The locations were manually digitized by the TNRCC into the database from the water rights adjudication maps maintained by the TNRCC and assigned unique 11-digit identifiers. The identifiers take the form:

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[98] HDR Engineering, Inc. (HDR), “Guadalupe-San Antonio River Basin Recharge Enhancement Study,” Vols. I, II and III, EUWD, September 1993.

[99] HDR, Paul Price Associates, Inc., LBG-Guyton Associates, and Fugro-McClelland, Inc., “Trans-Texas Water Program, West Central Study Area Edwards Aquifer Recharge Analysis – Phase II,” San Antonio River Authority, et al., March 1998.

ABBCCCCCDDD

Where: 'A' denotes certificates of adjudication (6) and permits (1);

'BB' represents basin number (18 for the Guadalupe River Basin and 19 for the San Antonio River Basin);

'CCCCC' represents the 5-digit water right number (certificate of adjudication number or permit application number); and

'DDD' represents the type and sequence number of each location (001-099 denote diversion locations; 101-199 denote the downstream point for a diversion segment; 201-299 denote the upstream boundary of a diversion segment; 301-399 denote on-channel reservoir locations; 401-499 denote off-channel reservoir locations; and 501-599 denote return flow points; 601-699 denote the off-channel diversion point; and 901-999 denote other locations).

For each location, the TNRCC provided the drainage area and the length to the basin outlet. Each location provided by the TNRCC was utilized as a control point in the model. These locations are generally referred to as "secondary" control points.

The locations of control points for which naturalized flows have been developed were provided to the TNRCC by HDR and were included in the GIS database provided by the TNRCC. Control points for which naturalized flows have been developed are referred to as "primary" control points and are identified as CP01, CP02, etc.

Some adjustment of the watershed data provided by the TNRCC was necessary. In certain instances, the computational algorithms utilized by the CRWR fail to capture portions of the total drainage area above a control point. This is most likely due to the control point being located too far from the digital stream network. In severe cases, this causes the sum of the drainage areas of control points directly upstream of a given control point to exceed the drainage area of the control point. This situation was corrected for 11 secondary control points at various locations throughout the Guadalupe-San Antonio River Basin.

One additional control point (CP75) that was not included in the original lists of primary and secondary control points was added to the model. This control point was added in order to differentiate between springflow from San Marcos Springs and ungaged runoff occurring upstream in the Sink Creek watershed.

Naturalized flows at secondary control points were calculated using the flow distribution algorithms within WRAP. The naturalized flows developed for the primary control points were distributed to the secondary control points using, generally, INMETHOD6, which utilizes drainage area ratios and channel loss factors. The theoretical basis of this flow distribution method can be found in a technical memorandum prepared by HDR for the TNRCC.[100] Naturalized flows for control points downstream of CP38 (Guadalupe River near Tivoli) were set equal to the naturalized flows at Tivoli using INMETHOD2. The estuary control point, CPEST, was not used to distribute naturalized flow to these locations because it does not represent flows passing a discrete point. Data used to distribute naturalized flows from primary control points to secondary control points are included in the WRAP flow distribution file. This file is included in Appendix X (separately bound).

Channel losses (CL), as summarized in the form of delivery factors (DF=1-CL), have been developed for mainstem reaches between primary control points, as shown in Table 3-3. These delivery factors were distributed to the subreaches between the secondary control points, apportioned by stream length using the following equation:

$$CL_{subreach} = 1\text{-}DF^{\text{subreach length/reach length}}$$

Channel loss factors for subreaches on tributaries for which delivery factors are not known were assumed zero. HDR provided to the TNRCC the locations where 40 such tributary streams converge with streams with known channel losses (18 in the San Antonio River Basin and 22 in the Guadalupe River Basin). Secondary control points are located upstream of each confluence. Channel loss factors were distributed to these confluence locations along the channel mainstems to correctly account for channel losses downstream from the tributary confluences. These secondary control points were assigned identifiers beginning with "S9" or "G9", according to the river basin, followed by sequential numbers within each river basin (G901 to G922 in the Guadalupe River Basin and S901 to S918 in the San Antonio River Basin).

The control points utilized in the model are listed in Appendix II and are shown in Figure 3-5. Because WRAP allows a maximum of 6 characters to identify a control point, the 11-digit control point identifiers were reduced to 6 digits in the WRAP input files. Both sets of identifiers are shown in Appendix II.

[100] HDR, "Technical Memorandum: Distribution of Naturalized Streamflows from Gaged to Ungaged Control Points Accounting for Aquifer Recharge and Channel Losses," December 1998.

4.2.2 Monthly Demand Distribution Factors

In previous modeling efforts for the EUWD,[101] HDR developed seasonal patterns used to distribute annual permitted diversions to monthly demands. These demand distribution patterns were developed for municipal, industrial, and irrigation uses for six segments in the Guadalupe-San Antonio River Basin (Figure 2-1) using reported water use data from 1955 through 1989. These demand patterns were also used in the development of naturalized flows for years prior to 1955, when only annual totals of reported water use are generally available. Surface water use for recreation, mining, and hydroelectric power generation was assumed to occur uniformly throughout the year. The seasonal demand patterns for municipal, industrial, and irrigation uses are shown in Table 4-1.

4.2.3 Water Rights

Data contained in the TNRCC water rights master file database table, WRDETAIL, dated January 7, 1999, were used to develop water rights input for WRAP. The paper certificates of adjudication and permits, as amended, for all municipal rights with authorized annual diversions greater than 2,000 acft and all industrial and mining rights with authorized annual diversions greater than 200 acft were compared with the data in WRDETAIL. Discrepancies between the paper rights and WRDETAIL were noted and supplied to the TNRCC in a technical memorandum.[102] Where appropriate, corrections were made to the WRDETAIL file utilized by HDR. In addition, paper permits were reviewed for instream flow requirements and other special conditions. While not the purpose of these additional reviews, some additional discrepancies for smaller rights were noted and corrected in the WRDETAIL file utilized by HDR. Appendix I is a table listing all rights in the revised WRDETAIL utilized by HDR to develop the water rights input file.

One or more WR records depict water rights in the WRAP input file. Each WR record is treated by WRAP as a separate water right. Each portion of any right with multiple types of use, dates of priority, or diversion locations can be included in a WRAP input file as a separate WR record. The model includes the capability to identify groups of WR records that represent

[101] HDR, Op. Cit., September 1993.
[102] HDR and Crespo Consulting Services, Inc., "Technical Memorandum: Review and Summary of Water Right Records," February 1999.

individual water rights and summarize water availability to the overall water right based on analysis of the individual portions depicted on WR records.

The revised WRDETAIL was used to develop a base WRAP water rights input file from which input files for the simulations described in Section 5 were developed. This file is included as Appendix XI (bound separately) and includes all of the water right information utilized in the Guadalupe-San Antonio River Basin WRAP model, as well as the records used to specify control points (CP records), treated effluent discharges (CI records), demand distribution factors (UC records), reservoir storage-area tables (SV and SA records), and job control information records. Additional information not utilized by WRAP is included on each WR record in fields to the right of where the model reads input. This information includes the water right owner, stream, river order number, primary control point downstream of the water right location, and a field denoting term conditions (A or B) for the right. Some rights include term conditions for a portion of the right. These fields are not read or utilized by WRAP but provide useful reference information. Comment records that describe specific modeling assumptions were added at appropriate locations throughout the file. Data for each WR record in this file are shown in Appendix III.

Many rights include special conditions specifying instream flow requirements, and records that describe these conditions (IF records) are also included in Appendix XI. Each instream flow requirement identifier includes the water right number to which it applies. Many of these instream flow requirements vary monthly, so unique demand distribution patterns were developed for each and included on UC records in the WRAP input file. The base WRAP simulation program currently limits the number of unique UC records to 30. The additional unique demand distribution patterns for instream flow requirements necessitated increasing this limit to at least 60. In order to accommodate additional demand patterns, the parameter MAXUSES was set equal to 100 and the basin-specific WRAP simulation program was recompiled.

4.2.3.1 Priority Dates

The priority date for each water right in the WRAP input file was determined from the revised WRDETAIL. Priority dates are represented in the model in year-month-day format as YYYYMMDD.

4.2.3.2 Treatment of Reservoir Storage

The maximum volume of water that a right is allowed to impound is specified in the permit or Certification of Adjudication. This volume is specified in WRAP with a water right storage (WS) record immediately following the WR record. Several general cases of impoundment rights can be identified.

> *Case 1.* Most rights are authorized to impound water in, and divert from, a single reservoir with a single date of priority for both the impoundment and diversion portions of the right. In these cases, the right is modeled with a single pair of WR/WS records. This is the general case used for most impoundment rights. In cases where the impoundment and diversion have different dates of priority, the individual portions are modeled at their respective dates of priority with separate WR and/or pairs of WR/WS records.
>
> *Case 2.* Many rights are authorized for impoundment in one or more reservoirs, each with a specific date of priority for impoundment, and diversion amounts authorized specifically for each reservoir. In these cases, each individual reservoir is modeled with a separate pair of WR/WS records.
>
> *Case 3.* Several rights are authorized to impound in multiple reservoirs, with the authorized diversion taken from any of the reservoirs. In these cases, each reservoir is modeled with an impoundment-only right (no authorized diversion), and the authorized diversion is placed at the furthest downstream control point associated with the right. The reservoirs are then specified as a system and allowed to make releases to the diversion point using the system operation capability in WRAP.
>
> *Case 4.* Several rights are authorized to impound to different storage levels in a reservoir subject to different dates of priority, with the greater storage levels having later dates of priority. In these cases, the impoundment portion of the right is modeled with multiple pairs of WR/WS records with different priority dates.
>
> *Case 5.* Several rights are authorized to impound water in multiple reservoirs with small storage capacities in small channel dams, located closely in series on a stream. In these cases, the sum of the individual authorized impoundment volumes is modeled as a single reservoir.
>
> *Case 6.* The model treats storage as if all flows at the reservoir location are available for impoundment, subject to senior rights. However, several rights are authorized to divert water into off-channel storage reservoirs that have little or no drainage area. The rights are then allowed to subsequently divert from the reservoir for the authorized use. WRAP includes a capability specifically designed to accommodate off-channel reservoir impoundment rights by specifying an alternate control point (main channel) from which water is to be diverted into the off-channel reservoir and specifying the monthly and annual maximum diversion amounts. If no maximum rate of diversion from the main

channel is specified in the right, the off-channel reservoir is treated as an on-channel reservoir.

Case 7 (Basin-Specific Modifications). The basin-specific modifications described in Section 4.1 were added to augment the reservoir computational capabilities in WRAP.

4.2.3.3 Return Flows

With the exceptions of recreational and hydropower rights, and rights for which consumptive use is specified in the certificate of adjudication or permit, all return flows in the Guadalupe-San Antonio River Basin were modeled using 12 monthly values input on CI records. Recreational and hydropower rights were modeled with zero consumptive use, and all flows appropriated were returned to the next downstream control point. Annual consumptive use is specified for certificates of adjudication C1975, C1997, C3824, C3829, C3836, C3859, C3861, C3865, C3869, and C5485 and for permits P3895 and P4025. Constant return flow factors (variable RFAC on WR records) were developed for each of these rights using the authorized annual consumptive use and authorized annual diversion to develop constant return flow factors (RFAC = 1 - Consumptive Use/Authorized Diversion). These return flow factors are included on WR records associated with each right, shown in Appendix XI.

Historical reported effluent discharge data for 1993 to 1997 were obtained from the TNRCC though Parsons Engineering Science, Inc. Each point of discharge was placed at the nearest downstream control point for performance of the required simulation. Releases associated with the circulating flow of cooling water for steam-electric plants were not included. The monthly minimum discharges for each discharge point (PNUM) were computed and then summed at each respective control point. The resulting data included on CI records for a control point represent the sum of the monthly minimum discharges for all discharge points grouped at that control point.

The TNRCC requested that return flow factors be developed using water use and effluent discharge data for non-municipal rights where appropriate. Analysis of effluent discharge and water use data for the years 1993 to 1997 indicate that reliable return flow factors cannot be developed for any of the rights for which data are available. The effluent discharges for many of the industrial rights for which effluent discharge data could be identified were greater than the water use data reported in the Watermaster database, indicating that surface water diversions are supplemented with groundwater or balanced with off-channel storage facilities. For other rights, return flows as a function of diversions and effluent discharge were highly variable.

Runs 1, 2, and 3 address the sensitivity of water availability and regulated streamflows to three alternative reuse scenarios: current levels (Run 1), 50 percent reuse (Run 2), and 100 percent reuse (Run 3). Run 1 includes treated effluent discharges representative of current conditions. For Runs 2 and 3, these effluent discharges are reduced by 50 and 100 percent to reflect 50 and 100 percent reuse of current levels of treated effluent discharge. Significant quantities of the effluent (24,941 acft/yr) from the Leon and Salado plants operated by SAWS are slated for reuse under various contracts held by SAWS. This reuse project is expected to become operational this year (1999) and therefore is not reflected in the historical effluent discharge summaries. In order to accurately (and conservatively) quantify water availability, the quantities of treated effluent for which SAWS holds contracts were subtracted from the historical summaries so that the "current" levels of reuse upon which the three reuse scenarios are based reflect the SAWS reuse project.

Table 4-2 lists those wastewater discharges included on CI records and the corresponding control points at which they were placed. The discharge points and corresponding downstream control points are shown in Figure 4-1.

4.2.3.4 Multiple Diversion Locations

Many rights are authorized for multiple diversion locations. When a diversion amount for each location is specified in the water right, the annual authorized diversion is divided between the specified locations according to the language in the water right. When a diversion amount from each location is not specified, the total annual authorized diversion amount is placed at the furthest downstream diversion location or proportioned by drainage area to each individual diversion location if a common downstream diversion location is not specified in the right.

Three power plant reservoirs in the Guadalupe-San Antonio River Basin (Coleto Creek, Braunig, and Calaveras) have multiple diversion locations. Each project has an authorized consumptive use directly from its off-channel reservoir facility, as well as an annual maximum make-up diversion from a nearby river. In the simulations performed for this study, make-up diversions were made only to the extent necessary to maintain the off-channel reservoir at full capacity, subject to the direct authorized consumptive use. Hence, maximum annual make-up diversions were not necessary in every year simulated.

The make-up diversion from the Guadalupe River for Coleto Creek Reservoir is actually senior to the consumptive and storage portions of the right from the Coleto Creek watershed. In order to accurately consider this right, the priority dates for the storage and consumptive portions from the Coleto Creek watershed were set equal to the priority date of the make-up diversion from the Guadalupe River.

4.2.3.5 Rights Requiring Special Consideration

Many rights in the Guadalupe-San Antonio River Basin were given special consideration in developing the WRAP input file. During the development of the WRAP water rights input file, each record in the WRDETAIL was inspected and used to develop one or more WR records. In many cases involving multiple dates of priority, uses, diversion locations, or authorized impoundments, the paper rights and amendments were consulted. Specific assumptions used to model each right are included as comment records in the WRAP input file in Appendix XI.

4.2.4 Changes in Springflows from the Edwards Aquifer

The naturalized flows downstream of Comal, San Marcos, Hueco, San Antonio, and San Pedro Springs include historical springflows, which reflect historical pumpage from the Edwards Aquifer. Pumpage has increased dramatically over the historical period of record, resulting in decreased water levels in the Edwards Aquifer during dry periods and concurrent declines in springflows.

Pursuant to SB1477, the legislation creating the Edwards Aquifer Authority (EAA), permitted pumpage from the Edwards Aquifer is to be limited to 400,000 acft/yr by the year 2008. Before the year 2013, the EAA must adopt critical period management rules that restrict pumpage during drought as necessary to sustain springflows at appropriate levels.

