Water Availability in the Nueces River Basin

Water Rights on Record as of January 7, 1999 (Priority dates through April 23, 1997)

Prepared in Cooperation with the

Texas Natural Resource Conservation Commission

The preparation of this report was financed through funds in part or in whole from the Texas Natural Resource Conservation Commission

TNRCC Contract No. 9880059200

Prepared by

HDR

HDR Engineering, Inc.

October 1999

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Kenneth L. Choffel, P.E

Samuel K. Vaugh, P.E.

David D. Dunn, P.E.

HDR Engineering, Inc.

October 1999

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Executive Summary

ES.1 Study Objectives

Pursuant to Senate Bill 1 (SB1) 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 SB1 and include the following:

- Develop an updated water availability model for the Nueces River Basin;
- Apply the model to provide water rights holders with information regarding long-term reliability (1934 to 1996) and water available for diversion 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.

ES.2 Description of the Basin

The Nueces River Basin encompasses an area of approximately 17,000 square miles, including portions of 24 counties in South Texas, as shown in Figure ES-1. Average annual rainfall in the semi-arid basin ranges from approximately 21 inches in the west to approximately 32 inches in the east. Rainfall in the basin is highly variable in magnitude and frequency, as most significant rainfall originates from localized convective thunderstorms or from tropical storms and hurricanes covering wider areas. The sporadic nature of rainfall in the basin results in short periods of high flows in the streams and rivers, preceded and followed by long periods of low or zero flows. This intermittent, variable nature of streamflow significantly affects the dependability of water available for diversion or water availability.

The Nueces River Basin is a highly complex hydrologic environment with active surface and ground water interaction. Streams throughout the basin cross several major aquifer outcrops or recharge zones. The most significant of these is the Edwards Aquifer recharge zone, where an average of 334,400 acre-feet per year (acft/yr) enters the aquifer.[1] Other major aquifer outcrops include the Carrizo-Wilcox, Queen City-Bigford, Sparta, and Gulf Coast-Goliad Sand (Figure ES-1). Although streamflows entering these aquifers are not as great as those entering the Edwards, these recharge zones can significantly affect channel loss rates and delivery of water from upstream to downstream locations.

Land use in the Nueces River Basin is predominately related to agriculture, with 10 percent classified as cropland, 6 percent pastureland, and 84 percent rangeland. The largest municipality located within the basin is the City of Uvalde, with a population of about 16,650. The City of Corpus Christi, located in the Nueces-Rio Grande Coastal Basin, is the single largest user of water from the Nueces River Basin. The City of Corpus Christi operates two large reservoirs: Choke Canyon Reservoir (on the Frio River upstream of Three Rivers) with a permitted capacity of 700,000 acft and Lake Corpus Christi (on the Nueces River near Mathis) with a permitted capacity of 300,000 acft. The City of Corpus Christi operates Choke Canyon Reservoir and Lake Corpus Christi as a system in order to supply water to municipal and industrial customers within its regional service area. The majority of the water supplied by these reservoirs is released and diverted downstream of Lake Corpus Christi at the Calallen Diversion

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

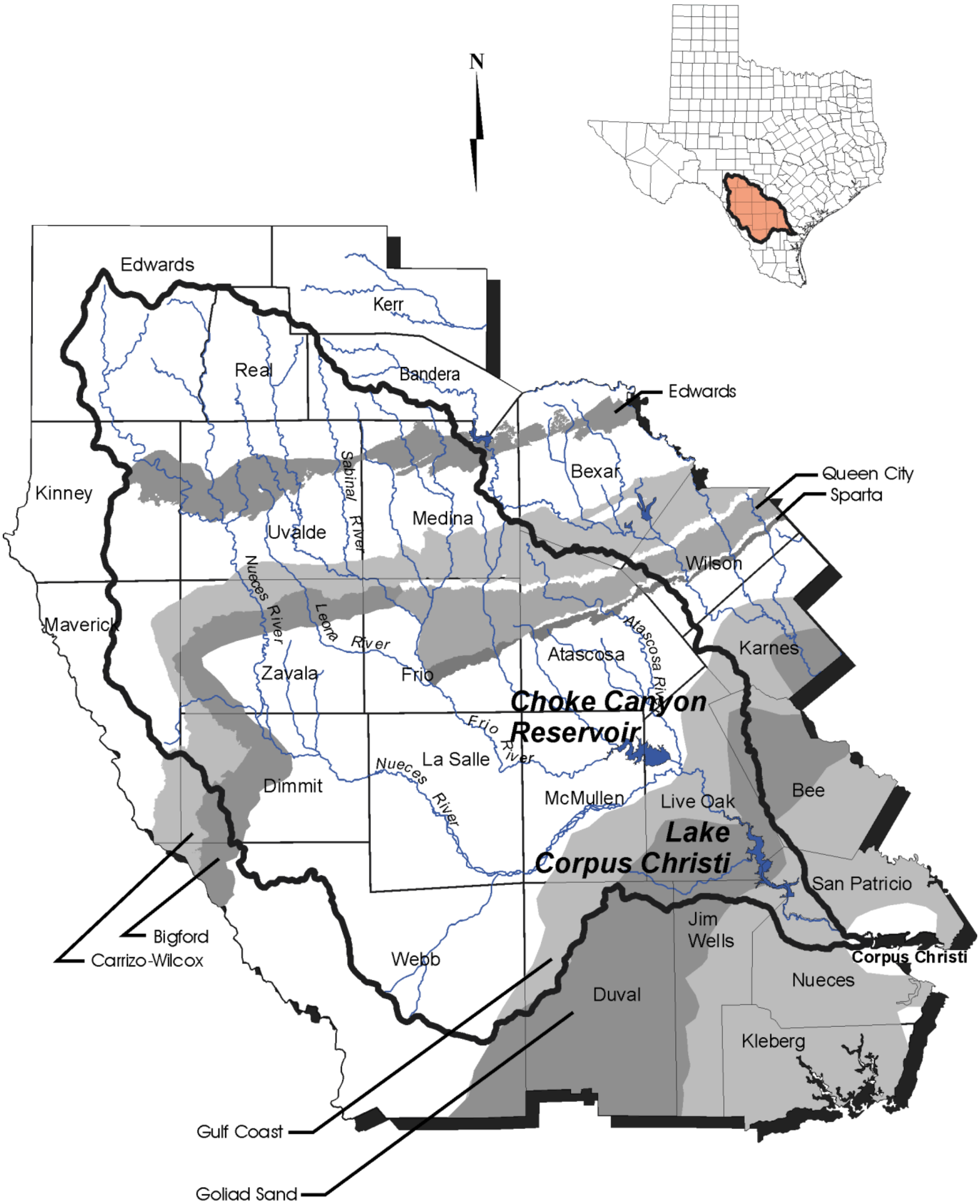


Figure ES-1. Nueces River Basin Map

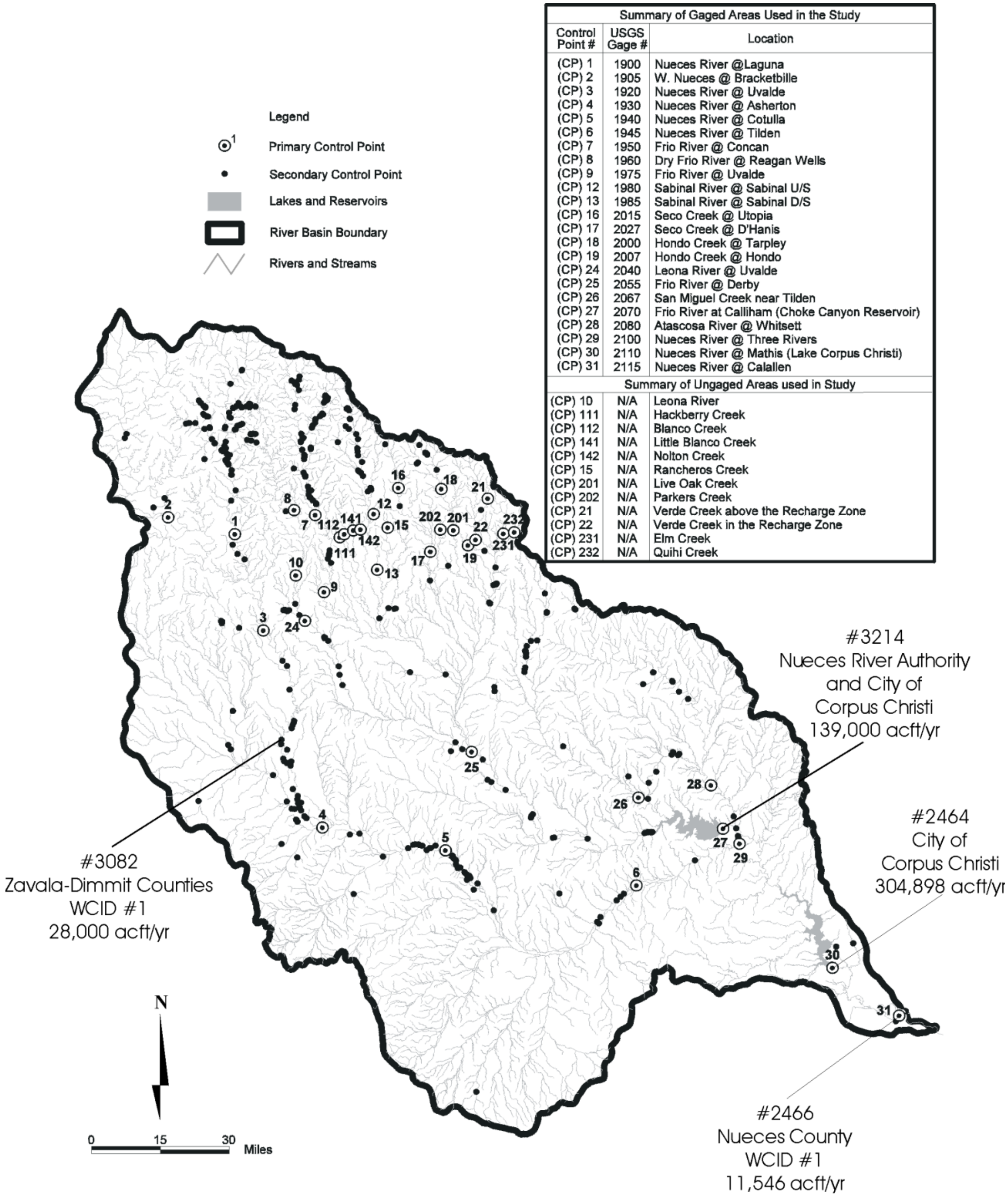
Dam near Calallen. The Calallen Diversion Dam is located at river mile 11 and is a saltwater barrier dam. The next largest permitted capacity of any reservoir operated for water supply in the basin is the Upper Nueces Reservoir, owned by the Zavala-Dimmit Counties Water Improvement District No. 1, with a combined permitted storage capacity of 5,633 acft.

ES.3 Water Availability Information

The TNRCC Water Rights Database Table WRDETAIL, dated January 7, 1999, lists 267 water rights in the Nueces River Basin having priority dates senior to February 21, 1997 and authorizing annual diversions and consumptive use totaling in excess of 533,000 acft. The two diversion rights associated with the Choke Canyon Reservoir/Lake Corpus Christi (CCR/LCC) System represent approximately 83 percent of the total authorized annual diversions in the Nueces River Basin. These rights, Certificates of Adjudication 2464 and 3214, are owned by the City of Corpus Christi and the Nueces River Authority and represent 98 percent of the municipal and industrial rights in the Nueces River Basin. These diversions are concentrated in the lower basin at Calallen Dam. The locations of rights with authorized annual diversions totaling more than 10,000 acft are shown in Figure ES-2, along with all other water rights which are associated with primary and secondary control points.

Records of water use maintained by the TNRCC and the TNRCC South Texas Watermaster indicate that annual surface water use in the Nueces River Basin is approaching 200,000 acft. Some inconsistencies exist between water use records reported by individual owners prior to 1991 and those maintained by the Watermaster in recent years. For example, records of water sales from the CCR/LCC System total only 101,200 acft in 1991, as compared to 197,597 acft in the Watermaster database. Clearly, reconciliation of Watermaster use records with those available from water right owners is desirable.

Many water rights throughout the basin are affected by the CCR/LCC System because of its downstream location and the early priority dates associated with its significant authorized diversion and storage rights. Because of the relative sizes and locations of Choke Canyon Reservoir and Lake Corpus Christi, system operation of the two reservoirs can provide significant benefits in terms of water availability and reliability of supply during drought. For this reason, operations of the CCR/LCC System in this study are subject to the Phase IV, or "maximum yield," policy adopted by the Corpus Christi City Council on August 27, 1996.



Summary of Gaged Areas Used in the Study

Control Point #	USGS Gage #	Location
(CP) 1	1900	Nueces River @Laguna
(CP) 2	1905	W. Nueces @ Bracketbille
(CP) 3	1920	Nueces River @ Uvalde
(CP) 4	1930	Nueces River @ Asherton
(CP) 5	1940	Nueces River @ Cotulla
(CP) 6	1945	Nueces River @ Tilden
(CP) 7	1950	Frio River @ Concan
(CP) 8	1960	Dry Frio River @ Reagan Wells
(CP) 9	1975	Frio River @ Uvalde
(CP) 12	1980	Sabinal River @ Sabinal U/S
(CP) 13	1985	Sabinal River @ Sabinal D/S
(CP) 16	2015	Seco Creek @ Utopia
(CP) 17	2027	Seco Creek @ D'Hanis
(CP) 18	2000	Hondo Creek @ Tarpley
(CP) 19	2007	Hondo Creek @ Hondo
(CP) 24	2040	Leona River @ Uvalde
(CP) 25	2055	Frio River @ Derby
(CP) 26	2067	San Miguel Creek near Tilden
(CP) 27	2070	Frio River at Calliham (Choke Canyon Reservoir)
(CP) 28	2080	Atascosa River @ Whitsett
(CP) 29	2100	Nueces River @ Three Rivers
(CP) 30	2110	Nueces River @ Mathis (Lake Corpus Christi)
(CP) 31	2115	Nueces River @ Calallen

Summary of Ungaged Areas used in Study

Control Point #	USGS Gage #	Location
(CP) 10	N/A	Leona River
(CP) 111	N/A	Hackberry Creek
(CP) 112	N/A	Blanco Creek
(CP) 141	N/A	Little Blanco Creek
(CP) 142	N/A	Nolton Creek
(CP) 15	N/A	Rancheros Creek
(CP) 201	N/A	Live Oak Creek
(CP) 202	N/A	Parkers Creek
(CP) 21	N/A	Verde Creek above the Recharge Zone
(CP) 22	N/A	Verde Creek in the Recharge Zone
(CP) 231	N/A	Elm Creek
(CP) 232	N/A	Quihi Creek

Figure ES-2 Control Points and Major Water Right Locations

Under this policy, flows originating in the Frio River Basin may be impounded in Choke Canyon Reservoir, allowing substantial depletion of storage in Lake Corpus Christi despite the fact that simple application of the Prior Appropriation Doctrine would call for immediate passage of these flows to replenish storage in Lake Corpus Christi.

Operations of the CCR/LCC System are governed, in part, by Special Conditions in the Certificate of Adjudication for Choke Canyon Reservoir that provide for maintenance of freshwater inflows to the Nueces Estuary. As a result of the cooperative efforts of the Nueces Estuary Advisory Council, implementation of the general objectives set forth in these Special Conditions has taken the form of an Agreed Order issued by the TNRCC on April 28, 1995. The Agreed Order established a monthly schedule of minimum desired freshwater inflows to Nueces Bay totaling between 97,000 and 138,000 acft/yr to be satisfied by spills, return flows, measured runoff below Lake Corpus Christi, and/or dedicated passage of CCR/LCC System inflows. Provisions for temporary reduction or suspension of freshwater inflow requirements are based on CCR/LCC System storage, monthly inflow banking, salinity variations in upper Nueces Bay, and implementation of drought contingency measures.

Groundwater/surface water interactions play a significant role in the hydrology of the Nueces River Basin. The Nueces River Basin is traversed by the outcrops of seven major aquifers (Figure ES-1). The most significant of these is the Edwards Aquifer, a highly porous, fractured limestone formation outcropping in Kinney, Uvalde, Medina, Bexar, Comal, and Hays Counties. The formation is so efficient in recharging the aquifer that only the Nueces River typically sustains a minimal base flow across the outcrop. Other streams in the upper Nueces River Basin such as the Frio and Sabinal Rivers are very often dry at the downstream edge of the Edwards outcrop. Significant natural depletions of streamflows or “channel losses” are also typical of the Nueces River Basin downstream of the Edwards outcrop as the stream segments traverse the outcrops of the Carrizo-Wilcox, Goliad Sand, and other aquifers. Components of channel loss (in addition to aquifer recharge) include bank storage, over-bank flooding, evaporation, and transpiration by riparian vegetation.

ES.4 Development of the Water Availability Model

The Water Rights Analysis Package (WRAP)[2,3] developed by Texas A&M University was selected by the TNRCC as the standard model for statewide application in the Water Availability Modeling (WAM) project. WRAP utilizes naturalized streamflows, evaporation data, geographic data, and water rights information to determine the availability of water to individual water rights under the Prior Appropriation Doctrine. With the completion of this study, WRAP, which includes modifications specifically for the Nueces River Basin, will replace the original water availability model of the Nueces River Basin developed by the Texas Department of Water Resources (TDWR).[4] Significant advantages of the new model relative to the TDWR model include:

- A 61 percent increase in the hydrologic database period of record (i.e., 1/1934 through 12/1996) including the recent severe drought of the 1990s, which is a new drought of record for the CCR/LCC System;
- Additional water rights issued since 1982;
- Consideration of channel losses in the downstream translation of changes in streamflow (a recent enhancement of WRAP completed by Texas A&M University);
- Consideration of Edwards Aquifer recharge (a basin-specific enhancement of WRAP completed by HDR); and
- More comprehensive simulation of the CCR/LCC System (a basin-specific enhancement of WRAP completed by HDR).

Verification of certain generic and basin-specific enhancements to WRAP was accomplished by comparison of simulation results with those from the Nueces River Basin Model and the Lower Nueces River Basin and Estuary Model. These models were developed by HDR in the performance of studies completed between 1990 and 1999 sponsored by the Nueces River Authority, Edwards Underground Water District, City of Corpus Christi, South Texas Water Authority, and Texas Water Development Board.[5,6]

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[2] Wurbs, R.A. and Dunn, D.D., "Water Rights Analysis Package (WRAP) Model Description and User's Manual," TR-146, Texas Water Resources Institute, Texas A&M University, October 1996.
[3] Wurbs, R.A., "Reference and Users Manual for the Water Rights Analysis Package (WRAP)," TR-180, Texas Water Resources Institute, Texas A&M University, August 1999.
[4] Texas Department of Water Resources (TDWR), "Interim Report on Water Availability in the Nueces River Basin, Texas," Draft, March 1982.
[5] HDR, "Nueces River Basin Regional Water Supply Planning Study – Phase I," Vols. I, II, and III, Nueces River Authority, et al., May 1991.
[6] HDR, "Water Supply Update for City of Corpus Christi Service Area," City of Corpus Christi, January 1999.

Naturalized streamflows form the basis for water availability modeling. Naturalized streamflows utilized herein were developed by HDR as part of the studies previously cited. The procedures used to develop these naturalized flows are consistent with those originally used by the TDWR and with those adopted by the TNRCC for the WAM project. Evaporation data were obtained from information compiled by the Texas Water Development Board and summarized for one-degree quadrangles of latitude and longitude. Monthly streamflow and evaporation data include the 63-year historical period from 1934 through 1996.

Water rights information was obtained from the TNRCC water rights database table, WRDETAIL, dated January 7, 1999. Data in this table include water right numbers and owners, authorized annual diversions and types of use, authorized storage capacities of reservoirs, and dates of priority. Data in this table were compared to information contained in the original Certificates of Adjudication and Permits, and corrected to match the paper water rights as closely as possible. The revised table was then used to develop the water rights information utilized in the WRAP Model input data sets.

Geographic information concerning reservoir and water right diversion locations was obtained from the TNRCC through the University of Texas Center for Research in Water Resources. Location (coordinates and stream lengths) and watershed information (drainage area) was obtained for more than 500 authorized diversion points, reservoirs, streamflow gages, and confluence points in the Nueces River Basin. These locations were utilized as "control points" or locations where streamflow and water availability information is computed in WRAP. The locations of all control points utilized in the model are shown in Figure ES-2.

Treated effluent discharges were analyzed for the 1993 through 1997 period to develop annual sets of monthly effluent discharges at several locations in the Nueces River Basin. These discharges were input to WRAP to account for return flows from surface water diversions and discharge of treated effluent originating from groundwater sources.

ES.5 Water Availability in the Nueces River Basin

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. SB1 required 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 Nueces 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 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.

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 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 assumptions concerning treated effluent discharges and cancellation of only those rights showing no use between 1987 and 1997 affect water availability very little in the Nueces River Basin. Treated effluent discharges throughout the basin are small, except near the coast. Large discharges near the coast discharge into the Nueces Estuary. None of the three reuse scenarios (Runs 1, 2, and 3) result in significant differences in regulated or unappropriated flows anywhere in the basin.

Consumptive reuse of treated effluent in the Corpus Christi service area, however, could significantly reduce freshwater inflows to the Nueces Estuary. Similarly, cancellation of rights showing 10 years of no use 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.

The most influential factor affecting overall water availability in the Nueces 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 use between 1987 and 1997. Very few rights in the Nueces River Basin have been fully perfected, 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 Nueces River Basin is small, and inclusion of term permits in Run 8 has no significant effect on water availability.

Water availability in the Nueces River Basin is greatly influenced by assumptions concerning the rights associated with the CCR/LCC System. These rights represent approximately 97 percent of the total reservoir storage and 88 percent of the diversion rights in the Nueces River Basin; are authorized to be diverted at the furthest practical downstream location, Calallen Dam; and are some of the most senior in the basin. The permitted capacity of Lake Corpus Christi is more than 25 percent greater than present capacity, and modeling the reservoir at its permitted capacity causes upstream junior rights to pass flows more frequently to refill storage in the reservoir. The estimated firm yield (178,700 acft/yr)[7] of the CCR/LCC System is only about 40 percent of the authorized diversions under the City of Corpus Christi rights (443,898 acft/yr). Nevertheless, diversions based on Corpus Christi's full authorized amounts are more than 82 percent available in all Runs performed. The combination of modeling Corpus Christi rights assuming full authorized storage capacity of the CCR/LCC System and full authorized annual diversions significantly reduces water availability for upstream junior rights, which must pass inflows to meet the storage and diversion requirements under the CCR/LCC System rights.

[7] Ibid.

At the request of the South Central Texas Regional Water Planning Group, an additional scenario (Run 9) was developed to reflect water management assumptions consistent with those adopted for development of their regional water plan. Results of Run 9 have been transmitted directly to the South Central Texas Regional Water Planning Group and are not included in this report.

Section 1
Introduction

1.1 Description of the Basin

The Nueces River Basin encompasses an area of approximately 17,000 square miles in South Texas, as shown in Figure 1-1. Average annual rainfall in the semi-arid basin ranges from approximately 21 inches in the west to approximately 32 inches in the east. Rainfall in the basin is highly variable in magnitude and frequency, as most significant rainfall originates from localized convective thunderstorms or from tropical storms and hurricanes covering wider areas. The sporadic nature of rainfall in the basin results in short periods of high flows in the streams and rivers, preceded and followed by long periods of low or zero flows. This intermittent, variable nature of streamflow in the Nueces River Basin significantly affects water availability.

The basin is a highly complex hydrologic environment with active surface and ground water interaction. Streams throughout the basin cross several major aquifer outcrops or recharge zones. The most significant of these is the Edwards Aquifer recharge zone, where an average of 334,400 acre-feet per year (acft/yr) entered the aquifer during the 1934 through 1996 historical period. Other major aquifer outcrops include the Carrizo-Wilcox, Queen City-Bigford, Sparta-Laredo, and Gulf Coast-Goliad Sand (Figure 1-1). Although streamflows entering these aquifers are not as great as those entering the Edwards, these recharge zones can significantly affect channel loss rates and delivery of water from upstream to downstream locations.

Topography varies from steep slopes in the Hill Country upstream of the Edwards Aquifer recharge zone to generally mild or flat as the streams and rivers traverse the Winter Garden area and Coastal Plains approaching the Gulf of Mexico. The steep slopes and characteristically thin soils of the Hill Country result in this area producing the greatest runoff per unit rainfall in the basin. In the Hill Country portion of the basin, an annual average of about 13 percent of precipitation appears as runoff or gaged streamflow.[8] Downstream of the Hill Country, average annual runoff volumes generally vary between 2 and 5 percent of average annual precipitation. Overall, about 3 percent of the average annual basin-wide precipitation appears as runoff flowing into Lake Corpus Christi in the lower basin.

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

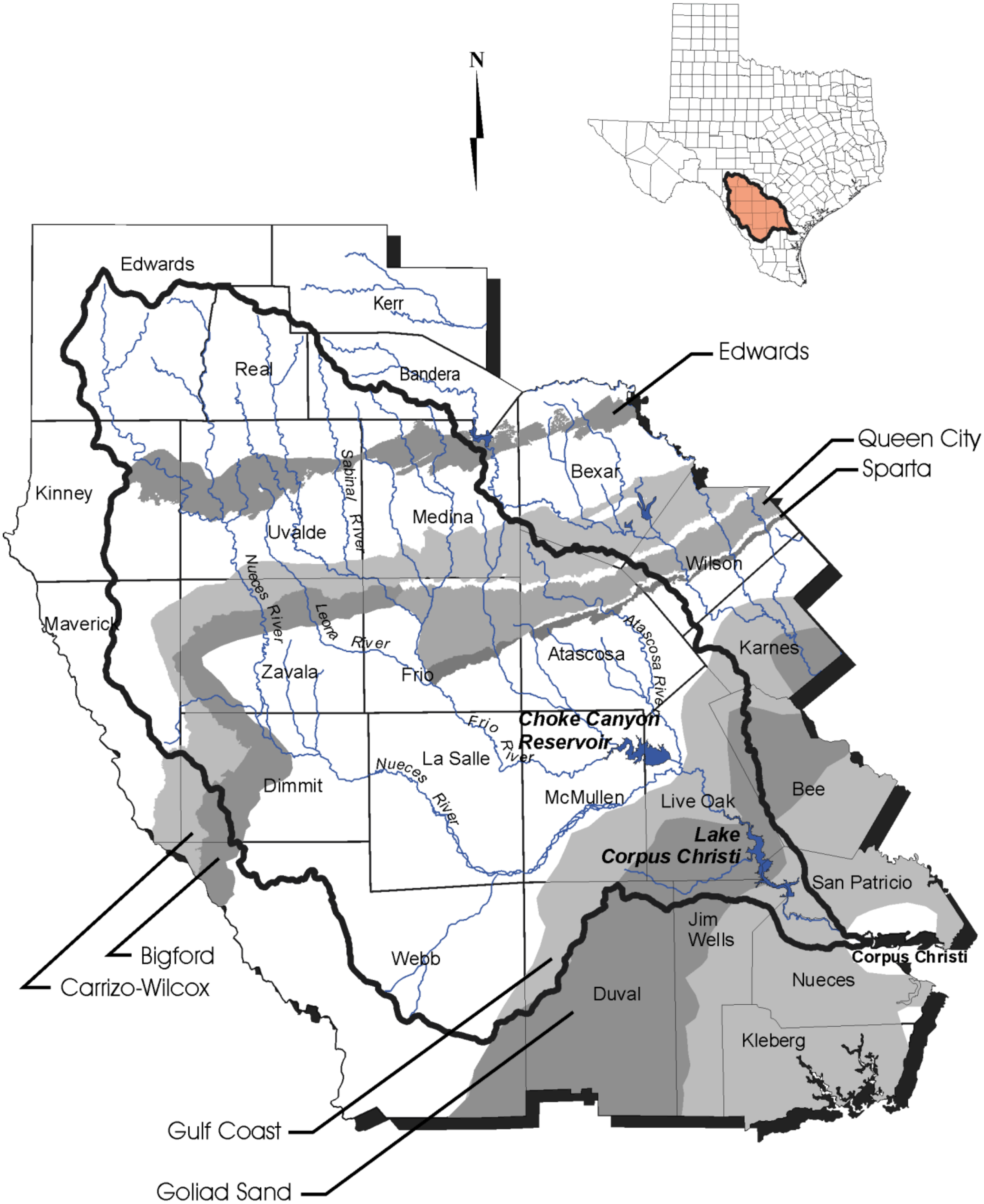

Figure 1-1. Nueces River Basin Map

Intermittent streams in the upper basin drain to the Nueces, Frio, and Atascosa Rivers, which confluence near the City of Three Rivers. The Nueces River then continues from Three Rivers to Nueces Bay. A unique feature of the Nueces River is an 81-mile-long segment upstream of Three Rivers, commonly referred to as the "braided reach." The braided reach begins about 15 miles downstream of Cotulla, where the single channel of the river transitions to a system of interconnected braided channels. These interconnected channels continue to about 12 miles upstream of Simmons. Studies performed by the U.S. Geological Survey (USGS)[9] indicate that significant streamflow losses occur in this reach.

Land use in the Nueces River Basin is predominately related to agriculture, with 10 percent classified as cropland, 6 percent pastureland, and 84 percent rangeland. The largest municipality located within the basin is the City of Uvalde, with a population of about 16,650. The City of Corpus Christi, located in the Nueces-Rio Grande Coastal Basin, is the single largest user of water from the Nueces River Basin. The City of Corpus Christi operates two large reservoirs: Choke Canyon Reservoir (on the Frio River upstream of Three Rivers) with a permitted capacity of 700,000 acft and Lake Corpus Christi (on the Nueces River near Mathis) with a permitted capacity of 300,000 acft. The City of Corpus Christi operates Choke Canyon Reservoir and Lake Corpus Christi as a system in order to supply water to municipal and industrial customers within its regional service area. The majority of the water supplied by these reservoirs is released and diverted downstream of Lake Corpus Christi at the Calallen Diversion Dam near Calallen. The next largest permitted capacity of any reservoir operated for water supply in the basin is the Upper Nueces Reservoir, owned by the Zavala-Dimmit Counties Water Improvement District No. 1, with a permitted capacity of 4,010 acft. Water diverted from this reservoir is used primarily for irrigation purposes.

1.2 Study Objectives

Pursuant to Senate Bill 1 (SB1) 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

[9] U.S. Geological Survey, "Conveyance Characteristics of the Nueces River, Cotulla to Simmons, Texas," Water-Resources Investigations Report 83-4004, 1983.

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 SB1 and include the following:

- Develop an updated water availability model for the Nueces River Basin;
- Apply the model to provide water rights holders with information regarding long-term reliability and water available during drought; and
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(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 Nueces 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. As a component of this study effort, all water rights have been reviewed and the electronic database maintained 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. In order to maintain consistency with current TNRCC practices, all rights conferred by Certificates of Adjudication will be referenced by Certificate of Adjudication Number; and all Permits by Permit Application Number.

There are 267 water rights in the Nueces River Basin having priority dates senior to February 21, 1997 and authorizing annual diversions and consumptive use totaling in excess of 533,000 acft. Summaries of these water rights, sorted by size of authorized annual diversion, type of use, and location, are provided in Table 2-1. Figure 2-1 identifies the locations of major water rights authorized to divert 2,000 acft/yr or more, along with any associated storage rights. In addition, Figure 2-1 identifies "segments" of the Nueces River Basin extending:

1) From the headwaters to the downstream edge of the outcrop of the Edwards Aquifer;
2) From Segment 1 to subwatershed boundaries approximately coincident with Interstate Highway 35;
3) From Segment 2 to the confluence of the Nueces, Frio, and Atascosa Rivers at Three Rivers; and
4) From Segment 3 to the Nueces Estuary.

Annual authorized diversions for the major water rights shown in Figure 2-1 comprise almost 92 percent of all authorized diversions in the Nueces River Basin.

