Water Availability in the Brazos River Basin and the San Jacinto-Brazos Coastal Basin

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List of Abbreviations

acft	acre feet
acft/yr	acre feet per year
ALCOA	Aluminum Company of America
AMC	antecedent moisture condition
BRA	Brazos River Authority
CDP	Census-Designated Place names
cfs	cubic foot per second
CL	channel loss
CRWR	University of Texas Center for Research in Water Resources
GIS	geographic information system
HDR	HDR Engineering, Inc.
MGD	million gallons per day
mg/L	milligrams per liter
SB1	Senate Bill 1
TAMUWRAP	Texas A&M University Water Rights Analysis Package
TNRCC	Texas Natural Resource Conservation Commission
TDWR	Texas Department of Water Resources
TDS	Total Dissolved Solids
TWDB	Texas Water Development Board
USGS	U.S. Geological Survey
USSC	U.S. Study Commission
WAM	Water Availability Model
WRAP	Water Rights Analysis Package

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Executive Summary

ES.1 Study Objectives

Pursuant to Senate Bill 1 of the 75th Texas Legislature, the Texas Natural Resource Conservation Commission (TNRCC) is developing new reservoir/river basin simulation models for 22 river basins in Texas in order to quantify available water in accordance with Chapter 11, Water Rights, Texas Water Code. The new models, commonly referred to as water availability models, are capable of assessing water available for diversion or impoundment under existing water rights and future permit applications subject to the doctrine of prior appropriation. Under the doctrine of prior appropriation, the right to divert, impound, or otherwise use water is based on the concept of "first in time, first in right," where priority is given to those making beneficial use of water first historically. This priority is generally expressed as a date of priority for a given water right.

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

- Develop an updated water availability model for the Brazos River Basin and San Jacinto-Brazos Coastal Basin;
- Apply the model to provide water rights holders with information regarding long-term reliability and water availability during a 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 (j) and (k) of the Water Code:

(j) 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.

(k) Within 90 days of completing a water availability model for a river basin, the commission, in coordination with the Parks and Wildlife Department and with input

> from the Department of Agriculture, where appropriate, 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 Brazos River Basin and adjoining San Jacinto-Brazos Coastal Basin encompass an area of over 47,000 square miles of which approximately 44,440 square miles are in Texas with approximately 2,500 square miles located in New Mexico. Approximately 9,500 square miles of the Brazos River Basin located in the High Plains is considered to be noncontributing drainage area including all of the area in New Mexico.[1]

Topography in the Brazos River Basin varies from the relatively level "caprock" escarpment in the High Plains portion of the basin, to rolling hills in the middle basin, to generally mild or flat slopes in the Coastal Prairies approaching the Gulf of Mexico. Portions of the Texas Hill Country and the Edwards Plateau extend into the south-central portion of the basin in Bell, Burnet, Comanche, Coryell, Hamilton, Lampasas, Travis and Williamson Counties. The steep slopes and characteristically thin soils of the Hill Country and Edwards Plateau result in this area producing significant runoff per unit of rainfall.

The San Jacinto-Brazos Coastal Basin is located entirely in the Gulf Coast Prairies and Marshes ecoregion. This area is a nearly flat plain, gently sloping toward the Gulf of Mexico, with low, wide valleys and slow surface drainage.

Average annual rainfall in the Brazos River Basin ranges from approximately 16 inches in the High Plains area of the basin to approximately 52 inches in the coastal areas of the basin and in the San Jacinto-Brazos Coastal Basin.[2] Rainfall in the upper portions of the basin is highly variable in magnitude and frequency, as most significant rainfall originates from localized convective thunderstorms in May and June. The sporadic nature of rainfall in the upper basin results in short periods of high flows in the smaller streams, preceded and followed by long periods of low or zero flows. In the lower portion of the basin and in the San Jacinto-Brazos

[1] U.S. Geological Survey, "Drainage Areas of Texas Streams, Brazos River Basin, " unnumbered Open-File Report, 1977.
[2] Texas Department of Water Resources, "Climatic Atlas of Texas", LP-192, December 1983, pg. 18.

Coastal Basin, rainfall is also highly variable, and is normally caused by convective thunderstorms and coastal storm systems originating in the Gulf of Mexico. The wettest months are usually April, May and September, while the least amount of rain typically occurs in the fall and late winter.

Land use in the Brazos River Basin and San Jacinto-Brazos Coastal Basin is predominately related to agriculture with 53.8 percent classified as cropland or pastureland and 30.6 percent as rangeland. Urban land uses comprise only about 0.9 percent of the basin. The cities of Lubbock, Abilene, Waco, Bryan, College Station, and that portion of Houston located in the San Jacinto-Brazos Coastal Basin had an estimated population in 1999 of approximately 582,000 people.[3]

In the Brazos River Basin, groundwater resources currently supply more than 82 percent of the water used for all purposes with surface water resources supplying the remaining 18 percent. In 1990, total water use in the basin from both groundwater and surface water totaled approximately 3.166 million acft, which represents a decline of 850,584 acft from the 1980 total basin water use. This decline in total water use is attributable to reductions in water use for irrigated agriculture of 927,271 acft, manufacturing of 17,154 acft, and mining of 13,074 acft. Over this same period of time, municipal water use increased by 22,000 acft, steam-electric use increased 75,026, and livestock use increased 10,124 acft. By far the largest water use category for the basin is irrigated agriculture, which accounts for 77 percent of all water used.[4] Irrigated agriculture use is concentrated on the High Plains and is supplied largely from the Ogallala Aquifer.

In the San Jacinto-Brazos Coastal Basin water used for municipal, industrial, and agricultural purposes totaled about 405,000 acft in 1990. The largest water-using category in the coastal basin is manufacturing with a current use of about 162,000 acft. Other major water use categories include irrigation and municipal use of about 131,000 and 107,000 acft respectively. In 1990, 166,341 acft of water were exported to the San Jacinto-Brazos Coastal Basin and

[3] Texas Water Development Board, Historical and Projected Population and Water Use Data for Regional Planning Groups (cd), April 26, 1999.
[4] Ibid.

114 acft were exported to the San Jacinto River Basin from the Brazos River Basin for municipal, industrial, and agricultural irrigation purposes.[5]

[5] Ibid.

The largest reservoir in the Brazos River Basin is Possum Kingdom Reservoir, which is located on the Brazos River in Palo Pinto County. Possum Kingdom Reservoir has an authorized storage capacity of 724,739 acft and an authorized annual diversion of 230,750 acft. Possum Kingdom Reservoir is owned and operated by the Brazos River Authority, which holds all of the authorized diversion rights in the reservoir. The authorized storage capacity of Possum Kingdom Reservoir is approximately 20 percent of the total combined capacity of all major reservoirs (capacity greater than 10,000 acft) in the Brazos River Basin and the San Jacinto-Brazos Coastal Basin.

ES.3 Water Availability Information

The TNRCC Water Rights Database Table WRDETAIL, dated July 20, 2000, lists 1,216 water rights in the Brazos River Basin (1,160 rights) and San Jacinto-Brazos Coastal Basin (56 rights) having priority dates senior to February 2, 2000. The oldest water right in the basins has a priority date of December 31, 1883. Authorized annual diversions total almost 3,988,329 acft and annual authorized consumptive use totals 2,673,592 acft, not counting rights that are saline in nature.[6]

The Brazos River Authority holds multiple rights to divert a total of 717,901 acft/yr, or about 34.2 percent of all municipal and consumptive industrial rights in the basins. Industrial users in the lower Brazos and Coastal basins hold multiple rights to consumptively use 620,711 acft/yr, or about 29.6 percent of all municipal and consumptive industrial rights.

Records of surface water use as reported by individual water right owners were collected and tabulated by TNRCC staff for the 1915 to 1997 historical period. These records are generally comprised of annual totals for the 1915 to 1954 period and monthly totals for the 1955 to 1997 period. Based on the maximum historical surface water use reported in the Brazos River Basin and San Jacinto-Brazos Coastal Basin over the ten-year period, 1988 through 1997, the sum of the individual maximum annual water uses reported by all rights in the basins is 1,428,585 acft. Historically, municipal and industrial uses have been the largest users of surface water in the Brazos River Basin and San Jacinto-Brazos Coastal Basin.

[6] Rights that divert primarily saline water are presented in the memorandum that is included as Appendix II.

A database of permitted effluent discharges maintained by the TNRCC was used to identify major treated wastewater discharges. The largest of these facilities, that is not a power plant, is operated by Aluminum Company of America (ALCOA) and is permitted to discharge an aggregate volume in excess of 784 million gallons per day (MGD) for overburden dewatering purposes into East Yegua Creek. (The largest reported discharge from the facility is 21 MGD.) ALCOA also discharges an average of about 11 MGD into East Yegua Creek for groundwater dewatering. Because the groundwater discharged meets water quality standards, a discharge permit is not required by the TNRCC. The next largest permitted industrial discharge is by Houston Industries, Inc. for approximately 100 MGD to be discharged into Big Creek in the lower part of the basin. The largest permitted municipal discharge is operated by the City of Abilene for 22 MGD and is discharged into Deadman Creek.

ES.4 Development of the Water Availability Model

The Water Rights Analysis Package (WRAP)[7,8] 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 utilized 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, and the datasets created for the Brazos River Basin and San Jacinto-Brazos Coastal Basin, will replace the original water availability model of the Brazos River Basin developed by the Texas Department of Water Resources (TDWR).[9,10] The TDWR did not previously develop a water availability model for the coastal basin. Significant differences between current (WRAP) model and the existing (Legacy) model are:

- The current model uses a hydrological database (1940 to 1997) some 56 percent longer than the Legacy model (1940 to 1976);
- The current model reflects completion of the adjudication process and changes in water rights between 1982 and mid 2000;

[7] 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.
[8] 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.
[9] Texas Department of Water Resources (TDWR), "Interim Report of Water Availability in the Brazos River Basin, Texas," Draft, July 1981.
[10] TDWR, "Revised Interim Report of Water Availability in the Brazos River Basin, Texas," Draft, July 1983.

- The current model addresses the effects of channel losses in the translation of changes in streamflow to downstream locations; and
- Naturalized flows in the Legacy model are differentiated into baseflows and runoff, whereas the WRAP model makes no distinction.

Naturalized streamflows form the basis for water availability modeling and were developed as part of this study. The procedures used to develop these naturalized flows are consistent with those originally used by 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 quandrangles of latitude and longitude. Monthly streamflow and evaporation data include the 58-year historical period from 1940 through 1997.

Water rights information was obtained from the TNRCC water rights database table, WRDETAIL, dated July 20, 2000. Data in this table includes 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 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, runoff curve number and mean annual precipitation) were obtained for 3,754 authorized diversion points, reservoirs, streamflow gages, return flow locations, and confluence points in the Brazos River Basin (3,460) and San Jacinto-Brazos Coastal Basin (294). These locations were utilized as "control points" or locations where streamflow and water availability information is computed in WRAP. Maps of the Brazos River Basin and San Jacinto-Brazos Coastal Basin, which show each control point location are included as Appendix XV.

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

ES.5 Water Availability in the Brazos River Basin and the San Jacinto-Brazos Coastal Basin

Water availability in a river basin is affected by numerous factors including assumptions regarding water rights, water management and use, and 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 Brazos River Basin and San Jacinto-Brazos Coastal 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. Runs 2 and 3 are identical to Run 1, except for assumed effluent discharges. In Run 2, effluent discharges were reduced to one-half of the Run 1 values, to reflect 50 percent reuse, and were set to zero in Run 3, to reflect full reuse.

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

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 1988 and 1997, and surveyed reservoir storage capacities for large reservoirs are modified to reflect sediment accumulation representative of the year 2000. Term permits are included at their maximum use between 1988 and 1997.

Simulation results for the various scenarios modeled indicate that cancellation of only those rights showing no use affects water availability very little in the Brazos River Basin and San Jacinto-Brazos Coastal Basin. Reuse of treated effluent has limited effects on overall (mean and median) water availability in either basin, but does substantially reduce minimum unappropriated flows at several locations.

The most influential factor affecting overall water availability in the Brazos 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 1988 and 1997. Many rights in the Brazos River Basin to date have not been fully utilized. Under the theoretical cancellation of these rights in Runs 5 and 7, a considerable amount of water could be available for appropriation if these rights were partially cancelled to their historical maximum use levels. Currently, the total amount of authorized diversions for term permits is relatively small, and inclusion of term permits in Run 8 has no significant affect on water availability. Neither partial nor full cancellation of unutilized water rights significantly affects water availability in the San Jacinto-Brazos Coastal Basin.

Full cancellation of unutilized rights (Runs 4 and 6) would not significantly increase water available for new appropriation. Most of the largest rights in the basin are currently being used and would not be subject to full cancellation. Partial cancellation of underutilized rights (Runs 4 and 7) would increase the reliability of other rights and could increase availability basinwide for new appropriations. Such new appropriations would, however, be subject to environmental flow needs. As many existing rights are not subject to environmental flow needs, partial cancellation of presently underutilized rights would convert a portion of the rights presently available for future increases in demand (or for transfer to others in need of additional supply, but lacking water rights) to enhanced instream flows and freshwater inflows to the Brazos River Estuary and Galveston Bay.

The TNRCC utilizes Run 3 for determining water available for appropriation by new, perpetual rights, and utilizes Run 8 (current conditions run) for granting new appropriations on a term, or temporary, basis. The assumptions utilized in Run 8 are the same as those utilized in Run 5, with the two exceptions that (1) Run 8 includes existing term permits at their “current” use levels (Run 5 does not include term permits), and (2) storage-area relationships for major reservoirs are included at their as-permitted conditions in Run 5 and at estimated Year 2000 sedimentation conditions in Run 8.

Section 1
Introduction

1.1 Description of the Basins

The Brazos River Basin and adjoining San Jacinto-Brazos Coastal Basin encompass an area of over 47,000 square miles of which approximately 44,440 square miles are in Texas with approximately 2,500 square miles located in New Mexico. Approximately 9,500 square miles of the Brazos River Basin located in the High Plains is considered to be noncontributing drainage area including all of the area in New Mexico.[11] The headwaters of the Brazos River Basin begin on the High Plains near the Texas-New Mexico border and extend through the Rolling Plains, Cross Timbers and Prairies, Blackland Prairies, Post Oak Savannah, and the Gulf Coast Prairies and Marshes, to its outlet at the Gulf of Mexico at Freeport. The overall length of the Brazos River mainstream is greater than 1,100 miles between the New Mexico border and Freeport. The Brazos River Basin varies in width from about 70 miles in the High Plains to approximately 110 miles in the vicinity of Waco, and then decreases gradually in width to approximately 10 miles near Richmond. The basin is crossed by six significant aquifer outcrops or recharge zones, including the Ogallala, Seymour, Edwards, Trinity, Carrizo-Wilcox and Gulf Coast (Figure 1-1).

Topography varies from the relatively level "caprock" escarpment in the High Plains portion of the basin, to rolling hills in the middle basin, to generally mild or flat slopes in the Coastal Prairies approaching the Gulf of Mexico. Portions of the Texas Hill Country and the Edwards Plateau extend into the south-central portion of the basin in Bell, Burnet, Comanche, Coryell, Hamilton, Lampasas, Travis and Williamson Counties. The steep slopes and characteristically thin soils of the Hill Country and Edwards Plateau result in this area producing significant runoff per unit of rainfall.

The headwaters of the White River, a tributary of the Brazos River, form near the City of Floydada in Floyd County, southeast of Plainview. In the High Plains area, another major tributary of the Brazos River is the Salt Fork, which forms in northwestern Garza County at an elevation of approximately 2,400 feet. The White River joins the Salt Fork of the Brazos River in northwestern Kent County. The confluence of the Salt Fork with another major tributary, the

[11] U.S. Geological Survey, "Drainage Areas of Texas Streams, Brazos River Basin," unnumbered Open-File Report, 1977.

Double Mountain Fork of the Brazos River, forms the Brazos River in eastern Stonewall County. The Brazos River then flows to its confluence with the Clear Fork near the City of Newcastle in Young County. Other principal tributaries of the Brazos River include the Bosque River which joins the main stem of the Brazos River near the City of Waco in McLennan County; the Little River (formed by the confluence of the Leon and Lampasas Rivers) which joins the main stem of the Brazos River on the Milam and Robertson county-line; Yegua Creek which joins the Brazos River approximately 15 miles downstream of Lake Somerville (located on Yegua Creek); and the Navasota River which joins the Brazos River at the Town of Washington (located on the Washington and Grimes county-line).

The San Jacinto-Brazos Coastal Basin is located entirely in the Gulf Coast Prairies and Marshes ecoregion. This area is a nearly flat plain, gently sloping toward the Gulf of Mexico, with low, wide valleys and slow surface drainage. In the San Jacinto-Brazos Coastal Basin small streams that drain into Galveston Bay and/or the Gulf of Mexico include Clear Creek, Oyster Creek, and Dickinson, Mustang, Chocolate, and Bastrop Bayous.

Average annual rainfall in the Brazos River Basin ranges from approximately 16 inches in the High Plains area of the basin to approximately 52 inches in the coastal areas of the basin and in the San Jacinto-Brazos Coastal Basin (Figure 1-2). Rainfall in the upper portions of the basin is highly variable in magnitude and frequency, as most significant rainfall originates from localized convective thunderstorms in May and June. The sporadic nature of rainfall in the upper basin results in short periods of high flows in the smaller streams, preceded and followed by long periods of low or zero flows. In the lower portion of the basin and in the San Jacinto-Brazos Coastal Basin, rainfall is also highly variable, and is caused by convective thunderstorms and coastal storm systems originating in the Gulf of Mexico. The wettest months are usually April, May and September, while the least amount of rain typically occurs in the fall and late winter.

The Brazos River Basin contains a few major springs. There are springs with discharges greater than 1 cubic foot per second (cfs) that issue from the Edwards-Balcones Fault Zone (BFZ) Aquifer in Bell and Williamson Counties and from the Marble Falls Aquifer in Lampasas County. Of the Edwards Aquifer springs, all but one are intermittent. The three largest Edwards springs are:

- Salado Springs at Salado along the Lampasas River with discharges ranging from 5 to 60 cfs;

Figure 1-1. Major Aquifers Crossing the Brazos River Basin and the San Jacinto-Brazos Coastal Basin

Figure 1-2. Mean Annual Precipitation in the Brazos River Basin and the San Jacinto-Brazos Coastal Basin, 1951-1980

- Berry Springs five miles north of Georgetown with discharges ranging from 0 to 50 cfs eventually flow into the San Gabriel River; and
- San Gabriel Springs at Georgetown with discharges ranging from 0 to 25 cfs eventually flow into the San Gabriel River.

Springs from the Marble Falls Aquifer include Hancock Park Springs along the Sulfur River, which is a tributary to the Lampasas River, with discharges reportedly ranging from 6 to 12 cfs, and Swimming Pool Springs at Hancock Park with a reported range in discharge of 1.3 to 1.6 cfs.[12] These major springs are shown in Figure 1-3, along with other miscellaneous geographic features noted in this section.

Limited data exist for quantifying interactions between ground and surface water in the Brazos River Basin and San Jacinto-Brazos Coastal Basin. Discharges from identified springs were not addressed in this study except to the extent that historical springflows constitute a portion of the flows reaching streamflow gages downstream.

Some springs and seeps in the basin significantly affect the amount of minerals and salt in the Brazos River. An area of approximately 1,500 square miles within the watershed of the Salt Fork of the Brazos River is the primary source of natural salt with Salt Croton Creek and Croton Creek being primary contributors (Figure 1-3). This semiarid region contributes up to 18 percent of the total flow of the Brazos River, but contributes up to 55 percent of the total dissolved minerals and up to 85 percent of the total salt load.[13] For example, from 1964 to 1986, TDS and chloride concentrations in Croton Creek near Jayton averaged 6,391 mg/L and 2,541 mg/L respectively. The mean values for TDS and chlorides in the Salt Croton Creek near Aspermont from 1969 to 1977 were 56,923 mg/L and 32,856 mg/L respectively. Comparatively, for the 1964 to 1986 period, TDS and chloride concentrations in the Double Mountain Fork upstream of the Salt Fork confluence averaged 1,540 mg/L and 416 mg/L, respectively. These natural saltwater sources cause the water in the main stem of the Brazos River above Lake Whitney to require salt removal prior to potable uses. Water in Possum Kingdom Reservoir usually contains more than 400 mg/L chloride and 1,200 mg/L TDS. The natural chloride pollution in the upper Brazos River affects water quality in the lower basin. In the Brazos River

[12] HDR Engineering, Inc. (HDR), "Brazos G Regional Water Planning Area – Regional Water Plan," Vols. I, II, and III, Brazos River Authority, January 2001.

[13] Brazos River Authority, "Executive Summary for the 2000 Annual Water Quality Report"

at Richmond, it has been estimated that 85 percent (or about 95 mg/L for the years 1946 to 1986)[14] of the chloride originates from sources in the upper basin.

The study area has been divided for descriptive purposes into four segments for the Brazos River Basin and one segment for the San Jacinto-Brazos Coastal Basin. The Brazos River segments are listed in Table 1-1 along with the river gage or location that defines the downstream limits of each segment. Boundaries of the segments are shown in Figure 1-3. Average annual rainfall ranges from 23.4-inches in the Upper Basin segment to 42.9-inches in the Lower Basin segment. Average rainfall in the San Jacinto-Brazos Coastal Basin is 46.3-inches. Table 1-2 lists the basin segments, annual average precipitation, and average annual runoff. Annual runoff for the entire Brazos River Basin averages about 3.2-inches, or about 11.2 percent of annual precipitation.

Land use in the Brazos River Basin and San Jacinto-Brazos Coastal Basin is predominately related to agriculture with 53.8 percent classified as cropland or pastureland and 30.6 percent as rangeland. Urban land uses comprise only about 0.9 percent of the basin. The cities of Lubbock, Abilene, Waco, Bryan, College Station, and that portion of Houston located in the San Jacinto-Brazos Coastal Basin had an estimated population in 1999 of approximately 582,000 people.

Table 1-1. River Basin Segment Descriptions

Basin Segment	***Downstream Control Point***
Upper Basin	Brazos River at Morris Sheppard Dam near Graford, SHGR26
Upper Middle Basin	Brazos River at Waco, BRWA41 Leon River near Belton, LEBE49
Lower Middle Basin	Brazos River at Hempstead, BRHE68
Lower Basin and Coastal	Brazos River at Gulf of Mexico, BRGM73 San Jacinto-Brazos at Galveston Bay, SJGBC3 San Jacinto-Brazos at Gulf of Mexico, SJGMC4

14 Ganze, C. Keith and Ralph A. Wurbs, "Compilation and Analysis of Monthly Salt Loads and Concentrations in the Brazos River Basin," U.S. Army Corps of Engineers, Contract No. DACW63-88-M-0793, January 1989.

Figure 1-3. Geographic Features Noted in the Text

Table 1-2. Precipitation and Runoff Volume by Basin Segment

Basin Segment	Contributing Drainage Area (sq. miles)	Average Annual Precipitation (inches)	Average Annual Runoff Volume (inches)	Runoff as Percent of Precipitation
Upper Basin	14,030	23.3	1.06	4.5%
Upper Middle Basin	9,519	30.7	3.27	10.7%
Lower Middle Basin	10,765	34.4	5.06	14.7%
Lower (Brazos only)	1,617	42.9	8.92	20.8%
Total Brazos River Basin	35,931	28.6	3.20	11.2%
San Jacinto-Brazos Coastal Basin	1,145	46.3	15.59	33.7%

In the Brazos River Basin, groundwater resources currently supply more than 82 percent of the water used for all purposes with surface water resources supplying the remaining 18 percent. In 1990, total water use in the basin from both groundwater and surface water totaled approximately 3.166 million acft, which represents a decline of 850,584 acft from the 1980 total basin water use. This decline in total water use is attributable to reductions in water use for irrigated agriculture of 927,271 acft, manufacturing of 17,154 acft, and mining of 13,074 acft. Over this same period of time, municipal water use increased by 22,000 acft, steam-electric use increased 75,026, and livestock use increased 10,124 acft. By far the largest water use category for the basin is irrigated agriculture, which accounts for 77 percent of all water used.[15] Irrigated agriculture use is concentrated on the High Plains and is supplied largely from the Ogallala Aquifer.

In the San Jacinto-Brazos Coastal Basin, water used for municipal, industrial, and agricultural purposes totaled about 405,000 acft in 1990. The largest water-using category in the coastal basin is manufacturing with a current use of about 162,000 acft. Other major water use categories include irrigation and municipal use of about 131,000 and 107,000 acft respectively. In 1990, 166,341 acft of water was exported to the San Jacinto-Brazos Coastal Basin and 114 acft was exported to the San Jacinto River Basin from the Brazos River Basin for municipal, industrial, and agricultural irrigation purposes.

[15] Ibid.

The largest reservoir in the Brazos River Basin is Possum Kingdom Reservoir, which is located on the Brazos River in Palo Pinto County. Possum Kingdom Reservoir has an authorized storage capacity of 724,739 acft, and an authorized annual diversion of 230,750 acft/yr. Possum Kingdom Reservoir is owned and operated by the Brazos River Authority, which holds all of the authorized diversion rights in the reservoir. The authorized storage capacity of Possum Kingdom Reservoir is approximately 20 percent of the total combined capacity of all major reservoirs (capacity greater than 10,000 acft) in the Brazos River Basin and the San Jacinto-Brazos Coastal Basin. Table 1-3 lists the major reservoirs in the basins along with this authorized storage capacity and annual diversion amounts. The locations of these reservoirs are shown in Figure 1-4.

The primary provider of water in the Brazos River Basin is the Brazos River Authority (BRA). The BRA operates water and wastewater treatment systems, has programs to assess and protect water quality, does water supply planning and supports water conservation efforts in the Brazos River Basin. BRA provides water from four wholly owned and operated reservoirs in the basin: Lake Alan Henry, Lake Granbury, Possum Kingdom Lake and Lake Limestone. BRA also contracts for conservation storage space in nine U.S. Army Corps of Engineers reservoirs in the basin: Lakes Waco, Proctor, Belton, Stillhouse Hollow, Georgetown, Granger, Somerville, Whitney and Aquilla. The total permitted capacity of these 13 reservoirs in the BRA system is approximately 2.3 million acft. BRA hold rights for diversion in the basin totaling 717,901 acft/yr, and contracts to supply water to municipal, industrial, and agricultural water customers in both the Brazos River Basin and the San Jacinto-Brazos Coastal Basin. Certain rights held by the BRA are also authorized to provide water in the Trinity River Basin.

1.2 Study Objectives

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

Table 1-3. Major Reservoirs in the Brazos River Basin and San Jacinto-Brazos Coastal Basin (Authorized Capacity Greater than 10,000 acft)

Reservoir	Stream	County	Authorized Storage (acft)	Authorized Diversion (acft/yr)	Owner
Abilene	Elm Creek	Taylor	11,868	1,675	City of Abilene
Alan Henry	S. Fork Dbl. Mnt. Fork	Garza	115,937	35,000	Brazos River Authority
Alcoa Lake	Sandy Creek	Milam	15,650	14,000	Aluminum Co. of America
Aquilla	Aquilla Creek	Hill	52,400	13,896	U.S. Army Corps of Engineers
Belton	Leon River	Bell	457,600	100,257	U.S. Army Corps of Engineers
Brazoria	Off-channel	Brazoria	21,700	75,656	Dow Chemical
Bryan Utilities	Unnamed Trib. Brazos River	Brazos	15,227	850	City of Bryan
Cisco	Sandy Creek	Eastland	45,000	2,027	City of Cisco
Cleburne	Nolan Creek	Johnson	25,600	6,000	City of Cleburne
Daniel	Gonzales Creek	Stephens	11,400	2,100	City of Breckenridge
Eagles Nest	Varners Creek	Brazoria	11,315	1,800	T.L. Smith Trust, et al
Fort Phantom Hill	Elm Creek	Jones	73,960	33,190	City of Abilene
Georgetown	North Fork San Gabriel River	Williamson	37,100	13,610	U.S. Army Corps of Engineers
Gibbons Creek	Gibbons Creek	Grimes	32,084	9,740	Texas Municipal Power Agency
Graham/Eddleman	Flint Creek	Young	52,386	20,000	City of Graham
Granbury	Brazos River	Hood	155,000	64,712	Brazos River Authority
Granger	San Gabriel River	Williamson	65,500	19,840	U.S. Army Corps of Engineers
Harris	Off-channel	Brazoria	10,200	230,000	Dow Chemical
Hubbard Creek	Hubbard Creek	Stephens	317,750	56,000	West Central Texas MWD
Leon	Leon River	Eastland	28,000	6,301	Eastland Co. WSD
Limestone	Navasota River	Robertson	225,400	65,074	Brazos River Authority
Millers Creek	Millers Creek	Baylor	30,696	5,000	North Central Texas MWD
Palo Pinto	Palo Pinto Creek	Palo Pinto	44,100	13,480	Palo Pinto MWD
Possum Kingdom	Brazos River	Palo Pinto	724,739	230,750	Brazos River Authority
Post	N. Fork Dbl. Mnt. Fork	Garza	57,420	10,600	White River M.W.D.
Proctor	Leon River	Comanche	59,400	19,658	U.S. Army Corps of Engineers
Smithers	Smithers Creek	Fort Bend	18,750	34,300	Houston L&P Co.
Somerville	Yegua Creek	Washington	160,110	48,000	U.S. Army Corps of Engineers
Squaw Creek	Squaw Creek	Somervell	151,500	23,180	Texas Utilities Electric Co.
Stamford	Paint Creek	Haskell	60,000	10,000	City of Stamford
Stillhouse Hollow	Lampasas River	Bell	235,700	67,768	U.S. Army Corps of Engineers
Tradinghouse	Tradinghouse Creek	McLennan	37,800	15,000	Texas Utilities Electric Co.
Twin Oaks	Duck Creek	Robertson	30,319	13,200	Texas Utilities Electric Co.
Waco Waco Enlargement	Bosque River	McLennan	104,100 87,962	59,100 20,770	U.S. Army Corps of Engineers U.S. Army Corps of Engineers
White River	White River	Crosby	44,897	6,000	White River MWD
Whitney	Brazos River	Hill	50,000	18,336	U.S. Army Corps of Engineers
Totals	—	—	3,678,570	1,366,870	—

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

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

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

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

(j) 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.

(k) 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.

1.3 Study Approach

Available data sources including water rights, historical water use, historical effluent discharges, streamflow, reservoir content, evaporation, precipitation, reservoir storage-capacity relationships and channel losses were compiled from available data sources. Hydrologic and water use data were then utilized to develop estimates of naturalized streamflows at 77 locations (primary control points) within the Brazos River Basin and the San Jacinto-Brazos Coastal Basin. The development of naturalized streamflows is documented in a separate report.[16]

[16] Freese and Nichols, Inc. and HDR Engineering, Inc., "Naturalized Flow Estimates for the Brazos River Basin and the San Jacinto-Brazos Coastal Basin," Texas Natural Resource Conservation Commission, October 2001.

Figure 1-4. Major Reservoirs

The TNRCC water rights database was carefully reviewed and compared to the paper copies of each individual water right held in the subject basins. Corrections to the database were noted and recommended to the TNRCC. The database (with recommended corrections) was utilized to develop a Water Availability Model (WAM) of the Brazos River Basin and the San Jacinto-Brazos Coastal Basin using the Water Rights Analysis Package (WRAP),[17] along with the databases of naturalized streamflows, effluent discharges and reservoir evaporation rates.

Model runs were completed and summarized reflecting eight different scenarios relating to reuse of treated effluent discharges, partial or full cancellation of unused or underutilized water rights, and current levels of use and effluent discharges in the basin. Individual firm yields were also determined for each of 44 large reservoirs in the Brazos River Basin and San Jacinto-Brazos Coastal Basin having authorized storage capacities greater than 5,000 acft.

The following sections of this report document the data compilation and processes used to develop the WAM for the Brazos River Basin and San Jacinto-Brazos Coastal Basin, and present key model output and findings regarding water availability for existing water rights in these basins.

[17] Wurbs, R.A., "Reference and Users Manual for the Water Rights Analysis Package (WRAP)," TR-180, Texas Water Resources Institute, College Station, Texas, July 2001 (model code updated November 2001).

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Section 2
Existing Water Availability Information

2.1 Water Rights

The TNRCC maintains records of all water rights in the Brazos River Basin and the San Jacinto-Brazos Coastal Basin. These water rights are comprised of certificates of adjudication based on the results of 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. All rights conferred by certificates of adjudication will be referred to by their certificate of adjudication numbers and all permits by their final permit numbers assigned by the TNRCC. As a component of this study effort, all water rights have been reviewed and the electronic database provided by the TNRCC has been revised to ensure that it accurately reflects priority date(s), authorized diversion(s), type(s) of use, special conditions, and other provisions associated with each water right.

There are 1,216 water rights in the Brazos River Basin (1,160 rights) and San Jacinto-Brazos Coastal Basin (56 rights) having priority dates senior to February 2, 2000. Authorized annual diversions total almost 3,988,329 acft and annual consumptive use 2,673,592 acft, not counting rights that are saline in nature.[18] Summaries of these water rights, sorted by size of authorized annual diversion, are provided in Table 2-1 (Brazos River Basin) and Table 2-2 (San Jacinto-Brazos Coastal Basin). These rights are sorted by type of use and sub-area location in Table 2-3. An individual water right may be comprised of multiple records in the water rights database, reflecting multiple priority dates, types of use, etc. Table 2-3 shows that there are 1,600 records in the water rights database for the Brazos and San Jacinto-Brazos basins. Figure 2-1 identifies the locations of major water rights authorized to divert and/or consume at least 2,000 acft/yr.