As a basis for the assessment of surface water availability in the Guadalupe-San Antonio River Basin, the TNRCC selected a regulated Edwards Aquifer pumpage of 400,000 acft/yr. At TNRCC's request, the TWDB agreed to apply their GWSIM4 Model[103] of the Edwards Aquifer to simulate springflows under this regulated pumpage regime. Technical assumptions and

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[103] TWDB, "Model Refinement and Applications for the Edwards (Balcones Fault Zone) Aquifer in the San Antonio Region, Texas," Report 340, July 1992.

resulting simulated springflows are presented in a brief report prepared by the TWDB.[104] Minor adjustments to the TWDB data sets were subsequently completed by HDR to reflect allowable domestic and livestock pumpage in excess of the 400,000 acft/yr permitted pumpage and to reflect appropriate geographical distribution of permitted pumpage. The GWSIM4 Model was rerun by HDR, and the results of this simulation were input into WRAP as time series of monthly changes in springflows. These changes are generally negative during early parts of the simulation (reflecting greater than historical pumpage) and positive in the later parts of the simulation (reflecting less than historical pumpage levels under the permitted pumpage restrictions). These changes in springflows are added by WRAP to the naturalized flows at or above control points CP75 (San Marcos Springs), CP04 (Hueco Springs), CP05 (Comal Springs), CP18 (San Antonio Springs), and CP29 (San Pedro Springs) and translated to control points downstream. The changes in springflows are added after flows are distributed from primary to secondary control points.

This capability was added to the basin-specific WRAP code by HDR, and the capability was included by Texas A&M University.[105] In the current implementation, the time series of changes in historical springflows are input in a separate file with the "*root*" file name established by the main WRAP input file, followed by the extension ".SPR." Records in the file follow the same format as those in the inflows file, *root*.INF, but are identified with "FA" record identifiers instead of "IN" record identifiers.

4.2.5 Data for Basin-Specific Features Added to WRAP

The data necessary to model the basin-specific features incorporated in WRAP are specified in two basin-specific input files and the base WRAP input file. The first basin-specific file contains all the parameters necessary for utilizing the features required for Canyon Reservoir, the Medina Lake System, the City of Victoria permit, and the Calaveras Lake permit. The second file contains the parameters needed to model recharge to the Edwards Aquifer. Both files must have the "*root*" file name established by the main WRAP input file followed by the extension ".BSP" for the first file and ".RCH" for the second (recharge) file. Data contained in both basin-specific input files are directly related to specific records in the main input file,

[104] TWDB, "Summary of a GWSIM-IV Model Run Simulating the Effects of the Edwards Aquifer Authority Critical Period Management Plan for the Regional Water Planning Process," July 1999.
[105] Ralph Wurbs, Texas A&M University, personal communications, 1999.

"*root*.DAT". Without the appropriate records and identifiers called out in each input file, the basin-specific features for the Guadalupe-San Antonio River Basin in WRAP will not function properly. This section provides a description of the information used to create the basin-specific files. A detailed discussion of the record formats, input file relationships and the methodology implemented in WRAP for modeling the Guadalupe-San Antonio River Basin is contained in Appendix X (bound separately).

4.2.5.1 Canyon Reservoir, Certificate of Adjudication C2074

The control point identifiers for the Spring Branch control point (CP02), the Canyon Reservoir control point (CP03), and the Dunlap control point (CPDUN) are entered in the *root*.BSP file using a basin-specific "CC" record. These control point identifiers must match those entered in the base WRAP input file for those locations.

Following the CC record, the identifiers for the instream flow requirements (IF records) associated with the FERC and downstream senior hydropower targets are entered on a CF record. These identifiers must match the identifiers for two IF records in the base WRAP input file, located at the Canyon (FERC) and Dunlap (hydropower) control points. The targets must be converted to annual values in units of acre-feet and entered on the IF record. The subroutine will convert the annual targets to monthly using the demand distribution pattern specified for the individual IF records and then will convert the monthly target to a daily rate in units of cubic feet per second. The target values entered for the FERC requirement are the "non-drought" flow requirements (120 cfs or 100 cfs, depending on month); the drought target (90 cfs) is hard-coded in the subroutine and is not entered in an input file.

The Canyon diversion requirement can be met at one or more locations downstream of the reservoir, each specified with a different WR record in the base WRAP input file. Following the CC and CF records, the identifiers of the Canyon diversions must be entered on a CW record and match those identifiers entered in the base WRAP input file. Finally, a separate file must be prepared that contains daily gaged flows at Spring Branch (CP02).

4.2.5.2 Medina Lake System, Certificate of Adjudication C2130

The reservoir identifiers for Medina and Diversion Lakes must be entered on an MR record in the *root*.BSP file. These identifiers must match those utilized for the reservoir in the base WRAP input file. Following the MR record, the control point identifiers for Medina Lake, tributaries to Diversion Lake, and Diversion Lake are entered on an MC record. Medina Lake and Diversion Lake water rights are entered on MW and DW records following the MC record. The Diversion Lake storage corresponding to a target elevation 5 feet below the spillway elevation is then entered on a DT record. Finally, the elevation-capacity data for both reservoirs are entered on PV and PE records. All other data for the operation of the Medina Lake System are hard-coded in the basin-specific subroutine.

4.2.5.3 Special Conditions Associated with City of Victoria Permit P5466

The City of Victoria water right is entered in the base WRAP input file as a special Type 1 right, with an alternative control point ID (ACPID) specified for the Guadalupe River diversion location. The control point identifier for the Victoria streamgage (CP15) and the IF record identifier of the instream flow requirement are entered on a VC record in the basin-specific input file. The monthly-varying normal and low flow conditions for the Victoria streamgage are input on NF and LF records, respectively, in units of acre-feet. These flow conditions are shown in units of acre-feet/month and in cubic feet per second in Table 4-3.

4.2.5.4 Make-up Diversions Associated with City Public Service Board Certificate of Adjudication C2162 (Calaveras Lake)

Calaveras Lake is modeled using two pairs of WR/WS records. The first pair utilizes naturalized flows at the reservoir control point and stored water to meet the consumptive needs of the right. Because the drainage area above Calaveras Lake is limited, flows into the reservoir are generally insufficient to meet the consumptive needs of the right and maintain storage. The

Table 4-3.
Instream Flow Conditions for the City of Victoria Permit P5466

Month	Normal Flow Condition (cfs)	Normal Flow Condition (acft/month)	Low Flow Condition (cfs)	Low Flow Condition (acft/month)
January	387	23,796	150	9,223
February	440	24,437	150	8,331
March	660	40,582	200	12,298
April	687	40,880	250	14,876
May	1,260	77,476	200	12,298
June	995	59,207	250	14,876
July	540	33,204	300	18,447
August	414	25,456	300	18,447
September	490	29,157	200	11,901
October	353	21,705	150	9,223
November	357	21,243	150	8,926
December	374	22,997	150	9,223

second pair of WR/WS records allows the reservoir to be refilled with make-up diversions from an alternate control point specified on the WS record. This alternate control point is the diversion location on the San Antonio River provided by the TNRCC, control point 216232. This control point identifier must also be entered in the basin-specific input file on a CA record. Also included on the CA record is the water right identifier of the second WR record and the number of effluent discharge locations to be considered when determining availability of water for the make-up diversion from the San Antonio River.

A set of CI records, identical in format to those required in the base WRAP input data, is required in the basin-specific input file for each City of San Antonio effluent discharge. The discharges included on these records represent only the City of San Antonio wastewater plants and generally are smaller than those discharges included on CI records in the base WRAP input file. The CI records included in the base WRAP input file include other effluent discharge sources in addition to the City of San Antonio discharges. The discharges included on the CI records in the basin-specific WRAP input file do not increase flows anywhere in the basin. They are included solely to track how much wastewater effluent comprises the regulated and available flow at the alternate control point location.

4.2.5.5 Edwards Aquifer Recharge

Recharge to the Edwards Aquifer is calculated using the information entered in the .RCH input file. Recharge is only calculated at specific primary control points located downstream of the Edwards Aquifer recharge zone. Estimating natural recharge in gaged areas and ungaged areas is discussed in Section 3.5.1. The location of recharge control points and the data necessary to calculate recharge in the basin-specific Guadalupe-San Antonio WRAP simulation program are based on previous studies[106] conducted by EAA.

Each recharge control point must be entered with a RC record in the .RCH file. The records and formats for the .RCH file are described in Appendix X. The recharge calculation is predicated on the parameter, RCTYPE, in the RC card. The RCTYPE field designates whether the control point is a gaged (RCTYPE = 1) or a partially or ungaged area (RCTYPE = 3). For gaged areas, it is necessary to specify the primary control points located near the upstream boundary of the recharge zone in the RB records. In ungaged or partially gaged recharge areas, natural recharge is based on that occurring in an adjacent gaged recharge area and is read in from the RO records. The natural recharge for the partially gaged and ungaged recharge control points read in from the RO cards is based in the methodology described in Section 3.5.1. Each recharge control point is shown in Table 4-4 with their RCTYPE parameters.

Although the Medina Lake and Diversion Lake control points do not use the same recharge algorithms used by the other recharge control points, they must be specified in the RC records with a RCTYPE equal to four. The control points for Medina and Diversion Lakes must also be entered in the last two fields of the RI record.

Additional recharge is calculated at SCS/FRS and at the permitted recharge structure constructed on San Geronimo Creek. In the input file, for the SCS/FRS, the KRRES parameter must be equal to four and the variables for the normal pool, active pool, and controlled area must be input in appropriate RC fields as shown in Table 4-5. The San Geronimo structure is modeled as a Type 2 water right in the main input file, and its water right identifier must be entered on

[106] HDR and EH&A., "Recharge Enhancement Study Guadalupe-San Antonio River Basin," Volume II-Technical Report, EUWD, September 1993.

Table 4-4.
Recharge Control Point Information Entered in .RCH file

Gaged (G) and Partially or Ungaged Recharge Area	*Recharge Control Point ID*	*RCTYPE*[2]
Guadalupe River, New Braunfels (G)	CP04	1
Comal River, New Braunfels	CP05	3
Sink Creek	CP71	3
Purgatory Creek	CP72	3
York Creek	CP73	3
Alligator Creek	CP74	3
Blanco River, San Marcos (G)	CP09	1
Olmos Creek, San Antonio	CP17	3
Salado Creek, San Antonio	CP19	3
Medina Lake	CP21	4
Tributaries to Diversion Lake	CP22	3
Diversion Lake	CP23	4
West Tributaries Downstream of Diversion Lake	CP241	3
East Tributaries Downstream of Diversion Lake	CP242	3
San Geronimo Creek	CP25	3
Leon Creek, Edwards	CP261	3
Helotes Creek, Edwards	CP262	3
Government Creek, Edwards	CP263	3
Cibolo Creek, Selma (G)	CP34	1

1 For gaged control points, control point ID's are entered on RB records. For ungaged or partially gaged control points, natural recharge is read in from RO records.
2 RCTYPE refers to the "type" of recharge control point.

the RW record in order for its diversion to be added to the recharge calculated in the basin-specific routines. The San Geronimo right, P3220-1, is associated with the primary control point CP25.

Estimation of recharge is contingent on the estimated potential runoff from intervening areas over the recharge zone. The procedure used to calculate potential runoff is detailed in Section 3.5. Monthly potential runoff volumes are entered on the QP records in the .RCH file. Each recharge control point specified in the RC records must have a QP record for each year of the simulation.

Table 4-5.
SCS/FRS Parameters

Location	Normal Pool Volume[1] (ac)	Active Pool Volume[1]* (ac)	Normal Pool Factor[2]	Active Pool Factor[2]	Area Controlled Ratio[3]
Comal River, New Braunfels – CP05	709	18,265	1.00	0.70	0.57
Sink Creek – CP71	524	10,445	1.00	0.70	1.00
Purgatory Creek – CP72	430	7,525	1.00	0.70	1.00
York Creek – CP73	204	3,560	1.00	0.70	1.00
Salado Creek, San Antonio	1,906	30,701	1.00	0.70	0.62

[1] Normal and Active pool volumes represent the sum of all SCS/FRS in the recharge zone above the control point.
[2] Normal pool factor of 1.00 assumes that 100 percent of the water impounded within the normal pools contribute to recharge neglecting evaporation and an Active Pool Factor of 0.70 assumes that 70 percent of the runoff temporarily impounded in the active pools contributes to recharge neglecting evaporation.
[3] Area Controlled Ratio represents the total watershed area controlled by SCS/FRS divided by the total watershed area.

In order to model the Edwards Aquifer flux on the Guadalupe River downstream of Hueco Springs, a time series of flux terms must be entered for each year on the HE records in the .HUE file. The flux term is added to the estimate of recharge at the Guadalupe River near New Braunfels control point. The Guadalupe River near New Braunfels control point identifier, CP04, must also be entered in the appropriate position on the RI record in the .RCH file.

4.3 Significant Assumptions Affecting Water Availability Modeling

4.3.1 Channel Losses and Streamflow Distribution

One significant assumption that affects water availability to any specific right is the methodology used to distribute naturalized flows to the water right location. The methodology used in WRAP assumes that runoff and channel loss will occur uniformly between primary control points, and that the only natural factors affecting the incremental runoff between primary control points are the drainage area and channel loss factors. The significance of channel losses in the Guadalupe-San Antonio River Basin cannot be overstated, as numerous studies based on gaged streamflow records have shown**. It is important to note, however, that WRAP applies channel loss factors only to changes in streamflow caused by impoundments, diversion, and/or effluent discharge.** This is because the gaged streamflow records on which natural streamflows are based already reflect naturally occurring losses.

Drainage area is the best single predictor that can be used to estimate runoff between gaged locations. Options in WRAP (INMETHOD4 and INMETHOD5) allow the use of areally averaged runoff curve numbers and mean annual precipitation to refine estimates of intervening runoff, but these have been shown to improve the estimates only slightly.[107] INMETHOD6 distributes naturalized flows to secondary control points, utilizing only drainage area and channel loss factors; runoff curve number and mean annual precipitation are not taken into account. Channel losses play a dominant role in the hydrology of the Guadalupe-San Antonio River Basin, and the effects of channel losses largely overshadow any effects due to differences in runoff curve number. For this reason, INMETHOD6 was selected to distribute naturalized flows to secondary control points.

4.3.2 Reuse

Treated effluent discharges in the Guadalupe-San Antonio River Basin play a significant role in water availability in the basin. Significant discharges occur in the upper San Antonio River Basin from the City of San Antonio and throughout the Guadalupe River Basin. Future reuse of this effluent would reduce discharges and would reduce the availability of water to specific rights located near and downstream of the discharge points. At the request of TNRCC, three reuse scenarios were modeled. These are described in more detail in Section 5.

4.3.3 Return Flow/Constant Inflow Assumptions

Other than discharges by the Upper Guadalupe River Authority and the GBRA, almost all treated effluent discharges in the Guadalupe-San Antonio River Basin originate from groundwater sources. It is assumed that treated effluent from municipalities holding surface water rights would not substantially decrease in the event of drought because alternative sources of supply would be activated. Moreover, a substantial component of reduced municipal water use during drought is typically associated with constraints placed on discretionary outdoor uses, such as lawn watering, that have little effect on wastewater volumes. For these reasons, municipal water rights were modeled as 100 percent consumptive, and return flows were not modeled as a fraction of the water diverted. Rather, all treated effluent discharges, with the

[107] Wurbs, R.A. and Sisson, E. D., "Comparative Evaluation of Watershed Characteristics and Methods for Distributing Naturalized Streamflows from Gaged to Ungaged Sites," prepared for the Texas Natural Resource Conservation Commission, Texas Water Resources Institute, Texas A&M University, Draft, June 1998.

exception previously noted, were treated as constant inflows, as described previously in Section 4.2.3.3.

4.3.4 Term Permits

Term permits are included only in Run 8, as described in Section 5. Thirteen term permits (Type A) are active in the Guadalupe-San Antonio River Basin, with authorized annual consumptive use totaling 5,518 acft, thereby representing about 1.03 percent of the total authorized consumptive use in the Guadalupe-San Antonio River Basin. Type A term permits have a defined date of expiration, whereas Type B term permits include a special condition that could cause cancellation of a right. Only Type A permits were excluded from Runs 1 through 7. Term permits do not significantly affect water availability in the Guadalupe-San Antonio River Basin.