Municipal and industrial diversion rights represent 84.9 percent of all authorized diversion rights in the Nueces River Basin. Based in large part on water stored in the Choke Canyon Reservoir/Lake Corpus Christi (CCR/LCC) System, which is subsequently delivered via the Nueces River to Calallen Dam at Corpus Christi for diversion, the City of Corpus Christi and

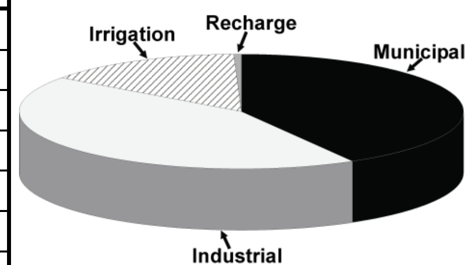
Table 2-1.
*Nueces River Basin Water Rights Summary**

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	2	443,898	443,898
10,000 – 49,999	2	39,546	39,546
2,000 – 9,999	4	9,581	7,721
1,000 – 1,999	9	10,781	10,781
200 – 999	52	18,493	18,493
<200	198	11,117	11,073
Total	267	533,416	531,512

Sorted by Type of Use

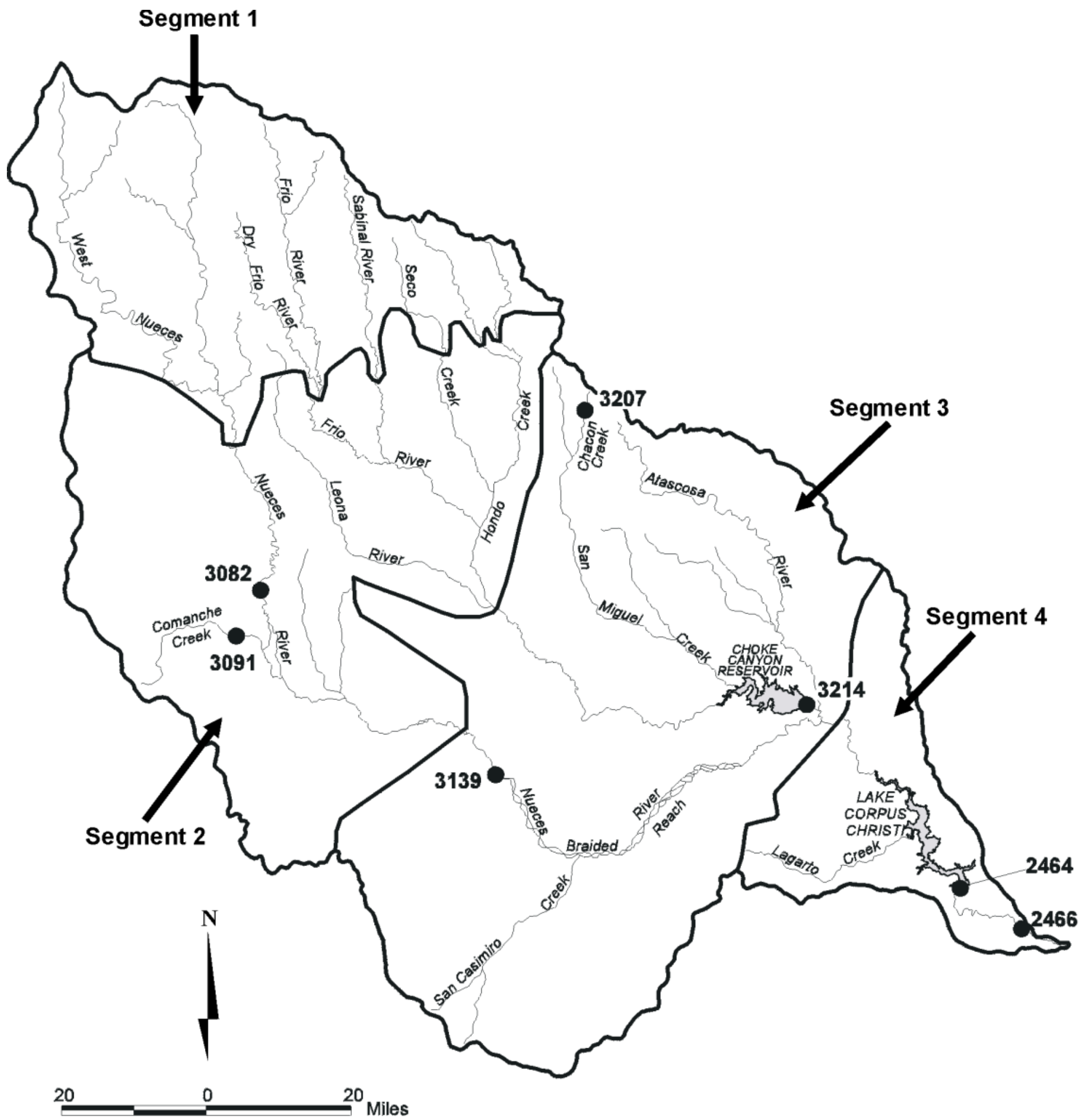
Type of Use	*Total Authorized Annual Diversions (acft)*	*Total Authorized Annual Consumptive Use (acft)*
Municipal/Domestic (1)	221,588	221,588
Industrial (2)	229,640	229,640
Irrigation (3)	79,565	77,705
Mining (4)	262	262
Hydroelectric (5)	0	0
Recreation (7)	44	0
Other (8)	28	28
Recharge (9)	2,290	2,290
Total	533,416	531,512



Sorted by Location

Basin Segments	*Total Authorized Annual Diversions (acft)*	*Total Authorized Annual Consumptive Use (acft)*
1	22,019	20,115
2	42,320	42,320
3	152,074	152,074
4	317,003	317,003
Total	533,416	531,512

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



Major Water Rights*					
Water Right #	Owner	Diversion Rights (acft/yr)	Consumptive Rights (acft/yr)	Storage Rights	Notes
2464	City of Corpus Christi	304,898	304,898	300,000 1,175	Lake Corpus Christi Calallen Reservoir
3214	City of Corpus Christi, Nueces River Authority	139,000	139,000	700,000	Choke Canyon Reservoir
3082	Zavala-Dimmit Co. WCID #1	28,000	28,000	5,633	
2466	Nueces County WCID #3	11,546	11,546	0	
3091	Turkey Creek Ranches	2,098	2,098	0	
3139	Holland Texas Dam & Irrigation Co.	2,023	2,023	700	
3207	Bexar-Medina-Atascosa Co. WCID #1	2,000	2,000	730	

*Authorized Annual Diversions > 2,000 acft

Figure 2-1. Major Water Rights in the Nueces River Basin

Nueces River Authority hold 98 percent of these municipal and industrial rights. Diversions for irrigation and for recharge and other purposes respectively comprise 14.7 percent and 0.4 percent of all authorized diversion rights. In general terms, diversions for irrigation are distributed throughout the river basin while municipal and industrial diversions are concentrated in Segment 4. Diversions for recharge purposes occur only in Segment 1 at the outcrop of the Edwards Aquifer.

2.2 Historical Water Use

Records of surface water use as reported by individual water right owners have been collected, tabulated, and maintained electronically by the 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. Figure 2-2 summarizes historical surface water use by type of use for the entire Nueces River Basin as diversions have grown to approach 200,000 acft/yr. Municipal and industrial water use currently comprise more than 70 percent of all surface water use.

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, records of water sales from the CCR/LCC System provided by the City of Corpus Christi total only 101,200 acft in 1991, as compared to almost 200,000 acft of municipal use reported by the Watermaster. On the other hand, 1995 water sales from the CCR/LCC System total 108,200 acft, which exceeds the Watermaster records for municipal and industrial use basin-wide by about 30 percent (due, in part, to missing data in the Watermaster records). Clearly, reconciliation of Watermaster use records with those available from water right owners is desirable.

2.3 Treated Wastewater Discharge

All significant municipal and industrial treated wastewater discharges or return flows derived from waters originating in the Nueces River Basin occur downstream of Calallen Dam and/or in adjacent coastal river basins. Based on detailed information available for calendar year

1997, return flows contributing to Nueces Bay and other receiving estuaries have been set at 52 percent of the total surface water diversions by the City of Corpus Christi, including all of its municipal and industrial customers. Other municipal and industrial treated wastewater discharges for which current records are maintained by the TNRCC are included at appropriate geographical locations throughout the basin in the water availability model. Return flows from irrigation operations are assumed negligible and are not included in the water availability model, except for water rights that specifically limit consumptive use.

2.4 Previous Water Availability and Planning Studies

Due to the vital importance of water in the semi-arid, desert environment prevalent in the Nueces 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 of the Nueces 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 an interim draft report,[10] which has never been formally published. Development of the model included extensive hydrological 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[11] and encoded 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.

[10] Texas Department of Water Resources (TDWR), "Interim Report on Water Availability in the Nueces River Basin, Texas," Draft, March 1982.
[11] 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.

Significant differences between the TDWR and current water availability models include the following:

1) The current model uses a hydrological database some 61 percent longer (1934 to 1996) than the original (1940 to 1978) and includes the most severe drought period on record for the CCR/LCC System, which occurred in the mid-1990s;
2) The current model reflects changes in water rights that have occurred between 1982 and 1997;
3) The current model addresses the effects of channel losses in the translation of changes in streamflow to downstream locations;
4) Simulations using the current model are continuous across the outcrop of the Edwards Aquifer and include the monthly estimation of recharge; and
5) Although the original model included Choke Canyon Reservoir, the current model more accurately simulates its system operation with Lake Corpus Christi subject to water delivery losses, actual points of diversion, Nueces Estuary freshwater inflow requirements, implementation of conservation and drought contingency programs, and maximization of available supply during drought.

Each of these differences is discussed in greater detail in subsequent sections of this report.

2.4.2 Regional Water Planning Studies

A regional water supply planning study,[12] administered by the Nueces River Authority, was initiated in 1990 with the primary objectives of quantifying the firm yield of the CCR/LCC System, computing natural recharge of the Edwards Aquifer, and assessing the potential effects of Edwards Aquifer recharge enhancement projects on the firm yield of the CCR/LCC System and on freshwater inflows to the Nueces Estuary. In order to accomplish these objectives, new natural streamflows and a river basin hydrologic simulation model were created to more realistically portray CCR/LCC System operations and the effects of channel losses and aquifer recharge on water availability. Resulting estimates of CCR/LCC System firm yield (without upstream recharge enhancement projects) proved substantially less than original estimates developed by the U.S. Bureau of Reclamation.[13,14] This was due in part to the consideration of channel and water delivery losses which are quite significant in the segments of the Nueces River between Choke Canyon Reservoir and Calallen Dam. The natural streamflows developed

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[12] HDR Engineering, Inc. (HDR), "Nueces River Basin Regional Water Supply Planning Study - Phase I," Vols. I, II, and III, Nueces River Authority, et al., May 1991.
[13] U.S. Bureau of Reclamation (USBR), "Nueces River Project, Texas, Feasibility Report," U.S. Department of the Interior, July 1971.
[14] USBR, "Nueces River Basin: A Special Report of the Texas Basins Project," U.S. Department of the Interior, Amarillo, Texas, December 1983.

in this regional water supply planning study are used in the new TNRCC water availability model of the Nueces River Basin.

In 1991, the Lower Nueces River Basin and Estuary Model was created by HDR under a contract with the City of Corpus Christi as a special version of the 1990 model of the entire river basin. Since 1991, both models have been refined and applied extensively in:

1) Development of an Agreed Order issued by TNRCC governing CCR/LCC System operations with respect to freshwater inflows to the Nueces Estuary;
2) Real-time drought contingency planning and operations in the Corpus Christi service area;
3) Consideration of treated wastewater diversions to the Nueces Delta for increased CCR/LCC System yield and enhanced primary productivity and fisheries harvest in the Nueces Estuary;[15]
4) Edwards Aquifer recharge enhancement project feasibility assessments;[16,17,18] and
5) Preliminary assessment of surface water/groundwater interactions involving the Carrizo-Wilcox Aquifer.[19]

Applications of these planning models were instrumental in the development a long-range water supply plan for the Corpus Christi service area under the Trans-Texas Water Program.[20] Recent completion of the Mary Rhodes Pipeline (September 1998) delivering water from Lake Texana to Corpus Christi and acquisition of surface water rights from the Garwood Irrigation Company represent deliberate implementation of this long-range water supply plan.

The recent drought, which began in 1993 (and continues as this report is prepared), has proven to be the most severe, or critical, drought on record for the CCR/LCC System and for much of the Nueces River Basin. This was confirmed in a recent study[21] completed for the City of Corpus Christi. The study's primary objective was updating estimates of the present and

[15] HDR, Naismith Engineering, Inc. (NEI), and University of Texas Marine Science Institute, "Nueces Estuary Regional Wastewater Planning Study – Phase II," City of Corpus Christi, et al., June 1993.
[16] HDR and Paul Price Associates (PPA), "Nueces River Basin Regional Water Supply Planning Study – Phase III, Recharge Enhancement," Nueces River Authority, et al., November 1991.
[17] HDR, Freese & Nichols, Inc., Fugro-McClelland, Inc., LBG-Guyton Associates (LBG), PPA, and International Aerial Mapping Co., "Nueces River Basin Edwards Aquifer Recharge Enhancement Project, Phase IV-A," Edwards Underground Water District, June 1994.
[18] HDR, PPA, LBG, and Espey, Huston & Associates, "Trans-Texas Water Program West Central Study Area Phase I Interim Report," San Antonio River Authority, et al., May 1994.
[19] LBG and HDR, "Interaction Between Groundwater and Surface Water in the Carrizo-Wilcox Aquifer," Texas Water Development Board (TWDB), August 1998.
[20] HDR, NEI, and PPA, "Trans-Texas Water Program Corpus Christi Study Area, Phase II Report," Lavaca-Navidad River Authority, et al., September 1995.
[21] HDR, "Water Supply Update for City of Corpus Christi Service Area," City of Corpus Christi, January 1999.

future firm yield of the CCR/LCC System subject to 1990s drought hydrology, new reservoir evaporation rates from the Texas Water Development Board (TWDB), potential increases in pumpage of the Carrizo-Wilcox Aquifer, sediment accumulation, and additional water supplies from Lake Texana via the Mary Rhodes Pipeline. Key findings during the study indicate that the firm yield of the CCR/LCC System subject to 2050 sediment accumulation is expected to range from 167,800 acft/yr to 178,700 acft/yr (4,200 acft/yr to 20,400 acft/yr, respectively, less than estimates based on earlier drought periods) depending upon system operation policy. This recent study included an update of natural streamflows throughout the Nueces River Basin for the 1990 to 1996 historical period.

2.5 Significant Considerations Affecting Water Availability

2.5.1 Choke Canyon Reservoir/Lake Corpus Christi System

Many water rights throughout the Nueces River Basin are affected by the CCR/LCC System because of its downstream location and the early priority dates associated with significant authorized diversion and storage rights held by the City of Corpus Christi. Figure 2-3 shows the relative locations of key CCR/LCC System components, including Calallen Dam, where a large percentage of diversions for the City of Corpus Christi and its customers are actually taken.

Calallen Dam is authorized to impound 1,175 acft and was constructed by the Corpus Christi Water Supply Company in the late 1800s. Lake Corpus Christi (authorized impoundment of 300,000 acft) was formed in 1958 by the construction of Wesley Seale Dam on the Nueces River, which inundated the smaller Lake Mathis that was completed in 1934. Choke Canyon Reservoir (authorized impoundment of 700,000 acft) was completed by the U.S. Bureau of Reclamation on the Frio River in 1982 and first filled to capacity in 1987. As bathymetric survey data collected by the USGS[22] and TWDB[23] indicate that the current capacity of each reservoir is less than the original, simulations using WRAP assume a higher conservation pool level sufficient to account for the full, authorized storage capacity.

Although the authorized storage capacity of Lake Corpus Christi is less than half of that at Choke Canyon Reservoir, the contributing drainage area at Lake Corpus Christi is more

[22] U.S. Geological Survey (USGS), "Preliminary Results of an Investigation of Factors Contributing to Water Storage Reduction with Lake Corpus Christi, Texas," 1987.
[23] TWDB, "Volumetric Survey of Choke Canyon Reservoir," September 23, 1993.

than three times that of Choke Canyon Reservoir. Hence, system operation of the two reservoirs as authorized in the Certificate of Adjudication for Choke Canyon Reservoir can provide significant benefits in terms of water availability and reliability of supply during drought. For this reason, operations of CCR/LCC System for this assessment of water availability are subject to the Phase 4, or "maximum yield," policy adopted by the Corpus Christi City Council on August 27, 1996. Under this policy, flows originating in the Frio River Basin may be impounded in Choke Canyon Reservoir, allowing substantial depletion of storage in Lake Corpus Christi prior to releasing water from Choke Canyon Reservoir to replenish storage in Lake Corpus Christi. Implementation of this operation policy within WRAP occurs subsequent to the assessment of water available to rights junior to Lake Corpus Christi, but senior to Choke Canyon Reservoir. Specific modifications to WRAP necessary to realistically simulate CCR/LCC System operations are described in Section 4.1.2 of this report.

2.5.2 Freshwater Inflows to the Nueces Estuary

Operations of the CCR/LCC System are governed, in part, by Special Conditions in the Certificate of Adjudication for Choke Canyon Reservoir that provide for the maintenance of freshwater inflows to the Nueces Estuary. As a result of the cooperative efforts of the Nueces Estuary Advisory Council, implementation of the general objectives set forth in these Special Conditions has taken the form of an Agreed Order issued by the TNRCC on April 28, 1995. The Agreed Order established a monthly schedule of minimum desired freshwater inflows to Nueces Bay (Figure 2-3) totaling between 97,000 and 138,000 acft/yr to be satisfied by spills, return flows, measured runoff below Lake Corpus Christi, and/or dedicated passage of CCR/LCC System inflows. Provisions for temporary reduction or suspension of freshwater inflow requirements are based on CCR/LCC System storage, monthly inflow banking, salinity variations in upper Nueces Bay, and implementation of drought contingency measures. Specific modifications to WRAP necessary to simulate CCR/LCC System operations under the Agreed Order are described in Section 4.1.2 of this report.

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

2.5.3 Groundwater/Surface Water Interactions

The Nueces River Basin is traversed by the outcrops of seven major aquifers including the Edwards, Carrizo-Wilcox, Bigford, Queen City, Sparta, Gulf Coast, and Goliad Sand. Figure 2-4 shows the location and extent of these major aquifer outcrops. With the exception of a few springs, interactions between groundwater and surface water in the Nueces River Basin occur primarily in form of recharge in outcrop areas where surface waters may percolate directly into the aquifer. 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, bank storage, over-bank flooding, evaporation, and transpiration by riparian vegetation. Channel losses can be quite significant and become most evident between streamflow gaging stations when intervening runoff is minimal. For example, less than 15 percent of the measured streamflow in the Nueces River at Uvalde (USGS #08192000) resulting from a major storm above Uvalde in October 1996 arrived downstream at Three Rivers (USGS #08210000). Hence, consideration of channel losses and aquifer recharge are essential components of accurate natural streamflow development and water availability modeling in the Nueces River Basin.

2.5.3.1 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 Nueces River typically sustains a minimal base flow across the outcrop. Other streams in the upper Nueces River Basin such as the Frio and Sabinal Rivers and Hondo, Seco, and Verde Creeks are very often dry at the downstream edge of the Edwards outcrop. Computational procedures for estimation of recharge were first established by the USGS[24] and subsequently modified by HDR in the development of natural streamflows. Recharge of the Edwards Aquifer

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

in the Nueces River Basin averaged an estimated 334,400 acft/yr[25] during the 1934 to 1996 historical period.

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

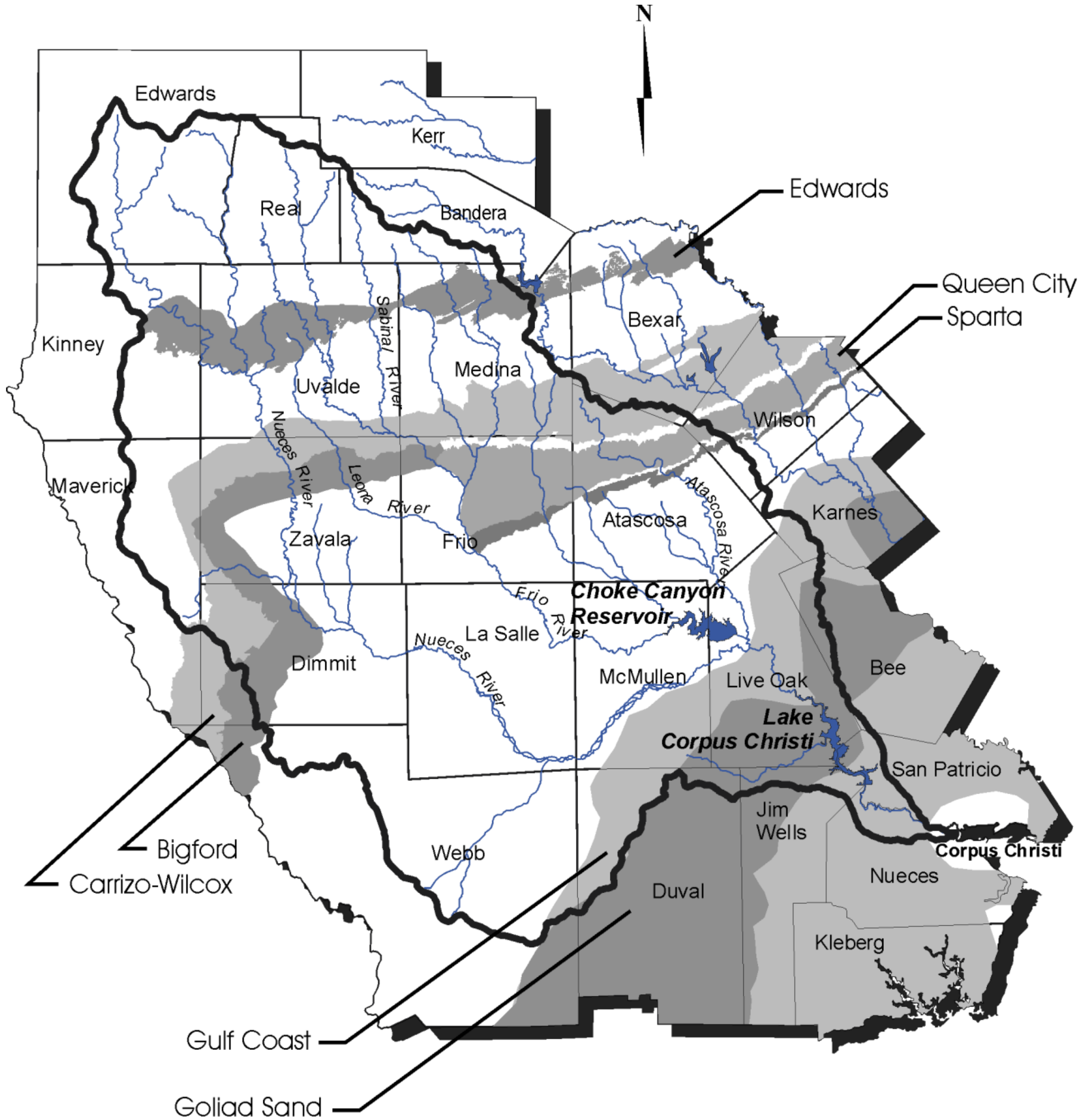

Figure 2-4. Outcrop Areas of Major Aquifers in the Nueces River Basin

The Edwards Aquifer Authority (EAA, formerly the Edwards Underground Water District) has constructed three recharge enhancement projects in the Nueces River Basin. Authorized diversions for these projects, located on Seco, Verde, and Parkers Creeks

(Figure 3-6), total 2,290 acft/yr. Recharge enhancement or water use associated with these projects is estimated on a monthly timestep in WRAP.

The only springflow contribution explicitly simulated in the Nueces River Basin occurs at Leona Springs near Uvalde. Flows at Leona Springs originate in the Edwards Aquifer and are highly correlated with water levels in the City of Uvalde well. In fact, historical water levels in this well were used to estimate springflows during periods before and after gaged records (USGS #08204000) were available for development of natural streamflows. In order to simulate aquifer levels and spring discharge subject to regulated, rather than historical, pumpage, the TWDB has completed modifications to and application of their Edwards Aquifer model (GWSIM4).[26,27,28] The most recent of these applications 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 that place limits on municipal pumpage during periods when aquifer levels are low; and
3) Estimates of recharge developed by HDR that reflect long-term recharge enhancement associated with existing projects.

The maximum annual pumpage of 400,000 acft is consistent with legislation (SB 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. 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 and recharge enhancement are described in Section 4.1.2 of this report.

[26] TDWR, "Ground-Water Resources and Model Applications for the Edwards (Balcones Fault Zone) Aquifer in the San Antonio Region, Texas," Report 239, October 1979.
[27] TWDB, "Model Refinement and Applications for the Edwards (Balcones Fault Zone) Aquifer in the San Antonio Region, Texas," Report 340, July 1992.
[28] 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.

2.5.3.2 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 Nueces River Basin. Similarly, channel losses will apply in the downstream translation of changes in flow associated with water rights diversions, authorized impoundments, and treated wastewater discharges 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[29,30] and are described in greater detail in Section 3.1.3 of this report.

2.5.3.3 Carrizo-Wilcox Aquifer

Upon review of Figure 2-4, 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[31] with the primary objectives of 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 continued pumpage at 1994 levels could reduce streamflows, CCR/LCC System firm yield, and freshwater inflows to the Nueces Estuary on the order of 1 to 2 percent. Based on these relatively small, simulated impacts, no additional consideration of groundwater/surface water interactions beyond that reflected in the gaged streamflow records and in the application of channel loss rates for translation of changes in upstream flow to downstream locations has been included.

2.5.3.4 Gulf Coast Aquifer

The presence of the Gulf Coast Aquifer, including the Goliad Sand formation, contributes to observed channel losses in the Nueces River from the City of Three Rivers to Calallen Dam. Furthermore, the USGS[32] reported that significant losses of surface water to the Goliad Sand formation occurred during the initial filling of Lake Corpus Christi. Due to the lack of streamflow gaging stations in the intervening watershed between Three Rivers and Lake Corpus Christi, however, neither the USGS nor HDR could conclusively differentiate between losses

[29] USGS, "Conveyance Characteristics of the Nueces River, Cotulla to Simmons, Texas," Water-Resources Investigations Report 83-4004, Austin, Texas, 1983.
[30] USGS, "Hydrologic Effects of Floodwater-Retarding Structures on Garza-Little Elm Reservoir, Texas," Water-Supply Paper 1984, 1970.
[31] LBG and HDR, Op. Cit., August 1998.
[32] USGS, "Water-Loss Studies of Lake Corpus Christi, Nueces River Basin, Texas, 1949-65," TWDB, January 1970.

from the river and losses from the lake. Hence, both loss components are reflected in the mass balance estimates of Lake Corpus Christi inflows used to derive natural streamflows and the channel loss rate between Three Rivers and Lake Corpus Christi.

Water supply deliveries from Lake Corpus Christi to Calallen Dam for diversion, treatment, and distribution are subject to groundwater/surface water interactions with the Gulf Coast Aquifer during transmission via the Nueces River. A study conducted by the USGS[33] indicates that losses (and occasional gains) in this segment of the river are highly variable. Discussions with Corpus Christi water supply personnel, however, have confirmed that an assumed 7 percent loss rate on deliveries from Lake Corpus Christi is reasonable.

[33] 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

Compilation of accurate estimates of historical natural streamflow is a key prerequisite to development of a useful model of the Nueces River Basin. Natural streamflow is defined to be that which would have occurred historically, exclusive of human influences. Natural streamflows used in the Nueces River Basin water availability model were developed by HDR in studies[34,35] of the Nueces River Basin sponsored by the Nueces River Authority, City of Corpus Christi, Edwards Underground Water District, and others. The following summarizes the development of natural streamflows for the primary model control points at gaged locations in the Nueces River Basin. Control points are locations where water availability information is desired.

3.1.1 Streamflow Naturalization Methodology

Monthly natural streamflows for the 1934 through 1996 period were developed in previous studies by adjusting gaged streamflows and calculated reservoir inflows for the effects of historical water supply diversions and reservoir operations. Translation of the effects of upstream diversions and/or impoundments to downstream locations (control points) was accomplished with the use of delivery factors representative of typical channel loss rates in each intervening reach. Natural streamflows at selected control points during portions of the 1934 to 1996 period when gage records do not exist were subsequently estimated using multiple linear regression techniques and records from a nearby gage(s).

The streamflow naturalization methodology applied in the performance of this study is summarized in schematic and equation form in Figure 3-1. Historical monthly diversions of all use types were grouped by watershed as delineated by primary control point. The natural flow at the outlet of headwater watersheds, such as Watershed 1 in Figure 3-1, was calculated by adding reported historical diversions to the gaged streamflows at Control Point 1 (CP1). Natural flow at

[34] HDR Engineering, Inc. (HDR) and Geraghty and Miller, Inc. (GMI), "Nueces River Basin Regional Water Supply Planning Study – Phase I," Vols. 1, 2, and 3, Nueces River Authority, et al., May 1991.
[35] HDR, "Water Supply Update for City of Corpus Christi Service Area," City of Corpus Christi, January 1999.

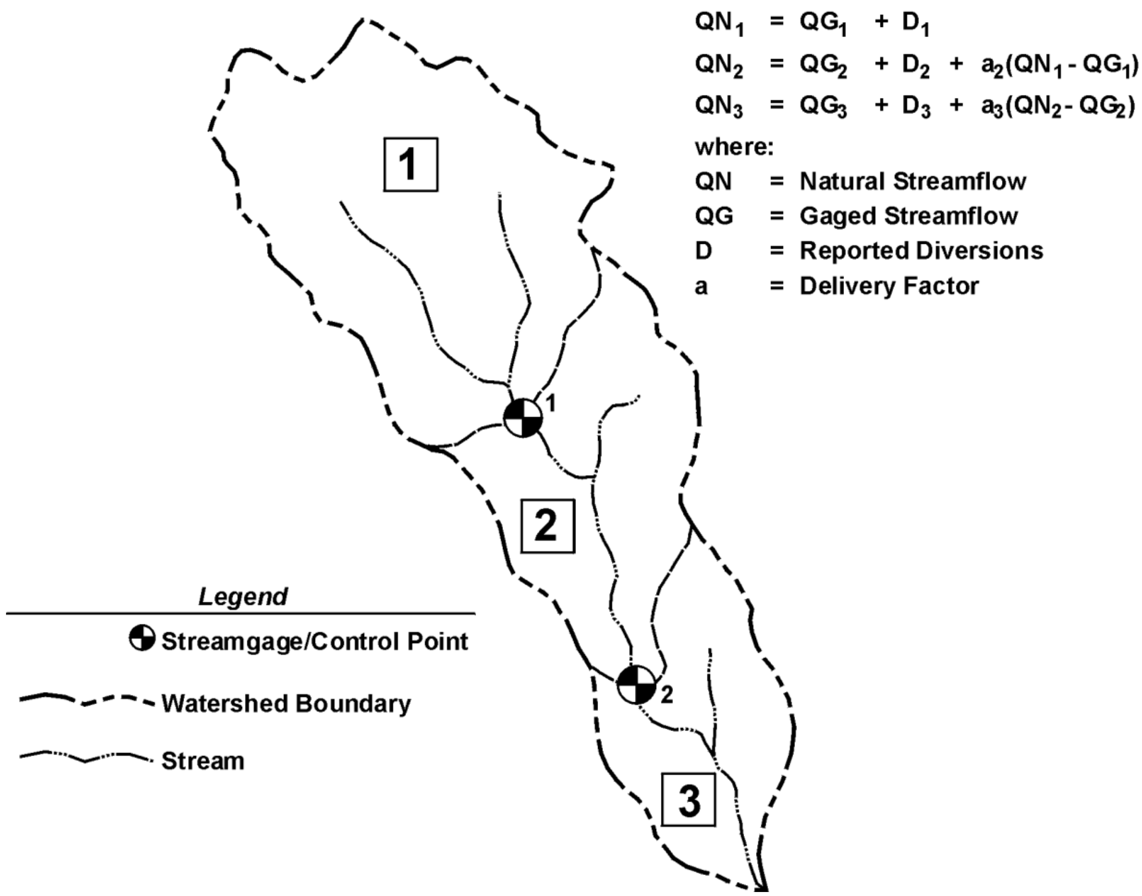

Figure 3-1. Streamflow Naturalization Methodology

the outlet of Watershed 2 (CP2) is equal to the gaged streamflow plus the local diversions in Watershed 2 plus the change in flow at CP1 due to diversions in Watershed 1 delivered to CP2. The delivery factor for the stream reach from CP1 to CP2 is generally the long-term average percentage of the flow passing CP1 that reaches CP2. In like manner, streamflows were naturalized at successive primary control points moving from upstream to downstream through the entire basin. It was not necessary to consider return flows in the streamflow naturalization process because return flows from agricultural operations are unquantified or non-existent, and all significant municipal and industrial return flows occur downstream of Calallen Dam or in another river basin.

3.1.2 Streamflow Data Sources

3.1.2.1 Streamflows

Records of streamflow in the Nueces River Basin have been collected at streamflow gaging stations maintained by the USGS since 1915. Figure 3-2 and Table 3-1 indicate the location, drainage area, and period of record of each station used in the development of Nueces River Basin Model flows, as well as several stations that were not used due to limited period of record. The drainage areas used in streamflow naturalization at the primary control points are those reported by the USGS and in previous studies.[36,37] The differences between the drainage areas from the data sources used 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 Section 3.2.2. Summaries of monthly gaged streamflow were obtained from the Texas Natural Resources Information System, water resources data summaries,[38,39] and directly from the USGS. The records from the gaging stations in the Nueces River Basin are generally classified by the USGS as "good," which means that about 95 percent of the daily discharges reported are within 10 percent of the true values.

