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F I N A L

Water Availability Modeling for the Colorado/Brazos-Colorado Basin

MODELING REPORT - TEXT

prepared for:

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1.0 INTRODUCTION

1.1 Description of the Basin

The Colorado River Basin extends from northwest to southeast across Texas, heading in southeastern New Mexico, generally southwest of Lubbock, Texas. The river's mouth is at Matagorda Bay south of Bay City near Matagorda, Texas. The length of the basin is about 600 miles, the maximum width is about 170 miles, and the total drainage area covers 42,344 square miles, of which approximately 11,400 square miles are probably non-contributing. The Colorado/Brazos-Colorado Basin comprises all or part of 64 counties. Figure 1-1 presents a map of the basin. Figure 1-1 also shows the subwatersheds and primary control points (locations where naturalized flows were calculated) established for the purpose of the water availability modeling.

The Colorado River system consists principally of the mainstem Colorado River and six major tributaries. The major tributaries are Beals Creek, Concho River, Pecan Bayou, San Saba River, Llano River, and Pedernales River. All of the major tributaries enter the Colorado River above Austin. There are 31 major reservoirs in the basin, defined as having a conservation storage capacity of 5,000 acre-feet or greater.

The Brazos-Colorado Coastal Basin borders the Colorado River Basin to the east. The length of the coastal basin is approximately 100 miles, and the total drainage area covers 1,850 square miles. The major streams in the coastal basin are the San Bernard River and Caney Creek. There are no major reservoirs in the coastal basin.

The climate varies widely throughout the Colorado/Brazos-Colorado Basin. The extreme western portions of the basin are desert, with an annual precipitation of approximately 12 to 16 inches. Precipitation increases toward the east and southeast; the southeastern portion of the basin is humid subtropical with a maximum annual precipitation of approximately 44 inches near the coast. Average annual lake surface evaporation ranges from about 72 inches in the northwest to 52 inches in the southeast. Elevations range from about 4,000 feet at the headwaters to sea level at the coast.

1.2 Study Objectives

This document presents the results of the Colorado/Brazos-Colorado water availability modeling study. The objective of this effort has been to meet the requirements of Senate Bill 1 of the 75th Texas Legislature regarding the development of new river basin simulation models for determining available water for individual water rights in accordance with Chapter 11, Water Rights, of the Texas Water Code. These models, once developed and operational, will be capable of determining water availability in the basins under a range of policy and planning scenarios under the doctrine of prior appropriation.

Figure 1-1 Location of Colorado/Brazos-Colorado Basin and Primary Control Points

The Texas Natural Resource Conservation Commission (TNRCC) is responsible for developing water availability models for all basins across the state. R. J. Brandes Company (RJBCO) of Austin, Texas, under contract with the TNRCC, has assisted the agency in the preparation, development, and application of a water availability model ("WAM") for the combined Colorado River Basin and the Brazos-Colorado Coastal Basin (referred to as the "Colorado WAM" or the "Colorado/Brazos-Colorado WAM"). Brown & Root Services of Houston, Texas; PBS&J of Austin, Texas; and Crespo Consulting Services, Inc. of Austin, Texas have served as subconsultants to RJBCO for this project.

In accordance with the provisions of Senate Bill 1, the following specific information is to be developed by the TNRCC through the water availability analysis:

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

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

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

1.3 Study Approach

The TNRCC, working with the Texas Water Development Board (TWDB) and the Texas Parks and Wildlife Department (TPWD), and with assistance from outside consultants, has developed specific procedures and criteria for development of the water availability models. The basic procedure applied in analyzing water availability in a particular river basin involves developing naturalized streamflows throughout the basin from historical hydrologic and other data, then simulating on a monthly basis the ability of individual water rights to meet their authorized diversions or storage quantities in accordance with the prior appropriation doctrine. The simulations are performed using the Water Rights Analysis Package (referred to as "WRAP") that was developed by Dr. Ralph A. Wurbs of Texas A&M University. The December 17, 2001 version of WRAP has been used in developing the Colorado WAM.

Naturalized streamflows represent historical streamflow conditions, including typical wet, dry, and normal flow periods, without the influence of man's historical activities as they relate to water rights and water use. In essence, naturalized streamflows exclude the effects of historical diversions, return flows, and reservoir storage and evaporation. For the Colorado/Brazos-Colorado WAM, the TNRCC has stipulated that the naturalized streamflow database must cover at least a 50-year period through calendar year 1998. The naturalized streamflow database that has been developed covers the 59-year period from January 1940 through December 1998. This longer period was selected because 1941 was a particularly wet year throughout the

Colorado/Brazos-Colorado Basin. The WRAP model begins simulations assuming that all reservoirs are full. The inclusion of these above-normal streamflow conditions at the beginning of the WAM streamflow database increases the validity of this assumption. The 1940-1998 historical period also includes the drought of the 1950s, which is believed to be the drought of record for most of the Colorado/Brazos-Colorado Basin.

2.0 EXISTING WATER AVAILABILITY INFORMATION

2.1 Water Rights

There are 1,287 water rights in the Colorado/Brazos-Colorado Basin as of October 17, 2000; 1,226 are in the Colorado Basin and 61 are in the Brazos-Colorado Coastal Basin. The most junior water right included in the WAM has priority date of May 5, 2000. The total amount of authorized diversions for these water rights is approximately 3.3 million acre-feet per year. As indicated in Table 2-1, approximately 66 percent of the total authorized diversion volume is for municipal supplies, 8 percent is for industrial purposes, 25 percent is for irrigation, and the remaining one percent is for mining, recreation, and other uses. Information on water rights was obtained from the TNRCC water rights database (WRDETAIL) and from hard copies of water rights permits and certificates of adjudication. Appendix A contains a copy of the TNRCC database sorted by subwatershed and water right number. Appendix B contains a memorandum with suggested corrections to the database. Figure 2-1 shows the location of all water rights in the basin.

TABLE 2-1
DIVERSION WATER RIGHTS BY USE CATEGORY

USE CATEGORY	NUMBER OF RIGHTS	AUTHORIZED DIVERSION acre-feet/yr	PERCENT OF TOTAL*
Municipal	63	2,172,213	65.9%
Industrial	57	270,291	8.2%
Irrigation	1,355	823,811	25.0%
Mining	32	22,757	0.7%
Hydroelectric	7	2,142,180	n/a
Recreation	76	3,712	0.1%
Other	13	1,363	0.0%
Recharge	1	0	0.0%
TOTAL	1,604**	3,294,147*	100.0%

* Does not include hydroelectric. Hydropower may only be generated from spills or releases made for other uses.
** Many rights have multiple use categories.

2.2 Historical Water Use

Information describing historical water use by month for the entire 1940-1998 analysis period has either been compiled from existing records or estimated from available data. The basic source of diversion information that has been relied upon has been the TNRCC's electronic records of historical monthly diversions by individual water rights holders. Some of these

Figure 2-1 Location of Colorado/Brazos-Colorado Basin Water Rights records date back to the early 1900's and most extend through 1998 (the end of the WAM analysis period). Many of the TNRCC electronic records, however, did not appear to be complete, or they seemed to reflect erroneous data. Because of these problems, extensive effort was expended in obtaining and reviewing hard copies of the historical annual diversion reports from TNRCC's Central Records files, as well as contacting individual water rights holders to discuss their historical water usage.

Hard copies of records of monthly water use by individual municipal and industrial water users within the Colorado/Brazos-Colorado Basin also have been obtained from the Texas Water Development Board (TWDB). These records begin around 1955 and extend to the present. Diversion data also have been obtained from the Lower Colorado River Authority (LCRA) for the major irrigation water users located along the lower Colorado River (Lakeside, Garwood, and Gulf Coast irrigation districts and Pierce Ranch) and from the Colorado River Municipal Water District (CRMWD) for salt water control diversions from the upper Colorado River and Beals Creek.

For municipal diversions, correlations with estimates of population served have been used to develop missing diversion data. Historical trends in industrial water usage based on available data have been used to fill in missing records. For both municipal and industrial diversions, communication with individual water rights holders has been necessary to obtain site-specific information regarding historical diversion locations, amounts, patterns, and periods of operation.

For purposes of the streamflow naturalization process, historical diversions by water rights holders authorized for irrigation use that could not be specifically quantified based on either the TNRCC or LCRA databases or other records obtained from individual irrigation water users have been assumed to be zero.

Appendix C contains information on water use by county in the Colorado/Brazos-Colorado Basin.

2.3 Historical Return Flows and Treated Wastewater Effluent Discharge

Irrigation return flows occur in the lower Colorado Basin as a result of rice farming operations. Return flows from irrigated lands can account for a significant portion of the historical streamflows that are reflected in gage records. This is particularly true in the Brazos-Colorado Coastal Basin (San Bernard River). Only very limited data regarding historical return flows from these irrigation operations are available, however, and for purposes of the streamflow naturalization process, estimates of the historical monthly irrigation return flows from the major irrigation operations have been made for the entire 1940-1998 WAM analysis period.

Monthly amounts of historical irrigation return flows have been estimated by multiplying typical return flow factors times historical irrigation water use. Information regarding irrigation return flow factors has been obtained from the LCRA, by contacting irrigators directly, and from available literature sources. Special studies of irrigation return flows from rice farms have been conducted within the irrigation districts served by LCRA, and results from these studies have provided useful information for establishing typical ranges of return flow factors (Tuck, 1974).

Since much of the flow at the San Bernard River near Boling (primary control point SR-BO) is composed of return flows during the summer and early fall, removal of the return flows as part of the streamflow naturalization process yielded negative flows in some cases. Final refinement of the return flow factors was made by calibrating the return flows to minimize negative flows using the gage records from SR-BO. The final irrigation return flow factors are summarized in Table 2-2.

TABLE 2-2
RICE FARMING IRRIGATION RETURN FLOW FACTORS

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVERAGE
0	0	0	0.08	0.09	0.09	0.25	0.15	0.13	0.14	0.07	0	0.18

Note: Factors based on total annual diversions.

Data that partially document historical monthly discharges from municipal and industrial wastewater treatment facilities within the Colorado/Brazos-Colorado Basin have been obtained from the TNRCC for the period beginning in the late 1970's and extending through 1998. These data have been examined and organized based on discharge amount. Missing records regarding known sources of return flows have been filled in by using correlations with either available surface-water diversions or the historical population served. Again, it has been necessary to contact directly some of the individual entities (cities, counties, river authorities, districts, industries, etc.) that discharge return flows into streams in the Colorado/Brazos-Colorado Basin to obtain site-specific information regarding historical discharge amounts, outfall locations, and periods of service.