4.3.5 Interbasin Transfers

The TNRCC provided information documenting seven rights authorized for interbasin transfers of water from the Guadalupe River Basin. These transfer water to the San Antonio River Basin and/or to the Lavaca-Guadalupe Coastal Basin. The TNRCC also provided information documenting four rights authorized for interbasin transfer of water from the San Antonio River Basin. Three of these are owned by the Bexar-Medina-Atascosa Water Control and Improvement District No. 1 and transfer water from the Medina Lake System to various canals operated by the district and to Chacon Reservoir in the Nueces River Basin. The fourth right is authorized to transfer water to the Guadalupe River Basin. Since all interbasin transfers direct water from the Guadalupe-San Antonio River Basin or between the Guadalupe and San Antonio River Basins, no special treatment of interbasin transfers was warranted. Information provided by the TNRCC regarding interbasin transfers is shown in Table 4-6.

Table 4-6. Interbasin Transfers in the Guadalupe-San Antonio River Basin

Water Right Number	*Owner*	*Basin From*	*Basin To*	*Source of Diversion*	*Authorized Amount (acft)*
C2074	GBRA	Guadalupe	Lavaca-Guadalupe, San Antonio	Canyon Lake	
C3861	E.I. du Pont de Nemours	Guadalupe	Lavaca-Guadalupe	Guadalupe River	60,000 (IND)
P3895	Kate S. O'Conner Trust	Guadalupe	Lavaca-Guadalupe	Guadalupe River	9,676 (IND) max (can consume 4,676 of the 9,676 authorized)
P4586	Del Williams, et ux	Guadalupe	Lavaca-Guadalupe	Guadalupe River	272 (IND) max (unspecified quantity)
P5012	Joe D. Hanes	Guadalupe	San Antonio	Elm Bayou	140(IRR)
C5173-5178	GBRA and Union Carbide	Guadalupe	Lavaca-Guadalupe	Guadalupe River	8,362 (IRR) 4,370 (IND & IRR) 42,559 (MUN, IND, & IRR) 940 (MUN, IND, IRR, and MIN) 10,000x (MUN, IND & IRR)
P5466	City of Victoria	Guadalupe	Lavaca-Guadalupe	Guadalupe River	20,000 (MUN) (either basin)
C2130	BMA WCID 1	San Antonio	Nueces	Lake Medina & Diversion Lake	65,830 ((MUN, IRR & IND) 750 (MUN) 170 (MUN)
C2131	BMA WCID 1	San Antonio	Nueces	Lake Medina & Diversion Lake	
C3207	BMA WCID 1	San Antonio	Nueces	Lake Medina & Diversion Lake	
P5489	Jess Y. Womack	San Antonio	Guadalupe	San Antonio River	Unquantified (floodwater wetlands maintenance)

Section 5
Water Availability in the Basin

5.1 Descriptions of Scenarios Modeled

Water availability in a river basin is affected by assumptions regarding water management and use, in addition to natural hydrologic influences, such as rainfall, runoff, and evaporation. Senate Bill 1 requires assessment of the sensitivity of water availability to key water management and use assumptions, including reuse of treated wastewater effluent and the cancellation of all or portions of rights showing little or no recent use. Sensitivity of water availability in the Guadalupe-San Antonio River Basin to these water management assumptions is addressed by comparisons between simulation results for eight alternative scenarios. These eight scenarios, identified as Run 1 through Run 8, are described in the following sections and summarized in Table 5-1.

Table 5-1.
Assumptions Utilized in Alternative Model Runs

		Reuse Runs			Cancellation Runs				Current Conditions
	Assumptions Utilized	**Run 1**	**Run 2**	**Run 3**	**Run 4**	**Run 5**	**Run 6**	**Run 7**	**Run 8**
Assumed Cancellations	Full Authorized Diversion Amounts (no cancellations)	X	X	X					
	Rights Showing 10-years Nonuse Cancelled				X		X		
	Authorized Diversion Amounts Set to Max. Use, 1987 - 97					X		X	X
	Term Water Rights Excluded	X	X	X	X	X	X	X	
Effluent Reuse	No Reuse of Current Return Flow Conditions	X			X	X			X
	50 percent Reuse of Current Return Flow Conditions		X						
	Full Reuse of Current Return Flow Conditions			X			X	X	
Large Reservoirs [1]	Authorized Area-Capacity Relationships	X	X	X	X	X	X	X	
	Projected Year 2000 Area-Capacity Relationships								X

[1] Area-capacity relationships for reservoirs greater than 4,000 acft for which reliable area-capacity data are available (Canyon Reservoir, Coleto Creek Reservoir, Medina Lake, Calaveras Lake, Braunig Lake, and Boerne Lake).

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 to the Guadalupe Estuary, will be considered when granting new water rights or amending existing water rights, thereby affecting the amount of water available for appropriation.

5.1.1 Reuse Runs 1, 2, and 3

Runs 1, 2, and 3 evaluate the effects on water availability of varying levels of reuse of treated effluent discharge. Run 1 includes honoring all rights, excluding term permits, at their full, authorized, annual diversion amounts. Treated effluent discharges representative of current conditions were developed as described in Section 4.2.3.3 and included in Run 1. Runs 2 and 3 are identical to Run 1, except for the effluent discharges reflected on CI records. These were reduced to one-half of the Run 1 values in Run 2, to reflect 50 percent reuse of current effluent discharges, and to zero in Run 3, to reflect full reuse. Term permits were excluded from Runs 1, 2, and 3. Constant inflow (CI) records are used in WRAP to input 12 monthly values of flow to be added to the naturalized flows at a control point.

5.1.2 Cancellation Runs 4, 5, 6, and 7

Runs 4, 5, 6, and 7 evaluate the effects on water availability of the simulated cancellation of certain rights. Under §11.173 of the Texas Water Code, permits, certified filings, and certificates of adjudication may be subject to cancellation after 10 years of nonuse. The use of water by rights during the last 10 years was evaluated using annual reported water use obtained from the TNRCC for the 1987 to 1997 period. The database obtained from the TNRCC consists of two distinct periods: 1987 to 1989 and 1990 to 1997, reflecting self-reported water use data collected by TNRCC staff through 1989 and records of water use collected and maintained by the TNRCC South Texas Watermaster since 1990. Data in the South Texas Watermaster database are missing for most of 1990, so an additional year, 1987, was added to obtain ten complete years of water use data.

The effects of potential full cancellations were evaluated in Runs 4 and 6 by assuming that those rights showing no use in the years 1987 to 1997 were cancelled. Rights showing partial or full use were simulated in Runs 4 and 6 at their full-authorized diversion amounts. The effects of potential partial cancellations were evaluated in Runs 5 and 7 by setting all authorized diversions (excluding term permits) to their maximum annual water use in the years 1987 to 1997. The maximum 10-year use was assigned first to the most senior portions of rights with multiple priority dates and the remainder assigned to more junior portions. The maximum 10-year use was assigned in the order of municipal, industrial, irrigation, and mining uses for rights authorized for multiple types of use.

The potential effects of effluent reuse in conjunction with full or partial cancellation were evaluated in these runs by including current return flows for Runs 4 and 5 and assuming full reuse for Runs 6 and 7. Term permits were excluded from Runs 4 through 7. Storage rights were not cancelled in any runs. Instream flow restrictions corresponding to rights assumed cancelled under Runs 4 and 6 were removed, but remained in place for Runs 5 and 7 for partially cancelled rights.

At the direction of TNRCC, new rights granted since 1987, for which no historical use has been reported, were assumed cancelled in Runs 4 and 6 in order to maintain consistency with assumptions used in other river basins. Similarly, maximum historical diversion amounts for these rights were set to zero for Runs 5 and 7.[108]

5.1.3 Current Conditions Run 8

Run 8 is intended to evaluate the availability of water under current water use conditions, effluent discharges, and reservoir capacities. Run 8 includes current effluent discharges (no reuse, except that already incorporated in the Run 1 CI records for the SAWS Leon Creek and Salado Creek Water Recycling Centers), authorized diversions set to those utilized in Runs 5 and 7 (maximum 10-year use), and reservoir area-capacity relationships modified to reflect sediment accumulation in the year 2000. Term water rights are included at their 10-year maximum use.

Appendix VIII summarizes the authorized annual diversions included for each right for Runs 1 through 8. The amounts shown in this table are the sums of the diversion amounts from the individual WR records included in the model for each right. Also shown is the maximum annual use for each right (1987 to 1997) included in the data provided by the TNRCC. These data were utilized to set the authorized diversion amounts for Runs 4 through 8.

5.2 Results of Water Availability Model Runs

5.2.1 Reuse Runs

The results for Reuse Runs 1, 2, and 3 are presented in Appendix V. Reliability of supply for each right is presented in Tables V-1, V-2, and V-3. Regulated and unappropriated flows for Runs 1 and 3 are presented in Tables V-4 through V-29. Graphical presentations of regulated and unappropriated flows at selected control points are shown in Figures V-1 through V-13. Reservoir storage traces for Canyon Reservoir and Medina Lake, Coleto Creek Reservoir, and Calaveras Lake are displayed in Figures V-14 through V-17.

5.2.1.1 Specific Large Rights

Tables 5-2 and 5-3 compare reliability summaries generated by each run for selected major rights in the Guadalupe River Basin held by GBRA (C2074), GBRA and Union Carbide (C5178), I.E. Du Pont (C3861), the City of Victoria (P5466); and major rights in the San Antonio River Basin held by BMA (C2130), CPS-Calaveras Lake (C2162), and the Bexar

[108] While the authorized direction amounts are set to zero for those model runs, those rights are not subject to cancellation at this time (TNRCC letter dated September 10, 1999).

Table 5-2.
Reliability Summary for Selected Major Rights in the Guadalupe River Basin[1]

Scenario		GBRA Canyon Reservoir (C2074)		GBRA/Union Carbide (C5178)		I.E. Du Pont (C3861)		City of Victoria (P5466)	
		by Volume[3]	by Month[4]	by Volume[3]	by Month[4]	by Volume[3]	by Month[4]	by Volume[3]	by Month[4]
Reuse	Run 1	96.0%	96.4%	98.7%	97.9%	99.5%	99.1%	86.2%	85.5%
	Run 2	95.8%	96.3%	97.3%	97.1%	99.1%	98.7%	85.8%	85.2%
	Run 3	95.6%	96.0%	95.8%	95.5%	98.0%	97.4%	85.4%	85.1%
Cancellation	Run 4	96.1%	96.6%	99.2%	98.4%	99.5%	99.1%	N/A[2]	N/A[2]
	Run 5	100.0%	100.0%	99.9%	99.7%	100.0%	100.0%	N/A[2]	N/A[2]
	Run 6	95.7%	96.3%	96.4%	95.9%	98.1%	97.6%	N/A[2]	N/A[2]
	Run 7	100.0%	100.0%	98.6%	97.8%	99.8%	99.5%	N/A[2]	N/A[2]
Current Conditions	Run 8	100.0%	100.0%	99.9%	99.7%	100.0%	100.0%	N/A[2]	N/A[2]

[1] Reliability summaries generated from water right group identifiers in WR records.
[2] Permit P5466 included with a zero authorized diversion amount in Runs 4 - 8 due to no water use indicated in database.
[3] Reliability by volume is the total water used (diversions met) divided by the total water needed (authorized diversion).
[4] Reliability by month is the total number of months during which the total water needed (authorized diversion) is met, divided by the total number of months in the simulation.

Table 5-3.
Reliability Summary for Selected Major Rights in the San Antonio River Basin[1]

Scenario		Bexar-Medina-Atascosa WCID (C2130)		City Public Service-Calaveras Lake (C2162)		Bexar Metropolitan Water District (C4768)	
		by Volume	by Month	by Volume	by Month	by Volume	by Month
Reuse	Run 1	83.1%	83.4%	100.0%	100.0%	93.4%	84.9%
	Run 2	83.0%	83.4%	98.5%	98.3%	79.5%	69.1%
	Run 3	83.1%	83.4%	21.7%	21.3%	62.0%	55.4%
Cancellation	Run 4	83.1%	83.4%	100.0%	100.0%	93.4%	84.9%
	Run 5	84.4%	84.7%	100.0%	100.0%	100.0%	100.0%
	Run 6	83.1%	83.4%	21.7%	21.3%	62.0%	55.4%
	Run 7	84.4%	84.7%	57.0%	54.4%	94.4%	94.7%
Current Conditions	Run 8	84.1%	84.4%	100.0%	100.0%	100.0%	100.0%

[1] Reliability summaries generated from water right group identifiers in WR records.

Metropolitan Water District (C4768). Reuse of treated effluent has a limited impact on the major rights in the Guadalupe River Basin. Reuse of treated water effluent in the San Antonio River Basin has a significant impact on the reliability of CPS rights at Calaveras Lake, which are dependent on effluent discharge. The effects of the reuse on Calaveras Lake are illustrated dramatically by the storage traces shown in Figure V-17.

5.2.1.2 Unappropriated Flows at Selected Locations

Tables 5-4 through 5-10 summarize annual regulated and unappropriated flows for each run at selected control points. Reuse of treated effluent has little impact on unappropriated flows at the selected control points in the Guadalupe River Basin but significantly reduces flows in the Medina and San Antonio Rivers downstream of the City of San Antonio. The wastewater treatment plants operated by SAWS discharge an aggregate mean annual volume of treated effluent that is equivalent to about 52 percent of the mean annual naturalized flow of the San Antonio River at Elmendorf (CP29).

Table 5-4.
Guadalupe River at Spring Branch, CP02
Annual Simulation Summaries

Scenario		Regulated Flows (acft/yr)				Unappropriated Flows (acft/yr)			
		Max	Min	Mean	Median	Max	Min	Mean	Median
Reuse	Run 1	945,111	10,058	254,414	226,863	627,965	0	38,724	0
	Run 2	944,242	9,124	253,500	225,929	625,202	0	38,068	0
	Run 3	943,312	8,208	252,586	224,994	622,439	0	37,435	0
Cancellation	Run 4	946,550	10,141	254,749	227,061	630,383	0	39,178	0
	Run 5	949,522	10,173	252,818	222,291	826,473	0	135,641	69,515
	Run 6	944,796	8,280	252,916	225,240	624,900	0	37,889	0
	Run 7	947,652	8,311	251,036	220,676	819,257	0	132,764	65,874
Current Conditions	Run 8	949,422	10,173	252,776	222,224	826,536	0	135,803	69,669

Table 5-5.
San Marcos River at Luling, CP10
Annual Simulation Summaries

Scenario		Regulated Flows (acft/yr)				Unappropriated Flows (acft/yr)			
		Max	Min	Mean	Median	Max	Min	Mean	Median
Reuse	Run 1	674,732	44,320	256,752	234,795	565,377	0	154,986	125,705
	Run 2	672,935	42,711	255,052	233,052	562,144	0	153,662	124,504
	Run 3	671,137	41,086	253,369	231,314	558,918	0	152,356	123,305
Cancellation	Run 4	676,391	44,395	258,035	236,365	567,346	0	155,975	126,545
	Run 5	682,582	45,525	263,222	242,428	588,363	0	173,561	148,447
	Run 6	672,795	41,166	254,625	232,847	560,881	0	153,316	124,277

	Run 7	678,986	43,021	259,708	238,842	584,767	0	170,825	145,145
Current Conditions	Run 8	682,585	45,516	263,221	242,425	588,366	0	173,562	148,443