Most of the streamflow gaging stations having a period of record in excess of 13 years (as of 1989) were used as primary control points in the computer model of the basin. Accurate calculation of recharge to the Edwards Aquifer necessitated the selection of additional primary control points for several ungaged watersheds. The locations of these ungaged primary control points are indicated in Figure 3-2. Two additional primary control points, CPBAY and CPEST, are necessary to quantify the amount of flows passing into the Nueces Bay and Estuary System. A total of 37 primary control points are included in the Nueces River Basin Model. More detailed discussions of the natural flows developed at the ungaged primary control points are found in Sections 3.2.1 and 3.5.1.

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[36] Ibid.
[37] U.S. Geological Survey (USGS), "Water Resources Data, Texas," Annual.
[38] Texas Department of Water Resources (TDWR), "Streamflow and Reservoir–Content Records in Texas, Compilation Report, January 1889 through December 1975," Report 244, April 1980.
[39] USGS, "Water Resources Data, Texas," Annual.

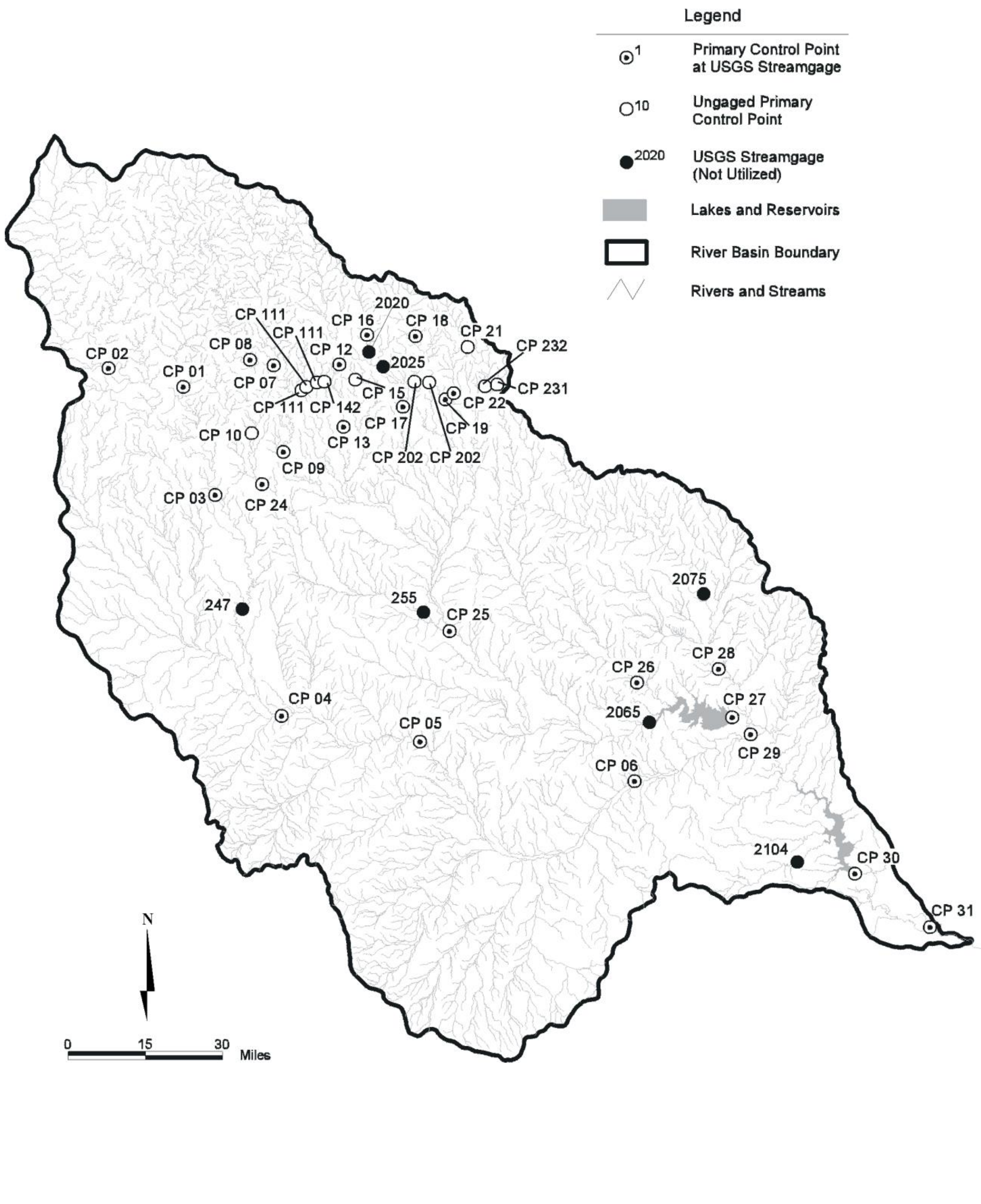

Figure 3-2. Locations of Primary Control Points and Streamgages Used in the Nueces River Basin Model Above Calallen Dam

Table 3-1.
Primary Control Points in the Nueces River Basin

Control Point	Gage Reference Number	Location	Drainage Area[1] (sq. mi.)	Period of Record
Primary Control Points at Gaged Locations				
CP01	1900	Nueces River, Laguna	737	10/23 to 12/96
CP02	1905	W. Nueces River, Brackettville	694	10/39 to 09/50 04/56 to 12/96
CP03	1920	Nueces River, Uvalde	1,861	10/27 to 12/96
CP04	1930	Nueces River, Asherton	4,082	10/39 to 12/96
CP05	1940	Nueces River, Cotulla	5,171	11/23 to 12/96
CP06	1945	Nueces River, Tilden	8,093	12/42 to 12/96
CP07	1950	Frio River, Concan	389	11/23 to 09/29 10/30 to 12/96
CP08	1960	Dry Frio River, Reagan Wells	126	09/52 to 12/96
CP09	1975	Frio River, Uvalde	631	09/52 to 12/96
CP12	1980	Sabinal River, Sabinal	206	10/42 to 12/96
CP13	1985	Sabinal River, Sabinal	241	09/52 to 12/96
CP16	2015	Seco Creek, Utopia	45.0	05/61 to 12/96
CP17	2027	Seco Creek, D'Hanis	168	10/60 to 12/96
CP18	2000	Hondo Creek, Tarpley	95.6	09/52 to 12/96
CP19	2007	Hondo Creek, Hondo	149	10/60 to 12/96
CP24	2040	Leona River, Uvalde	Spring	01/39 to 09/65
CP25	2055	Frio River, Derby	3,429	08/15 to 12/96
CP26	2067	San Miguel Creek, Tilden	783	02/64 to 12/96
CP27	2070	Frio River, Calliham	5,491	10/24 to 04/26 05/32 to 08/81
CP28	2080	Atascosa River, Whitsett	1,171	10/25 to 04/26 06/32 to 12/96
CP29	2100	Nueces River, Three Rivers	15,427	07/15 to 12/96
CP30	2110	Nueces River, Mathis	16,660	09/39 to 12/96
Primary Control Points at Ungaged Locations				
CP10	—	Leona River	34	N/A
CP111	—	Hackberry Creek	9	N/A
CP112	—	Blanco Creek	23	N/A

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Table 3-1 (continued)

Control Point	Gage Reference Number	Location	Drainage Area[1] (sq. mi.)	Period of Record
Primary Control Points at Ungaged Locations (continued)				
CP 141	—	Little Blanco Creek	16	N/A
CP142	—	Nolton Creek	2	N/A
CP15	—	Ranchero Creek	5	N/A
CP201	—	Live Oak Creek	2	N/A
CP202	—	Parkers Creek	10	N/A
CP21	—	Verde Creek Above Recharge Zone	57	N/A
CP22	—	Verde Creek In Recharge Zone	105	N/A
CP231	—	Elm Creek	33	N/A
CP232	—	Quihi Creek	14	N/A
CP31	—	Calallen Diversion Dam	16,721	N/A
CPBAY	—	Upper Nueces Bay	16,850	—
CPEST	—	Nueces Bay and Estuary	17,147	—
Streamgages Not Used for Primary Control Points[2]				
—	247	Nueces River, Cinonia	2,150 (E)	08/15 to 09/25
—	253	Frio River, Frio Town	1,460 (E)	05/24 to 09/27
—	1942	San Casimiro Creek, Freer	469	01/62 to 12/96
—	1946	Nueces River, Simmons	8,561	04/65 to 09/77
—	255	Leona River, Divot	565 (E)	05/24 to 09/29
—	2005	Hondo Creek, Hondo	132	05/52 to 10/64
—	2020	Seco Creek, Utopia	53	08/52 to 09/61
—	2025	Seco Creek, D'Hanis	87	08/52 to 10/64
—	2066	Frio River, Tilden	4,493	10/78 to 12/96
—	2075	Atascosa River, McCoy	530	08/51 to 08/57
—	2104	Lagarto Creek, George West	155	10/71 to 12/96
—	2112	Nueces River, Bluntzer	16,772	03/92 to 12/96
—	2115	Nueces River, Calallen	16,920	10/89 to 12/96
Reservoir Contents Gages				
—	Lake	Choke Canyon Reservoir	5,490	10/82 to 12/96
—	Lake	Lake Corpus Christi	16,656	09/48 to 12/96

[1] The drainage areas reported at USGS gaged locations are the official drainage areas reported by the USGS and the drainage areas reported at ungaged locations are those reported by HDR in "Nueces River Basin Regional Water Supply Planning Study – Phase I," Vols. 1, 2, and 3, Nueces River Authority, et al., May 1991.

[2] Many of these limited record streamflow gaging stations were used in basic data development and refinement.

3.1.2.2 Reservoir Inflows

Historical reservoir inflows were computed for Choke Canyon Reservoir (October 1982 through December 1996) and Lake Corpus Christi (September 1948 through December 1996) to supplement gaged streamflow records for the Frio River at Calliham and the Nueces River near Mathis, respectively. Computation of historical inflows for Lake Corpus Christi was based on the principle of continuity as formulated in the following simplified equation:

$$I_t = (Z_t - Z_{t-1}) + E_t + S_t + D_t$$

Where:
- I_t = Inflow
- Z_t = End-of-Month Storage
- Z_{t-1} = End-of-Month Storage, Previous Month
- E_t = Net Evaporation
- S_t = Spill and/or Release
- D_t = Direct Diversion

Basic data sets for inflow computations, including end-of-month contents, outflow, precipitation, and pan evaporation, were obtained from Operator's Daily Logs provided by the City of Corpus Christi. Net monthly water surface evaporation rates were derived as described in Section 3.3. Elevation-area-capacity relationships representative of conditions in 1948,[40] 1959,[41] 1972,[42] and 1987[43] were used for Lake Corpus Christi. Spills and releases from Lake Corpus Christi were assumed equal to the concurrent gaged streamflow reported by the USGS for the Nueces River near Mathis. Records of direct diversions from Lake Corpus Christi for the Alice Water Authority, Beeville Water Supply District, and City of Mathis were obtained from the TNRCC for the period of record prior to 1982. For the 1982 to 1996 period of record, the City of Corpus Christi supplied records of raw water sales directly diverted from the lake. Computed historical inflows to Lake Corpus Christi were naturalized in the same manner as gaged streamflows.

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[40] Soil Conservation Service (SCS), "Report on Sedimentation in Lake Corpus Christi and the Water Supply of Corpus Christi, Texas," USDA, December 1948.
[41] Texas Water Development Board (TWDB), "Engineering Data on Dams and Reservoirs in Texas," Report 126, February 1971.
[42] McCaughan & Etheridge Consulting Engineers, "Report on Sedimentation Survey of Lake Corpus Christi," Corpus Christi, Texas, March 1973.
[43] USGS Map of Reservoir Bottom Developed in 1987 Report Entitled, "Preliminary Results of an Investigation of Factors Contributing to Water Storage Reduction within Lake Corpus Christi, Texas," USGS, 1987.

In the natural streamflow development for Choke Canyon Reservoir, inflows were not computed using the same mass balance techniques as described for Lake Corpus Christi. Unlike Lake Corpus Christi, Choke Canyon Reservoir has only a partial flow gaging station downstream, which is not rated to measure the full range of releases and/or spills. Therefore, in the mass balance computations for Choke Canyon Reservoir, outflow estimates are dependent on theoretical discharge relationships developed for the reservoir outlet works during the design of the dam. Consideration of available gaged streamflow records upstream of the dam and recent analysis of flows computed using the reservoir outlet works ratings[44] suggest that another approach for estimating inflows to Choke Canyon Reservoir might be more accurate.

The total watershed upstream of Choke Canyon Reservoir measures 5,490 square miles (sq. mi.). Two USGS streamflow gaging stations immediately upstream of the reservoir, Frio River at Tilden (4,493 sq. mi.) and San Miguel Creek at Tilden (783 sq. mi.), directly measure runoff from approximately 96 percent of the contributing drainage area of Choke Canyon Reservoir. Given uncertainties as to the accuracy in outflow measurements from Choke Canyon Reservoir in conjunction with the significant gaged coverage of the watershed, the best method for estimating inflows to Choke Canyon Reservoir is believed to be a combination of the two gaged flows at the Frio River at Tilden and San Miguel Creek at Tilden adjusted for the intervening drainage area located downstream of the gages and upstream of the dam. The reservoir inflows to Choke Canyon for the October 1982 to December 1996 period of record were therefore estimated using the following equation:

$$I = QG_{2066} + QG_{2067}\left(\frac{DA_{CCR} - DA_{2066}}{DA_{2067}}\right)$$

Where:
I = Inflow
QG_{2066} = Monthly Gaged Flow, Frio River at Tilden
QG_{2067} = Monthly Gaged Flow, San Miguel Creek at Tilden
DA_{CCR} = Drainage Area, Choke Canyon Reservoir (5,490 sq. mi.)
DA_{2066} = Drainage Area, Frio River at Tilden (4,493 sq. mi.)
DA_{2067} = Drainage Area, San Miguel Creek at Tilden (783 sq. mi.)

It is assumed that the runoff characteristics of San Miguel Creek at Tilden most closely match the characteristics of the intervening watershed below the gages and above the dam, therefore,

[44] HDR, Op. Cit., January 1999.

the flows on San Miguel Creek were adjusted by drainage area to account for the intervening runoff.

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.** The 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 following equation:

$$\text{Delivery Factor} = 1 - \text{Channel Loss}$$

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

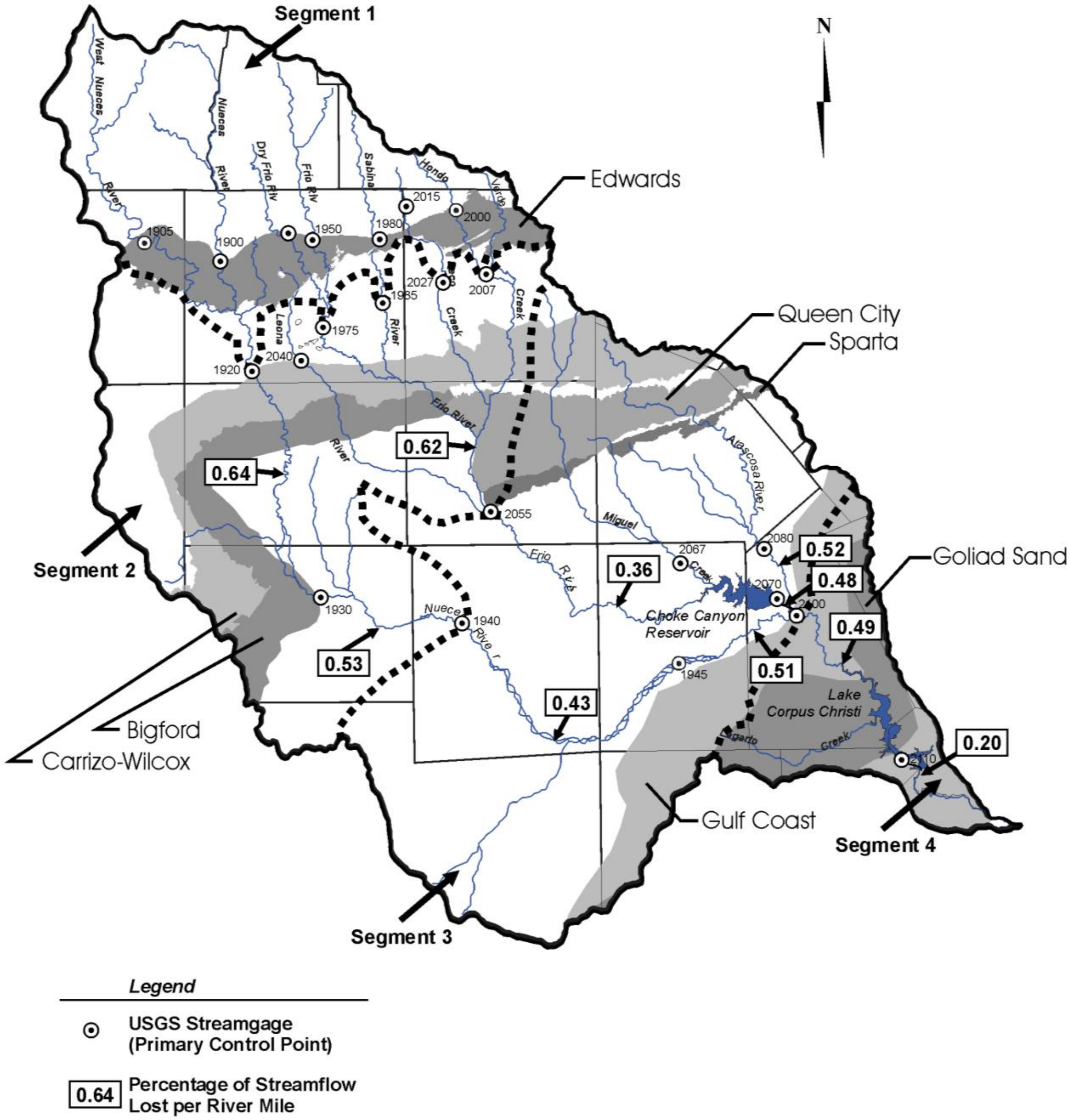
A streamflow delivery factor representing the percentage of water passing an upstream control point that arrives at the next downstream control point was estimated for each stream reach linking primary control points in the Nueces River Basin as part of the natural streamflow development. Delivery factors used in the model are summarized between primary control points in Table 3-2. The factors presented in Table 3-2 were derived using one of two methods, depending upon location or major segment within the river basin. Figure 3-3 displays the location of the major segments used in the delivery factor and channel loss calculations. Delivery factors in Segment 1, where intervening watersheds between upstream and downstream control points are relatively small and typically lie atop the outcrop of the Edwards Aquifer, were obtained using stepwise multiple linear regression. In Segments 2, 3, and 4, where intervening watersheds are substantially larger and channel loss rates are of great consequence in this study, delivery factors were derived using rainfall/runoff techniques in conjunction with gaged streamflow records. Each of these methods is discussed in the following subsections.

The delivery factors shown in Table 3-2 for the primary control points were apportioned to the secondary control points based on reach lengths as discussed in Section 4.2.1.

Table 3-2.
Summary of Delivery Factors by Stream Reach

Stream	*Reach Reference Numbers*		*Delivery Factor*[1]
	From Gage No. (Control Point)	*To Gage No. (Control Point)*	
Nueces River	1900 (CP01)	1920 (CP03)	**0.95**
West Nueces River	1905 (CP02)	1920 (CP03)	**0.97**
Nueces River	1920 (CP03)	1930 (CP04)	**0.53**
Nueces River	1930 (CP04)	1940 (CP05)	**0.74**
Nueces River	1940 (CP05)	1945 (CP06)	**0.65**
Nueces River	1945 (CP06)	2100 (CP20)	**0.82**
Frio River	1950 (CP07)	1975 (CP09)	**0.51**
Dry Frio River	1960 (CP08)	1975 (CP09)	**0.78**
Frio River	1975 (CP09)	2055 (CP25)	**0.51**
Sabinal River	1980 (CP12)	1985 (CP13)	**0.84**
Sabinal River	1985 (CP13)	2055 (CP25)	**0.51**
Seco Creek	2015 (CP16)	2027 (CP17)	**0.51**
Seco Creek	2027 (CP17)	2055 (CP25)	**0.51**
Hondo Creek	2000 (CP18)	2007 (CP19)	**0.77**
Hondo Creek	2007 (CP19)	2055 (CP25)	**0.51**
Verde Creek	CP21	CP22	**0.77**
Verde Creek	CP22	2055 (CP25)	**0.51**
Leona River	CP10	2040 (CP24)	**0.51**
Leona River	2040 (CP24)	2055 (CP25)	**0.51**
Misc. Ungaged	CP10, CP111, CP112, CP141, CP142, CP15, CP201, CP202, CP23	2055 (CP25)	**0.51**
Frio River	2055 (CP25)	2070 (CP27)	**0.66**
San Miguel Creek	2067 (CP26)	2070 (CP27)	**0.53**
Frio River	2070 (CP27)	2100 (CP29)	**0.95**
Atascosa River	2080 (CP28)	2100 (CP29)	**0.90**
Nueces River	2100 (CP29)	2110 (CP30)	**0.74**
Nueces River	2110 (CP30)	CP31	**0.93**

1 Delivery factor represents an estimate of the average percentage of water passing an upstream control point that arrives at the next downstream control point. For example, 0.95 equal 95 percent.



Note: Channel loss rate of 0.62 percent/mile for the Frio River below the Edwards Aquifer recharge zone is assumed reasonable for the Leona River, Hondo Creek, and Seco Creek

Figure 3-3. Average Channel Loss Rates in the Nueces River Basin

3.1.3.1 Segment 1 – Multiple Linear Regression

Stepwise multiple linear regression techniques were used to estimate delivery factors for gaged stream reaches in Segment 1, which include the Nueces, Frio, and Sabinal Rivers, and Hondo and Seco Creeks. The delivery factor for Verde Creek, which is ungaged, was assumed equal to that derived for adjacent Hondo Creek, due to comparable soil-cover complex, intervening drainage area size, and geographic proximity. Using these regression techniques, candidate independent variables were evaluated individually for significance and retained if they significantly improved estimates of the dependent variable. The general form of the regression equation was assumed to be as follows:

$$QNH = a\,(QG) + b\,(QI) + c$$

Where: QNH = Downstream Gaged Flow Adjusted for Diversions in Intervening Area;
QG = Upstream Gaged Flow;
QI = Estimated Flow from Intervening Area; and
a, b & c = Regression Coefficients

If two upstream gaged flow records exist above any one downstream gage, records from each upstream gage were included as independent variables for the period of concurrent record. The estimated flow from the intervening area, QI, was calculated monthly based on soil-cover complex, antecedent moisture conditions, and local precipitation. Only independent variables or regression coefficients significant at the 90 percent confidence level based on the Students t Test[45] were retained in the regression equations. The coefficient "a" associated with upstream gaged flow, QG, approximates the long-term average delivery factor for upstream gaged flow to a downstream gage location.

The five resulting regression equations for stream reaches in Segment 1 had coefficients of determination, r^2, ranging from 0.96 for the Nueces River to 0.57 for Seco Creek. The coefficient of determination of 0.96 for the Nueces River implies that 96 percent of the variation in the flow recorded at the gage below Uvalde can be explained by the regression equation. A weighted average r^2 for the equations representative of Segment 1 is 0.91 based on the dependent (downstream) mean monthly flow for each stream.

[45] Haan, C.T., "Statistical Methods in Hydrology," Iowa State University Press, Ames, Iowa, 1977.

In Segment 1, upstream gaged flow and estimated intervening flow were significant in each of the five equations with the exception of the Frio River, where the intervening flow was not statistically significant. Well levels at the City of Uvalde well were also considered as candidate independent variables in developing regression equations for the Nueces and Frio Rivers. Consideration of well levels did not significantly improve estimates of downstream flow when all months with concurrent upstream and downstream flow records were considered in the regression analyses. The USGS[46] found well levels along with upstream flow and a time/cumulative volume variable to be significant in one regression analysis of the Nueces River obtaining an r^2 of 0.89 using 103 data points. Runoff from the intervening watershed, however, was not directly considered by the USGS. The regression equation selected in this study was based on 536 data points, included both upstream and intervening flow, and resulted in an r^2 of 0.96.

3.1.3.2 Segments 2, 3, and 4 – Rainfall/Runoff Techniques

Delivery factors or channel loss rates for stream reaches in Segments 2, 3, and 4 were calculated by performing long-term comparisons of concurrent upstream and downstream gaged streamflows using a modified SCS curve number procedure[47,48] and monthly areal precipitation to estimate intervening runoff arriving at the downstream gage. The resulting channel loss rates showing the percentage of flow lost per river mile for each stream reach are presented in Figure 3-3 and should not be confused with the delivery factors presented in Table 3-2, which represent the cumulative effects of channel losses for an entire stream reach of interest. Channel loss rates upstream of Lake Corpus Christi ranged from a minimum of 0.36 percent per mile on the Frio River from Derby to Choke Canyon Reservoir to a maximum of 0.64 percent per mile on the Nueces River from Uvalde to Asherton. The average loss rate of 0.20 percent per mile on the Nueces River from Lake Corpus Christi to Calallen Dam was based on field measurements reported by the USGS and TWDB[49] and is representative of the loss rate during periods of normal water deliveries with minimal intervening flows. Channel losses in the “braided reach”

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[46] USGS, “Streamflow Losses Along the Balcones Fault Zone, Nueces River Basin, Texas,” Water Resources Investigations Report 83-4368, Austin, Texas, 1983.
[47] SCS, “Section 4, Hydrology, SCS National Engineering Handbook,” USDA, 1972.
[48] USGS, “Conveyance Characteristics of the Nueces River, Cotulla to Simmons, Texas,” Water Resources Investigation Report 83-4004, Austin, Texas, 1983.
[49] USGS, “Water-Delivery Study, Lower Nueces River Valley, Texas,” TWDB Report 75, May 1968.

of the Nueces River between Cotulla and Tilden averaged 0.43 percent per mile, which is within the range of loss rates reported for this reach by the USGS.[50] Loss rates developed throughout Segments 2 and 3 compared well with the results of water delivery studies reported by the USGS.[51] As is apparent in Figure 3-3, channel loss rates were generally higher in stream reaches crossing major aquifer recharge zones. Table 3-3 summarizes composite estimates of the percentage of upstream flow lost for four reaches of significant interest.

Table 3-3.
Summary of Channel Losses Downstream
of the Edwards Aquifer Recharge Zone

River Reach	*Reach Length (miles)*	*Percentage of Upstream Flow Lost*
Nueces River between Uvalde and Lake Corpus Christi	**291.4**	**84.5**
Frio River between Edwards Aquifer Recharge Zone and Choke Canyon Reservoir	**173.7**	**66.3**
Frio and Nueces Rivers between Choke Canyon Reservoir and Lake Corpus Christi	**63.3**	**29.7**
Nueces River between Lake Corpus Christi and Calallen Dam	**35**	**7.0**

The first step in the derivation delivery factors downstream of the Edwards Aquifer Recharge Zone was estimation of appropriate SCS map curve numbers for each subwatershed. This was accomplished by detailed review of available county soil surveys[52] and adjustment to account for typical antecedent moisture conditions.[53] The resulting map curve numbers are summarized in Table 3-4. Six gaged headwater watersheds, including the Nueces, Frio, Sabinal, and Atascosa Rivers, and San Miguel and San Casimiro Creeks, were analyzed to obtain a relationship between the map curve number and the volumetric curve number. The volumetric

[50] USGS, Op. Cit., 1983.
[51] USGS, "Hydrologic Effects of Floodwater-Retarding Structures on Garza-Little Elm Reservoir, Texas," Water Supply Paper 1984, 1970.
[52] SCS, Soil Surveys for Maverick, Uvalde, Frio, Dimmit and Zavala, San Patricio and Aransas, Bandera, Webb, Bee, Nueces, Atascosa, Medina, and Jim Wells Counties, USDA.
[53] SCS, "Engineer-Hydrology Memorandum TX-1, (Rev. 1), (Supplement 3)," USDA, Temple, Texas, May 1978.

Table 3-4.
Summary of Runoff Curve Numbers
Downstream of the Edwards Aquifer Recharge Zone

Streamgage/Control Point		***Map Curve Number[1]***
Reference Number	***Location***	
1930 (CP04)	**Nueces River near Asherton**	**52.5**
1940 (CP05)	**Nueces River at Cotulla**	**50.5**
1942 (—)	**San Casimiro Creek near Freer**	**57**
1945 (CP06)	**Nueces River near Tilden**	**51.5**
1946 (—)	**Nueces River at Simmons**	**54**
2055 (CP25)	**Frio River near Derby**	**56**
2067 (CP26)	**San Miguel Creek near Tilden**	**55**
2070 (CP27)	**Frio River at Calliham**	**52.5**
2080 (CP28)	**Atascosa River at Whitsett**	**57.5**
2100 (CP29)	**Nueces River near Three Rivers**	**58**
2110 (CP30)	**Nueces River near Mathis**	**59.5**

[1] These curve numbers represent average antecedent moisture conditions typical of the Nueces River Basin.

curve number is defined herein to be the curve number for which long-term average gaged runoff equals that computed from monthly areal precipitation using the following general equation:

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

Where: Q_{CN} = Calculated Runoff (acft),
A = Watershed Area (sq. mi.),
P = Areal Precipitation (inches), and
CN = Volumetric Curve Number

The following relationship ($r^2 = 0.91$) was obtained by simple linear regression of map and volumetric curve number for the headwater watersheds:

$$CN = 0.728\ (CN_m) - 0.271$$

Where: CN = Volumetric Curve Number
CN_m = Map Curve Number

Using this relationship, volumetric curve numbers were calculated from map curve numbers for each subwatershed and intervening runoff arriving at the downstream gage location was estimated on a monthly basis from areal precipitation using the preceding general equation. The percentage of flow passing the upstream control point and arriving at the downstream control point was computed for each month of concurrent record. Actual delivery factors were then computed using average upstream, intervening, and downstream flow volumes from only those months when losses were between 0 and 100 percent. Months when losses were calculated to be greater than or equal to 100 percent (intervening flow exceeds measured downstream flow) and months when no losses were calculated (measured downstream flow minus intervening flow exceeds measured upstream flow) were not included in the averages. Calculated losses in these months represent extreme or impossible conditions that generally result from inaccuracies inherent in estimating runoff for large intervening watersheds on the basis of monthly areal precipitation and estimated curve numbers.

3.1.4 Completion of Streamflow Records

Streamflow records missing during the 1934 to 1996 historical period were estimated for 14 streamflow gaging stations located throughout the Nueces River Basin using multiple linear regression techniques. Regression equations were generally derived from natural flows for nearby gaged subwatersheds; however, local runoff estimates based on areal precipitation, and curve numbers were used when appropriate and statistically significant. Well levels from the City of Uvalde well were used to extend the springflow records of the Leona River near its origin. The synthesis of streamflow records for the eight ungaged subwatershed control points located near the Edwards Aquifer recharge zone, with a total drainage area of 256 sq. mi. (less than 2 percent of the basin), is discussed in Sections 3.2.1 and 3.5.1.

The regression equations used to estimate missing monthly streamflow records are summarized in Table 3-5, along with the coefficients of determination (r^2) and lengths of concurrent record on which the equations are based. In general, the equations were developed to calculate missing natural flow directly from natural flow in upstream or adjacent subwatersheds, as well as local runoff, in order to be consistent with the upstream to downstream streamflow naturalization process. Calculated negative monthly flow values from the regression equations were set to zero. Missing gaged, rather than natural, streamflows were calculated at two locations on the Nueces River (Asherton = 1930 and Tilden = 1945) and one location on the Frio River (Calliham = 2070) because equations based on downstream flow records provided more accurate estimates. More than one regression equation was used for control points on Hondo Creek (2000) and Seco Creek (2015) because the availability of additional flow records in adjacent subwatersheds improved the estimates of missing streamflow. The length of the concurrent records on which the regression equations were based averaged 3.5 times the length of the estimated records. Coefficients of determination for the regression equations ranged from 0.53 to 0.99, with the average weighted by dependent mean being 0.94.

3.1.5 Comparison with TNRCC Naturalized Streamflows

Natural streamflows applied in the performance of this study were compared to those used by the TDWR (now TNRCC) in their water availability computer model. Figure 3-4 presents both HDR and TDWR natural streamflows for the Nueces River near Three Rivers 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. The magnitudes of the annual differences between the HDR and TDWR flows generally increased with time, as did historical diversions during the same period. Differences between the TDWR and HDR flows, however, average only 2.4 percent of the mean annual streamflow.