Annual authorized consumptive uses for the major rights shown in Figure 2-1 comprise 88.5 percent of all authorized consumptive uses in the Brazos River Basin and San Jacinto-Brazos Coastal Basin. Municipal and industrial diversion rights represent 78.5 percent of all authorized consumptive uses in the river and coastal basin. The Brazos River Authority holds

[18] Rights that divert primarily saline water are presented in the memorandum that is included as Appendix II.

multiple rights to divert 717,901 acft/yr, or about 34.2 percent of all municipal and consumptive industrial rights in the basins. Multiple industrial users in the lower Brazos and Coastal basins hold rights to consumptively use 620,711 acft/yr, or about 29.6 percent of all municipal and consumptive industrial rights.

Table 2-1. Brazos River Basin Water Rights Summary

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	16	2,991,663	1,679,275
10,000 – 49,999	26	600,190	600,190
2,000 – 9,999	34	131,781	129,933
1,000 – 1,999	20	27,348	27,348
200 – 999	149	65,581	65,128
<200	915	44,513	44,466
Total	1,160	3,861,076	2,546,339

Table 2-2. San Jacinto-Brazos Coastal Basin Water Rights Summary

Range of Permitted Annual Diversions (acft)	Number of Water Rights in Range Category	Total Authorized Annual Diversions (acft)	Total Authorized Annual Consumptive Use (acft)
>50,000	1	57,500	57,500
10,000 – 49,999	2	30,159	30,159
2,000 – 9,999	6	21,427	21,427
1,000 – 1,999	7	10,530	10,530
200 – 999	12	6,488	6,488
<200	28	1,149	1,149
Total	56	127,253	127,253

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Figure 2-1. Major Water Rights

Figure 2-1 here

2.2 Historical Water Use

Records of surface water use as reported by individual water right owners were collected and tabulated by TNRCC staff for the 1915 to 1997 historical period. These records are generally comprised of annual totals for the 1915 to 1954 period and monthly totals for the 1955 to 1997 period. Based on the maximum historical surface water use reported in the Brazos River Basin and San Jacinto-Brazos Coastal Basin over the ten-year period, 1988 through 1997, the sum of the individual maximum annual water uses reported by all rights in the two basins is 1,428,585 acft. This value is the cumulative amount that is used in the maximum use and current conditions scenarios runs of the model. Historically, municipal and industrial uses have been the largest users of surface water in the Brazos River Basin and San Jacinto-Brazos Coastal Basin. Figure 2-2 summarizes historical diversions in the Brazos River Basin. The data shown in Figure 2-2 were accumulated during the stream flow naturalization processes for control points in the Brazos River Basin. Due to differences in methodology, similar historical basin-wide information was not compiled for the San Jacinto-Brazos Coastal Basin.

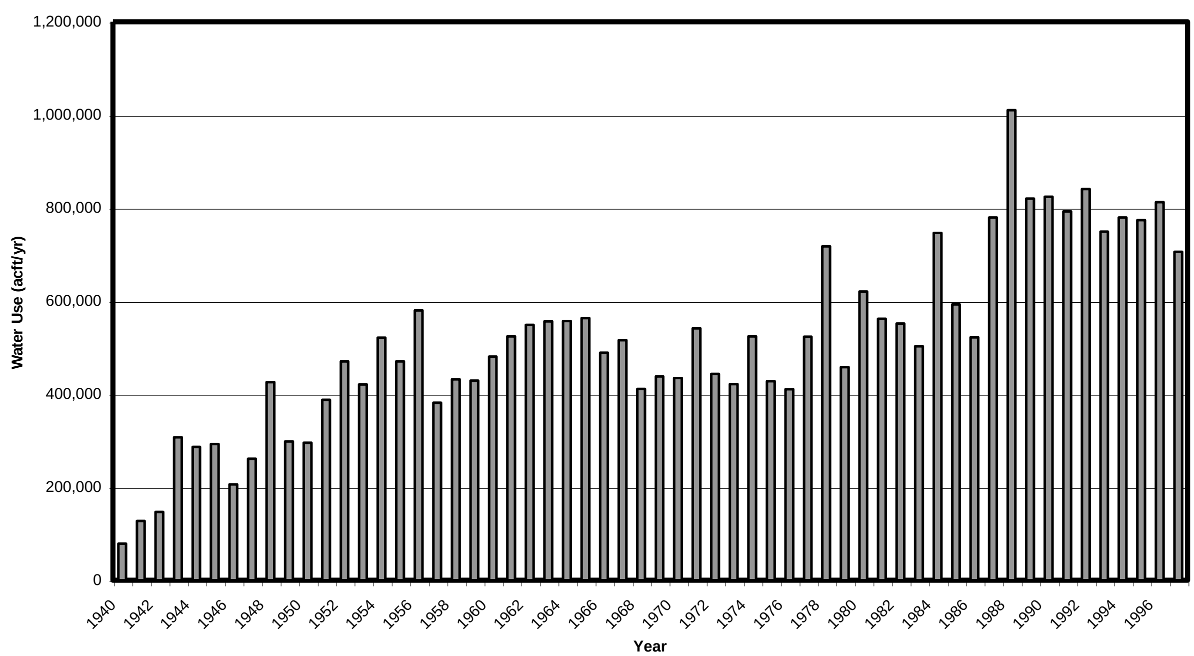

Figure 2-2. Historical Water Use in the Brazos River Basin

2.3 Historical Return Flows and Treated Wastewater Effluent Discharge

The locations of major facilities discharging treated wastewater into receiving streams in the Brazos River Basin and San Jacinto-Brazos Coastal Basin are shown in Figure 2-3. A database of permitted effluent discharges maintained by the TNRCC was used to identify these major treated wastewater discharges. The largest of these facilities, that is not a power plant, is operated by Aluminum Company of America (ALCOA) and is permitted to discharge an aggregate volume in excess of 784 million gallons per day (MGD) for overburden dewatering purposes into East Yegua Creek. (The largest reported discharge from the facility is 21 MGD.) ALCOA also discharges an average of about 11 MGD into East Yegua Creek for groundwater dewatering. Because the groundwater discharged meets water quality standards, a discharge permit is not required by the TNRCC. The next largest permitted industrial discharge is by Houston Industries, Inc. for approximately 100 MGD to be discharged into Big Creek in the lower part of the basin. The largest permitted municipal discharge is operated by the City of Abilene for 22 MGD and is discharged into Deadman Creek. Major and relatively minor municipal and industrial treated wastewater discharges, for which current records are maintained by the TNRCC, are included at appropriate geographical locations in the water availability model. Return flows from irrigation operations are assumed negligible and are not included in the water availability model. The methodology used to incorporate return flows is described in Section 4.2.3.3.

2.4 Previous Water Availability and Planning Studies

Due to the vital importance of surface water to future development in the Brazos River Basin and the San Jacinto-Brazos Coastal 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.

Figure 2-3. Locations of Effluent Discharges Permitted for Greater than 0.9 MGD

Figure 2-3 here

Table 2-3 Water Rights Records Summary for Basin Segments[1] (annual diversion amounts in acft)

Basin Segment	Municipal		Industrial		Irrigation		Mining		Hydroelectric[3]		Recreation		Other		Domestic & Livestock		Total	
	#	Amount	#	Consumptive Amount[2]	#	Amount	#	Amount	#	Amount	#	Amount	#	Amount	#	Amount	#	Amount
Upper Basin	34	166,093	26	24,890	166	65,120	29	29,084	0	0	22	54	7	43	8	21	292	285,306
Upper Middle Basin	40	721,848	21	68,629	628	58,473	12	1,941	2	1,257,530	44	114	4	79	24	30	775	851,115
Lower Middle Basin	30	132,346	35	111,632	226	54,095	10	558	0	0	61	1,318	5	2,119	5	425	372	302,493
Lower Basin	8	223,072	19	592,809	19	236,260	3	54,300	0	0	17	3,227	5	0	1	20	72	1,109,687
Coastal Basin	2	30,000	22	27,902	46	66,348	0	0	0	0	14	601	5	141	0	0	89	124,991
Total	114	1,273,359	123	825,862	1,085	480,296	54	85,883	2	1,257,530	158	5,314	26	2,382	38	496	1,600	2,673,592

Notes:
[1] Summary based on water rights included in the TNRCC database table, WRDETAIL, dated July 7, 2000.
[2] All amounts listed for industrial diversions are only the consumptive portion of the right.
[3] The hydroelectric diversion is 100% non-consumptive.

2.4.1 TNRCC/TWC/TDWR Model Development and Application

The original water availability model (legacy model) of the Brazos River Basin was developed and applied by the staff of the former Texas Department of Water Resources (TDWR). Pertinent data and assumptions are presented, along with summaries of model application results in interim draft reports[19,20] that have never been formally published. Development of the model included extensive hydrologic data collection and analysis resulting in the creation of complete databases of natural streamflow, water rights, net evaporation, and reservoir characteristics. The original computational algorithms used in the model are described by Murthy[21] and written in the Fortran programming language. Application(s) of the model focused primarily on the quantification of water available to large rights and unappropriated streamflow at locations throughout the river basin. Natural streamflows computed by the TDWR are compared to those used in the current water availability in Section 3.1.5.

Significant differences between current (WRAP) model and the existing (Legacy) model are:

- The current model uses a hydrological database (1940 to 1997) some 56 percent longer than the Legacy model (1940 to 1976);
- The current model reflects completion of the adjudication process and changes in water rights between 1982 and mid 2000;
- The current model addresses the effects of channel losses in the translation of changes in streamflow to downstream locations; and
- Naturalized flows in the Legacy model are differentiated into baseflows and runoff, whereas the WRAP model makes no distinction.

2.4.2 Hydrologic and Institutional Water Availability in the Brazos River Basin

In a report[22] by Wurbs, Bergman, Carriere, and Walls, the hydrologic and institutional availability of water in the Brazos River Basin was investigated. The study included a review of: reservoir operation practices and procedures; the legal system for allocating water between users

[19] Texas Department of Water Resources (TDWR), “Interim Report of Water Availability in the Brazos River Basin, Texas,” Draft, July 1981.
[20] TDWR, “Revised Interim Report of Water Availability in the Brazos River Basin, Texas,” Draft, July 1983.
[21] 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.
[22] Wurbs, R.A., Bergman, C.E., Carriere, P.E., and Walls, W.B., “Hydrologic and Institutional Water Availability in the Brazos River Basin,” TR-144, Texas Water Resources Institute, August 1988.

in Texas; surface water management in the Brazos River Basin; and state-of-the-art computer modeling capabilities for evaluating reservoir yield and surface water availability. The simulation modeling analysis of reservoir yield and water simulation study included: compilation, synthesis, and analysis of the input data required for the modeling effort; implementation of selected computer models; organization and execution of simulation runs; and analysis of model results.

The report found that roughly 10 percent of the precipitation falling in the basin becomes streamflow. The report also found that the naturalized streamflow at the Richmond gage averaged 5,670,000 acft/yr over the 1900–1984 simulation period. The Richmond gage was the most downstream control point in the simulation models for which streamflow was input. The naturalized flow at this location represents the total inflow to the modeled stream/reservoir system. The sum of the mean naturalized streamflows at the most downstream dam on the Brazos River and the tributaries was found to be about 60 percent of the mean naturalized flow at the Richmond gage. Thus, about 40 percent of the flow enters the river below the largest reservoirs in the basin.

The report presents firm yields for the 12-reservoir system operated by the Brazos River Authority based alternatively on each reservoir operating individually and with multiple reservoir system operations. System firm yields (diverted at the Richmond gage) are shown excluding and including local flows, which enter the river below the dams. These local flows are intervening runoff that enters streams below the dams and cannot be captured by the dams. The flows can, however, be diverted downstream at the Richmond gage. The firm yields were based on 2010 sediment conditions.

Individual reservoir hydrologic firm yields (not considering senior water rights) totaled 813,000 acft/yr for the 12 reservoirs, which included 29,000 acft/yr, 77,000 acft/yr, and 707,000 acft/yr for Lake Whitney, Lake Waco, and the other ten reservoirs respectively. System firm yields were computed based on the 10 reservoirs (Lakes Whitney and Waco were excluded because they are committed to local uses) making coordinated releases for a diversion at the Richmond gage. By diverting only flows released by the system reservoirs and not diverting any intervening runoff between the dams and the Richmond gage, the 10 reservoir system firm yield was found to be 1,066,000 acft/yr or 151 percent of the sum of the individual reservoir firm yields. Including downstream local flows below the dams, the 10-reservoir system firm yield was found to be 1,474,000 acft/yr or 208 percent of the sum of the individual reservoir firm yields.

Individual reservoir firm yields constrained by senior water rights total 548,000 acft/yr for the 10 reservoirs. The corresponding 10 reservoir system firm yields were found to be 649,000 acft/yr and 845,000 acft/yr, respectively, excluding and including downstream unappropriated flows, or 118 percent and 154 percent of the sum of the individual reservoir firm yields. Individual reservoir firm yields computed considering senior water rights were 77 percent of the hydrologic firm yields for the 12 reservoirs. The system firm yield for the 10-reservoir system, considering senior water rights, was found to be 61 percent and 57 percent of the hydrologic system firm yield, excluding and including downstream intervening flows, respectively. Thus, honoring senior water rights significantly decreases firm yields, and system operations significantly increase firm yields.

2.4.3 Natural Salt Pollution and Water Supply Reliability in the Brazos River Basin

In a report[23] by Wurbs, Karama, Saleh, and Ganze, salinity considerations are incorporated in evaluating water availability. Water supply reliability estimates are demonstrated to be highly sensitive to specified allowable salt concentrations.

The generalized RESSALT river/reservoir system simulation model was developed in conjunction with the study. RESSALT simulated river basin system capabilities for meeting specified water use requirements during as assumed repetition of historical hydrology. The Brazos River Basin hydrology is represented by monthly streamflows, salt loads, and reservoir evaporation rates at selected locations covering a 1900–1984 simulation period. Two alternative approaches were adopted for representing water use in the modeling and analysis exercises: (1) water use scenarios consisting of simplified representations of actual historical water use during the year 1984 and projected water use for the year 2010; and (2) the traditional concept of hypothetical yields. Numerous simulations were performed to evaluate the effects of alternative management strategies and modeling assumptions.

The high salinity in the three main stem (Possum Kingdom, Granbury and Whitney) reservoirs almost always precludes lakeside withdrawals when maximum allowable salt

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[23] Wurbs, R.A., Karama, A.S., Saleh, I., and Ganze, K.G., "Natural Salt Pollution and Water Supply Reliability in the Brazos River Basin," TR-160, Texas Water Resources Institute, August 1993.

concentrations are specified in the model at essentially any reasonable level. Salinity is not a controlling factor for diversions on the better quality tributaries. Diversions from the lower reaches of the Brazos River represent a large portion of the total amount of water withdrawn from the main stream and tributaries for beneficial use. These downstream diversions are very sensitive to the level of maximum allowable salt concentrations specified in the model.

Although shortages occur at isolated upstream locations, the simulation modeling study indicates that, from a basin wide perspective, meeting the demands of the 1984 water use scenario, during an assumed repetition of historical period-of-record hydrology, is well within the water supply capabilities of the river/reservoir system if salinity is not considered. However, adopting maximum allowable TDS, chloride, and sulfate concentration limits of 500 mg/l, 250 mg/l, and 250 mg/l, respectively, for all uses, greatly reduces water supply reliabilities. With the 1984 water use scenario, hypothetically specifying these fairly stringent allowable salt concentration criteria reduces the overall system reliability from about 99.8 percent to 69.6 percent. The 2010 water use scenario results in significant shortages even without salt constraints and specifying allowable salt concentrations significantly lowers the reliabilities. Overall system reliabilities for the year 2010 water use scenario are 95.9 percent and 61.5 percent, respectively, with and without designation of allowable TDS, chloride, and sulfate concentrations of 500 mg/l, 250 mg/l, and 250 mg/l.

Relationships between yield, allowable salt concentrations, and reliability were developed for a hypothetical diversion target at the Richmond gage, in the lower basin, met by streamflows supplemented by releases from nine reservoirs. With no maximum allowable salt concentration limits specified, the firm yield is about 2,200 cfs. However, specifying a maximum allowable TDS concentration of 1,000 mg/L reduces the firm (100 percent reliability) yield to zero. It is interesting to note that lower salt concentrations caused by less reservoir evaporation result in a yield of 2,000 cfs having a greater reliability than a minimal yield of 100 cfs. Thus, as relatively stringent salt constraints are incorporated into the analysis, water supply reliabilities are controlled more by water quality than volume availability. For example, with the 1,000 mg/l TDS constraint, a minimal yield of 100 cfs has a reliability of about 90 percent, and a yield of 2,000 cfs has a reliability of about 96 percent. With a maximum allowable TDS concentration of 500 mg/l, yields of 100 cfs and 2,000 cfs have reliabilities of 67 percent and 74 percent, respectively.

Consideration of water quality as well as quantity is important in evaluating water supply reliability in the Brazos River Basin. For municipal, irrigation, and other salinity-sensitive uses, quality rather than quantity is the limiting factor controlling water availability. Water supply reliability depends upon the (1) allocation of water between types of use, (2) allowable salt concentrations reflecting the sensitivity of the water uses and users to salinity, and (3) location of diversions and reservoir releases.

2.4.4 SB1 Regional Water Planning

Several of the regional water planning groups instituted by Senate Bill 1 (SB1) are located wholly or partially within counties within the Brazos River Basin and the San Jacinto-Brazos Coastal Basin. By far, the most significant to this study are the Llano Estacado (Region O), Brazos G and Region H regional water planning groups, all of which are located primarily in the Brazos River Basin or the San Jacinto-Brazos Coastal Basin. Regions B, C and F are located adjacent to the Brazos River Basin and have limited significance within the basin.

2.4.4.1 Llano Estacado Regional Water Plan

The Llano Estacado Regional Water Plan (Region O)[24] provided water supply plans for 16 counties located in whole or partially within the Brazos River Basin. The counties located in the Brazos River Basin portion of the Llano Estacado region are:

1. Bailey
2. Castro
3. Cochran
4. Crosby
5. Dawson
6. Dickens
7. Floyd
8. Garza
9. Hale
10. Hockley
11. Lamb
12. Lubbock
13. Lynn
14. Parmer
15. Swisher
16. Terry

The population of the Brazos River Basin portion of these counties is projected to increase from 374,593 in 2000 to 458,420 in 2050, an increase of 22.4 percent. This compares to projected statewide population growth during the same period of 81.3 percent. Most of this growth is concentrated in Hale and Lubbock counties.

[24] HDR Engineering, Inc., "Llano Estacado Regional Water Planning Area – Regional Water Plan," High Plains Underground Water Conservation District No. 1, January 2001.

Water demand projections were compiled for each type of consumptive water use: municipal, manufacturing, steam-electric, mining, irrigation, and livestock. Total water use in the Brazos River Basin area of the Llano Estacado Region is projected to decrease from 1,939,253 acft in 2000 to 1,690,102 acft in 2050, a 12.5 percent decrease. Municipal, manufacturing, steam-electric, and livestock water use as a percentage of the total water use increases from 2000 to 2050, while mining and irrigation water use decrease as a percentage of the total.

As part of the regional water planning effort, the available supplies to each city and use category within each county were compared to the projected demand to determine projected needs within the planning region. The comparison of supply and demand for all use categories would show a deficit of about 183,000 acft in the Brazos River Basin for the year 2050. Much of this shortage can be attributed to projected deficits for irrigation water use within the Llano Estacado Region.

The regional water planning process also included identifying water management options and strategies through public input to meet each of the projected needs of the region. Water management strategies included in the plan to meet the projected needs include drilling additional municipal water supply wells and constructing a pipeline from Hartley County to deliver additional groundwater to the Region.

2.4.4.2 Brazos G Regional Water Plan

At the completion of the first round of Senate Bill 1 (SB1) regional water planning, the Brazos G Region prepared a report,[25] which provided water supply plans for 37 counties located in whole or partially within the Brazos River Basin. The counties included in the Brazos G planning area are:

1. Bell
2. Bosque
3. Brazos
4. Burleson
5. Callahan
6. Comanche
7. Coryell
8. Eastland
9. Erath
10. Falls
11. Fisher
12. Grimes
13. Hamilton
14. Haskell
15. Hill
16. Hood
17. Johnson
18. Jones
19. Kent
20. Knox
21. Lampasas
22. Lee
23. Limestone
24. McLennan
25. Milam
26. Nolan
27. Palo Pinto
28. Robertson
29. Shackleford
30. Somervell
31. Stephens
32. Stonewall
33. Taylor
34. Throckmorton
35. Washington
36. Williamson
37. Young

In July of 1998, the TWDB published population and water demand projections[26] for each county in the state. In the Brazos G Region, population projections were developed for 133 cities and Census-Designated Place names (CDP) with a population greater than 500. To account for people living outside the cities, projections were also developed for a 'county-other' category for each county. The population of the 37-county region is projected to increase from 1,671,446 in 2000 to 3,095,273 in 2050, an increase of 85.2 percent (1.24 percent annual growth). This compares to projected statewide population growth during the same period of 81.3 percent (1.20 percent annually). In 2050, it is projected that 24 percent of the Brazos G

[25] HDR Engineering, Inc. (HDR), "Brazos G Regional Water Planning Area – Regional Water Plan," Vols. I, II, and III, Brazos River Authority, January 2001.
[26] The population and water demand projections were developed in consultation with the Texas Parks and Wildlife Department and Texas Natural Resource Conservation Commission. The completed projections are referred to as the 1997 Consensus Population and Water Demand Projections.

Region will live in Williamson County, 13 percent in Bell County, 11 percent in McLennan County, 9 percent in Brazos County, 8 percent in Johnson County, 7 percent in Taylor County, 6 percent in Coryell County, and less than 6 percent in each of the remaining counties.

Growth is concentrated along the I-35 corridor, stretching from Williamson County in the south to Johnson County in the north. Growth is also taking place along US Highway 183 in Williamson and Lampasas Counties, Taylor and Jones Counties (Abilene area), and Brazos County (Bryan/College Station area).

Water demand projections were compiled for each type of consumptive water use: municipal, manufacturing, steam-electric, mining, irrigation, and livestock. (Note: Projections for non-consumptive water uses, such as navigation, hydroelectric generation, and recreation, were not presented.) Total water use for the region is projected to increase from 725,766 acft in 2000 to 1,034,262 acft in 2050, a 42.5 percent increase. Municipal, manufacturing, and steam-electric water use as percentages of the total water use increase from 2000 to 2050, while mining, irrigation, and livestock water use decrease as percentages of the total.

As part of the regional water planning effort, the available supplies to each city and use category within each county were compared to the projected demands to determine projected needs within the planning region. The comparison of supply and demand for all use categories in the region would show a surplus of about 500,000 acft in the year 2050. However, much of this surplus is attributable to supplies available from the Carrizo-Wilcox Aquifer. This regional comparison masks shortages that are projected to occur to individual water supply entities and water user groups. Even in counties that have projected surpluses, there are entities that do not have sufficient supply to meet projected needs. There are 30 counties with a projected shortage in at least one of the water use types. There are seven counties with no shortages in any water use category: (1) Burleson, (2) Falls, (3) Grimes, (4) Hamilton, (5) Kent, (6) Stonewall, and (7) Washington.

The regional water planning process also included identifying water management options and strategies through public input to meet each of the projected needs of the region. Water management strategies included in the plan to meet the projected needs include voluntary redistribution, new main-stem and off-channel reservoirs, additional water purchase agreements, additional groundwater development, and wastewater reuse.

2.4.4.3 Region H Regional Water Plan

The Region H Water Plan[27] provided water supply plans for eight counties located in whole or partially within the Brazos River Basin or the San Jacinto-Brazos Coastal Basin. The counties located in these areas are:

1. Austin
2. Brazoria
3. Fort Bend
4. Galveston
5. Harris
6. Leon
7. Madison
8. Waller

The population of the Brazos River Basin and/or San Jacinto-Brazos Coastal Basin portion of these counties is projected to increase from 1,049,992 in 2000 to 2,559,634 in 2050, an increase of 144 percent. This compares to projected statewide population growth during the same period of 81.3 percent. Most of this growth is concentrated in Brazoria and Harris counties.

Water demand projections were compiled for each type of consumptive water use: municipal, manufacturing, steam-electric, mining, irrigation, and livestock. Total water use in the Brazos River Basin and San Jacinto-Brazos Coastal Basin areas of Region H is projected to increase from 801,335 acft in 2000 to 1,171,253 acft in 2050, a 46.2 percent increase. Municipal and steam-electric water use as a percentage of the total water use increases from 2000 to 2050, while manufacturing, mining, irrigation, and livestock water use decrease as a percentage of the total.

As part of the regional water planning effort, the available supplies to each city and use category within each county were compared to the projected demand to determine projected needs within the planning region. The comparison of supply and demand for all use categories would show a deficit of about 350,000 acft in the Brazos River Basin and San Jacinto-Brazos Coastal Basin for the year 2050. Much of this shortage can be attributed to projected deficits for manufacturing in Brazoria and Harris Counties.

The regional water planning process also included identifying water management options and strategies through public input to meet each of the projected needs of the region. Water

[27] Brown & Root, Inc. and Turner Collie & Braden, Inc., "Region H Regional Water Plan," San Jacinto River Authority, January 2001.

management strategies included in the plan to meet the projected needs include additional municipal conservation, renewal of existing contracts, and the Allens Creek (Permit 2925) and Little River Reservoirs.

2.4.4.4 Regional Water Plans for Regions B, C and F [28]

Although the assessment of current water supplies in Region B assumes that the water quality will continue to be acceptable for current uses, future changes in allowable standards could curtail some of these supplies. Unless water-quality standards prevent use of some current available supplies, all municipal water user groups are expected to have sufficient water supplies to meet drought-of-record conditions if one or a combination of recommended strategies is implemented. Thirteen groundwater-supplied water systems in Region B are not compliant with Primary Drinking Water Quality Standards, Lake Arrowhead may contain arsenic levels above the allowed limit, and salinity in Lake Kemp and Diversion Lake are three major concerns when these water supply sources are considered.

The Region C plan recommends water management strategies to meet all municipal needs by 2050. Most water supplied in Region C is provided by five major water providers in the region: Dallas Water Utilities, Tarrant Regional Water District, North Texas Municipal Water District, Fort Worth Utilities, and the Trinity River Authority. Consequently most municipal needs will be met by one of these providers. The significant regional needs result primarily from a large and expanding population base. In 1998 the region included 38 communities having 20,000 or more in population. The region has 12 of the 20 fastest-growing communities in Texas.

The Region F plan meets all projected municipal needs during the planning horizon. For many of the water user groups, existing supplies in the region could be developed further to meet needs. In addition, irrigation (the largest water user in the region) also lacks a readily expandable supply source to meet future needs. Municipal needs include the cities of Midland and San Angelo and cities that rely on the Hickory Aquifer.

[28] Texas Water Development Board, "Final Draft State Water Plan – Water for Texas – 2002," December 2001.

2.4.5 Trans-Texas Water Program

The predecessor to the SB1 process was the Trans-Texas Water Program which was initiated by the TWDB in 1992 in an effort to address the water supply needs of four water short areas of Texas (Travis and Williamson Counties, San Antonio/Edwards Aquifer Area, Corpus Christi Area, and the Houston Metropolitan Area) in a coordinated, logical, and environmentally responsible manner. The North-Central Trans-Texas study area report[29] included Travis, Williamson, and a small portion of northeastern Hays Counties. As part of the Trans-Texas Water Program, population and water demand projections were prepared for each study area. These water demand projections were then compared against existed supplies to determine those entities with projected needs.

The North-Central Trans-Texas study area identified a total of 18 primary water supply alternatives located in both the Brazos River Basin and the Colorado River Basin to meet the needs identified in the report. Those alternatives which would effect water supply in the Brazos River Basin include: (1) Purchase of water from the BRA at Lake Stillhouse Hollow with delivery to Lake Georgetown; (2) Purchase of water from the BRA at Lake Granger with delivery to Lake Georgetown; (3) Water availability from Little River or Brushy Creek; (4) South Fork Reservoir; (5) Use of Carrizo-Wilcox Aquifer to augment the yield of Lake Georgetown; (6) Purchase and transfer of yield from Lake Somerville to the Colorado River; and (7) System operation of Lake Stillhouse Hollow and Lake Travis.

2.4.6 U.S. Study Commission Report

In a report[30] completed by the U.S. Study Commission in 1962, the water resources of the Brazos River Basin were studied and recommendations made to ensure an adequate water supply in the future. The recommended plan for development of additional water resources in the Brazos River Basin contained with the plan included the construction of 18 new major reservoirs, including Millers Creek, Turkey Creek, Aquilla, Stillhouse Hollow, Somerville, and Allens Creek. The recommended plan also included 805 floodwater-retarding structures and 167 miles of stream-channel improvements for upstream flood protection. In addition to these

[29] HDR Engineering, Inc. (HDR), "North Central Study Area – Phase II Report," Volume II, Brazos River Authority, et al., February 1998.
[30] U.S. Study Commission, "The Report of the U.S. Study Commission – Texas," Part 1 – The Commission Plan, March 1962.

recommendations, the plan recognized the ultimate need for a saltwater barrier on the lower Brazos River to permit maximum utilization of the basin resources and to eliminate saltwater intrusion.

The study estimated that approximately 12 percent of the municipal and industrial water demand in 2010 will be met from groundwater sources, while the remaining 88 percent of the projected demand will be met from surface water sources. Most of the surface water supplies were projected to be from in-basin sources, although limited supplies from inter-basin diversions were projected to be used to meet projected demands in the lower basin area. The study also found that of the existing reservoirs with capacities greater than 5,000 acft, 11 of those reservoirs, including off-channel storage developments, would not produce a dependable yield throughout a recurrence of the 1950–1957 drought period. These projects, with a total conservation storage of about 124,000 acft, are Lake Mineral Wells, Lake Lytle, William Harris Reservoir, Lake Daniel, Eagle Nest Lake, Manor Lake, Smithers Lake, Camp Creek Lake, Lake Creek Steam Electric Station, Alcoa Lake, and Brazoria Reservoir.

The study projected a diversion in 2010 of 682,700 acft annually for irrigation use. Return flows from this irrigation, which could be used for downstream water supplies, was projected to total 107,000 acft annually. In 2010, the total irrigation from groundwater in the Brazos River Basin was projected to be only about 80,000 acres, with approximately 75 percent of this amount, or 60,000 acres, being in the central portion of the basin from Waco to Hempstead and in the lower portion of the basin. The study found that if present irrigation use persists (irrigation use in the early 1960's), depletion of the groundwater supply would cause farmers in the High Plains portion of the Brazos River Basin to revert to dry land farming by 2010.

2.5 Significant Considerations Affecting Water Availability in the Basins

2.5.1 Brazos River Authority System Operation

The Brazos River Authority (BRA), with 14 individual water rights, is the most significant single water right holder in the Brazos Basin. Table 2-4 summarizes pertinent information regarding these rights. The BRA rights are located throughout the basin, ranging from Lake Alan Henry in Garza County to direct diversions from the Brazos River in Fort Bend County. There are 12 priority rights with a total authorized diversion of 696,901 acft/yr, or about

18 percent of the total authorized diversions in the basin, and a total authorized storage of 2,338,886 acft, or about 60 percent of the authorized storage in the basin. Certificate of Adjudication 5167 authorizes the re-diversion and interbasin transfer of water released from upstream system reservoirs to the San Jacinto-Brazos Coastal Basin. Certificate of Adjudication 5166 authorizes diversion and use of excess stream flows on a non-priority basis. Each of the 14 water rights contains special provisions that allow BRA to operate its supplies in a coordinated way to help increase the reliability and quality of its supplies.

At the request of TNRCC, provisions in the BRA water rights that authorize diversion of excess flows (Certificate of Adjudication 5166) and overdrafting of system reservoirs were not modeled in the current study. These provisions do not increase BRA's cumulative authorized diversions. However, they do increase the flexibility and overall reliability of BRA's supply to its customers, allowing BRA to use reservoirs with relatively greater volumes of water in dry times, reducing reservoir drawdowns and enhancing recreational opportunities, as well as allowing BRA to maximize use of the better quality water in their system (see Section 2.5.3).

Diversion of excess flows from the Brazos River is authorized by Certificate of Adjudication 5166, which has diversion locations in Austin and Fort Bend Counties. BRA may divert up to 650,000 acft/year of the flows of the Brazos River originating below the BRA reservoirs as long as flows at the Richmond gage exceed 1,100 cfs (there are provisions for a lower flow rate with the agreement of downstream water rights holders, but the flow at Richmond must not be less than 650 cfs). Water diverted under this water right must be accounted for as part of the total authorized diversions of the 12 priority water rights, although there is no corresponding release of water stored in these reservoirs. This water right does not increase the total amount of water that BRA is authorized to divert (the total diversion by the BRA must never exceed the sum of the diversions authorized by the 12 priority rights). However, it increases the reliability of the BRA system by reducing demands on upstream reservoirs and channel losses associated with delivering water from upstream reservoirs. This, in turn, keeps reservoir levels higher, thereby enhancing recreational aspects.