All municipal and industrial wastewater discharges (return flows) within the contributing drainage area of the Colorado/Brazos-Colorado Basin with a permitted flow greater than or equal to 0.9 million gallons per day (mgd), or approximately 1,000 acre-feet per year, were considered significant and were accounted for in the streamflow naturalization process. In addition, five dischargers in Travis and Wharton Counties with permitted flows of approximately 0.5 mgd were included. The Travis County return flows were included because they are concentrated in one area and discharge to the same stream segment. The City of Wharton has two wastewater treatment plants with capacities of 1.5 and 0.5 mgd, so both were included. This resulted in a total of 35 significant municipal and industrial wastewater discharges, as shown in Table 2-3. Power plants utilizing once-through cooling were not included in the return flow adjustments since their return flows are essentially equal to their diversions. However, the heating of the water results in additional evaporation ("forced evaporation") in the receiving stream as the

Table 2-3 Significant Wastewater Discharges

Table 2-3 cont'd

water returns to thermal equilibrium. Forced evaporation losses were handled as an additional diversion. Modeling of return flows is discussed in detail in section 4.2.3.3.

2.4 Previous Water Availability and Planning Studies

A bibliography of previous studies and other references pertinent to the Colorado/Brazos-Colorado WAM is presented in Appendix D. Previous investigations of particular relevance to this study include the Legacy Water Availability Model for the Colorado River Basin that was developed in 1977 by the Texas Department of Water Resources (TNRCC, 1998) and "Present and Future Surface-Water Availability in the Colorado Basin," which is referred to as the LP-60 Study (TDWR, 1978). Both of these previous investigations involved the development of water availability models for portions of the Colorado/Brazos-Colorado Basin.

2.5 Significant Considerations Affecting Water Availability in the Basin

Significant assumptions made in this study that may affect water availability include:

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

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

- Return flows from rice irrigation in the lower basin are not measured and have been estimated based on literature values and other information.

- Negative incremental monthly flows that resulted from the streamflow naturalization process, except for those related to recharge of the Edwards-Balcones Fault Zone aquifer, have been assumed to be the result of timing errors between upstream and downstream gages and/or attributable to errors in gaging, reservoir storage changes, or reported diversion amounts. They have been eliminated to the extent possible by making corresponding adjustments to flows occurring in adjacent months.

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

- For the most part, channel losses have been determined to be negligible based on historical streamflow analyses, but adjustments for salt cedar uptake in the upper basin and groundwater recharge from Barton and Onion Creeks into the Barton Springs segment of the Edwards Aquifer have been accounted for in the streamflow naturalization process and in the water availability modeling.

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

3.0 HYDROLOGIC DATA REFINEMENT

3.1 Natural Streamflow at Gaged Locations

3.1.1 Streamflow Naturalization Methodology

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

Naturalized Streamflow = Historical Streamflow
+ Historical Upstream Diversions
– Historical Upstream Return Flows
+ Historical Changes in Upstream Reservoir Storage
+ Historical Upstream Reservoir Evaporation Loss

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

In deriving the naturalized streamflows for certain gages located downstream of major springs, the historical spring discharges have been removed from the measured streamflows at a downstream gage location in order to derive flow values at the gage that only represent historical watershed runoff. These watershed runoff flow values then have been naturalized using the above equation. For modeling purposes, the corresponding spring discharges have been specified separately in WRAP (using time series FA cards) as a single water source at the actual location of the spring.

The difficulty in the streamflow naturalization process, of course, has been the development of reliable data regarding historical diversions, return flows, and reservoir storage and evaporation for the entire 1940-1998 period. While the data that have been developed for this purpose very likely do not fully and accurately reflect actual historical diversions, return flows, and reservoir storage and evaporation, they are believed to represent reasonable estimates of these quantities that probably could not be significantly refined or improved upon without the availability of additional data records. Such records are not known to exist. Furthermore, such refinements or improvements in these data would require a substantial amount of additional effort and time. The data that have been developed in this study for purposes of the streamflow naturalization process are believed to be adequate and satisfactory for purposes of developing and operating a meaningful WAM for the Colorado/Brazos-Colorado Basin.

Occasionally, the calculation of incremental naturalized flows between control points yielded a negative incremental flow. This can be caused by a variety of factors, such as inaccuracies in streamflow data or reservoir contents or spills, incorrect diversions or return flows, stream channel losses and reservoir seepage losses, but most commonly by travel time effects of high discharge events. In the latter case, a flood near the end of a month at an upstream control point could result in a higher monthly total discharge at the upstream control point than the downstream control point, because the full effects of the flood are not recorded downstream until the following month. This would result in not only a negative incremental flow at the downstream control point for that month, but also a disproportionately large incremental flow for the following month.

The primary means in which negative incremental flows have been handled has been to set the incremental flow to zero for the current month and reduce the flow for the following month by the amount of the negative value. In cases where the negative adjustment was larger than the following month's flow, the process was repeated for the next month(s), or in some cases for the previous month(s), until the negatives were eliminated. For Onion Creek, numerous negative incremental flows were calculated between the upstream control point (OC-DR), and the downstream control point (OC-DS). This is because this incremental area encompasses the recharge zone of the Edwards-Balcones Fault Zone aquifer and has significant channel losses. Consequently, for Control Point OC-DS, no adjustments were made for negative incremental flows.

3.1.2 Streamflow Data Sources

All of the known U.S. Geological Survey (USGS) streamflow gages, both existing and discontinued, for which there are historical records within the Colorado/Brazos-Colorado Basin for all or part of the 1940-1998 period have been identified through research of USGS reports and other documents. There are over 100 gages in the basin; of these, 50 gages have been identified as containing records useful for the streamflow naturalization process. Forty-five gages were selected as primary control points (see Figure 1-1). Appendix E presents a list of all gaging stations used and the streamflow naturalization procedures for each of those stations.

3.1.3 Delivery Factors and Channel Loss Rates

For purposes of the Colorado/Brazos-Colorado WAM, channel losses along the streams within the Colorado/Brazos-Colorado Basin have been evaluated through the following activities:

- Review of the geology and hydrogeology of the Basin.
- Analysis of previous delivery-of-water and low-flow investigations.
- Analysis of historical streamflows for selected reaches.
- Examination of potential evapotranspiration losses from salt cedar infestation.

3.1.3.1 Geology/Hydrogeology

Above the Edwards-Balcones Fault Zone (BFZ) aquifer recharge zone (located near Austin), groundwater movement is generally toward streams. Streams tend to be discharge areas rather than recharge areas; in other words, streams crossing these aquifers are gaining flow from groundwater and springs, rather than losing flow through channel seepage. Streams flowing over the Edwards-BFZ recharge zone, such as Onion and Barton Creeks in the Colorado Basin, experience streamflow losses and are primary points of recharge to the Edwards. Downstream of Austin in the lower Colorado Basin, studies suggest that groundwater in the Carrizo-Wilcox, Queen City, Sparta, and Colorado Alluvium aquifers is generally flowing toward streams and the Colorado River, and that the streams are gaining flow from the aquifers rather than losing flow (Woodward, 1989; Thorkildsen, 1991; RJBCO, 2000; Ryder, 1988).

3.1.3.2 Delivery-of-Water and Low-Flow Investigations

Delivery-of-water investigations were conducted on the Colorado River in 1918 and 1934 (TBWE, 1960). The former involved a release from Lake Austin to Wharton, and the latter involved discharges from Lake Brownwood to Eagle Lake prior to the construction of the Highland Lakes. These studies indicated that losses occurred with respect to the total volume of water released over a period of two to four weeks. Losses along the Colorado River were observed primarily in the reach below Austin, and the losses stabilized after about two to three weeks. This is attributable to the increased stage of the river resulting in water going into bank storage and prism (channel) storage during the early part of the release. As the river stage decreases, it would be expected that the bank and channel storage would be released, resulting in no significant net channel losses.

Several low-flow investigations have been performed in the Colorado Basin (TWBE, 1960; Holland, 1964; Holland, 1965; Rawson, 1973; Baker, 1974). In general, results were consistent with the geologic and hydrogeologic analysis presented above. Above Austin, mainly gains with some losses were observed, but these were generally small and were frequently offsetting. On the mainstem, one study from Robert Lee to Wharton in 1918 showed gains on every major reach of the river. Investigations on Onion and Barton Creeks showed steady gains outside of the Edwards-BFZ recharge zone and significant losses over the recharge zone.

3.1.3.3 Historical Streamflow Records

Channel losses and gains along selected stream reaches in the Colorado Basin have been examined in this study based on analysis of historical streamflow gage records. Nine reaches were selected between gages that had concurrent data and were not influenced by nearby reservoirs. These reaches are shown in Figure 3-1. Adjustments for diversions and additional inflows from tributaries and return flows were accounted for. These reaches were analyzed by calculating gains and losses as a percentage of the upstream flow for numerous specific periods of time characterized by non-runoff (base flow) conditions lasting a minimum of 15 days. The median values of the gains and losses have been summarized in Table 3-1. The results of the analysis indicate that none of the reaches were characterized by losses, and all showed small to moderate gains, which is consistent with the geologic and hydrogeologic assessment.

A separate analysis was performed on Onion and Barton Creeks, which cross the Edwards-BFZ recharge zone. Loss threshold flow rates determined by Barrett and Charbeneau (1996) were applied to long-term daily records from gaging stations above the recharge zone on both creeks. Based on these calculations, the overall average percentage loss factor for the recharge zone reach of Onion Creek was determined to be 93 percent. For Barton Creek, it was determined to be 79 percent.

3.1.3.4 Evapotranspiration by Salt Cedars

Salt cedars (*Tamarix, sp.*, also known as tamarisk) have been documented in riparian areas throughout the Colorado Basin above O. H. Ivie Reservoir (UCRA, 2000), which is represented by Subwatersheds A through D in the Colorado WAM. These exotic plants grow in dense thickets along streams and consume unusually large quantities of water, contributing to streamflow depletion. Estimates of channel losses attributable to salt cedar uptake have been calculated based on assumed densities along major streams and published estimates of uptake rates (Bureau of Reclamation, 1992; Parkhill, 2000). The loss rate for the upper Colorado Basin has been estimated at approximately 24 acre-feet/mile/year. This rate has been applied to the median annual flows at the primary control points in the upper basin to yield overall loss rate factors for each reach, ranging from 0.3 percent to 20.1 percent of the flow, as shown in Table 3-2. The column labeled “Total Salt Cedar Loss Factor for Reach” is the channel loss value input to the WRAP model for the stated reach ending at the primary control point listed. This value was pro-rated between the secondary control points in the reach as discussed in section 3.2.1.