The differences in natural streamflow are due to differences in the streamflow naturalization methodologies applied. The TDWR adjusted gaged streamflows for historical diversion on a one-to-one basis throughout the basin, while HDR used delivery factors to translate the effects of historical diversions to downstream gages. A brief analysis of average historical water use (1940 to 1978) in each subwatershed of the basin applying HDR delivery

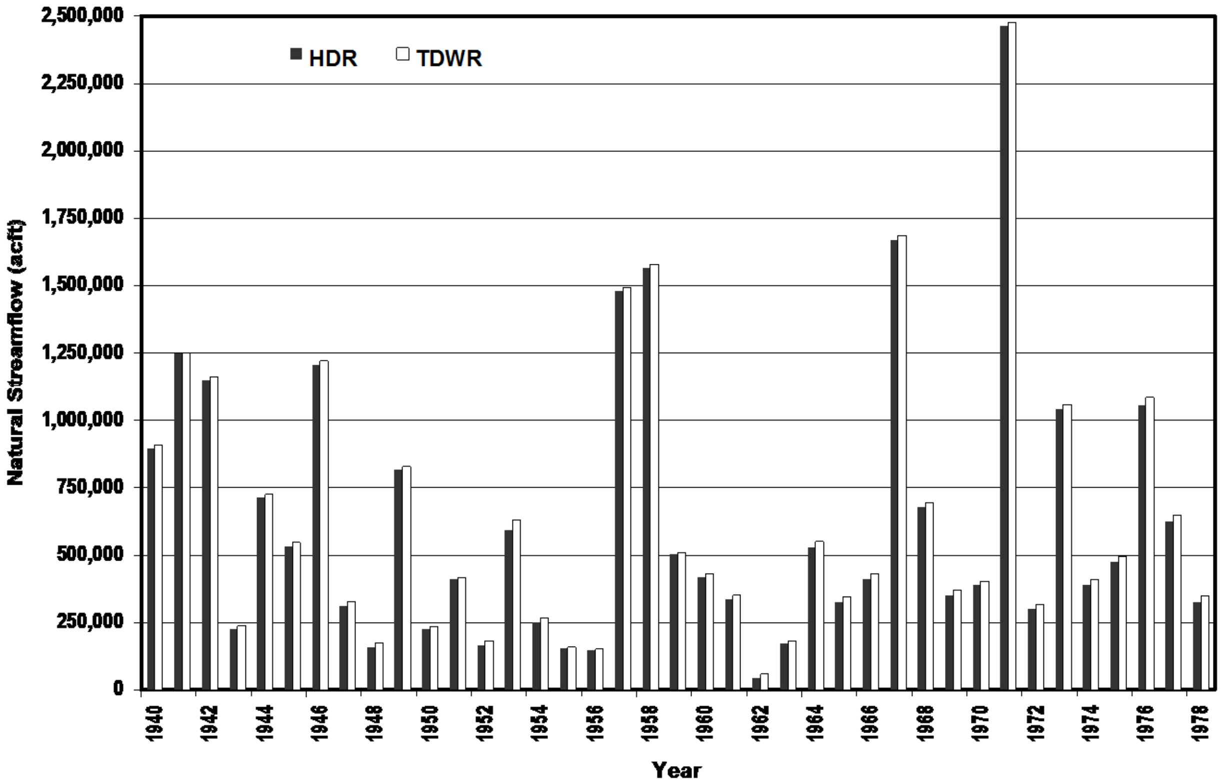

Figure 3-4. Comparison of Annual HDR and TDWR Naturalized Streamflows for the Nueces River near Three Rivers

factors indicates that more than 90 percent of the average difference between HDR and TDWR flows is attributable to the consideration of channel losses or delivery factors. The remainder of the difference may be attributable to 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 recharge enhancement projects. Use of the TDWR procedures neglecting channel losses is reasonable in basins where authorized diversion rights approximate historical diversions. In the Nueces River Basin, however, underestimation of inflows to the CCR/LCC System would result because authorized diversion rights significantly exceed historical diversions, particularly in the early portion of the 1934 to 1996 period. 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.[54]

3.1.6 Statistical Assessment of Trends in Streamflow

In relatively arid watersheds like the Nueces River Basin, it is not uncommon for streamflow characteristics to be influenced over time by changes occurring in the watershed. Examples of these changes may include: 1) farming techniques intended to reduce runoff such as furrow diking, contour plowing, and terracing; 2) allowing previously farmed land to revert to pasture or rangeland; 3) increased groundwater use resulting in lowering of the water table which, in turn, reduces the baseflow of streams and increases aquifer recharge and natural channel losses; 4) increased prevalence of certain types of vegetation which enhance evapotranspiration losses; and 5) construction of farm ponds and other water control structures. Each of the above changes tends to decrease runoff, while the converse of the above items may tend to increase runoff. Climatic changes, such as global warming, may also affect the frequency and intensity of precipitation events, wind speed and direction, temperature, and other factors, which, in turn, influence streamflow characteristics. This 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.

3.1.6.1 Previous Studies

As early as 1959, studies were performed which involved the detection of trends in the runoff characteristics of rivers and creeks in the Nueces River Basin.[55,56,57,58] Studies by the USBR indicated that future inflows to Choke Canyon Reservoir could be expected to be about 5 to 10 percent less than those that were observed historically due to changes in the watershed. Specifically, these changes include land management practices (e.g., contour plowing and terracing), construction of farm ponds, and construction of other water control structures.

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[54] 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.
[55] USBR, "Nueces River Project, Texas, Appendices to Feasibility Report," U.S. Dept. of the Interior, July 1971.
[56] USBR, "Nueces River Feasibility Report," U.S. Dept. of the Interior, July 1971.
[57] USBR, "Runoff: Nueces River Basin," Texas Basins Project, U.S. Dept. of the Interior, June 1959.
[58] HDR and GMI, Op. Cit., May 1991.

More recent studies have been performed in Texas evaluating the effects of brush modification and brush control on river flow and water supply. The Nueces River Basin is approximately 90 percent rangeland and pastureland, with significant percentages of canopy cover made up of mesquite, prickly pear, and black brush.[59] It has been observed, and in some cases shown, that after brush control was applied to watersheds, springs and creeks of local and neighboring areas began to flow. Among the notable examples are Rocky Creek in Tom Green and Irion Counties, the Bridgeford Ranch in Nolan County, the Chaparrosa Ranch in Zavala County, the Seco Creek watersheds,[60] and on ranches in the Fredricksburg/Kerrville area.[61] Quantitative information about the potential effects on aquifer recharge and surface water streamflows resulting from brush management programs remain sufficiently inconclusive to limit feasibility of large-scale brush management as a water development tool.

3.1.6.2 Recent Experience

Recent analyses of the potential effects of declining runoff per unit rainfall in the Nueces River Basin have ranged from purely statistical assessments[62] to computer modeling of groundwater/surface water interactions.[63] A few of those recent analyses are summarized in this subsection.

In the 1991 Nueces River Basin Study,[64] historical trends in streamflow were evaluated in eight watersheds in the basin. In a qualitative attempt to identify potential trends in selected portions of the basin, 10-year moving average analyses of runoff per unit rainfall were performed for watersheds upstream of eight long-term streamflow gaging stations. For these analyses, annual rainfall and runoff totals (expressed in inches over the watershed area) were tabulated, averages were calculated for each of the 10-year periods (overlapping) in the series. The 56-year period from 1934 to 1989 was used, resulting in forty-seven 10-year averages with ending years from 1943 to 1989. The moving averages of runoff as a percentage of rainfall were tabulated at

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[59] Texas State Soil and Water Conservation Board, "Texas Watersheds, A Comprehensive Study of Agriculture's Impacts on Water Quality and Water Quantity," Temple, Texas, December 1990.
[60] Dugas, W.A., et al., "Effect of Removal of *Juniper ashei* on Evapotranspiration and Runoff in the Seco Creek Watershed," Water Resources Research, Vol. 34, No. 6, pp. 1499-1506, June 1998.
[61] TWDB, "Water Yield Improvement from Rangeland Watersheds," January 1988.
[62] HDR and GMI, Op. Cit., May 1991.
[63] LBG-Guyton (LBG) and HDR, "Interaction between Groundwater and Surface Water in the Carrizo-Wilcox Aquifer," TWDB, August 1998.

each of eight selected stations: Nueces River at Laguna, Nueces River below Uvalde, Nueces River at Cotulla, Nueces River near Three Rivers, Frio River at Concan, Frio River near Derby, Frio River at Calliham, and Atascosa River at Whitsett.

Runoff as a percentage of rainfall in the four most upstream watersheds in the basin has a generally increasing trend during the period considered. These four gages include the Nueces River at Laguna and below Uvalde, and the Frio River at Concan and near Derby. Runoff percentages at the next downstream gaging stations (i.e., Nueces River at Cotulla and Frio River at Calliham), however, do not exhibit this increasing trend and appear generally uniform throughout the period. Since rainfall and runoff values for these two watersheds include the upper four watersheds, it is possible that a negative or decreasing trend may exist in the intervening watersheds that is masked by the apparently increasing runoff from the upstream areas. Runoff percentages for the other two watersheds (i.e., Atascosa River at Whitsett and Nueces River near Three Rivers) apparently exhibit negative trends in runoff over the period.

A number of statistical tests for trend were performed as part of the 1991 study.[65] Interpretation of the results of the statistical tests indicated that, at that point in time, the Atascosa River could be exhibiting a significant decreasing trend in runoff per unit of precipitation. The overall significance of the apparent trend is somewhat diminished by the fact that the Atascosa River watershed above Whitsett represents only about 7 percent of the contributing basin area above Lake Corpus Christi. At the end of the 1991 study, understanding of the physical causes of the apparent decreasing runoff trend in the Atascosa River watershed was insufficient to warrant adjustments to historical streamflows for apparent trends in runoff. Since 1991, additional studies have been performed exploring this issue and discussion of these studies follows.

Prompted by observed water level declines in the outcrop of the Carrizo-Wilcox Aquifer and indications of decreasing runoff per unit rainfall in the Atascosa River Basin, HDR performed an updated statistical evaluation of apparent declining runoff trends in the Atascosa River Basin.[66] In these studies, potential long-term changes in runoff per unit rainfall for the Atascosa River Basin were analyzed by subdividing available hydrologic data into three 20-year

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[64] HDR and GMI, Op. Cit., May 1991.
[65] Ibid.
[66] HDR, "Summary of Preliminary Findings: Consideration of Potential Runoff Trends in the Atascosa River Watershed," City of Corpus Christi, Texas, 1995.

periods. These three periods are 1935 to 1954, 1955 to 1974, and 1975 to 1994, with each period including a time of severe drought. Streamflow decile averages were computed by ranking the monthly flows per unit rainfall within a subperiod and averaging the values within successive 10-percentile groups. Average monthly runoff per unit rainfall decreased with time in each streamflow decile average confirming indications of decreasing annual runoff.

To assess the impact of the apparent trend of decreasing runoff per unit rainfall on the firm yield of the CCR/LCC System, instream flows, and freshwater inflows to the Nueces Estuary, two alternative streamflow sets were developed for the Atascosa River Basin. The first flow set was representative of "present" conditions and developed by applying a regression equation based on the most recent period to estimate runoff for the earlier two periods. A second alternative flow set was developed to be representative of "original" conditions by applying the regression equation based on the 1935 to 1954 period to estimate runoff for the two more recent periods. Estimated annual runoff volumes in each flow set were distributed on a monthly basis using ratios of historical monthly to annual flows. In summary, these analyses support previous indications of decreasing runoff per unit rainfall in the Atascosa River Basin.

In 1998, a research study of the interaction between groundwater and surface water[67] was completed for the Nueces and Guadalupe-San Antonio River Basins focusing on aquifers outcropping downstream of the Edwards Aquifer. One of the primary goals of this study was to create a groundwater model that could be used to estimate the effects of future pumpage scenarios for the Carrizo-Wilcox Aquifer on streamflows in the rivers and streams that contact the outcrop of the aquifer.

While the completion of this research study represents a very significant step, definition of the interactions between surface and ground water in the Nueces River Basin remains a developing science. Without a full understanding of the physical causes of apparently decreasing runoff from the Atascosa River watershed, whether they be increased aquifer withdrawals, agricultural practices, brush proliferation, climatic changes, or other factors, one has no assurance that observed historical trends would continue into the future. For these reasons, no adjustments to natural streamflows for apparent historical trends in runoff in this watershed have

[67] LBG and HDR, Op. Cit., August 1998.

been made as a part of the development of an updated water availability model for the Nueces River Basin.

3.2 Natural Streamflow at Ungaged Locations

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

In previous studies cited in Section 2, monthly natural streamflow and potential runoff data sets were developed for selected ungaged watersheds originating upstream of or atop the Edwards Aquifer outcrop. 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 over the upstream area using the modified Soil Conservation Service (SCS) method presented in Section 3.5.1. These monthly estimates of potential runoff were reduced by the monthly estimates of historical recharge in those basins. Resulting estimates of natural flow were then utilized to distribute flows to ungaged water right diversion locations as described in the ensuing 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 Nueces River Basin above Calallen Dam. Control points CPBAY and CPEST represent flows contributing from multiple locations and, as such, do not represent discrete points and are not shown on Figure 3-5.

Several alternative algorithms are coded into WRAP to distribute naturalized flows from primary (“known-flow”) control points to secondary control points (Figure 3-5) 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

Gaged Primary Control Points		
Control Point #	USGS Gage #	Location
(CP) 1	1900	Nueces River @Laguna
(CP) 2	1905	W. Nueces @ Bracketbille
(CP) 3	1920	Nueces River @ Uvalde
(CP) 4	1930	Nueces River @ Asherton
(CP) 5	1940	Nueces River @ Cotulla
(CP) 6	1945	Nueces River @ Tilden
(CP) 7	1950	Frio River @ Concan
(CP) 8	1960	Dry Frio River @ Reagan Wells
(CP) 9	1975	Frio River @ Uvalde
(CP) 12	1980	Sabinal River @ Sabinal U/S
(CP) 13	1985	Sabinal River @ Sabinal D/S
(CP) 16	2015	Seco Creek @ Utopia
(CP) 17	2027	Seco Creek @ D'Hanis
(CP) 18	2000	Hondo Creek @ Tarpley
(CP) 19	2007	Hondo Creek @ Hondo
(CP) 24	2040	Leona River @ Uvalde
(CP) 25	2055	Frio River @ Derby
(CP) 26	2067	San Miguel Creek near Tilden
(CP) 27	2070	Frio River at Calliham (Choke Canyon Reservoir)
(CP) 28	2080	Atascosa River @ Whitsett
(CP) 29	2100	Nueces River @ Three Rivers
(CP) 30	2110	Nueces River @ Mathis (Lake Corpus Christi)
(CP) 31	2115	Nueces River @ Calallen
Ungaged Primary Control Points		
(CP) 10	N/A	Leona River
(CP) 111	N/A	Hackberry Creek
(CP) 112	N/A	Blanco Creek
(CP) 141	N/A	Little Blanco Creek
(CP) 142	N/A	Nolton Creek
(CP) 15	N/A	Rancheros Creek
(CP) 201	N/A	Live Oak Creek
(CP) 202	N/A	Parkers Creek
(CP) 21	N/A	Verde Creek above the Recharge Zone
(CP) 22	N/A	Verde Creek in the Recharge Zone
(CP) 231	N/A	Elm Creek
(CP) 232	N/A	Quihi Creek

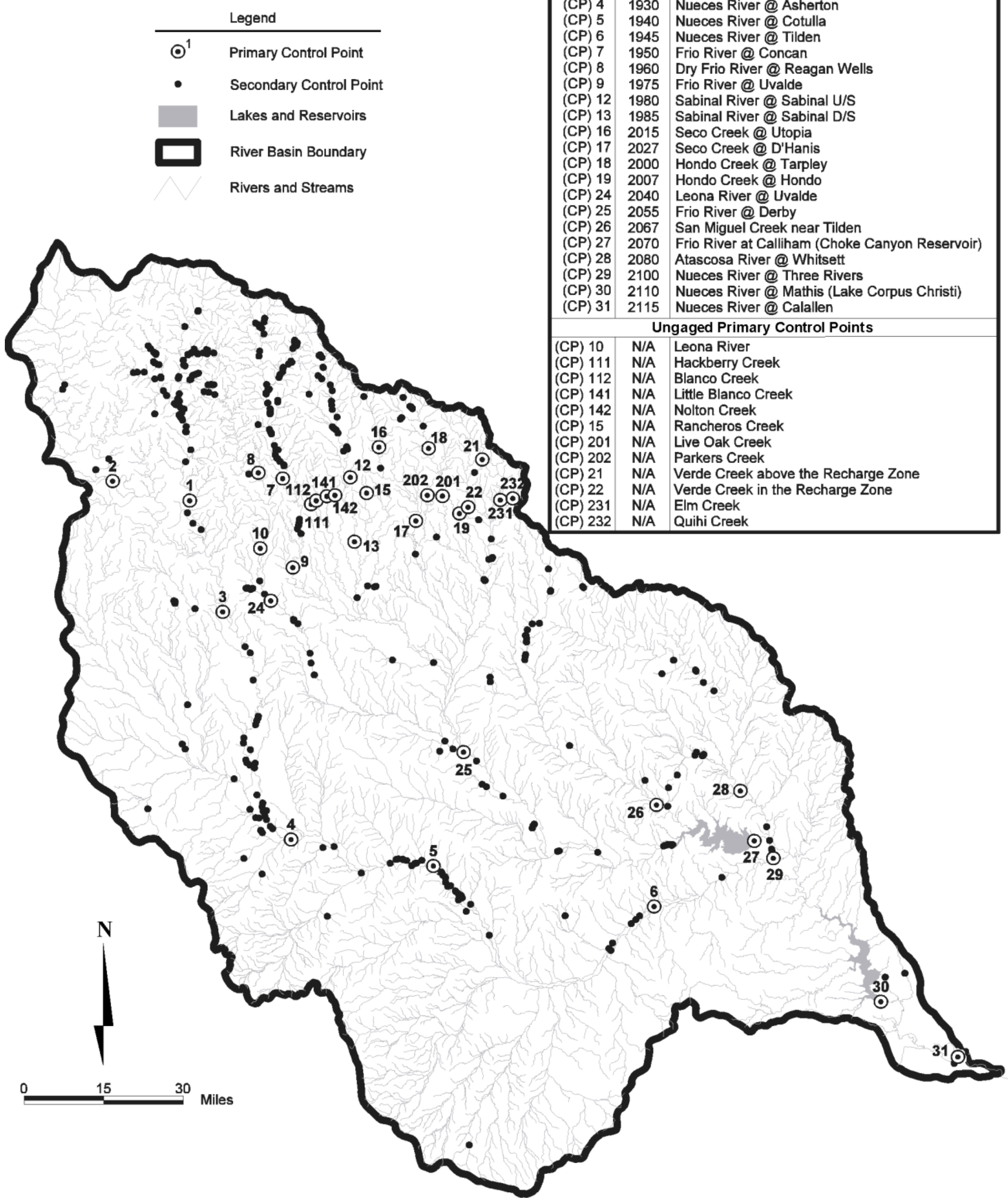

Figure 3-5. Primary and Secondary Control Points in the Nueces River Basin Above Calallen Dam

correctly account for channel losses when distributing flows, INMETHOD3 and INMETHOD6. 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.[68] The application of INMETHOD3 and INMETHOD6 is described in the WRAP User's Manual.

Because channel losses play a significant role in the Nueces River Basin, INMETHOD6 was used for all secondary control points, with the exception of several in the vicinity of Leona Springs (319401, 319402, 319501, 319601, 319602, 529731, 399101, 398801, 398802, 398901, 398902, 399001, and 430401). Water availability to rights at these locations is predominately determined by discharge from Leona Springs. Hence, flows available to each of these rights were set equal to those at primary control point CP24, Leona Springs at Uvalde, since the gage at that location measured accumulated flow from multiple upstream springs.

3.2.3 Ungaged Freshwater Inflows to the Nueces Estuary

Runoff estimates for the ungaged coastal area below Lake Corpus Christi were required to develop a natural flow record at the Calallen Diversion Dam, and to develop a record of natural freshwater inflows into Nueces Bay and the Nueces Estuary. The ungaged areas include 190 sq. mi. of intervening area between Lake Corpus Christi and the Calallen Diversion Dam; 129 sq. mi. of intervening area between the Calallen Diversion Dam and Corpus Christi Bay; and the remaining 292 sq. mi. that contribute flows to the Nueces Estuary. As such, the Corpus Christi Bay and Nueces Estuary control points (CPBAY and CPEST) do not represent discrete points, but rather, all of the watershed areas contributing flows to Nueces Bay and the Nueces Estuary.

Naturalized flows at these control points were developed by adding estimates of intervening runoff to the naturalized flows developed for Lake Corpus Christi. The estimates of intervening runoff were developed during previous studies[69,70] using rainfall-runoff techniques developed by the TWDB.[71]

[68] HDR, "Distribution of Naturalized Streamflows from Gaged to Ungaged Control Points Accounting for Aquifer Recharge and Channel Losses," Technical Memorandum, TNRCC, December 1998.
[69] HDR, et al, "Nueces Estuary Regional Wastewater Planning Study - Phase II," City of Corpus Christi, et al., June 1993.
[70] HDR, Op. Cit., January 1999.
[71] TWDB, "User's Manual for the TWDB's Rainfall-Runoff Model, Draft-1," 1992.

3.3 Net Reservoir Evaporation

3.3.1 Evaporation and Precipitation Data Sources

Since the turn of the century, evaporation pans and precipitation gages 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[72] and developed monthly reservoir net and gross evaporation rates for the entire state by one-degree quadrangles of latitude and longitude for the 1940 to 1990 period. In 1998, the TWDB recomputed gross evaporation rates for all quadrangles and issued updated data for the 1954 to 1996 historical period.[73] The primary reason for recomputation of gross evaporation was recent work done by the National Weather Service regarding geographical variability in evaporation pan coefficients.[74] The net effect of these adjustments in the TWDB's data is a general reduction in estimated annual evaporation rates across the state.

3.3.2 Procedures for Estimation of Net Evaporation

Evaporation data used in this study were derived from the following combinations of data sources. For the 1934 to 1939 historical period, net evaporation was computed using pan evaporation data and measured precipitation. For the major reservoirs, Choke Canyon Reservoir and Lake Corpus Christi, a regression equation based on the 1953 to 1990 period was developed for each month of the year expressing new TWDB gross evaporation as a function of old TWDB gross evaporation by quadrangle. These equations were then used to estimate new monthly gross evaporation values for the 1940 to 1953 period. In the end, this extended the new TWDB gross evaporation data to cover the 1940 to 1996 period. A standard inverse distance ratio procedure was used to interpolate values from the centroids of the quadrangles to values representative of specific reservoir sites. Gross evaporation was adjusted by locally measured precipitation to obtain net evaporation. For the smaller reservoirs, net evaporation was calculated using TWDB gross evaporation quadrangle data (using the older data for the period from 1940 to 1953 and the recently published data for 1954 to 1996) minus precipitation representative of the quadrangles

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[72] TWDB, "Evaporation Data in Texas, Compilation Report, January 1907 - December 1970," Report 192, June 1975.
[73] TWDB, "Monthly Reservoir Evaporation Rates for Texas Using GIS," March 1998.
[74] 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.

in which the reservoirs are located. Precipitation values used were either locally measured or calculated from nearby rain gage sites using a standard inverse distance ratio procedure.

Old and new TWDB evaporation rates for Choke Canyon Reservoir were compared to evaporation rates derived by mass balance calculations for a 13-year period.[75] These comparisons indicate that the new TWDB evaporation rates more closely approximate "actual" rates based on observed historical content fluctuations. Hence, the new TWDB gross evaporation rates were adopted for use in this study.

3.3.3 Adjusted Net Evaporation

Gross evaporation rates have traditionally been estimated by recording changes in water level in evaporation pans and adjusting the readings using pan coefficients to reflect differences between evaporation from a pan and evaporation from the surface of a reservoir. These gross evaporation values are then reduced by precipitation to calculate net evaporation. Net evaporation is generally defined to be the difference between gross evaporation and direct precipitation at the free water surface of a reservoir. "Adjusted" net evaporation is calculated by subtracting the effective (rather than observed) precipitation from the gross evaporation. Based on a TNRCC technical memorandum issued in 1998, 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 (infiltration, consumptive use, interception, etc.) 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."[76]

Whether or not the net evaporation needs to be "adjusted" depends on the method used to calculate reservoir inflow. If runoff from the area inundated by the reservoir area is included in the naturalized inflows, as is the case when a drainage area ratio method is used, then the "adjusted" net evaporation rates are appropriate. If naturalized inflows have been developed based on mass balance equations at the reservoir site, then the unadjusted net evaporation rates should be used.

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[75] HDR, Op. Cit., January 1999.
[76] TNRCC, "Net Evaporation," Technical Memorandum, TNRCC, November 23, 1998.

A routine exists within WRAP to adjust net evaporation rates for effective precipitation. This routine was used for all reservoirs except Lake Corpus Christi, for which inflows have been calculated based on a mass balance method. Inflows to all other reservoirs were calculated based on a drainage area ratio method and therefore require the net evaporation rate adjustment.

3.4 Reservoir Elevation-Area-Capacity Relationships

3.4.1 Large Reservoirs

Choke Canyon Reservoir and Lake Corpus Christi are the only two major reservoirs (capacity greater than approximately 5,000 acft) in the Nueces River Basin. Both reservoirs are authorized to impound volumes of water in excess of the capacity currently available below the conservation pool levels.

3.4.1.1 Choke Canyon Reservoir

Choke Canyon Reservoir was originally authorized to impound up to 700,000 acft of water. This is slightly greater than the capacity reported in a recent sedimentation survey performed by the TWDB in 1993 (695,271 acft).[77] The most current area-capacity relationship was extended to reflect the permitted capacity of the reservoir. This area-capacity relationship was utilized in all model runs with the exception of Run 8 (Current Conditions Run). For Run 8, the 1993 TWDB area-capacity relationship was utilized, reduced by a sediment accumulation rate of 240 acft/yr[78] to bring the reservoir to the estimated year 2000 condition using the USBR "Empirical Area-Reduction Method" for sediment deposition computations.[79,80]

3.4.1.2 Lake Corpus Christi

Lake Corpus Christi was originally authorized to impound up to 300,000 acft of water. This is approximately 20 percent greater than the capacity (241,241 acft) computed by HDR from bathymetric maps prepared by the USGS in 1987,[81] the year of the most recent

[77] TWDB, "Volumetric Survey of Choke Canyon Reservoir," September 23, 1993.
[78] USBR, "Choke Canyon Reservoir and Lake Corpus Christi System Yield Evaluation: Supporting Documentation for Repayment Obligation Investigation, August 1994.
[79] Borland, W.M. and Miller, C.R., "Distribution of Sediment in Large Reservoirs," Journal of the Hydraulic Division, ASCE, April 1958.
[80] USBR, "Revision of the Procedure to Compute Sediment Distribution in Large Reservoirs," Sedimentation Section, Hydrology Branch, U.S. Dept. of the Interior, May 1962.
[81] USGS, "Preliminary Results of an Investigation of Factors Contributing to Water Storage Reduction Within Lake Corpus Christi, Texas," 1987.

sedimentation survey. The 1987 area-capacity relationship was extended to reflect the permitted capacity of the reservoir. This area-capacity relationship was utilized in all runs with the exception of Run 8. For Run 8, the 1987 area-capacity relationship was utilized, reduced by a sediment accumulation rate of 1,223 acft/yr[82] to bring the reservoir to the estimated year 2000 condition using the USBR "Empirical Area-Reduction Method" for sediment deposition computations.

3.4.1.3 Comanche Reservoir

An area-capacity relationship was obtained from TNRCC files for Comanche Reservoir, a 4,865 acft reservoir authorized by water right number 5201 (application number). While not a "major" reservoir, its authorized storage capacity approaches 5,000 acft, and the best available information was utilized for its area-capacity relationship. This relationship was utilized for all runs except Run 8. For Run 8, the relationship was adjusted to year 2000 conditions using a sediment accumulation rate of 161.3 acft/yr.[83]

Table 3-6 lists the original authorized impoundment for the reservoirs cited above and the capacity from the most recent sedimentation survey. Table 3-7 lists the estimated year 2000 storage capacity and annual sediment accumulation rates for each major reservoir.

Table 3-6.
Sources for Area-Capacity Data for
Major Reservoirs in the Nueces River Basin

Reservoir	*Authorized Impoundment (acft)*	*Surveyed Capacity (acft)*	*Source*	*Year*
Choke Canyon Reservoir	**700,000**	**695,271**	**TWDB Survey**	**1993**
Lake Corpus Christi	**300,000**	**241,241**	**USGS Survey**	**1987**

[82] HDR, Op. Cit., January 1999.
[83] TDWR, "Erosion and Sedimentation by Water in Texas," Report 268, 1982.

Table 3-7.
Summary of Reservoir Year 2000 Capacities

Reservoir	Surveyed Capacity (acft)	Year	Sediment Accumulation Rate (acft/yr)	Year 2000 Capacity (acft)
Choke Canyon Reservoir	695,271	1993	240	693,591
Lake Corpus Christi	241,241	1987	1,223	225,248
Comanche	4,865	1988	161.3	4,704

3.4.2 Small Reservoirs

Reliable area-capacity relationships for small reservoirs (less than 5,000 acft) generally are not available in the Nueces River Basin. For these reservoirs, the generalized relationship[84] 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[85]:

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

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 four major recharge basins within the Nueces River Basin. The methodology implemented in

[84] 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.
[85] R.J. Brandes Company, "Water Availability Modeling for the Sulphur River Basin, Draft Report," January 1999.

the WRAP Model is identical to that used and accepted in previous studies of the Nueces River Basin.[86] Simulation of the permitted recharge structures on Seco Creek, Parkers Creek, and Verde Creek account for the only differences in methodology between this study and that of previous work. In this analysis, the structures are only allowed to recharge up to their annual permitted amount. Once the permitted amount is satisfied for the year, the structure is not allowed to recharge even though water may be available and in reality would have recharged. The previous work allowed for the structure to recharge up to its entire storage capacity during the monthly time step; therefore recharge due to the structure equaled inflows up to the capacity of the reservoir. Both methods have limitations, but the maximum annual permitted amount was chosen for its applicability in the legal context of this study.

The gaged and ungaged areas within the four major recharge basins are shown in Figure 3-6. The boundaries of the four recharge basins used in this and previous studies are the same as those utilized by the USGS in their annual reports,[87] prepared in cooperation with the EAA (formerly Edwards Underground Water District). Drainage areas and corresponding percentages of the total drainage area included in each recharge basin are summarized in Table 3-8. Table 3-9 summarizes drainage areas for all gaged and ungaged areas. Gaged areas total about 3,050 sq. mi. above and within the recharge zone, and ungaged areas total about 256 sq. mi. In the recharge zone proper, about 30 percent of the area is ungaged. Procedures applied for recharge calculation in both gaged and ungaged areas are described in the following sections.

3.5.1.1 Recharge in Gaged Areas

In the Nueces River Basin portion of the Edwards Aquifer recharge zone, there are 12 stream gages operated by the USGS that were utilized to calculate recharge. The locations of these gages are shown in Figure 3-6, along with drainage area boundaries and general limits of the recharge zone. Seven of these gages can be classified as upstream gages (i.e., gages upstream of the recharge zone) and the other five as downstream gages. A schematic diagram showing typical gage locations is included as Figure 3-7. All but one of the seven upstream

[86] HDR and GMI, Op. Cit., May 1991.
[87] USGS, “Compilation of Hydrologic Data for the Edwards Aquifer, San Antonio Area, Texas, 1988, With 1934-88 Summary,” Bulletin 48, November 1989.

Table 3-8.
Drainage Areas of Recharge Basins

Recharge Basin	***Drainage Area (sq. mi.)***	***Percent of Total***
Nueces – W. Nueces	**1,861**	**56%**
Frio – Dry Frio	**699**	**21%**
Sabinal	**265**	**8%**
Area between Sabinal and Medina	**481**	**15%**
Total	**3,306**	**100%**

gages are located near the upstream boundary of the recharge zone and are generally unaffected by losses to the aquifer. The gage on the West Nueces River near Brackettville is the one exception, as it is located within the recharge zone. Consultation with the USGS[88] indicates that losses occurring above this gage generally recharge that portion of the Edwards that flows to the southwest and not toward the San Antonio area. Therefore, losses that occur upstream of the West Nueces River gage were not calculated for this study. Losses occurring downstream of the West Nueces gages were calculated and included in estimates of Edwards Aquifer recharge.

Because all of the gages were not in place during the entire 1934 through 1996 period, it was necessary to extend monthly streamflow estimates at many of the gages. For the upstream gages with missing records, this was accomplished utilizing standard linear regression methods in which monthly flows were estimated based on a relationship with a long-term partner gage (or gages). For downstream gages with missing records, this was accomplished during the process of developing recharge estimates by using a multiple linear regression method in which monthly downstream flows were calculated as a function of upstream flow and intervening flow.

In gaged areas, recharge is calculated in accordance with the following equation:

$$R_k = Qreg_{us} + QI - [Qreg_k + Qwr]$$

Where: R_k = Recharge at control point, k,
$Qreg_{us}$ = Summation of regulated flow at upstream boundary of recharge zone,

QI **= Poter**

[88] USGS, Personal Communication, October 16, 1990, Larry Land, Austin, Texas.