With the exception of Lake Alan Henry, each system reservoir water right has a special provision that allows for diversion of water in excess of the reservoir's permitted diversion, also known as overdrafting the reservoir. BRA system reservoirs may be overdrafted as long as the total permitted diversion authorized for the BRA system is not exceeded. Each water right has a specified maximum amount of overdraft. The maximum diversions are in Table 2-4 under the column heading 'System Operation Diversion.' Overdrafting gives BRA a great deal of flexibility in providing a reliable, good quality water supply to their customers. For example, if a reservoir in the BRA system is experiencing a period of higher than average inflows, BRA can increase diversions of water from that reservoir beyond the priority diversion, leaving water in storage in other reservoirs that are not experiencing similarly high inflows.

Lake Alan Henry (Permit 4146) is a relatively new addition to the BRA system and has water right provisions that are different than the other reservoirs. Diversions from Lake Alan Henry are not counted as part of the overall system diversion described in the preceding paragraphs. However, like other system reservoirs, Lake Alan Henry may be overdrafted. The authorized diversion is more than the estimated firm yield of the reservoir. The water right was designed so that this source of water could be used in a coordinated way with other supply sources, allowing for diversions greater than the yield of the reservoir during relatively wet periods. A corresponding reduction during dry periods is implied but is not specified in the water right. Lake Alan Henry is modeled at its full-authorized diversion in this study.

2.5.2 Water Quality

Salinity is a major factor in water supply in the Brazos Basin. The upper portion of the basin is impacted by highly saline inflows from both natural and man-made sources. As a result, the water in Possum Kingdom Lake, Lake Granbury, and Lake Whitney is not suitable for municipal purposes without advanced treatment. In the lower potion of the basin, a salt-water wedge from the Gulf of Mexico can encroach 40 miles or more upstream during low-flow periods. Water may be released from upstream reservoirs to control salt-water encroachment, but this tends to reduce the reliability of supplies from these upstream reservoirs.

2.5.3 Revised Storage Capacities of Major Reservoirs

Recent reservoir sedimentation surveys have revealed that the actual storage capacities of several major reservoirs (authorized capacity greater than 10,000 acft) are substantially different from the published "as-built" capacities. The as-built capacities typically form the basis for the authorized capacities. For example, Lake Palo Pinto has an authorized capacity of 44,100 acft. However, a volumetric survey conducted in 1985 by HDR determined the capacity to be

27,650 acft.[31] An unpublished survey by the Texas Water Development Board verified the results of the 1985 survey. These differences are usually due to limited accuracy of the data that are available at the time of reservoir construction. Storage capacities substantially different from permitted capacities will have an impact on actual reliable supply from the reservoirs, as compared to the theoretical supplies calculated during this study.

Table 2-4. Summary of Brazos River Authority Water Rights

Water Right ID	Stream	Priority Diversion (acft/yr)	System Operation Diversion (acft/yr)	Authorized Impoundment (acft)	Priority Date	Remarks
P4146	S Frk Dbl Mtn Frk	56,000[1]		115,937	5-Oct-81	Lake Alan Henry
C5155	Brazos River	230,750	724,800	724,739	6-Apr-38	Possum Kingdom Lake
C5156	Brazos River	64,712	100,000	155,000	13-Feb-64	Lake Granbury
C5157	Brazos River	18,336	50,000	50,000 [2]	30-Aug-82	Lake Whitney
C5158	Aquilla Crk	13,896	35,400	52,400	25-Oct-76	Lake Aquilla
C5159	Leon River	19,658	54,000	59,400	16-Dec-63	Lake Proctor
C5160	Leon River	100,257	395,000	457,600	16-Dec-63	Lake Belton
C5161	Lampasas River	67,768	222,000	235,700	16-Dec-63	Stillhouse Hollow Reservoir
C5162	N Frk San Gabriel River	13,610	37,100	37,100	12-Feb-68	Lake Georgetown
C5163	San Gabriel River	19,840	65,500	65,500	12-Feb-68	Lake Granger
C5164	Yegua Crk	48,000	150,000	160,110	16-Dec-63	Lake Somerville
C5165	Navasota	65,074	217,500	225,400	6-May-74	Lake Limestone
C5166	Brazos River		650,000			Excess Flows
C5167	Brazos River		200,000			Transbasin to San Jacinto – Brazos

[1] Includes secondary use of 21,000 acft/yr of treated effluent which is not included in the model.
[2] Authorized water supply storage in Lake Whitney between the elevations of 520 and 533 msl. Lake Whitney has a total storage volume of 627,100 acft.

[31] HDR Engineering, Inc., "Yield Studies of Lake Palo Pinto and Turkey Peak Reservoir Site," 1986.

2.5.4 Hydropower Generation at Lake Whitney

The United States Army Corps of Engineers owns and operates Lake Whitney. One of the federally authorized purposes of Lake Whitney is hydropower generation. However, there is no corresponding State of Texas water right for the hydropower generation. Because hydropower generation at Lake Whitney is not a specific authorization within the certificate, hydropower releases from Lake Whitney are not included in the model, although hydropower releases occur most of the time that the lake is within its power generation pool. Not including hydropower releases probably will have little impact on senior downstream water rights because the WRAP model inherently protects these rights. It also is not desirable to assess water availability for downstream rights that is based on hydropower releases from upstream reservoirs. In actual practice, however, hydropower releases would be available to downstream users, possibly increasing the reliability of downstream rights.

2.6 Estuary Freshwater Inflow

Unlike most estuaries in Texas, the Brazos River estuary is a riverine estuary and does not include a large bay behind a barrier island system. Open water and wetland areas are small and most of the water in the riverine estuary is fresh water. Data on fisheries harvest in the Brazos estuary are not reported separately, and the estuary is not part of the freshwater inflow studies sponsored by the Texas Water Development Board.[32]

Streams in the San Jacinto-Brazos Coastal Basin flow directly into the Gulf of Mexico, into small estuaries, or into the Galveston Bay estuary. However, most of the surface water used in the San Jacinto-Brazos Coastal Basin originates in the Brazos Basin. Return flows from irrigated agriculture and municipal use of Brazos River water contribute a portion of the freshwater inflows into these estuaries. Flows into Galveston Bay from the San Jacinto-Brazos Coastal Basin represent only about 10 percent of the total flow to Galveston Bay.[33]

2.7 Groundwater / Surface Water Interaction

Interactions between groundwater and surface water can occur over a wide spatial extent as water seeps between a river channel and an underlying aquifer system, and as water is

[32] Freese and Nichols, Inc. and Brown and Root, Inc., "Report on Allens Creek Reservoir Supporting an Application to Amend Permit 2925," prepared for the Brazos River Authority and others, May 2000.
[33] Longley, W. (ed.), "Freshwater Inflows to Texas Bays and Estuaries," Texas Water Development Board, 1994.

discharged from springs. Defining these interactions requires historical knowledge of aquifer levels and how changes in aquifer levels affect recharge to or discharge from an aquifer system. The effects of historical recharge and groundwater development on surface water flows are reflected in gage records, and are therefore reflected in the naturalized flow records developed for a water availability model. When these effects are small or unknown, or when pumpage patterns have not changed substantially over time, no adjustment to the gage records is warranted to remove the effects of groundwater development on streamflows.

Except for the Ogallala Aquifer, groundwater development in the Brazos River Basin has not been extensive, and its effects on streamflows have not been documented other than to the extent channel losses consider these interactions. Groundwater development is more extensive in the San Jacinto-Brazos Coastal Basin, but data on the impact of groundwater development on surface water flows in this basin are also not available. More detailed information is available in other basins (such as the Guadalupe-San Antonio River Basin[34]) regarding the interactions between ground and surface water, and adjustments of gaged or naturalized flows can be made in these basins to account for the effects of groundwater development. Because a sufficient level of detailed information is not available, the interaction of ground and surface water was not evaluated or included in the model other than for discharges of treated effluent originating from groundwater sources, as previously discussed. Groundwater development is not expected to have a major impact on water availability in either basin.

Channel losses are significant throughout the basin. At least part of channel losses may be attributed to groundwater/surface water interaction, although there are other factors that contribute as well. Adjustments for channel losses have been made in the current study and are discussed more thoroughly in Section 3.1.3 and Appendix VIII. Because the BRA uses the bed and banks of the Brazos River and its tributaries to deliver water to customers many miles downstream, channel losses during delivery have an impact on the actual amount of water available to many of its contractual commitments.

[34] HDR Engineering, Inc., "Water Availability in the Guadalupe-San Antonio River Basin," Texas Natural Resource Conservation Commission, December 1999.

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Section 3
Hydrologic Data Refinement

3.1 Naturalized Streamflow at Gaged Locations

The compilation of accurate estimates of historical naturalized streamflow is a key prerequisite to the development of a useful model of the Brazos River Basin and San Jacinto-Brazos Coastal Basin. Naturalized streamflow is defined as that which would have occurred historically, exclusive of human influences. Development of the naturalized streamflows used in the Brazos River Basin and San Jacinto-Brazos Coastal Basin water availability model is documented in detail in a separate report prepared by Freese and Nichols and HDR[35] for the TNRCC. The following summarizes the development of naturalized streamflows for the primary control points included in the Brazos River Basin and San Jacinto-Brazos Coastal Basin water availability model.

3.1.1 Streamflow Naturalization Methodology

Monthly naturalized streamflows for the 1940 to 1997 period were developed by adjusting gaged streamflows for the effects of historical water supply diversions, municipal and industrial return flows, and reservoir operations. Translation of the effects of upstream diversions, return flows and reservoir operations to downstream locations was accomplished using delivery factors (1 minus channel loss) representative of typical channel loss rates in each intervening reach. Derivation of delivery factors is described in Section 3.1.3.

The streamflow naturalization methodology applied in this study is summarized in schematic and equation form in Figure 3-1. Historical monthly diversions made by each individual water right, as well as return flows, were grouped by subwatersheds between primary control points, which were generally the locations of long-term U.S. Geological Survey (USGS) stream flow gaging stations. The naturalized flow at the downstream end of a headwater subwatershed, such as Subwatershed 1 shown in Figure 3-1, is calculated by adding the historical diversions, reservoir evaporation and changes in reservoir content that occurred upstream of Control Point 1 (CP1) to the gaged streamflow at CP1, and subtracting the historical return flows. Naturalized flow at the downstream end of Subwatershed 2 (CP2) is equal to the gaged

[35] Freese and Nichols, Inc. (F&N) and HDR Engineering, Inc. (HDR), "Naturalized Flow Estimates for the Brazos River Basin and the San Jacinto-Brazos Coastal Basin," Texas Natural Resource Conservation Commission, October 2001.

streamflow adjusted for intervening diversions, reservoir operations and return flows that occurred in Subwatershed 2 plus the portion of the change in flow (from gaged to natural) at CP1 that arrives at CP2. The change in flow that arrives at CP2 is the total change in flow at CP1, multiplied by the delivery factor between the two control points. In like manner, streamflows were naturalized at consecutive control points moving from upstream to downstream through the entire river basin.

$$QN_1 = QG_1 + D_1 + E_1 + \Delta S - R_1$$

$$QN_2 = QG_2 + D_2 + E_2 + \Delta S_2 - R_2 + a_2(QN_1 - QG_1)$$

$$QN_3 = QG_3 + D_3 + E_3 + \Delta S_3 - R_3 + a_3(QN_2 - QG_2)$$

where:
QN = Naturalized Sreamflow
QG = Gaged Streamflow
D = Reported Diversions
E = Evaporation from Reservoir
ΔS = Change in Reservoir Storage
R = Return Flows
a = Delivery Factor

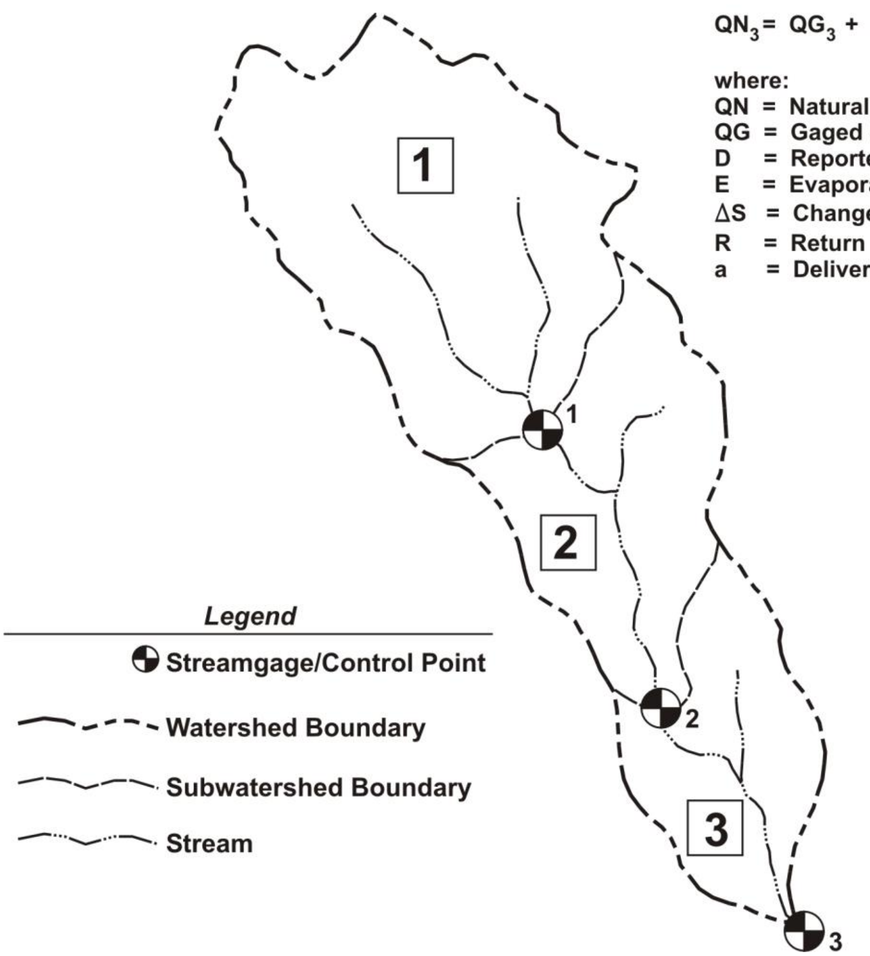

Figure 3-1. Streamflow Naturalization Methodology

The incorporation of channel losses into the streamflow naturalization methodology applied in this study was originally developed by HDR in the performance of a regional water supply planning study of the Nueces River Basin[36] and is different from the more traditional methodology incorporated in previous naturalized streamflow databases and river basin models.[37,38,39] Traditionally, successive downstream gaged streamflows were adjusted for historical upstream diversions and return flows on a one-to-one basis to obtain naturalized streamflows, thereby neglecting the fact that channel losses reduce the effects of diversions as diversions are translated downstream. Simply stated, diversion of 1 acft of streamflow in the headwaters of the basin does not reduce inflow to the Gulf of Mexico by 1 acft. Application of traditional methodology generally results in higher estimates of naturalized flow. Potential errors resulting from this traditional technique were mitigated, in part, by the one-to-one adjustment of naturalized flows to account for full water rights diversions and applicable return flows in the evaluation of water available for appropriation. However, if full water rights use significantly exceeds historical water use (which is often the case), application of the traditional methodology can significantly underestimate both water availability and remaining downstream flows during the simulation process. Accounting for channel losses more accurately reflects the natural physical processes that affect streamflows throughout the basin. Channel loss factors applied in this study are presented in Section 3.1.3.

3.1.2 Streamflow Data Sources

3.1.2.1 Streamflows

Records of streamflow in the Brazos River Basin and the San Jacinto-Brazos Coastal Basin have been collected at numerous streamflow gaging stations maintained by the USGS. Figure 3-2 indicates the location of all 77 primary control points, of which only five are not at USGS streamflow gages: BSLU7 (Buffalo Springs Lake near Lubbock), GHGH24 (Lake Graham near Graham), BRGM73 (Brazos River at Gulf of Mexico), SJGBC3

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

(San Jacinto-Brazos Coastal Basin at Galveston Bay), and SJGMC4 (San Jacinto-Brazos Coastal Basin at Gulf of Mexico). Downstream releases documented in reservoir operator logs for the reservoirs located at BSLU7 and GHGH24 were utilized as streamgage records for BSLU7 and GHGH24, for which USGS reservoir contents gage data are available, but not streamflow records. Control points BRGM73, SJGBC3 and SJGMC4 were added in order to facilitate the Senate Bill 1 requirement that estimates be made of total inflow to Galveston Bay and the Gulf of Mexico from the basins studied. Flows for BRGM73 represent flows passing BRRO72 (Brazos River at Rosharon) plus all ungaged runoff to the Gulf of Mexico. Flows for SJGBC3 and SJGMC4 represent total flows (gaged and ungaged) draining from all streams in the San Jacinto-Brazos Coastal Basin to Galveston Bay and the Gulf of Mexico, respectively.

Summary data for all primary control points are presented in Table 3-1. The drainage areas used in the streamflow naturalization at the primary control points are those reported by the USGS and in previous studies.[40,41,42] However, the distribution of naturalized flows from primary (gaged) control points to secondary (ungaged) control points as described in Section 3.2.2 utilized the drainage areas provided by the TNRCC through the University of Texas Center for Research in Water Resources (CRWR). Table 3-2 presents a comparison of drainage areas published by the USGS and those provided by the TNRCC. The differences between the total drainage areas are minimal (<1.0 percent) in most cases, with the largest differences occurring in the upper basin where the delineation of non-contributing drainage area is difficult. More significant, however, are differences in incremental drainage areas between adjacent gages. These incremental drainage areas are utilized by WRAP to distribute naturalized flows from primary to secondary control points (Section 3.2.2). Relatively small differences (on a percentage basis) in total drainage area can result in significantly large differences in incremental drainage areas when the total drainage areas are large compared to the incremental drainage area. Table 3-2 presents several relatively large (>5 percent) differences in incremental drainage area between the USGS values and those provided by the TNRCC. The cause of the discrepancy between the USGS and CRWR incremental drainage areas is not known.

[40] USGS, "Water Resources Data, Texas," Annual.
[41] USGS, "Drainage Areas of Texas Streams, Brazos River Basin," Open-File Report, 1977.
[42] Texas Water Commission, "Drainage Areas of Texas Streams, San Jacinto River Basin and San Jacinto-Brazos Coastal Area," Circular No. 62-05, October 1962.

Figure 3-2. Primary Control Point Locations

Figure 3-2. Primary Control Point Locations

Table 3-1. Primary Control Points in the Brazos River Basin and San Jacinto-Brazos Coastal Basin

ID	Stream Name, Location	USGS Gage Number	Contributing Drainage Area (mi^2)	Incremental Drainage Area (mi^2)	Period with Data Available
RWPL01	Running Water Draw at Plainview	08080700	382	382	1/39–9/53; 10/56–4/60; 3/61–9/78
WRSP02	White River Reservoir near Spur	08080910	689	307	4/64–9/76
DUG03I	Duck Creek near Girard	08080950	279	279	10/64–9/89
SFPE04	Salt Fork Brazos River near Peacock	08081000	1,985	1,017	1/50–9/51; 10/64–9/86
CRJA05	Croton Creek near Jayton	08081200	290	290	9/59–9/86
SFAS06	Salt Fork Brazos River near Aspermont	08082000	2,496	221	6/39–1997
BSLU07	Buffalo Springs Lake near Lubbock	08079550	236	236	9/59–1997
DMJU08	Double Mountain Fork Brazos River at Justiceburg	08079600	244	244	12/61–1997
DMAS09	Double Mountain Fork Brazos River near Aspermont	08080500	1,864	1,384	6/39–1997
NCKN10	North Croton Creek near Knox City	08082180	251	251	10/65–9/86
BRSE11	Brazos River at Seymour	08082500	5,972	1,361	12/23–1997
MSMN12	Millers Creek near Munday	08082700	104	104	7/63–1997
CFRO13	Clear Fork Brazos River near Roby	08083100	228	228	1/62–1997
CFHA14	Clear Fork Brazos River at Hawley	08083240	1,416	1,188	10/67–9/89
MUHA15	Mulberry Creek near Hawley	08083245	205	205	10/67–9/89
CFNU16	Clear Fork Brazos River at Nugent	08084000	2,199	578	2/24–1997
CAST17	California Creek near Stamford	08084800	478	478	10/62–1997
CFFG18	Clear Fork Brazos River at Fort Griffin	08085500	3,988	1,311	12/23–1997
HCAL19	Hubbard Creek below Albany	08086212	613	613	10/66–1997

Table 3-1. Primary Control Points in the Brazos River Basin and San Jacinto-Brazos Coastal Basin (Continued)

ID	Stream Name, Location	USGS Gage Number	Contributing Drainage Area (mi^2)	Incremental Drainage Area (mi^2)	Period with Data Available
BSBR20	Big Sandy Creek above Breckenridge	08086290	280	280	3/63–1997
HCBR21	Hubbard Creek near Breckenridge	08086500	1,089	196	5/55–1997
CFEL22	Clear Fork Brazos River at Eliasville	08087300	5,697	620	7/28–9/51; 10/61–9/82
BRSB23	Brazos River near South Bend	08088000	13,107	1,334	9/38–1997
GHGH24	Lake Graham near Graham	08088400	221	221	1/40–4/62; 10/63–5/70; 9/71–4/73; 8/74–7/77; 3/79–7/82; 10/84–6/89; 1/90–1997
CCIV25	Big Cedar Creek near Ivan	08088450	97	97	12/64–9/89
SHGR26	Brazos River at Morris Sheppard Dam near Graford	08088600	14,030	605	10/76–1997
BRPP27	Brazos River near Palo Pinto	08089000	14,245	215	2/24–1997
PPSA28	Palo Pinto Creek near Santo	08090500	573	573	5/51–9/76
BRDE29	Brazos River near Dennis	08090800	15,671	853	5/68–1997
BRGR30	Brazos River near Glen Rose	08091000	16,252	581	10/23–1997
PAGR31	Paluxy River at Glen Rose	08091500	410	410	6/47–1997
NRBL32	Nolan River at Blum	08092000	282	282	12/47–2/87; 10/92–9/96; 10/97–1997
BRAQ33	Brazos River near Aquilla	08093100	17,678	734	10/38–1997
AQAQ34	Aquilla Creek near Aquilla	08093500	308	308	1/39–1997
NBHI35	North Bosque River at Hico	08094800	359	359	1/62–1997
NBCL36	North Bosque River near Clifton	08095000	968	609	10/23–1997
NBVM37	North Bosque River At Valley Mills	08095200	1,146	178	8/59–1997

Table 3-1. Primary Control Points in the Brazos River Basin and San Jacinto-Brazos Coastal Basin (Continued)

ID	Stream Name, Location	USGS Gage Number	Contributing Drainage Area (mi^2)	Incremental Drainage Area (mi^2)	Period with Data Available
MBMG38	Middle Bosque River near McGregor	08095300	182	182	9/59–9/85; Partial 10/85–1997
HGCR39	Hog Creek near Crawford	08095400	78	78	9/59–9/85; Partial 10/85–1997
BOWA40	Bosque River near Waco	08095600	1,656	250	10/59–9/81; 4/82–6/82
BRWA41	Brazos River at Waco	08096500	20,007	365	10/14–1997
BRHB42	Brazos River near Highbank	08098290	20,870	863	10/65–1997
LEDL43	Leon River near De Leon	08099100	479	479	9/60–9/86
SADL44	Sabana River near De Leon	08099300	264	264	9/60–9/86
LEHS45	Leon River near Hasse	08099500	1,261	518	1/39–9/91
LEHM46	Leon River near Hamilton	08100000	1,891	630	9/60–1997
LEGT47	Leon River at Gatesville	08100500	2,342	451	10/50–1997
COPI48	Cowhouse Creek at Pidcoke	08101000	455	455	10/50–1997
LEBE49	Leon River near Belton	08102500	3,542	745	10/23–1997
LAKE50	Lampasas River near Kempner	08103800	818	818	10/62–1997
LAYO51	Lampasas River at Youngsport	08104000	1,240	422	3/24–9/80
LABE52	Lampasas River near Belton	08104100	1,321	81	2/63–10/89; 4/99–1997
LRLR53	Little River near Little River	08104500	5,228	365	8/62–1997
NGGE54	North Fork San Gabriel River near Georgetown	08104700	248	248	7/68–1997
SGGE55	South Fork San Gabriel River at Georgetown	08104900	133	133	12/67–1997
GAGE56	San Gabriel River at Georgetown	08105000	405	24	8/34–9/73; 11/84; 6/85–9/85; 1/86; 4/86; 7/86–8/86

Table 3-1. Primary Control Points in the Brazos River Basin and San Jacinto-Brazos Coastal Basin (Concluded)

ID	Stream Name, Location	USGS Gage Number	Contributing Drainage Area (mi^2)	Incremental Drainage Area (mi^2)	Period with Data Available
GALA57	San Gabriel River at Laneport	08105700	738	333	10/65–1997
LRCA58	Little River at Cameron	08106500	7,065	1,099	11/16–1997
BRBR59	Brazos River near Bryan	08109000	29,949	2,014	7/26–9/93
MYDB60	Middle Yegua Creek near Dime Box	08109700	236	236	8/62–1997
EYDB61	East Yegua Creek near Dime Box	08109800	244	244	8/62–1997
YCSO62	Yegua Creek near Somerville	08110000	1,009	529	6/24–8/91
DCLY63	Davidson Creek near Lyons	08110100	195	195	10/62–1997
NAGR64	Navasota River above Groesbeck	08110325	240	240	6/78–1997
BGFR65	Big Creek near Freestone	08110430	97	97	7/78–1997
NAEA66	Navasota River near Easterly	08110500	968	631	3/24–1997
NABR67	Navasota River near Bryan	08111000	1,454	486	1/51–9/94
BRHE68	Brazos River near Hempstead	08111500	34,314	1,707	10/38–1997
MCBL69	Mill Creek near Bellville	08111700	376	376	8/63–9/92
BRRI70	Brazos River at Richmond	08114000	35,441	751	10/22–1997
BGNE71	Big Creek near Needville	08115000	43	43	6/47–6/50; 4/52–1997
BRRO72	Brazos River at Rosharon	08116650	35,773	289	4/67–9/80; 5/84–1997
BRGM73	Brazos River at Gulf of Mexico		35,931	158	None
CLPEC1	Clear Creek near Pearland		39	39	8/44–10/44; 3/46–10/46; 4/47–12/59; 4/63–9/92
CBALC2	Chocolate Bayou near Alvin		88	88	8/44; 4/46; 1/47–1/58; 3/59–1997
SJGBC3	San Jacinto-Brazos Coastal Basin at Galveston Bay		1,145	1,019	None
SJGMC4	San Jacinto-Brazos Coastal Basin at the Gulf of Mexico		293	293	None

Table 3-2. Comparison of USGS and CRWR Drainage Areas at Primary Control Points in the Brazos River Basin

Control Point ID	USGS Stream Gage	Contributing USGS Area (mi^2)	Contributing CRWR Area (mi^2)	Difference	USGS Incremental Area (mi^2)	CRWR Incremental Area (mi^2)	Difference
RWPL01	08080700	382	295	–22.7%	382	295	–22.7%
WRSP02	08080910	689	689	0.0%	307	393	28.2%
DUGI03	08080950	279	300	7.4%	279	300	7.4%
SFPE04	08081000	1,985	2,007	1.1%	1,017	1,018	0.1%
CRJA05	08081200	290	293	0.9%	290	293	0.9%
SFAS06	08082000	2,496	2,504	0.3%	221	205	–7.4%
BSLU07	08079550	236	245	4.0%	236	245	4.0%
DMJU08	08079600	244	265	8.7%	244	265	8.7%
DMAS09	08080500	1,864	1,891	1.5%	1,384	1,380	–0.3%
NCKN10	08082180	251	250	-0.3%	251	250	–0.3%
BRSE11	08082500	5,972	5,996	0.4%	1,361	1,351	–0.8%
MSMN12	08082700	104	106	1.8%	104	106	1.8%
CFRO13	08083100	228	266	16.7%	228	266	16.7%
CFHA14	08083240	1,416	1,456	2.8%	1,188	1,190	0.2%
MUHA15	08083245	205	208	1.5%	205	208	1.5%
CFNU16	08084000	2,199	2,236	1.7%	578	572	–1.1%
CAST17	08084800	478	476	–0.4%	478	476	–0.4%
CFFG18	08085500	3,988	4,031	1.1%	1,311	1,319	0.6%
HCAL19	08086212	613	612	–0.1%	613	612	–0.1%
BSBR20	08086290	280	285	1.7%	280	285	1.7%
HCBR21	08086500	1,089	1,092	0.3%	196	195	–0.4%
CFEL22	08087300	5,697	5,738	0.7%	620	615	–0.8%
BRSB23	08088000	13,107	13,171	0.5%	1,334	1,331	–0.3%
GHGH24	08088400	221	224	1.3%	221	224	1.3%
CCIV25	08088450	97	97	0.4%	97	97	0.4%
SHGR26	08088600	14,030	14,093	0.5%	605	601	–0.6%
BRPP27	08089000	14,245	14,309	0.4%	215	216	0.3%
PPSA28	08090500	573	574	0.2%	573	574	0.2%

Table 3-2. Comparison of USGS and CRWR Drainage Areas at Primary Control Points in the Brazos River Basin (Continued)

Control Point ID	USGS Stream Gage	Contributing USGS Area (mi^2)	Contributing CRWR Area (mi^2)	Difference	USGS Incremental Area (mi^2)	CRWR Incremental Area (mi^2)	Difference
BRDE29	08090800	15,671	15,733	0.4%	853	850	–0.4%
BRGR30	08091000	16,252	16,320	0.4%	581	587	1.1%
PAGR31	08091500	410	411	0.1%	410	411	0.1%
NRBL32	08092000	282	282	0.1%	282	282	0.1%
BRAQ33	08093100	17,678	17,746	0.4%	734	734	–0.1%
AQAQ34	08093500	308	307	–0.3%	308	307	-0.3%
NBHI35	08094800	359	360	0.2%	359	360	0.2%
NBCL36	08095000	968	977	0.9%	609	617	1.4%
NBVM37	08095200	1,146	1,159	1.1%	178	181	2.0%
MBMG38	08095300	182	181	–0.4%	182	181	–0.4%
HGCR39	08095400	78	77	–1.1%	78	77	–1.1%
BOWA40	08095600	1,656	1,660	0.2%	250	243	–2.8%
BRWA41	08096500	20,007	20,065	0.3%	365	352	–3.7%
BRHB42	08098290	20,870	21,243	1.8%	863	1,178	36.5%
LEDL43	08099100	479	476	–0.7%	479	476	–0.7%
SADL44	08099300	264	267	1.3%	264	267	1.3%
LEHS45	08099500	1,261	1,283	1.7%	518	539	4.1%
LEHM46	08100000	1,891	1,928	2.0%	630	645	2.4%
LEGT47	08100500	2,342	2,379	1.6%	451	451	0.0%
COPI48	08101000	455	455	–0.1%	455	455	–0.1%
LEBE49	08102500	3,542	3,579	1.1%	745	746	0.1%
LAKE50	08103800	818	817	–0.2%	818	817	–0.2%
LAYO51	08104000	1,240	1,240	0.0%	422	424	0.4%
LABE52	08104100	1,321	1,321	0.0%	81	81	0.2%
LRLR53	08104500	5,228	5,266	0.7%	365	365	0.0%
NGGE54	08104700	248	248	0.2%	248	248	0.2%
SGGE55	08104900	133	132	–0.6%	133	132	–0.6%

Table 3-2. Comparison of USGS and CRWR Drainage Areas at Primary Control Points in the Brazos River Basin (Concluded)

Control Point ID	USGS Stream Gage	Contributing USGS Area (mi^2)	Contributing CRWR Area (mi^2)	Difference	USGS Incremental Area (mi^2)	CRWR Incremental Area (mi^2)	Difference
GAGE56	08105000	405	404	–0.2%	24	24	–2.0%
GALA57	08105700	738	737	–0.1%	333	333	0.1%
LRCA58	08106500	7,065	7,100	0.5%	1,099	1,097	–0.2%
BRBR59	08109000	29,949	30,016	0.2%	2,014	1,673	–17.0%
MYDB60	08109700	236	235	–0.4%	236	235	–0.4%
EYDB61	08109800	244	239	–1.9%	244	239	–1.9%
YCSO62	08110000	1,009	1,011	0.2%	529	536	1.4%
DCLY63	08110100	195	195	–0.1%	195	195	–0.1%
NAGR64	08110325	240	240	–0.1%	240	240	–0.1%
BGFR65	08110430	97	97	–0.2%	97	97	–0.2%
NAEA66	08110500	968	936	–3.3%	631	599	–5.0%
NABR67	08111000	1,454	1,427	–1.9%	486	491	1.1%
BRHE68	08111500	34,314	34,374	0.2%	1,707	1,726	1.1%
MCBL69	08111700	376	377	0.2%	376	377	0.2%
BRRI70	08114000	35,441	35,454	0.0%	751	703	–6.4%
BGNE71	08115000	43	46	6.4%	43	46	6.4%
BRRO72	08116650	35,773	35,775	0.0%	289	276	–4.7%

Although the USGS has been virtually the only source, and is regarded as setting the standard for drainage areas, there is an unknown amount of error in their datasets. The WAM management team made the decision to use the GIS-based CRWR-developed drainage areas. The TNRCC is pursuing analyses of the differences between the datasets and until the causes of the differences are known, no adjustments to the CRWR-developed data will be made to improve agreement with the USGS values.