Table 5-6.
Guadalupe River at Cuero, CP14
Annual Simulation Summaries

Scenario		***Regulated Flows (acft/yr)***				***Unappropriated Flows (acft/yr)***			
		Max	***Min***	***Mean***	***Median***	***Max***	***Min***	***Mean***	***Median***
Reuse	Run 1	3,133,837	77,296	1,137,281	1,002,392	2,910,683	4,191	922,059	787,703
	Run 2	3,126,665	71,410	1,130,379	995,469	2,903,469	3,720	916,003	782,178
	Run 3	3,119,544	66,505	1,123,590	988,596	2,896,307	3,188	909,999	776,641
Cancellation	Run 4	3,141,694	77,829	1,141,982	1,006,122	2,921,851	7,357	932,730	802,157
	Run 5	3,142,757	79,266	1,163,609	1,019,812	2,922,915	9,443	955,248	812,453
	Run 6	3,127,387	66,994	1,128,184	992,135	2,907,544	6,303	920,522	790,508
	Run 7	3,128,799	67,959	1,149,428	1,005,069	2,908,956	6,895	942,723	800,932
Current Conditions	Run 8	3,142,779	79,258	1,163,740	1,019,914	2,922,936	9,443	955,380	812,449

Table 5-7.
Medina River at Somerset, CP27
Annual Simulation Summaries

Scenario		***Regulated Flows (acft/yr)***				***Unappropriated Flows (acft/yr)***			
		Max	***Min***	***Mean***	***Median***	***Max***	***Min***	***Mean***	***Median***
Reuse	Run 1	600,194	4,435	90,390	53,871	592,578	0	72,680	31,328
	Run 2	598,064	4,449	90,229	55,270	583,491	0	63,989	17,727
	Run 3	596,107	3,419	89,379	54,723	581,446	0	61,784	16,881
Cancellation	Run 4	606,257	4,443	94,539	58,470	598,642	0	77,711	38,150
	Run 5	621,520	6,205	100,458	63,498	613,964	196	87,021	49,542
	Run 6	602,049	3,431	92,388	56,832	588,184	0	65,794	20,030
	Run 7	617,243	3,438	96,616	59,640	602,213	0	71,075	27,381
Current Conditions	Run 8	618,132	6,024	100,162	63,401	610,576	196	86,767	49,473

Table 5-8.
San Antonio River at Falls City, CP32
Annual Simulation Summaries

Scenario		Regulated Flows (acft/yr)				Unappropriated Flows (acft/yr)			
		Max	Min	Mean	Median	Max	Min	Mean	Median
Reuse	Run 1	1,039,182	79,344	285,849	226,391	896,405	0	156,761	83,444
	Run 2	986,084	48,970	238,266	175,748	843,306	0	127,932	54,620
	Run 3	963,235	20,310	222,238	163,159	820,469	0	118,289	45,246
Cancellation	Run 4	1,052,251	79,290	295,348	235,113	909,474	0	165,466	94,722
	Run 5	1,093,161	94,983	329,444	266,175	950,384	1,966	193,150	128,378
	Run 6	976,180	20,385	229,440	169,777	833,403	0	124,396	52,084
	Run 7	996,501	26,116	239,663	178,332	853,724	0	131,911	60,100
Current Conditions	Run 8	1,091,169	95,182	329,405	266,286	948,392	2,004	193,060	128,467

Table 5-9.
Guadalupe River at Tivoli, CP38
Annual Simulation Summaries

Scenario		Regulated Flows (acft/yr)				Unappropriated Flows (acft/yr)			
		Max	Min	Mean	Median	Max	Min	Mean	Median
Reuse	Run 1	4,617,867	67,308	1,678,987	1,439,402	4,617,595	67,036	1,678,715	1,439,130
	Run 2	4,561,970	56,275	1,630,124	1,387,061	4,561,698	56,003	1,629,852	1,386,789
	Run 3	4,530,549	49,703	1,607,370	1,361,819	4,530,277	49,431	1,607,098	1,361,547
Cancellation	Run 4	4,676,283	78,552	1,728,484	1,494,555	4,676,011	78,280	1,728,212	1,494,283
	Run 5	4,778,639	123,637	1,841,736	1,636,414	4,778,414	123,392	1,841,529	1,636,190
	Run 6	4,588,850	57,211	1,653,979	1,414,803	4,588,578	56,939	1,653,707	1,414,530
	Run 7	4,674,878	71,488	1,745,143	1,536,144	4,674,653	71,218	1,744,937	1,535,920
Current Conditions	Run 8	4,776,440	123,750	1,841,532	1,636,122	4,776,215	123,506	1,841,325	1,635,898

Table 5-10.
Guadalupe Estuary, CPEST
Annual Summaries for Each Scenario

Year	Annual Regulated Flows (acft) for each Scenario							
	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8
1934	1,394,726	1,344,518	1,324,766	1,447,775	1,539,007	1,375,373	1,445,842	1,538,807
1935	2,806,840	2,750,476	2,711,498	2,864,994	3,005,712	2,768,362	2,890,827	3,005,685
1936	3,405,659	3,350,013	3,309,754	3,464,022	3,602,970	3,367,919	3,488,000	3,602,109
1937	1,220,563	1,166,114	1,140,993	1,275,988	1,368,554	1,195,769	1,268,365	1,368,218
1938	1,568,795	1,516,803	1,496,436	1,623,633	1,717,104	1,547,917	1,621,378	1,717,035
1939	411,632	366,695	351,308	458,182	552,202	392,563	464,041	552,206
1940	2,039,386	1,989,411	1,966,448	2,092,829	2,178,476	2,015,937	2,082,908	2,178,086
1941	3,472,351	3,419,350	3,389,360	3,529,001	3,730,193	3,443,470	3,622,633	3,730,584
1942	2,472,917	2,419,993	2,385,639	2,529,363	2,630,871	2,440,521	2,520,870	2,630,648

1943	808,463	758,795	741,207	863,156	960,979	790,279	867,336	960,778
1944	1,747,268	1,695,199	1,673,136	1,803,386	1,922,803	1,725,747	1,825,849	1,922,725
1945	1,541,467	1,492,004	1,469,790	1,596,756	1,752,438	1,521,896	1,656,902	1,752,324
1946	2,863,054	2,808,912	2,768,617	2,919,972	3,019,055	2,824,492	2,902,666	3,018,755
1947	1,186,088	1,136,075	1,114,004	1,241,359	1,360,488	1,165,026	1,264,051	1,360,329
1948	526,227	480,356	463,007	568,975	662,705	499,928	572,561	662,384
1949	1,545,982	1,492,860	1,464,512	1,600,596	1,692,891	1,516,101	1,588,502	1,692,526
1950	380,949	340,355	325,016	421,674	516,373	356,633	429,022	516,409
1951	473,724	433,820	421,548	500,791	590,199	446,793	508,492	590,054
1952	897,714	857,432	843,661	934,954	1,021,195	878,344	937,490	1,020,973
1953	894,271	855,412	842,772	931,244	1,024,656	876,706	936,802	1,024,730
1954	110,911	92,216	82,075	129,102	181,525	96,189	131,945	181,654
1955	175,909	156,954	145,841	202,366	298,359	166,066	218,730	298,539

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Table 5-10 (continued)

Year	Annual Regulated Flows (acft) for each Scenario							
	Run 1	***Run 2***	***Run 3***	***Run 4***	***Run 5***	***Run 6***	***Run 7***	***Run 8***
1956	75,149	64,116	57,544	86,435	131,543	65,099	79,373	131,656
1957	3,165,544	3,112,700	3,080,401	3,217,144	3,293,918	3,128,233	3,171,384	3,295,885
1958	2,851,446	2,776,209	2,764,437	2,907,790	3,107,417	2,820,549	2,993,498	3,106,745
1959	1,418,211	1,364,739	1,343,458	1,472,438	1,579,434	1,395,292	1,482,730	1,579,198
1960	3,127,225	3,078,191	3,054,523	3,183,362	3,349,553	3,106,647	3,251,813	3,349,230
1961	2,277,598	2,225,474	2,201,252	2,333,602	2,484,830	2,255,197	2,385,798	2,484,327
1962	520,594	476,312	458,343	567,467	668,689	499,338	577,572	668,526
1963	236,391	205,350	192,188	263,256	349,399	218,632	268,411	349,019
1964	523,544	476,199	463,523	571,475	673,725	503,900	578,982	673,623
1965	2,053,203	1,994,946	1,972,559	2,106,902	2,175,038	2,024,914	2,074,500	2,175,326
1966	1,196,122	1,149,819	1,129,418	1,248,714	1,334,496	1,177,446	1,242,921	1,334,347
1967	3,088,006	3,037,486	3,018,415	3,127,795	3,204,315	3,054,069	3,109,526	3,203,961
1968	3,040,986	2,987,053	2,956,745	3,096,208	3,277,124	3,010,382	3,169,923	3,277,140
1969	1,764,014	1,714,601	1,689,745	1,818,062	1,904,832	1,739,655	1,805,489	1,904,686
1970	1,515,415	1,463,100	1,440,640	1,566,665	1,692,187	1,491,064	1,596,815	1,691,920
1971	1,410,882	1,359,682	1,336,506	1,456,183	1,573,904	1,379,961	1,476,093	1,573,868
1972	2,117,089	2,064,236	2,037,740	2,173,159	2,327,849	2,090,219	2,226,811	2,328,028
1973	4,182,171	4,120,270	4,068,138	4,243,952	4,472,901	4,129,910	4,351,288	4,471,916
1974	2,173,015	2,119,197	2,094,888	2,228,679	2,343,634	2,150,120	2,244,973	2,343,230
1975	2,781,665	2,724,946	2,691,751	2,840,019	2,960,525	2,749,354	2,854,451	2,959,621
1976	3,369,723	3,315,658	3,281,190	3,426,481	3,561,654	3,337,489	3,450,855	3,561,350
1977	2,940,617	2,883,385	2,855,748	2,998,456	3,102,874	2,913,166	3,003,510	3,102,195
1978	1,490,693	1,435,474	1,407,203	1,545,937	1,684,533	1,461,291	1,579,719	1,684,018
1979	3,435,874	3,381,482	3,351,429	3,493,900	3,611,867	3,408,242	3,508,449	3,611,308
1980	925,018	874,733	852,959	976,820	1,049,205	901,936	956,539	1,048,905
1981	3,490,386	3,434,562	3,411,598	3,548,051	3,728,861	3,467,614	3,626,900	3,728,199
1982	1,187,064	1,138,845	1,118,285	1,239,369	1,340,213	1,166,550	1,247,109	1,340,108
1983	964,577	914,386	895,246	1,016,643	1,105,045	943,023	1,011,225	1,105,030
1984	414,091	382,990	370,502	444,634	532,169	398,246	448,732	532,235
1985	1,804,169	1,743,598	1,731,578	1,859,878	2,004,848	1,786,430	1,904,940	2,005,057
1986	1,762,611	1,707,313	1,678,457	1,819,273	1,989,272	1,732,984	1,888,544	1,989,123
1987	4,689,365	4,633,468	4,602,047	4,747,884	4,850,287	4,660,451	4,746,526	4,848,088
1988	513,791	465,735	448,939	565,435	649,500	496,953	561,984	649,518
1989	383,224	348,029	335,146	420,146	513,793	363,731	426,497	513,813
Maximum	4,689,365	4,633,468	4,602,047	4,747,884	4,850,287	4,660,451	4,746,526	4,848,088
Minimum	75,149	64,116	57,544	86,435	131,543	65,099	79,373	131,656
Mean	1,764,899	1,716,036	1,693,284	1,814,506	1,927,825	1,740,002	1,831,234	1,927,621
Median	1,543,724	1,492,432	1,467,151	1,598,676	1,704,997	1,518,998	1,609,096	1,704,781

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5.2.1.3 Regulated Flows at Selected Locations

As shown in Tables 5-4 through 5-10, reuse of treated effluent has a noticeable impact on the regulated flows at control points CP27 and CP32 in the San Antonio River Basin, but little impact at locations in the Guadalupe River Basin upstream of the San Antonio River-Guadalupe River confluence.

5.2.2 Cancellation Runs

The results for Cancellation Runs 4, 5, 6, and 7 are presented in Appendix VI. Reliability of supply for each right is presented in Tables VI-1, VI-2, VI-3, and VI-4. Graphical presentation of regulated and unappropriated flows at selected control points are shown in Figures VI-1 through VI-26. Reservoir storage traces for Canyon Reservoir, Medina Lake, Coleto Creek Reservoir, and Calaveras Lake are displayed in Figures VI-27 through VI-30.

5.2.2.1 Specific Large Rights

Tables 5-2 and 5-3 compare reliability summaries generated by each run for selected major rights in the Guadalupe River Basin held by GBRA (C2074), GBRA and Union Carbide (C5178), I.E. Du Pont (C3861), the City of Victoria (P5466); and major rights in the San Antonio River Basin held by BMA (C2130), CPS-Calaveras Lake (C2162), and the Bexar Metropolitan Water District (C4768). Comparison of Runs 1 and 4 and Runs 3 and 6 shows that water available to these large rights would not be significantly affected by the full cancellation of unused rights. However, the partial cancellation or maximum historical use scenarios (Runs 5 and 7) significantly improve the reliability of the GBRA Canyon Reservoir right (C2074). The maximum use recorded for the downstream hydropower rights is about 60 percent of the authorized diversion amounts, and this significantly increases the amount of water available for impoundment in Canyon Reservoir. Additionally, the maximum use recorded for the GBRA Canyon Reservoir right (C2074) is only about 29 percent of the authorized annual diversion. This, in combination with small pass-through requirements to downstream senior hydropower rights, results in significantly higher reliability and increased storage levels in Canyon Reservoir.

5.2.2.2 Unappropriated Flows at Selected Locations

Tables 5-4 through 5-10 summarize annual regulated and unappropriated flows for each run at selected control points. As with the reliability for the large rights, the unappropriated flows at selected locations show little change from Run 1 to Run 4 and from Run 3 to Run 6. However, reducing authorized annual use to historical maximum use increases unappropriated flows upstream of control point CP06 on the Guadalupe River at Lake Wood (H-5) because of the reduction in the authorized diversion for the senior hydropower rights. Because these hydropower diversions are immediately returned to the stream, unappropriated flows downstream of those rights are reduced in the partial cancellation runs. Unappropriated flow in the Guadalupe-San Antonio River Basin is much more sensitive to partial cancellation of rights down to historical maximum use levels than to full cancellation of unutilized rights.

5.2.2.3 Regulated Flows at Selected Locations

Regulated flows remain fairly constant when comparing Run 4 to Run 1 and Run 6 to Run 3. Regulated flows in the Guadalupe River Basin are generally higher for Runs 5 and 7 than Runs 4 and 6, due to the substantially smaller authorized diversions included in the partial cancellation runs.

5.2.3 Current Conditions Run

The results for Current Conditions Run 8 are presented in Appendix VII. Reliability of supply for each right is presented in Table VII-1. Regulated and unappropriated flows for Run 8 are shown in Table VII-2 through VII-14. Graphical presentations of regulated and unappropriated flows at selected control points are shown in Figures VII-1 through VII-13. Reservoir storage traces for Canyon Reservoir, Medina Lake, Coleto Creek Reservoir, and Calveras Lake are displayed in Figures VII-14 through and VII-17.

5.2.3.1 Specific Large Rights

Tables 5-2 and 5-3 compare reliability summaries generated by each run for selected major rights in the Guadalupe River Basin held by GBRA (C2074), GBRA and Union Carbide (C5178), I.E. Du Pont (C3861), the City of Victoria (P5466); and major rights in the San Antonio River Basin held by BMA (C2130), CPS-Calaveras Lake (C2162), and the Bexar Metropolitan Water District (C4768). The reliability at the larger rights for the Current Conditions run (Run 8) is very similar to the results of Run 5.

5.2.3.2 Unappropriated Flows at Selected Locations

Tables 5-4 through 5-10 summarize annual regulated and unappropriated flows for each run at selected control points. Regulated and unappropriated flows for Run 8 are moderately greater than those in Run 1 throughout the Guadalupe-San Antonio River Basin, due to the reduced consumptive use in Run 8.

5.2.3.3 Regulated Flows at Selected Locations

The regulated flows for Run 8 are almost equal to those calculated in Run 5, largely because the total authorized diversions (max use last 10 years) included in both runs are approximately equal.