Figure 3-1 Stream Reaches Used in Streamflow Records Channel Loss Analysis

TABLE 3-1
STREAMFLOW RECORDS CHANNEL LOSS ANALYSIS RESULTS

REACH NAME	UPSTREAM GAGE NAME & NUMBER	DOWN-STREAM GAGE NAME & NUMBER	PERIOD ANALYZED	RIVER MILES ALONG REACH	MEDIAN GAIN(+) / LOSS(-) PER MILE
Upper Colorado	Colorado R nr Cuthbert 8120700	Colorado R at Colorado City 8121000	1/75-9/86	13.7	5.1%
Middle Colorado No. 1	Colorado R at Robert Lee 8124000	Colorado R nr Ballinger 8126380	1/90-12/98	50.2	3.0%
Concho	Concho R at San Angelo 8136000	Concho R at Paint Rock 8136500	1/90-12/98	41.9	1.1%
Middle Colorado No. 2	Colorado R nr Stacy 8136700	Colorado R at Winchell 8138000	1/90-9/93; 10/97-12/98	44.1	0.0%
San Saba	San Saba R at Menard 8144500	San Saba R nr Brady 8144600	7/79-9/93	43.4	2.4%
Pecan Bayou	Pecan Bayou at Brownwood 8143500	Pecan Bayou nr Mullin 8143600	6/77-10/83	35.0	11.6%
Llano	Llano R nr Junction 8150000	Llano R nr Mason 8150700	1/80-5/93; 10/97-12/98	53.7	0.4%
Pedernales	Pedernales R nr Fred'burg 8152900	Pedernales R nr Johnson City 8153500	4/80-5/93	40.7	4.9%
Lower Colorado	Colorado R at Columbus 8161000	Colorado R at Wharton 8162000	1/90-12/98	68.5	0.3%

TABLE 3-2
DETERMINATION OF SALT CEDAR STREAMFLOW LOSS FACTORS

WATERSHED	PCP NO.	REACH DESCRIPTION	REACH LENGTH (miles)	MEDIAN ANNUAL FLOW (acre-feet)	SALT CEDAR LOSS FACTOR[1] (% / mile)	TOTAL SALT CEDAR LOSS FACTOR FOR REACH[2]
A	A30000	Above Colorado R near	41	36,004	0.07%	2.8%
	A20000	Above Deep Creek near Dunn	15	5,426	0.45%	6.8%
	A10000	Colorado R: Ira to Colorado City	30	19,732	0.12%	3.7%
B	B50000	Lake Colo. City near Colo. City	16	No Flow Data	0.35%	5.6%
	B40000	Above Champion Ck near Colo. City	14	7,645	0.32%	4.3%
	B30000	Above Beals Ck near Westbrook	50	12,689	0.19%	9.5%
	B20000	Colorado R: At Colo. City to above Silver	40	19,732	0.12%	5.0%
	B10000	Colorado R: Above Silver to Robert Lee	44	112,849	0.02%	0.9%
C	C70000	Above N Concho R near Carlsbad	38	4,564	0.53%	20.1%
	C60000	Above Middle Concho above Tankersley	20	5,960	0.41%	8.1%
	C50000	Above Spring Ck above Tankersley	19	6,785	0.36%	7.0%
	C40000	Above Dove Ck at Knickerbocker	11	8,545	0.28%	3.1%
	C30000	Above S Concho at Christoval	5	14,162	0.17%	0.9%
	C20000	Concho R: Confluence to San Angelo	22	15,565	0.16%	3.5%
	C10000	Concho R: San Angelo to Paint Rock	42	47,136	0.05%	2.2%
D	D40000	Colorado R: Robert Lee to Ballinger	56	68,268	0.04%	2.0%
	D30000	Above Elm Ck at Ballinger	24	23,732	0.10%	2.5%
	D20000	Colorado R: Ballinger to Stacy	61	112,579	0.02%	1.3%
	D10000	Colorado R: Stacy to Winchell	27	224,020	0.01%	0.3%

[1] Annual per-mile salt cedar loss (24.24 acre-feet) divided by median annual flow
[2] Loss factor per mile times reach length.

3.1.4 Completion of Streamflow Records

Historical streamflow records for many of the gages located throughout the Colorado/Brazos-Colorado Basin are not available for the entire 1940-1998 period for which naturalized flows have been developed. Records from other gages have been used to fill in missing records. These streamflow fill-in procedures involved the development of correlations of flows between gages or the application of appropriate flow or drainage area ratios.

All of the gages designated as primary control points were examined to determine periods of missing records, and an appropriate means for filling in missing monthly streamflow values was identified based on an analysis of the existing data. This information is summarized in Appendix F. For each control point, the required fill-in periods are indicated, and for each fill-in period, another gage is identified that was used as the basis for filling in the missing records. The relationship that was used is listed under the column heading "Fill-In Procedure." For example, A30000 (CR-IR) between January 1940 and May 1946 was filled in using the values from B10000 (CR-RL) with the relationship $y = 0.2866x$. This equation was generated from a scatter plot of A30000 (control point to be filled) monthly flows versus B10000 (control point used to fill missing records) monthly flows using a linear regression analysis forced through the origin. This type of analysis was used for the majority of the fills.

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

In addition, several other methods were used for situations where they were determined to be appropriate, including monthly scatter plots not forced through the origin, correlations with three-year averages of flow data from surrounding gages, ratios of cumulative flows ("Double Mass Curves") from two gages, and scatter plots of annual flow data forced through the origin. In using the annual flow relationship to fill in monthly values, a monthly flow distribution percentage was developed for each month of the year by summing all the historical data for a given month and dividing this value by the total flow for the period of record. These monthly flow distribution percentages were then multiplied by the filled annual flow values to obtain filled values for each month.

The resulting monthly and annual naturalized flows for the primary control points are tabulated in Appendix G.

3.1.5 Comparison With Other Naturalized Flows

Plots comparing the annual naturalized flows for the 1940-1998 period developed in this study to those included in the TNRCC's Legacy Water Availability Model for the Colorado River Basin are presented in Appendix H. Since the Legacy model's streamflow database extends from 1940 through 1972, the annual naturalized flow values from the Legacy model are plotted only for this period.

For most of the control points, the annual naturalized flows developed in this study agree fairly well with those from the Legacy model. The flows for some periods, however, do exhibit significant deviations. For these periods, the data and procedures utilized in this study have been re-examined to assure that no major errors or data inconsistencies have been incorporated into the naturalized streamflow process undertaken in this study. To date, no such problems have been identified, and consequently, the naturalized streamflows developed in this study are believed to properly reflect actual conditions within the limits of the available database. Detailed information describing the data and procedures used in developing the Legacy model naturalized flows is not available; therefore, the reasons for the deviations between the two sets of naturalized flows cannot be fully explored.

The Texas Department of Water Resources (TDWR) investigated water availability in the Colorado River Basin in the late 1970's and developed naturalized streamflows at various locations. This investigation is described in the TDWR Report LP-60 (1978). Plots comparing the LP-60 annual naturalized flows, which are available for the 1941-1965 period, with those developed in this study at gage locations from Austin downstream are presented in Appendix I. The naturalized streamflows developed in this study generally are somewhat greater than those from the LP-60 investigation. Again, the data and procedures utilized in this study have been re-examined to assure that no major errors or data inconsistencies have been incorporated into the naturalized streamflow process undertaken in this study. The primary reason for the deviations from the LP-60 naturalized flows is that in LP-60, flows at Mansfield Dam (Lake Travis, WAM Control Point I20000) were estimated, and those estimated flows were added to the incremental flows calculated at the downstream gages. Figure I-1 shows that those estimated flows are consistently lower than the flows calculated for the WAM, but follow the same temporal pattern. The flows at all of the downstream control points show the same pattern. It is concluded that the naturalized streamflows developed in this study are consistent with the flows developed in LP-60.

Comparisons of the annual naturalized streamflows developed in this study with the historical gaged streamflows at all of the primary control points are presented on plots in Appendix J. The annual historical flow values in the plots correspond to the periods of record for the individual gages. As expected, most of the plots indicate some level of differences between the historical gaged flows and the naturalized streamflows developed in this study. These occur, of course, because of the adjustments made in deriving the naturalized streamflows to account for the historical effects of diversions, return flows, and reservoir depletions.

3.1.6 Statistical Assessment of Trends in Streamflow

The monthly naturalized streamflows developed in this study at the downstream end of each of the subwatersheds have been statistically analyzed, and monthly values of totals, maximums, minimums, medians, means, and standard deviations have been determined. The percentage that each monthly flow represents of its corresponding total annual flow has also been determined. These values are summarized in Table 3-3.

The increasing trend in all of the streamflow values in the downstream direction is consistent with the normal streamflow variations in river basins. For example, the mean flow values for Subwatershed B are greater than those for Subwatershed A, and those for Subwatershed D are greater than those for Subwatersheds B plus C. Similar trends are noted for the other subwatersheds. The magnitudes of the standard deviations are large compared to their respective monthly and annual mean flows, especially the monthly flows. This suggests that monthly flows, and even total annual flows, can vary substantially from year to year. This effect is more pronounced in the upper basin, reflecting more variability in rainfall from year to year.
Figure 3-2 presents the monthly flow distribution by subwatershed. The average distributions among subwatersheds is generally similar, with peaks in the spring and fall. The subwatersheds in the upper basin, particularly A and B, show more extreme seasonal variability. Conversely, the lower basin, particularly Subwatersheds L and N (Brazos-Colorado Coastal Basin), shows less variability because of the higher and more consistent rainfall.

3.1.7 Springflow Correlations

Of the 20 springs included in the WRAP model, only Barton Springs near Austin and Dove Creek Springs near Tankersley had consistent long-term daily or monthly records of springflow discharges. The remaining springflow records consisted of measurements at irregular intervals. Correlations between the historical data and the long-term records of Barton and Dove Creek Springs yielded varying degrees of fit, but they are the best data available, and it allowed for the completion of the springflow records for the entire 1940-1998 simulation period.

Historical monthly flows for Barton Springs are presented in Table 3-4. Discharges for Cold/Deep Eddy Springs were developed from the Barton Springs historical records, as these two spring groups are located near Barton Springs and are associated with the Edwards-Balcones Fault Zone Aquifer.

Figure 3-2 Monthly Flow Distribution by Subwatershed

Table 3-3 Monthly Streamflow Statistics by Subwatershed

Table 3-3, cont'd

Table 3-4 Barton Springs Monthly Springflow

The remaining 17 springs or groups of springs, all associated with the Edwards-Trinity (Plateau) Aquifer, were correlated against the Dove Creek Springs monthly flow values. The monthly historical discharges for Dove Creek Springs are listed in Table 3-5.

Table 3-6 lists all of the significant springs that were modeled and the regression equations used to develop the monthly discharges for these springs.