Daily streamflow records were obtained directly from the USGS and aggregated to monthly values. Records from these gaging stations, with few exceptions, are classified by the

USGS[43] as “good,” which means that 95 percent of the published daily discharges are within 10 percent of their true values.

3.1.3 Delivery Factors and Channel Loss Rates Between Primary Control Points

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 reservoir operations, diversions and effluent discharges (return flows).** These losses are applied during both the streamflow naturalization and the simulation processes. The channel loss factors are applied in the form of delivery factors, related by the equation:

Delivery Factor = 1 – Channel Loss

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

A streamflow delivery factor was developed for each stream reach linking primary control points and major confluences in the Brazos River Basin using estimates of the typical percentage of water passing an upstream control point that arrives at the next downstream control point. Throughout most of the basin, channel loss rates were adapted from those utilized by the Brazos River Authority (BRA) to determine reservoir release requirements to downstream contractual diversions.[44] Delivery factors from past studies and segment-specific analyses performed for this study were generally used for stream segments for which the BRA has not estimated delivery factors.

The factors from past studies and the segment-specific analyses performed for this study were derived using gaged streamflow records at the upstream and downstream control points, along with estimates of runoff from the intervening area. For segments linking primary control points and major confluences that lacked BRA delivery factors and lacked the data necessary for a segment-specific analysis, the factors from adjacent BRA and segment-specific reaches were assumed applicable when soil, channel and geologic characteristics of the adjacent reaches were

[43] USGS, Op. Cit., Annual.
[44] Brazos River Authority (BRA), Spreadsheet of channel losses and travel times from BRA reservoir to downstream points.

similar. Loss rates estimated in a previous study below the proposed Lake Bosque project were applied to main stem segments throughout the Bosque River watershed, loss rates determined for the Double Mountain Fork of the Brazos River between Justiceburg and Aspermont in the upper basin were applied to all segments in the upper basin upstream of Possum Kingdom Reservoir, and loss rates for the lower Brazos River Basin were assumed applicable throughout the San Jacinto-Brazos Coastal Basin.

The development and selection of the delivery factors between primary control points used in this study are described in greater detail in Appendix VIII.

3.1.4 Completion of Streamflow Records

Streamflow records missing during the 1940 to 1997 historical period were estimated for 57 streamflow gaging stations located throughout the Brazos River Basin and San Jacinto-Brazos Coastal Basin. Records were completed using multiple linear regression techniques based on available streamflow records or drainage area ratio based on available streamflow records in the same or an adjacent watershed. The equations used to estimate these missing monthly streamflow records are summarized in Table 3-3.

Generally, regression equations were developed to calculate missing flows from available upstream or downstream flows. When suitable upstream or downstream flow records were not available, however, regression equations were developed from available natural flows in one or more adjacent watersheds. Table 3-3 indicates the length of concurrent record on which each regression equation was based.

Table 3-3. Relationships Used to Complete Streamflow Records

Control Point ID	Name	Data Missing	Fill Relationship Used	R^2 for Fill Rel.
RWPL01	Running Water Draw at Plainview	10/53–9/56; 5/60–2/61	RWPL01 = 0.033 * SFAS06	0.194
		10/78–1997	RWPL01 = 0.141 * WRSP02	0.442
WRSP02	White River Reservoir near Spur	1/40–8/63	WRSP02 = 0.207 * SFAS06	0.391
DUGI03	Duck Creek near Girard	1/40–9/64; 10/89–1997	DUGI03 = 0.138 * SFAS06	0.609
SFPE04	Salt Fork Brazos River near Peacock	1/40–12/49; 10/51–9/64; 10/86–1997	SFPE04 = 0.701 * SFAS06	0.921
CRJA05	Croton Creek near Jayton	1/40–9/59; 10/86–1997	CRJA05 = 0.153 * SFAS06	0.540
SFAS06	Salt Fork Brazos River near Aspermont	None	—	—
BSLU07	Buffalo Springs Lake near Lubbock	1/40–8/59	BSLU07 = 0.129 * DMAS09	0.447
DMJU08	Double Mountain Fork Brazos River at Justiceburg	1/40–11/61	DMJU08 = 0.201 * DMAS09	0.682
DMAS09	Double Mountain Fork Brazos R. near Aspermont	None	—	—
NCKN10	North Croton Creek near Knox City	1/40–9/65; 10/86–1997	NCKN10 = 0.154 * SFAS06	0.615
BRSE11	Brazos River at Seymour	None	—	—
MSMN12	Millers Creek near Munday	1/40–6/63	MSMN12 = 0.050 * [(CFFG18-(0.56482*CFNU16)]	0.695
CFRO13	Clear Fork Brazos River near Roby	1/40–12/61	CFRO13 = 0.061 * DMAS09	0.346
CFHA14	Clear Fork. Brazos River at Hawley	1/40–9/67; 10/89–1997	CFHA14 = 0.464 * CFNU16	0.670

Table 3-3. Relationships Used to Complete Streamflow Records (Continued)

Control Point ID	Name	Data Missing	Fill Relationship Used	R^2 for Fill Rel.
MUHA15	Mulberry Creek near Hawley	1/40–9/67; 10/89–1997	MUHA15 = 0.081 * CFNU16	0.651
CFNU16	Clear Fork Brazos River at Nugent	None	—	—
CAST17	California Creek near Stamford	1/40–9/62	CAST17 = 0.156 * CFFG18	0.741
CFFG18	Clear Fork Brazos River at Fort Griffin	None	—	—
HCAL19	Hubbard Creek below Albany	1/40–9/51	HCAL19 = 0.241 * CFEL22	0.738
		10/51–4/55	HCAL19 = 0.179 * [BRSB23– (0.57884 * BRSE23)-(0.62646*CFFG18)]	0.543
		5/55–9/66	HCAL19 = 0.600 * HCBR21	0.864
BSBR20	Big Sandy Creek above Breckenridge	1/40–9/51	BSBR20 = 0.121 * [CFEL22-(0.68637*CFFG18)]	0.639
		10/51–4/55	BSBR20 = 0.067 * [BRSB23–(0.57884 * BRSE11) – (0.62646*CFFG18)]	0.507
		5/55–2/62	BSBR20 = 0.193 * HCBR21	0.694
HCBR21	Hubbard Creek near Breckenridge	1/40–9/51	HCBR21 = 0.586 * [CFEL22-(0.68637*CFFG18)]	0.846
		10/51–4/55	HCBR21 = 0.285 * [BRSB23–(0.57884 * BRSE11) – (0.62646*CFFG18)]	0.699

Table 3-3. Relationships Used to Complete Streamflow Records (Continued)

Control Point ID	Name	Data Missing	Fill Relationship Used	R^2 for Fill Rel.
CFEL22	Clear Fork Brazos River at Eliasville	10/51–9/61; 10/82–1997	CFEL22 = 0.604 * [BRSB23–(0.57884 * BRSE11)]	0.907
BRSB23	Brazos River near South Bend	None	—	—
GHGH24	Lake Graham near Graham	5/62–9/63; 6/70–8/71; 5/73–7/74; 8/77–2/79; 8/82–9/84; 7/89–12/89; 11/96–12/97	GHGH24 = 0.305 * [BRPP27 – (0.97733 * BRSB23)]	0.569
CCIV25	Big Cedar Creek near Ivan	1/40–11/64; 10/89–1997	CCIV25 = 0.086 * [BRPP27 – (0.97733 * BRSB23)]	0.613
SHGR26	Brazos River at Morris Sheppard Dam near Graford	1/40–9/76	SHGR26 = 0.991 * BRPP27	0.990
BRPP27	Brazos River near Palo Pinto	None	—	—
PPSA28	Palo Pinto Creek near Santo	1/40–4/51; 10/76–1997	PPSA28 = 0.172 * [BRGR30 - (0.96071 * BRPP27)]	0.753
BRDE29	Brazos River near Dennis	1/40–4/68	BRDE29 = 0.904 * BRGR30	0.984
BRGR30	Brazos River near Glen Rose	None	—	—
PAGR31	Paluxy River at Glen Rose	1/40–5/47	PAGR31 = 0.190 * [BRAQ33 – (0.97801 * BRGR31)]	0.696
NRBL32	Nolan River at Blum	1/40–11/47; 3/87–9/92; 10/96–9/97	NRBL32 = 0.230 * [BRAQ33 – (0.97801 * BRGR31)]	0.635
BRAQ33	Brazos River near Aquilla	None	—	—
AQAQ34	Aquilla Creek near Aquilla	None	—	—

Table 3-3. Relationships Used to Complete Streamflow Records (Continued)

Control Point ID	Name	Data Missing	Fill Relationship Used	R^2 for Fill Rel.
NBHI35	North Bosque River at Hico	1/40–12/61	NBHI35 = 0.250 * NBCL36	0.796
NBCL36	North Bosque River near Clifton	None	—	—
NBVM37	North Bosque River At Valley Mills	1/40–7/59	NBVM37 = 1.186 * NBCL36	0.962
MBMG38	Middle Bosque River near McGregor	1/40–7/59; 10/85–1997	MBMG38 = 0.089 * [BRWA41 – (0.98733 * BRAQ33)]	0.592
HGCR39	Hog Creek near Crawford	1/40–8/59; 10/85–1997	HGCR39 = 0.045 * [BRWA41 – (0.98733 * BRAQ33)]	0.788
BOWA40	Bosque River near Waco	1/40–9/59; 10/81–3/82; 7/82–1997	BOWA40 = 0.609 * [BRWA41 – (0.98733 * BRAQ33)]	0.922
BRWA41	Brazos River at Waco	None	—	—
BRHB42	Brazos River near Highbank	1/40–9/65	BRHB42 = 0.801 * BRWA41 + 0.191 * BRBR59	0.986
LEDL43	Leon River near De Leon	1/40–8/60 & 10/86–9/91	LEDL43 = 0.426 * LEHS45	0.830
		10/91–9/96 & 10/97–1997	LEDL43 = 0.324 * LEHM46	0.674
SADL44	Sabana River near De Leon	1/40–8/60; 10/86–9/91	SADL44 = 0.268 * LEHS45	0.913
		9/91–1997	SADL44 = 0.209 * LEHM46	0.710
LEHS45	Leon River near Hasse	10/91–1997	LEHS45 = 0.941 * LEHM46	0.872
LEHM46	Leon River near Hamilton	1/40–9/50	LEHM46 = 1.086 * LEHS45	0.870
		10/50–8/60	LEHM46 = 0.493 * LEHS45 + 0.424 * LEGT47	0.967
LEGT47	Leon River at Gatesville	1/40–9/50	LEGT47 = 0.588 * LEHS45 + 0.357 * LEBE49	0.960

Table 3-3. Relationships Used to Complete Streamflow Records (Continued)

Control Point ID	Name	Data Missing	Fill Relationship Used	R^2 for Fill Rel.
COPI48	Cowhouse Creek at Pidcoke	1/40–9/50	COPI48 = 0.193 * [LEBE49 – (0.59655 * LEHS45)]	0.879
LEBE49	Leon River near Belton	None	—	—
LAKE50	Lampasas River near Kempner	1/40–9/62	LAKE50 = 0.566 * LAYO51	0.915
LAYO51	Lampasas River at Youngsport	10/80–1997	LAYO51 = 1.648 * LAKE50	0.911
LABE52	Lampasas River near Belton	1/40–1/63	LABE52 = 1.087 * LAYO51	0.987
		11/89–1997	LABE52 = 0.290 * LRLR53	0.945
LRLR53	Little River near Little River	1/40–7/62	LRLR53 = 1.158 * (LAYO51 + LEBE49)	0.985
NGGE54	North Fork San Gabriel River near Georgetown	1/40–6/68	NGGE54 = 0.565 * GAGE56	0.970
SGGE55	South Fork San Gabriel River at Georgetown	1/40–11/67	SGGE55 = 0.358 * GAGE56	0.931
GAGE56	San Gabriel River at Georgetown	10/73–10/84; 12/84–5/85; 10/85–12/85; 2/86–3/86; 5/86–6/86; 9/86–1997	GAGE56 = 1.115 * (NGGE54 + SGGE55)	0.984
GALA57	San Gabriel River at Laneport	1/40–9/65	GALA57 = 1.818 * GAGE56	0.915
LRCA58	Little River at Cameron	None	—	—
BRBR59	Brazos River near Bryan	10/93–1997	BRBR59 = 1.099 * (BRHB42 + LR_CA)	0.990
MYDB60	Middle Yegua Creek near Dime Box	1/40–7/62	MYDB60 = 0.178 * YCSO62	0.783

Table 3-3. Relationships Used to Complete Streamflow Records (Continued)

Control Point ID	Name	Data Missing	Fill Relationship Used	R^2 for Fill Rel.
EYDB61	East Yegua Creek near Dime Box	1/40–7/62	EYDB61 = 0.186 * YCSO62	0.850
YCSO62	Yegua Creek near Somerville	9/91–1997	YCSO62 = 4.772 * EYDB61	0.848
DCLY63	Davidson Creek near Lyons	1/40–9/62	DCLY63 = 0.204 * YCSO62	0.767
NAGR64	Navasota River above Groesbeck	1/40–5/78	NAGR64 = 0.265 * NAEA66	0.794
BGFR65	Big Creek near Freestone	1/40–6/78	BGFR65 = 0.099 * NAEA66	0.895
NAEA66	Navasota River near Easterly	None	—	—
NABR67	Navasota River near Bryan	1/40–12/50; 10/94–1997	NABR67 = 1.228 * NAEA66	0.941
BRHE68	Brazos River near Hempstead	None	—	—
MCBL69	Mill Creek near Bellville	1/40–7/63	MCBL69 = 0.622 * YCSO62	0.693
		10/93–12/96	MCBL69 = 2.633 * CY_CY (CY_CY is Cypress Bayou at Cypress in the San Jacinto Basin [37])	0.651
		1/97–12/97	MCBL69 = 2.566 * DCLY63	0.621
BRRI70	Brazos River at Richmond	None	—	—
BGNE71	Big Creek near Needville	1/40–5/47; 7/50–3/52	BGNE71 = 0.297 * BR_HO (BR_HO is Brays Bayou at Houston in the San Jacinto Basin [37])	0.619
BRRO72	Brazos River at Rosharon	1/40–3/67; 10/80–4/84	BRRO72 = 1.036 * BRRI70	0.994
BRGM73	Brazos River at Gulf of Mexico	1/40–12/97	BRGM73 = 0.98344 * BRRO72 + $(DA_{BR\_GM} / DA_{BG\_NE})$ * BGNE71	N/A

Table 3-3. Relationships Used to Complete Streamflow Records (Concluded)

Control Point ID	Name	Data Missing	Fill Relationship Used	R^2 for Fill Rel.
CLPEC1	Clear Creek near Pearland	1/40–7/44, 11/44–2/46, 11/46–3/47, 1/60–3/63, 10/92–12/96	CLPEC1 = 0.299 * BR_HO (BR_HO is Brays Bayou at Houston in the San Jacinto Basin (see Note))	0.630
		1/97–12/97	CLPEC1 = 0.326 * CBALC2	0.573
CBALC2	Chocolate Bayou near Alvin	1/40–12/40	CBALC2 = 0.733 * BR_HO (BR_HO is Brays Bayou at Houston in the San Jacinto Basin (see note))	0.395
		1/44–7/44; 11/44–2/46; 11/46–12/46	CBALC2 = 0.716 * Texas Rainfall / Runoff Model	0.686
		9/44–10/44; 3/46; 5/46–10/46; 2/58–2/59	CBALC2 = 2.478 * CLPEC1	0.706
SJGBC3	San Jacinto-Brazos Coastal Basin at Galveston Bay	1/40–12/97	SJGBC3 = [(DA_{SJ_GB} – DA_{CL_PE} – DA_{CB_AL}) / (DA_{CL_PE} + DA_{CB_AL})] * (CB_AL + CL_PE) + 0.98899 * CLPEC1 + 0.99427 * CBAL2	N/A
SJGMC4	San Jacinto-Brazos Coastal Basin at the Gulf of Mexico	1/40–12/97	SJGMC4 = [DA_{SJ_GM} / (DA_{CL_PE} + DA_{CB_AL})] * (CLPEC1 + CBALC2)	N/A

Note: Espy-Padden Consultants, Inc., “Naturalized Flow Estimates in the San Jacinto River Basin,” Texas Natural Resource Conservation Commission, August 1999.

3.1.5 Comparison with Existing Naturalized Streamflow Datasets

Naturalized streamflows used in the performance of this study were compared to those used by the TDWR (now TNRCC) in the legacy computer model (Legacy WAM), and those developed by the U.S. Study Commission (USSC). The WRAP model previously developed and applied by Texas A&M University utilized the Legacy WAM flows for 1940–1976, and “unregulated” flows developed by Texas A&M for the 1977–1984 period. The Texas A&M flows for 1977–1984 are not included here. Figures 3-3, 3-4, 3-5, 3-6 and 3-7 present doublemass curves for the Brazos River at South Bend, Brazos River at Palo Pinto, Brazos River at Waco, Little River at Cameron and Brazos River at Richmond control points. Agreement between the data sets is quite good, with the Legacy WAM flows always being slightly greater than those developed in this study and the USSC flows slightly smaller.

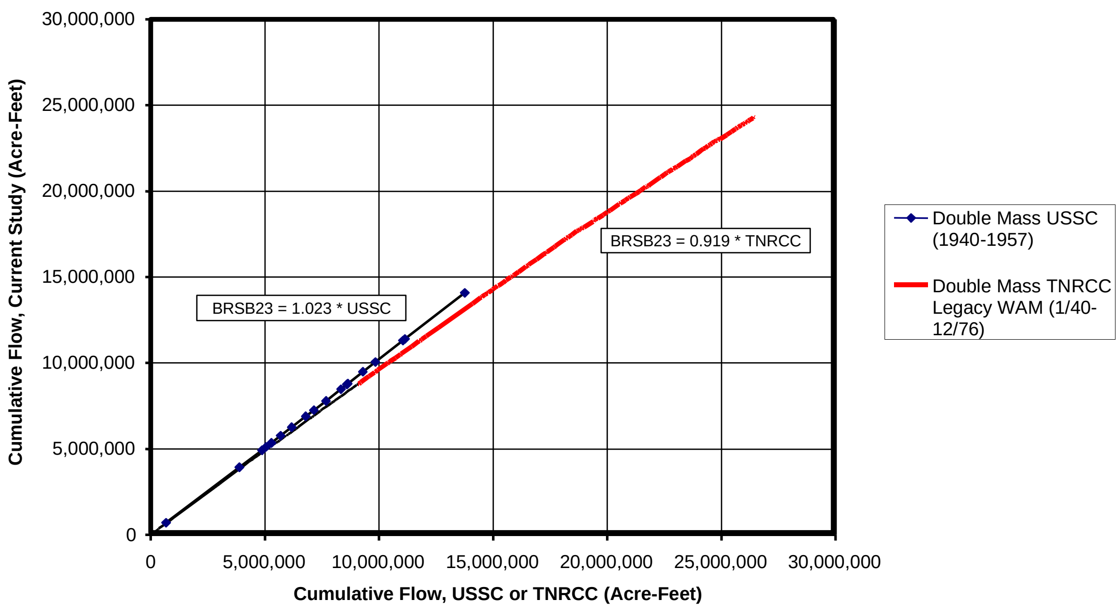

Figure 3-3. Comparison of Naturalized Streamflows, Brazos River near South Bend (BRSB23)

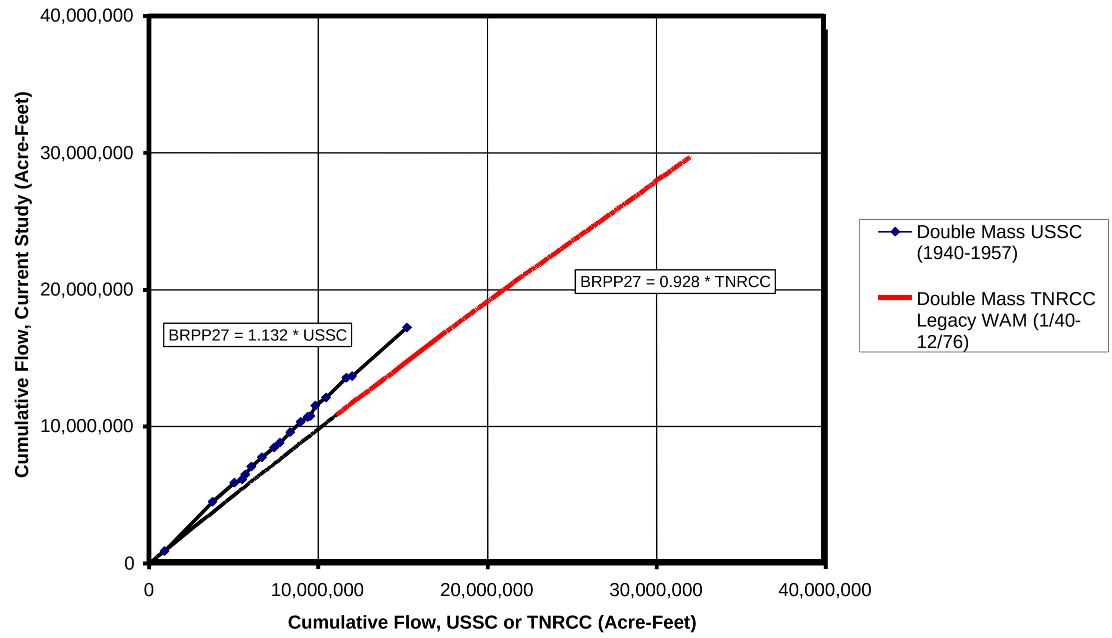

Figure 3-4. Comparison of Naturalized Streamflows, Brazos River near Palo Pinto (BRPP27)

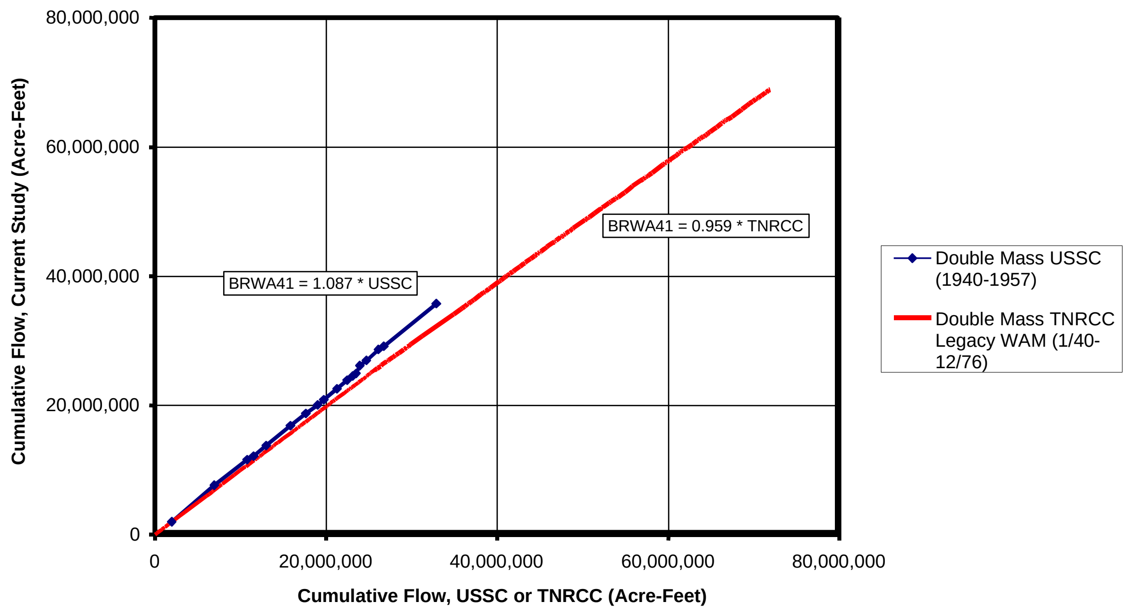

Figure 3-5. Comparison of Naturalized Streamflows, Brazos River at Waco, (BRWA41)

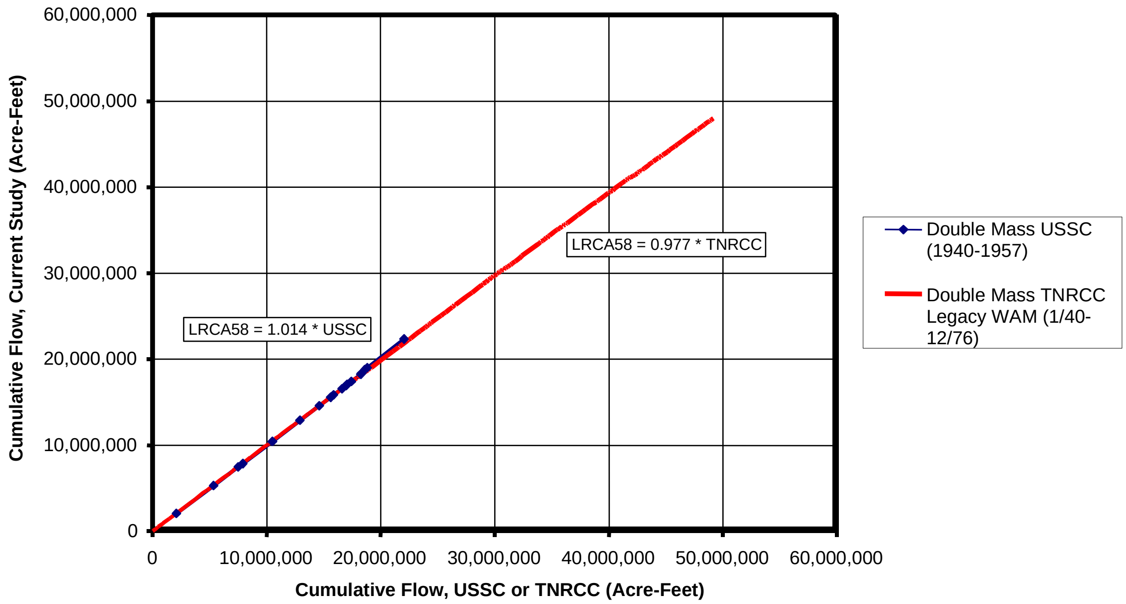

Figure 3-6. Comparison of Naturalized Streamflows, Little River at Cameron, (LRCA58)

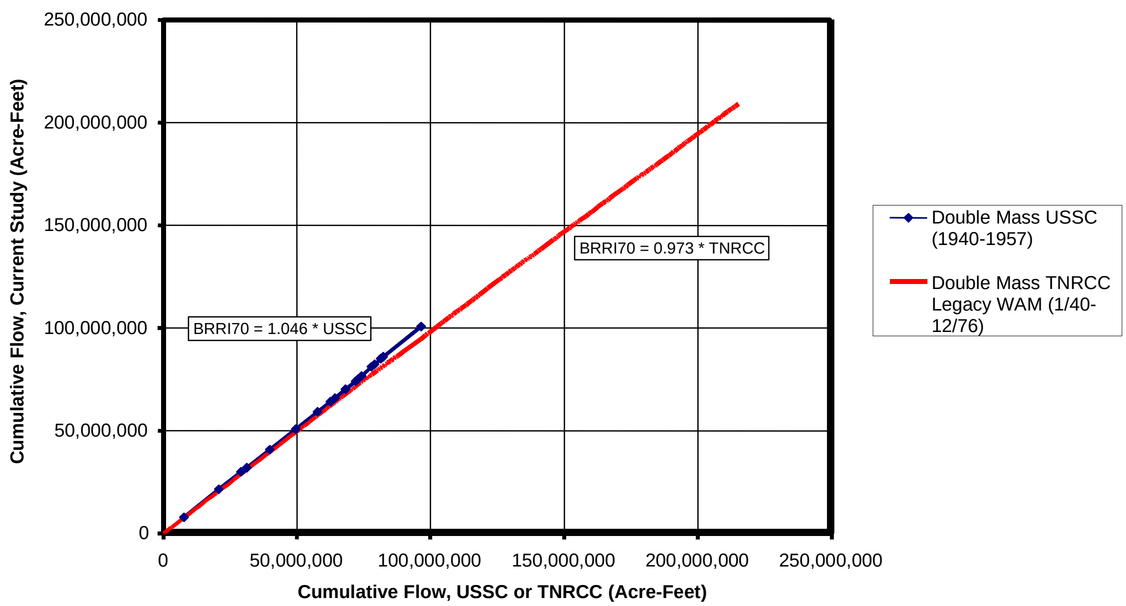

Figure 3-7. Comparison of Naturalized Streamflows, Brazos River at Richmond, (BRRI70)

The differences in naturalized streamflow are likely due to differences in the streamflow naturalization methodologies applied. The exact differences are not known, because the exact procedures used to develop the Legacy WAM and USSC naturalized flows are not fully documented. It is believed that the TDWR adjusted gaged streamflows for historical diversions, effluent discharge and reservoir storage on a one-to-one basis throughout the basin when developing the Legacy WAM flows, while the current study considered channel losses and applied delivery factors to translate the effects of historical streamflow changes to downstream gages. The other differences between the flows developed for current study and those developed for the Legacy WAM and USSC may include alternative procedures for estimating missing flow records and/or historical diversions, historical adjustments to account for minor reservoirs, and other factors.

3.1.6 Statistical Assessment of Trends in Annual Streamflow

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

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

Reduced springflow and baseflow due to development of groundwater supplies are not considered in this study because of the lack of available linkage data. Reduced baseflow and other changes in flow due to urbanization and other land use changes are generally assumed to be of insufficient magnitude on a basin-wide scale to warrant consideration. Long-term climatic change may affect the frequency and intensity of precipitation events and other factors that influence streamflows, but its effects cannot be quantified with sufficient precision to include in the model data.

Temporal trends in naturalized streamflows at each primary control point were checked using Kendall's rank correlation coefficient, tau, a non-parametric test.[45] Kendall's tau tests for a monotonic increasing or decreasing tendency within the annual data. Non-parametric tests such as Kendall's tau are uniquely suited for detecting trends in hydrologic data because the tests are insensitive to the large variability inherent to hydrologic data. Kendall's tau provides a more powerful test than a simple linear regression, which is often utilized to detect trends in streamflow data. At the 90 percent confidence level, statistically significant trends were detected in the naturalized flow data for six primary control points. These points are presented in Table 3-4.

Decreasing trends detected for three of the control points (WRSP02, DUGI03 and CRJA05) cannot be considered independent because significant portions of the naturalized flow data developed for these control points are based on filled-in data from flows for the Salt Fork near Aspermont control point, SFAS06 (Table 3-3). The trends detected for these three control points are almost certainly influenced by the trend detected for SFAS06. The trend detected in annual flows of the Salt Fork could represent a general decrease in runoff from the upper basin watershed. However, corresponding trends are not apparent in data for adjacent control points in the upper watershed. Annual naturalized streamflow and the computed trend line are presented in Figure 3-8.

Increasing trends in annual naturalized streamflow were detected for control points GHGH24 and LEHM46. Significant portions of missing record for these control points were filled in using the functional relationships presented in Table 3-3. The trends in these naturalized streamflows cannot be attributed to changes in natural runoff because of the significant periods of filled in record from other gages.

[45] Helsel, D.R. and Hirsch, R.M., Statistical Methods in Water Resources, Elsevier, New York, 1992, pp. 212-215.