$Qreg_k$ Regula

Qwr= Summation of streamflow depletions made by water rights over recharge zor

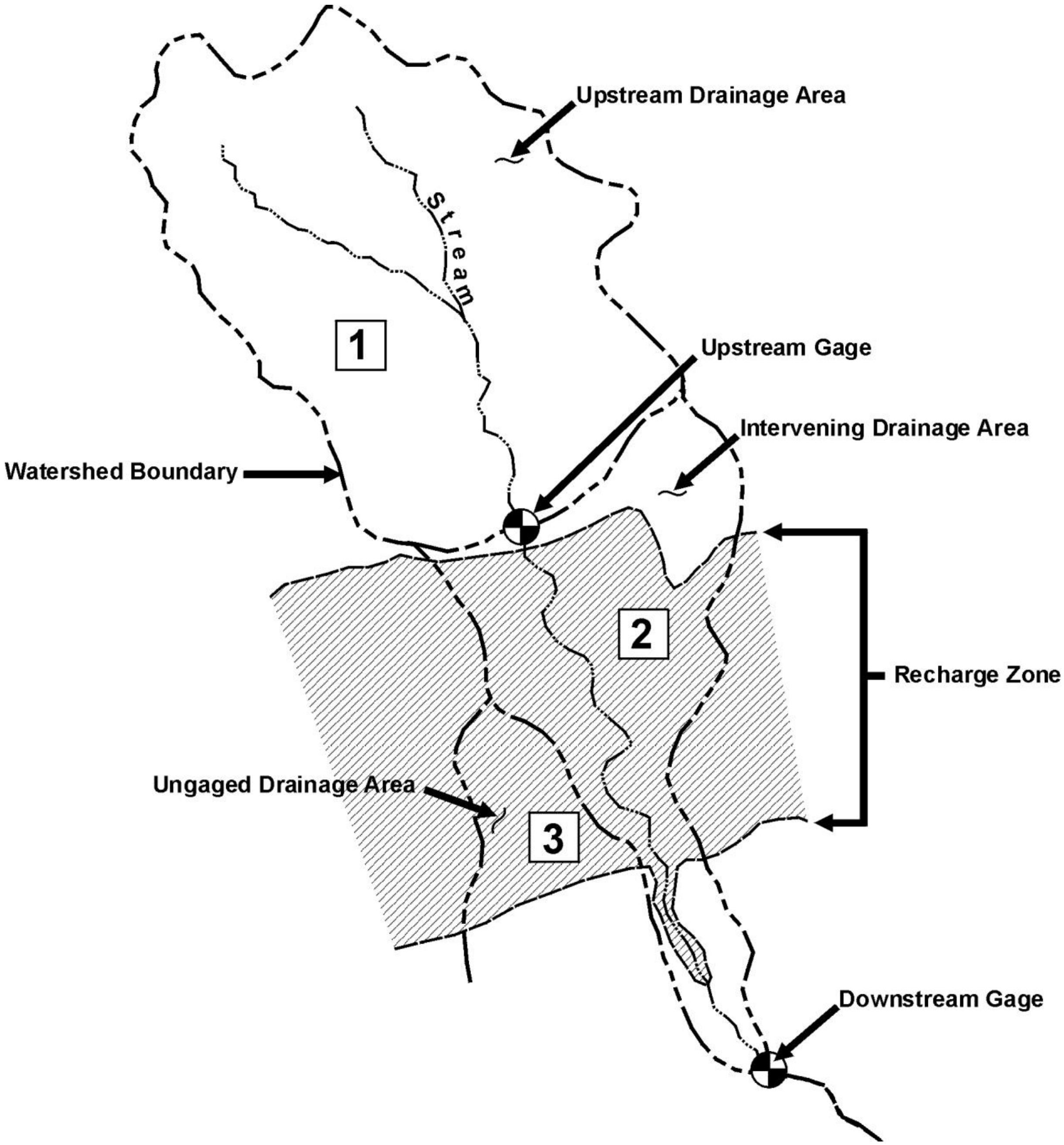

Figure 3-7. Schematic of Typical Gaged Recharge Area

The term QI in the preceding equation, which is the most difficult to quantify, is the potential runoff from the intervening area which could have arrived at the downstream location if the intervening area were not located over the recharge zone. Reasonable estimates of potential runoff in this area are necessary to accurately calculate recharge. Analyses performed by HDR[89] indicate that a reasonable procedure for estimating intervening runoff over the recharge zone may be developed using a variation of the SCS Runoff Curve Number procedure.[90,91] The HDR procedure takes into account differences in soil-cover complex as well as differences in precipitation between the gaged headwater (partner) watershed and the intervening subwatershed over the outcrop.

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. A summary of curve numbers for each watershed based on average antecedent moisture conditions (AMC II) is provided in Table 3-9. The CN is adjusted each month based on antecedent moisture conditions as reflected in the corresponding upstream (partner) 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 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 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 between the upstream and intervening drainage areas. Since the modified SCS method works in terms of inches of total runoff at the upstream gage (the base flow component of which is actually delayed infiltration from the upstream drainage

[89] HDR and GMI, Op. Cit., May 1991.
[90] SCS, Op. Cit., 1972.
[91] SCS, Op. Cit., May 1978.

area), use of the SCS method indirectly accounts for infiltration or deep percolation in the intervening area.

3.5.1.2 Recharge in Ungaged Areas

All of the ungaged areas, with the exception of the upper Verde Creek drainage area, are located directly over the recharge zone. The locations of all these areas are shown in Figure 3-6. Recharge calculations for ungaged areas are based on monthly recharge in an adjacent gaged area. The grouping of ungaged areas with adjacent gaged areas is as previously indicated in Table 3-9.

Recharge calculations for ungaged areas are performed utilizing two equations for different types of flow conditions. The first equation was utilized in those months when zero flow was recorded at the adjacent downstream gage. For this condition, the following equation represents recharge in the ungaged area:

$$R_3 = QI_3$$

Where: R_3 = Recharge in Ungaged Area
QI_3 = Potential Runoff in Ungaged Area

Estimates of monthly potential runoff for the ungaged areas are developed using the same SCS procedures as in the adjacent intervening gaged areas. Curve numbers for each ungaged area are adjusted for antecedent moisture conditions for each month based on observed watershed response at the adjacent upstream (partner) gage. Rainfall for the ungaged areas is assumed equal to rainfall in the adjacent intervening area, with the exception of the Verde Creek area for which composite rainfall data was developed independently.

In months when the flow at the adjacent downstream gage was not zero, a second equation is utilized. In these months, recharge in the ungaged area is assumed to be proportional to recharge in the intervening gaged area adjusted for flow differences based on curve number and drainage area. The following equation represents this condition:

$$R_3 = \left(\frac{QI_3}{QI_a}\right)RI$$

Where: R_3 = Recharge in Ungaged Area
QI_3 = Potential Runoff in Ungaged Area
QI_a = Potential Runoff in Intervening Area directly over Recharge Zone

RI = Recharge in Intervening Area

The USGS procedure for estimating potential runoff in ungaged areas is similar, with recharge in ungaged areas assumed to be proportional to recharge in the adjacent gaged areas. HDR has, however, employed the modified SCS curve number procedure described above in the estimation of potential runoff for the ungaged areas atop the Edwards Aquifer recharge zone.

3.5.1.3 Recharge in the Verde Creek Area

The Verde Creek watershed is the only ungaged watershed that has a significant drainage area (55 sq. mi.) located upstream of the recharge zone. A more accurate estimate of recharge may be obtained for the Verde Creek watershed by treating it as a gaged, rather than ungaged, watershed because the other ungaged areas are located entirely over the recharge zone. Monthly flow estimates for Verde Creek for the upstream and two intervening areas were developed based on the modified SCS procedure as previously described with average curve numbers for each watershed adjusted for antecedent moisture conditions as calculated at the upper Hondo Creek gage. These curve numbers were then applied to monthly rainfall to calculate flows for the three subwatersheds in the Verde Creek watershed (see control points CP21, CP22, CP231, and CP232 in Figure 3-6). Flows at the downstream limit of the recharge zone in area CP22 (established by the USGS 1983 intensive survey to be where Verde Creek crosses Highway 173)[92] were estimated by using the regression equation developed for Hondo Creek. This equation estimates downstream flows on the basis of upstream flows and potential intervening runoff. After estimates of both upstream and downstream flows were developed, the same procedure as described in Section 3.5.1.1 was utilized to estimate the combined recharge for areas CP21 and CP22 in the Verde Creek watershed. In the ungaged areas above CP231 and CP232, the same procedures as described in Section 3.5.1.2 were used to calculate recharge with area above CP22 utilized as the adjacent intervening area.

3.5.2 Enhanced Recharge

Artificial Edwards Aquifer recharge, in addition to the estimates of natural recharge, occurs at three projects located on Seco, Parkers, and Verde Creeks, as shown in Figure 3-6. As previously mentioned, these projects are modeled in WRAP such that they cannot recharge more than 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. Table 3-10 compares the authorized recharge with the maximum and average historical recharge.

Table 3-10.
Recharge at Existing Projects

Structure	*Water Right ID Number*	*Authorized Recharge (acft/yr)*	*Maximum Reported Recharge[1] (acft/yr)*	*Average Reported Recharge[1] (acft/yr)*
Seco Creek	**P3806_1**	**1,185**	**14,631**	**2,074**
Parkers Creek	**C3192_1**	**520**	**723**	**177**
Verde Creek	**P3745_1**	**585**	**2,874**	**455**

1 Information provided by Edwards Aquifer Authority for the 1988 to 1996 historical period.

[92] USGS, Op. Cit., 1983.

Table 3-5.
Estimation of Missing Streamflow Records

eference Number of Control Point / Streamgage with Missing Records	*Period of Missing Records*	*Regression Equation*	*Length of Concurrent Records (years)*	*Coefficient o Determinatio (r^2)*
1905 (CP02)	1/34-9/39, 10/50-3/56	$QN_{1905} = 0.5738\ QN_{1900} - 3322$	44	0.53
1930 (CP04)	1/34-9/39	$QG_{1930} = (QNH_{1940} - 0.1361\ QI_{1940})/1.1623$	50	0.90
1945 (CP06)	1/34-11/42	$QG_{1945} = (QNH_{2100} - 0.8340\ QG_{2070} - 1.2805\ QG_{2080} - 0.1146\ QI_{2100} + 485)/1.0032$	47	0.98
1960 (CP08)	1/34-8/52	$QN_{1960} = 0.2643\ QN_{1950} + 0.0345\ QN_{1900} - 249$	37	0.78
1975 (CP09)	1/34-8/52	$QN_{1975} = 0.5137\ QN_{1950} + 0.7844\ QN_{1960} - 3540$	37	0.80
1980 (CP12)	1/34-9/42	$QN_{1980} = 0.6865\ QN_{1950} - 1101$	47	0.81
1985 (CP13)	1/34-8/52	$QN_{1985} = 0.8394\ QN_{1980} + 0.6839\ QI_{1985} - 1812$	37	0.93
2000 (CP18)	1/34-9/42	$QN_{2000} = 0.4164\ QN_{1950} - 782$	37	0.65
2000 (CP18)	10/42-8/52	$QN_{2000} = 0.6088\ QN_{1980}$	37	0.83
2007 (CP19)	1/34-8/52	$QN_{2007} = 0.7690\ QN_{2000} + 0.3276\ QI_{2007} - 1377$	29	0.81
2015 (CP16)	1/34-9/42	$QN_{2015} = 0.1975\ QN_{1950} - 516$	28	0.72
2015 (CP16)	10/42-8/52	$QN_{2015} = 0.2799\ QN_{1980}$	28	0.86
2015 (CP16)	9/52-4/61	$QN_{2015} = 0.3073\ QN_{2000} - 0.0927\ QN_{1980}$	28	0.94
2027 (CP17)	1/34-9/60	$QN_{2027} = 0.5074\ QN^*_{2015} + 0.1176\ QI^*_{2027} - 781$	28	0.57
2040 (CP24)	1/34-12/38, 10/65-12/89	$QN_{2040} = 136.85\ W_{UV} - 118{,}131.1$	17	0.92
2067 (CP26)	1/34-2/64	$QN_{2067} = 0.203\ QN_{2030} + 1769.6\ P_{2067} - 2168.3$	32	0.70
2070 (CP27)	3/81-9/82	$QG_{2070} = 0.8879\ QG_{2066} + 0.5342\ QG_{2067} + 1765$	9	0.99
2110 (CP30)	1/34-8/48	$QNH_{2110} = 1.0390\ QG_{2100} + 0.0621\ QI_{2110} - 2040$	41	0.98

efinition of Terms: QG = Gaged Flow QN = Natural Flow QNH = Gaged Flow Adjusted for Local Diversion
QI = Intervening Runoff Calculated from Precipitation W_{UV} = Well Level at Uvalde P = Monthly Areal Precipitation (in inches)

nits: Acft/Month: QG, QGN, QNH, and QI Feet-Mean Seal Level: W_{UV}

Drainage areas adjusted to reflect entire Seco Creek watershed above Edwards Aquifer recharge zone.

Length of concurrent record based on non-zero flow valves at Leona River springflow gage (2040). Spring ceased flow for extended periods during the 1/39 – 9/64 period.

Table 3-9.
Summary of Gaged and Ungaged Drainage Areas in Edwards Aquifer Recharge Zone

Recharge Basin	*Gaged Areas*	*Drainage Area (sq. mi.)*	*Curve Number*[1]	*Ungaged Areas*	*Drainage Area (sq. mi.)*	*C Nu*
eces – W. Nueces	**W. Nueces near Brackettville**	**694**	**N/A**	**None**	0	I
	Nueces at Laguna	**737**	**87**		0	I
	Nueces below Uvalde	**430**[2]	**84**		0	I
		1,861			**0**	
o – Dry Frio	**Dry Frio near Reagan Wells**	**126**	**N/A**	**Leona River (CP10)**	**36**	
	Frio at Concan	**389**	**88**	**Hackberry & Blanco (CP111, CP112)**	**32**	
	Frio below Dry Frio near Uvalde	**116**[2]	**84.5**		**0**	
		631			**68**	
binal	**Sabinal near Sabinal**	**206**	**85.5**	**L. Blanco & Nolton (CP141, CP142)**	**18**	8
	Sabinal at Sabinal	**35**[2]	**81.5**	**Ranchero Cr. (CP15)**	**6**	
		241			**24**	
ea Between Sabinal & Medina	**Seco near Utopia**	**45**	**87**	**Parkers & Live Oak (CP201, CP202)**	**12**	
	Seco near D'Hanis	**123**[2]	**84**	**Above Recharge (CP21)**	**55**	
	Hondo near Tarpley	**96**	**85**	**In Recharge-Verde (CP 22)**	**50**	8
	Hondo near Hondo	**53**[2]	**83.5**	**In Recharge-Other (CP231, CP232)**	**47**	8
		317			**164**	
		3,050			**256**	

sed on SCS Soil Surveys for Uvalde, Medina, and Bandera Counties with areas outside these counties estimated on the basis of geologic maps and topography. Curve numb
own are based on antecedent moisture condition II.

presents total intervening drainage area between downstream and upstream gages as reported in the 1988 USGS annual report. Of this total, the following drainage areas w
imated to be downstream of areas contributing to the recharge zone, based on the 1983 intensive surveys by the USGS: Sabinal – 7 sq. mi. and Hondo – 2 sq. mi. A portion
eces River watershed above the Uvalde gage is also located below the recharge zone; however, it was not necessary to compute this drainage area for purposes of this study
as not necessary to compute recharge for an adjacent ungaged area. Drainage areas for gaged areas are taken from the 1988 USGS annual report. Drainage areas for ung
as are taken from 1978 USGS report "Method of Estimating Natural Recharge to the Edwards Aquifer in the San Antonio Area, Texas."

Section 4
Water Availability Model of the Nueces 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[93] as a single simulation program written in the FORTRAN programming language. The initial application of the model to the Brazos River Basin is documented by Wurbs, et al.,[94] and by Walls.[95] 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[96] and by Dunn.[97]

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 develop naturalized flows, WRAP-HYD. The December 1999 version of WRAP is documented in a user's manual.[98] 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.

[93] 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.
[94] 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.
[95] 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.
[96] 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.
[97] Dunn, D.D., "Incorporation of System Operation Strategies in Water Rights Modeling and Analysis," Master of Science Thesis, Texas A&M University, December 1993.
[98] Wurbs, R.A., "Reference and Users Manual for the Water Rights Analysis Package (WRAP)," TR-180, Texas Water Resources Institute, Texas A&M University, August 1999.

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 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 Model

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 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[99].

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. Such hydrologic and water management complexities in the Nueces River Basin required additional capabilities to be added to the base WRAP simulation program. These additional capabilities,

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

some of which are basin-specific and some of which are generic, are described generally in the following sections, and more specifically in the WRAP User's Manual Addendum found in Appendix IX (separately bound).

4.1.2.1 Choke Canyon Reservoir / Lake Corpus Christi System

System operations of Choke Canyon Reservoir and Lake Corpus Christi required specific modifications to the base WRAP model. The City of Corpus Christi operates Choke Canyon Reservoir and Lake Corpus Christi as a system in order to maximize the firm yield or dependable supply. Algorithms that reflect this aspect of the City's management of the reservoir system have been added to WRAP as a basin-specific modification. Due to their geographic locations and the hydrology associated with each reservoir, holding as much water for as long as possible in Choke Canyon Reservoir maximizes the yield of the system. However, rights associated with Lake Corpus Christi are senior to those for Choke Canyon Reservoir. Therefore, under WRAP's strict application of the prior appropriation doctrine, Choke Canyon Reservoir would be forced to pass flows to Lake Corpus Christi without regard to the City's system operation policies. In order to account for CCR/LCC System operations, WRAP has been modified so that flows initially passed by Choke Canyon Reservoir to replenish the more senior Lake Corpus Christi impoundment rights are reallocated back to Choke Canyon after the Choke Canyon Reservoir impoundment right is processed in the priority loop.

The City operates the CCR/LCC System under four policies, depending upon hydrologic conditions. Each policy impacts the system yield differently. Only the Phase IV (maximum yield) policy has been incorporated into WRAP. The Phase IV policy states:[100]

1. A minimum of 2,000 acft/month will be released from Choke Canyon Reservoir to meet conditions of the release agreement between the City of Corpus Christi and the Texas Parks and Wildlife Department.
2. In order to maintain maximum dependable yield from the two reservoirs, the water level in Lake Corpus Christi will be allowed to drop to elevation 74 feet before water is released from Choke Canyon Reservoir in excess of the 2,000 acft/month requirement.
3. When the elevation of Choke Canyon Reservoir drops to 155 feet, Lake Corpus Christi will be lowered to its minimum elevation.

[100] City of Corpus Christi Code of Ordinances, Chapter 55, Utilities, Article XII, Water Conservation, Sections 55-156, Water Conservation and Drought Contingency Plan.

The new routines in WRAP ensure that the reallocation meets the guidelines of the Phase IV policy and consider the following in calculating the volume of water reallocated from Lake Corpus Christi to Choke Canyon Reservoir:

1. Only water from the Frio River can be reallocated to Choke Canyon Reservoir;
2. Water rights senior to Choke Canyon Reservoir and junior to Lake Corpus Christi are not shorted due to the reallocation;
3. Choke Canyon Reservoir has enough storage capacity to handle the reallocated volume with consideration for evaporation and lakeside releases; and
4. The volume of water reallocated accounts for the channel losses incurred between the two reservoirs.

The volume of reallocated water is directly related to the storage volume and storage area relations entered for both Choke Canyon Reservoir and Lake Corpus Christi. For this analysis, both reservoirs are modeled to store their full authorized impoundment volumes, which are greater than each reservoir's present storage capacity.

4.1.2.2 Inflow Requirements to Nueces Bay

In addition to the Phase IV operations policy, WRAP has been modified to model the CCR/LCC System inflow passage requirements necessary to honor the 1995 Agreed Order[101] governing freshwater inflows to the Nueces Estuary. In general, operations under the 1995 Agreed Order are in accordance with the following:

1. Water passed through the CCR/LCC System to satisfy bay and estuary requirements in a given month is limited to the estimated inflow to Lake Corpus Christi as if Choke Canyon Reservoir did not exist.
2. When CCR/LCC System storage exceeds 70 percent of capacity, the Agreed Order provides for 138,000 acft/yr of freshwater for the Nueces Bay and/or the Nueces Delta to be obtained from a combination of return flows, reservoir pass-throughs or spills, and measured runoff downstream of Lake Corpus Christi. When system storage is less than 70 percent, but more than 40 percent of capacity, minimum desired freshwater inflows to Nueces Bay/Delta total 97,000 acft/yr. In any month when system storage is less than 40 percent, but greater than 30 percent of capacity, required Nueces Bay inflows may be reduced to 1,200 acft/month when the City and its customers implement Condition II of the City's Water Conservation and Drought Contingency Plan (herein referred to as Plan). If the system storage drops below 30 percent of capacity, bay and estuary pass-throughs may be suspended when the City and its customers implement Condition III of the Plan.

[101] TNRCC, Agreed Order Establishing Operational Procedures Pertaining to Special Condition B., Certificate of Adjudication No. 21-3214, held by the City of Corpus Christi, et al., April 28, 1995.

3. Mechanisms for relief from reservoir pass-throughs are based on inflow banking, salinity in upper Nueces Bay, and the implementation of drought contingency provisions.

Water right types (Type 1, Type 2, etc.) are a mechanism within WRAP to specify general procedures for how the rights depicted by individual WR records are to be simulated. They are fully explained in the WRAP User's Manual.

The model is programmed so that bay and estuary (B&E) requirements are modeled using a special "Type 9" B&E water right. The new Type 9 B&E right functions similar to a Type 2 water right with Choke Canyon Reservoir and Lake Corpus Christi acting as system reservoirs. The new routines calculate a monthly freshwater inflow requirement subject to provisions in the Agreed Order, including those that allow for reduced CCR/LCC System inflow passage during drought. Once the requirement is calculated, WRAP determines whether the regulated flows at the Nueces Bay control point (CPBAY) are adequate to satisfy the requirement. If the regulated flows are less than the requirement, then flows are passed through the CCR/LCC System to supplement the regulated flows. Although the model allows for different system storages to be specified to trigger the Condition II and Condition III drought conditions, model data have been set for these simulations so that the drought contingency provisions are implemented immediately once the system storage reaches 40 percent and 30 percent of capacity, respectively.

4.1.2.3 Edwards Aquifer Recharge

The WRAP model has been modified to estimate recharge of the Edwards Aquifer in the Nueces River Basin. The methodology encoded is identical to that used and accepted in previous studies[102,103] of the Nueces 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 rights for existing recharge structures on Seco, Parkers, and Verde Creeks is included in the calculation of recharge. The recharge rights are modeled as Type 2 water rights with maximum annual diversion amounts. The monthly

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[102] HDR Engineering, Inc. (HDR) and Geraghty and Miller, Inc. (GMI), "Nueces River Basin Regional Water Supply Planning Study – Phase I," Vols. 1, 2, and 3, Nueces River Authority, et al., May 1991.

[103] HDR, Paul Price Associates, Inc., LBG-Guyton Associates, and Fugro-McClelland, Inc., West Central Study Area Edwards Aquifer Recharge Analysis – Phase II," San Antonio River Authority, et al., March 1998.

streamflow depletions calculated for these recharge rights in the priority loop are passed to the recharge routines and added to the natural recharge estimates for the appropriate control points. Recharge estimation is limited to the Edwards Aquifer in areas between the primary control points designated as recharge points in the 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 those locations are also specified.

The TNRCC, through the University of Texas CRWR, provided a database of water right locations and watershed parameters in a geographic information system (GIS). These 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:

ABBCCCCCDDD

Where: 'A' denotes Certificates of Adjudication (6) and Permits (1);
'BB' represents basin number (21 for the Nueces River Basin);
'CCCCC' represents the 5-digit water right number (Certificate of Adjudication Number or Permit Application Number); and
'DDD' represents the types and sequence numbers of the water right locations (001-099 denote diversion locations; 101-199 denote the downstream boundaries of diversion segments; 201-299 denote upstream boundaries of diversion segments; 301-399 denote on-channel reservoir locations; 401-499 denote off-channel reservoir locations; 501-599 denote return flow points; and 601-699 denote off-channel diversion points).

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

The locations of control points for which naturalized flows have been developed were provided by HDR to the TNRCC, and these 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, CPBAY, 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 ten secondary control points on the Nueces River upstream of CP04 (Nueces River at Asherton) by adding 23.6 sq. mi. to the drainage area of each. The sum of the drainage areas of the control points directly upstream of secondary control point 308604 was 23.6 sq. mi. greater (approximately 1 percent) than the drainage area of 308604. This adjustment was made to the drainage areas of secondary control points 308603, 308602, 308601, 309401, 309601, 309631, 309732, 309731, and 309531, all of which are downstream of, and proximate to, 308604. Adjustment to these drainage areas was necessary to remove negative incremental drainage areas caused by the adjustment to 308604. This adjustment was not made to control points further downstream because the adjustment to 308604 would not have caused any additional negative incremental drainage areas.

Several additional control points were added to the model that were not included in the original lists of primary and secondary control points. These control points were added as "computational" control points in order to allow the April 1999 version of WRAP to function correctly. Computational control points CP2731, CP3031, and CP3131 were added immediately upstream of control points CP27 (Choke Canyon Reservoir), CP30 (Lake Corpus Christi), and CP31 (Calallen Dam), respectively, to avoid errors in the net reservoir evaporation adjustment computation in WRAP. In the April version of the base WRAP, the net evaporation adjustment is not computed correctly for primary control points (i.e., those for which naturalized flows are read from a file).[104] These three reservoirs were placed at these computational control points in data sets for the December version of WRAP as well. An additional computational control point (4365AA) was added immediately downstream of control point 436501 (above CP2 on the West Nueces River) in order to treat return flows correctly from the recreational use authorized by Permit 4365. A final computational control point, CPBAY1, was added immediately upstream of primary control point CPBAY. This addition was necessary to allow the basin-specific modification related to Bay and Estuary inflow requirements under the TNRCC Agreed Order to calculate regulated flows correctly.

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.[105] Water availability for several rights in the vicinity of Leona Springs (CP24) is dependent on flows originating from multiple springs in the area, and the normal naturalized flow distribution algorithms are not appropriate for secondary control points in this area. The naturalized flows calculated for the Leona Springs control point are comprised of flows originating from several springs upstream of USGS gage 08204000, Leona River, Uvalde. Naturalized flows for control points in the vicinity, and upstream, of Leona Springs were set equal to the naturalized flows at CP24 using INMETHOD2. 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 main-stem reaches between primary control points, as shown in Table 3-2. 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 13 such tributary streams confluence with streams with known channel losses. Secondary control points are located upstream of each confluence. Channel loss factors were distributed to these confluence locations

[104] This is an error in the base WRAP model that will be corrected in future versions of the model (Ralph Wurbs, Texas A&M University, telephone conversation, 1999).
[105] HDR Engineering, Inc., “Technical Memorandum: Distribution of Naturalized Streamflows from Gaged to Ungaged Control Points Accounting for Aquifer Recharge and Channel Losses,” December 1998.

along the channel main stems in order to correctly account for channel losses downstream from the tributary confluences. These secondary control points were assigned identifiers beginning with 99 and were numbered sequentially from 991 to 9913.

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 six characters to identify a control point, the 11-digit control point identifiers were reduced to six digits in the WRAP input files. Both sets of identifiers are shown in Appendix II.

4.2.2 Monthly Demand Distribution Factors

In previous modeling efforts for the Nueces River Authority[106], 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 four segments in the Nueces 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 the WRAP Model. 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.[107] Where appropriate, corrections were made to the WRDETAIL file utilized by HDR. In addition, all paper permits were reviewed for instream flow requirements and other special conditions. While not the purpose of these additional reviews,

[106] HDR and GMI, Op. Cit., May 1991.
[107] HDR Engineering, Inc. and Crespo Consulting Services, Inc., "Technical Memorandum: Review and Summary of Water Right Records," February 1999.

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 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 Runs 1 through 8 were developed. This file is included as Appendix X (separately bound), and includes all of the water right information utilized in the Nueces 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 X. 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 uses 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, but the authorized diversion can be 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, which 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. The City of Corpus Christi is authorized to impound in Choke Canyon Reservoir and Lake Corpus Christi Reservoir and to operate those reservoirs as a system, subject to the Agreed Order described in Section 4.1. Choke Canyon Reservoir and Lake Corpus Christi are included in the WRAP input file as standard impoundment rights at their respective dates of priority and operated as a system to meet diversion requirements at Calallen Dam. The basin-specific modifications described in Section 4.1 augment the reservoir system operations capabilities in WRAP.

4.2.3.3 Return Flows

With the exception of recreational rights, Certificate of Adjudication 3158, and specific consideration of the City of Corpus Christi rights regarding Bay and Estuary inflow requirements, all return flows in the Nueces River Basin were modeled using 12 monthly values input on CI records. Recreational rights were modeled with zero consumptive use, and all flows appropriated were returned to the next downstream control point. Certificate of Adjudication 3158 authorizes diversion of 3,460 acft/year from the Frio River into a canal for irrigation. The certificate states that the right is allowed consumptive use of 1,600 acft, with the remaining 1,860 acft returned to the Frio River at a point downstream of the diversion location. A return flow factor of 1,860/3,460=0.537 was utilized for this right.

Return flows into the Nueces River and Nueces Bay from diversions made under the rights held by the City of Corpus Christi and the Nueces River Authority (Certificates of

Adjudication 2464 and 3214) were included in the model using CI records as described below. The City of Corpus Christi provides water to multiple municipal and industrial entities located in the surrounding coastal basins. Return flows from these entities discharge directly into, or to streams that drain to, the greater Nueces Estuary. These return flows are not available for diversion within the Nueces River Basin and, hence, do not directly affect water availability to rights within the Nueces River Basin. These discharges reduce salinity in the Nueces Estuary, which affects the total amount of inflows that the CCR/LCC System must pass in accordance with the TNRCC Agreed Order. In 1997, return flows from City of Corpus Christi customers were totaled and approximately 52 percent of the water diverted under the City of Corpus Christi's rights is returned to the Nueces Estuary. A return flow factor of 0.52 for the municipal and industrial portions of the City's rights was utilized. These flows are returned directly to the Nueces Estuary control point, CPEST, and are included to ensure proper accounting for freshwater inflows and estimation of salinity in Upper Nueces Bay. These return flow fractions were reduced by 50 percent and 100 percent in accordance with the reuse assumptions applied in Run 2 and in Runs 3, 6, and 7, respectively.

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 the 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 City of Portland and the Central Power & Light (CP&L) Lon C. Hill Power Station utilize water diverted from the Nueces River Basin, and discharge into Nueces Bay. Discharges from these sources were included in the CI records for the Nueces Bay control point (CBAY) in order to more accurately account for bay and estuary inflow requirements under the CCR/LCC System Agreed Order.

Five entities in the Nueces River Basin hold rights authorizing industrial use:

1. City of Corpus Christi, Certificate of Adjudication 2464
2. R.L. White Company, Certificate of Adjudication 3087
3. Nueces River Authority, Certificate of Adjudication 3214

4. City of Three Rivers, Certificate of Adjudication 3215
5. San Miguel Electric Cooperative, Permits 5145 (Industrial) and 5511 (Mining)

Return flow factors were not developed for these rights. Treated effluent discharges from water diverted for industrial use under the City of Corpus Christi and the Nueces River Authority rights are mixed with water returned from municipal diversions. In addition, some of the water diverted for industrial use is returned out of the basin. Reliable return flow factors cannot readily be determined for these industrial diversions. The City of Three Rivers provides water to the Diamond Shamrock Corporation. Effluent discharges from the Diamond Shamrock facility are returned to an off-channel reservoir, where they are used for irrigation under Permit 5065 held by the Diamond Shamrock Corporation. No effluent discharge from this industrial diversion is returned to the Frio River. The right held by the R.L. White Company authorizes an annual diversion of only 10 acft/yr, and return flows from that right are not included. The San Miguel Electric Cooperative discharges from its mining operation under PNUM 2043. Return flow data for the San Miguel Electric Cooperative indicate that these discharges occur infrequently, and therefore should not be included in the model as a source of return flows. No information is available for PNUM 2601 associated with industrial steam-electric power generation use by the San Miguel Electric Cooperative.