3.2 Natural Streamflow at Ungaged Locations

3.2.1 Distribution of Natural Flows Considering Channel Losses

There are approximately 2,300 control points in the Colorado/Brazos-Colorado WAM. Naturalized streamflows were developed for the primary control points as discussed above. These naturalized streamflows then were distributed to the other (ungaged, or secondary) control points throughout the basin using procedures provided in the WRAP program. The basic method used for distributing the naturalized flows from gaged to ungaged control points was the drainage area ratio method, as directed by TNRCC. With this method, flows at gaged points are multiplied by the ratio of drainage areas between the ungaged and gaged points to obtain the flows at the ungaged point.

During the course of the study, the TNRCC discovered problems in some simulations with using the WRAP model option that uses the U.S. Natural Resources Conservation Service (NRCS) Curve Number (CN) method, which is documented and described in detail in the WRAP users manual (Wurbs, 2001). This method uses total drainage areas, curve numbers, and mean annual precipitation to distribute the flows from gaged to ungaged control points. Drainage areas, mean annualprecipitation, and CNs for the gaged watersheds and ungaged subwatersheds associated with the control points used in the WAM were provided by the University of Texas Center for Research in Water Resources (CRWR) using a geographic information system (GIS) data base. These data have been included in the WRAP input file for possible later use, but were not used in this analysis. The TNRCC is working with Texas A&M University and the CRWR to resolve this issue, and the CN method may be used in the future.

For control points representing off-channel reservoirs with no significant contributing drainage area, zero watershed inflows have been assumed, and no naturalized flows were distributed to these points. However, direct precipitation on these impoundments has been accounted for in the water availability analyses. Appendix K presents a summary of control point subwatershed data provided by CRWR.

Channel losses were applied in developing the naturalized flows at primary control points as discussed in Section 3.1.3. These channel loss factors were also used in the WRAP model to distribute naturalized flows to secondary control points, with the exception of Onion Creek,

Table 3-5 Dove Creek Springs Monthly Springflow

TABLE 3-6
LINEAR REGRESSION EQUATIONS FOR SIGNIFICANT SPRINGS

SPRING NAME	NO. OF DATA POINTS	EQUATION
Correlation with Barton Springs Record		
COLD/DEEP EDDY SPRINGS	3	=(A1)*0.0082+2.2445
Correlation with Dove Creek Springs Record		
SPRING CREEK SPRINGS	14	=(A1)*0.5683+3.4923
ANSON SPRINGS	22	=(A1)*0.8852+3.2331
MAIN/GOV'T SPRINGS	15	=(A1)*0.9566+4.4557
WILKINSON SPRINGS	6	=(A1)*1.4643+0.7361
HALL/BIG SPRINGS	4	=(A1)*0.0800-0.4220
RICHLAND SPRING	3	=(A1)*0.2473-1.3971
BAKER SPRING	5	=(A1)*0.5084-1.5207
HART/BERRY/MUD/BOGARD	3	=(A1)*0.1066+1.7738
SLOAN/WALNUT SPRING	4	=(A1)*0.2654+2.4567
DEEP CREEK	4	=(A1)*0.1144+1.3567
SYCAMORE/COTTON	2	=(A1)*0.1012-0.3480
SAN SABA SPRINGS	9	=(A1)*1.0341-0.6236
PARKER/HOLLAND/BRISTER	3	=(A1)*0.0907+0.0671
FLEMING/KING SPRING	3	=(A1)*0.4777-1.2159
WALLACE SPRING	1	=(A1)*0.50
TANNER SPRINGS	34	=(A1)*0.2408+9.7573
SEVEN HUNDRED SPRINGS	6	=(A1)*1.5407+5.9734

which has primary control points that are above and below the Edwards-BFZ recharge zone (see discussion below). Channel loss rates are also applied by WRAP to diversions, return flows, springs, and reservoir depletions and releases. For these purposes, the loss rates determined for each loss reach discussed in Section 3.1.3 were prorated to the secondary control points within each losing reach proportional to the stream channel length between a control point and the next downstream control point within the incremental drainage area that included the relevant reach.

Where there are major losses between primary control points, such as on Onion Creek, the basic flow distribution procedure results in negative incremental flows between those points. Figure 3-3 shows a map of the Edwards-BFZ recharge zone and the surrounding control points in the Onion and Barton Creek watersheds. There are no primary control points on Barton Creek. Flow distribution to the secondary control points in this area were handled two different ways. Those points above the recharge zone in both the Onion and Barton Creek watersheds, and those points below the recharge zone where their entire drainage area is below the recharge zone, were distributed flows from Onion Creek near Driftwood (J50000), which is upstream of the recharge zone. Those downstream of the recharge zone, but including drainage area both in and out of the recharge zone were distributed flows from Onion Creek at Hwy 183 (J40000), which is downstream of the recharge zone. The entire drainage area of J40000 was used rather than the incremental area between the gages, because the incremental flows in this area are mostly negative and the secondary points would receive zero flow if the incremental area were used. This approach has avoided creating negative incremental flows and has produced flows that are considered to be reasonably representative of the area in the vicinity of the recharge zone.

Figure 3-4 shows all of the reaches to which channel losses were applied in the WAM. A memorandum of modeling assumptions regarding channel losses is presented in Appendix L.

3.2.2 Ungaged Freshwater Inflows to Matagorda Bay

Matagorda Bay and East Matagorda Bay receive very little inflow from ungaged drainage areas. These ungaged drainage areas are located below the Bay City streamflow gage on the Colorado River and from a small portion of the Brazos-Colorado Coastal Basin. Additional control points have been established at the mouth of the Colorado River and in the ungaged portion of the Brazos-Colorado Coastal Basin to account for all inflows to these bays. Naturalized flows have been distributed to these points using the NRCS Curve Number method.

3.3 Adjusted Net Reservoir Evaporation

3.3.1 Evaporation and Precipitation Data Sources

Monthly values of historical average reservoir gross evaporation amounts have been derived by the Texas Water Development Board for all of Texas based on available evaporation data. These

Figure 3-3 Edwards-BFZ Recharge Zone, Onion and Barton Creeks

Figure 3-4 Colorado WAM Channel Loss Reaches gross evaporation rates are available for each month of the entire 1940-1998 analysis period for the Colorado/Brazos-Colorado Basin, and they are provided at the center of each one-degree quadrangle covering the basin. Similarly, historical monthly average precipitation amounts have been determined at the same locations. The relevant boundaries of these one-degree quadrangles as well as the locations of the major reservoirs (see Section 3.4) are overlaid on the map of the Colorado/Brazos-Colorado Basin in Figure 3-5.

3.3.2 Procedures for Estimation of Adjusted Net Evaporation

For each major reservoir in the Colorado/Brazos-Colorado Basin, distance-weighted factors have been determined and used to calculate average gross evaporation and precipitation values at the approximate centroid of the reservoir based on the reported gross evaporation rates and precipitation amounts at the centers of the nearest TWDB one-degree quadrangles. The weighting given to each quadrangle was inversely proportional to the distance from the reservoir to the center of the quadrangle. The equations incorporating these factors and used to calculate the historical monthly gross evaporation and precipitation rates for each of the major reservoirs in the Colorado/Brazos-Colorado Basin are listed in Table 3-7.

Adjusted net reservoir evaporation is defined by the following relationship:

Adjusted Net Reservoir Evaporation	=	Gross Reservoir Evaporation
	–	Precipitation on the Reservoir Surface
	+	Runoff from Reservoir Area in Absence of Reservoir

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

For the other reservoirs in the basin, gross evaporation and precipitation values were assigned based on the quadrangle in which the reservoir is located. Adjusted net reservoir evaporation was calculated using the evaporation adjustment feature in the WRAP model. This feature computes the precipitation-runoff adjustment term based on the reservoir inflows and drainage area, as described in the WRAP users manual (Wurbs, 2001).

Figure 3-5 Evaporation Quadrangles and Reservoir Locations

Fig 3-5 page 2

TABLE 3-7
RESERVOIR EVAPORATION-PRECIPITATION EQUATIONS

WATER-SHED	RESERVOIR NAME	EQUATIONS FOR AVERAGE EVAP/PRECIP USING DATA FROM FOUR QUADRANGLES *
A	Lake J.B. Thomas	0.025(406) + 0.663(506) + 0.312(507)
B	Lake Colorado City	0.383(506) + 0.537(507) + 0.080(607)
B	Mitchell Co. Reservoir	0.491(506) + 0.318(507) + 0.150(606) + 0.041(607)
B	Sulphur Springs Draw	0.214(505) + 0.653(506) + 0.133(606)
B	Natural Dam	0.077(505) + 0.663(506) + 0.260(606)
B	Red Draw Dam	0.671(506) + 0.081(507) + 0.248(606)
B	Champion Creek Reservoir	0.311(506) + 0.555(507) + 0.134(607)
B	E.V. Spence Reservoir	0.420(507) + 0.580(607)
C	Twin Buttes Reservoir	0.029(606) + 0.835(607) + 0.136(707)
C	Lake Nasworthy	0.877(607) + 0.003(608) + 0.120(707)
C	O.C. Fisher Lake	0.990(607) + 0.010(707)
D	Oak Creek Reservoir	0.455(507) + 0.100(508) + 0.387(607) + 0.058(608)
D	Lake Winters	0.136(507) + 0.288(508) + 0.202(607) + 0.374(608)
D	Ballinger Municipal Lake	0.099(507) + 0.054(508) + 0.461(607) + 0.386(608)
D	O.H. Ivie Reservoir	0.024(508) + 0.166(607) + 0.810(608)
E	Brady Creek Reservoir	0.616(608) + 0.038(609) + 0.346(708)
F	Lake Clyde	0.026(507) + 0.683(508) + 0.291(608)
F	Hords Creek Lake	0.349(508) + 0.003(607) + 0.648(608)
F	Lake Coleman	0.530(508) + 0.470(608)
F	Lake Brownwood	0.162(508) + 0.141(509) + 0.363(608) + 0.334(609)
I	Lake Buchanan	0.283(609) + 0.692(709) + 0.025(710)
I	Inks Lake	0.229(609) + 0.689(709) + 0.082(710)
I	Lake LBJ	0.057(609) + 0.811(709) + 0.132(710)
I	Lake Marble Falls	0.029(609) + 0.777(709) + 0.194(710)
I	Lake Travis	0.410(709) + 0.590(710)
I	Lake Austin	0.246(709) + 0.637(710) + 0.117(810)
J	Decker Lake	0.068(709) + 0.732(710) + 0.200(810)
J	Lake Bastrop	0.571(710) + 0.130(711) + 0.299(810)
J	Lake Fayette	0.036(710) + 0.348(711) + 0.124(810) + 0.492(811)
K	Eagle Lake	0.051(711) + 0.799(811) + 0.150(812)
L	STP Main Cooling Reservoir	0.124(811) + 0.081(812) + 0.431(911) + 0.364(912)

* Numbers in parentheses are the ID numbers of the quadrangles for which monthly values of either evaporation or precipitation are to be inserted. See Figure 3-5 for locations of quadrangles covering the Colorado/Brazos-Colorado Basin.