Table 3-4. Primary Control Points for Which Trends in Annual Naturalized Streamflow Were Detected (α = 0.10 significance level)

Control Point ID	Name	Annual Streamflow (acft)				Slope of Trend Line (acft/yr)	Slope as Percent of Median
		Minimum	Maximum	Mean	Median		
WRSP02	White River Reservoir near Spur	1,941	97,862	16,730	13,751	–170	–1.20%
DUGI03	Duck Creek near Girard	728	65242	10,078	6,614	–79	–1.20%
CRJA05	Croton Creek near Jayton	1,244	72,331	12,399	10,191	–100	–1.00%
SFAS06	Salt Fork Brazos River near Aspermont	10,725	472,766	77,052	59,872	–637	–1.10%
GHGH24	Lake Graham near Graham	670	401,247	35,827	22,145	398	1.80%
LEHM46	Leon River near Hamilton	10,414	637,756	166,469	106,318	1,515	1.40%

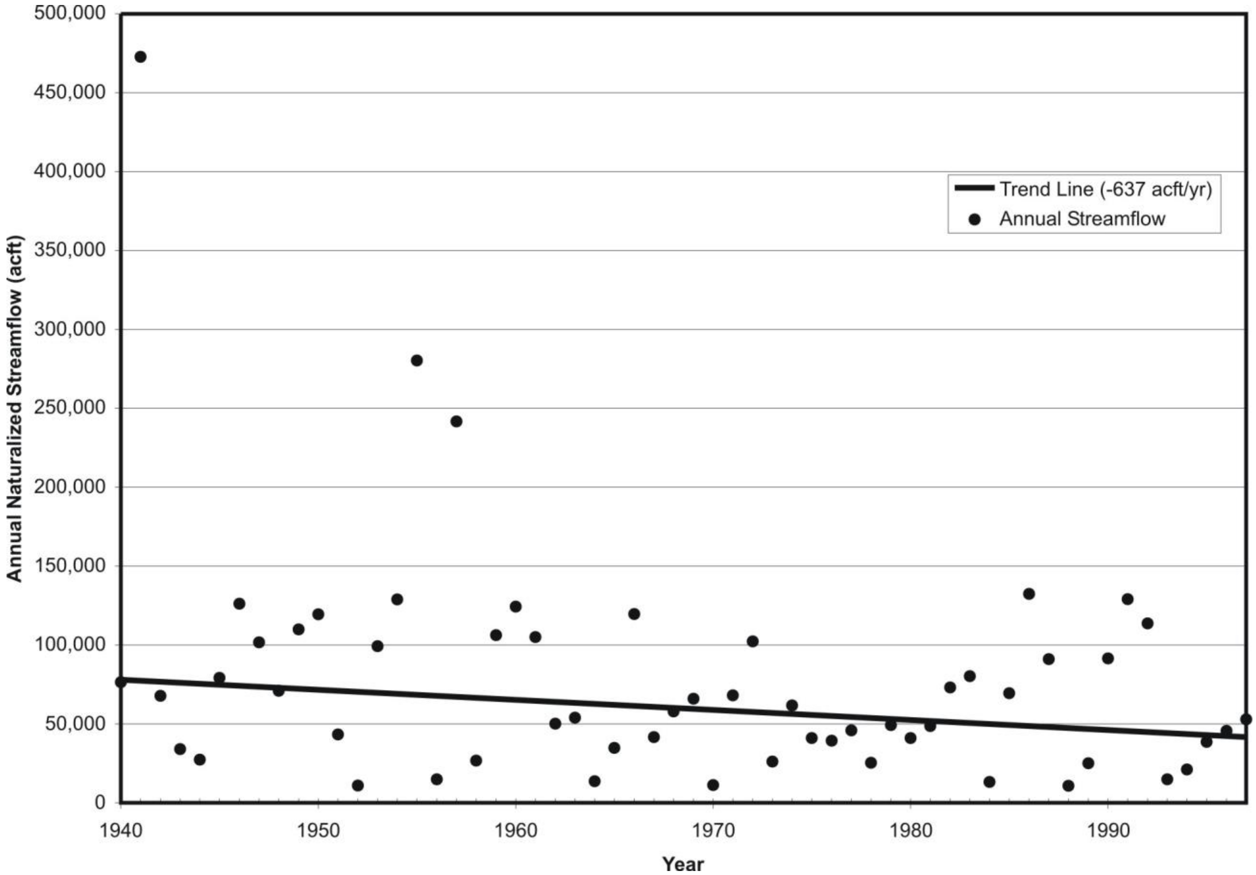

Figure 3-8. Annual Naturalized Streamflows, Salt Fork of the Brazos River near Aspermont (SFAS06)

3.2 Naturalized Streamflow at Ungaged Locations

3.2.1 Distribution of Naturalized 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 include reservoir locations, diversion points, and the ends of classified stream segments. The locations of all primary and secondary control points utilized in the water availability model of the Brazos River Basin and the San Jacinto-Brazos Coastal Basin are shown in the maps included as Appendix XV.

Several alternative algorithms are coded into the WRAP Model to distribute naturalized flows from primary ("known-flow") control points to secondary ("unknown-flow") control points using watershed characteristics such as drainage area, runoff curve number, and mean annual precipitation. The method used can vary by control point. Only three of the methods available in WRAP can correctly account for channel losses when distributing flows, INMETHOD3, INMETHOD6 and INMETHOD8. INMETHOD3 utilizes a regression-type equation that can incorporate channel losses into the formulation. INMETHOD6 utilizes drainage area ratios adjusted for channel losses. INMETHOD8 utilizes the NRCS runoff curve number approach, adjusted for channel losses. The theoretical bases and the application of all INMETHOD's are described in the WRAP Users Manual.

Due to data irregularities in the curve number and precipitation data provided by the TNRCC through the CRWR, naturalized flows were distributed to secondary control points using INMETHOD6 (drainage area ratios adjusted for channel losses), except for instances where INMETHOD2 was used to set flows at a secondary control point equal to those at a primary control point. INMETHOD2 was used in instances when the drainage areas between secondary control points and proximate primary control points were nearly identical.

3.2.2 Ungaged Freshwater Inflows to Galveston Bay and the Gulf of Mexico

Naturalized streamflows for control points BRGM73 (Brazos River at the Gulf of Mexico), SJGBC3 (San Jacinto-Brazos Coastal Basin at Galveston Bay) and SJGMC4 (San Jacinto-Brazos Coastal Basin at the Gulf of Mexico) represent all flows from the subject basins to Galveston Bay and the Gulf of Mexico, including ungaged runoff. As such, these control points do not represent discrete points, but rather, all of the watershed area in the two basins that contributes flow to Galveston Bay and Gulf of Mexico. The naturalized flows for those control points were developed utilizing the functional relationships presented in Table 3-3.

3.3 Net Reservoir Evaporation

3.3.1 Evaporation and Precipitation Data Sources

3.3.1.1 TWDB Quadrangle Data

Since the turn of the century, precipitation gages and evaporation pans have been maintained at various locations throughout the state by numerous federal and state agencies, municipalities, and local interests. The TWDB has compiled much of the available historical precipitation and pan evaporation data and developed monthly precipitation and reservoir gross evaporation rates for the entire state by one-degree quadrangles of latitude and longitude for the

1940 to 1997 period.[46,47] The precipitation and gross evaporation data can be combined into "net" reservoir evaporation rates for each one-degree quadrangle by subtracting the precipitation depths from the evaporation depths.

For large reservoirs (capacity greater than 5,000 acft), the TWDB quadrangle data were used to determine reservoir evaporation rates during both the naturalization and simulation processes if data were not available from proximate evaporation and precipitation stations. Evaporation from the numerous smaller reservoirs and stock ponds was not considered in the streamflow naturalization process.

3.3.1.2 Evaporation and Precipitation Stations Near Major Reservoirs

Precipitation gages and evaporation pans maintained near ten reservoirs in the Brazos River Basin are listed in Table 3-5. Data from these gages were used for the reservoirs listed in Table 3-5, supplemented with the TWDB quadrangle data for periods of incomplete or missing record.

Table 3-5. Evaporation and Precipitation Stations Near Major Reservoirs

Reservoir	*Evaporation Stations*	*Period*	*Precipitation Stations*	*Period*
Abilene	None		Lake Abilene	1960–1998
Whitney	Whitney Dam	1952–1998	Whitney Dam	1948–1998
Waco	Waco Dam	1963–1998	Waco Airport	1880–1998
Proctor	Proctor Reservoir	1961–1998	Proctor Reservoir	1961–1998
Belton	Belton Dam	1962–1998	Belton Dam	1962–1998
Stillhouse Hollow	Stillhouse Hollow Dam	1962–1998	Stillhouse Hollow Dam	1961–1998
Georgetown	Georgetown Lake	1977–1998	Georgetown Lake	1977–1998
Granger	Granger Dam	1977–1998	Granger Dam	1977–1998
Somerville	Somerville Dam	1963–1998	Somerville Dam	1963–1998
Smithers	Thompsons 3 WSW	1956–1998	Thompsons 3	1956–1998

[46] TWDB, "Monthly Reservoir Evaporation Rates for Texas Using GIS," March 1998.
[47] TWDB, "Revised Gross Evaporation and Precipitation Data for Texas, " 2000.

3.3.2 Procedures for Estimation of Adjusted Net Evaporation

Based on a TNRCC technical memorandum issued in 1999,[48] this document defines effective precipitation as "the quantity of precipitation that does not contribute to the surface water flows in a subject watershed because of natural depletions (e.g., infiltration, consumptive use, or interception). Effective precipitation is usually calculated by reducing observed precipitation by an estimate of precipitation that is expected to runoff and contribute to streamflow based on rainfall/runoff relationships in the subject watershed." Until 1996, the TWDB[49] published "adjusted net" evaporation rates on a quadrangle basis for the 1940–1990 period, but has since ceased doing so. The precipitation subtracted from the gross evaporation rates was "effective" precipitation, representing "rainfall over the reservoir site less the amount that has run off and is already reflected in the runoff records. The part of the rainfall that appears as runoff must be deducted to prevent duplication of this amount of water in planning studies."[50] Because the TWDB no longer publishes "adjusted net" evaporation on a quadrangle basis, the quadrangle data published by the TWDB and the gage data at major reservoirs were adjusted during the course of this study.

3.3.2.1 Adjusted Net Evaporation Utilized in the Streamflow Naturalization Process

When adjusting gaged streamflows for upstream reservoir evaporation (Figure 3-1), the evaporation depths utilized must be the "adjusted net" evaporation, as previously defined. The data from the precipitation and evaporation stations identified in Table 3-5 were used for the associated reservoirs to compute adjusted net evaporation. For major reservoirs without nearby data stations, weighted averages of data for proximate TWDB quadrangles were used. Quadrangle and gage precipitation were adjusted to represent "effective" precipitation using unit runoff values from selected headwater streamflow gages located in each quadrangle, and the resulting effective precipitation was subtracted from the applicable evaporation data to arrive at adjusted net evaporation for each reservoir. Specific techniques for determining unit runoff for each quadrangle are described in a report on streamflow naturalization.[51]

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[48] TNRCC, "WAM Resolved Technical Issues: 7. Net Evaporation," January 1999.
[49] TWDB, "Report 64, Monthly Reservoir Evaporation Rates Data for Texas, 1940 through 1965, " October 1967.
[50] Ibid.
[51] F&N and HDR, "Naturalized Flow Estimates for the Brazos River Basin and the San Jacinto-Brazos Coastal Basin," TNRCC, October 2001.

3.3.2.2 Adjusted Net Evaporation Utilized in the Model Simulations

WRAP includes a procedure to "adjust" net evaporation rates for effective precipitation on a control point-by-control point basis during the model simulation. Most reservoirs are located at secondary control points, to which naturalized flows are distributed from adjacent primary control points. In order to maintain consistency between the distributed naturalized flows and the adjustments to net reservoir evaporation made by WRAP, net reservoir evaporation data (not adjusted) were utilized in the model instead of the adjusted net reservoir evaporation used in during streamflow naturalization. All reservoir evaporation rates input to the model were unadjusted net rates, and net reservoir adjustments were made internally by WRAP.

3.4 Reservoir Elevation-Area-Capacity Relationships

3.4.1 Large Reservoirs

Table 3-6 lists large reservoirs (generally with capacity greater than 5,000 acft) in the Brazos River Basin and San Jacinto-Brazos Coastal Basin, for which area-capacity data are available. For the reservoirs listed in Table 3-6, the as-built area-capacity relationship was obtained and utilized for Runs 1 through 7, limited by the authorized storage for each reservoir. For Run 8 (Current Conditions Run), the area-capacity relationship from the most recent bathymetric survey was utilized, adjusted for estimated sediment accumulation between the date of survey and year 2000. Sediment accumulation was distributed uniformly throughout the area-capacity curve using the average end area method.

Table 3-6. Large Reservoirs in the Brazos River Basin and San Jacinto-Brazos Coastal Basin

Reservoir	Conservation Storage (acft) Permitted	Conservation Storage (acft) Original	Conservation Storage (acft) Surveyed	Original Source	Recent Source if different from the Original	Year	Accumulation Rate (acft/yr)	Year 2000 Capacity (acft)
White River	44,897	44,910	31,843	TWDB [1]	TWDB [6]	1993	438.8	28,774
Buffalo Springs	4,730	4,200 [9]		TWDB [1]			21.24	3,411
Alan Henry	115,937	115,937		Freese and Nichols [2]			35.5	115,773
Davis	4,477	4,477		Freese and Nichols [2]			9.6	4,085
Sweetwater	10,000	11,900 [8]		TWDB [1]			21.84	10,764
Abilene	11,868	5,064		TWDB [1]			50.6	4,184
Kirby	8,500	8,500 [7]		TWDB [1]			20.24	6,426
Fort Phantom Hill	73,960	74,310	70,036	TWDB [1]	TWDB [6]	1994	109.58	69,379
Stamford	59,810	63,080	47,608	TWDB [1]	TWDB [6]	1999	70.27	47,557
Cisco	45,000	26,000		TWDB [1]			4.16	25,501
Hubbard	320,000	317,750	324,983	Freese and Nichols [2]	TWDB [6]	1997	172.96	324,464
Daniel	11,400	10,005	9,515	Freese and Nichols [2]	TWDB [1]	1973	9.2	8,847
Millers Creek	30,696	31,210	29,171	TWDB [1]	TWDB [6]	1993	186.3	26,631
Graham	52,389 [11]	53,680	45,302	TWDB [1]	TWDB [6]	1998	209.45	44,883
Possum Kingdom	724,739	724,700	556,220	TWDB [1]	TWDB [6]	1993	701.15	552,013
Palo Pinto	44,100 [12]	44,100	27,650	TWDB [1]	HDR [14]	1985	82.98	26,405
Mineral Wells (HDR did study on Mineral Wells)	8,140 [13]	6,760		TWDB [1]			20.16	6,155
Squaw Creek	151,500	151,047		Freese and Nichols [2]	TWDB [6]	1997	23.04	151,015
Granbury	155,000	153,485	136,823	TWDB [1]	TWDB [6]	1994	667.08	132,821
Pat Cleburne	25,600	25,560	25,730	TWDB [1]	TWDB [6]	1998	59.0	25,612
Whitney	50,000	642,179	627,100	TWDB [1]			1,855.66	549,788
Aquilla	52,400	50,740	44,359	Freese and Nichols [2]	TWDB [6]	1996	531.75	41,700
Waco	104,100	152,500	144,830	TWDB [1]	TWDB [6]	1995	174.36	143,958
Tradinghouse	37,814	37,814		TWDB [1]			23.4	37,065
Lake Creek	8,500	8,400		TWDB [1]			10.2	7,910

Table 3-6. Large Reservoirs in the Brazos River Basin and San Jacinto-Brazos Coastal Basin (Continued)

Reservoir	Conservation Storage (acft)			Original Source	Recent Source if different from the Original	Year	Accumulation Rate (acft/yr)	Year 2000 Capacity (acft)
	Permitted	Original	Surveyed					
Leon	28,000	27,290	26,940	TWDB [1]			12.6	26,710
Proctor	59,400	59,387	55,588	TWDB [1]	TWDB [6]	1994	126.63	54,702
Belton	457,600	457,600	434,500	TWDB [1]	TWDB [6]	1994	577.5	432,978
Stillhouse Hollow	235,700	235,700	226,063	TWDB [1]	TWDB [6]	1995	356.85	224,279
Georgetown	37,100	37,100	37,010	TWDB [1]	TWDB [6]	1995	6.0	36,980
Granger	65,500	65,500	54,280	TWDB [1]	TWDB [6]	1995	748.0	50,540
Bryan Utilities	15,227	15,277		Freese and Nichols [2]			0.0	15,227
Alcoa	14,750	14,750		TWDB [1]			3.18	13,876
Somerville	160,110	160,100	155,062	TWDB [1]	TWDB [6]	1996	148.0	154,254
Mexia	9,600	10,000	4,806	TWDB [1]	TWDB [6]	1996	157.1	4,191
Limestone	225,400	225,400	215,751	Freese and Nichols [3]	TWDB [6]	1993	645.9	211,230
Twin Oaks	30,319	30,300		Freese and Nichols [2]			32.4	29,611
Camp Creek	8,400	8,550		TWDB [1]			28.8	7,052
Gibbons Creek	32,084	26,800		Freese and Nichols [2]			11.52	31,946
Smithers	16,500	18,700		TWDB [1]			8.9	18,425
Eagle Nest Lake & Manor Lake	18,000	11,315		Freese and Nichols [4]			0.0	11,315
William Harris	10,200	12,000		TWDB [1]			0.0	12,000
Post	57,240			Freese and Nichols [2]			0.0	57,240
Brushy Creek	6,560			SCS			0.0	6,560

[1] TWDB, "Report 126: Engineering Data on Dams and Reservoirs in Texas Part II," November 1973.
[2] Freese and Nichols, Inc. files
[3] Freese and Nichols, Inc., "Memorandum Report on Yield Analysis of Lake Limestone for the Brazos River Authority," January 1990.
[4] Freese and Nichols, Inc., calculations from USGS quad maps.
[5] Freese and Nichols and Brown and Root, "Report on Allens Creek Reservoir Supporting an Application to Amend Permit 2925 prepared for Brazos River Authority, City of Houston, and TWDB," May 2000.
[6] Bathymetric Survey by TWDB
[7] Capacity in 1941 US SCS survey
[8] Capacity in 1948 Water Supply Report by Freese and Nichols
[9] Capacity in 1957
[10] Capacity in 1971 by Freese, Nichols, and Endress
[11] Combined permitted capacity of Lake Eddleman and Lake Graham when they combined in 1959
[12] Lake Palo Pinto enlarged from 34,250 acre-feet in 11/65
[13] Lake Mineral Wells enlarged from 7300 acre-feet in 1943
[14] HDR, "Yield Studies of Lake Palo Pinto and Turkey Peak Reservoir Site," Palo Pinto Municipal Water District No. 1, March 1986.

3.4.2 Small Reservoirs

Reliable area-capacity relationships for small reservoirs (less than 5,000 acft) generally are not available in the Brazos River Basin and San Jacinto-Brazos Coastal Basin. For these reservoirs, five generalized relationships were developed according to location within the basin and type of reservoir.

Data were obtained from the TNRCC dam safety inventory for all recorded dams and reservoirs in the Brazos and San Jacinto-Brazos basins.[52] The reservoirs were sorted into two categories based upon whether the dams impounded a main stem river or a smaller stream, and grouped into upper, middle or lower portions of the basins. Off-channel reservoirs were placed into a separate group.

The normal storage capacity and reservoir surface area was plotted for each reservoir in each group, and a curve of the form:

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

was fit to the data using least squares regression. The form of the equation follows that required by WRAP for generalized reservoir area-capacity curves.

Inspection of the data indicated that a single relationship was satisfactory for reservoirs on smaller streams in the upper and middle portion of the basin. Limited data were available for reservoirs on main stem rivers in the lower basin, so the relationship for main stem reservoirs in the middle portion of the basin was adopted. Coefficients for the resulting reservoir area-capacity curves utilized for smaller reservoirs in the WRAP model are shown in Table 3-7. The curves are plotted in Figure 3-9.

Table 3-7. Generalized Reservoir Area-Capacity Curves for Small Reservoirs

Category	***a***	***b***	***c***	***R^2 Value***
Upper Segment and Middle Segment Creeks	0.4897	0.7633	0.0	0.7921
Lower Segment Creeks	0.8475	0.6756	0.0	0.9343
Upper Segment Rivers	0.8109	0.6681	0.0	0.8880
Middle Segment and Lower Segment Rivers	0.5228	0.8206	0.0	0.9286
Off Channel Reservoirs	0.2710	0.8958	0.0	0.8156
Where: SA = a*(storage^b)+c				

[52] TNRCC, dam safety inventory database obtained from Mike Lowe, October 2000.

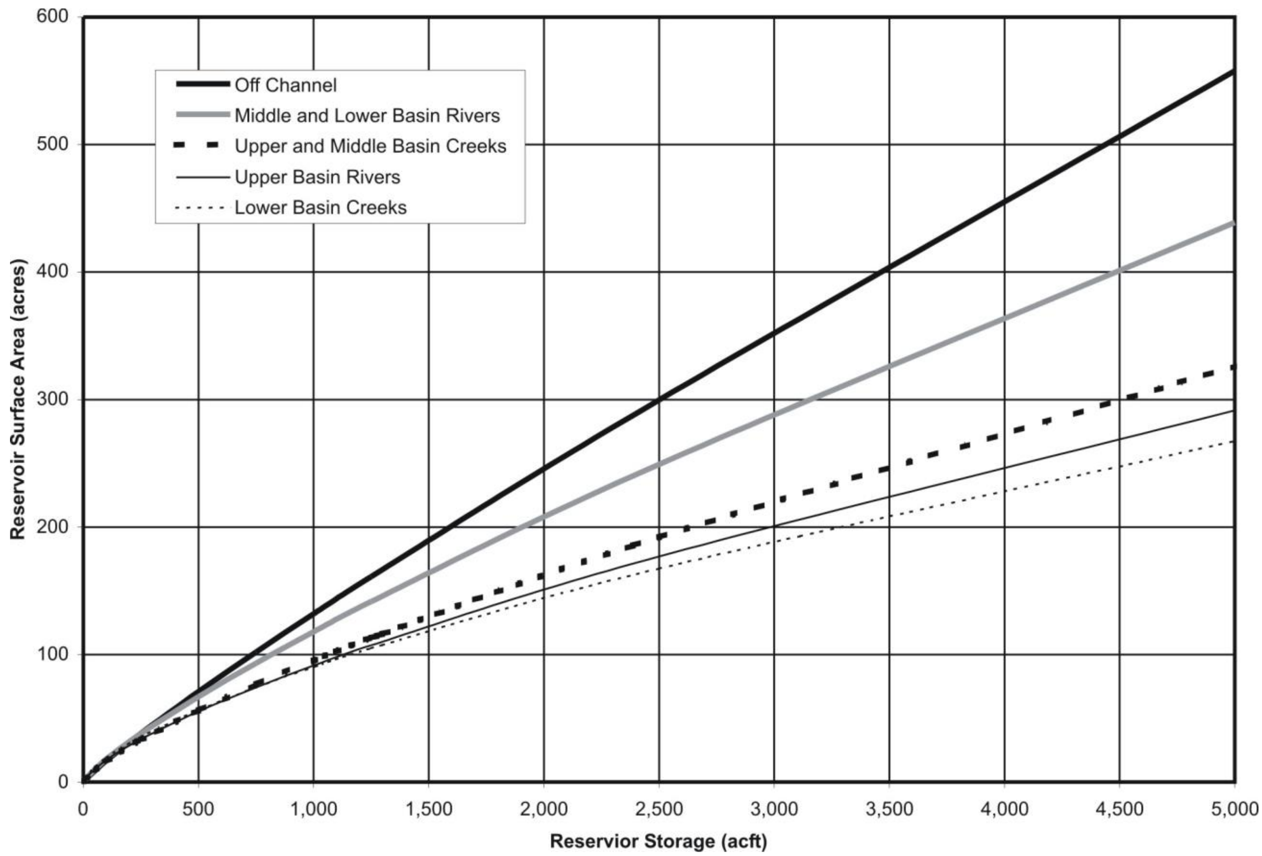

Figure 3-9. Generalized Storage-Area Relationships for Small Reservoirs

3.5 Aquifer Recharge

Aquifer recharge is not addressed in the water availability model for the Brazos River Basin and San Jacinto-Brazos Coastal Basin.

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Section 4
Water Availability Model of the Brazos River Basin and the San Jacinto-Brazos Coastal Basin

4.1 Description of the WRAP Model

The Texas A&M University Water Rights Analysis Package (TAMUWRAP) was developed and initially documented in 1988[53] as a single simulation program written in the Fortran programming language. The initial application of the model to the Brazos River Basin was documented by Wurbs, et al.,[54] and by Walls.[55] 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[56] and by Dunn.[57]

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 July 2001 version of the package (WRAP) includes the simulation program, WRAP-SIM, which is an enhanced version of WRAP3; the post-processor program, TABLES; and an input processor used to facilitate development of hydrologic input, WRAP-HYD. The July 2001 version of WRAP is documented in a user's manual.[58] 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. The WRAP simulation program used

[53] 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.
[54] 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.
[55] 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.
[56] 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.
[57] Dunn, D.D., "Incorporation of System Operation Strategies in Water Rights Modeling and Analysis," Master of Science Thesis, Texas A&M University, December 1993.
[58] Wurbs, R.A., "Reference and Users Manual for the Water Rights Analysis Package (WRAP)," Third Edition, TR-180, Texas Water Resources Institute, Texas A&M University, July 2001 (model code updated November 2001).

for this study is the July 2001 version, modified in November 2001 to correct known problems with the algorithms for distributing naturalized flows from primary to secondary control points.[59]

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

4.1.1 Base WRAP Simulation Program

A WRAP simulation requires several input data files. Data within these files describe the locations of water rights (control points—CP records); inflows (naturalized flows, return flows and gains/losses) and evaporation at those control points (IN, FD, WP, CI, FA 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, SO, 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 its primary computation with 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,

[59] Wurbs, R.A., email transmittal of updated July 2001 WRAP, November 26, 2001.

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 specified. 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, SO 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 WRAP simulation program used for this study is the July 2001 version, modified in November 2001 to correct known problems with the algorithms for distributing naturalized flows from primary to secondary control points.[60]

[60] Wurbs, R.A., email transmittal of updated July 2001 WRAP, November 26, 2001.

4.1.2 Basin-Specific WRAP Model

No basin-specific modifications to the WRAP Model were made for the Brazos River Basin and San Jacinto-Brazos Coastal Basin.

4.2 Development of WRAP Water Rights Input File

4.2.1 Control Points

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

The TNRCC provided a database of 3,113 water right locations in a geographic information system (GIS). Water right locations include diversion locations, the locations of on- and off-channel reservoirs, and return flow locations when specified in an individual water right. 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 (12 for the Brazos River Basin and 11 for the San Jacinto-Brazos Basin);

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

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

In addition to the water right locations, the TNRCC supplied the locations of 109 water quality segment endpoints.

Other locations were provided to the TNRCC by HDR to facilitate model input development. HDR identified 239 confluence points located immediately downstream of the confluences with main stem rivers of tributary drainages in which water right diversions are located; the locations of 210 wastewater treatment plant outfalls permitted for 0.9 MGD or greater; and locations of 77 control points for which naturalized flows have been developed.

Control points for which naturalized streamflows have been developed from streamgage data are referred to as “primary” control points. Control points for which naturalized flows have not been developed are referred to as “secondary” control points.

Watershed data for the drainage areas above each primary and secondary control point were developed by the University of Texas Center for Research in Water Resources (CRWR) and provided by the TNRCC. For each control point, the CRWR calculated drainage area, NRCS composite runoff curve number (antecedent moisture condition (AMC) II), mean annual precipitation, and stream length from the point to the basin outlet. These data are utilized in WRAP to distribute naturalized flows from primary to secondary control points during model simulation. Due to data irregularities in the curve number and precipitation data, the TNRCC directed that only the drainage area data be used to distribute naturalized flows to secondary control points.

Six additional control points were added to the data set during preparation of the model input data. Control points IB4128, IB5287, IB5291 and D56771 were added so that interbasin transfers could be addressed associated with Certificates of Adjudication 4128, 5287 and 5291, and Permit 5677. Control points D34583 and D53251 were added to facilitate modeling of special conditions associated with Certificates of Adjudication C3458 (Lakes Eddleman and Graham) and Certificates of Adjudication 5320 and 5325 (Smithers Lake). None of these points required watershed data except for D34583, which represents the combined drainage areas of Lakes Eddleman and Graham.

All return flow points were included in the model as headwater tributary points with zero drainage areas, so that naturalized flows would not be distributed to return flow points. This was done so that the only flows available at a return flow point are those returned from a water right diversion or included on a CI record as a groundwater return. For rights dependent upon continuation of upstream wastewater effluent, water availability was determined at the applicable return flow points only. This facilitates development of data sets for the various reuse scenarios, because diversions dependant upon return flows do not have to be modified.

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[61] and in the WRAP Users Manual. 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 XIV (bound separately).

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

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

Channel loss factors for subreaches on tributaries for which delivery factors are not known were set to zero. The channel loss factors distributed to subreaches are shown in Appendix V.

The control points utilized in the model are shown on the maps included in Appendix XV. The table in Appendix V lists each control point included in the model and the channel loss factors distributed to subreaches between secondary control points. Control points listed in Appendix V with downstream control point IDs of "OUT" either discharge out of the basin or are off-channel reservoir or diversion points. Because WRAP allows a maximum of 6 characters to identify a control point, the 11-digit control point identifiers assigned by the TNRCC were reduced to 6 digits in the WRAP input files. Both sets of identifiers are shown in Appendix V.

The 11-character identifiers assigned by the TNRCC were reduced to 6-characters by retaining the 4-digit certificate or permit number, followed by two digits to represent the last three digits in the 11-character ID (the middle digit is dropped). For example, a 6-character ID for a reservoir point will end in "31" instead of "301." Occasionally, the 6-character IDs for a permit and a certificate of adjudication were identical, and a "C" or a "P" was added at the front, dropping one of the last two digits to retain the maximum allowed length of 6 characters. IDs for

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

confluence points begin with "CON" and end in sequential three-digit numbers, generally progressing from upstream to downstream in the basin. Six-character IDs for wastewater effluent discharge points are based upon the first five and last digits of the PNUM identifiers of the wastewater outfalls each represents.

4.2.2 Monthly Demand Distribution Factors

WRAP utilizes seasonal patterns to distribute annual permitted diversions to monthly diversion targets. The water use data utilized in the flow naturalization process were used to develop demand distribution patterns for the four basin segments: upper, upper middle, lower middle and lower and coastal. Surface water use for mining, recreation and other uses was assumed to occur uniformly throughout the year. The seasonal demand patterns for municipal, industrial and irrigation uses are shown in Table 4-1. Demand patterns for water rights authorized for domestic and livestock use were assumed to follow the municipal patterns.

4.2.3 Water Rights

Data contained in the TNRCC water rights master file database table, WRDETAIL, dated July 20, 2000, were used to develop water rights input for WRAP. Paper copies of all certificates of adjudication and permits, as amended, were compared with the data in WRDETAIL. Discrepancies between the paper rights and WRDETAIL were noted and supplied to the TNRCC in a memorandum[62] (Appendix II), and corrections were made to 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 group based on analysis of the individual portions depicted on WR records.

[62] HDR, "Brazos WAM: Review of Water Rights Database," memorandum, June 20, 2001 (revised August 24, 2001).

The revised WRDETAIL was used to develop a base WRAP water rights input file from which input files for the simulations described in Section 5 were developed. The data file for Run 1 is included as Appendix XIV (bound separately) and includes all of the water right information utilized in the Brazos River Basin and San Jacinto-Brazos Coastal Basin WRAP model, as well as the records used to specify control points (CP records), groundwater-based 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.

Many rights include special conditions specifying instream flow requirements, and records that describe these conditions (IF records) are also included in Appendix XIV. 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.

4.2.3.1 Priority Dates

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

4.2.3.2 Treatment of Reservoir Storage

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

Case 1. Most rights are authorized to impound water in, and divert from, a single reservoir with a single date of priority for both the impoundment and diversion portions of the right. In these cases, the right is modeled with a single pair of WR/WS records. This is the general case used for most impoundment rights. In cases where the impoundment and diversion have different dates of priority, the individual portions are modeled at their respective dates of priority with separate WR and/or pairs of WR/WS records.

Case 2. Many rights are authorized for impoundment in one or more reservoirs, each with a specific date of priority for impoundment, and diversion amounts authorized specifically for each reservoir. In these cases, each individual reservoir is modeled with a separate pair of WR/WS records.

Case 3. Several rights are authorized to impound in multiple reservoirs, with the authorized diversion taken from any of the reservoirs. In these cases, each reservoir is modeled with an impoundment-only right (no authorized diversion), and the authorized diversion is placed at the furthest downstream control point associated with the right. The reservoirs are then specified as a system and allowed to make releases to the diversion point using the system operation capability in WRAP.

Case 4. Several rights are authorized to impound to different storage levels in a reservoir subject to different dates of priority, with the greater storage levels having later dates of priority. In these cases, the impoundment portion of the right is modeled with multiple pairs of WR/WS records with different priority dates.

Case 5. Several rights are authorized to impound water in multiple reservoirs with relatively small storage capacities. 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 and instream flow requirements. However, several rights are authorized to divert water into off-channel storage reservoirs that have little or no drainage area. The rights are then allowed to subsequently divert from the reservoir for the authorized use. WRAP includes a capability specifically designed to accommodate off-channel reservoir impoundment rights by specifying an alternate control point (main channel) from which water is to be diverted into the off-channel reservoir and specifying the monthly and annual maximum diversion amounts. If no maximum rate of diversion from the main channel is specified in the right, the off-channel reservoir is treated as an on-channel reservoir.

Most rights authorized for off-channel storage of flows diverted from adjacent rivers or streams specify a maximum annual amount that may be diverted from the stream, with subsequent diversion allowed from the off-channel reservoir. Generally, with few exceptions, the maximum amount that can be diverted from the off-channel reservoir is identical to the maximum annual amount that can be diverted from the stream, and no consideration is made for evaporative loss from the off-channel reservoir. In these cases, the annual quantity that can be diverted from the reservoirs is less than the quantity that can be diverted from the stream because of evaporative losses. The TNRCC has directed that, unless allowance for reservoir evaporation is specified in the water right or the authorized diversion from the reservoir is less than the authorized diversion from the stream, that the two diversion amounts be modeled at the diversion amount authorized from the stream. Rights modeled in this fashion will never achieve 100 percent reliability because the evaporative losses will reduce stored water available for diversion.

4.2.3.3 Return Flows

Table 4-2 presents two interbasin transfers and 76 discharges of treated effluent (permitted for 0.9 MGD or greater) originating from groundwater sources or from water imported from outside the Brazos River Basin and San Jacinto-Brazos Coastal Basin. These data are included in the model at their respective points of discharge using the 12 monthly values input on CI records. Each monthly value for a given wastewater plant represents the minimum quantity discharged for the given month during the five year 1993–1997 period. The discharges for the two interbasin transfers are made available only to the two receiving rights in the Brazos River Basin, and are included at the direction of the TNRCC such that 100 percent reliability will be computed for those rights.