5.3 Comparison to Existing River Basin Models

5.3.1 Guadalupe-San Antonio River Basin Model

Although the existing Guadalupe-San Antonio River Basin Model (GSA) developed by HDR[109] was used to develop the basin-specific routines implemented in WRAP, the basic computation algorithms that compute water availability in each model are considerably different. WRAP is coded for strict application of the prior appropriation doctrine and, upon execution, analyzes each water right in order based on priority dates listed in the input file, regardless of location in the basin. Once WRAP finishes with this "priority loop," it has calculated water availability at each control point and the streamflow depletions or shortages associated with each water right listed in the main input file. GSA does not have a priority loop. In the monthly computation loop, GSA works from upstream to downstream without regard for seniority, and makes no availability calculations for individual water rights. However, GSA does differentiate between rights junior to and senior to Canyon Reservoir.

In order to compare the two models, it was necessary to modify the input parameters of the GSA Model so that they would correlate with the assumptions used in WRAP. Following are the modifications and assumptions used for building the GSA input files for comparison with WRAP:

- Conservation storage at the five major reservoirs (Canyon, Medina, Braunig, Calaveras, and Coleto Creek) was set equal to full authorized amounts;

[109] HDR Engineering, Inc. (HDR), "Guadalupe-San Antonio River Basin Recharge Enhancement Study," EUWD, September 1993.

- GBRA Canyon contracts were aggregated to two diversion locations (10,000 acft at Canyon Lake (CP03) and 40,000 acft at Guadalupe at New Braunfels (CP04));
- Naturalized inflows, evaporation rates, and springflows were the same for both models;
- Channel loss factors were changed from log functions (GSA) to straight percent of flows (WRAP); and
- Annual return flows were calculated based on monthly return flow records developed for WRAP.

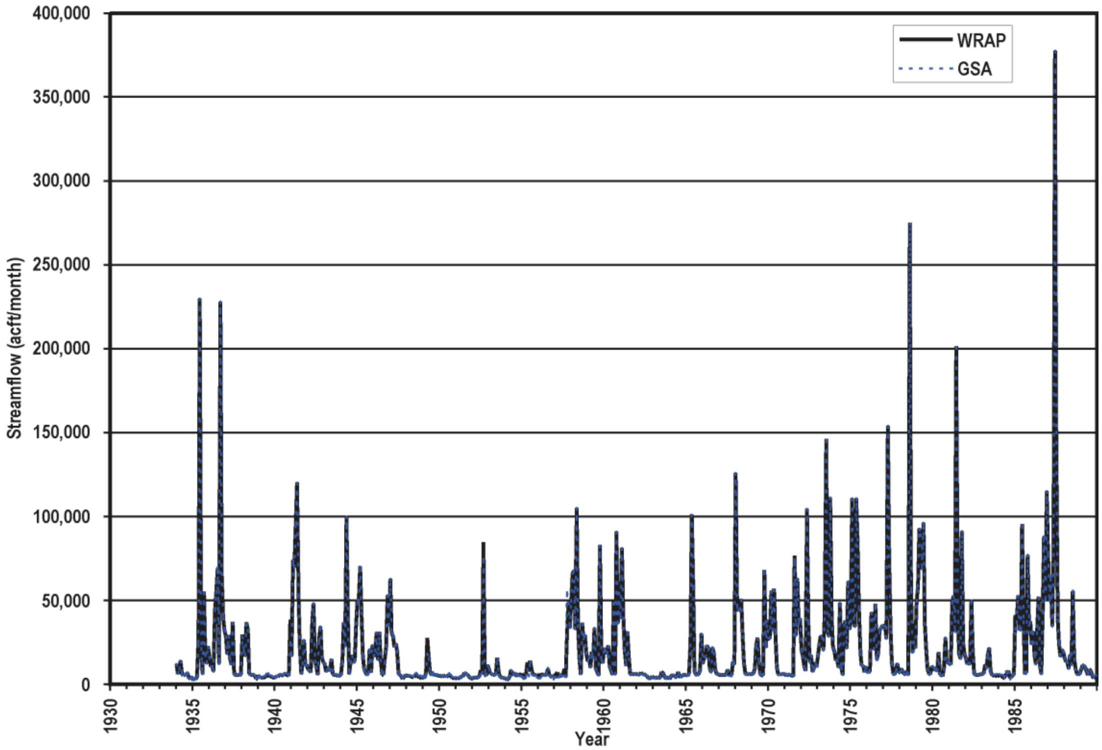
Modifications were also made to the WRAP input file. GSA does not typically model non-consumptive water rights, include instream flow requirements found in the special conditions of many water rights, or include any water rights that are upstream of and junior to Canyon Reservoir. These three components were removed from the WRAP input files so that comparison could be made.

5.3.1.1 Guadalupe-San Antonio River Basin Primary Control Points

Figures 5-1, 5-2, and 5-3 show time series plots and correlation plots for three primary control points in the Guadalupe-San Antonio River Basin. The plots compare the regulated flows calculated by GSA to those calculated by WRAP at Canyon Lake near Sattler (CP03), the Guadalupe River at Victoria (CP15), and the Guadalupe River at Tivoli (CP38). As displayed, there is very little difference between the outputs of the two models. At each location, WRAP predicts slightly higher regulated flows, which is expected due to the fundamental differences between the two models. Since the larger, more senior rights are located in the lower portion of the basin, the smaller junior rights in the upper basin must pass flows downstream in WRAP resulting in higher regulated flows; whereas, the GSA Model makes the upper basin diversions regardless of the demands in the lower basin resulting in lower regulated flows. Modeling return flows from smaller reservoirs associated with rights in the upper basin in WRAP and not in the GSA Model also causes WRAP to predict higher regulated flows.

5.3.1.2 Canyon Lake and Medina Lake Reservoirs

Figures 5-4 and 5-5 compare the WRAP and GSA time series traces and correlation plots for storage in Canyon Lake and Medina Lake, subject to equivalent conditions. As is apparent in these figures, agreement is very good between the models. Although every effort has been made



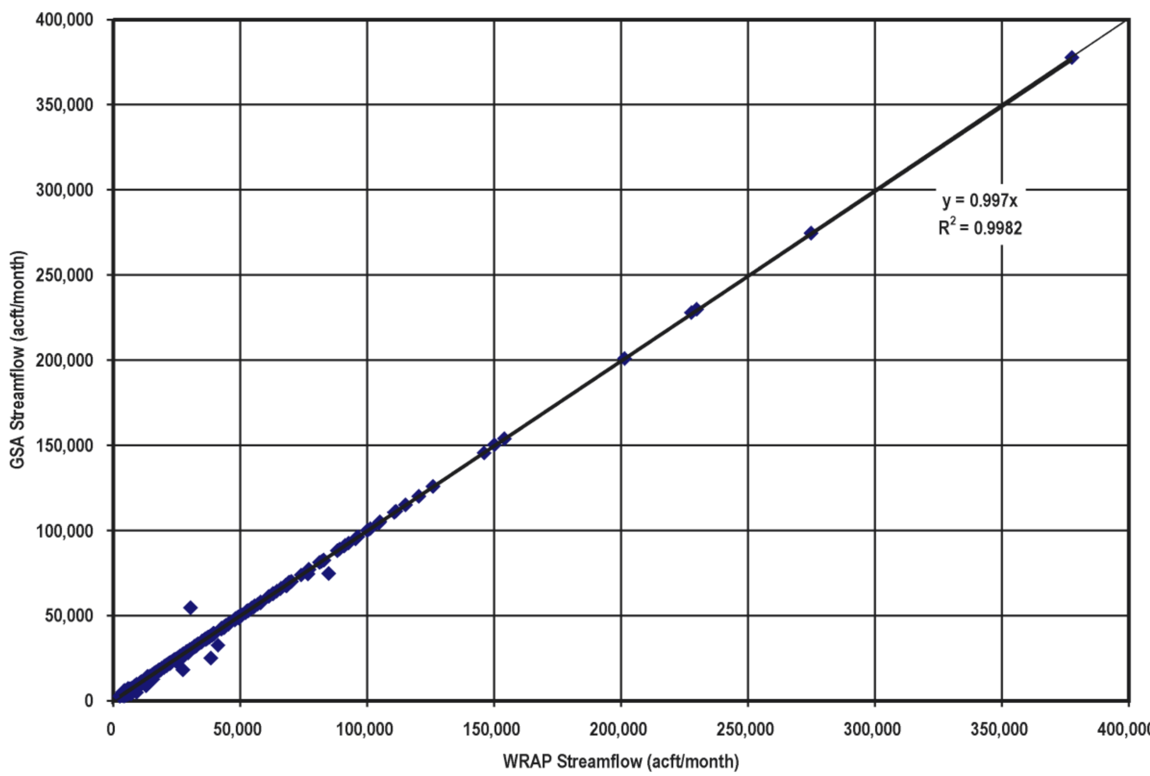


Figure 5-1. Regulated Flows at Canyon Lake near Sattler (CP03) WRAP vs. GSA

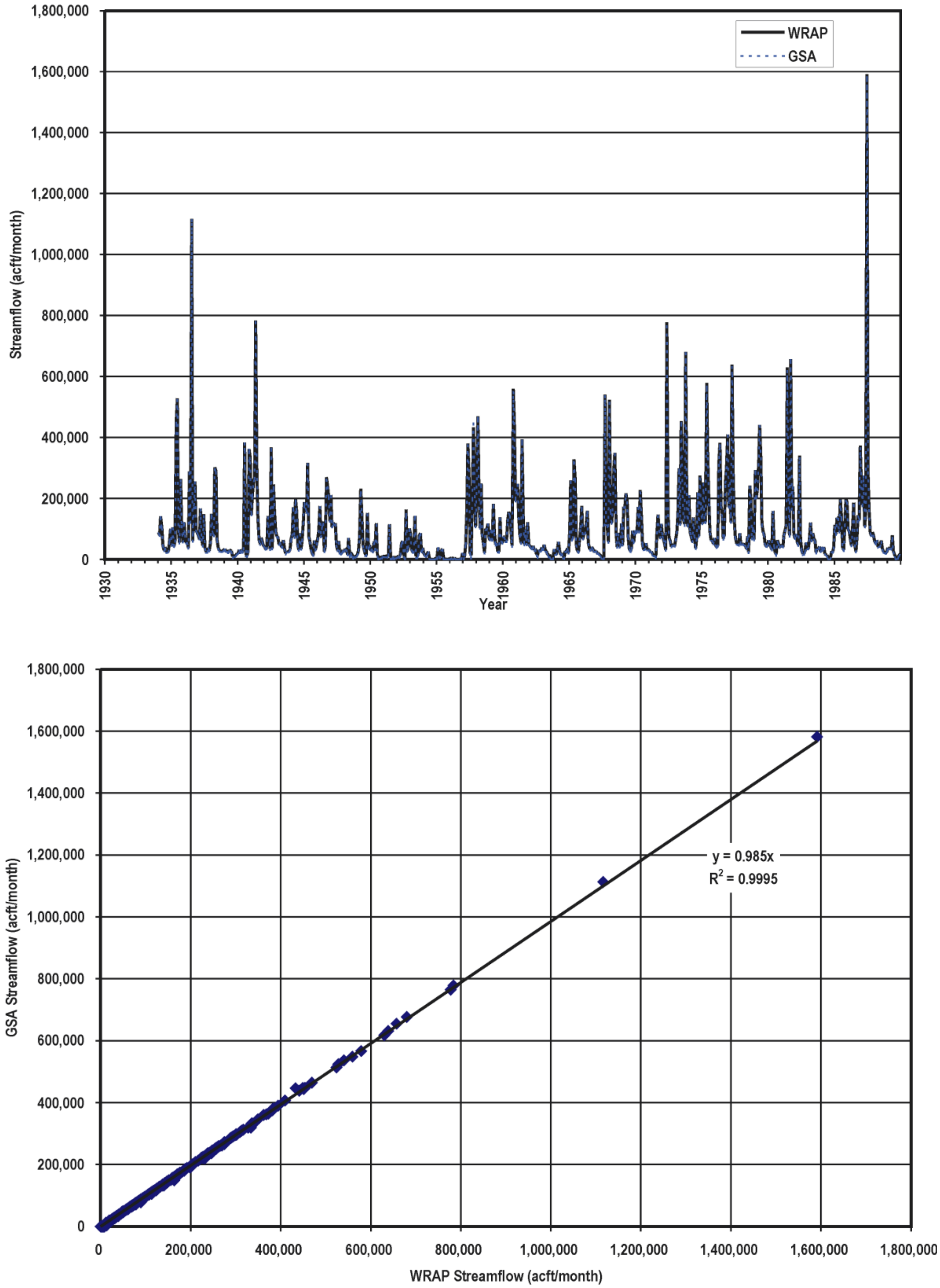


Figure 5-2. Regulated Flows at the Guadalupe River at Victoria (CP15) WRAP vs. GSA