3.3.3 Comparison of Evaporation Data Sets

The annual values from the adjusted net evaporation data for the 1940-1998 analysis period for the 31 major reservoirs are plotted on Figure 3-6. These data sets have been separated into three groups for comparison purposes, representing the reservoirs in the upper (Subwatersheds A-D), middle (E-I), and lower (J-L) parts of the basin. As expected, the trend is for higher net evaporation in the upper part of the basin, and decreasing through the middle and lower parts of the basin. In general, the highest evaporation rates were observed during the drought of the 1950's.

3.4 Reservoir Elevation-Area-Capacity Relationships

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

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

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

3.4.1 Major Reservoirs

The major reservoirs in the Colorado/Brazos-Colorado Basin are listed along with pertinent descriptive information in Table 3-8. Also indicated are the years in which area-capacity relationships are known to have been developed from pre-reservoir topographic maps and/or post-reservoir sedimentation surveys of the actual impoundments, along with the estimated year-2000 capacities.

Figure 3-6 Comparison of Annual Adjusted Net Evaporation

TABLE 3-8
MAJOR RESERVOIRS IN THE COLORADO/BRAZOS-COLORADO BASIN

RESERVOIR	CONTRIB. DRAINAGE AREA SQ. MILES	YEAR OF IMPOUND-MENT	ORIGINAL CONSERV. CAPACITY AC-FT	YEAR OF SURVEY	SURVEY STORAGE CAPACITY AC-FT	SEDIMENT RATE AC-FT/ SQ. MI/YR	YEAR 2000 CAPACITY AC-FT
Lake J.B. Thomas	1,018	1952	203,600	1999	200,604	0.06	200,604
Lake Colorado City	302	1949	n/a	1964	31,800	0.17	29,950
Mitchell Co. Reservoir	15	1993	27,266		n/a	n/a	off-channel
Sulphur Draw Reservoir[a]	258	1992	7,997		n/a	n/a	not modeled
Natural Dam Lake[a]	550	1940	32,975	1986	54,560	n/a	not modeled
Red Draw Reservoir	3	1985	8,538		n/a	n/a	off-channel
Champion Creek Res.	186	1959	42,500		n/a	0.15	41,356
E.V. Spence Reservoir	5,018	1968	488,760	1999	517,272	n/a	517,272[b]
Twin Buttes Reservoir	2,813	1962	186,200		n/a	0.08	177,648
Lake Nasworthy	2,920	1930	14,604	1993	10,108	0.02	9,608
O.C. Fisher Lake	1,383	1952	119,200	1962	115,700	0.25	102,400
Oak Creek Reservoir	238	1953	39,360		n/a	0.15	37,682
Lake Winters	64	1983	8,374		n/a	0.26	8,091
Ballinger Municipal Lk.	234	1978	6,050	1978	6,050	0.20	5,020
O.H. Ivie Reservoir	12,647	1990	554,340		n/a	0.12	539,164
Lake Clyde	37	1970	5,748		n/a	0.23	5,493
Hords Creek Lake	48	1948	8,640		n/a	0.36	7,741
Lake Coleman	292	1966	40,000		n/a	0.10	39,007
Lake Brownwood	1,565	1933	135,963[c]	1997	131,429	0.24	131,429[d]
Brady Creek Reservoir	523	1963	30,430		n/a	0.08	28,882
Lake Buchanan	20,512	1937	992,000	1997	888,864	0.08	888,864
Inks Lake	620	1938	17,545	1997	15,722	0.00	15,722
Lake LBJ	5,000	1951	138,000	1997	134,353	0.00	134,353
Lake Marble Falls	35	1957	8,760	1997	6,420	0.00	6,420
Lake Travis	27,352	1940	1,170,752	1997	1,132,172	0.02	1,132,172
Lake Austin	26,837	1939	21,000	1999	21,725	n/a	21,725[e]
Decker Lake	9	1967	33,940		n/a	0.69	33,724
Lake Bastrop	9	1964	16,590		n/a	0.69	16,375
Lake Fayette	6	1977	71,400		n/a	0.69	71,300
Eagle Lake	20	1900	9,600		n/a	0.55	off-channel
STP Main Cooling Pond	0	1979	202,600		n/a	n/a	off-channel

a Reservoirs located within non-contributing area of Colorado Basin.

b Water right authorizes 488,760 acre-feet. Dead storage = 28,512 acre-feet.

c Based on 1959 survey. No curve available for original capacity of 149,925 acre-feet. Water right authorizes only 114,000 acre-feet. Dead storage = 21,963 acre-feet.

d Water right authorizes 114,000 acre-feet. Dead storage = 17,129 acre-feet.

e Water right authorizes 21,000 acre-feet. Dead storage = 725 acre-feet.

n/a = Not applicable (reservoir is off channel, not modeled, or survey indicates negative sediment rate), or not available (no original or re-survey data available)

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

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

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

Estimates of historical sediment delivery to the different reservoirs have been obtained primarily from Texas Department of Water Resources Report 268, “Erosion and Sedimentation by Water in Texas” (1982). Where volumetric surveys have been performed since construction, sediment accumulation rates were calculated based on the capacity lost as determined by the re-survey. Sedimentation rates are presented as part of Table 3-8. For those reservoirs that have been re-surveyed since 1997, which includes all of the LCRA Highland Lakes, those surveys were used to represent the year-2000 conditions for the purposes of modeling.

For those major reservoirs where re-surveys have not been performed since 1997, the estimated sediment loadings have been distributed within the reservoirs using an unpublished computer program called SEDDIS2. This program distributes sediment throughout the elevations of a reservoir between the bottom of the original streambed at the dam and the maximum normal water surface. Computations are based on the U. S. Bureau of Reclamation's Empirical Area-Reduction Method (Borland and Miller, 1958). Distribution of the sediment is based primarily on the reservoir type: lake, floodplain-foothill, hill, or gorge. The program determines the type based on the original elevation-area-capacity data. Distribution of the sediment in the reservoirs in the Colorado/Brazos-Colorado Basin has been limited to the area below the elevation of the top of the conservation pool.

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

3.4.2 Small Reservoirs

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

Area-capacity curves for these reservoirs have been developed using several methods. The NRCS (formerly SCS) was involved in the design and construction of some of these impoundments, and elevation-area-capacity curves for these impoundments were obtained from the NRCS office in Temple, Texas or from available SCS reports. The TNRCC Dam Safety files and Water Rights database also have been examined, and in most cases, specified maximum reservoir capacities or area-capacity curves have been found.

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

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

where:
$a = 0.911$
$b = 0.695$
$c = 0$
$r^2 = 0.943$

To calculate the coefficients a, b, and c, regression analyses of available area-capacity data for existing small reservoirs have been performed. Available area-capacity curves for 46 small reservoirs in the Colorado/Brazos-Colorado Basin were plotted, and power function regression analyses were performed to obtain the best-fit equation. The analyses indicated that categorizing minor reservoirs by size and/or geographic location did not improve the correlation when compared to when no categorizations were considered. This best-fit equation resulted in the above coefficients. The plot is presented as Figure 3-7.

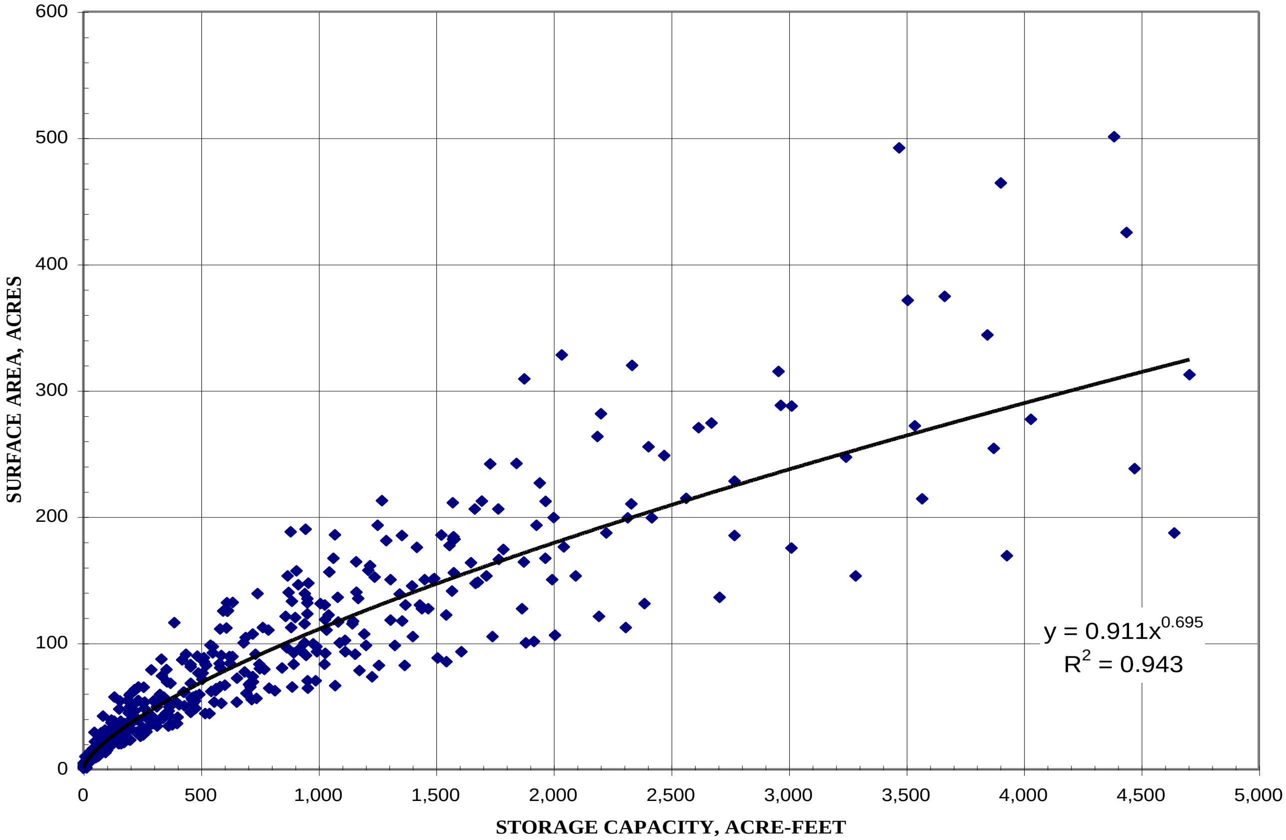
3.5 Aquifer Recharge

Aquifer recharge with respect to water availability is a consideration in the Colorado/Brazos-Colorado Basin where streams (Barton Creek and Onion Creek) cross the Edwards-BFZ Aquifer recharge zone, as discussed in sections 3.1.3 and 3.2.1.