Discharges of treated effluent originating from surface water sources (water right diversions) were included in the model using either constant or monthly varying return flow factors (RFAC = 1 - Consumptive Use/Authorized Diversion), depending upon availability of data. These return flow factors were developed from the self-reported discharges and associated diversions for each municipal and industrial water right in the basin for which sufficient data were available. Many rights authorized for municipal use do not return flows to a specific wastewater treatment facility and have no associated return flow factors. In many instances wastewater from customers served by the holders of these rights is usually discharged into septic

Table 4-1. Seasonal Demand Patterns

Type of Use	Basin Segment	Monthly Fraction of Annual Authorized Use											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Irrigation	Upper	0.024	0.033	0.050	0.058	0.082	0.182	0.201	0.178	0.087	0.046	0.036	0.023
Irrigation	Upper Middle	0.005	0.007	0.017	0.033	0.092	0.163	0.267	0.235	0.117	0.044	0.014	0.007
Irrigation	Lower Middle	0.005	0.008	0.018	0.032	0.075	0.189	0.304	0.253	0.079	0.022	0.008	0.007
Irrigation	Lower and Coastal	0.006	0.009	0.018	0.056	0.110	0.203	0.239	0.209	0.069	0.046	0.028	0.007
Industrial	Upper	0.054	0.060	0.070	0.083	0.094	0.105	0.113	0.106	0.096	0.083	0.072	0.062
Industrial	Upper Middle	0.054	0.060	0.070	0.083	0.094	0.105	0.113	0.106	0.096	0.083	0.072	0.062
Industrial	Lower Middle	0.058	0.077	0.087	0.097	0.107	0.124	0.128	0.124	0.078	0.041	0.038	0.041
Industrial	Lower and Coastal	0.058	0.077	0.087	0.097	0.107	0.124	0.128	0.124	0.078	0.041	0.038	0.041
Municipal	Upper	0.066	0.064	0.071	0.077	0.092	0.100	0.115	0.104	0.092	0.079	0.070	0.068
Municipal	Upper Middle	0.065	0.063	0.068	0.072	0.085	0.093	0.118	0.114	0.095	0.087	0.071	0.069
Municipal	Lower Middle	0.065	0.063	0.066	0.069	0.082	0.105	0.111	0.106	0.100	0.089	0.074	0.069
Municipal	Lower and Coastal	0.063	0.066	0.074	0.082	0.091	0.099	0.108	0.103	0.094	0.085	0.073	0.063

Table 4-2. Interbasin Transfers and Treated Effluent Discharges from Groundwater or Out-of-Basin Sources Included on CI Records (All Values in acft)

Control Point ID	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total	Permit Owner	PNUM	Comment
105371	163	164	176	168	180	168	182	185	180	184	167	169	2,086	City of Plainview	10537.000	Import from CRMWA
BRSE11	6	6	6	6	1	6	7	0	7	7	6	7	65	City of Seymour	10281.000	Groundwater
GHGH24	19	20	24	4	30	31	28	27	26	24	21	19	273	City of Olney	10050.000	Imported from City of Wichita, Lake Olney/Cooper
370751	9	8	10	11	10	11	11	11	11	11	12	13	128	City of Ransom Canyon	10778.000	Imported surface water and groundwater from Lubbock
101782	11	9	10	14	14	19	25	21	13	14	10	10	170	City of Granbury	10178.002	Groundwater
515651	10	13	6	6	10	8	7	10	8	9	12	11	110	Acton MUD	11208.000	Groundwater
515651	7	11	4	4	8	7	6	8	6	7	9	9	86	Acton MUD	11415.000	Groundwater
410501	4	3	3	4	2	4	1	3	2	1	3	4	34	City of Godley	10542.001	Groundwater
409631	11	10	14	14	17	17	17	17	16	18	15	11	177	City of Glen Rose	10177.001	Groundwater
515731	5	14	14	13	9	6	10	10	10	10	12	3	116	City of Whitney	11408.002	Groundwater
106301	10	9	9	8	10	7	7	9	7	9	10	9	104	City of Itasca	10423.001	Groundwater
NBHI35	5	4	5	5	3	5	4	5	5	5	5	5	56	City of Hico	10188.001	Groundwater
102902	113	112	115	126	126	127	110	83	72	116	109	104	1,313	City of Stephenville	10290.001	Groundwater
555151	16	12	10	11	5	13	12	2	11	12	8	9	121	City of Clifton	10043.001	Groundwater
228202	10	10	9	11	11	2	7	4	5	6	7	11	93	City of Meridian	10113.002	Groundwater
110711	291	273	271	292	287	237	272	278	275	308	257	307	3,348	BRA WMARSS Plant	11071.001	Groundwater
W12252	1	2	2	0	0	2	2	0	4	0	2	0	15	City of Valley Mills	10307.001	Groundwater

Table 4-2. Interbasin Transfers and Treated Effluent Discharges from Groundwater or Out-of-Basin Sources Included on CI Records (Continued)

Control Point ID	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total	Permit Owner	PNUM	Comment
CON070	8	10	18	10	7	6	4	4	5	7	13	8	100	City of West	10544.001	Groundwater
435201	5	6	7	5	5	5	4	4	5	5	5	5	61	City of Lorena	12195.001	Groundwater
W12431	3	3	5	4	6	3	4	3	4	3	3	4	45	City of Florence	10944.001	Groundwater
LRLR53	7	2	7	6	6	6	6	5	5	6	6	7	69	City of Little River/Academy	10318.001	Groundwater
104893	79	67	85	85	80	84	80	78	87	84	82	87	978	City of Georgetown	10489.002	Groundwater
104892	33	29	36	36	34	35	34	33	37	36	35	37	415	City of Georgetown	10489.003	Groundwater
102641	61	33	44	51	60	54	60	77	81	92	87	83	783	City of Round Rock	10264.001	Groundwater
102642	69	37	49	57	67	60	68	85	91	102	97	92	874	City of Round Rock	10264.002	Groundwater
372751	8	9	10	2	8	6	1	3	3	7	10	10	77	City of Bartlett	10880.001	Groundwater
W12441	26	22	15	15	18	19	22	22	3	22	23	25	232	Brushy Creek MUD	11865.001	Groundwater
126441	10	7	7	8	9	9	10	11	12	12	12	11	118	City of Leander	12644.001	Groundwater
W12441	9	9	11	7	8	8	6	6	6	8	1	9	88	Block House MUD	13031.001	Groundwater/Import
114591	68	59	69	76	92	89	83	84	82	78	67	68	915	Anderson Mill MUD	11459.001	Import
123081	39	31	32	30	31	33	35	32	29	30	30	33	385	City of Cedar Park	12308.001	Import
100462	5	27	58	52	56	49	53	57	57	33	33	29	509	City of Hearne	10046.002	Groundwater
100462	10	9	10	9	10	10	10	0	10	10	9	10	107	City of Calvert	10095.001	Groundwater
MYDB60	4	4	5	6	6	0	6	6	0	5	5	5	52	City of Lexington	10016.001	Groundwater
CON224	18	15	16	16	20	19	18	19	24	25	20	32	242	City of Rockdale	10658.001	Groundwater
CON125	15	16	17	17	24	17	19	14	18	19	16	18	210	City of Giddings	10456.001	Groundwater
DCLY63	20	19	21	23	42	39	38	37	37	38	33	37	384	City of Caldwell	10813.001	Groundwater

Table 4-2. Interbasin Transfers and Treated Effluent Discharges from Groundwater or Out-of-Basin Sources Included on CI Records (Continued)

Control Point ID	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total	Permit Owner	PNUM	Comment
BGFR65	6	5	0	0	6	5	5	5	4	6	5	5	52	City of Teague	10300.001	Groundwater
NAGR64	42	23	39	40	42	39	36	42	32	36	37	41	449	City of Mexia	10222.001	Groundwater
NAGR64	14	8	13	13	14	13	12	14	10	12	12	14	149	Tx. Dept. MHMR	10717.001	Groundwater
25851	18	14	1	12	14	20	22	22	22	36	26	23	230	Texas A&M University	2585.001	Groundwater
100241	452	471	486	501	468	442	462	489	505	501	475	442	5,694	City of College Station	10024.006	Groundwater
102311	49	44	50	46	45	34	55	57	52	51	49	51	583	City of Navasota	10231.001	Groundwater
516451	3	3	3	15	14	1	4	1	3	3	3	0	53	City of Somerville	10371.001	Groundwater
104261	375	341	311	277	384	372	362	366	343	281	276	364	4,052	City of Bryan	10426.001	Groundwater
104262	140	94	113	94	139	147	141	140	153	160	154	132	1,607	City of Bryan	10426.002	Groundwater
526851	25	24	24	25	24	22	26	27	28	27	27	28	307	City of Bryan	10426.003	Groundwater
109681	94	94	112	121	125	127	134	129	127	131	115	106	1,415	Texas A&M University	10968.003	Groundwater
BRHE68	6	3	3	12	4	5	5	5	4	5	5	5	62	Texas Dept. of Criminal Justice	12458.002	Groundwater
BRHE68	19	17	19	18	18	16	16	17	18	17	18	19	212	Texas Dept. of Criminal Justice	13743.001	Groundwater
103851	36	34	33	32	36	31	33	36	30	31	27	29	388	City of Bellville	10385.002	Groundwater
516604	21	21	21	20	24	22	24	23	25	20	22	22	265	Brookshire MWD	10001.001	Groundwater
102581	56	55	56	55	62	56	57	59	54	56	54	59	679	City of Richmond	10258.001	Groundwater
102761	36	34	38	36	35	32	34	33	31	32	33	42	416	City of Sealy	10276.001	Groundwater
106073	10	45	60	67	104	117	99	102	94	76	73	81	928	City of Rosenberg	10607.003	Groundwater

Table 4-2. Interbasin Transfers and Treated Effluent Discharges from Groundwater or Out-of-Basin Sources Included on CI Records (Continued)

Control Point ID	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total	Permit Owner	PNUM	Comment
CON153	8	7	7	7	8	6	7	7	6	7	7	8	85	City of Wallis	10765.001	Groundwater
112751	55	62	51	50	53	26	25	32	67	62	55	37	575	Praire View A&M University	11275.002	Groundwater
CON150	16	1	17	13	18	23	29	27	28	29	29	28	258	City of Hempstead	10948.001	Groundwater
BRRI70	0	0	0	0	0	3	2	1	2	2	1	1	12	Fort Bend Co. MUD 081	13051.002	Groundwater
24431	35	9	22	17	12	5	5	4	0	10	1	1	121	Frito-Lay Inc.	2443.001	Groundwater
106072	106	82	102	96	90	89	90	89	89	83	82	91	1,089	City of Rosenburg	10607.002	Groundwater
102582	104	78	100	97	113	108	124	124	107	111	100	103	1,269	City of Richmond	10258.003	Groundwater
BRRO72	11	9	11	14	14	7	12	9	9	11	12	10	129	Texas Dept. of Criminal Justice	10986.001	Groundwater
113171	288	229	254	271	300	280	264	266	240	257	262	307	3,218	Brazos River Authority	11317.001	Groundwater
BRRO72	13	12	14	14	14	14	15	15	17	14	14	14	170	Texas Dept. of Criminal Justice	11475.001	Groundwater
BRRO72	10	9	10	10	10	10	10	10	11	10	10	10	120	Texas Dept. of Criminal Justice	11475.003	Groundwater
116551	49	48	49	56	66	63	63	59	60	56	47	55	671	Pecan Grove MUD	11655.001	Groundwater
BRRO72	21	16	17	18	17	15	17	18	16	17	17	17	206	Plantation MUD	11971.001	Groundwater
BRRO72	12	10	10	11	11	11	12	11	12	12	12	11	135	Fort Bend MUD 025	12003.001	Groundwater
BRRO72	1	1	1	1	2	3	4	5	4	3	2	1	28	Fort Bend MUD 041	12475.001	Groundwater
128331	167	149	165	165	185	188	204	215	206	193	173	184	2,194	City of Sugarland	12833.002	Groundwater
128332	523	473	523	506	523	506	523	523	506	523	506	523	6,158	City of Sugarland	12833.003	Groundwater

Table 4-2. Interbasin Transfers and Treated Effluent Discharges from Groundwater or Out-of-Basin Sources Included on CI Records (Concluded)

Control Point ID	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total	Permit Owner	PNUM	Comment
133551	4	4	10	7	10	11	13	13	12	16	9	8	117	Fort Bend MUD 106	13355.001	Groundwater
136281	1	1	1	1	1	1	2	2	1	1	1	1	14	Fort Bend MUD 112	13628.001	Groundwater
103121	77	74	69	66	61	51	58	49	52	49	52	53	711	City of West Columbia	10312.001	Groundwater
100471	34	6	16	30	40	46	24	29	34	42	14	12	327	City of Lake Jackson	10047.001	Groundwater
D56771	437	398	417	437	519	708	703	657	633	562	464	465	6,400	City of Leander	N/A	Interbasin transfer from Colorado River Basin
IB4128	478	436	457	477	568	774	769	718	692	615	508	508	7,000	City of Sweetwater	N/A	Interbasin transfer from Colorado River Basin

fields and not returned to a stream. Rights for which return flows could not be identified were assumed to have zero return flows.

Several industrial and mining rights include special conditions stipulating minimum percentages of flow to be returned. For these rights, the applicable monthly return flow factor was determined from the language of the water right.

Table 4-3 lists rights at reservoirs that are operated primarily for steam-electric or cooling water at power plants. These rights often include extremely large authorized diversions from the reservoirs, which are returned immediately to the reservoir (recirculated cooling water). A consumptive portion is also specified, representing additional evaporative loss due to the increased water temperature of the water returned to the reservoir (forced evaporation). For these rights, only the consumptive amounts (i.e., forced evaporation) are included as authorized use in the model and no return flows are specified.

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. Groundwater-based return flows included in CI records were reduced by 50 percent for Run 2 and set to zero for Run 3. Return flow factors were similarly reduced to one half the Run 1 factor for Run 2 and set to zero for Run 3. Return flow factors were reduced for all rights except those rights with return flow percentages stipulated by special condition.

Table 4-2 lists wastewater discharges included on CI records and the corresponding control points at which they were placed. Table 4-4 lists wastewater discharges included as return flows from water right diversions, and the method for calculating the return flow percentage (constant or monthly-varying factors). Table 4-5 presents the monthly-varying return flow factors referenced in Table 4-4. The discharge points (return flow locations) listed in Tables 4-2 and 4-4 are shown in Figure 4-1.

Table 4-3. Steam Electric Cooling Rights

Water Right ID	Owner	Reservoir	Authorized Reservoir Capacity (acft)	Authorized Annual Diversion (acft)	Authorized Annual Consumptive Use (acft)
C2939	Brazos Electric Cooperative	None[2]	none	65,058	38,800
C3758	Aluminum Company of America	None[3]	none	18,000	18,000
C4097	Texas Utilities Electric	Squaw Creek	151,500	3,547,500[1]	23,180
C4342	Texas Utilities Electric	None[4]	none	12,000	12,000
C4342	Texas Utilities Electric	Tradinghouse Creek	37,800	1,608,800[1]	15,000
C4345	Texas Utilities Electric	Lake Creek	8,500	329,400[1]	10,000
C4345	Texas Utilities Electric	None[5]	none	8,996	8,996
C5268	City of Bryan	Byran Utilities Lake	15,227	55,708	850
C5272	Aluminum Company of America	Alcoa Lake	15,650	291,200[1]	14,000
C5298	Texas Utilities Electric	Twin Oaks	30,319	1,378,000	13,200
C5307	Texas Municipal Power	Unnamed channel dam	17 [6]	6,000	6,000
C5311	Texas Municipal Power	Gibbons Creek	32,084	unlimited recirculation rate	9,740
C5325	Houston Lighting & Power	Smithers Lake	18,750	2,452,900[1]	34,300
P2925	TWDB/Brazos River Authority	Allens Creek	138,441	6,435,400[1]	46,256

1. No annual maximum diversion specified, only consumptive use. Annual authorized diversion estimated from maximum diversion rate for recirculation.
2. Run-of-the-river (once through cooling) from the Leon River.
3. Makeup diversions from the Little River into Alcoa Lake.
4. Makeup diversions from Brazos River into Tradinghouse Creek Reservoir.
5. Makeup diversions from the Brazos River into Lake Creek Reservoir.
6. Channel dam for makeup diversions from the Navasota River into Gibbons Creek Reservoir.

Table 4-4. Return Flows from Water Right Diversions

Water Right ID	Reservoir Name	Water Right Owner	Use	Authorized Diversions (acft/yr)	Return Flow Factor or Pattern	Return CP	Return PNUM	Owner of PNUM	Notes
C41 61	Fort Phantom Hill	City Of Abilene	Mun	500	RABIL1	10334 1	10786-002	City of Merkel	
C37 37		Alamo Concrete Products Ltd	Min	30	1.0	SGGE 55			
C51 61	Lake Stillhouse Hollow	Brazos River Authority	Mun	6,97 3	RBLSH1	10205 1	10205. 002	City of Lampasas	
P50 94	Lake Waco	City Of Waco	Mun	20,7 70	R50941	11071 1	11071. 001	Brazos River Authority	Remainder of Lake Waco right
C51 55	Possum Kingdom Lake	Brazos River Authority	Mun	1,00 0	0.5	02789 1	02789. 001	Double Diamond Utilities	
C51 55	Possum Kingdom Lake	Brazos River Authority	Mun	1,20 0	R43551	10110 2	10110. 002	City of Marlin	
C51 55	Possum Kingdom Lake	Brazos River Authority	Mun	315	R51711	10627 1	10627. 001	Baycliff MUD	GCWA to Baycliff MUD
C51 55	Possum Kingdom Lake	Brazos River Authority	Mun	473	R51711	10410 1	10410. 001	City of LaMarque	GCWA to City of LaMarque
C51 55	Possum Kingdom Lake	Brazos River Authority	Mun	2,05 1	R51711	10568 5	10568. 005	City of League City	GCWA to City of League City
C51 55	Possum Kingdom Lake	Brazos River Authority	Mun	3,54 9	R51711	10375 1	10375. 001	City of Texas City	GCWA to City of Texas City
C51 55	Possum Kingdom Lake	Brazos River Authority	Mun	1,49 9	R51711	10173 1	10173. 001	Galveston Co. WCID #1	GCWA to Galveston Co WCID#1
C51 55	Possum Kingdom Lake	Brazos River Authority	Ind	3,60 0	1.0	51555 1			Hydropower contract w Brazos Elec
C51 55	Possum Kingdom Lake	Brazos River Authority	Min	15	1.0	SHGR 26			MW Sands contract
C51 56	Lake Granbury	Brazos River Authority	Mun	6,70 5	R51561	10178 2	10178. 002	City of Granbury	
C51 58	Lake Aquilla	Brazos River Authority	Mun	1,65 0	R51581	10630 1	10630. 001	City of Hillsboro	Lakeside Municipal Use - Aquilla WSD
C51 60	Lake Belton	Brazos River Authority	Mun	7,05 6	RBLSH1	10219 1	10219. 002	City of McGregor	
C51	Lake Belton	Brazos River	Mun	3,43	RBLSH1	10176	10176.	City of	

60		Authority		2		1	002	Gatesville	

Table 4-4. Return Flows from Water Right Diversions (Continued)

Water Right ID	Reservoir Name	Water Right Owner	Use	Authorized Diversions (acft/yr)	Return Flow Factor or Pattern	Return CP	Return PNUM	Owner of PNUM	Notes
C5160	Lake Belton	Brazos River Authority	Mun	2,016	RBLSH1	101741	10176.001	City of Gatesville	
C5160	Lake Belton	Brazos River Authority	Mun	27,735	RBLSH1	103513	10351.002	Bell Co. WCID #1	
C5160	Lake Belton	Brazos River Authority	Mun	7,745	RBLSH1	103512	10351.003	Bell Co. WCID #1	
C5160	Lake Belton	Brazos River Authority	Mun	1,758	RBLSH1	100451	10045.004	City of Copperas Cove	Bell WCID to Copperas Cove
C5160	Lake Belton	Brazos River Authority	Mun	4,549	RBLSH1	100455	10045.005	City of Copperas Cove	Bell WCID to Copperas Cove
C5160	Lake Belton	Brazos River Authority	Mun	1,758	RBLSH1	100451	10045.003	City of Copperas Cove	Bell WCID to Copperas Cove
C5160	Lake Belton	Brazos River Authority	Mun	5,424	RBLSH1	101551	10155.001	City of Harker Heights	Bell WCID to Harker Heights
C5160	Lake Belton	Brazos River Authority	Mun	17,484	RBLSH1	113181	11318.001	Brazos River Authority	BRA Regional Plant - City of Temple releases
C5160	Lake Belton	Brazos River Authority	Mun	10,469	RBLSH1	104702	10470.002	City of Temple	
C5162	Lake Georgetown	Brazos River Authority	Mun	4,764	R51621	104893	10489.002	City of Georgetown	
C5162	Lake Georgetown	Brazos River Authority	Mun	2,041	R51621	104892	10489.003	City of Georgetown	
C5162	Lake Georgetown	Brazos River Authority	Mun	3,198	R51621	102641	10264.001	BRA & LCRA	Round Rock
C5162	Lake Georgetown	Brazos River Authority	Mun	3,607	R51621	102642	10264.002	BRA & LCRA	Round Rock
C5163	Lake Granger	Brazos River Authority	Mun	6,721	R51631	102991	10299.001	City of Taylor	
C5163	Lake Granger	Brazos River Authority	Mun	6,566	R51631	GALA57			Remaining right
C5164	Lake Somerville	Brazos River Authority	Mun	4,619	R51641	103881	10388.001	City of Brenham	
C53		Brazosport	Mu	11,7	R53661	10548	10548.	City of	

66		Water Auth.	n	00		1	001	Angleton	
C53 66		Brazosport Water Auth.	Mu n	13,5 00	R53661	10047 1	10047. 001	City of Lake Jackson	

Table 4-4. Return Flows from Water Right Diversions (Continued)

Water Right ID	Reservoir Name	Water Right Owner	Use	Authorized Diversions (acft/yr)	Return Flow Factor or Pattern	Return CP	Return PNUM	Owner of PNUM	Notes
C5366		Brazosport Water Auth.	Mun	7,650	R53661	108821	10882.001	City of Freeport	
C5366		Brazosport Water Auth.	Mun	12,150	R53661	100441	10044.001	City of Clute	
P3913		Capitol Aggregates Ltd	Min	70	1.0	373403			Sand and gravel mining
C4142	Lake Abilene	City Of Abilene	Mun	1,675	RABIL1	103341	10334.004	City of Abilene	
C4150	Lake Kirby	City Of Abilene	Mun	3,765	RABIL1	103341	10334.004	City of Abilene	
C4161	Fort Phantom Hill	City Of Abilene	Mun	25,190	RABIL1	103341	10334.004	City of Abilene	
C4214	Lake Daniel	City Of Breckenridge	Mun	2,100	R42131	100401	10040.001	City of Breckenridge	
C3761		City Of Cameron	Mun	2,792	R37611	100041	10004.001	City of Cameron	
C4106	Lake Pat Cleburne	City Of Cleburne	Mun	5,760	R41061	100061	10006.001	City of Cleburne	
C3458	Lake Graham/Eddleman	City Of Graham	Mun	4,000	R34581	104871	10487.001	City of Graham	
C3458	Lake Graham/Eddleman	City Of Graham	Mun	7,000	R34581	104871	10487.001	City of Graham	
C2971		City Of Lampasas	Mun	3,760	RBLSH1	102051	10205.002	City of Lampasas	
C4355	New Marlin Reservoir	City Of Marlin	Mun	4,000	R43551	101102	10110.002	City of Marlin	
C4355	New Marlin Reservoir	City Of Marlin	Mun	2,000	R43551	101102	10110.002	City of Marlin	
C4039	Lake Mineral Wells	City Of Mineral Wells	Mun	1,092	R40311	105852	10585.001	City of Mineral Wells	
C4039	Lake Mineral Wells	City Of Mineral Wells	Mun	588	R40311	105851	10585.004	City of Mineral Wells	
C40	Lake Mineral	City Of Mineral	Mu	546	R40311	10585	10585.	City of Mineral	

39	Wells	Wells	n			2	001	Wells	
C40 39	Lake Mineral Wells	City Of Mineral Wells	Mu n	294	R40311	10585 1	10585. 004	City of Mineral Wells	
P50 85		City Of Robinson	Mu n	3,29 0	R50941	11071 1	11071. 001	Brazos River Authority	
P50 85		City Of Robinson	Mu n	3,17 2	R50941	11071 1	11071. 001	Brazos River Authority	

Table 4-4. Return Flows from Water Right Diversions (Continued)

Water Right ID	Reservoir Name	Water Right Owner	Use	Authorized Diversions (acft/yr)	Return Flow Factor or Pattern	Return CP	Return PNUM	Owner of PNUI
P5085		City Of Robinson	Mun	1,805	R50941	110711	11071.001	Brazos River Autho
P5085		City Of Robinson	Mun	4,833	R50941	110711	11071.001	Brazos River Autho
C4179	Lake Stamford	City of Stamford	Mun	10,000	R41791	417951	10472.001	City of Stamford
C2938		City Of Temple	Mun	9,957	RBLSH1	113181	11318.001	Brazos River Autho
C2938		City Of Temple	Mun	5,847	RBLSH1	104702	10470.002	City of Temple
C2315	Lake Waco	City Of Waco	Mun	58,200	R50941	110711	11071.001	Brazos River Autho
C4340	Lake Waco	City Of Waco	Mun	5,600	R50941	110711	11071.001	Brazos River Autho
C5328	Brazoria Reservoir (Off-channel)	Dow Chemical Company	Mun	3,136	R53561	108821	10882.001	City of Freeport
C3465	Lake Eastland	Eastland County WSD	Mun	450	R34701	106371	10637.001	City of Eastland
C3470	Lake Leon	Eastland County WSD	Mun	1,560	R34701	106371	10637.001	City of Eastland
C3470	Lake Leon	Eastland County WSD	Mun	1,118	R34701	106371	10637.001	City of Eastland
C3470	Lake Leon	Eastland County WSD	Mun	810	R34701	106371	10637.001	City of Eastland
C2944		Franklin Limestone Co.	Min	138	1.0	294501		
C5168		Gulf Coast (Galveston County) Water Authority	Mun	1,999	R51711	106271	10627.001	Baycliff MUD
C5168		Gulf Coast (Galveston County) Water Authority	Mun	2,998	R51711	104101	10410.001	City of LaMarque
C5168		Gulf Coast (Galveston County) Water Authority	Mun	12,991	R51711	105685	10568.005	City of League City
C5168		Gulf Coast (Galveston County) Water Authority	Mun	22,485	R51711	103751	10375.001	City of Texas City
C5168		Gulf Coast (Galveston County) Water Authority	Mun	9,493	R51711	101731	10173.001	Galveston Co. WC #1

Table 4-4. Return Flows from Water Right Diversions (Concluded)

Water Right ID	Reservoir Name	Water Right Owner	Use	Authorized Diversions (acft/yr)	Return Flow Factor or Pattern	Return CP	Return PNUM	Owner of PNUI
C5171		Gulf Coast Water Auth.	Mun	3,000	R51711	106271	10627.001	Baycliff MUD
C5171		Gulf Coast Water Auth.	Mun	4,500	R51711	104101	10410.001	City of LaMarque
C5171		Gulf Coast Water Auth.	Mun	19,500	R51711	105685	10568.005	City of League City
C5171		Gulf Coast Water Auth.	Mun	33,750	R51711	103751	10375.001	City of Texas City
C5171		Gulf Coast Water Auth.	Mun	14,250	R51711	101731	10173.001	Galveston Co. WC #1
C4175		H R Stasney & Sons Ltd	Min	63	1.0	CON029		
C4136		Nelson Puett	Min	338	0.5	CON024		
C4031	Lake Palo Pinto	Palo Pinto M W D No 1	Mun	6,500	R40311	105852	10585.001	City of Mineral We
C4031	Lake Palo Pinto	Palo Pinto M W D No 1	Mun	3,500	R40311	105851	10585.004	City of Mineral We
C4031	Lake Palo Pinto	Palo Pinto M W D No 1	Mun	1,625	R40311	105852	10585.001	City of Mineral We
C4031	Lake Palo Pinto	Palo Pinto M W D No 1	Mun	875	R40311	105851	10585.004	City of Mineral We
C3710		R E Janes Gravel Co	Min	450	1.0	OUT		
C4100		Trinity Materials Inc	Min	125	1.0	W12041		
C4213	Hubbard Creek Lake	West Central TX MWD	Mun	17,362	RABIL1	103344	10334.004	City of Abilene
C4213	Hubbard Creek Lake	West Central TX MWD	Mun	2,487	R42131	100401	10040.004	City of Breckenrid

Table 4-5. Monthly Return Flow Factors Identified in Table 4-4

Return Flow Pattern Identifier	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
R36931	0.1657	0.1694	0.1147	0.0993	0.0774	0.0760	0.0363	0.0486	0.1527	0.1873	0.2308	0.1838
R41791	0.4927	0.4654	0.4210	0.3466	0.3683	0.3359	0.2570	0.2792	0.3333	0.3841	0.4088	0.4795
RABIL1	0.7226	0.7138	0.5753	0.4824	0.4602	0.4082	0.3228	0.3411	0.4636	0.5381	0.6894	0.6892
R42131	0.5556	0.5910	0.6053	0.4697	0.4703	0.4235	0.3051	0.3240	0.3544	0.4142	0.4784	0.5055
R42132	0.3918	0.3270	0.3287	0.2822	0.2461	0.1911	0.1391	0.1546	0.1993	0.2160	0.2401	0.2235
R42021	0.6571	0.6298	0.7268	0.6866	0.6518	0.5053	0.4949	0.4493	0.5477	0.6074	0.7121	0.6661
R42111	0.6809	0.6566	0.6561	0.5666	0.5763	0.5312	0.3797	0.3925	0.4882	0.5306	0.6281	0.6286
R34441	0.4587	0.4999	0.4735	0.4248	0.3979	0.3523	0.2825	0.3029	0.3601	0.3916	0.4271	0.4359
R34501	0.4240	0.4067	0.4948	0.4257	0.3511	0.3162	0.3004	0.3064	0.3545	0.3887	0.4563	0.4164
R34581	0.4986	0.4886	0.4659	0.4062	0.4011	0.3140	0.2630	0.2569	0.3371	0.3676	0.4652	0.4747
R43551	0.4665	0.5713	0.6838	0.6103	0.5956	0.4831	0.3280	0.3958	0.3612	0.3965	0.3872	0.3809
R40311	0.4597	0.5288	0.5362	0.4578	0.4499	0.3643	0.2617	0.2969	0.2907	0.3230	0.4041	0.4509
R51561	0.4080	0.5012	0.5302	0.4492	0.4043	0.3695	0.3589	0.3719	0.3952	0.4475	0.4517	0.4642
R41061	0.6750	0.7401	0.7253	0.7387	0.7054	0.6268	0.5306	0.5863	0.6303	0.6373	0.6275	0.6819
R43601	0.6591	0.7251	0.7036	0.6456	0.6464	0.5877	0.4356	0.4176	0.4706	0.5167	0.5161	0.6128
R51581	0.7444	0.6968	0.6647	0.6608	0.6648	0.6122	0.4939	0.5045	0.5807	0.6035	0.6234	0.7166
R50941	0.8119	0.8291	0.8120	0.7529	0.6557	0.6047	0.4785	0.5086	0.6143	0.6568	0.7570	0.7817
R34701	0.6169	0.6320	0.6067	0.6406	0.6479	0.6749	0.6788	0.6780	0.6499	0.5751	0.6029	0.5936
R51591	0.6469	0.6861	0.6611	0.6013	0.5452	0.5003	0.3547	0.3873	0.4808	0.5303	0.5869	0.5960
RBLSH1	0.6927	0.7025	0.7020	0.6479	0.6188	0.5700	0.4006	0.3864	0.4648	0.5102	0.6148	0.6616
R51621	0.6844	0.7162	0.6943	0.6456	0.6070	0.5507	0.4019	0.4277	0.5388	0.5711	0.7049	0.7091
R51631	0.7417	0.8049	0.8121	0.7430	0.6969	0.6061	0.5992	0.6410	0.6577	0.6799	0.7915	0.7925
R37611	0.6784	0.7452	0.7271	0.6778	0.6533	0.5072	0.3335	0.3357	0.3918	0.5152	0.6499	0.7170
R51641	0.7727	0.8159	0.8273	0.7883	0.7514	0.6607	0.5548	0.5874	0.6285	0.6799	0.7419	0.7334
R52871	0.5187	0.5517	0.5896	0.5773	0.5590	0.5741	0.4154	0.4170	0.4475	0.4709	0.5221	0.5616
R52891	0.4405	0.4804	0.5003	0.4825	0.4946	0.4138	0.3428	0.3385	0.3460	0.3850	0.4087	0.5301
R52911	0.3160	0.3602	0.3460	0.3165	0.3070	0.2243	0.1487	0.1661	0.1715	0.2667	0.2735	0.2575
R53661	0.9152	0.9198	0.8840	0.8817	0.7707	0.7429	0.7504	0.7477	0.8175	0.8129	0.8461	0.8357
R51711	0.7300	0.7629	0.7424	0.6949	0.6974	0.6860	0.7018	0.7100	0.7289	0.7348	0.7271	0.7081

Figure 4-1. Modeled Return Flow Locations

Figure 4-1.