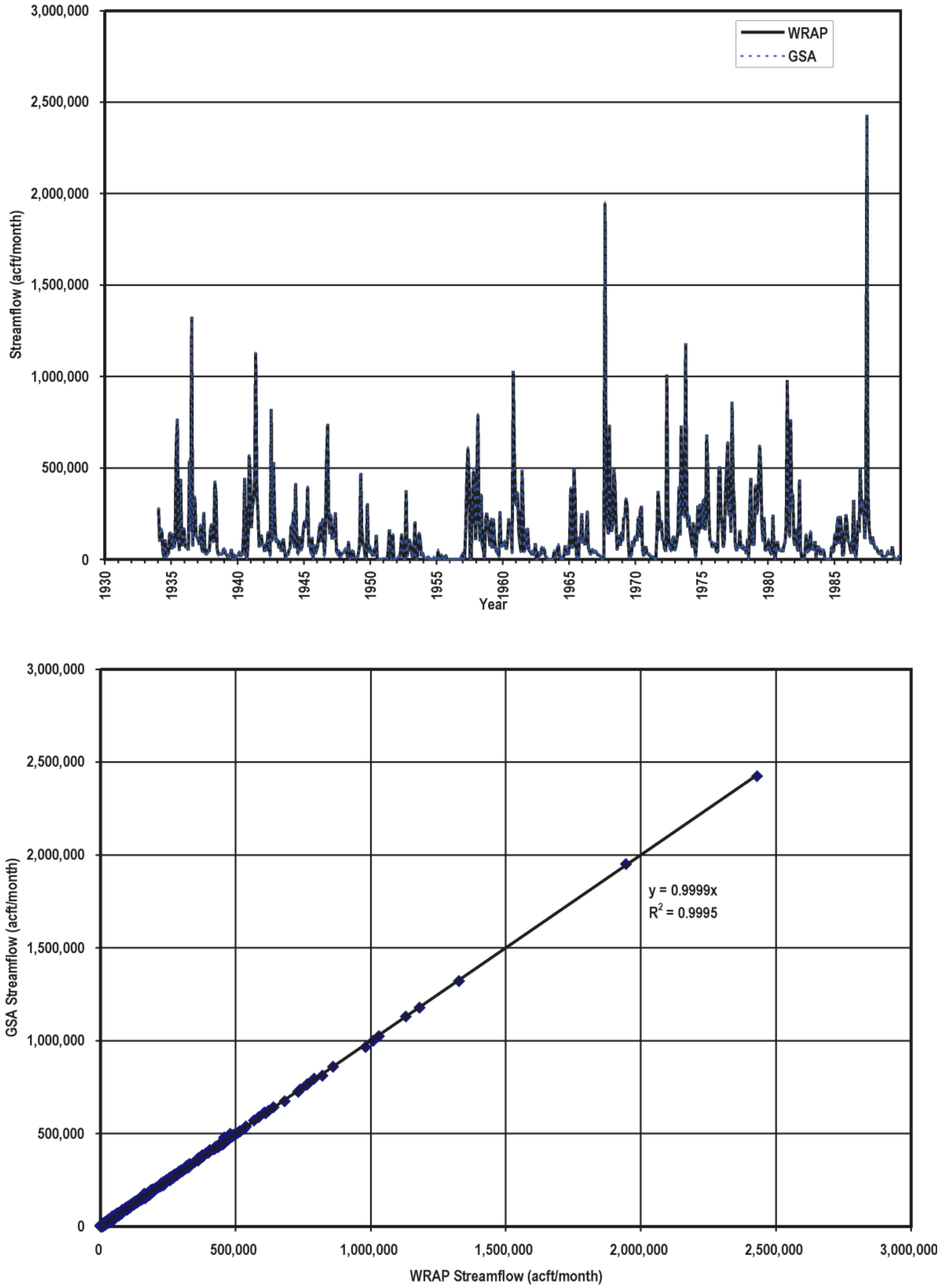
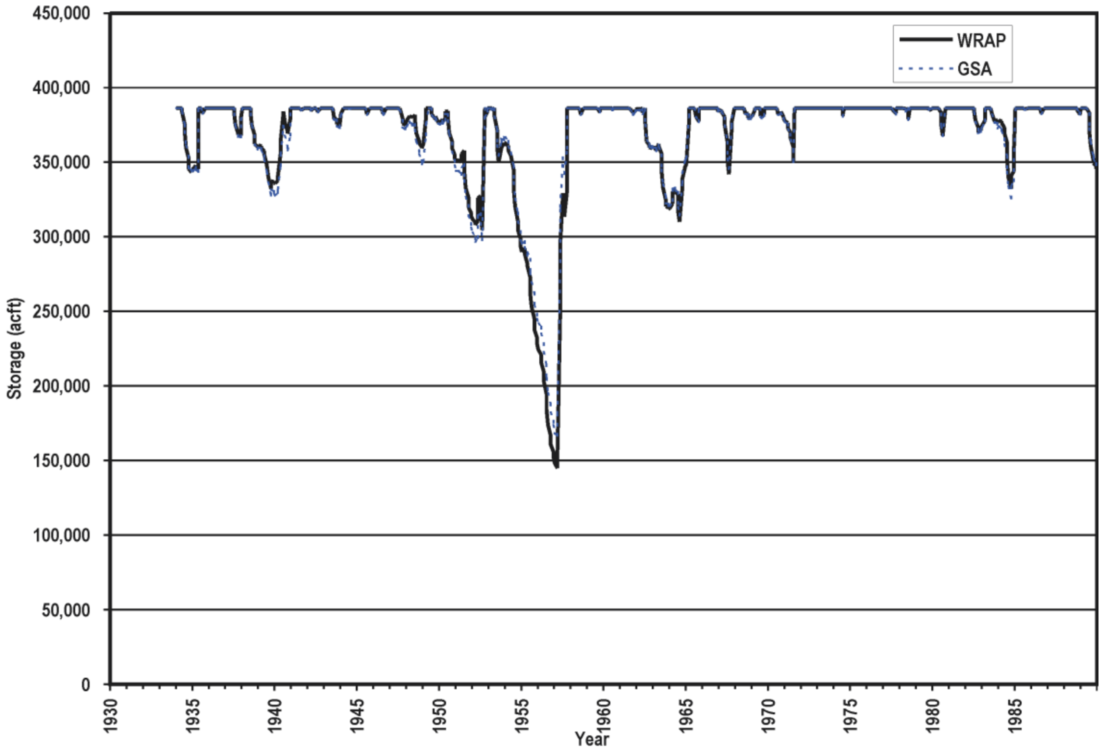


Figure 5-3. Regulated Flows at the Guadalupe River at Tivoli (CP38) WRAP vs. GSA



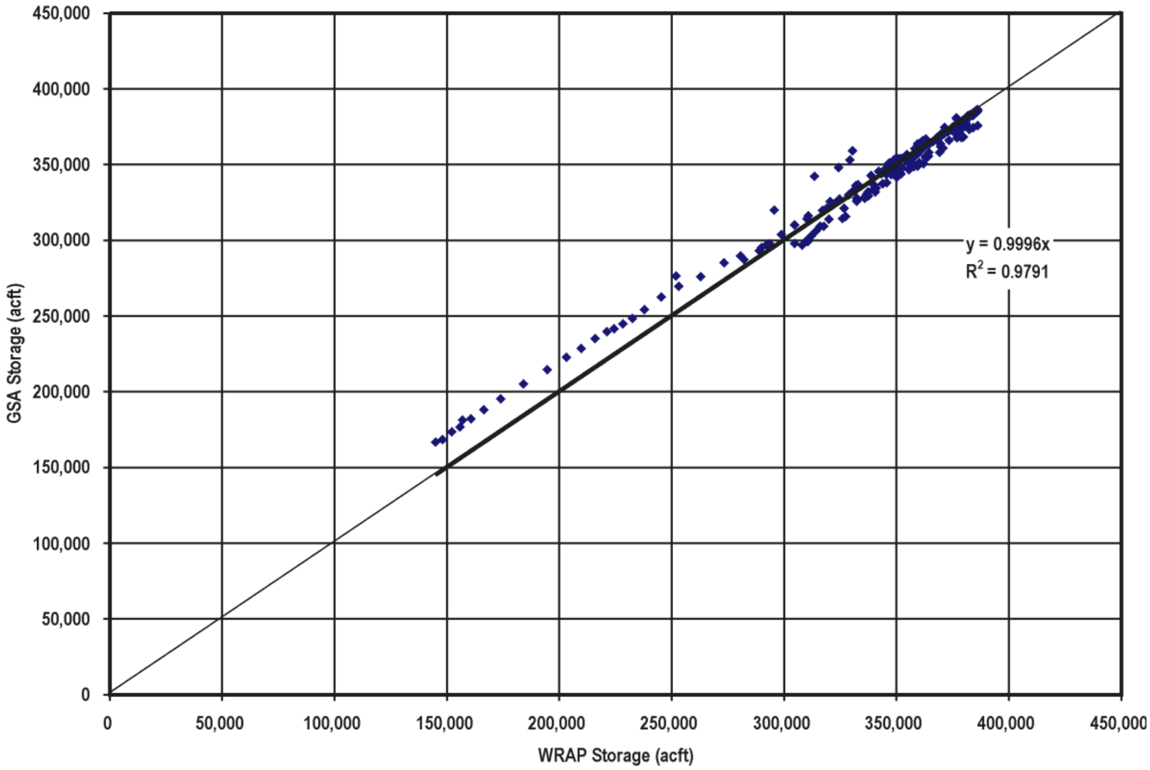
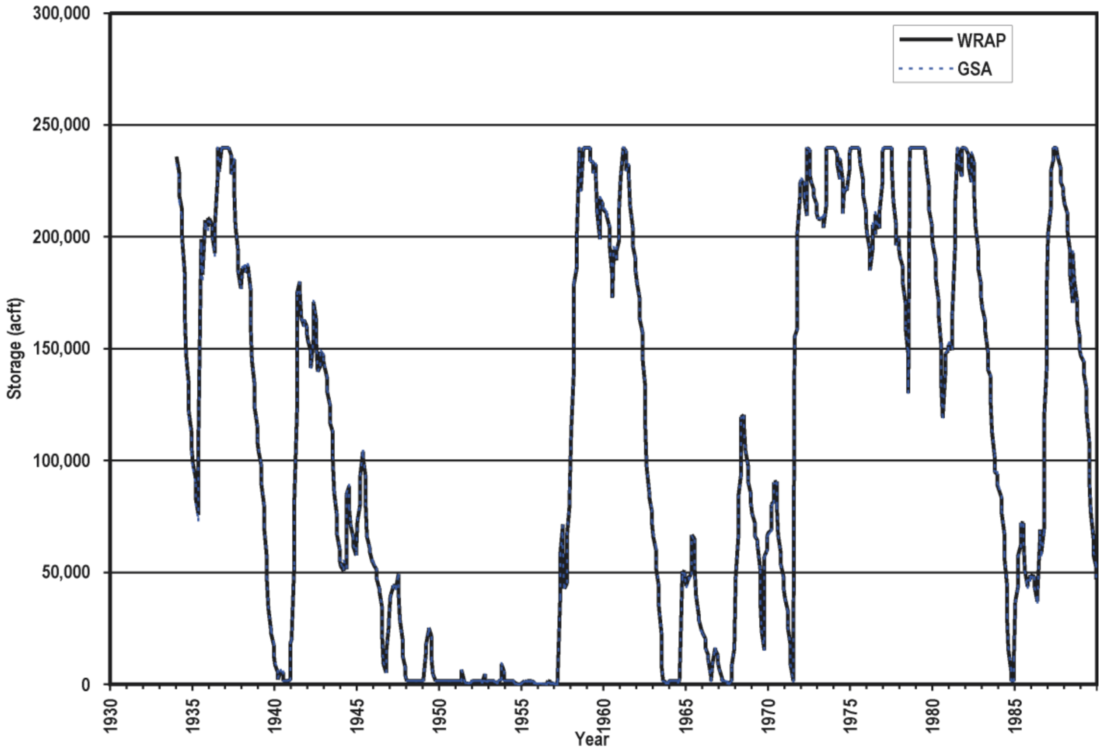


Figure 5-4. Canyon Lake Storage
WRAP vs. GSA



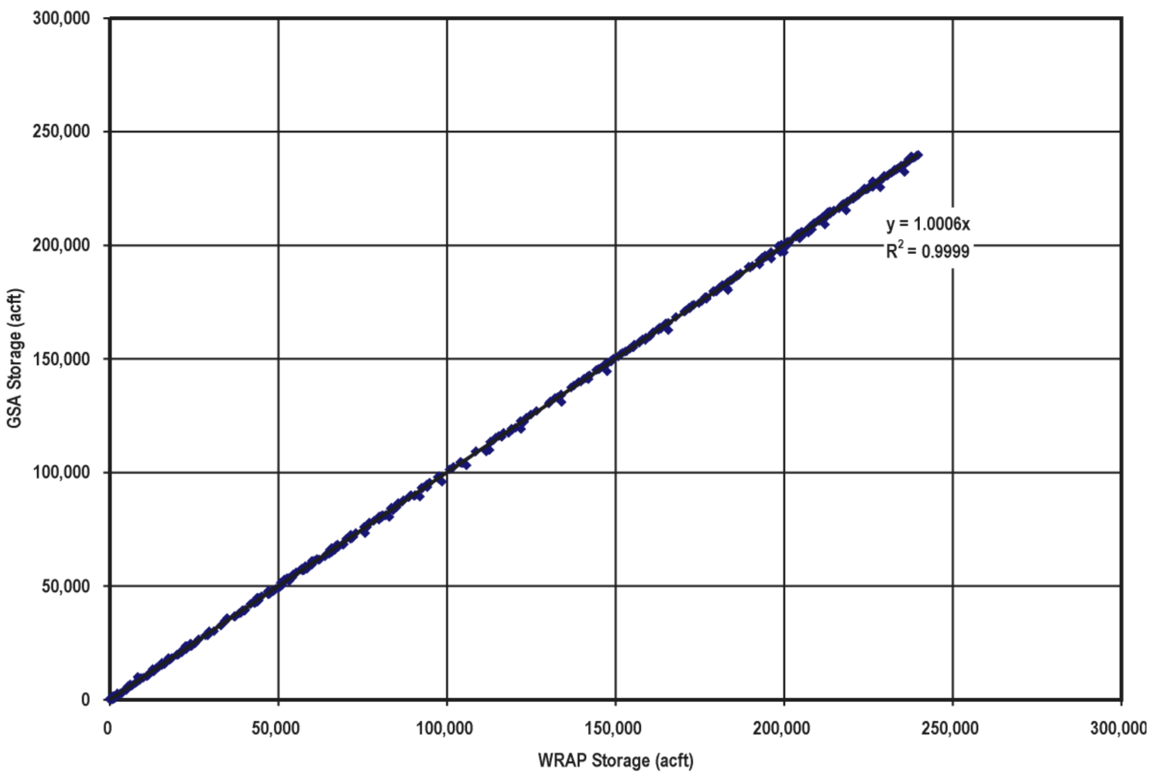


Figure 5-5. Medina Lake Storage WRAP vs. GSA

to compare models with equivalent assumptions, differences between the models remain. The most significant being the priority order in which water rights are met, and the locations at which diversions are placed. WRAP satisfies rights in order of date of priority and places diversion at their exact locations. GSA groups rights in three priority categories (senior to Canyon, Canyon, and junior to Canyon) and works from upstream to downstream. It also groups diversions at primary control points. These or other differences likely account for the very small differences at Canyon Lake. Note that the basic assumptions for these simulations were based on full subordination of downstream senior hydropower rights to Canyon Lake.

5.3.1.3 Edwards Aquifer Recharge

Table 5-11 compares first order statistics for each of the Edwards Aquifer recharge control points in WRAP and GSA. As shown in the table, WRAP output is very similar to GSA. The primary differences between the two models are attributable to the different methods for calculating channel losses and the handling of the recharge reservoir on San Geronimo Creek.

GSA uses a logarithmic relationship between flow and channel loss, whereas, WRAP assumes a linear relationship with flow. For gaged recharge control points (CP04, CP09, and CP34), the regulated flows used in the recharge calculations are not the same between the two models, due to the different treatment of channel losses. Hence, the recharge estimates vary between the two models at these locations.

For the recharge reservoirs, GSA assumes that all inflows up to the specified storage volume are recharged in a single month. In WRAP, the recharge structures are only allowed to recharge up to their annual permitted amounts. Once the annual permitted amount is recharged in a year, the structure is not allowed to recharge later in the year even though water may be available and, in reality, would have recharged. The total recharge numbers in Table 5-11 for San Geronimo Creek (CP25) reflect this difference. At this location, GSA allows more recharge to occur at the structures than WRAP as shown in Figure 5-6. At this structure, GSA allows up to 271 acft/month to recharge, whereas WRAP only allows a maximum annual authorized recharge of 961 acft. Since WRAP models the San Geronimo Creek structure as a water right, the quantity of recharge is also influenced by the application of the Prior Appropriation Doctrine. There are times when GSA allows the structure to capture flow that WRAP must pass to more senior downstream water rights.