3.5.1 Historical Recharge

Channel losses attributable to historical recharge were evaluated in developing the naturalized flows. The same loss factors were used in the WRAP modeling. This is discussed in Section 3.1.3.

FIGURE 3-7
AREA-CAPACITY CURVE FOR SMALL RESERVOIRS



3.5.2 Enhanced Recharge

There are no known enhanced recharge features or projects in the Colorado/Brazos-Colorado Basin.

4.0 WATER AVAILABILITY MODEL OF THE BASIN

4.1 DESCRIPTION OF *WRAP* MODEL

4.1.1 Base *WRAP* Model

The computer program or code used to develop the water availability model (WAM) of the Colorado/Brazos-Colorado Basin is referred to as "WRAP." The basic WRAP program is described in the report titled "Reference and Users Manual for the Water Rights Analysis Package (WRAP)," published in July 2001, by the Texas Water Resources Institute at Texas A&M University (Wurbs, 2001). The version of the WRAP program dated December 17, 2001 has been used for the final Colorado/Brazos-Colorado WAM.

Dr. Ralph Wurbs of Texas A&M is the primary author of the WRAP program. The WRAP program is coded in FORTRAN and is operational in DOS or Windows operating systems on desktop personal computers. The WRAP program is in the public domain and is available upon request from the Texas Water Resources Institute at Texas A&M. The TNRCC is responsible for distributing versions of the WRAP program, including data files, as used in this study for the Colorado/Brazos-Colorado/Brazos-Colorado Basin.

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

While the basic WRAP program in its original form does provide the fundamental framework for structuring water availability models of Texas river basins, numerous additional features and routines have been incorporated into the WRAP program that have enhanced its capabilities for performing the required water availability analyses. These program modifications have been made, for the most part, by Dr. Ralph Wurbs under contract to the TNRCC. As noted above, the December 17, 2001 version of the revised WRAP program has been used for developing the Colorado/Brazos-Colorado WAM.

4.1.2 Basin-Specific *WRAP* Model

No basin-specific modifications have been made to the WRAP program for purposes of developing and structuring the Colorado/Brazos-Colorado WAM.

4.2 DEVELOPMENT OF *WRAP* WATER RIGHTS INPUT FILES

4.2.1 Control Points

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

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

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

The locations of all of the control points specified in the Colorado/Brazos-Colorado WAM are shown on the map of the stream network of the basin in Figure 4-1. Detailed maps of each subwatershed showing the location and ID of every control point are contained in the map pockets. A summary of the number of different types of control points used in structuring the network for the Colorado/Brazos-Colorado WAM is presented in Table 4-1. Although there are approximately 3,000 points by type in Table 4-1, there are only approximately 2,200 locations where control points have been defined for purposes of applying the WRAP program to develop the WAM for the Colorado/Brazos-Colorado Basin. Many of the control points are physically at the same location (e.g. reservoir, diversion point, and/or return flow point).

TABLE 4-1
SUMMARY OF CONTROL POINT TYPES

TYPE OF CONTROL POINT	NUMBER OF POINTS*
Primary Control Points	45
Water Rights	2,607
Other Stream Gages	63
Water Quality Segment Terminus	34
Significant Springs	66
Wastewater Discharge Outfalls	131
Other Miscellaneous Locations	7

* Some points represent more than one type or are spatially coincident with other points.

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

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

For each control point location, a unique identification number has been defined which identifies the point with respect to its general location within either the Colorado River Basin or the Brazos-Colorado Coastal Basin. This number is referred to as the “WRAP_CP_ID” in the GIS shape file, and the structure of this number is as follows:

“X01111”

The “X0” denotes the first two characters of the WRAP CP ID number of the downstream primary control point (“X” denotes the subwatershed) above which the particular control point lies. The “1111” denotes a unique sequential number assigned to each control point. These

FIGURE 4-1 Location of All Colorado/Brazos-Colorado Basin Control Points
(11x17 drawing of the basin showing control points without ID numbers)

numbers have been incremented by 10 to allow room to insert intermediate-numbered control points in the future. Note that if a particular control point is a primary control point, then the "1111" of the identification number for this control point is assigned "0000," and the "X0" does not represent the next downstream control point number, but rather the actual primary control point number at its own location. Primary control points have also been assigned alpha IDs representing abbreviations of the USGS gage name. Table 4-2 lists the primary control points in the Colorado/Brazos-Colorado Basin along with their associated streamflow gages.

4.2.2 Monthly Demand Distribution Factors

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

To establish appropriate demand distribution factors for each of the water rights, historical monthly water use data as reported by water rights holders to the TNRCC and the TWDB have been compiled and analyzed. These are the same data that have been used in the streamflow naturalization process. For water rights with authorized diversions, the average reported water use has been determined by month for the last ten years, and the fractions of the total annual water use represented by the average monthly water use values have been calculated.

For municipal and industrial water rights, an analysis of the data generally revealed no significant seasonal differences between subwatersheds. Therefore, the same sets of monthly demand distribution factors were used for describing these demand patterns throughout the entire basin, with one set for municipal use and one set for industrial use. These monthly demand patterns are represented by the demand distribution factors listed in Table 4-3 and identified as "MUN" and "IND," respectively. It should be noted that case-specific demand distribution factors were used for several industrial water diverters in the upper basin with unique water use patterns. These also are listed in Table 4-3 and are identified with "IN" prefixes.

The historical diversion data for irrigation water use do exhibit significant seasonal differences between the various subwatersheds of the Colorado/Brazos-Colorado Basin and, in some cases, between individual diverters within the same subwatershed but for different types of crops. Consequently, a unique set of monthly demand distribution factors has been developed to represent the average irrigation demand patterns for each of the individual subwatersheds. For the major diverters in the lower basin where rice is grown and where water also is used for wildlife and waterfowl management, an additional individual set of monthly demand distribution factors has been developed and used to describe these demand patterns. The different demand distribution factors that have been determined for irrigation for each of the subwatersheds and for rice irrigation and wildlife and waterfowl management in the lower basin also are presented in

TABLE 4-2
PRIMARY CONTROL POINTS USED IN WAM

CONTROL POINT		CONTROL POINT LOCATION	USGS GAGE NUMBER
WRAP CP ID	ALPHA ID		
A30000	CR-IR	Colorado R nr Ira	08119500
A20000	DC-DU	Deep Ck nr Dunn	08120500
A10000	CR-CC	Colorado R at Colorado City	08121000
B40000	CC-RV	Champion Ck Reservoir	08123600
B30000	BC-WE	Beals Ck nr Westbrook	08123800
B20000	CR-SI	Colorado R abv Silver	08123850
B10000	CR-RL	Colorado R at Robert Lee	08124000
C70000	CN-CA	North Concho R nr Carlsbad	08134000
C60000	CM-TA	Middle Concho R abv Tankersley	08128400
C50000	SC-TA	Spring Ck abv Tankersley	08129300
C40000	DC-KN	Dove Ck at Knickerbocker	08130500
C30000	CS-CH	South Concho R at Christoval	08128000
C20000	CN-SA	Concho R at San Angelo	08136000
C10000	CN-PR	Concho R at Paint Rock	08136500
D40000	CR-BA	Colorado R nr Ballinger	08126380
D30000	EC-BA	Elm Ck at Ballinger	08127000
D20000	CR-ST	Colorado R nr Stacy	08136700
D10000	CR-WI	Colorado R at Winchell	08138000
E40000	SR-ME	San Saba R at Menard	08144500
E30000	SR-BR	San Saba R nr Brady	08144600
E20000	BC-BR	Brady Ck at Brady	08145000
E10000	SR-SS	San Saba R at San Saba	08146000
F30000	PB-BR	Pecan Bayou at Brownwood	08143500
F20000	PB-MU	Pecan Bayou nr Mullin	08143600
F10000	CR-SS	Colorado R nr San Saba	08147000
G50000	LN-JU	North Llano R nr Junction	08148500
G40000	LR-JU	Llano R nr Junction	08150000
G30000	LR-MA	Llano R nr Mason	08150700
G20000	BC-MA	Beaver Ck nr Mason	08150800
G10000	LR-LL	Llano R at Llano	08151500
H20000	PR-FR	Pedernales R nr Fredericksburg	08152900
H10000	PR-JC	Pedernales R nr Johnson City	08153500
I40000	CR-BU	Lake Buchanan nr Burnet	08148000
I30000	SC-KI	Sandy Ck nr Kingsland	08152000
I20000	CR-TR	Lake Travis nr Austin	08154500
I10000	CR-AU	Colorado R at Austin	08158000
J50000	OC-DR	Onion Ck nr Driftwood	08158700

J40000	OC-DS	Onion Ck at U.S. Hwy 183	08159000
J30000	CR-BS	Colorado R at Bastrop	08159200
J20000	CR-SM	Colorado R at Smithville	08159500
J10000	CR-CO	Colorado R at Columbus	08161000
K20000	CR-WH	Colorado R at Wharton	08162000
K10000	CR-BC	Colorado R nr Bay City	08162500
L20000	BC-WA	Big Boggy Ck nr Wadsworth	08117900
L10000	SR-BO	San Bernard R nr Boling	08117500