4.2.3.4 Multiple Diversion Locations

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

4.2.3.5 Instream Flow Requirements

Many rights include special conditions specifying minimum instream flows that must be maintained as a water right diverts. These instream flow requirements are generally specified as flow rates in cubic feet per second (cfs) at a specified point (usually the diversion location or a downstream USGS streamgage), and often vary seasonally. The discharge rates specified were changed to monthly values in acft (monthly (acft) = cfs * 1.9835 * days in month) and summed to develop annual instream flow requirements in acft. The annual instream flow requirements were included in the model using IF records, and distributed to monthly values using UC records. The monthly factors included on UC records are equivalent to the monthly values used to compute the annual total. Instream flow requirements included in the model are shown in Table 2 of Appendix X.

Those rights denoted as Hale Clause rights include language in the special condition that makes the instream flow requirement "exclusive of any releases dedicated by the Brazos River Authority from its conservation storage for subsequent use downstream."[63] WRAP does not include the capability to specify instream flow requirements that do not consider total regulated flows. Regulated flows computed by WRAP include water released from upstream reservoirs to diversion points downstream. This should not be a concern in this application of the model because releases from the BRA reservoirs to downstream contractual commitments are not included in the WAM; all diversions from reservoirs are included in the model as lakeside diversions. However, in the application of the WAM for water supply planning, releases from

[63] Permit to Appropriate State Water No. 4042.

BRA reservoirs to downstream contractual commitments will likely be included and WRAP should be modified to include consideration of Hale Clause instream flow requirements.

4.2.3.6 Rights Requiring Special Consideration

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 most cases involving multiple dates of priority, uses, diversion locations, or authorized impoundments, the paper rights and amendments were also consulted. The memorandum included as Appendix IX discusses specific approaches for modeling some of the more complex rights. For those and all other rights, specific assumptions used to model each right are included as comment records where necessary in the WRAP input file (Appendix XIV).

4.2.4 Data for Basin-Specific Features Added to WRAP

No basin-specific features were added to WRAP for the Brazos River Basin and San Jacinto-Brazos Coastal Basin.

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 adopted for the Brazos River Basin and San Jacinto-Brazos Coastal Basin 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. **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, INMETHOD5 and INMETHOD8) allow the use of aerially 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.[64] INMETHOD8 also includes the capability to account for channel losses when distributing flows. Due to data irregularities in the curve number and precipitation data provided by the TNRCC through the CRWR, naturalized flows were distributed to secondary control points using INMETHOD6, except for instances where INMETHOD2 was used to set flows at a secondary control point equal to those at a primary control point. INMETHOD6 distributes naturalized flows to secondary control points utilizing only drainage area and channel loss factors.

4.3.2 Reuse

Treated effluent discharges in the Brazos River Basin and San Jacinto-Brazos Coastal Basin do not play a significant role in overall water availability in the basin. However, in isolated locations on smaller streams, effluent discharges probably constitute the majority of the water available for diversion. Future reuse of effluent would reduce discharges and would reduce the availability of water to specific rights located near and downstream of the discharge points, but should not have a major effect on overall water availability in the basins. At the request of TNRCC, three reuse scenarios were modeled. These are described in more detail in Section 5.

4.3.3 Return Flow/Constant Inflow Assumptions

Treated effluent from municipalities holding surface water rights probably 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. At the direction of the TNRCC, return flows from rights authorized for municipal use are computed as a fraction of the water diverted (see Section 4.2.3.3). During drought periods of the simulation, reduced quantities of water will be available to these rights and return flows will exhibit a corresponding reduction. However, this should not

[64] 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.

have a great effect on overall water availability in the basins because discharge of treated water effluent generally does not constitute a large portion of the water available for diversion.

4.3.4 Term Permits

Term permits are included only in Run 8, as described in Section 5. The WRDETAIL file (as edited) contains 124 records of Type A term permits, totaling 30,467 acft/yr of authorized diversions. Type A term water rights have defined dates of expiration. Of the 124 records, 106 list non-zero authorized diversions with 95 of those records totaling 25,889 acft/yr for irrigation, 2 records totaling 345 acft/yr for industrial use, 4 records totaling 4,118 acft/yr for mining, 2 records totaling 50 acft/yr for recreation, 1 record for 30 acft/yr for domestic and livestock use, and 2 records for 35 acft/yr for "other" uses. In the Lake Proctor watershed, 48 of these records specify diversions located upstream of Lake Proctor with a total authorized diversion of 4,996 acft for irrigation use, all of which have a date of expiration of December 31, 2000. Because the WRDETAIL upon which the water rights input files are based pre-dates the expiration date for these rights, and it is not known which of these rights have applied for extension of term, these rights will be included in the Run 8 analyses. Term water rights represent a small fraction (0.4 percent) of the annual diversions authorized in the Brazos River Basin and San Jacinto-Brazos Coastal Basin and do not significantly affect water availability in these basins.

4.3.5 Interbasin Transfers

The TNRCC provided information documenting rights authorized for interbasin transfers of water into and from the Brazos River Basin and the San Jacinto-Brazos Coastal Basin. HDR reviewed these rights and added additional rights to this list based upon review of the paper water rights and WRDETAIL. The memorandum included in Appendix II discusses the 44 rights identified as being authorized to transfer water into or from the Brazos River Basin and San Jacinto-Brazos Coastal Basin. The majority of these rights transfer water between the Brazos River Basin and the San Jacinto-Brazos Coastal Basin. Generally, interbasin transfers of water into the Brazos River Basin and San Jacinto-Brazos Coastal Basin are not included in the model unless there is a right held in the receiving basin for the transferred water. The only other exceptions are for discharges of treated effluent that originate outside of the basins. These are included on CI records as discussed in Section 4.2.3.3 and summarized in Table 4-2. Interbasin transfers of water out of the Brazos and San Jacinto-Brazos Basins are not included in Runs 1-7, because these generally represent contractual agreements. However, rights that have documented transfers of water out of the basins within the last 10 years are included in Run 8 to simulate current conditions.

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Section 5
Water Availability in the Brazos River Basin and the San Jacinto-Brazos Coastal Basin

5.1 Descriptions of Scenarios Modeled

Water availability in a river basin is affected by numerous factors including assumptions regarding water rights, water management and use, and natural hydrologic influences such as rainfall, runoff, and evaporation. Senate Bill 1 requires assessment of the sensitivity of water availability to key water management and use assumptions, including reuse of treated wastewater effluent and the cancellation of all or portions of rights showing little or no recent use. Sensitivity of water availability in the Brazos River Basin and the San Jacinto-Brazos Coastal Basin to these water management assumptions is addressed by comparisons between model 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.

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 Galveston Bay and the Brazos River 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 included in Run 1 as described in Section 4.2.3.3. Runs 2 and 3 are identical to Run 1, except for the effluent discharges reflected on CI records and return flow factors included on WR records. In Run 2, these were reduced to one-half of the Run 1 values, to reflect 50 percent reuse of current effluent discharges, and were set to zero in Run 3, to reflect full reuse. Term permits were excluded from Runs 1, 2 and 3. Constant inflow (CI) records are used in WRAP to input 12 monthly values of flow to be added to the naturalized flows at a control point.

5.1.2 Cancellation Runs 4, 5, 6, and 7

Runs 4, 5, 6, and 7 evaluate the effects on water availability of the simulated cancellation of certain rights. Under §11.173 of the Texas Water Code, permits, certified filings, and certificates of adjudication may be subject to cancellation after 10 years of nonuse. The use of water by rights during the last 10 years was evaluated using annual reported water use obtained from the TNRCC for the 1988 to 1997 period.

The effects of potential full cancellations were evaluated in Runs 4 and 6 by assuming that those rights showing no use in the years 1988 through 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 reported annual water use in the years 1988 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 associated with 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 1988, for which no historical use has been reported, were assumed cancelled in Runs 4 and 6 in order to maintain consistency with assumptions used in other river basins. Similarly, maximum historical diversion amounts for these rights were set to zero for Runs 5 and 7. The cancellation involved only the cancellation of the diversion portion of those rights. Rights associated with existing reservoirs maintained the authorized reservoir storage. The authorized storage for Permit 2925, associated with the proposed Allens Creek Reservoir project, was removed completely from the model for Runs 5-7 since this is not an existing reservoir.

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, 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. As in Runs 5-7, the proposed Allens Creek Reservoir project associated with Permit 2925 was not included.

Appendix VIII summarizes the authorized annual diversions included for each right for Runs 1 through 8. The amounts shown in this appendix are the sums of the diversion amounts from the individual WR records included in the model for each right. Also shown is the maximum annual use for each right (1988 to 1997) included in the data provided by the TNRCC. These data were utilized to set the authorized diversion amounts for Runs 4 through 8.

5.2 Results of Water Availability Model Runs

Model results output from WRAP are quite extensive, and detailed information can be obtained for any water right, reservoir or control point. The Brazos River Basin is a large, complex basin with many major rights. It is impossible to provide sufficient summary information within this report for all water rights or all control points. Appendices XI, XII and XIII present tabulated reliability summaries for each water right for Runs 1-8. Also included in the appendices are summary tables and graphs of regulated and unappropriated flows at 10 selected control points, and reservoir storage traces for 11 selected major reservoirs. The locations of the selected control points and major reservoirs are shown in Figure 5-1. The control points were selected so as to provide summary information near major confluence points in the basins.

5.2.1 Reuse Runs

The results for Reuse Runs 1, 2, and 3 are presented in Appendix XI. Reliability of supply for each right is presented in Tables XI-1, XI-2, and XI-3. Regulated and unappropriated flows for Runs 1 and 3 at the selected control points are presented in Tables XI-4 through XI-39. Graphical presentations of regulated and unappropriated flows at the selected control points are shown in Figures XI-1 through XI-18. Reservoir storage traces for the selected reservoirs are displayed in Figures XI-19 through XI-29.

Figure 5-1. Locations of Control Points and Major Reservoirs Selected for Summary Output

Table 5-1. Assumptions Utilized in Alternative Model Runs

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

[1] Area-capacity relationships for reservoirs greater than 5,000 acft for which reliable area-capacity data are available. No adjustments made for numerous smaller reservoirs.

Figure 5-1

Tables 5-2 through 5-11 summarize annual regulated and unappropriated flows for each run at the ten selected control points. Reuse of treated effluent has little impact on average (mean and median) unappropriated and regulated flows at most of the selected control points. However, reuse of treated effluent does substantially reduce minimum annual flows at several of the selected locations, including the Brazos River at Waco, Little River at Cameron, Brazos River near Byan, and the Brazos River at Richmond.

Table 5-2. Annual Simulation Summaries, Brazos River at South Bend, BRSB23

Scenario		Regulated Flows (acft/yr)				Unappropriated Flows (acft/yr)			
		Max	Min	Mean	Median	Max	Min	Mean	Median
Reuse	Run 1	3,064,137	56,952	569,984	451,727	2,863,059	0	308,771	143,351
	Run 2	3,051,251	52,724	561,172	444,773	2,845,947	0	296,485	130,592
	Run 3	3,038,434	50,045	553,754	438,846	2,828,707	0	283,128	113,409
Cancellation	Run 4	3,075,967	55,672	573,011	453,126	2,939,130	0	315,100	148,384
	Run 5	3,137,470	58,641	582,355	462,759	3,092,300	0	437,113	276,924
	Run 6	3,053,545	50,251	557,179	439,314	2,908,578	0	291,330	114,914
	Run 7	3,125,687	50,092	572,114	453,236	3,076,389	0	417,488	247,003
Current Conditions	Run 8	3,143,285	59,472	584,317	464,780	3,100,245	0	446,998	296,708

Table 5-3. Annual Simulation Summaries, Brazos River at Palo Pinto, BRPP27

Scenario		Regulated Flows (acft/yr)				Unappropriated Flows (acft/yr)			
		Max	Min	Mean	Median	Max	Min	Mean	Median
Reuse	Run 1	3,160,612	7,513	438,829	268,014	2,959,984	0	363,453	181,082
	Run 2	3,143,489	7,108	427,147	251,461	2,940,057	0	348,740	159,976
	Run 3	3,126,570	5,387	416,868	240,643	2,920,365	0	333,142	143,606
Cancellation	Run 4	3,172,289	7,210	442,032	268,211	3,034,365	0	371,708	182,550
	Run 5	3,399,874	14,967	619,439	465,982	3,262,021	0	534,585	357,793
	Run 6	3,141,443	5,387	420,285	241,764	2,998,492	0	343,193	151,069
	Run 7	3,382,274	15,178	604,124	450,290	3,241,733	0	511,179	335,248
Current Conditions	Run 8	3,409,619	15,416	627,850	478,586	3,272,583	0	545,817	368,595

Table 5-4. Annual Simulation Summaries, Bosque River near Waco, BOWA40

Scenario		Regulated Flows (acft/yr)				Unappropriated Flows (acft/yr)			
		Max	Min	Mean	Median	Max	Min	Mean	Median
Reuse	Run 1	959,147	329	257,947	198,749	953,488	2	248,707	195,024
	Run 2	954,927	666	253,990	193,426	949,259	2	243,994	189,374
	Run 3	950,744	219	250,102	187,717	945,135	0	238,568	183,806
Cancellation	Run 4	983,162	1,378	280,508	215,322	977,620	17	271,025	215,102
	Run 5	1,012,094	2,139	308,853	244,788	1,007,582	87	298,716	244,557
	Run 6	974,746	2,552	272,455	207,408	969,209	0	260,171	201,691
	Run 7	1,005,890	2,726	302,762	237,916	1,001,361	69	291,797	237,774
Current Conditions	Run 8	1,013,361	2,240	311,167	247,215	1,008,845	87	301,523	246,986

Table 5-5. Annual Simulation Summaries, Brazos River at Waco, BRWA41

Scenario		Regulated Flows (acft/yr)				Unappropriated Flows (acft/yr)			
		Max	Min	Mean	Median	Max	Min	Mean	Median
Reuse	Run 1	5,139,049	120,904	1,281,252	1,022,175	4,966,840	3,553	1,113,444	840,892
	Run 2	5,059,908	131,305	1,256,893	1,002,940	4,865,489	3,553	1,079,471	779,401
	Run 3	4,985,752	129,402	1,233,974	978,189	4,751,557	3,553	1,042,986	728,156
Cancellation	Run 4	5,238,068	134,395	1,312,271	1,045,665	5,063,806	3,565	1,143,960	873,499
	Run 5	5,863,344	178,348	1,548,266	1,283,798	5,658,093	54,943	1,365,620	1,127,199
	Run 6	5,097,549	143,750	1,264,166	1,014,530	4,872,766	0	1,076,122	765,886
	Run 7	5,795,850	170,377	1,515,937	1,252,196	5,569,536	29,557	1,322,634	1,074,658
Current Conditions	Run 8	5,901,112	182,384	1,561,027	1,298,516	5,696,027	61,420	1,381,406	1,138,132

Table 5-6. Annual Simulation Summaries, Leon River near Belton, LEBE49

Scenario		Regulated Flows (acft/yr)				Unappropriated Flows (acft/yr)			
		Max	Min	Mean	Median	Max	Min	Mean	Median
Reuse	Run 1	1,492,877	19,241	344,081	149,484	1,424,790	0	307,418	109,357
	Run 2	1,487,521	16,332	339,311	142,272	1,416,423	0	300,811	101,616
	Run 3	1,482,489	13,265	334,872	137,192	1,409,235	0	294,603	96,088
	Run 4	1,497,042	13,287	345,124	164,911	1,448,248	0	323,507	132,421

Cancellation	Run 5	1,506,609	10,859	352,859	176,006	1,457,816	0	332,071	148,589
	Run 6	1,486,469	8,344	335,435	146,204	1,431,080	0	308,825	115,025
	Run 7	1,499,688	7,983	346,472	166,540	1,443,915	0	320,911	130,906
Current Conditions	Run 8	1,503,021	10,859	351,209	173,285	1,455,074	0	328,588	144,959

Table 5-7. Annual Simulation Summaries, Little River at Cameron, LRCA58

Scenario		***Regulated Flows (acft/yr)***				***Unappropriated Flows (acft/yr)***			
		Max	***Min***	***Mean***	***Median***	***Max***	***Min***	***Mean***	***Median***
Reuse	Run 1	4,175,921	102,463	1,123,514	961,633	4,101,353	12,944	1,042,106	897,675
	Run 2	4,108,582	51,212	1,058,340	892,062	4,027,839	8,214	984,751	836,193
	Run 3	4,044,994	16,939	994,869	822,154	3,955,872	0	930,695	776,748
Cancellation	Run 4	4,193,456	110,659	1,140,002	984,042	4,115,003	12,637	1,058,983	919,770
	Run 5	4,186,788	78,952	1,131,559	971,977	4,113,702	9,902	1,062,987	917,098
	Run 6	4,061,008	22,219	1,010,543	844,829	3,976,981	3,601	947,942	796,790
	Run 7	4,097,474	18,855	1,043,494	881,909	4,029,927	4,365	987,622	833,844
Current Conditions	Run 8	4,183,318	78,982	1,130,684	971,275	4,122,636	7,954	1,054,301	906,737

Table 5-8. Annual Simulation Summaries, Brazos River near Bryan, BRBR59

Scenario		***Regulated Flows (acft/yr)***				***Unappropriated Flows (acft/yr)***			
		Max	***Min***	***Mean***	***Median***	***Max***	***Min***	***Mean***	***Median***
Reuse	Run 1	10,707,347	438,073	3,262,603	3,052,791	10,257,645	27,145	2,752,641	2,537,865
	Run 2	10,553,489	330,894	3,108,273	2,893,337	10,111,410	13,698	2,626,665	2,419,699
	Run 3	10,407,533	249,899	2,957,357	2,740,894	9,970,855	3,470	2,506,343	2,297,170
Cancellation	Run 4	10,742,911	423,663	3,287,980	3,092,905	10,307,023	34,226	2,796,133	2,590,077
	Run 5	11,048,434	406,895	3,491,205	3,363,528	10,612,939	78,261	3,013,151	2,862,932
	Run 6	10,466,925	246,268	3,007,223	2,788,946	10,040,185	3,470	2,564,366	2,365,917
	Run 7	10,874,380	280,365	3,320,470	3,180,068	10,439,546	45,218	2,869,852	2,696,845
Current Conditions	Run 8	11,048,172	413,139	3,499,336	3,365,644	10,597,779	84,169	3,012,448	2,852,326

Table 5-9. Annual Simulation Summaries, Brazos River at Richmond, BRRI70

Scenario		Regulated Flows (acft/yr)				Unappropriated Flows (acft/yr)			
		Max	Min	Mean	Median	Max	Min	Mean	Median
Reuse	Run 1	14,769,774	512,339	4,881,964	4,678,818	13,973,399	25,741	4,117,139	3,899,432
	Run 2	14,611,434	399,601	4,724,368	4,507,618	13,815,060	12,990	3,982,222	3,735,312
	Run 3	14,461,199	323,861	4,570,671	4,330,975	13,667,753	3,300	3,852,138	3,573,810
Cancellation	Run 4	14,917,674	498,802	4,957,874	4,774,591	14,196,295	34,165	4,256,669	4,056,647
	Run 5	15,230,733	484,430	5,185,425	5,125,510	14,509,353	76,203	4,493,425	4,408,136
	Run 6	14,630,904	318,597	4,668,252	4,459,410	13,909,525	12,645	4,003,764	3,754,881
	Run 7	15,040,588	349,549	4,998,945	4,928,133	14,319,209	43,034	4,329,825	4,218,998
Current Conditions	Run 8	15,230,940	490,500	5,194,791	5,133,836	14,509,561	82,428	4,502,745	4,416,179

Table 5-10. Annual Simulation Summaries, San Jacinto-Brazos Coastal Basin at Galveston Bay, SJGBC3

Scenario		Regulated Flows (acft/yr)			
		Max	Min	Mean	Median
Reuse	Run 1	2,703,805	106,390	962,500	899,474
	Run 2	2,697,843	101,134	956,489	893,605
	Run 3	2,692,159	96,142	950,742	888,003
Cancellation	Run 4	2,703,877	106,536	962,622	899,600
	Run 5	2,703,839	106,566	962,799	899,758
	Run 6	2,692,162	96,145	950,744	888,005
	Run 7	2,692,162	96,145	950,744	888,005
Current Conditions	Run 8	2,703,584	106,265	962,516	899,474

Table 5-11. Annual Simulation Summaries, San Jacinto-Brazos Coastal Basin at Gulf of Mexico, SJGMC4

Scenario		*Regulated Flows (acft/yr)*			
		Max	*Min*	*Mean*	*Median*
Reuse	Run 1	1,325,595	53,907	461,613	441,029
	Run 2	1,319,731	44,899	454,493	434,158
	Run 3	1,315,907	41,710	450,167	429,664
Cancellation	Run 4	1,326,217	54,451	462,170	441,711
	Run 5	1,330,411	46,590	459,958	439,502
	Run 6	1,316,517	42,175	450,684	430,207
	Run 7	1,326,904	43,670	456,350	435,596
Current Conditions	Run 8	1,330,411	46,590	459,958	439,502

5.2.2 Cancellation Runs

The results for Cancellation Runs 4, 5, 6 and 7 are presented in Appendix XII. Reliability of supply for each right is presented in Tables XII-1, XII-2, XII-3 and XII-4. Graphical presentation of regulated and unappropriated flows at the selected control points are shown in Figures XII-1 through XII-36. Reservoir storage traces for the selected reservoirs are displayed in Figures XI-37 through XI-58.

Tables 5-2 through 5-11 summarize annual regulated and unappropriated flows for each run at the selected control points. The unappropriated and regulated flows at those locations show little change from Run 1 to Run 4 and from Run 3 to Run 6, because the cancellation scenario depicted in Runs 4 and 6 does not reduce the total authorized diversions substantially. The rights assumed cancelled for non-use are small in comparison to the larger rights in the basin, which generally show use and therefore retain their authorized diversion amounts in Run 4 and Run 6. However, reducing authorized annual use to historical maximum use (Runs 5 and 7) increases unappropriated flows throughout the Brazos River Basin (as compared to Runs 1 and 3), but has limited effect in the San Jacinto-Brazos Coastal Basin. Diversions included in Run 8 are less than one half the total authorized diversions in the Brazos River Basin. Unappropriated and regulated flows in the Brazos River Basin are much more sensitive to partial cancellation of rights down to historical maximum use levels than to full cancellation of unutilized rights. Flows in the San Jacinto-Brazos Coastal Basin are sensitive to neither.

5.2.3 Current Conditions Run

The results for Current Conditions Run 8 are presented in Appendix XIII. Reliability of supply for each right is presented in Table XIII-1. Regulated and unappropriated flows for Run 8 are shown in Table XIII-2 through XIII-19. Graphical presentations of regulated and unappropriated flows at selected control points are shown in Figures XIII-1 through VIII-18. Reservoir storage traces for the selected reservoirs are displayed in Figures XIII-19 through XIII-29.

Tables 5-2 through 5-11 summarize annual regulated and unappropriated flows for each run at the selected control points. Regulated and unappropriated flows for Run 8 are substantially greater than those in Run 1 throughout the basins due to the reduced consumptive use in Run 8. The regulated flows for Run 8 are almost equal to those calculated in Run 5, largely because the total authorized diversions (maximum use last 10 years) included in both runs are approximately equal.

5.3 Comparison to Existing River Basin Models

5.3.1 Existing WRAP Model of the Brazos River Basin

The existing WRAP model of the Brazos River Basin developed at Texas A&M University has been updated and applied in support of the Brazos G Regional Water Planning Group.[65] The Brazos G WRAP model includes some significant differences including:

1. The Brazos G WRAP utilizes an earlier version of WRAP, whereby water rights are lumped together at primary control points and flows are not distributed to secondary control points. Water rights are, however, simulated individually within the constraints of the prior appropriation doctrine. The approach utilized in the Brazos G WRAP will tend to increase water availability to rights located on smaller tributaries, since the model simulates those rights as being diverted at main stem control points.
2. Naturalized flows utilized by the Brazos G WRAP model are those developed for the existing TNRCC Legacy WAM for years 1940-1976. Texas A&M University developed a dataset of "unregulated" flows for the periods 1905-1939 and 1980-1984 and utilized these flows in conjunction with the TNRCC Legacy WAM flows in order to extend the simulation period. In addition, naturalized flows were developed for only 19 control points throughout the Brazos River Basin, as compared to 73 control points in the Brazos River Basin portion of the current model.

[65] HDR, "Brazos G Regional Water Planning Area, Regional Water Plan, Volume I, Executive Summary and Regional Water Plan," Brazos G Regional Water Planning Group, January 2001.

3. The Brazos G WRAP does not account for channel losses. The current model utilizes naturalized flows that were developed using channel losses, and considers losses when translating changes in flow downstream.
4. The current model includes a number of model enhancements that allow greater flexibility in defining how individual water rights are simulated. These enhancements allow a much closer approximation to real-world conditions.
5. The Brazos G WRAP utilizes the original WRAP method (Negative Incremental Inflow Option 1) for determining water available to individual rights and translating changes in flow downstream. This method does not account for channel losses, and will result in conservatively low estimates of water availability.

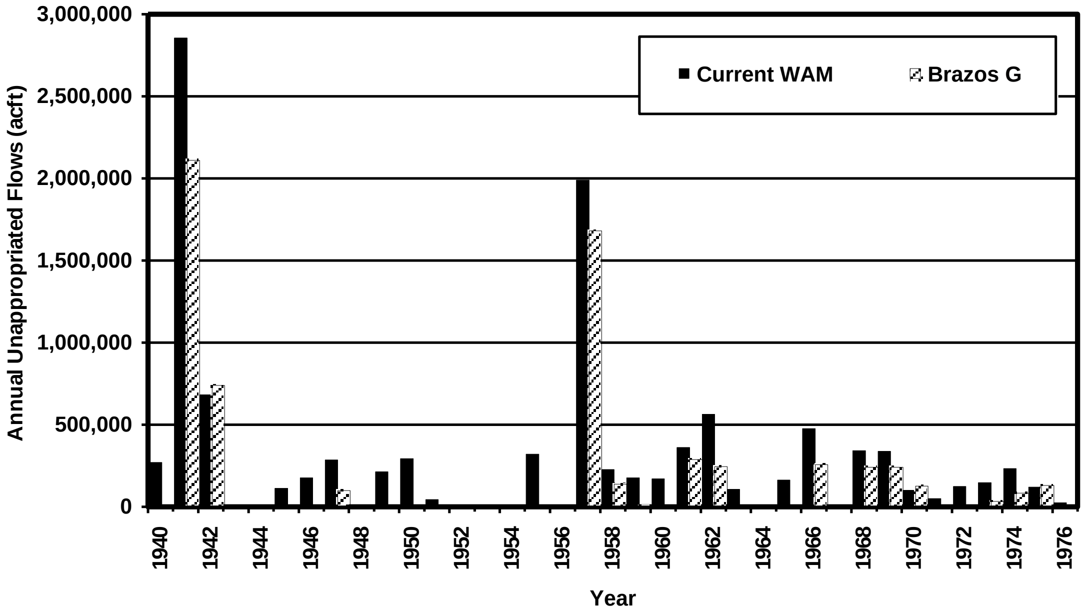
Figures 5-2 through 5-7 compare annual unappropriated flows for the Brazos River at the South Bend, Bryan and Richmond control points (BRSB23, BRBR59 and BRRI70) for the 1940 through 1976 common period. In general, unappropriated flows computed by the current model are greater than those computed by the earlier model.

5.3.2 Existing TNRCC Water Availability Model

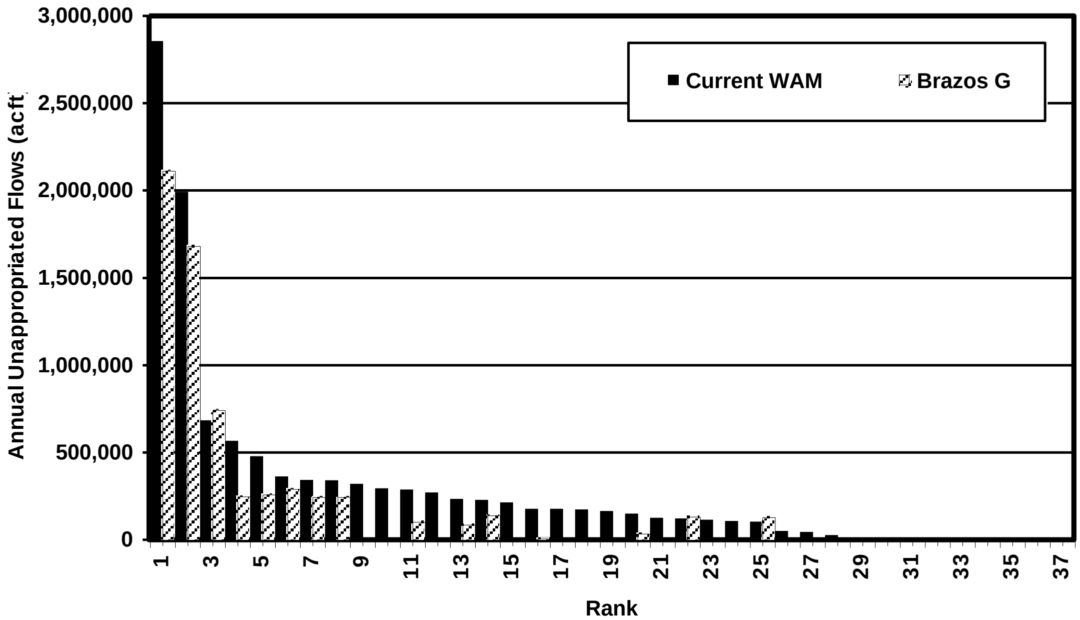
The assumptions, modeling methodologies, and data utilized in the existing TNRCC Water Availability Model (Legacy WAM) are substantially different from those used in the WRAP model described herein. The Legacy WAM utilized a considerably shorter period of simulation (1940 to 1976); does not account for channel losses; and includes fewer rights than the currently developed WRAP model. Hence, comparisons between the two models may be of limited utility. Output data from the last run of the Brazos River Basin Legacy WAM (Run 5) were obtained from a CD-ROM published by the TNRCC.[66] This is the only run available from the Legacy WAM.

Figures 5-8 through 5-13 compare annual unappropriated flows for the Brazos River at South Bend, Bryan and Richmond control points (BRSB23, BRBR59 and BRRI70) for the 1940 through 1976 common period. In general, unappropriated flows computed by the current model are greater than those computed by the Legacy WAM, and the differences are considerably larger than those between the Brazos G WRAP and current models.