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

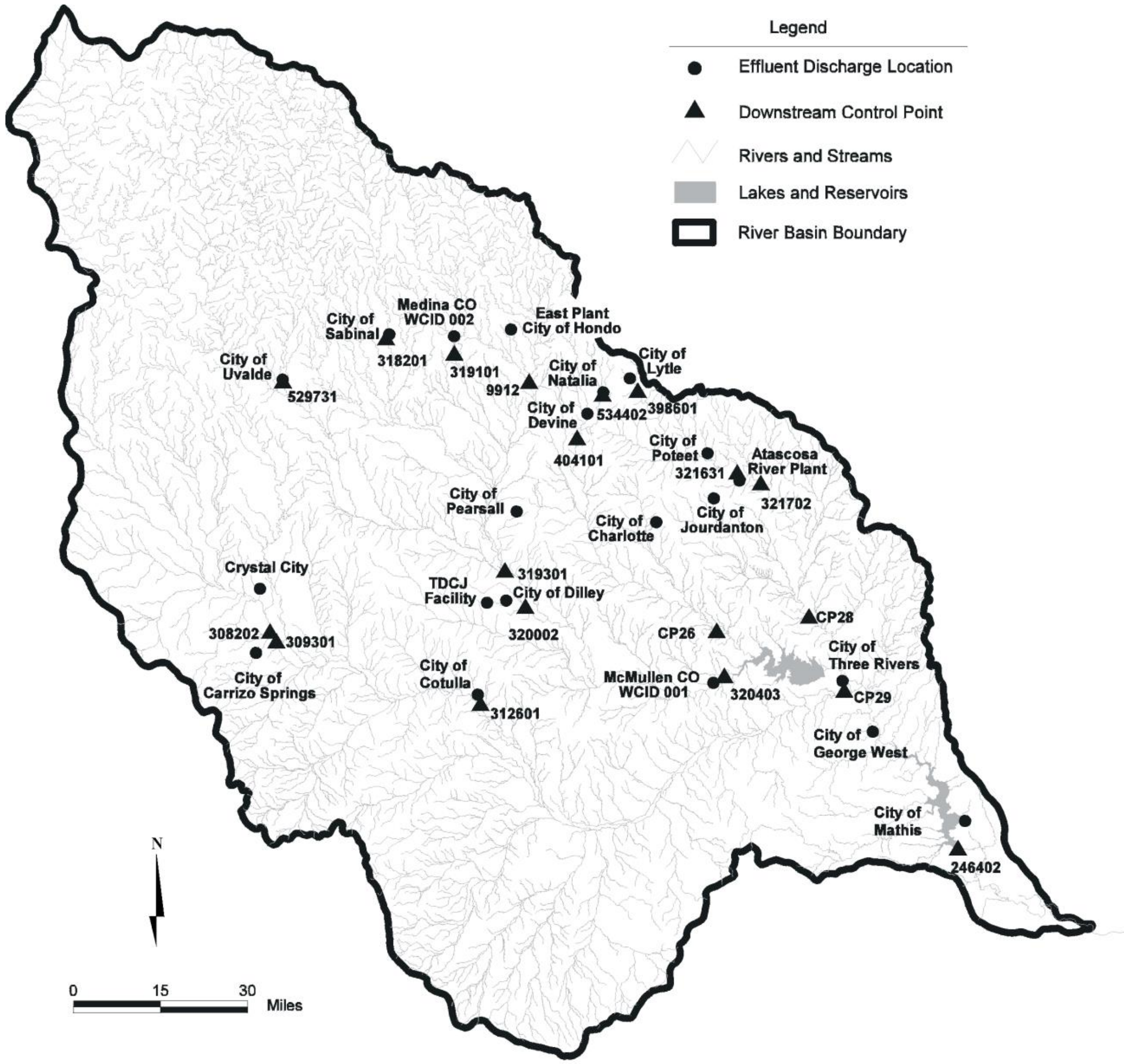


Figure 4-1. Treated Effluent Discharge Locations in the Nueces River Basin Upstream of the Calallen Dam

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.

4.2.3.5 Rights Requiring Special Consideration

Many rights in the Nueces 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 X.

4.2.4 Changes in Springflows from the Edwards Aquifer

The naturalized flows downstream of Leona Springs near Uvalde (CP24) 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 Nueces and Guadalupe-San Antonio River Basins, the TNRCC selected a regulated Edwards Aquifer pumpage of 400,000 acft/yr. At TNRCC's request, the Texas Water Development Board (TWDB) agreed to apply their GWSIM4 Model[108] of the Edwards Aquifer to simulate springflows under this regulated pumpage regime. Technical assumptions and resulting simulated springflows are presented in a brief report prepared by the TWDB.[109] As the GWSIM4 Model was calibrated

[108] TWDB, "Model Refinement and Applications for the Edwards (Balcones Fault Zone) Aquifer in the San Antonio Region, Texas," Report 340, July 1992.
[109] 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.

with primary focus on replication of discharge minima at Comal Springs during the drought of record, long-term simulation results in Uvalde County including estimates of aquifer levels, springflows, and interformational leakance are questionable. Therefore, historical discharges from Leona Springs, as measured by the USGS (1939 to 1965) or as computed by HDR from City of Uvalde well level records,[110] were utilized in the water availability model.

4.2.5 Data for Basin-Specific Features Added to WRAP

The data necessary to model the Nueces basin-specific features incorporated in WRAP is specified in two basin-specific input files and the main WRAP input file. The first file contains all the parameters necessary for modeling the CCR/LCC System operations and the B&E inflow requirements discussed in Section 4.1.2. 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 ".NUE" for the first Nueces file and ".RCH" for recharge input file. Data contained in both basin-specific input files is directly related to specific records in the main input file, "ROOT.DAT." Without the appropriate records and identifiers called out in each input file, the basin-specific features for the Nueces 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 Nueces River Basin is contained in Appendix IX.

4.2.5.1 Choke Canyon Reservoir/Lake Corpus Christi System

The City of Corpus Christi impoundment rights at Choke Canyon Reservoir and Lake Corpus Christi are used by the basin-specific routines to calculate the reallocation of water to Choke Canyon Reservoir from Lake Corpus Christi. Each right is entered with its appropriate priority date and its water right identifier (C3214_5 for Choke Canyon Reservoir and C2426_1 for Lake Corpus Christi) on the WR cards. These identifiers must be identical to the identifiers entered on the CR records of the .NUE file. In addition to the water right identifiers, the CR record must contain the storage associated with the water surface elevations 74 ft-msl in Lake Corpus Christi and 155 ft-msl in Choke Canyon as referenced in the Phase IV operations

[110] HDR and GMI, Op. Cit., May 1991.

policy.[111] Table 4-3 shows the storage entered in the CR fields. These data were obtained from elevation-area-capacity curves developed for both Choke Canyon Reservoir[112] and Lake Corpus Christi.[113]

Table 4-3.
Phase IV Reservoir Elevations and Storage

Reservoir	*Elevation (ft-msl)*	*Storage (acft)*
Choke Canyon Reservoir	**155**	**2,101**
Lake Corpus Christi	**74**	**14,953**

The 33 cfs (2,000 acft/month) instream flow/release requirement[114] below Choke Canyon Reservoir is handled with IF record CCR_IF1 in the main input file. Its priority date is one day junior to the Lake Corpus Christi impoundment right, C2426_1. This ensures that rights senior to Choke Canyon Reservoir have access to releases made to honor this requirement. A second Lake Corpus Christi impoundment right, C2464_10, with priority junior to the Choke Canyon Reservoir impoundment right, C3214_5, captures any water that the intervening rights allow to pass, but Lake Corpus Christi would not have a chance to store due to earlier location in the priority loop.

4.2.5.2 Bay and Estuary Freshwater Inflow Requirements

Most of the basin-specific parameters entered in the .NUE file are necessary to model the freshwater inflow or B&E requirements called for in the Agreed Order.[115] As previously mentioned, the freshwater inflow requirements are modeled as a special water right specified in both the .DAT and .NUE files. The B&E right, WRB&E_1, is designated as a Type 2 right with the most junior priority in the basin. The B&E right is located at the control point representing Nueces Bay, CPBAY1, and must be identified on the BA record in the .NUE input file.

[111] City of Corpus Christi Code of Ordinances, Chapter 55, Utilities, Article XII, Water Conservation, Sections 55-156, Water Conservation and Drought Contingency Plan.
[112] TWDB, "Volumetric Survey of Choke Canyon Reservoir," September 23, 1993.
[113] USGS, "Preliminary Results of an Investigation of Factors Contributing to Water Storage Reduction Within Lake Corpus Christi, 1987.
[114] Special Condition E., Certificate of Adjudication No. 21-3214, held by the City of Corpus Christi, et al., July 19, 1976.
[115] TNRCC, Agreed Order Establishing Operational Procedures Pertaining to Special Condition B., Certificate of Adjudication No. 21-3214, held by the City of Corpus Christi, et al., April 28, 1995.

CPBAY1 is a computational control point necessary to calculate the B&E inflow requirements. The streamflow depletions made by the B&E right are returned immediately downstream to the primary control point, CPBAY. The regulated flows at Calallen Dam are compared with the monthly B&E inflow requirement necessary to honor the Order. Since the monthly B&E inflow requirements are dependent on CCR/LCC System storage, the RT records in the .NUE file are used to input the pass-through schedules associated with system storage triggers set forth in the Order. As system storage decreases, the B&E requirements are reduced contingent upon the City's implementation of specific drought contingency measures detailed in their Water Conservation and Drought Contingency Plan.[116] Therefore, the DC records are provided in the .NUE file to specify the System storages that trigger implementation of different drought contingency provisions. The triggers specified in the Water Availability Model of the Nueces River Basin assume that the City of Corpus Christi implements Condition II and Condition III of their Drought Contingency Plan at system storages of 40 percent and 30 percent, respectively. Tables 4-4 and 4-5 display the required freshwater inflows to Nueces Bay and the drought condition triggers entered in the .NUE file.

If the regulated flows passing Calallen Dam are less than the inflow requirement, checks are made to see if the requirement can be reduced based on provisions outlined in the Order. The first check is based on the previous month's inflows into Nueces Bay. If the previous month's inflows exceed the required B&E requirement, the following month's required amount can be reduced by the "excess" inflow up to a maximum 50 percent.

The second check is based on monthly salinity bounds for upper Nueces Bay and the potential reductions reported in the Order. The inflow requirement may be reduced depending on the difference between the calculated salinity and the salinity bounds input in SL and SU records in the .NUE input file. The model calculates salinity using an equation accepted by the Nueces Estuary Advisory Council chaired by TNRCC. The salinity bounds entered in the .NUE file are shown in Table 4-6. The salinity calculation is influenced somewhat by return flows that enter Nueces Bay downstream of Calallen Dam which are input with CI records at the Nueces Bay control point, CPBAY, in the .DAT input file. The City is credited for 5.35 mgd

[116] City of Corpus Christi Code of Ordinances, Chapter 55, Utilities, Article XII, Water Conservation, Sections 55-156, Water Conservation and Drought Contingency Plan.

Table 4-4.
Required Freshwater Inflows to Nueces Bay and/or Nueces Delta (acft)[1]

Month	*System Storage*[2]			
	> 70%	*< 70% but > 40%*	*< 40% but > 30%*	*< 30%*
January	**2,500**	**2,500**	**1,200**	**0**
February	**2,500**	**2,500**	**1,200**	**0**
March	**3,500**	**3,500**	**1,200**	**0**
April	**3,500**	**3,500**	**1,200**	**0**
May	**25,500**	**23,500**	**1,200**	**0**
June	**25,500**	**23,000**	**1,200**	**0**
July	**6,500**	**4,500**	**1,200**	**0**
August	**6,500**	**5,000**	**1,200**	**0**
September	**28,500**	**11,500**	**1,200**	**0**
October	**20,000**	**9,000**	**1,200**	**0**
November	**9,000**	**4,000**	**1,200**	**0**
December	**4,500**	**4,500**	**1,200**	**0**

1 TNRCC, Agreed Order Establishing Operational Procedures Pertaining to Special Condition B., Certificate of Adjudication No. 21-3214, held by the City of Corpus Christi, et al., April 28, 1995.

2 System Storage equals Choke Canyon Reservoir storage plus Lake Corpus Christi storage as a percentage of full conservation capacity.

Table 4-5.
Drought Condition Triggers Used in the Water Availability Model of the Nueces River Basin[1]

Drought Condition	*System Storage Trigger*[2]
I	**45%**
II	**40%**
III	**30%**
IV	**20%**

1 Drought Conditions represents measures described in the City of Corpus Christi's "Water Conservation and Drought Contingency Plan."

2 System Storage equals Choke Canyon Reservoir storage plus Lake Corpus Christi storage as a percentage of full conservation capacity.

Table 4-6.
Lower (SLB) and Upper (SUB) Salinity Bounds
for the Upper and Mid-Nueces Bay
(parts per thousand)[1]

Month	*SLB*	*SUB*
January	**5**	**30**
February	**5**	**30**
March	**5**	**30**
April	**5**	**30**
May	**1**	**20**
June	**1**	**20**
July	**2**	**25**
August	**2**	**25**
September	**5**	**20**
October	**5**	**30**
November	**5**	**30**
December	**5**	**30**

[1] TNRCC, Agreed Order Establishing Operational Procedures Pertaining to Special Condition B., Certificate of Adjudication No. 21-3214, held by the City of Corpus Christi, et al., April 28, 1995.

(500 acft/month) of return flows into Nueces Bay until such time as effluent discharged to Nueces Bay exceeds this amount. Salinity in upper Nueces Bay is calculated from regulated flows at control point CPEST.

A third and final check ensures that water passage through the CCR/LCC System for maintenance of B&E inflows does not exceed inflow to Lake Corpus Christi had Choke Canyon Reservoir never existed. The calculation of inflows into Lake Corpus Christi as prescribed in the Agreed Order is the sum of the flows measured at the USGS streamflow gaging stations on the Nueces River Near Three Rivers (USGS No. 08210000), the Frio River at Tilden (USGS No. 08206600), and the San Miguel Creek near Tilden (USGS No. 08206700) less computed releases and spills from Choke Canyon Reservoir. This is approximated in WRAP as the regulated flows at the Three Rivers control point less flows passing the Choke Canyon Reservoir control point (this includes releases from Choke Canyon Reservoir). In order to carry out the calculation detailed above, the GA record in the .NUE file must specify the control point representing the USGS gage at Three Rivers.

If the B&E inflow requirement exceeds the Calallen Dam regulated flow, the model calls for passage of amounts up to CCR/LCC System inflows as calculated above in order to make up the balance of the necessary B&E inflows. Inflows added to system storage during the current month's priority loop are reallocated from system storage to meet the B&E requirement. If this amount is not adequate to fully meet the B&E requirement, water allocated to City of Corpus Christi rights earlier in the priority loop is reallocated to the B&E requirement in reverse priority order. Under no circumstance is water reallocated from system storage and City of Corpus Christi's rights in excess of system inflows as computed above.

4.2.5.3 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 Nueces River Basin WRAP are based on previous studies[117] conducted by the Nueces River Authority, Edwards Underground Water District, and City of Corpus Christi.

Each recharge control point must be entered with an RC record in the .RCH file. The records and formats for the .RCH file are described in Appendix IX. In gaged recharge 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, recharge is based on that occurring in an adjacent gaged recharge area specified on the CA records. Each recharge control point is shown in Table 4-7, along with its boundary or companion control points.

Additional recharge is calculated at permitted structures constructed by the Edwards Underground Water District on Seco, Parkers, and Verde Creeks. These structures are modeled as Type 2 water rights in the main input file, and their water rights identifiers must be entered on the RW records in order for their diversions to be added to the recharge calculated in the basin-specific routines. Table 4-8 lists the water right identifiers for the recharge structures in the Nueces Basin and the primary control points with which they are associated in the recharge calculations.

[117] HDR and GMI, Op. Cit., May 1991.

Table 4-7.
Recharge Control Point Information Entered in .RCH file

Gaged (G) and Ungaged (U) Recharge Area	*Recharge Control Point ID*	*Boundary or Companion Control Point IDs*[1]
Nueces River near Uvalde (G)	**CP03**	**CP01, CP02**
Frio River near Uvalde (G)	**CP09**	**CP07,CP08**
Leona River (U)	**CP10**	**CP09**
Hackberry Creek (U)	**CP111**	**CP09**
Blanco Creek (U)	**CP112**	**CP09**
Sabinal River near Sabinal (G)	**CP13**	**CP12**
Little Blanco Creek (U)	**CP141**	**CP13**
Nolton Creek (U)	**CP142**	**CP13**
Ranchero Creek (U)	**CP15**	**CP13**
Seco Creek near D'Hanis (G)	**CP17**	**CP16**
Hondo Creek near Hondo (G)	**CP19**	**CP18**
Live Oak Creek (U)	**CP201**	**CP19**
Parkers Creek (U)	**CP202**	**CP19**
Verde Creek in Recharge Zone (U)	**CP22**	**CP21**[2]
Elm Creek (U)	**CP231**	**CP22**
Quilin Creek (U)	**CP232**	**CP22**

1 For gaged control points, control point ID's are entered on RB records. For ungaged control points, control point ID is entered on CA records
2 Verde Creek is an ungaged area but is treated as a gaged recharge control point.

Table 4-8.
Recharge Structures in the Nueces River Basin

Location	*Water Right ID*	*Recharge Control Point*
Seco Creek	**P3806_1**	**CP17**
Parkers Creek	**C3192_1**	**CP202**
Verde Creek	**P3745_1**	**CP22**

Estimation of recharge is contingent on the estimated potential runoff from intervening area 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.

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 Nueces 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.[118] 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 Nueces 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.

[118] 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.

4.3.2 Reuse

Treated effluent discharges in the Nueces River Basin are relatively small compared to overall basin flows, and play a small role in water availability to the largest rights in the basin. The most significant discharges occur in the lower basin and most of these discharge into tributary streams draining to Corpus Christi Bay, and are not available for subsequent diversion. However, for small rights located downstream of treated effluent discharges, treated effluent discharge could have a substantial influence on water availability. Future reuse of this effluent would reduce discharges and could reduce the availability of water to specific rights located near the discharge points. At the request of the TNRCC, three reuse scenarios were modeled. These are described in more detail in Section 5.

4.3.3 Return Flow/Constant Inflow Assumptions

In the Nueces River Basin, 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 exception previously noted, were treated as constant inflows, as described previously in Section 4.2.3.3.

4.3.4 Off-Channel Reservoirs

Off-channel reservoirs do not significantly affect water availability in the Nueces River Basin.

4.3.5 Term Permits

Term permits are included in only Run 8, as described in Section 5. Sixteen term permits (Type A) are active in the Nueces River Basin, with authorized annual consumptive use totaling 1,398 acft for irrigation and 100 acft for mining purposes, thereby representing about 0.3 percent of the total authorized diversions in the Nueces 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 Nueces River Basin.

4.3.6 Interbasin Transfers

The TNRCC provided information documenting four rights authorized for interbasin transfers of water originating in the Nueces River Basin. These rights transfer water to the San Antonio-Nueces and/or the Nueces-Rio Grande Coastal Basins. Since all four rights transfer water from the basin and are not modeled with return flow factors, no special treatment of those interbasin transfers was warranted. One of these rights, Permit P5509, was not included in the model, as its diversion point is located below Calallen Dam, which acts as a saltwater barrier. This right, held by the U.S. Bureau of Reclamation, authorizes occasional redirection of flood flows to the Rincon Bayou Watershed in the San Antonio-Nueces River Basin through a notch cut into the bank of the lower Nueces River.

The TNRCC also provided information documenting four rights authorized for interbasin transfer of water from the San Antonio River Basin to the Nueces River Basin. These rights are owned by the Bexar-Medina-Atascosa Water Control and Improvement District No. 1 (BMA), and transfer water from the Medina Lake System to various canals operated by the district, and to Chacon Reservoir, which provides balancing storage within the BMA canal system. The Nueces River Basin right for Chacon Reservoir (C3207) is also listed in the San Antonio River Basin under water right C2131, with no authorized annual diversion. As Chacon Reservoir has a small watershed of its own located in the Nueces River Basin, its authorized diversion of 2,000 acft/yr has been simulated based solely on natural inflow originating in the Nueces River Basin. One should refer to the water availability modeling results for the Guadalupe-San Antonio River Basin[119] for assessment of the overall reliability of BMA's rights associated with the Medina Lake System. Information provided by the TNRCC regarding interbasin transfers is shown in Table 4-9.

[119] HDR, "Water Availability in the Guadalupe-San Antonio River Basin," TNRCC, 1999.

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

egment	Use	January	February	March	April	May	June	July	August	September	October	November	Decemb
	MUN	6	5	6	8	9	10	11	13	11	7	7	6
1	**IND**	7	7	8	8	9	9	10	10	8	8	8	8
	IRR	4	4	7	9	12	16	16	14	8	4	3	3
	MUN	7	7	7	8	8	9	11	11	9	8	8	8
2	**IND**	7	7	8	8	9	9	10	10	8	8	8	8
	IRR	8	7	10	10	9	11	9	7	7	9	7	6
	MUN	7	7	7	8	8	9	11	11	9	8	8	8
3	**IND**	7	7	8	8	9	9	10	10	8	8	8	8
	IRR	6	7	8	11	13	12	10	9	6	5	6	6
	MUN	7	7	8	8	9	9	10	10	8	8	7	7
4	**IND**	7	7	8	8	9	9	10	10	8	8	8	8
	IRR	4	4	3	13	21	19	8	6	6	5	6	4

Values are monthly percentages of annual total.

Table 4-2.
Treated Effluent Discharges (acft) and Corresponding Downstream Control Points

NUM	Name	DS CPID	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	An T
42.001	City of Charlotte	26	6	4	5	4	5	5	3	5	4	5	4	4	
18.001	City of Jourdanton	28	17	16	19	22	23	23	23	19	20	18	14	13	
01.001	City of Three Rivers	29	10	10	11	11	12	9	10	11	12	11	12	11	
55.001	Lon C. Hill Power Station	Bay	12	10	31	41	51	41	68	67	40	38	15	17	
01.006	Allison Plant	Bay	219	217	209	230	238	239	228	247	221	228	221	228	2
vailable	Portland (Self Reporting)	Bay	90	84	97	91	101	94	99	99	94	96	92	95	1
89.001	East Plant/City of Hondo	9912	64	56	65	65	75	74	70	74	68	57	63	66	
15.001	City of Mathis	246402	31	30	25	25	28	18	33	30	30	27	32	32	
55.001	City of George West	246402	8	5	5	8	7	9	11	13	12	10	9	10	
98.001	Crystal City	308202	72	66	68	49	56	68	62	63	57	50	39	36	
45.001	City of Carrizo Springs	309301	47	43	50	47	51	49	49	53	49	49	46	48	
53.001	City of Cotulla	312601	38	33	40	34	35	32	35	38	39	36	38	42	
04.001	City of Sabinal	318201	2	1	2	1	2	2	1	3	2	2	2	1	
44.001	Medina Co WCID 002	319101	2	2	2	1	3	3	3	3	3	3	2	3	
60.001	City of Pearsall	319301	68	62	65	65	74	75	74	77	72	69	64	68	
04.001	City of Dilley	320002	15	16	16	13	12	12	10	15	13	12	13	15	
04.002	TDCJ Facility	320002	2	2	2	2	1	0	1	0	1	2	1	1	
43.001	McMullen Co WCID 001	320403	1	1	1	1	2	1	1	1	2	2	1	1	
98.001	Atascosa River Plant	321702	43	40	46	45	45	46	51	55	48	45	37	47	
96.001	City of Lytle	398601	6	6	6	5	6	4	5	4	6	5	5	8	
60.001	City of Devine	404101	28	25	27	26	27	26	26	28	29	29	29	29	
06.001	City of Uvalde	529731	123	112	98	108	101	101	104	97	104	106	86	146	1
06.001	City of Natalia	534402	7	6	8	8	9	8	8	9	8	7	8	7	
30.001	City of Poteet	321631	13	12	16	17	19	19	18	17	16	16	14	13	
—	Monthly Total	—	923	858	915	920	983	961	997	1027	950	922	852	943	

Table 4-9.
Interbasin Transfers in the Nueces River Basin

Water Right Number	*Owner*	*Basin From*	*Basin To*	*Source of Diversion*	*Author (a*
2130	**BMA WCID 1**	**San Antonio**	**Nueces (BMA Canals)**	**Lake Medina and Lake Diversion**	**65,830 MUN, IRR, IND;**
2131	**BMA WCID 1**	**San Antonio**	**Nueces (BMA Canals and Chacon Reservoir)**	**Lake Medina and Lake Diversion**	**2,000 IRR (this is the same water 6).**
3207	**BMA WCID 1**	**San Antonio**	**Nueces (BMA Canals and Chacon Reservoir)**	**Lake Medina and Lake Diversion**	**1,800 IRR (states 90% of water or Basin).**
2464	**City of Corpus Christi**	**Nueces**	**Nueces-Rio Grande (Alice Terminal Reservoir)**	**Lake Corpus Christi**	**150,000 MUN; 150,000 I (not broken down by ba**
2464	**City of Corpus Christi**	**Nueces**	**Nueces-Rio Grande (Corpus Christi)**	**Calallen Reservoir**	**4,872 MUN; 14 IRR; 12 basin or recipient)**
2464	**City of Corpus Christi**	**Nueces**	**Nueces-Rio Grande (Corpus Christi Industries)**	**Calallen Reservoir**	**see ** above**
2464	**City of Corpus Christi**	**Nueces**	**Nueces-Rio Grande (South Texas Water Authority)**	**Calallen Reservoir**	**see ** above**
2464	**City of Corpus Christi**	**Nueces**	**San Antonio-Nueces (Beeville)**	**Lake Corpus Christi**	**see * above**
2464	**City of Corpus Christi**	**Nueces**	**San Antonio-Nueces (San Patricio MWD and Nueces Co. WCID #4)**	**Calallen Reservoir**	**see ** above**
2466	**Nueces Co. WCID**	**Nueces**	**Nueces-Rio Grande (Nueces Co. WCID #3 – Robstown and surrounding area)**	**Calallen Reservoir**	**7,300 IRR; 4,246 MUN (not broken down by ba**
4402	**City of Taft**	**Nueces**	**San Antonio-Nueces (Taft drainage canal)**	**Lake Corpus Christi**	**600 IRR**
5509	**U.S. Dept. of Interior Bureau of Reclamation**	**Nueces**	**San Antonio-Nueces (Rincon Bayou)**	**Nueces River**	**Unlimited (≥300 cfs) (expires 12/31/2001, un**

[1] **MUN = Municipal** **IRR = Irrigation** **IND = Industrial** **D&L = Domestic and Livestock**

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. SB1 required 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 Nueces 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.

At the request of the South Central Texas Regional Water Planning Group, an additional scenario (Run 9) was developed to reflect water management assumptions consistent with those adopted for development of their regional water plan. Results of Run 9 have been transmitted directly to the South Central Texas Regional Water Planning Group and are not included in this report.

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 Nueces 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. CI (constant inflow) records are used in WRAP to input 12 monthly values of flow to be added to the naturalized flows at a control point. 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.

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 to be 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.[120]

The maximum use recorded by the TNRCC South Texas Watermaster for the City of Corpus Christi's right, C2464, occurred in 1991 and is approximately 41 percent larger than its next largest reported annual use. This value likely represents an error in the records, since no industrial use was reported and 1991 was a very wet year in Corpus Christi. The value recorded by the TNRCC South Texas Watermaster was used in Runs 5, 7, and 8.

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), 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. Also shown are the maximum annual use for each right (1987 to 19097) included in the data provided by the TNRCC. These data were utilized to set the authorized diversion amounts for Runs 4 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.

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. Graphical presentations of regulated and unappropriated flows at selected control points are shown in Figures V-1 through V-11. Reservoir storage traces for Choke Canyon Reservoir and Lake Corpus Christi are displayed in Figures V-12 and V-13.

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

5.2.1.1 Specific Large Rights

Tables 5-2 through 5-4 compare reliability summaries generated by each run for three groups of rights held by the City of Corpus Christi (C2464 and C3214), Zavala-Dimmit (C3028), and Nueces County WCID No. 3 (C2466). The rights held by the City of Corpus Christi exhibit relatively low reliability due to authorized annual diversion (443,898 acft/yr) that are in excess of the firm yield of the CCR/LCC System (178,700 acft/yr).[121] Corpus Christi currently operates the system under demands much less than the firm yield, and has taken steps to obtain alternative sources of supply (Lake Texana). Reuse of treated effluent has a very limited impact on the reliability of the major water rights, as shown by the results of Runs 1, 2, and 3.

5.2.1.2 Unappropriated Flows at Selected Locations

Tables 5-5 through 5-10 summarize annual regulated and unappropriated flows for each run at selected control points in the Nueces River Basin. Reuse of treated effluent has almost no impact on unappropriated flows at the selected control points.

Table 5-2.
Reliability Summary for City of Corpus Christi's Water Rights[1]

Scenario		C2464[2]		C3214[3]		CCR/LCC[4]	
		by Volume	by Month	by Volume	by Month	by Volume	by Month
Reuse	Run1	85.7%	79.8%	79.9%	74.4%	83.1%	73.8%
	Run2	84.2%	79.3%	80.0%	73.7%	82.9%	73.2%
	Run3	83.8%	78.7%	80.1%	74.0%	82.6%	73.1%
Cancellation	Run4	84.9%	79.7%	79.5%	74.0%	83.2%	73.7%
	Run5	99.2%	98.9%	99.1%	99.1%	99.2%	98.8%
	Run6	84.6%	79.8%	79.1%	73.3%	82.9%	73.3%
	Run7	99.1%	98.8%	98.5%	98.5%	99.0%	98.5%
Current Conditions	Run8	98.6%	98.2%	98.0%	98.0%	98.5%	97.9%

1 Reliability summaries generated from water right group identifiers in WR records.
2 C2464 represents diversions authorized at Lake Corpus Christi and Calallen Dam.
3 C3214 represents diversions authorized at Choke Canyon Reservoir.
4 CCR/LCC represent summary of all the City of Corpus Christi water rights.