Table 5-11.
Estimated Annual Recharge in the Guadalupe River Basin (acft)
WRAP vs. GSA

Control Point	Location	Maximum		Minimum		Mean		Median		Total	
		WRAP	GSA	WRAP	GSA	WRAP	GSA	WRAP	GSA	WRAP	GSA
CP04	Guadalupe River, New Braunfels	32,290	32,360	0	0	9,261	9,305	4,593	6,678	518,591	521,063
CP05	Comal River, New Braunfels	127,235	127,235	4,006	4,006	48,923	48,923	41,169	41,169	2,739,676	2,739,676
CP71, CP72, CP73, CP74	Sink, Purgatory, York, and Alligator Creeks	101,010	101,375	3,997	4,005	41,245	41,330	34,968	35,055	2,309,706	2,314,493
CP09	Blanco River, San Marcos	53,519	53,723	11,817	11,363	26,547	26,676	25,060	25,140	1,486,617	1,493,849
CP17	Olmos Creek, San Antonio	5,502	5,502	87	87	2,056	2,056	1,776	1,776	115,114	115,114
CP19	Salado Creek, San Antonio	133,221	133,440	10,812	10,572	50,433	50,366	39,817	39,758	2,824,238	2,820,510
CP21	Medina Lake	35,133	35,137	1,575	1,380	22,541	22,577	25,295	25,320	1,262,293	1,264,332
CP22	Tributaries to Diversion Lake	10,306	10,306	164	164	3,850	3,850	3,326	3,326	215,590	215,590
CP23	Diversion Lake	16,896	16,896	979	1,055	15,293	15,192	16,896	16,817	856,402	850,756
CP241, CP242	Tributaries downstream of Diversion Lake	8,588	8,588	137	137	3,208	3,208	2,772	2,772	179,664	179,664
CP25	San Geronimo Creek	34,073	35,269	610	906	12,507	14,093	11,197	12,690	700,370	789,210
CP261, CP262, CP263	Leon, Helotes, and Government Creeks	57,638	57,639	1,059	1,058	22,555	22,555	19,863	19,863	1,263,062	1,263,057
CP34	Cibolo Creek, Selma	148,084	148,245	9,584	1,683	63,619	63,092	60,351	61,342	3562674	3,533,138

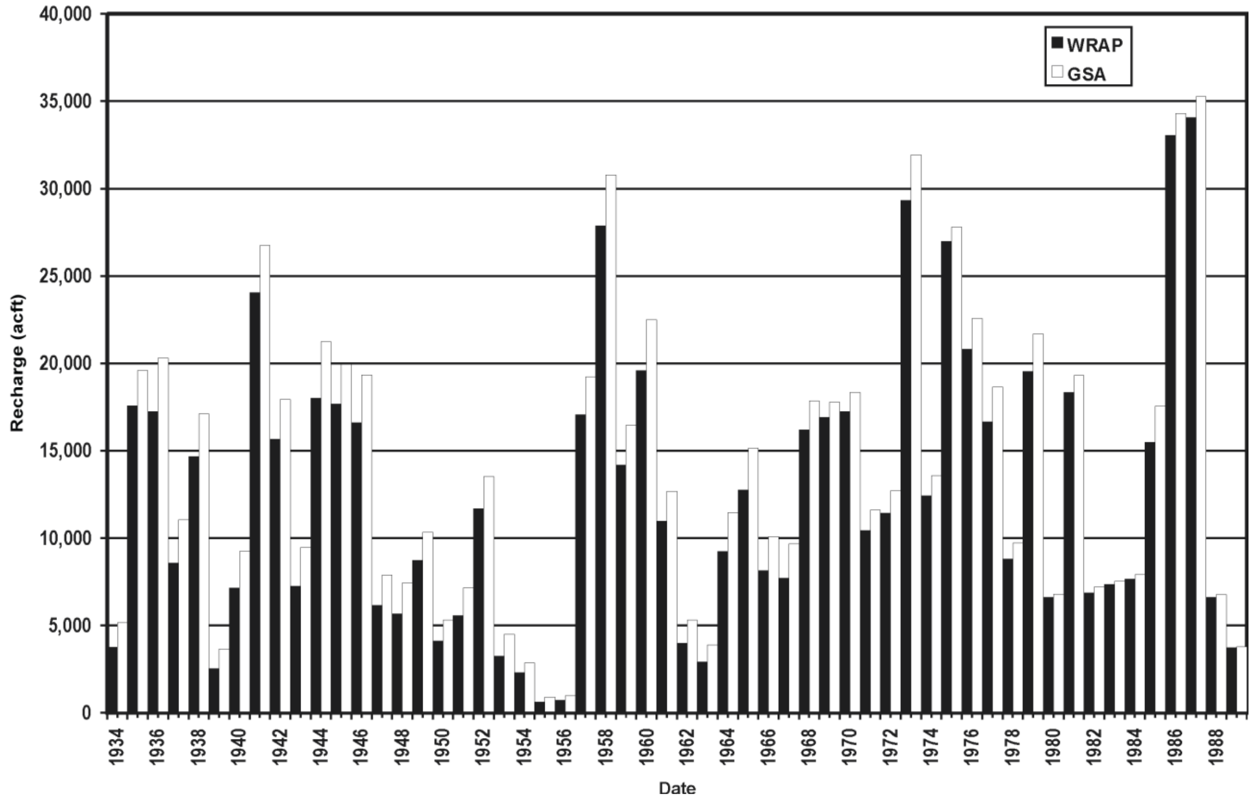


Figure 5-6. Annual Recharge at CP25, San Geronimo Creek WRAP vs. GSA

5.3.2 Existing TNRCC Water Availability Model

The assumptions, modeling methodologies, and data utilized in the existing TNRCC Water Availability Model (Legacy WAM) are substantially different from those used in the WRAP model described herein. The Legacy WAM utilized a considerably shorter period of simulation (1940 to 1979); does not account for channel losses; treats operations of the Medina Lake System, Canyon Reservoir, and other major reservoirs differently; and includes fewer rights than WRAP. Hence, comparisons between the two models may be of limited utility. Since output from the last runs of the Legacy WAM has been relied upon for permitting, however, simple comparisons of results at a few key locations are warranted. Output data from Run 1 from the revised Guadalupe-San Antonio River Basin Legacy WAM (RG-1983) were obtained from a CD-ROM published by the TNRCC.[110] In this model run, the documentation

[110] TNRCC, "TNRCC Documentation for Legacy Water Availability Models Used for Water Rights Permitting," June 25, 1998.

provided by the TNRCC states that hydroelectric rights are given priority based on their actual dates of priority, and return flows from the City of San Antonio are allowed to satisfy downstream water rights. These assumptions most closely match those utilized in Run 1 of this study; therefore, model comparisons herein are based on Run 1 from each of the models.

Figure 5-7 compares annual unappropriated flows for the Guadalupe River at Cuero (CP14) and the San Antonio River at Falls City (CP32) for years 1940 to 1979. During dry years at both locations, unappropriated flows computed by the Legacy WAM are consistently greater than those computed by WRAP. During wet years, unappropriated flows computed by WRAP at Falls City are usually greater than those computed by the Legacy WAM; while at Cuero, unappropriated flows computed by the models do not differ in a consistent pattern.

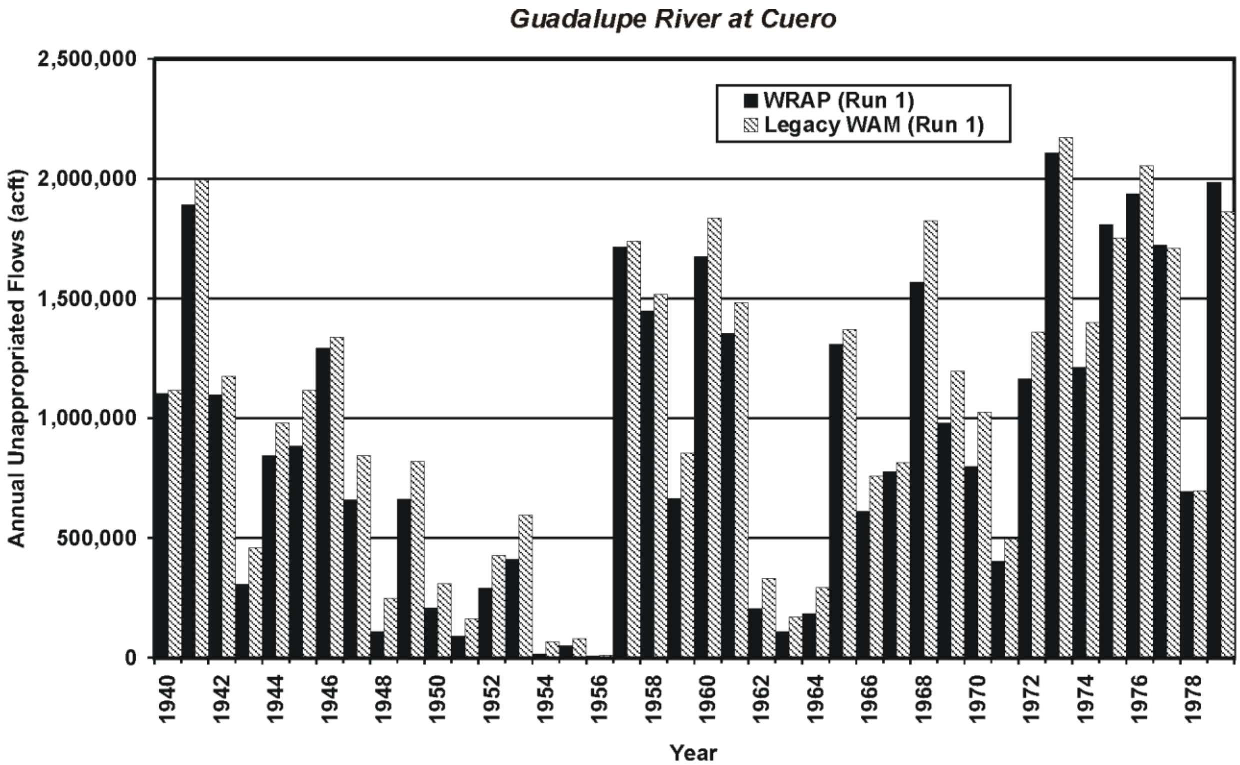
Figure 5-8 illustrates significant differences between annual diversions met for the GBRA right at Canyon Reservoir (Certificate of Adjudication C2074) during drought years. The average annual diversion met by the right as computed by the Legacy WAM (48,946 acft/yr) is greater that that computed by WRAP (47,186 acft/yr). In all but four years, both models simulate the full authorized diversion being met. However, in years 1952 and 1955-57, the WRAP model simulates a significantly smaller annual diversion met from Canyon Reservoir.

Previous experience and the results of this study have shown that the reliability of the Canyon Reservoir right computed solely by monthly flows is greatly dependent on the treatment of the downstream senior hydropower rights. Assumptions utilized in the Legacy WAM[111,112] are stated to be consistent with those utilized for Run 1 in WRAP (i.e., that the full annual authorized diversion amount for the senior hydropower rights be honored on a monthly basis). Therefore, these differences cannot be explained by differences in the treatment of the senior hydropower rights, as both were treated identically.

Limited analysis of the TNRCC Legacy WAM output shows large inconsistencies between computed inflows to Canyon Reservoir and those that the reservoir would be expected to pass in order to honor the downstream senior hydropower rights. Detailed explanation is beyond the scope of this report. However, in summary, two items of note are apparent:

1. In contradiction to the documentation of the Legacy WAM, the Canyon Reservoir right does not appear to honor downstream senior hydropower rights in a manner consistent with conventional methodologies; and

[111] TDWR, Revised Interim Report of Water Availability in the Guadalupe River Basin, Texas, March 1983.
[112] TDWR, Revised Interim Report of Water Availability in the San Antonio River Basin, Texas, 1983.



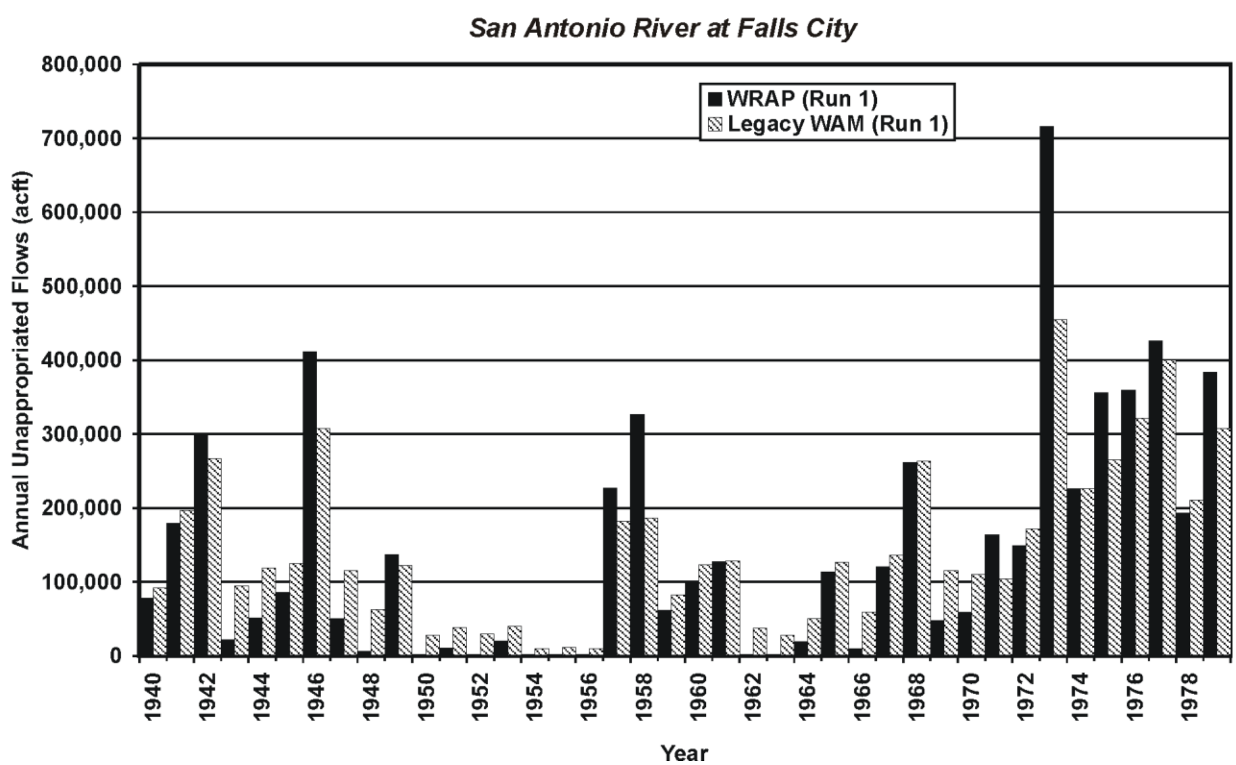


Figure 5-7. Annual Unappropriated Flows

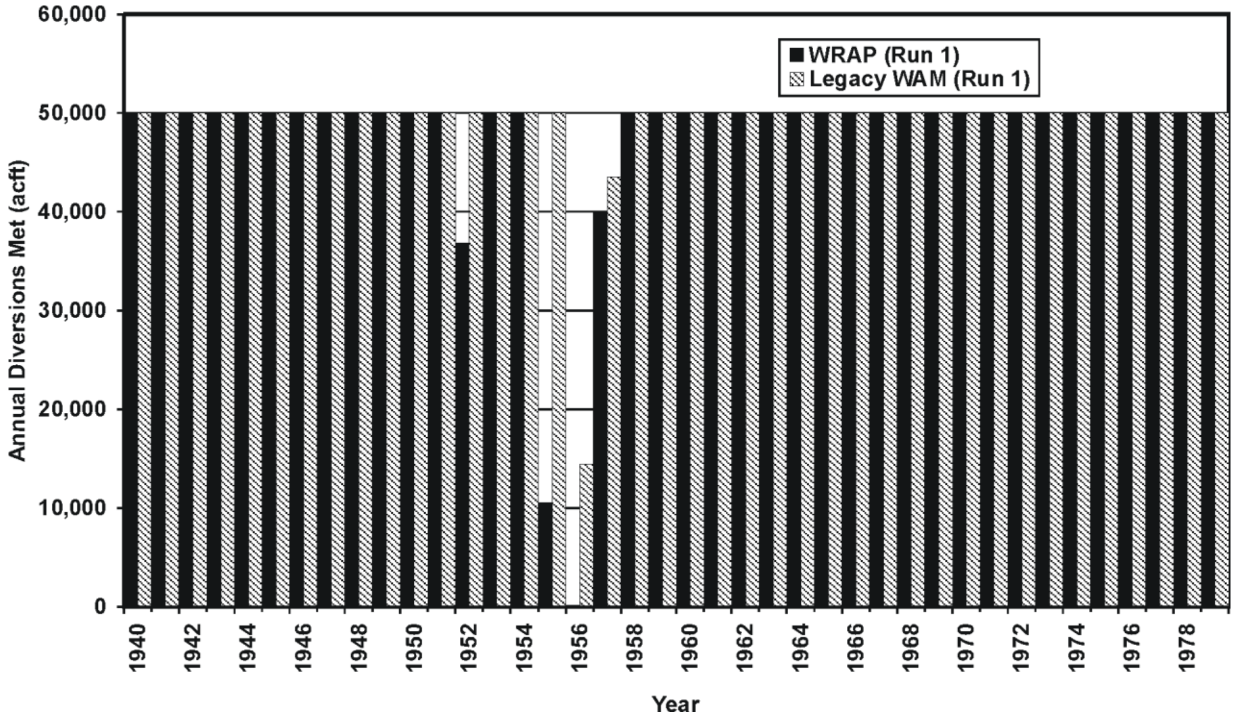


Figure 5-8. Annual Diversions Met by Certificate of Adjudication C2074

2. Mass balance computations for several months for Canyon Reservoir that take into account beginning and ending storages, evaporation losses, inflows and outflows, and diversions met by the Canyon Reservoir right result in correct mass balances only when Canyon Reservoir is full at the beginning and end of a month. In months where Canyon Reservoir is not full, portions of Canyon Reservoir inflows are apparently "lost" from the mass balance. This water does not appear downstream of Canyon Reservoir and effectively disappears from the model. Water is lost from the mass balance both in dry and wet months, and when Canyon Reservoir is nearly full and nearly empty. The quantity of inflow lost is not consistent among the months considered, and does not appear to represent water lost to the Edwards Aquifer. No clear explanation of these apparent discrepancies in the Legacy WAM is available at this time.