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

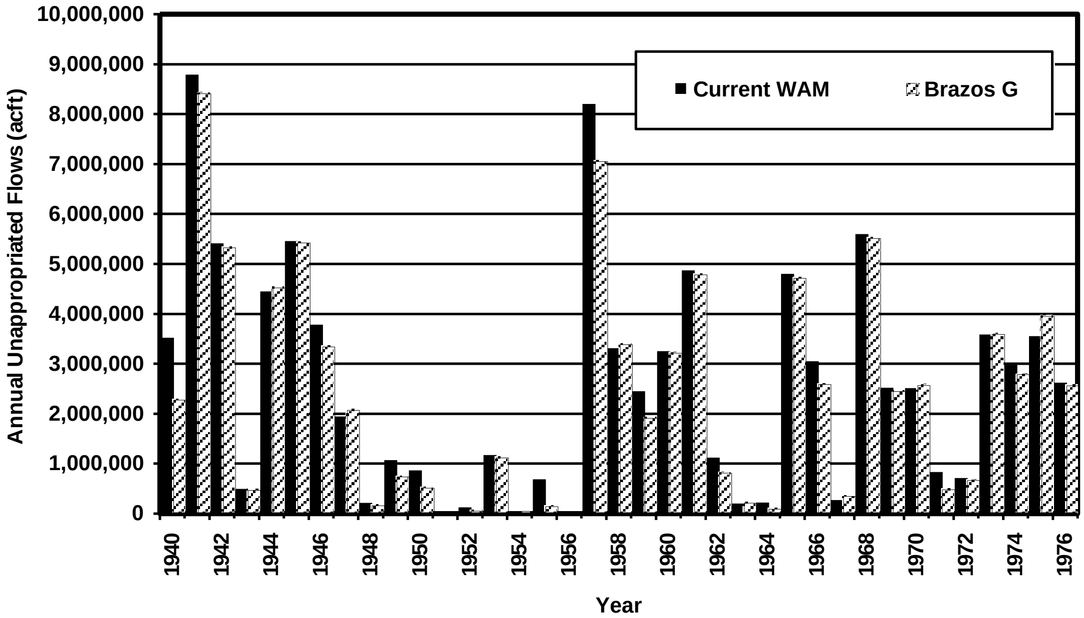


a. Time Series of Annual Unappropriated Flows

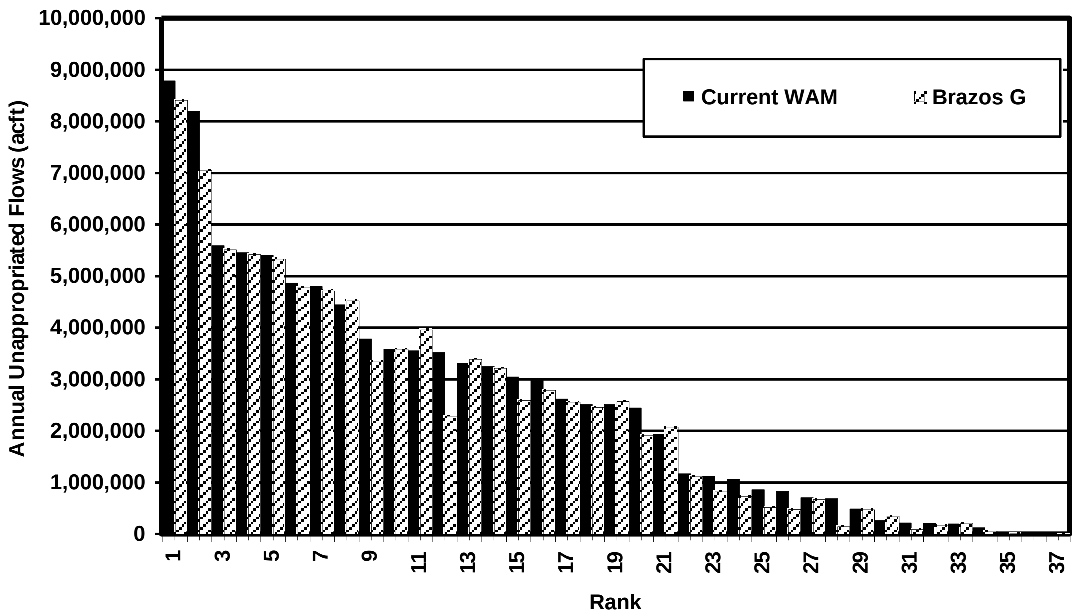


b. Annual Unappropriated Flows Ranked by Magnitude

Figure 5-2. Comparison with Brazos G WRAP Model,
Brazos River at South Bend (BRSB23)

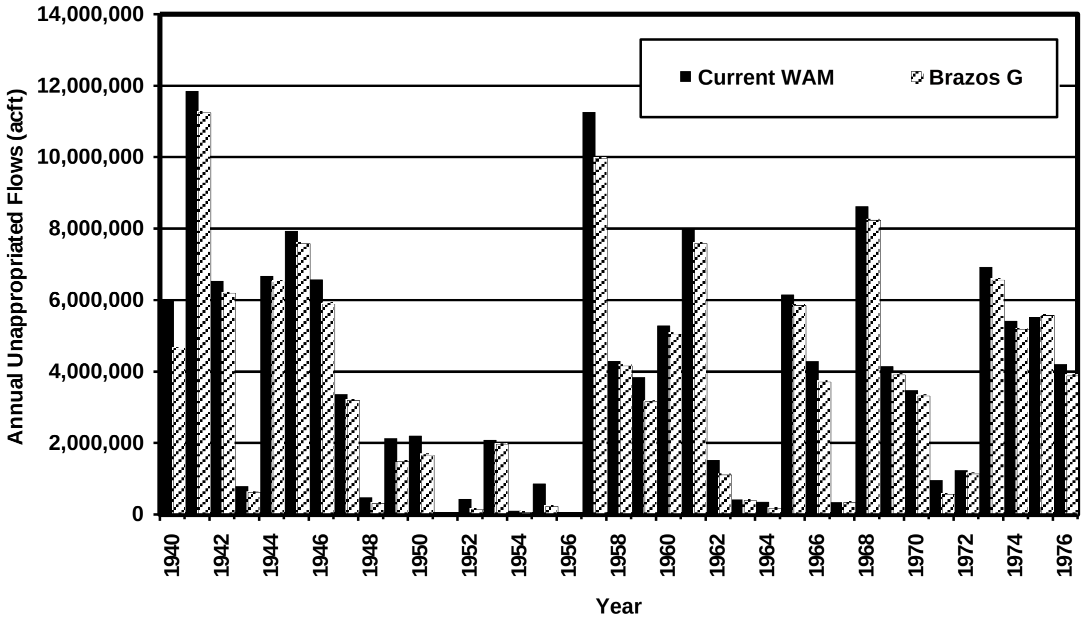


a. Time Series of Annual Unappropriated Flows

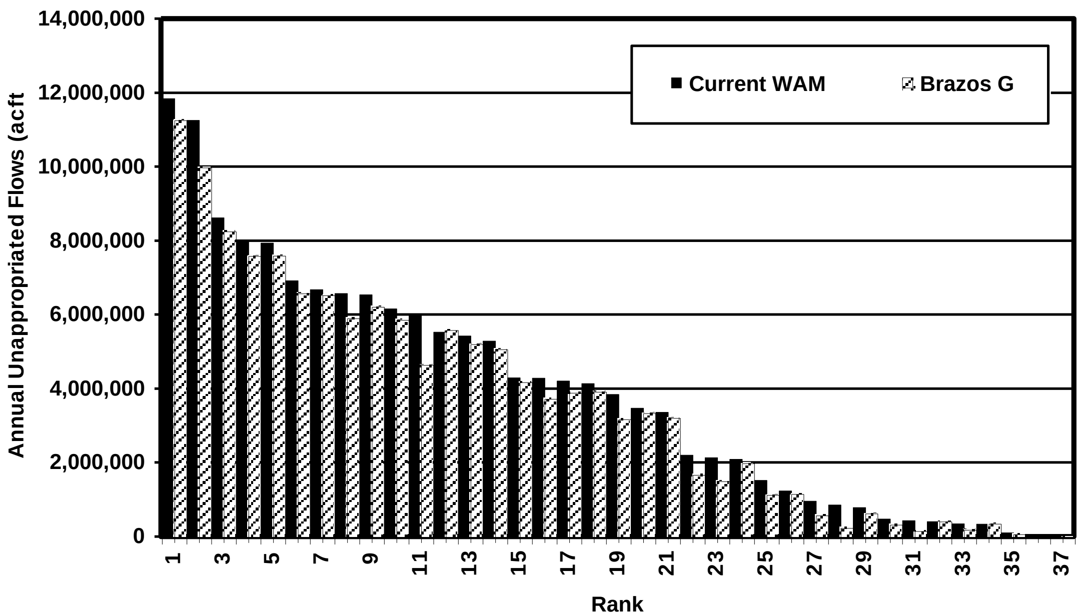


b. Annual Unappropriated Flows Ranked by Magnitude

Figure 5-3. Comparison with Brazos G WRAP Model, Brazos River at Bryan (BRBR59)

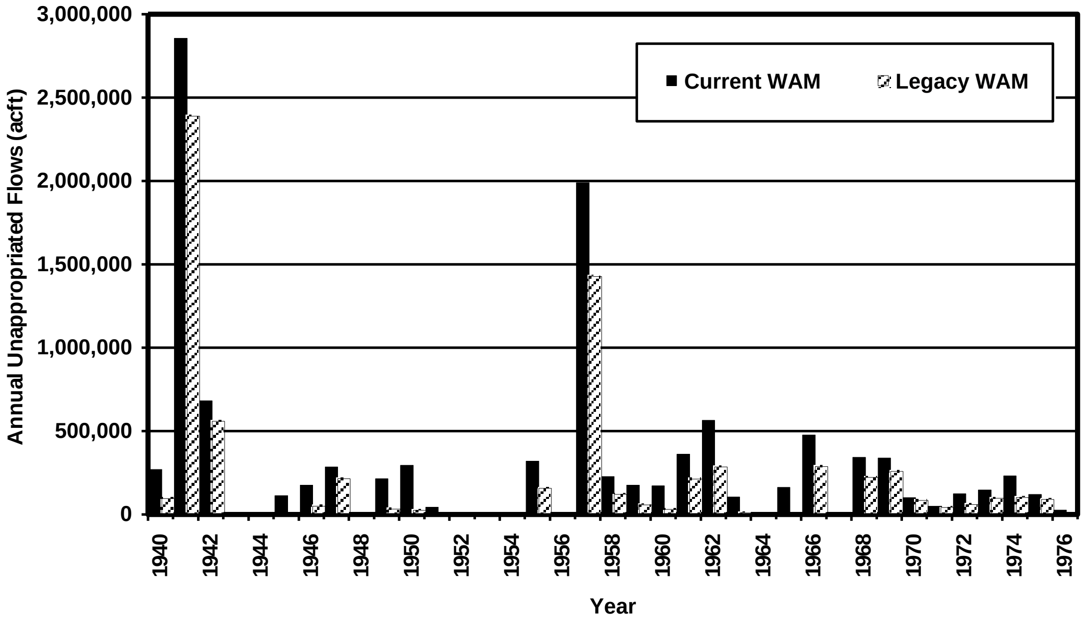


a. Time Series of Annual Unappropriated Flows

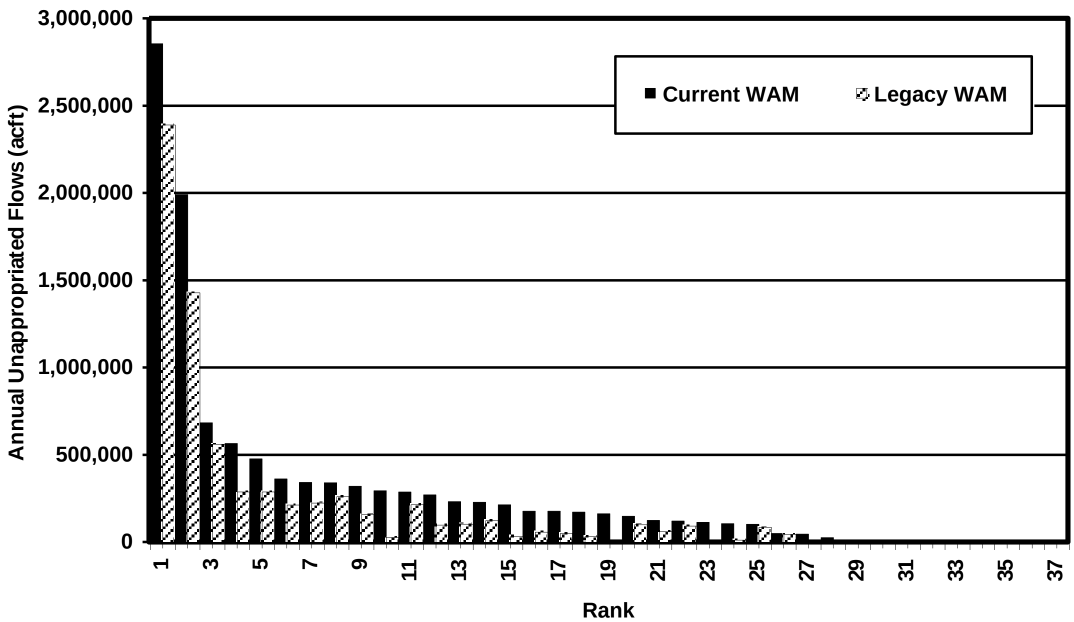


b. Annual Unappropriated Flows Ranked by Magnitude

Figure 5-4. Comparison with Brazos G WRAP Model, Brazos River at Richmond (BRRI70)

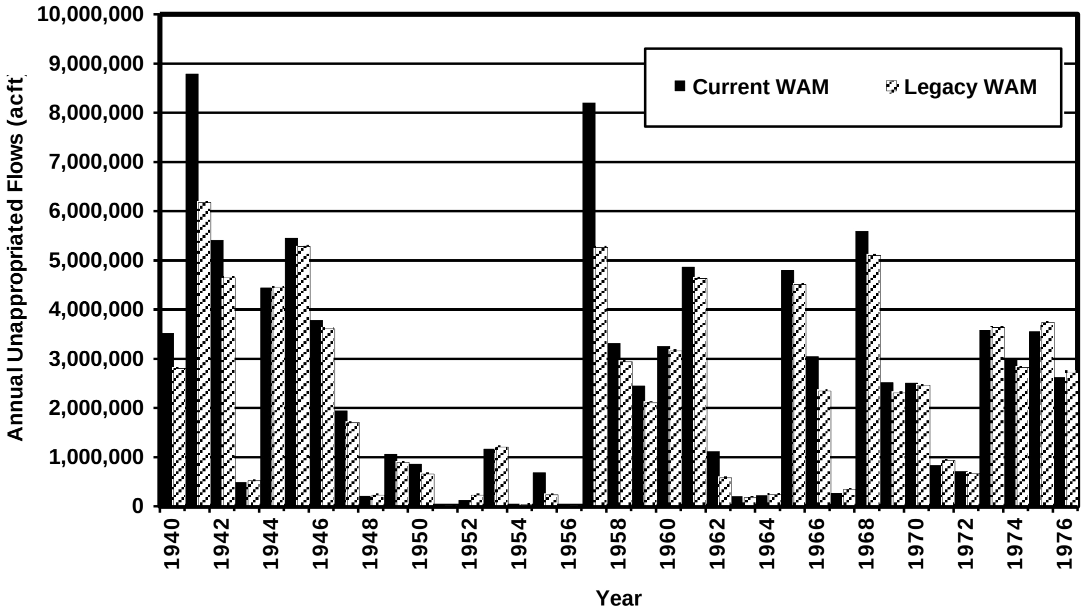


a. Time Series of Annual Unappropriated Flows

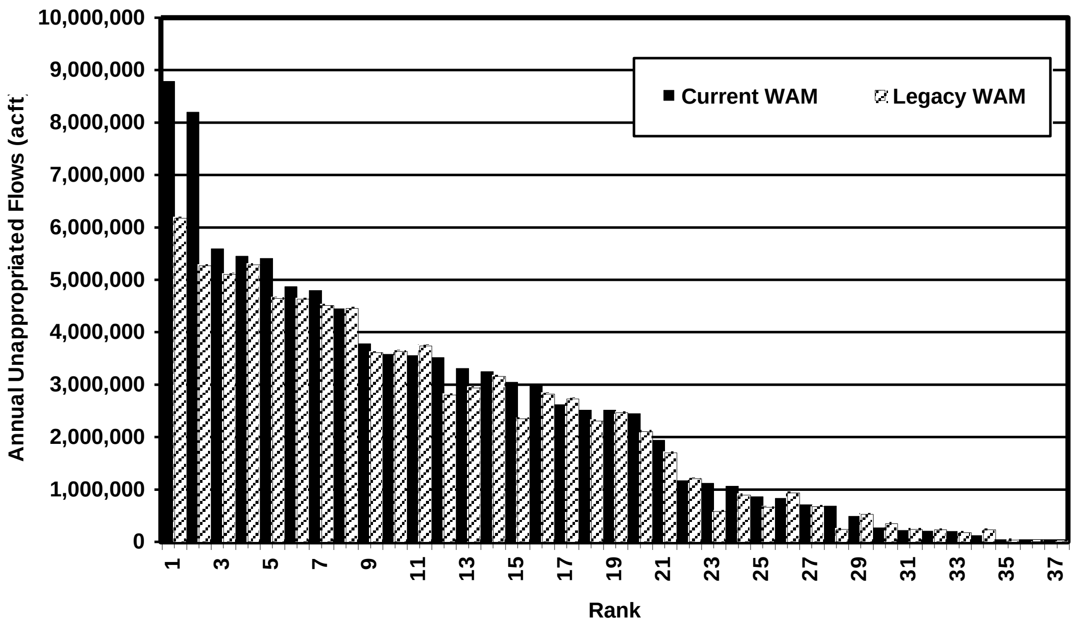


b. Annual Unappropriated Flows Ranked by Magnitude

Figure 5-5. Comparison with Legacy WAM, Brazos River at South Bend (BRSB23)

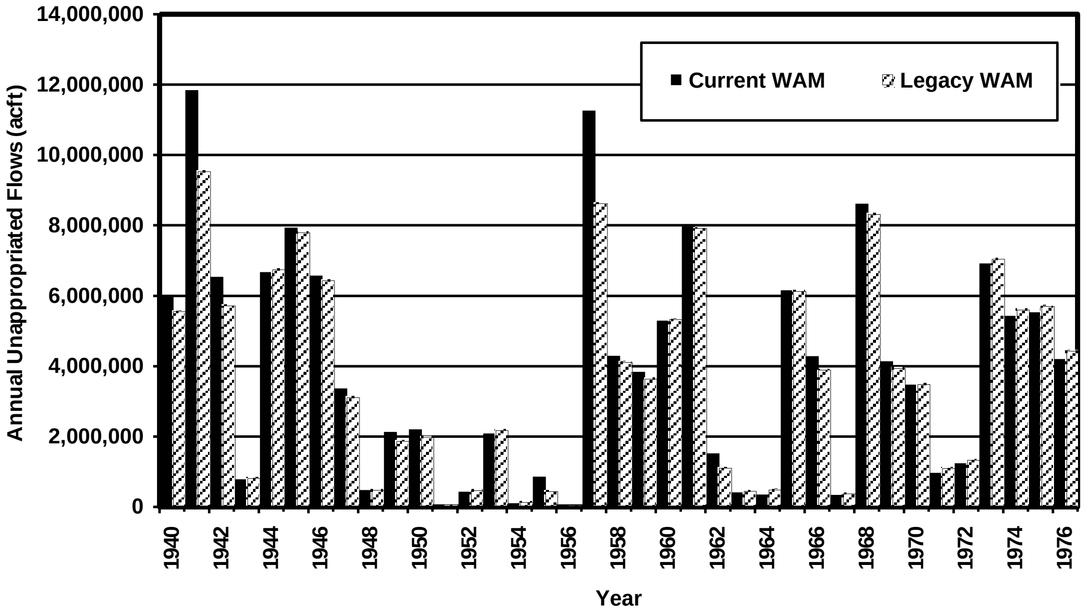


a. Time Series of Annual Unappropriated Flows

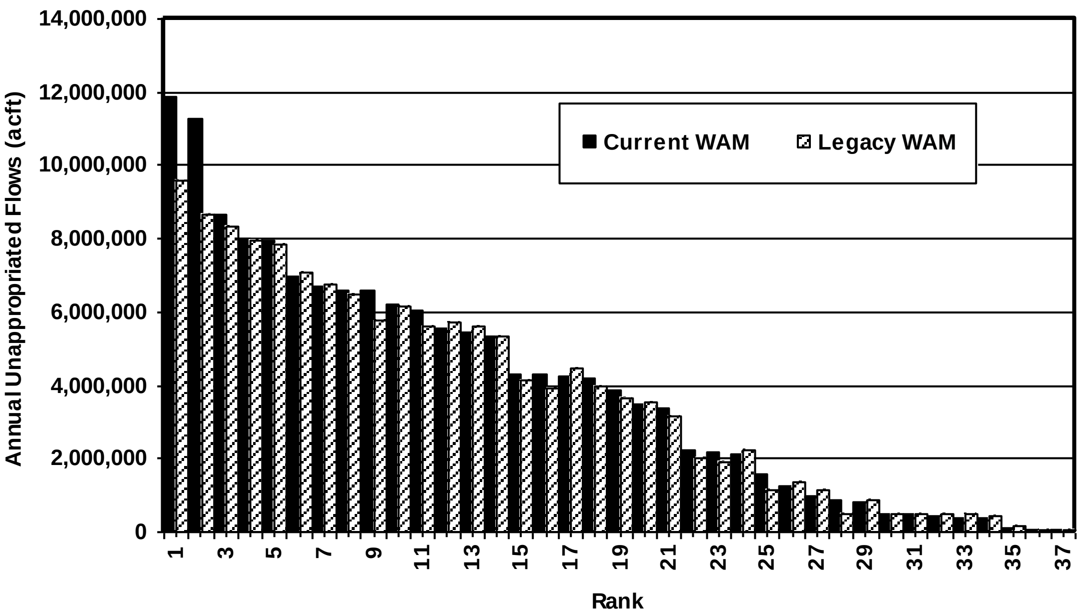


b. Annual Unappropriated Flows Ranked by Magnitude

Figure 5-6. Comparison with Legacy WAM, Brazos River at Bryan (BRBR59)



a. Time Series of Annual Unappropriated Flows



b. Annual Unappropriated Flows Ranked by Magnitude

Figure 5-7. Comparison with Legacy WAM, Brazos River at Richmond (BRRI70)

5.4 Yield Analyses at Large Reservoirs

The results of firm yield analyses for large reservoirs having authorized storage capacities greater than 5,000 acft are presented in Table 5-12. The yields presented herein are based upon the Run 3 dataset and assumptions (full authorized diversion amounts for all non-term rights, full authorized conservation capacities for all reservoirs, and 100 percent reuse [zero return flows]). Reservoirs associated with rights experiencing no shortages during the Run 3 simulation are reported with firm yields equal to the full-authorized diversions of all rights associated with the reservoir. Demands on reservoirs that experienced Run 3 shortages were systematically reduced by reducing the modeled diversion targets for rights associated with the reservoir, starting with the most junior right and proceeding in reverse priority order (junior to senior). Demands were iterated until successive approximations differed by less than 0.1 percent and 1.0 acft, and the most recent approximation did not experience a shortage. Each yield was estimated on a stand-alone basis, i.e., during the analysis for a given reservoir all other rights were set to their full authorized diversion amounts.

As shown in Table 5-12, several of the reservoirs are computed with Run 3 yields substantially less than the authorized diversions from the reservoir. Comments included in Table 5-12 note possible explanations for the reason the Run 3 yields are substantially less than authorized. For example, several of the reservoirs are authorized to receive contractual diversions to maintain reservoir storage, but these contractual diversions are not included in the simulations.

5.5 Factors Affecting Water Availability and Modeling Results

As shown by the results from the various cancellation runs, the most influential factor that affects the overall water availability in the Brazos River Basin and the San Jacinto-Brazos Coastal Basin is the assumption concerning authorized versus maximum historical use. Treated effluent discharges in both basins do not have nearly as a significant affect on water availability as water use. Cancellation of rights showing 10 years of nonuse in Runs 4 and 6 does not significantly affect overall water availability in the basin because none of the cancelled rights are of consequential size, and most of the largest rights in the basin have shown recent use and are unaffected by the cancellation scenario. None of the larger rights in the basin were assumed cancelled in Runs 4 and 6. However, many rights in the Brazos River Basin and San Jacinto-

Brazos Coastal Basin have to date not been fully utilized. Under the theoretical cancellation of these rights in Runs 5 and 7 a considerable amount of water could be made available for appropriation if these rights were partially cancelled to their historical maximum use levels. Future appropriations are subject to environmental flow restrictions pursuant to Chapter 11 of the Texas Water Code. Environmental flow needs, including instream flows and freshwater flows to Galveston Bay and the Brazos River Estuary, might be considered when granting new water rights or amending existing water rights, thereby affecting the amount of water available for appropriation.

The TNRCC utilizes Run 3 for determining water available for appropriation by new, perpetual rights, and utilizes Run 8 (current conditions run) for granting new appropriations on a term, or temporary, basis. The assumptions utilized in Run 8 are the same as those utilized in Run 5, with the two exceptions that (1) Run 8 includes existing term permits at their "current" use levels (Run 5 does not include term permits), and (2) storage-area relationships for large reservoirs are included at their as-permitted conditions in Run 5 and at estimated Year 2000 sedimentation conditions in Run 8.

5.6 Requirements for Model Rerun and/or Model Update

Input data sets for each of the scenarios modeled have been transmitted to the TNRCC. The water availability model can be rerun using these data sets without any special considerations. Inclusion of additional water rights and secondary control points should incorporate prorated channel loss factors for the affected stream reaches, using the equation presented in Section 4.2.1.

Table 5-12. Run 3 Yields at Large Reservoirs

Reservoir	Authorized Storage Capacity (acft)	Associated Water Rights	Total of Authorized Diversions (acft/yr)	Run 3 Yield (acft/yr)	Percent of Authorized	Comment
Lake Abilene	11,868	C4142	1,675	1,675	100.0%	
Lake Alan Henry	115,937	P4146	35,000	9,595	27.4%	Junior priority date (1981) located in the upper Brazos River Basin with infrequent flows. Permit allows for overdrafting.
Lake Alcoa	15,650	C5272 (14,000 consumptive use from reservoir) C3758 (makeup diversions from Little River)	14,000	14,000	100.0%	
Allens Creek Reservoir	138,441	P2925	46,256	13,150	28.4%	Authorized for makeup diversions from Brazos River (BRA reservoir releases), which are not included in the model. Permit allows for overdrafting
Lake Aquila	52,400	C5158	13,896	13,767	99.1%	
Lake Belton	457,600	C5160 (BRA, 102,257acft/yr) C2936 (U.S. Army, 10,000 acft/yr)	112,257	109,796	97.8%	
Brazoria Reservoir	21,700	C5328	75,656	41,446	54.8%	Off-channel reservoir supplied with senior run-of-the-river diversions from the Brazos River.
Brushy Creek Reservoir	6,560	C4355	1,000	67	6.7%	Small watershed (43 sq mi) with junior priority dates for refilling of storage and diversion from reservoir (1982 and 1990). Permit allows for overdrafting. Modeled as system wtih two other reservoirs (New Marlin Reservoir and Marlin City Lake), both of which are considerably senior in priority (1948 and 1956). Certificate allows water to be diverted from the Brazos River for subsequent storage and diversion from the reservoirs. This contractual diversion is not modeled. "Yield" diversion modeled is the amount authorized at 1982 priority data for diversion from the reservoir.
Bryan Utilities	15,227	C5268	85	85	100.0%	Extremely small watershed (0.82 sq mi), essentially an off-channel reservoir supplied by effluent discharges originating as groundwater. Water right authorized for power plant

Reservoir	Authorized Storage Capacity (acft)	Associated Water Rights	Total of Authorized Diversions (acft/yr)	Run 3 Yield (acft/yr)	Percent of Authorized	Comment
						cooling, of which 850 acft/yr can be consumed. Of the consumed water, only 85 acft/yr can be state water (from watershed flows).
Camp Creek Reservoir	8,400	C5301	-	-	n/a	Authorized for recreation use only - no authorized diversions included in model.
Lake Cisco	45,000	C4211	2,027	1,524	75.2%	Small watershed (27 sq mi). Permit allows for overdrafting.
Lake Cleburne	25,600	C4106	6,000	5,026	83.8%	
Lake Daniel	11,400	C4214	2,100	1,664	79.2%	Small watershed (83 sq mi). Permit allows for overdrafting.

Table 5-12. Run 3 Yields at Large Reservoirs (Continued)

Reservoir	Authorized Storage Capacity (acft)	Associated Water Rights	Total of Authorized Diversions (acft/yr)	Run 3 Yield (acft/yr)	Percent of Authorized	Comment
Lakes Eddleman and Graham	52,386	C3458	20,000	6,191	31.0%	Reservoirs modeled as combined storage. Yield constrained by low inflows. Permit allows for overdrafting.
Eagles Nest Lake	11,315	C5492	1,800	1,800	100.0%	
Fort Phantom Hill Reservior	73,960	C4151, C4161, C4139 and C4165	33,190	19,796	59.6%	Yield constrained by low flows. Owner has contract for make up water. Permit allows for overdrafting.
Gibbons Creek Reservoir	32,084	C5307 and C5311	9,740	9,740	100.0%	
Lake Georgetown	37,100	C5162	13,610	11,285	82.9%	
Lake Granbury	155,000	C5156	64,712	64,712	100.0%	
Lake Granger	65,500	C5163	19,840	19,729	99.4%	
Harris Reservoir	10,200	C5328	230,000	46,448	20.2%	Off-channel reservoir supplied with senior run-of-the-river diversions from the Brazos River.
Hubbard Creek Reservoir	317,750	C4213	56,000	20,670	36.9%	Low inflows throughout the simulation period. Permit allows for overdrafting.
Lake Kirby	8,500	C4150	3,880	1,362	35.1%	Small watershed (44 sq mi), yield is constrained by low inflows. Permit allows for overdrafting.
Lake Creek Reservoir	8,500	C4345	10,000	9,861	98.6%	
Lake Davis	5,395	C3440	2,000	409	20.4%	Small watershed (37 sq mi) in upper Brazos River Basin with low inflows. Permit allows for overdrafting.
Lake Leon	28,000	C3470	6,300	6,144	97.5%	
Lake Waco	192,062	C2315 (original) P5094 (enlargement)	79,870	79,870	100.0%	See note at end of table.
Lake Limestone	225,400	C5165	65,074	65,074	100.0%	
Lake Sweetwater	10,000	C4130	3,740	1,442	38.6%	Low inflows during drought of record. Permit allows for overdrafting.
Lake Mexia	9,600	C5287	2,952	2,952	100.0%	
Millers Creek Reservoir	30,696	C3444	5,000	4,732	94.6%	
Lake Mineral Wells	7,065	C4039	2,520	2,520	100.0%	
Lake Palo Pinto	44,100	C4031	13,480	13,480	100.0%	
Possum Kingdom Reservoir	724,739	C5155	230,750	230,750	100.0%	

Reservoir	Authorized Storage Capacity (acft)	Associated Water Rights	Total of Authorized Diversions (acft/yr)	Run 3 Yield (acft/yr)	Percent of Authorized	Comment
Post Reservoir	57,420	C3711	10,600	5,464	51.6%	Relatively junior priority date (1970) in upper Brazos River Basin. Yield constrained by low flows. Permit allows for overdrafting.
Lake Proctor	59,400	C5159	19,658	19,658	100.0%	

Table 5-12. Run 3 Yields at Large Reservoirs (Concluded)

Reservoir	Authorized Storage Capacity (acft)	Associated Water Rights	Total of Authorized Diversions (acft/yr)	Run 3 Yield (acft/yr)	Percent of Authorized	Comment
Lake Somerville	160,110	C5164	48,000	44,277	92.2%	
Smithers Lake	18,750	C5325 (diversion from reservoir) C5320 (makeup diversions from Brazos River)	34,300	16,078	46.9%	
Squaw Creek Reservoir	151,500	C4097	23,180	9,064	39.1%	Small watershed (58 sq mi) with a relatively junior priority date (1973). A contractual agreement to divert water from Lake Granbury is not modeled.
Lake Stillhouse Hollow	235,700	C5161	67,768	62,970	92.9%	
Lake Stamford	60,000	C4179	10,000	4,407	44.1%	Located in upper Brazos River Basin with low flows. Permit allows for overdrafting.
Tradinghouse Creek Reservoir	37,800	C4342	15,000	4,690	31.3%	Small watershed (38 sq mi). A contractual agreement to supplement reservoir with water from the Brazos River is not modeled. Permit allows for overdrafting.
Twin Oaks Reservior	30,319	C5298	13,200	2,999	22.7%	Small watershed (48 sq mi). Permit allows for overdrafting.
Lake Whitney	642,179	C5157	18,336	18,336	100.0%	
White River Reservior	44,897	C3693	6,000	3,456	57.6%	Located in upper Brazos River Basin with low flows. Permit allows for overdrafting.
Note: The priority of the impoundment (pre-enlargement) for Lake Waco is not explicitly assigned in the paper right. However, the Final Adjudication for the Bosque River Watershed clearly assigns the priority for impoundment at 1/10/1929. The priority for impoundment in the reservoir can have a significant effect on the firm yield.						

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Section 6
Summary and Conclusions

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

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

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

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 1988 and 1997, and surveyed reservoir storage capacities for large reservoirs are modified to reflect sediment accumulation representative of the year 2000. Term permits are included at their maximum use between 1988 and 1997.

Simulation results for the various scenarios modeled indicate that cancellation of only those rights showing no use affects water availability very little in the Brazos River Basin and San Jacinto-Brazos Coastal Basin. Reuse of treated effluent has limited effects on overall (mean and median) water availability in either basin, but does substantially reduce minimum unappropriated flows at several locations.

The most influential factor affecting overall water availability in the Brazos River Basin is the assumption concerning authorized versus maximum historical use in Runs 5, 7 and 8. Significant increases in overall water availability result when rights are limited to divert at their maximum reported annual use between 1988 and 1997. Many rights in the Brazos River Basin to date have not been fully utilized. Under the theoretical cancellation of these rights in Runs 5 and 7, a considerable amount of water could be available for appropriation if these rights were partially cancelled to their historical maximum use levels. Currently, the total amount of authorized diversions for term permits is relatively small, and inclusion of term permits in Run 8 has no significant effect on water availability. Neither partial nor full cancellation of unutilized water rights significantly affects water availability in the San Jacinto-Brazos Coastal Basin.

Considering water use records for years 1988 through 1997, the total volume of authorized diversions for rights included in the model (3,552,616 acft/yr) in the Brazos River Basin and San Jacinto-Brazos Coastal Basin is currently about 40 percent (1,416,096 acft/yr) utilized. The difference between unappropriated flows for Run 8 and Run 3 at any given location is a theoretical indication of the quantity of water that might be available for temporary, or term, appropriation under a partial cancellation scenario. This water would be available due to the differences between current levels of water use and return flows (Run 8) and fully authorized levels of water use and zero return flows (Run 3). As existing water rights become more fully utilized in the future and reuse projects more prevalent, the difference in unappropriated flows between Run 8 and Run 3 could decrease and opportunities for term appropriation will likely decrease.

Full cancellation of unutilized rights (Runs 4 and 6) would not significantly increase water available for new appropriation. Most of the largest rights in the basin are currently being used and would not be subject to full cancellation. Partial cancellation of underutilized rights (Runs 4 and 7) would increase the reliability of other rights and could increase availability basinwide for new appropriations. Such new appropriations would, however, be subject to environmental flow needs. As many existing rights are not subject to environmental flow needs, partial cancellation of presently underutilized rights would convert a portion of the rights presently available for future increases in demand (or for transfer to others in need of additional supply, but lacking water rights) to enhanced instream flows and freshwater inflows to the Brazos River Estuary and Galveston Bay.

The TNRCC utilizes Run 3 for determining water available for appropriation by new, perpetual rights, and utilizes Run 8 (current conditions run) for granting new appropriations on a term, or temporary, basis. The assumptions utilized in Run 8 are the same as those utilized in Run 5, with the two exceptions that (1) Run 8 includes existing term permits at their "current" use levels (Run 5 does not include term permits), and (2) storage-area relationships for large reservoirs are included at their as-permitted conditions in Run 5 and at estimated Year 2000 sedimentation conditions in Run 8.

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