TABLE 4-3
MONTHLY DEMAND DISTRIBUTION FACTORS USED IN WAM

TYPE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
MUN	7	6	7	8	9	9	12	12	9	9	7	7
IND	5	4	6	7	7	10	16	18	11	8	5	4
IRR A	7	7	7	6	10	8	9	11	9	8	9	9
IRR B	8	7	8	8	8	9	10	10	8	8	8	8
IRR C	5	6	7	8	10	10	12	11	10	10	7	5
IRR D	0	0	3	6	12	19	22	19	12	3	2	2
IRR E	1	1	4	11	10	13	19	16	9	10	4	2
IRR F	2	4	5	8	11	11	16	18	11	7	3	3
IRR G	1	2	5	12	13	12	15	22	14	1	0	3
IRR H	0	0	2	2	12	19	18	33	11	2	0	1
IRR I	2	2	5	7	11	18	15	16	11	6	4	3
IRR J	0	0	0	2	4	8	16	30	22	17	1	0
IRR K	1	1	4	8	16	19	18	14	12	5	0	1
IRR L	0	0	1	6	15	24	18	16	14	5	0	0
IRR	1.3	2.5	2.4	12.8	18.8	19.7	17.6	12.8	5.9	2.3	1.0	2.9
IN1002	8.5	7.9	8.5	8.2	8.5	8.2	8.5	8.5	8.2	8.5	8.2	8.5
IN1008	8.2	7.2	7.4	8.2	9.1	9.4	9.5	8.7	8.3	8.1	7.5	8.4
IN1009	8.2	7.3	8.1	7.9	9.0	9.8	10.8	10.2	9.1	7.7	5.7	6.3
IN1031	6.2	3.3	6.5	10.7	9.4	11.3	11.3	11.5	9.9	8.1	6.3	5.4
IN1697	1	1	1	1	1	1	1	1	1	1	1	1
IN1702	6.2	5.8	6.2	7.6	9.0	9.9	11.1	12.4	10.0	8.7	6.8	7.2
IN1920	1	1	1	1	1	1	1	1	1	1	1	1
IN2454	0	1.3	0	6.1	8.3	7.0	20.2	33.8	18.0	3.9	0	1.3
IN2508	3.8	3.8	7.7	7.7	11.5	11.5	11.5	11.5	11.5	7.7	7.7	3.8
IN2553	1	1	1	1	1	1	1	1	1	1	1	1
IN2561	1	1	1	1	1	1	1	1	1	1	1	1
IN3676	10.6	9.9	10.2	10.8	10.7	9.4	5.8	5.0	4.6	4.7	8.9	9.4
CAT	1	1	1	1	1	1	1	1	1	1	1	1
MIN	5	4	6	7	7	10	16	18	11	8	5	4

OTH	1	1	1	1	1	1	1	1	1	1	1	1
REC	1	1	1	1	1	1	1	1	1	1	1	1
POWER	1	1	1	1	1	1	1	1	1	1	1	1
WETH1	1	1	1	0	0	0	0	0	1	1	1	1
WETH2	0	0	0	1	1	1	1	1	0	0	0	0
IR1006	2.1	4.1	3.9	11.0	16.1	16.9	15.1	11.0	9.7	3.8	1.6	4.8

Table 4-3. The subwatershed irrigation demand distribution factors are identified as “IRR X,” where “X” is the alphabetic identifier for the subwatershed. The set of rice irrigation and wildlife and waterfowl management demand distribution factors is identified as “IRR RICE.”

A number of other sets of demand distribution factors have been derived and used for case-specific diverters and water users. These also have been derived based on actual historical monthly diversion patterns, and they are listed at the bottom of Table 4-3.

4.2.3 Water Rights

The general features and characteristics of the existing water rights in the Colorado/Brazos-Colorado Basin have been previously identified and described in Section 2.1. Specific information regarding each water right is contained in the TNRCC database contained in Appendix A, with previously identified corrections in Appendix B. The water rights in Appendix A are indexed by water right number within each subwatershed. The map of the basin presented in Figure 2-1 shows the locations of the water rights with respect to the stream network. Detailed maps of each subwatershed showing the location and ID of every control point are contained in the map pockets and are also available in ArcView or .pdf format from the TNRCC. A correlation table showing the water right(s) associated with each control point is contained in Appendix N.

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

Water Right ID (WRID) - TNRCC_ID
Second WRID (group ID #1) - TNRCC_ID less the last 3 numbers of the TNRCC_ID
Third WRID (group ID #2) - Primary Control Point number

There were some exceptions/additions to the above. Specifically, additional identifiers were added to the end of some of the Water Right ID's to represent run-of-river (RR) or back up (BU) portions of a water right, different priority dates for the same water right (A,B,C, etc.), or different types of use being simulated for the same water right (A,B,C, etc.). In addition, some water rights that were modeled by refilling storage with one WR record and making a diversion on another WR record were differentiated by associating the words FILLONLY to the WR record that only fills the reservoir.

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

4.2.3.1 Priority Dates

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

Other water rights have multiple dates establishing their time priorities for diverting and/or impounding water. This occurs for a variety of reasons, including amendments to the original permit increasing the diversion amount, increasing the storage capacity of a reservoir, adding additional reservoirs, incorporating different operating procedures, or providing for minimum environmental flows or bay and estuary inflows. Each priority date for use and/or impoundment of water, with its associated authorized amount, has been accounted for separately in the Colorado/Brazos-Colorado WAM. The WRAP program readily accommodates these types of water rights with multiple priority dates. Some multiple priority dates are the result of modeling decisions, such as changes made to facilitate the modeling of the Lower Colorado River Authority (LCRA) Water Management Plan. This is discussed below in detail in section 4.2.3.5.2.

Table 4-4 provides a listing of those water rights in the Colorado/Brazos-Colorado Basin with multiple priority dates that have been accounted for in the WAM. Of the 69 water rights with multiple priority dates, 48 of them have different priority dates associated with reservoir storage.

4.2.3.2 Treatment of Reservoir Storage

Generally, the maximum conservation storage for each reservoir has been specified in the WRAP model of the Colorado/Brazos-Colorado Basin in accordance with the maximum authorized storage amounts listed in the TNRCC water rights data base in Appendix A, with the previously identified corrections in Appendix B. Exceptions are those water rights with multiple priority dates for different storage amounts as listed in Table 4-4. Also, the special provisions for storing water in the Highland Lakes and in O.H. Ivie Reservoir in accordance with the LCRA Water Management Plan for the Lower Colorado River Basin have been accounted for as described later in Section 4.2.3.5.2. Similarly, the special authorizations for diverting and storing poor quality water under the water rights held by the Colorado River Municipal Water District have been represented to the extent possible with the WRAP program. These procedures are described later in Section 4.2.3.5.3.

When simulating storage in a particular reservoir with multiple priority dates for specific storage amounts, the WRAP program uses the priority dates to determine when water can be stored in the reservoir up to the associated authorized amounts, after accounting for the demands of upstream and downstream senior water rights. Once water is stored in the reservoir under any one of its multiple priority dates, no further accounting of the water within the reservoir with respect to the different priority dates is performed by the WRAP program. Hence, the total

TABLE 4-4
WATER RIGHTS WITH MULTIPLE PRIORITY DATES
(Water Right Numbers)

DIFFERENT PRIORITY DATES ASSOCIATED WITH RESERVOIR STORAGE			
11403262	61401118	61401405	61401746
11403569	61401129	61401475	61402452
61303418	61401259	61401533	61402550
61303435	61401280	61401570	61402631
61401001	61401282	61401571	61405376
61401006	61401288	61401589	61405380
61401008	61401289	61401600	61405387
61401009	61401290	61401650	61405434
61401046	61401298	61401660	61405471
61401072	61401300	61401697	61405475
61401083	61401303	61401726	61405476
61401095	61401357	61401745	61405478
DIFFERENT PRIORITY DATES ASSOCIATED WITH DIVERSIONS ONLY			
11303810	61401086	61401763	61401920
11303955	61401132	61401764	61402632
11403956	61401220	61401825	61405386
61303422	61401360	61401856	
61303432	61401397	61401898	
61303438	61401735	61401908	

quantity of water in storage is available to satisfy any and all specified diversions associated with the reservoir, subject to their specified priority dates.

4.2.3.3 Return Flows

All municipal and industrial wastewater discharges (return flows) with a permitted flow greater than or equal to 0.9 million gallons per day (mgd), or approximately 1,000 acre-feet per year, plus five dischargers in Travis and Wharton Counties with permitted flows of approximately 0.5 mgd, were considered significant and were included in the naturalized flow calculations and the WRAP model (see Table 2-3). In addition, two other return flows in the non-contributing portion of the upper basin were included in the WRAP model because downstream irrigation water rights depend on those return flows. These two return flows are the City of Brownfield (Subwatershed

A) and the City of Lamesa (Subwatershed B). These were modeled as separate systems (downstream control point = “OUT”) so that these flows would not be available to the rest of the basin.

The permitted municipal and industrial discharges accounted for in the Colorado/Brazos-Colorado WAM are listed in Table 4-5 along with descriptive information, including permit number, subwatershed location, the source of the discharged water, and other data.

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

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

The constant inflow method also has been used to describe the return flows from some of the municipal and industrial water users that obtain their water supplies through contractual agreements with water rights holders within the Colorado/Brazos-Colorado Basin. This group includes primarily those entities that rely upon and purchase water from entities such as the Lower Colorado River Authority in the lower basin and the Colorado River Municipal Water District in the upper basin. Analyses of these return flows have been made to assure that they are not also included in the return flows for the in-basin water rights holders. These return flows would not necessarily be reduced or curtailed when the available supplies for in-basin water rights holders become limited during drought periods.

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

Table 4-5 Wastewater Discharges Return Flow Status water right authorizes a large diversion amount and a smaller consumptive use, as with the South Texas Project in the lower basin, then the full diversion has been modeled with an appropriate return flow factor.

Irrigation return flows from rice irrigation in the lower basin have been modeled using appropriate return flow factors applied to diversion amounts. These return flow factors were estimated based on flow balance analyses performed during the streamflow naturalization process (see Table 2-2). These return flow factors vary from month to month as required to derive proper and meaningful quantities of return flows based on the actual monthly diversion patterns for rice irrigation. All other irrigation return flows were assumed to be zero.

For purposes of the water availability analyses for the Colorado/Brazos-Colorado Basin, five different sets of return flow data have been developed as required for the different simulation conditions specified by the TNRCC. These are listed below:

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

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

4.2.3.4 Multiple Diversion Locations

There are numerous water rights in the Colorado/Brazos-Colorado Basin with multiple diversion or impoundment points. Multiple diversion points, in this context, include only those water rights with diversion points on different streams or different locations on the same stream where drainage areas, and thus streamflows, are significantly different. This excludes water rights with multiple diversion points on the same reservoir, or water rights with multiple diversion points on a short reach of a stream. In general, the authorized diversion for a particular water right with multiple diversion points on the same stream has been assigned to the most downstream diversion location. For those water rights with multiple diversion points on different streams, the “BACKUP” feature in WRAP has been used to allow diversions from secondary streams to supplement the available supply from a designated primary stream. For water rights with multiple diversions authorized from storage in different reservoirs, the diversions and the reservoirs have been modeled using the system operation capability of WRAP. Table 4-6 lists those water rights with multiple diversion locations.

4.2.3.5 Water Rights Requiring Special Consideration

A number of water rights in the Colorado/Brazos-Colorado Basin have special conditions or special operating procedures that affect water availability. These conditions relate to such items as the amount and/or location of authorized storage, inter-basin transfers, diversion or storage limitations based on minimum instream flow requirements or minimum bay and estuary inflow requirements, subordination of senior rights to junior rights, drought contingencies and demand curtailment, and diversions of high-salinity waters to improve downstream water quality.