121 HDR, "Water Supply Update for City of Corpus Christi Service Area," City of Corpus Christi, January 1999.

Table 5-3.
Reliability Summary for
Nueces County WCID No. 3 Water Rights[1]

Scenario		***by Volume***	***by Month***
Reuse	**Run1**	96.1%	86.7%
	Run2	95.4%	85.6%
	Run3	94.6%	84.8%
Cancellation	**Run4**	96.3%	87.1%
	Run5	99.5%	98.7%
	Run6	94.8%	85.6%
	Run7	98.3%	96.2%
Current Conditions	**Run8**	99.5%	98.7%

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

Table 5-4.
Reliability Summary for
Zavala-Dimmit Water Rights[1]

Scenario		***by Volume***	***by Month***
Reuse	**Run1**	72.9%	50.6%
	Run2	72.6%	50.2%
	Run3	72.5%	49.9%
Cancellation	**Run4**	74.3%	51.4%
	Run5	76.6%	54.8%
	Run6	73.4%	51.0%
	Run7	75.2%	53.5%
Current Conditions	**Run8**	76.6%	54.8%

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

Table 5-5.
Nueces River near Laguna, CP01
Annual Summaries for Each Scenario

Scenario		*Regulated Flows (acft/yr)*				*Unappropriated Flows (acft/yr)*			
		Max	*Min*	*Mean*	*Median*	*Max*	*Min*	*Mean*	*Median*
Reuse	Run 1	460,956	15,091	113,267	79,399	371,327	0	24,387	0
	Run 2	460,956	15,091	113,278	79,431	371,327	0	24,385	0
	Run 3	460,956	15,084	113,289	79,431	371,327	0	24,330	0
Cancellation	Run 4	461,473	15,122	113,470	79,456	372,476	0	25,947	0
	Run 5	462,891	15,760	114,191	80,114	427,129	0	29,545	0
	Run 6	461,473	15,118	113,483	79,489	372,476	0	26,901	0
	Run 7	462,891	15,765	114,204	80,128	427,129	0	30,176	0
Current Conditions	Run 8	462,891	15,760	114,185	80,114	427,129	0	30,285	40

Table 5-6.
Nueces River near Cotulla, CP05
Annual Summaries for Each Scenario

Scenario		*Regulated Flows (acft/yr)*				*Unappropriated Flows (acft/yr)*			
		Max	*Min*	*Mean*	*Median*	*Max*	*Min*	*Mean*	*Median*
Reuse	Run 1	999,631	5,889	179,060	113,412	852,140	0	60,014	0
	Run 2	999,631	5,635	178,860	113,157	851,932	0	59,506	0
	Run 3	998,868	5,510	178,649	112,901	851,755	0	59,492	0
Cancellation	Run 4	1,001,375	6,150	179,828	114,273	853,954	0	60,533	0
	Run 5	1,002,665	5,895	179,683	113,623	941,408	0	90,644	10,119
	Run 6	1,000,685	5,861	179,441	113,731	853,570	0	59,713	0
	Run 7	1,001,944	5,940	179,328	113,058	940,883	0	88,868	9,036
Current Conditions	Run 8	1,002,490	5,895	179,586	113,600	941,406	0	95,157	16,636

Table 5-7.
Frio River near Derby, CP25
Annual Summaries for Each Scenario

Scenario		Regulated Flows (acft/yr)				Unappropriated Flows (acft/yr)			
		Max	Min	Mean	Median	Max	Min	Mean	Median
Reuse	Run 1	791,696	2,575	100,618	56,783	614,777	0	11,081	0
	Run 2	791,002	1,967	99,930	56,041	614,426	0	11,019	0
	Run 3	790,393	1,484	99,341	55,392	614,073	0	10,969	0
Cancellation	Run 4	792,484	2,268	100,511	56,540	615,625	0	11,149	0
	Run 5	793,054	2,276	100,413	56,590	702,256	0	25,513	0
	Run 6	791,157	1,176	99,210	55,149	614,924	0	11,034	0
	Run 7	791,732	1,177	99,115	55,199	696,693	0	25,259	0
Current Conditions	Run 8	793,016	2,276	100,426	56,590	702,977	0	24,321	0

Table 5-8.
Nueces River near Three Rivers, CP29
Annual Summaries for Each Scenario

Scenario		Regulated Flows (acft/yr)				Unappropriated Flows (acft/yr)			
		Max	Min	Mean	Median	Max	Min	Mean	Median
Reuse	Run 1	2,370,461	90,979	558,296	473,586	1,992,688	0	164,873	0
	Run 2	2,368,172	89,489	556,243	478,132	1,991,313	0	163,688	0
	Run 3	2,366,046	88,078	554,996	463,311	1,989,977	0	163,302	0
Cancellation	Run 4	2,375,035	92,759	559,679	474,781	1,995,589	0	165,661	0
	Run 5	2,398,021	185,513	540,390	369,190	2,184,564	0	242,727	48,597
	Run 6	2,370,690	89,774	557,986	478,052	1,992,962	0	163,817	0
	Run 7	2,392,862	157,432	537,559	369,211	2,170,540	0	238,433	44,362
Current Conditions	Run 8	2,398,350	126,528	542,247	369,188	2,200,894	0	255,603	52,158

Table 5-9.
Nueces River at Calallen Dam, CP31
Annual Summaries for Each Scenario

Scenario		Regulated Flows (acft/yr)				Unappropriated Flows (acft/yr)			
		Max	Min	Mean	Median	Max	Min	Mean	Median
Reuse	Run 1	1,710,322	0	161,392	32,159	1,679,734	0	137,773	0
	Run 2	1,708,904	0	161,239	33,690	1,678,861	0	136,807	0
	Run 3	1,708,724	0	161,597	35,127	1,677,987	0	136,527	0
Cancellation	Run 4	1,713,712	0	162,111	32,159	1,681,446	0	138,381	0
	Run 5	2,058,492	0	262,954	69,643	1,943,203	0	209,260	33,453
	Run 6	1,710,292	0	162,065	35,127	1,679,667	0	136,794	0
	Run 7	2,052,005	0	261,793	66,897	1,932,755	0	206,019	30,537
Current Conditions	Run 8	2,070,316	0	271,198	85,227	1,955,027	0	220,191	35,904

Table 5-10.
Nueces Bay, CPBAY
Annual Summaries for Each Scenario

Scenario		Regulated Flows (acft/yr)			
		Max	Min	Mean	Median
Reuse	Run 1	1,757,516	4,308	173,992	44,386
	Run 2	1,755,192	2,163	171,692	40,911
	Run 3	1,752,867	18	169,905	39,850
Cancellation	Run 4	1,759,228	4,308	174,767	44,664
	Run 5	2,074,601	4,399	275,610	75,828
	Run 6	1,754,547	18	170,431	40,025
	Run 7	2,063,824	109	270,159	74,786
Current Conditions	Run 8	2,086,425	4,374	283,854	96,402

5.2.1.3 Regulated Flows at Selected Locations

As shown in Tables 5-5 through 5-10, reuse of treated effluent in the Nueces Basin would have almost no impact on the regulated flows at the selected control points.

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, V-3, and VI-4. Graphical presentation of regulated and unappropriated flows at selected control points are shown in Figures VI-1 through VI-22. Reservoir storage traces for Choke Canyon Reservoir and Lake Corpus Christi are displayed in Figures VI-23 through VI-26.

5.2.2.1 Specific Large Rights

Tables 5-2 through 5-4 compare reliability summaries generated by each run for three groups of rights held by the City of Corpus Christi (C2464 and C3214), Zavala-Dimmit (C3028), and Nueces County WCID No. 3 (C2466). 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) show an improvement in the reliability of the City of Corpus Christi's combined rights. Since the City's maximum historical use is much less than their full authorized diversion amounts, the reliability to their combined rights increases by about 15 percent from that in Runs 1 and 3. The Nueces County WCID No. 3 rights exhibit a less pronounced increase, which is due to more water being available to their rights that are junior to a portion of the City of Corpus Christi's rights. Since the Zavala-Dimmit diversions are upstream of and senior to Corpus Christi, their rights are not effected by the large change in the City's diversions. Their rights show a small increase in reliability for both Runs 5 and 7, when compared to Runs 1 and 3, respectively.

5.2.2.2 Unappropriated Flows at Selected Locations

Tables 5-5 through 5-10 summarize annual regulated and unappropriated flows for each run at selected control points in the Nueces River Basin. 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. The unappropriated flows for Runs 5 and 7 are also analogous to the results of the reliability analysis for the large rights. With the City of Corpus Christi having less maximum use than their permitted amounts, unappropriated flows show a substantial increase from Run 1 to Run 5 and Run 3 to Run 7. Unappropriated flow in the Nueces River Basin is much more sensitive to partial cancellation of rights down to historical maximum use levels than it is 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. Runs 5 and 7 show decreases in regulated flow at CP29, the Nueces River near Three Rivers, and substantial increases at CP31, the Nueces River at Calallen Dam. Since the City's maximum diversion over the past 10 years is considerably less than their full authorized diversion amount, Choke Canyon Reservoir is not called upon as often to make releases to the City's rights diverted at Calallen Dam, thereby reducing the regulated flows on average. The substantial increase in average regulated flows at Calallen Dam is due to the smaller amounts being diverted between Runs 1 and 5 and Runs 3 and 7.

5.2.3 Current Conditions Run

The results for Current Condition Run 8 are presented in Appendix VII. Reliability of supply for each right is presented in Table VII-1. Graphical presentations of regulated and unappropriated flows at selected control points are shown in Figures VII-1 through VII-11. Reservoir storage traces for Choke Canyon Reservoir and Lake Corpus Christi are displayed in Figures VII-12 through and VII-13.

5.2.3.1 Specific Large Rights

Tables 5-2 through 5-4 compare reliability summaries generated by each run for three groups of rights held by the City of Corpus Christi (C2464 and C3214), Zavala-Dimmit (C3028), and Nueces County WCID No. 3 (C2466). The reliability at the larger rights for Current Conditions Run 8 is very similar to the results of Run 5. Only the Corpus Christi rights show a small decrease in reliability due to the year 2000 storage-area relations used for both Choke Canyon Reservoir and Lake Corpus Christi. The year 2000 capacities are substantially less than their full permitted impoundment volumes, resulting in less supply to the Corpus Christi right.

5.2.3.2 Unappropriated Flows at Selected Locations

Tables 5-5 through 5-10 summarize annual regulated and unappropriated flows for each run at selected control points in the Nueces River Basin. The unappropriated flows for Run 8 are slightly greater than those in Run 4, as a result of Corpus Christi's maximum use over the past 10 years being less than their full authorized amount.

5.2.3.3 Regulated Flows at Selected Locations

The regulated flows for Run 8 are very similar to those calculated in Run 5.

5.3 Comparison to Existing River Basin Models

5.3.1 Nueces River Basin and Lower Nueces River Basin Models

Although the existing Nueces River Basin Model (NRB) and the Lower Nueces River Basin and Estuary Model (Nubay) developed by HDR[122] were 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, marches from one water right to the next 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. The existing Nueces River Basin models (Nubay and NRB) do not have a priority loop. In the monthly computation loop, they work from upstream to downstream without regard for seniority, and make no availability calculations for individual water rights. However, since the largest rights are located in the lower basin and the downstream impact of upstream diversions is reduced by channel losses, WRAP and the existing Nueces River Basin models provide similar estimates of streamflow, reservoir contents, estuarine inflows, and Edwards Aquifer recharge.

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

- Choke Canyon Reservoir and Lake Corpus Christi conservation pools increased to store fully authorized amounts;
- The City of Corpus Christi is allowed to divert their full authorized amounts at Calallen rather than the actual firm yield of CCR/LCC System;

[122] HDR Engineering, Inc. (HDR), "Nueces River Basin Regional Water Supply Planning Study – Phase I," Nueces River Authority, et al., May 1991.

- WRAP allows intervening runoff below Lake Corpus Christi and above Calallen Dam to be diverted at Calallen. Nubay does not make this water available for diversion at Calallen;
- Both models use the same natural flows; and
- Both models use the same monthly evaporation data at Choke Canyon Reservoir and Lake Corpus Christi.

5.3.1.1 Upper Nueces 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 upper Nueces River Basin. The plots compare the regulated flows calculated by NRB to those calculated by WRAP at the Nueces River near Laguna (CP01), the Nueces River near Cotulla (CP05), and the Frio River near Derby (CP25). As displayed, there is very little difference between the output 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 existing 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 existing model also causes WRAP to predict higher regulated flows.

5.3.1.2 Choke Canyon Reservoir and Lake Corpus Christi

Figures 5-4 and 5-5 compare the WRAP and Nubay time series traces and correlation plots for storage in Choke Canyon Reservoir and Lake Corpus Christi. As is apparent in these figures, agreement is quite reasonable between the models. The following sections discuss the observed differences between the two models at Choke Canyon Reservoir and Lake Corpus Christi.

5.3.1.2.1 Choke Canyon Reservoir

During portions of the simulation, WRAP simulates greater storage in Choke Canyon Reservoir than Nubay. The difference in the amount of releases calculated for Choke Canyon Reservoir and the channel losses between Choke Canyon Dam and Calallen Dam are the reasons for this difference.

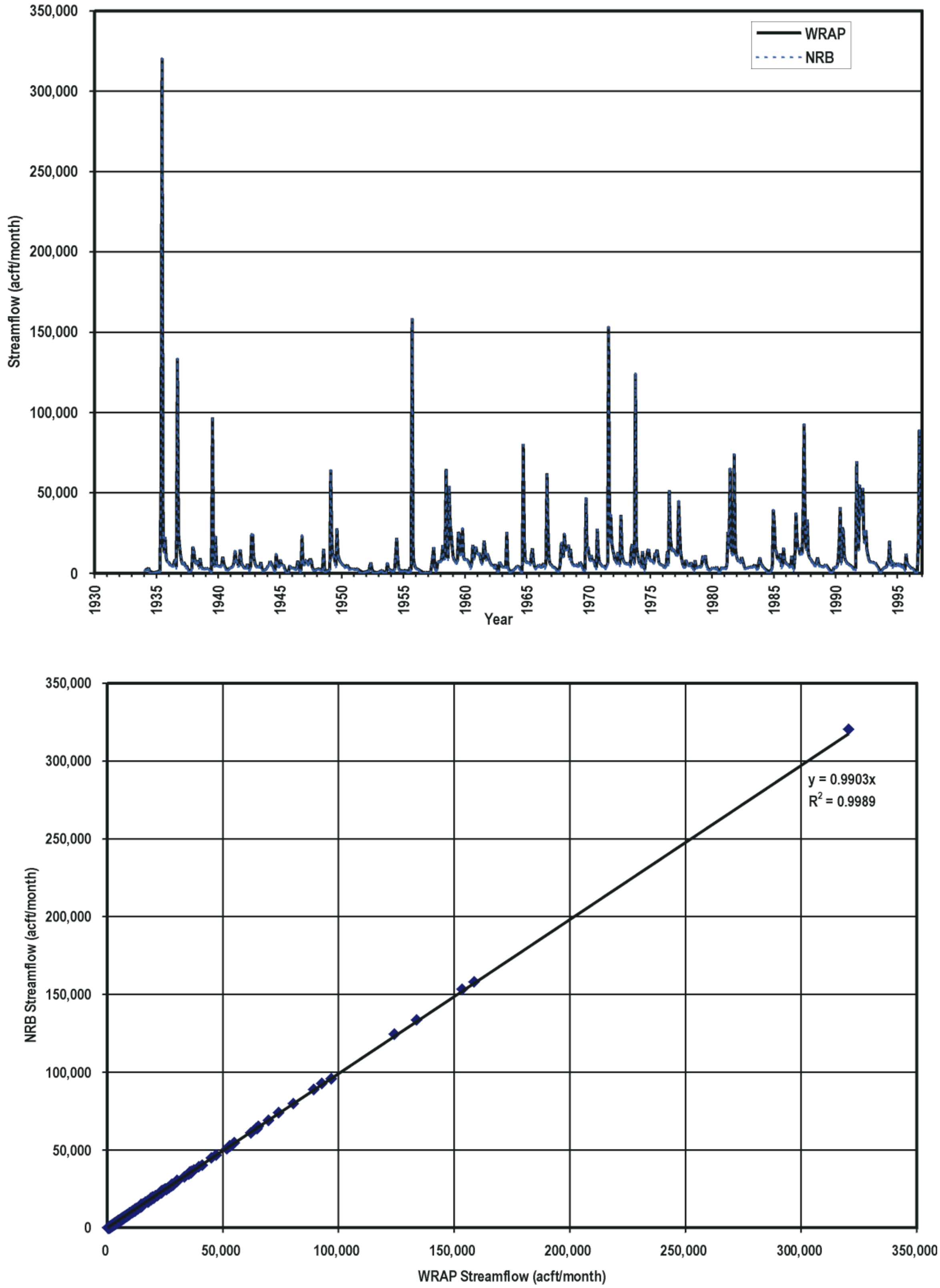
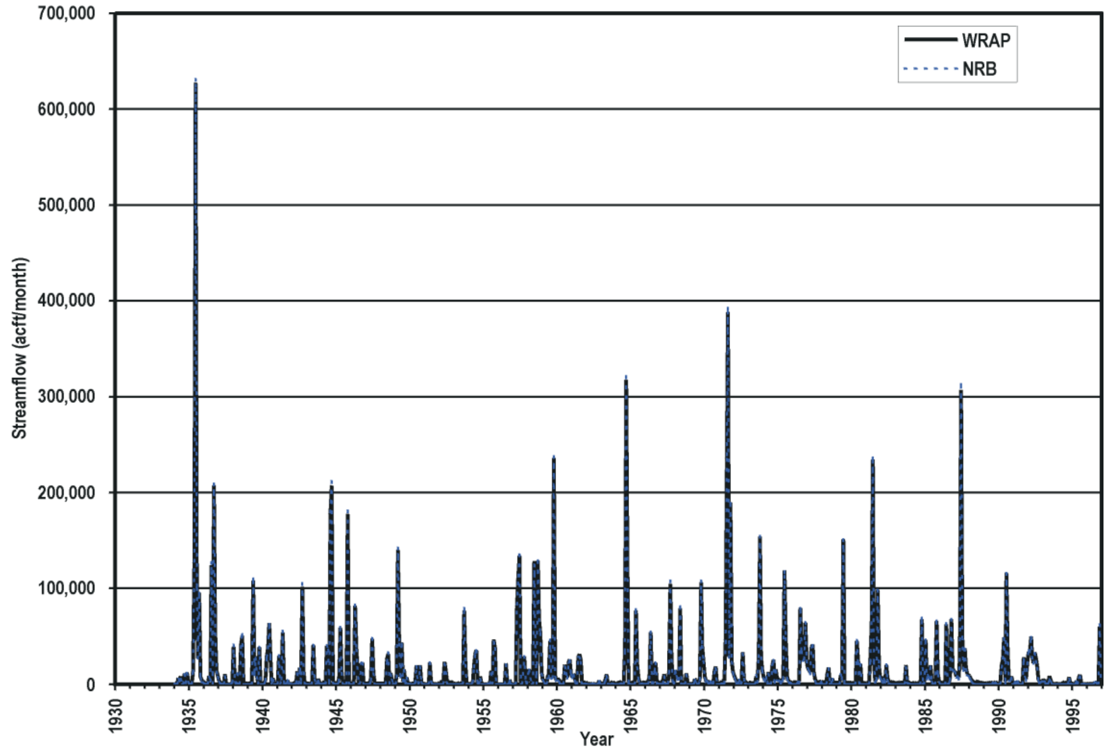


Figure 5-1. Regulated Flows at the Nueces River near Laguna, CP01 WRAP vs. NRB



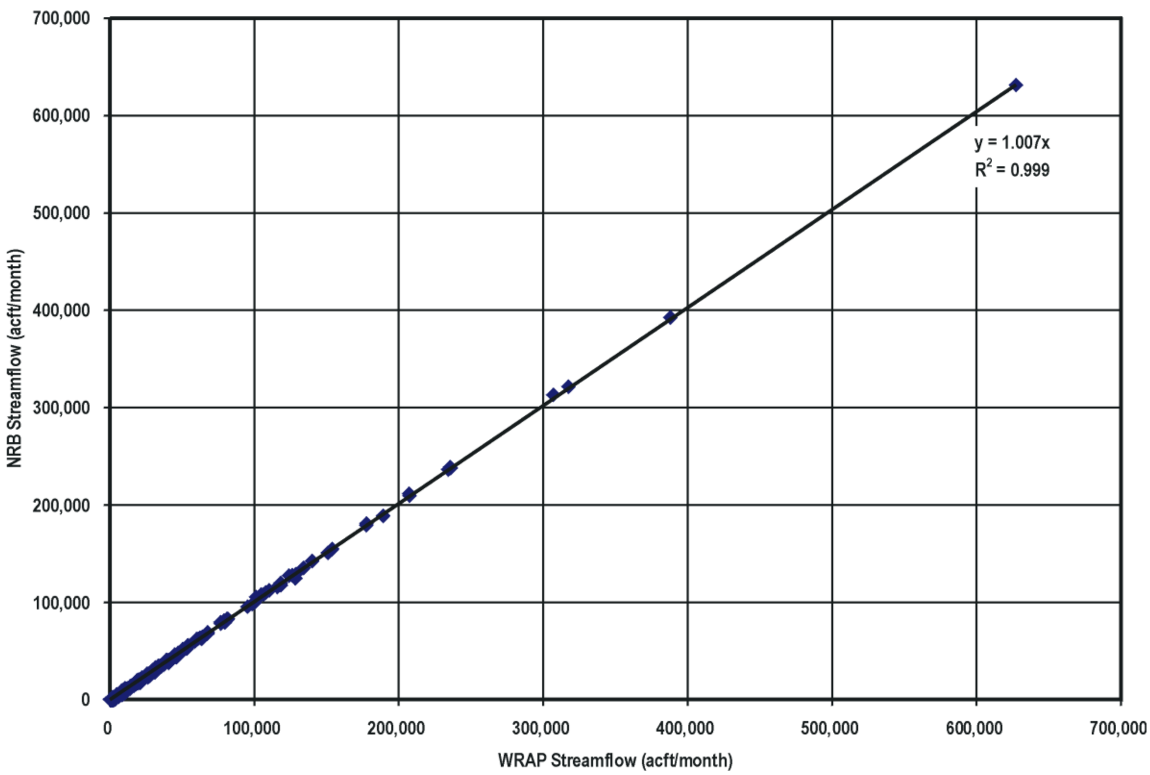
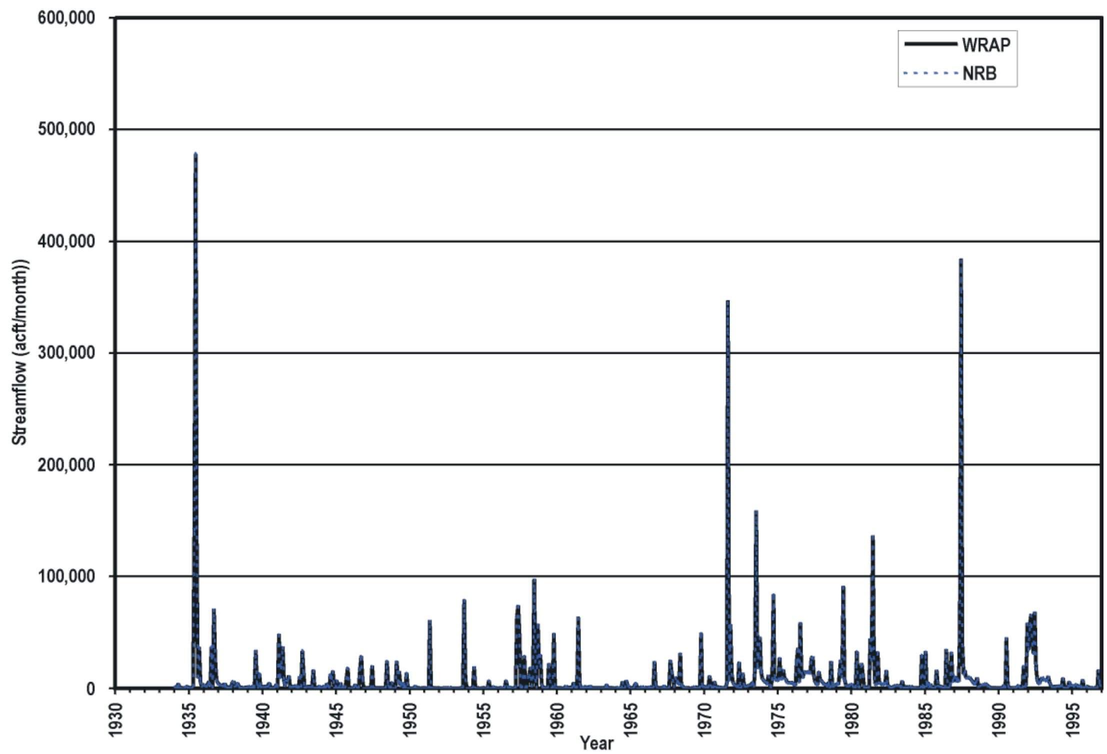


Figure 5-2. Regulated Flows at the Nueces River near Cotulla, CP05 WRAP vs. NRB



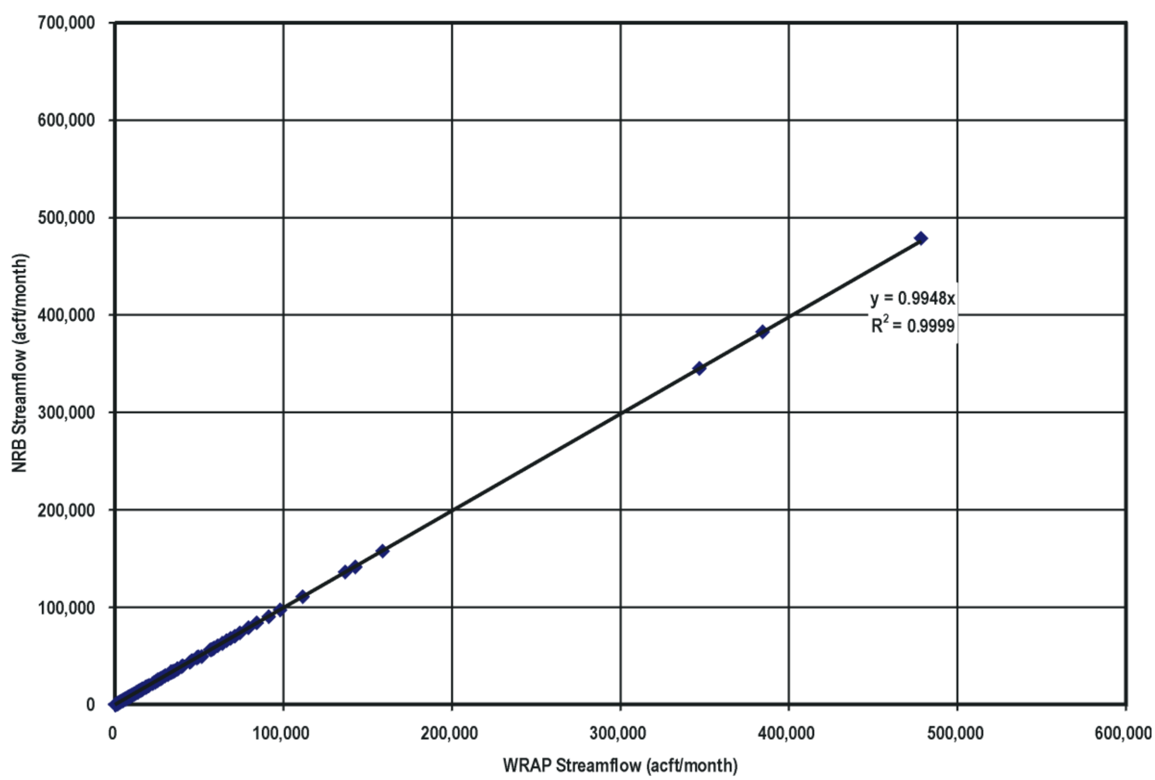
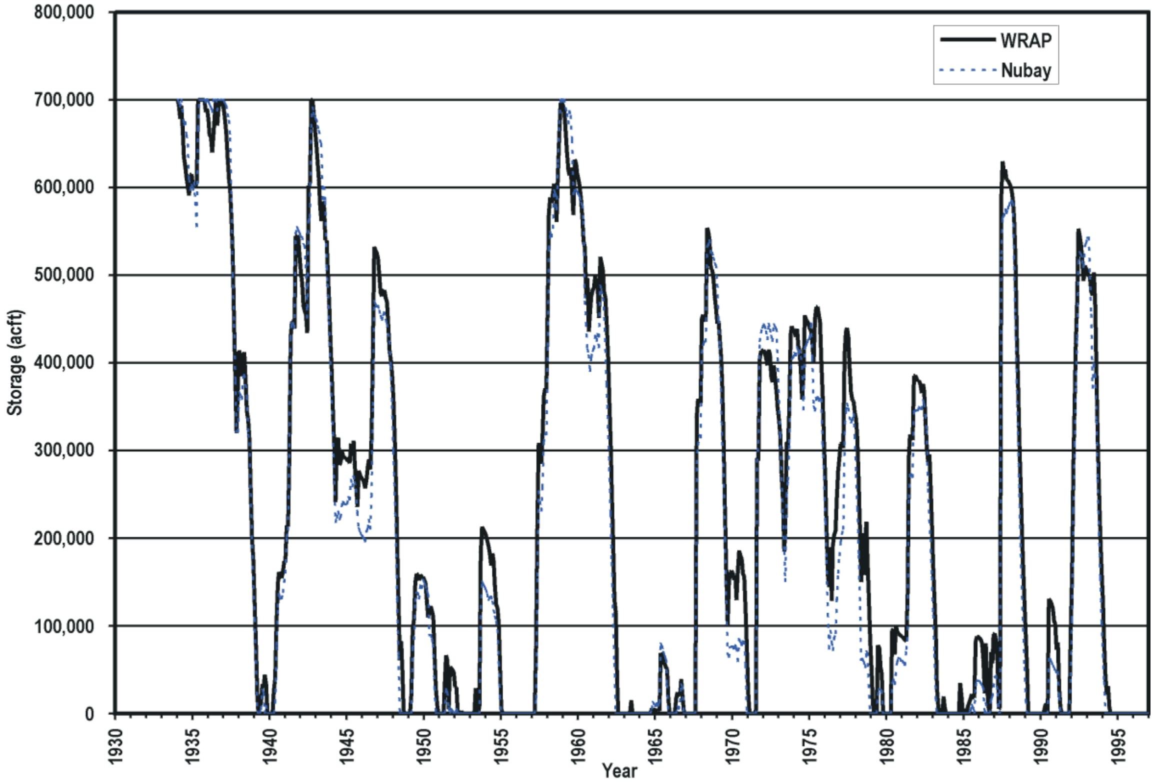


Figure 5-3. Regulated Flows at the Frio River near Derby, CP25 WRAP vs. NRB



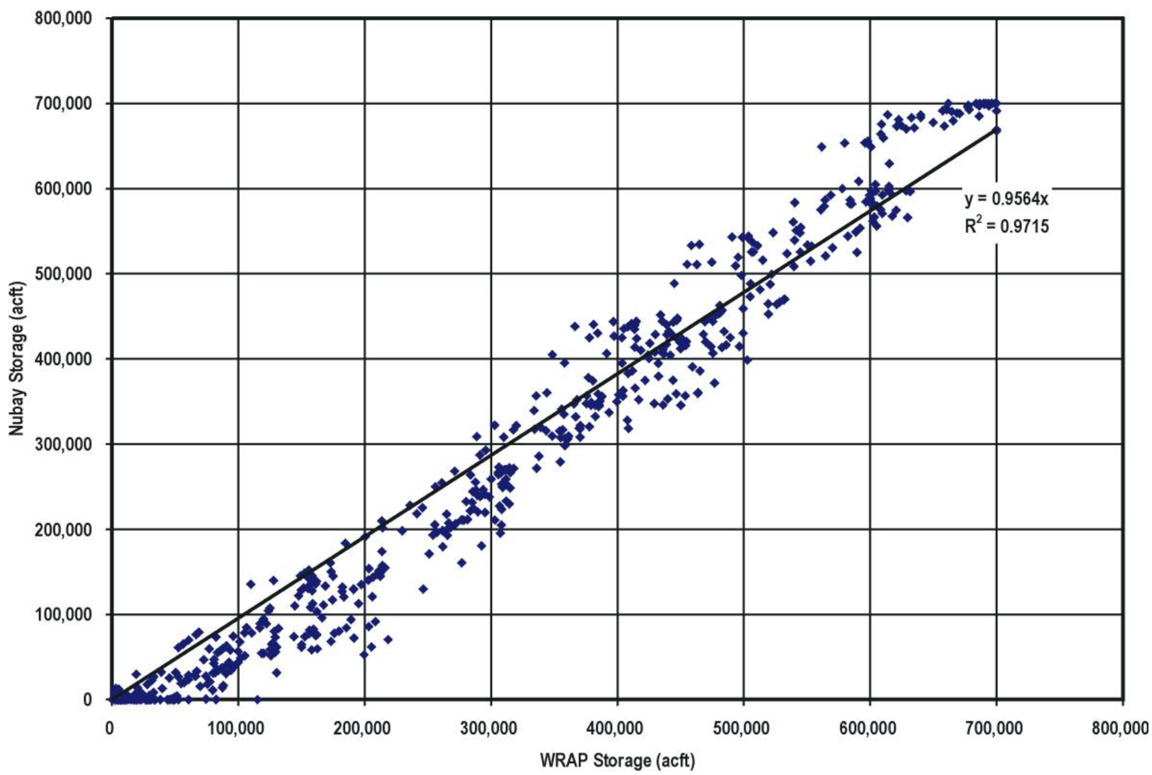
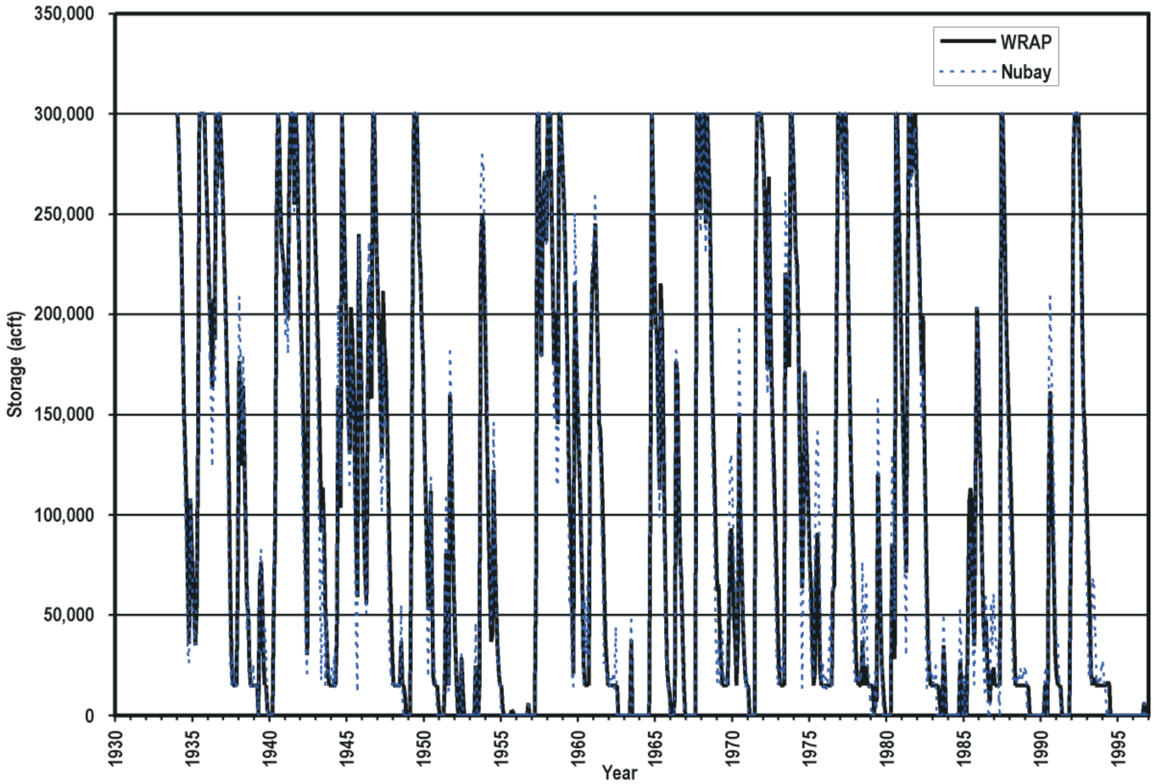


Figure 5-4. Choke Canyon Reservoir Storage WRAP vs. Nubay



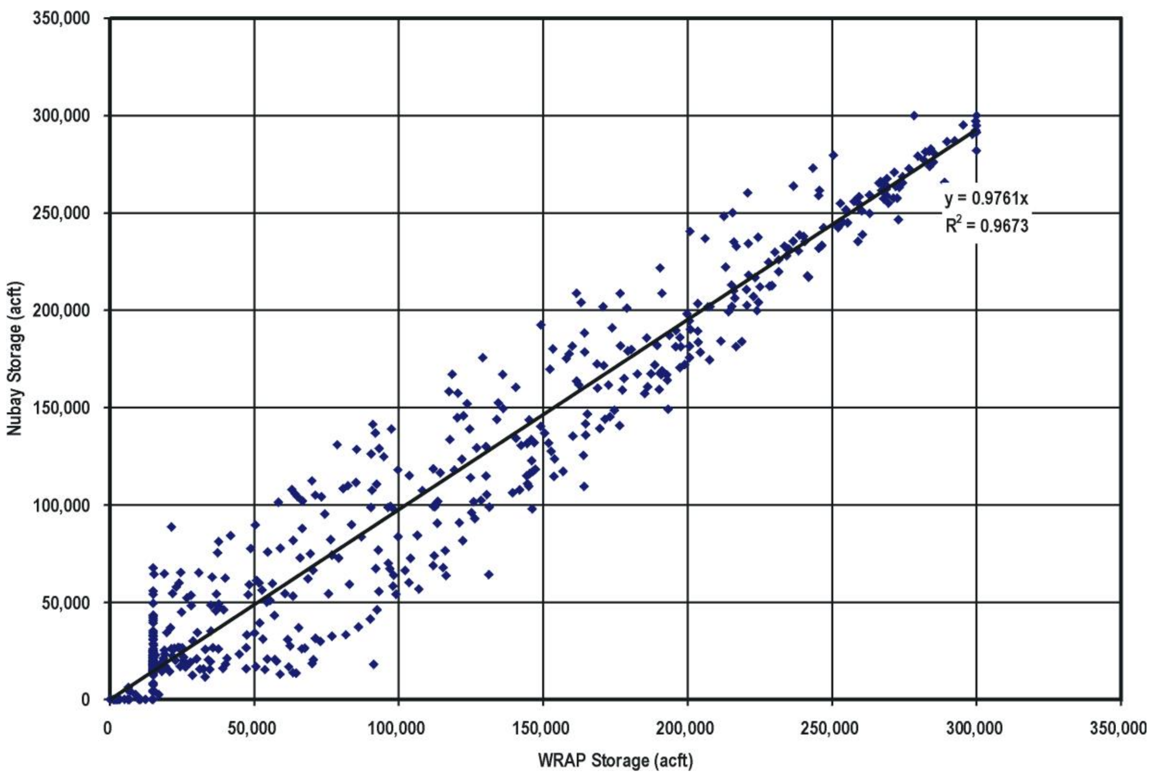


Figure 5-5. Lake Corpus Christi Reservoir Storage WRAP vs. Nubay

Once Nubay encounters the Choke Canyon Reservoir control point, it estimates the water supply and Nueces Bay demands at Calallen Dam. If demands at Calallen are greater than the storage remaining in Lake Corpus Christi, Nubay releases water from Choke Canyon Reservoir to satisfy downstream demands and intervening channel losses. These releases are made without knowledge of the current month's inflows into Lake Corpus Christi from the Nueces River. Therefore, Nubay is essentially making the release decision at the beginning of each month. In WRAP, the releases from Choke Canyon Reservoir are made with knowledge of the current month's inflows to Lake Corpus Christi from the Nueces River. Therefore, WRAP models an end-of-month release decision. In doing so, there are months when Nubay releases more water from Choke Canyon Reservoir than the WRAP Model. This occurs when large events are coming down the Nueces River in the same month when the beginning-of-month storage in Lake Corpus Christi is not adequate to satisfy the demands at Calallen, but end-of-month storage in Lake Corpus Christi is more than enough to meet the Calallen demands.