5.4 Factors Affecting Water Availability and Modeling Results

As shown by the results from the various cancellation runs, the most influential factor that affects the overall water availability in the Guadalupe-San Antonio River Basin is the assumption concerning authorized versus maximum historical use. Treated effluent discharges in the San Antonio River Basin are significant, and the three reuse scenarios (Runs 1, 2, and 3) result in significant differences in regulated and unappropriated flows downstream of the City of San Antonio. Cancellation of rights showing 10 years of nonuse in Runs 4 and 6 does not significantly affect overall water availability in the basin because none of the cancelled rights are of consequential size. None of the larger rights in the basin were assumed cancelled in Runs 4 and 6. However, very few rights in the Guadalupe-San Antonio River Basin have been fully perfected, and a considerable amount of water could be considered available for temporary appropriation on an interruptible basis, depending on the location in the basin.

Water availability in the Guadalupe River Basin is greatly influenced by assumptions concerning the senior hydropower rights. These rights are some of the most senior in the basin, and represent more than 85 percent of the authorized diversions in the Guadalupe River Basin. Limiting their annual authorized diversions to their maximum reported use (a 40 percent reduction) and honoring those on a monthly basis has a similar effect to subordinating the rights to Canyon Reservoir.

The impact of the partial cancellation can also be seen in Figure 5-9. Annual make-up diversions from the Guadalupe River into Coleto Creek Reservoir are substantially reduced in most years when the annual authorized diversion is reduced to the maximum use.

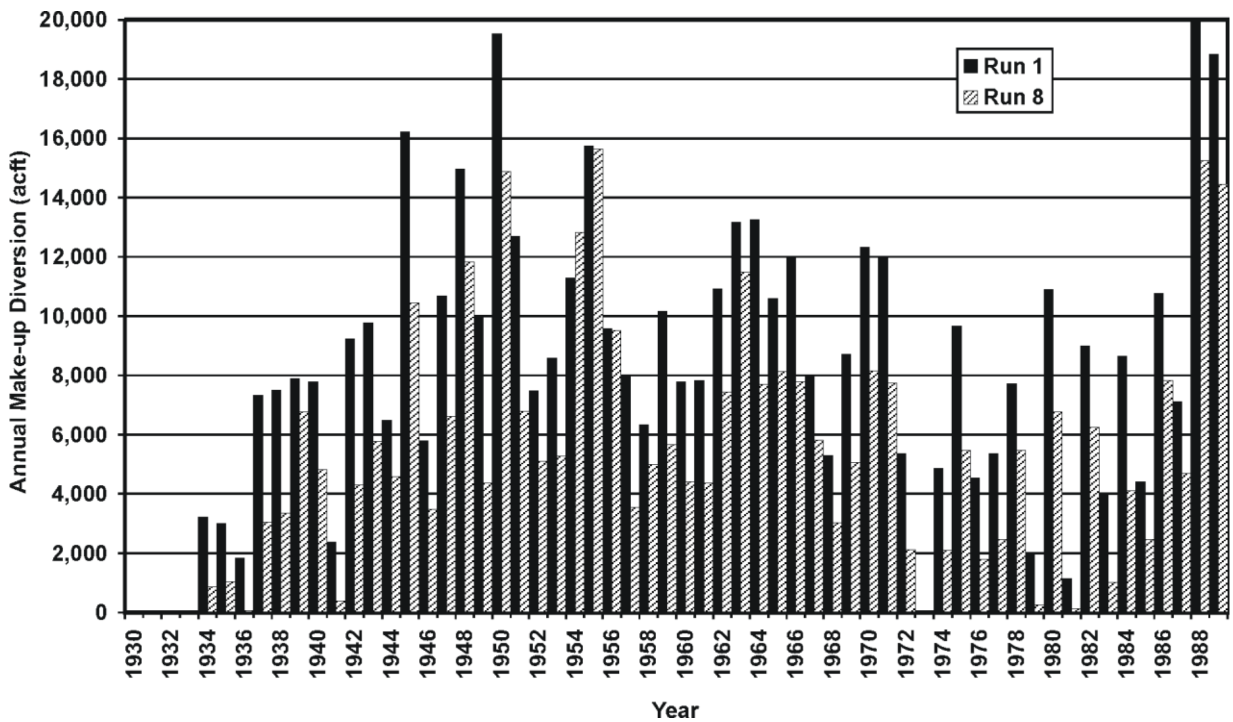


Figure 5-9. Annual Make-up Diversions from the Guadalupe River to Coleto Creek Reservoir

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 flows to the Guadalupe Estuary, will be considered when granting new water rights or amending existing water rights, thereby affecting the amount of water available for appropriation.

5.5 Requirements for Model Rerun and/or Model Update

Input data sets for each of the scenarios modeled have been transmitted to the TNRCC. The water availability model can be rerun using these data sets and the basin-specific, modified WRAP code developed by HDR. Specific requirements for model reruns and updates to this model are documented in Appendix IX (bound separately). Additional rights or modifications to specific existing rights not associated with Canyon Reservoir, the Medina Lake System, Calaveras Lake, or the City of Victoria permit can be readily incorporated into the data sets provided. Modifications to existing rights associated with Canyon Reservoir, the Medina Lake System, Calaveras Lake, or the City of Victoria permit should be incorporated with due consideration given to the basin-specific modifications associates with those rights.

Section 6
Summary and Conclusions

Water availability in the Guadalupe-San Antonio River Basin is affected by assumptions regarding water management and use, in addition to natural hydrologic influences such as rainfall, runoff, and evaporation. SB1 requires assessment of the sensitivity of water availability to key water management and use assumptions including reuse of treated wastewater effluent and cancellation of all or portions of rights showing little or no recent use. Sensitivity of water availability in the Guadalupe-San Antonio River Basin to these water management assumptions is addressed by comparisons between simulation results for eight alternative scenarios defined by TNRCC and identified as Run 1 through Run 8.

Runs 1, 2, and 3 address the sensitivity of water availability and regulated streamflows to three alternative reuse scenarios: current levels (Run 1), 50 percent reuse (Run 2), and 100 percent reuse (Run 3). Run 1 included treated effluent discharges representative of current conditions. For Runs 2 and 3, these effluent discharges are reduced by 50 and 100 percent to reflect 50 and 100 percent reuse of current levels of treated effluent discharge.

Runs 4, 5, 6, and 7 address the sensitivity of water availability and regulated streamflows to two different water rights cancellation scenarios. Run 4 assumes that those rights showing no use for the past 10 years are cancelled, while rights showing use remain in the model at their full authorized diversion amounts. Run 5 assumes that the authorized diversions of all rights are reduced to their maximum reported use during the preceding 10-year period. Runs 4 and 5 reflect current levels of reuse. Runs 6 and 7 are identical to Runs 4 and 5, respectively, except that 100 percent reuse is assumed.

Term permits are excluded from Run 1 through Run 7, and reservoir storage capacities are assumed to be as permitted.

Run 8 addresses the availability of water assuming current conditions. In Run 8, authorized diversions for all rights are reduced to their maximum use between 1987 and 1997, and surveyed reservoir storage capacities are modified to reflect sediment accumulation representative of the year 2000. Term permits are included at their maximum use between 1987 and 1997.

Simulation results for the various scenarios modeled indicate that cancellation of only those rights showing no use affects water availability very little in the Guadalupe-San Antonio River Basin. Reuse of treated effluent reduces the availability of water to rights in the San Antonio River Basin significantly, but has limited effects on rights in the Guadalupe River Basin. Large discharges of treated effluent from multiple wastewater plants operated by the San Antonio Water System (SAWS) originate from groundwater pumped from the Edwards Aquifer. The wastewater treatment plants operated by SAWS discharge an aggregate mean annual volume of treated effluent that is equivalent to about 52 percent of the mean annual naturalized flow of the San Antonio River at Elmendorf (CP29).

The most influential factor affecting overall water availability in the Guadalupe-San Antonio River Basin is the assumption concerning authorized versus maximum historical use in Runs 5, 7, and 8. Significant increases in overall water availability would result from limitation of authorized diversions to their maximum reported use between 1987 and 1997. Very few rights in the Guadalupe-San Antonio River Basin have been fully utilized, and considerable volumes of interruptible water could be available for temporary appropriation, depending on location in the basin. Currently, the total amount of authorized diversions for term permits in the Guadalupe-San Antonio River Basin is small, and inclusion of term permits in Run 8 has no significant effect on water availability.

Water availability in the Guadalupe-San Antonio River Basin is also greatly influenced by assumptions concerning the hydropower rights on the Guadalupe River downstream of Canyon Reservoir. The largest of these rights is approximately 1.75 times greater than the total annual authorized consumptive use in the Guadalupe River Basin. For partial cancellation scenarios Run 5 and Run 7, authorized annual diversions for the senior hydropower rights are reduced by about 40 percent, the reliability of the right associated with Canyon Reservoir significantly increases, and storage in Canyon Reservoir does not fall below about 150,000 acft at any time in the simulation. Reducing the annual authorized diversions for the senior hydropower rights and honoring them on a monthly basis has essentially the same effect as subordinating those rights to Canyon Reservoir.

Substantial quantities of water remain available for appropriation at many locations in the Guadalupe-San Antonio River Basin. While large quantities of unappropriated flows occur frequently in all simulations, unappropriated flows are limited, or zero, at some locations during severe drought periods. Above Canyon Reservoir, the minimum and median annual unappropriated flows are zero for most runs, primarily due to flows having to be passed to honor storage in Canyon Reservoir and to honor the large downstream hydropower rights held by the GBRA and the City of Seguin. Below the confluence of the San Antonio and Guadalupe Rivers at the saltwater barrier (CP38), approximately 49,400 acft/yr and 1,362,000 acft/yr are the respective minimum and median annual unappropriated flows for Run 3. These flows could be available for diversion or impoundment, however, any new water right granted by the TNRCC will be subject to environmental flow needs including instream flows and freshwater inflows to the Guadalupe Estuary. These environmental flow needs will reduce the availability of water for diversion or impoundment. In general, applicants for new water rights will need storage or a supplemental source of supply to create a dependable, consistent supply of water during drought periods.

Considering water use records for years 1987 through 1997 and neglecting hydropower rights and the non-consumptive steam-electric cooling right held by Central Power and Light on the Guadalupe River, the total volume of authorized diversions (682,476 acft/yr) in the Guadalupe-San Antonio River Basin is currently about 65 percent (445,873 acft/yr) utilized. The difference between unappropriated flows for Run 8 and Run 3 at any given location is an indication of the quantity of water that might be available for temporary, or term, appropriation. This water would be available due to the differences between current levels of water use and return flows (Run 8) and fully authorized levels of water use and zero return flows (Run 3). As existing water rights become more fully utilized in the future and reuse projects more prevalent, the difference in unappropriated flows between Run 8 and Run 3 will decrease and opportunities for term appropriation will also decrease. Quantities of water available for term appropriation vary considerably throughout the basin. At the saltwater barrier, the difference between the minimum annual unappropriated flows for Run 8 and Run 3 suggests that at least 74,000 acft of run-of-river diversion might be available for appropriation on a term basis. Additional flows could be available on an interruptible basis.

Full cancellation of unutilized rights (Runs 4 and 6) would not significantly increase water available for new appropriation. Most rights in the basin exhibit use that is less than that authorized. Partial cancellation of these underutilized rights (Runs 5 and 7) would increase the reliability of other rights and could increase availability in the Guadalupe-San Antonio River

Basin for new appropriations. Such new appropriations would, however, be subject to environmental flow needs. As most existing rights are not subject to environmental flow needs, partial cancellation of presently underutilized rights would convert a portion of the rights presently available for future increases in demand (or for transfer to others in need of additional supply, but lacking water rights) to enhanced instream flows and freshwater inflows to the Guadalupe Estuary.

Tables 6-1 and 6-2 summarize increases in minimum and mean annual unappropriated flows at several key control points for each of the cancellation and reuse scenarios. Assuming that new run-of-river diversion permits would be based, in part, on minimum available unappropriated flows (Table 6-1), cancellation of unutilized or underutilized portions of rights would increase unappropriated flows available for run-of-river diversion at lower control points in the Guadalupe River Basin, and could result in very limited additional available flows in the lower San Antonio River Basin. Assuming that mean annual unappropriated flows indicate the viability of new rights firmed up with storage (Table 6-2), full cancellation of unutilized rights would increase long-term average water availability for new rights by a maximum of about 6 percent. Partial cancellation of underutilized rights would provide a greater increase in long-term average water availability for new rights prior to consideration of environmental flow needs, but the increases vary considerably throughout the basin.

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

Table 6-1.
Effects of Full and Partial Cancellation of Unutilized and Underutilized Rights on Minimum Annual Unappropriated Flows

		Difference in Minimum Annual Unappropriated Flows			
		Current Return Flows		*No Return Flows (100 percent Reuse)*	
	Control Point	*(acft)*	*(percent)*	*(acft)*	*(percent)*
		Increase from Run 1 to Run 4		**Increase from Run 3 to Run 6**	
Full Cancellation of Unutilized Rights	CP02	—[1]	—[1]	—[1]	—[1]
	CP10	—[1]	—[1]	—[1]	—[1]

	CP14	3,166	75.5	3,115	97.7
	CP27	—[1]	—[1]	—[1]	—[1]
	CP32	—[1]	—[1]	—[1]	—[1]
	CP38	11,244	16.8	7,508	15.2
Partial Cancellation of Underutilized Rights (includes full cancellation of unutilized rights)		Increase from Run 1 to Run 5		Increase from Run 3 to Run 7	
	CP02	—[1]	—[1]	—[1]	—[1]
	CP10	—[1]	—[1]	—[1]	—[1]
	CP14	5,252	125.3	3,708	116.3
	CP27	196	N/A[2]	—[1]	—[1]
	CP32	1,966	N/A[2]	—[1]	—[1]
	CP38	56,356	84.1	21,788	44.1

[1] Indicates no increase in minimum annual unappropriated flows.
[2] N/A indicated that Run 1 had zero minimum annual unappropriated flows, and a percentage increase cannot be computed.

Table 6-2.
Effects of Full and Partial Cancellation of Unutilized and Underutilized Rights on Mean Annual Unappropriated Flows

		Difference in Mean Annual Unappropriated Flows			
		Current Return Flows		*No Return Flows (100 percent Reuse)*	
	Control Point	*(acft)*	*(percent)*	*(acft)*	*(percent)*
Full Cancellation of Unutilized Rights		**Increase from Run 1 to Run 4**		**Increase from Run 3 to Run 6**	
	CP02	454	1.2	454	1.2
	CP10	989	0.6	960	0.6
	CP14	10,671	1.2	10,523	1.2
	CP27	5,031	6.9	4,010	6.5
	CP32	8,705	5.6	6,107	5.2
	CP38	49,496	2.9	46,610	2.9
Partial Cancellation of Underutilized Rights (includes full cancellation of unutilized rights)		**Increase from Run 1 to Run 5**		**Increase from Run 3 to Run 7**	
	CP02	96,917	250.3	95,330	254.7
	CP10	18,575	12.0	18,469	12.1
	CP14	33,189	3.6	32,724	3.6
	CP27	14,341	19.7	9,292	15.0
	CP32	36,389	23.2	13,621	11.5
	CP38	162,814	9.7	137,839	8.6