The extra water needed to overcome channel/delivery loss from Choke Canyon to Calallen Dam magnifies the differences between the two models. Not only is WRAP keeping more water in Choke Canyon Reservoir by making end-of-month releases, it also avoids some of the channel losses simulated in Nubay. For this reason, the storage traces for WRAP lag the major drawdowns in Nubay, as seen in Figure 5-4.

5.3.1.2.2 Lake Corpus Christi

Storage at Lake Corpus Christi is depleted more frequently in Nubay than in WRAP because by the treatment of intervening runoff below Lake Corpus Christi and above Calallen Dam. Since Nubay does not make intervening runoff available to the rights at Calallen, Lake Corpus Christi or Choke Canyon Reservoir must make releases even if the intervening runoff is greater than the demands at Calallen. This assumption is coded in Nubay because available storage above Calallen Dam to retain intervening runoff is very limited, meaning that any intervening runoff in excess of Corpus Christi's daily demands will simply spill into Nueces Bay. In WRAP, releases will not be made if the intervening monthly runoff is adequate to satisfy the Calallen demands. This results in WRAP predicting higher storage volumes in Lake Corpus Christi than Nubay.

5.3.1.3 Freshwater Inflows to Nueces Estuary

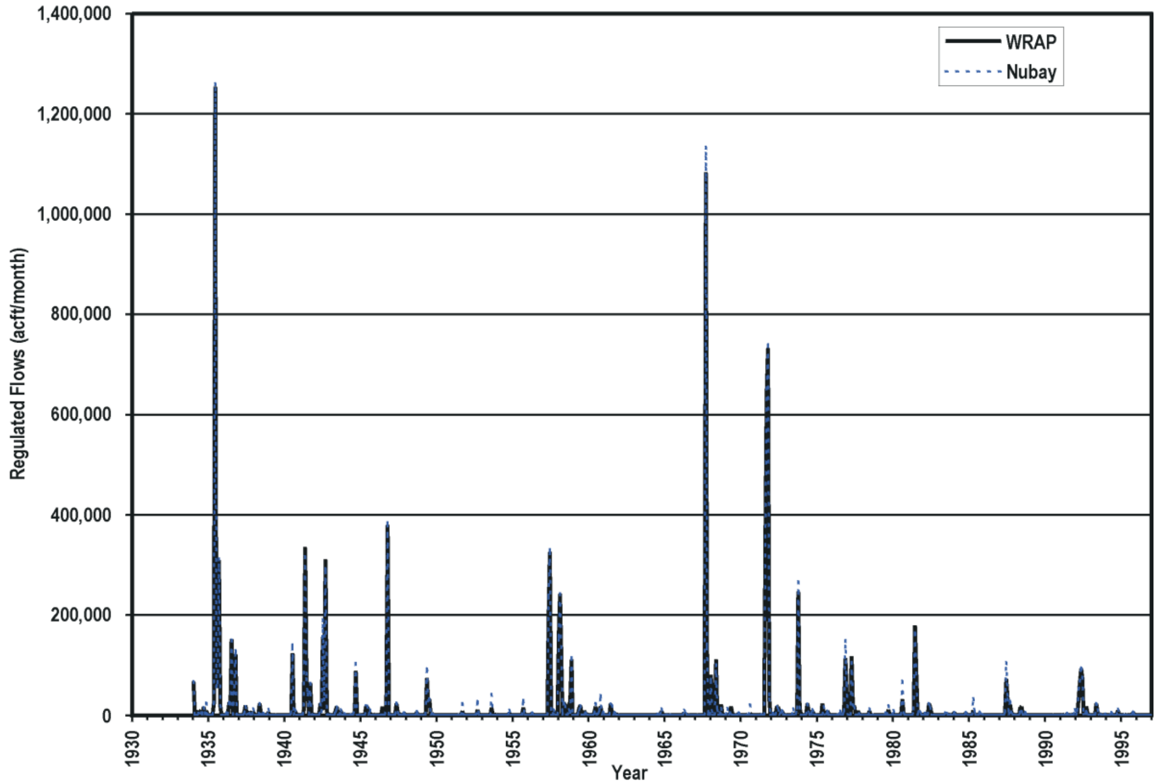
The regulated inflows to the Nueces Estuary calculated by WRAP and Nubay are plotted in Figure 5-6. As indicated in the correlation plot, Nubay typically predicts more inflow to the Nueces Estuary than WRAP.

The primary reason Nubay predicts higher inflows into the Nueces Estuary than WRAP is attributable to WRAP's ability to divert intervening monthly runoff below Lake Corpus Christi. When intervening flows provide ample supply to satisfy the demands at Calallen and meet the freshwater inflow requirements of the Agreed Order, the inflows predicted by WRAP are always less than those predicted by Nubay. Another cause for estuarine inflows to be less in WRAP than in Nubay occurs when the intervening runoff below Lake Corpus Christi and above Calallen is greater than the estimated flow into Lake Corpus Christi had Choke Canyon Reservoir never existed. In this scenario, WRAP diverts the intervening runoff and limits the Nueces Bay requirements to the estimated inflows into Lake Corpus Christi, whereas Nubay allows all intervening runoff to pass directly into Nueces Bay.

5.3.1.4 Edwards Aquifer Recharge

Table 5-11 compares first order statistics for each of the Edwards Aquifer recharge control points in the WRAP and Nueces River Basin (NRB) Models. As shown, WRAP output is very similar to NRB. The primary differences between the two models are attributable to the location of the water rights in each model and handling of the recharge reservoirs on Seco (CP17), Parkers (CP202), and Verde Creeks (CP22).

NRB lumps the water rights located in the recharge zone at the nearest control point immediately upstream of the recharge zone so that recharge will not be overestimated, whereas WRAP keeps the rights at their permitted locations. Lumping the rights above the recharge zone reduces the regulated flows at the upstream boundary control points in the existing model. This manifests in a smaller difference between regulated flows upstream and downstream of the recharge zone creating less potential for recharge in the existing model. Application of the prior appropriation doctrine in WRAP also increases the differences between the two models. Since the existing model diverts regardless of priority and WRAP applies priority before making a diversion, regulated flows at the recharge boundary control points are often times different between the two models.



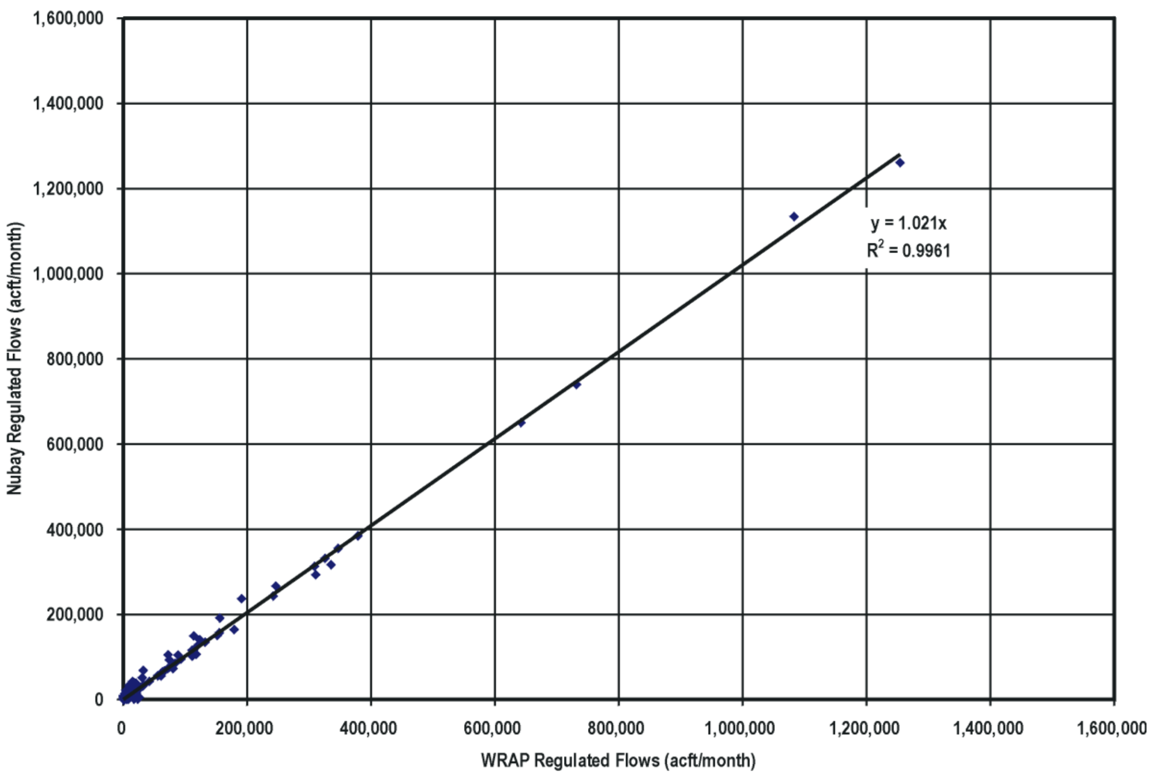


Figure 5-6. Regulated Flows at Nueces Estuary, CPEST WRAP vs. Nubay

For the recharge reservoirs, NRB 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 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 Seco Creek (CP17) and Parkers Creek (CP202) reflect this difference. At both locations, NRB allows more recharge to occur at the structures than WRAP. The Verde Creek structure (CP22) does not reflect this behavior due to the limited amount of water captured by the structure in both models. Figure 5-7 shows an annual comparison of recharge at CP20, which is the sum of CP201 (Live Oak Creek) and CP202 (Parkers Creek). In years 1935 and 1987, the Parkers Creek structure accounts for the substantial increase in recharge estimated by the existing model. At this structure, NRB allows up to 2,507 acft/month to recharge, whereas WRAP only allows a maximum annual authorized recharge of 1,185 acft/yr.

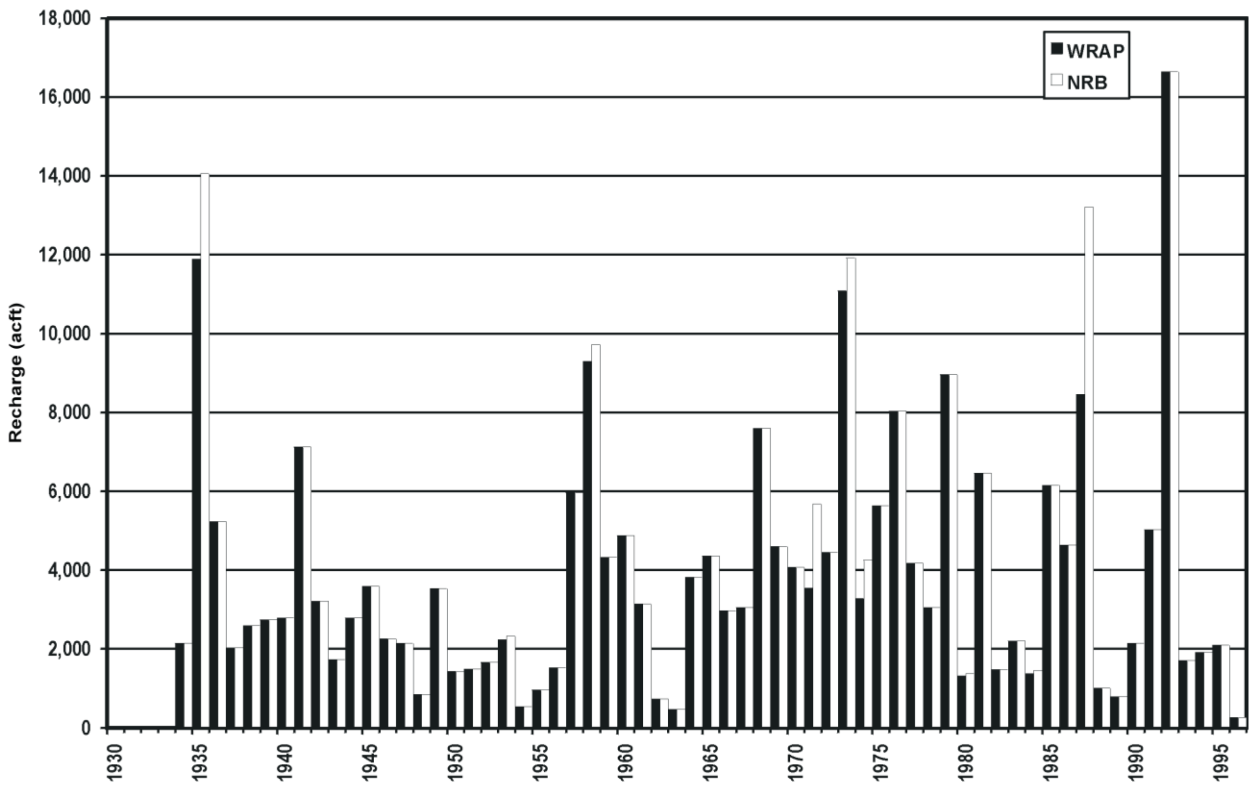


Figure 5-7. Annual Recharge at CP20, Live Oak and Parkers Creek*
WRAP vs. NRB

***Recharge at CP20 is the sum of CP201 and CP202**

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 1978); does not account for channel losses, except for isolated losses across the Edwards Aquifer Balcones Fault Zone; treats operations of the CCR/LCC System 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, a limited comparison of results is warranted. Output data from Run 1 from the revised Nueces River Basin Legacy WAM were obtained from a CD-ROM published by the TNRCC.[123] In the Legacy WAM, the documentation provided by the TNRCC[124] states that the model includes "about 285 permits, certified filings and claims with an appropriation of about 525,000 acre-feet per year." All reservoirs greater than 10 acft capacity were included. Based upon statements in the Legacy WAM documentation,[125] storage does not appear to have been treated with equal priority to diversions. The documentation states that water remaining after all demands were met was used to refill reservoir storages. Losses across the Edwards Aquifer Balcones Fault Zone were accounted for by making flows from watersheds upstream of the fault zone unavailable to rights downstream of the fault zone.

Choke Canyon Reservoir and Lake Corpus Christi were operated in the Legacy WAM as a system, although differently than the methodology utilized in WRAP. The Certificate of Adjudication for Choke Canyon Reservoir (C3214) stipulates that the 139,000 acft/yr authorized diversion from Choke Canyon Reservoir is to be achieved through system operation with Lake Corpus Christi. This was modeled in the Legacy WAM by routing simulated diversions from Choke Canyon Reservoir through Lake Corpus Christi with a combined demand of 439,000 acft/yr (300,000 acft/yr from LCC; 139,000 acft/yr from CCR) taken at Lake Corpus Christi. The remaining 4,898 acft/yr authorized under the City of Corpus Christi's Certificate of Adjudication (C2464) was diverted near Calallen Dam and not included in the CCR/LCC System.

[123] TNRCC, "TNRCC Documentation for Legacy Water Availability Models Used for Water Rights Permitting," June 25, 1998.
[124] TDWR, "Interim Report of Water Availability in the Nueces River Basin, Texas," DRAFT, March 1982.
[125] Ibid (page 26).

The documentation of the Legacy WAM is unclear whether or how the CCR/LCC System was operated to provide for 151,000 acft/yr of freshwater inflows to the Nueces Estuary, to be supplied by spills, return flows, and reservoir releases as stipulated in the Certificate of Adjudication (C3214) for Choke Canyon Reservoir. Since development of the Legacy WAM, the CCR/LCC System operates under an Agreed Order issued by the TNRCC on April 28, 1995. The Agreed Order established a monthly schedule of minimum desired freshwater inflows to Nueces Bay, totaling between 97,000 and 138,000 acft/yr, to be satisfied by spills, return flows, measured runoff below Lake Corpus Christi, and/or dedicated passage of CCR/LCC inflows. Operation of the CCR/LCC System in WRAP is described in Sections 4.1.2 and 4.2.5, and Appendix IX (bound separately).

Figure 5-8 compares annual unappropriated flows for the Nueces River at Three Rivers (CP29) for years 1940 through 1978. Annual unappropriated flows computed by the Legacy WAM generally occur in the same years as those computed by WRAP (Run 1), but are generally greater than those computed by WRAP in early years, and less than those computed by WRAP in later years. The naturalized flows (Figure 3-4) do not follow this pattern, and without more detailed information concerning the Legacy WAM, no explanation is postulated. WRAP simulates Lake Corpus Christi storage as less than capacity throughout most of the simulation.

Figure 5-9 illustrates the similarity between simulated diversions for the rights associated with the CCR/LCC System. Annual diversions met simulated by the two models agree very well, considering the differences in model development and treatment of the CCR/LCC System. The diversion shortages depicted by Figure 5-9 are due to simulation of the CCR/LCC System with demands in excess of the firm yield of the system. This is also noted in the documentation of the Legacy WAM.

5.4 Factors Affecting Water Availability and Modeling Results

As shown by the results from the various cancellation runs, the single most influential factor that affects the overall water availability in the Nueces River Basin are those assumptions concerning authorized versus maximum historical use. Treated effluent discharges throughout the basin are small, except near the coast, and none of the three reuse scenarios (Runs 1, 2, and 3) result in significant differences in regulated or unappropriated flows anywhere in the basin. Similarly, cancellation of rights showing 10 years of nonuse in Runs 4 and 6 does not

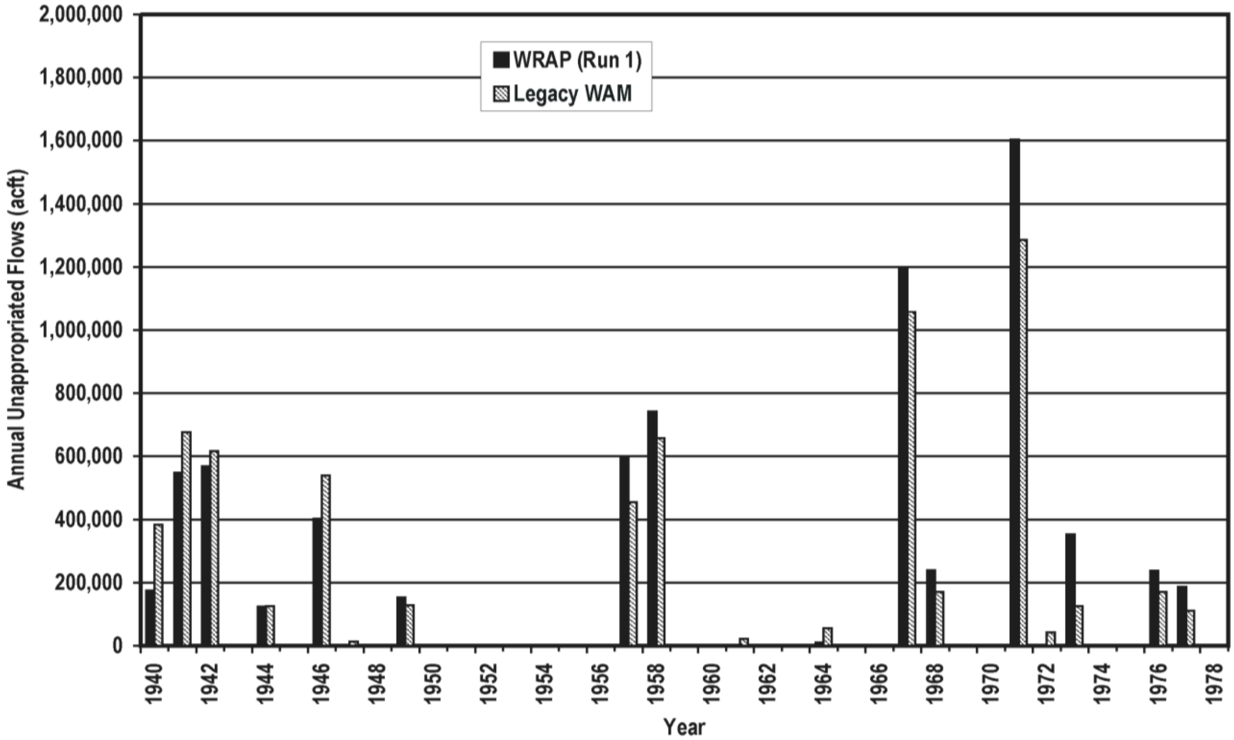


Figure 5-8. Annual Unappropriated Flows, Nueces River at Three Rivers

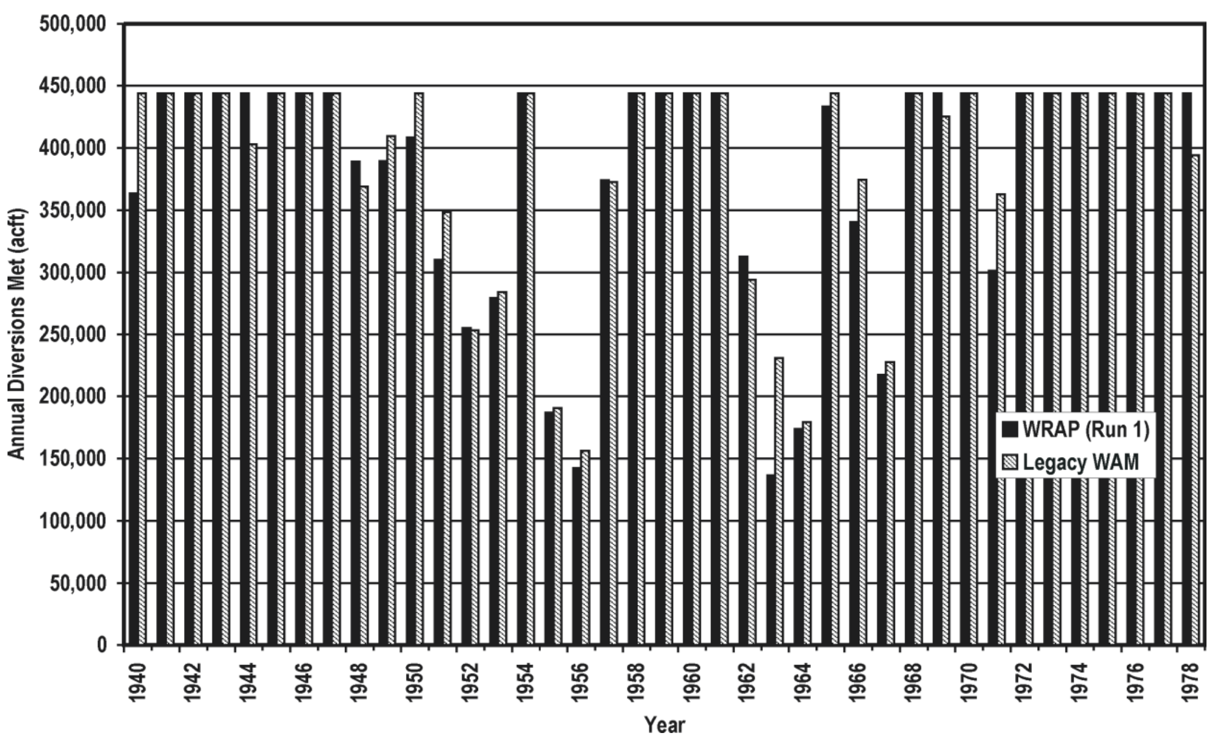


Figure 5-9. Annual Diversion Met by the CCR/LCC System

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 Nueces 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 Nueces River Basin is greatly influenced by assumptions concerning the rights associated with the CCR/LCC System. These rights represent approximately 97 percent of the total reservoir storage and 88 percent of the diversion rights in the Nueces River Basin; are authorized to divert at the furthest practical downstream location, Calallen Dam; and are some of the most senior in the basin. The permitted capacity of Lake Corpus Christi is approximately 20 percent greater than the reservoir's present capacity, and modeling the reservoir at its permitted capacity will cause upstream junior rights to pass flows more frequently to refill storage in the reservoir. In addition, the estimated firm yield (178,700 acft/yr) of the CCR/LCC System is only about 40 percent of the authorized diversions under the City of Corpus Christi's rights (443,898 acft/yr). The combination of modeling Corpus Christi's rights assuming the full authorized storage capacity of the CCR/LCC System and the full authorized annual diversions significantly reduces availability to upstream junior rights, which must pass inflows to meet the storage and diversion requirements under the CCR/LCC System rights.

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 Nueces 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 Re-run 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 the CCR/LCC System can be readily incorporated into the data sets provided.

Table 5-1.
Assumptions Utilized in Alternative Model Runs

	Assumptions Utilized	Reuse Runs			Cancellation Runs				Current Conditions
		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% 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 (Choke Canyon Reservoir, Lake Corpus Christi, and Comanche Reservoir).

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

Control Point	Location	Maximum		Minimum		Mean		Median	
		WRAP	NRB	WRAP	NRB	WRAP	NRB	WRAP	NRB
CP03	Nueces River near Uvalde	219,815	218,792	18,126	17,943	90,427	89,334	87,835	87,518
CP09	Frio River near Uvalde	277,806	274,693	7,412	5,106	104,040	98,094	91,293	85,586
CP10	Leona River	18,959	18,959	307	307	4,128	4,136	2,773	2,773
CP111 and CP112	Hackberry and Blanco Creeks	23,006	23,006	1,116	1,116	6,478	6,478	5,575	5,575
CP13	Sabinal River near Sabinal	69,909	69,780	1,555	1,317	28,428	28,087	24,793	24,197
CP141 and CP142	Little Blanco and Nolton Creeks	13,623	13,560	483	483	3,806	3,800	2,648	2,648
CP15	Ranchero Creek	4,024	4,006	102	102	957	956	614	614
CP17	Seco Creek near D'Hanis	168,237	169,620	1,452	1,452	31,544	32,265	23,123	24,081
CP19	Hondo Creek near Hondo	118,756	118,760	1,638	1,536	27,350	27,253	20,716	20,611
CP201 and CP202	Live Oak and Parkers Creeks	16,640	16,640	258	258	3,834	4,017	3,049	3,049
CP22	Verde Creek in Recharge Zone	71,983	71,983	1,379	1,379	19,561	19,541	15,584	15,584
CP231 and CP232	Elm and Quihi Creeks	57,079	54,512	1,268	1,268	14,453	14,212	11,120	10,866

Section 6
Summary and Conclusions

Water availability in the Nueces River Basin is affected by assumptions regarding water management and use, in addition to natural hydrologic influences, such as rainfall, runoff, and evaporation. SB1 required 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 Nueces 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 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 assumptions concerning treated effluent discharges and cancellation of only those rights showing no use affect water availability very little in the Nueces River Basin. Treated effluent discharges throughout the basin are small, except near the coast, and large discharges near the coast discharge into the Nueces Estuary. None of the three reuse scenarios (Runs 1, 2, and 3) result in significant differences in regulated or unappropriated flows anywhere in the basin. Consumptive reuse of treated effluent in the Corpus Christi service area, however, could significantly reduce freshwater inflows to the Nueces Estuary. Similarly, cancellation of rights showing 10 years of no use 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.

The most influential factor affecting overall water availability in the Nueces 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 use between 1987 and 1997. Very few rights in the Nueces River Basin have been fully perfected, 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 Nueces River Basin is small, and inclusion of term permits in Run 8 has no significant effect on water availability.

Water availability in the Nueces River Basin is greatly influenced by assumptions concerning the rights associated with the CCR/LCC System. These rights represent approximately 97 percent of the total reservoir storage and 88 percent of the diversion rights in the Nueces River Basin; are authorized to be diverted at the furthest practical downstream location, Calallen Dam; and are some of the most senior in the basin. The permitted capacity of Lake Corpus Christi is more than 25 percent greater than present capacity, and modeling the reservoir at its permitted capacity causes upstream junior rights to pass flows more frequently to refill storage in the reservoir. The estimated firm yield (178,700 acft/yr)[126] of the CCR/LCC System is only about 40 percent of the authorized diversions under the City of Corpus Christi rights (443,898 acft/yr). Nevertheless, diversions based on Corpus Christi's full authorized

[126] HDR Engineering, Inc., "Water Supply Update for City of Corpus Christi Service Area," City of Corpus Christi, January 1999.

amounts are more than 82 percent available in all Runs performed. The combination of modeling Corpus Christi rights assuming full authorized storage capacity of the CCR/LCC System and full authorized annual diversions significantly reduces water availability for upstream junior rights, which must pass inflows to meet the storage and diversion requirements under the CCR/LCC System rights.

At the request of the South Central Texas Regional Water Planning Group, an additional scenario (Run 9) was developed to reflect water management assumptions consistent with those adopted for development of their regional water plan. Results of Run 9 have been transmitted directly to the South Central Texas Regional Water Planning Group and are not included in this report.

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

Submitted to the Texas Water Digital Library on June 4, 2014, by Grant J. Gibson, P.G., Texas Commission on Environmental Quality.