Appendix B contains a memorandum to TNRCC related to corrections to the Water Rights Database, and includes brief descriptions of special conditions associated with specific water rights. A summary of the water rights containing special conditions is presented in Table 4-7. A summary of all known inter-basin transfers affecting the Colorado/Brazos-Colorado Basins is presented in Table 4-8.

Appendix O contains memoranda describing special conditions and modeling assumptions regarding the LCRA Water Management Plan for the Lower Colorado River Basin, water rights owned by Colorado River Municipal Water District, and saline water rights in tidally influenced areas near the Gulf coast. As discussed in the saline water rights memorandum, there are only two such water rights with diversions, and they are in the Brazos-Colorado Coastal Basin: Texas Parks and Wildlife Department, no. 11305645, 2800 acre-feet; and Phillips Petroleum Co., no. 61303425, 5350 acre-feet. As directed by TNRCC, these water rights have been included in the model for completeness, but have been given zero diversion amounts since they use saline water.

TABLE 4-6
WATER RIGHTS WITH MULTIPLE DIVERSION LOCATIONS

11303814	61401023	61401203	61401369
11303926	61401025	61401204	61401370
11303957	61401033	61401205	61401371
11303967	61401034	61401206	61401372
11303992	61401035	61401232	61401382
11303996	61401040	61401245	61401385
11304229	61401041	61401253	61401389
11305324	61401042	61401256	61401394
11305338	61401043	61401257	61401397
11305459	61401045	61401262	61401405
11305645	61401046	61401264	61401406
11403122	61401048	61401267	61401407
11403150	61401053	61401272	61401408
11403158	61401059	61401274	61401409
11403262	61401062	61401275	61401411
11403325	61401063	61401276	61401412
11403355	61401069	61401277	61401413
11403409	61401070	61401280	61401414
11403414	61401078	61401282	61401415
11403569	61401081	61401288	61401416
11404169	61401082	61401289	61401417
11405070	61401091	61401290	61401418
11405086	61401095	61401294	61401419
11405111	61401096	61401295	61401421
11405273	61401097	61401296	61401424
61303418	61401098	61401298	61401425
61303419	61401100	61401303	61401427
61303420	61401101	61401310	61401428
61303424	61401102	61401311	61401432
61303426	61401112	61401312	61401435
61303429	61401115	61401318	61401437
61303434	61401121	61401321	61401438
61303435	61401122	61401322	61401439
61303436	61401124	61401325	61401440
61303438	61401125	61401326	61401442
61305331	61401126	61401329	61401444
61400995	61401127	61401330	61401445
61400998	61401128	61401338	61401448
61401002	61401132	61401343	61401449
61401003	61401136	61401346	61401450
61401004	61401138	61401348	61401452
61401005	61401141	61401350	61401454

61401006	61401189	61401353	61401459
61401008	61401193	61401354	61401460
61401009	61401196	61401354	61401461
61401011	61401197	61401360	61401464
61401012	61401198	61401361	61401465
61401015	61401199	61401362	61401466
61401018	61401200	61401363	61401467
61401019	61401201	61401364	61401468

TABLE 4-6, cont'd.
WATER RIGHTS WITH MULTIPLE DIVERSION LOCATIONS

61401021	61401202	61401368	61401471
61401473	61401628	61401819	61402507
61401474	61401629	61401828	61402509
61401476	61401632	61401830	61402512
61401477	61401634	61401832	61402513
61401489	61401647	61401835	61402515
61401491	61401650	61401841	61402522
61401495	61401655	61401842	61402523
61401498	61401662	61401846	61402525
61401503	61401663	61401851	61402530
61401507	61401665	61401852	61402531
61401511	61401666	61401865	61402533
61401515	61401676	61401871	61402535
61401517	61401677	61401873	61402536
61401518	61401678	61401882	61402541
61401527	61401681	61401890	61402546
61401528	61401683	61401894	61402550
61401532	61401687	61401897	61402552
61401533	61401688	61401903	61402555
61401534	61401690	61401906	61402556
61401537	61401695	61401914	61402563
61401538	61401696	61401915	61402564
61401541	61401701	61401919	61402565
61401545	61401706	61401922	61402566
61401546	61401708	61401924	61402570
61401547	61401709	61401928	61402571
61401548	61401713	61401929	61402574
61401549	61401715	61402451	61402575
61401552	61401726	61402452	61402576
61401556	61401735	61402454	61402577
61401560	61401739	61402470	61402578
61401563	61401741	61402472	61402579
61401564	61401742	61402475	61402580
61401571	61401745	61402476	61402581
61401574	61401746	61402477	61402583
61401576	61401755	61402479	61402584
61401579	61401756	61402480	61402587
61401589	61401759	61402481	61402588
61401591	61401760	61402483	61402592
61401593	61401761	61402484	61402598
61401594	61401762	61402487	61402599
61401601	61401768	61402488	61402601
61401604	61401770	61402490	61402603

61401608	61401773	61402491	61402605
61401609	61401777	61402492	61402606
61401613	61401795	61402493	61402607
61401615	61401800	61402495	61402610
61401621	61401803	61402499	61402615
61401622	61401804	61402500	61402619
61401624	61401806	61402501	61402621
61401626	61401811	61402503	61402622

TABLE 4-6, cont'd.

WATER RIGHTS WITH MULTIPLE DIVERSION LOCATIONS

61401627	61401817	61402504	61402624
61402625	61405372	61405394	61405471
61402626	61405374	61405401	61405473
61402630	61405375	61405411	61405474
61402631	61405376	61405413	61405475
61402633	61405379	61405421	61405476
61402645	61405385	61405424	61405482
61402649	61405387	61405425	61405489
61402650	61405388	61405427	61405491
61405368	61405390	61405432	
61405369	61405391	61405433	
61405371	61405393	61405434	

Table 4-7 Water Rights With Noted Special Conditions – 6 pages

Table 4-8 Inter-Basin Transfers – 3 pages

Specific information pertaining to water rights with instream flow restrictions, the LCRA Water Management Plan for the Lower Colorado River Basin, and water rights owned by the Colorado River Municipal Water District is contained in the following sections.

4.2.3.5.1 Water Rights With Instream Flow Restrictions

There are several water rights in the Colorado/Brazos-Colorado Basin that are authorized to divert and/or impound surface water only when streamflows at a specified location exceed certain prescribed levels. These restrictions are intended to protect downstream senior water rights or instream environmental uses or both. Table 4-7 contains a listing of the water rights in the Colorado/Brazos-Colorado Basin with special conditions related to streamflow restrictions and other water quantity-related conditions. These are exclusive of the instream flow restrictions contained in the LCRA Water Management Plan for the Lower Colorado River Basin.

4.2.3.5.2 LCRA Water Management Plan for Lower Colorado River Basin

WMP BACKGROUND

The document entitled "Water Management Plan for the Lower Colorado River Basin; Effective September 20, 1989 Including Amendments Through March 1, 1999" was used to understand the Water Management Plan (WMP) and its associations with other water rights in the Colorado River Basin. Before the WMP for Lower Colorado River Basin was adopted by the TNRCC (or its predecessor agencies), the Lower Colorado River Authority (LCRA) had the following water right authorizations pertaining to water supply as stated in Certification of Adjudication (COA) 14-5478 (Lake Buchanan), COA 14-5479 (Inks Lake), COA 14-5480 (Lake LBJ), COA 14-5481 (Lake Marble Falls), and COA 14-5482 (Lake Travis):

Impoundments:	Highland Lakes (Buchanan, Inks, LBJ, Marble Falls, and Travis)
Diversions:	1,500,000 acre-feet per year from Lakes Buchanan and Travis together for municipal, industrial, irrigation, and other types of uses
	15,700 acre-feet per year from Lake LBJ for power plant cooling
Priority Dates:	March 7, 1926 for storage in Lakes Buchanan and Travis
	March 7, 1938 for diversions from Lakes Buchanan and Travis

Pursuant to the provisions of the COAs for Lakes Buchanan and Travis, to date, the following four orders relating to LCRA's water rights for Lakes Buchanan and Travis have been issued by the TNRCC (or its predecessor agencies). These orders approve and authorize the WMP and/or various parts of the current plan. Although the WMP was not a part of the LCRA's original water right authorizations for Lakes Buchanan and Travis (before the adjudication process), provisions for the WMP are stipulated and generally described (similar to a special condition) in the COA's for Lakes Buchanan and Travis.

1. 9/7/1989 - Order Approving LCRA's Water Management Plan and Amending Certificates of Adjudication Nos 14-5478 and 14-5482. (20 page order containing 94 findings of fact, 7 conclusions of law, 5 stipulations which included 15 special conditions).

2. 12/18/1991 - Order Approving LCRA's Drought Management Plan. (6 page order containing 9 findings of fact, 3 conclusions of law, 4 stipulations which included 10 special conditions).

3. 12/2/1992 - Order Approving Amendments to LCRA's Water Management Plan and Drought Management Plan. (10 page order containing 18 findings findings of fact, 2 conclusions of law, 4 stipulations which included 3 special conditions).

4. 2/24/1999 - Order Approving Amendments to LCRA's Water Management Plan Including its Drought Mangement Plan. (11 page order containing 24 findings of fact, 2 conclusions of law, 5 stipulations which included 6 special conditions).

With the WMP adopted and implemented, the LCRA is authorized the same impoundments stipulated in its COAs, but with different logic for diversions and priorities. The WMP lays out all of the details of how LCRA is to operate the Highland Lakes and discusses the quantities of water associated with each type of water use, establishes the operational triggers to be used for all purposes, and quantifies the amounts of water to be released or passed for instream uses along the lower Colorado River and/or for maintaining minimum levels of bay and estuary (B&E) freshwater inflows, as well as numerous other details. The WMP, together with agreements between LCRA and other water users such as the City of Austin, now provides the specific procedures and the day-to-day guidance for operating the lower Colorado River water supply and delivery system.

WMP OVERVIEW

The initial order that established the framework for the WMP sets out the following five guidelines for LCRA in implementing the WMP:

1. All demands for water from the Colorado River downstream of the Highland Lakes will be satisfied to the extent possible by run-of-river flows of the Colorado River;

2. Inflows will be passed through the Highland Lakes to honor downstream senior water rights only when those rights cannot be satisfied by the flow in the river below the Highland Lakes;

3. The firm, uninterruptible commitments of water from Lakes Travis and Buchanan will not exceed their combined firm yield;

4. Water from Lakes Travis and Buchanan will be available on an interruptible basis only as long as LCRA's ability to meet the demand for uninterruptible water is not impaired; and

5. Water shall not be released through any dam solely for hydroelectric generation, except during emergency shortages of electricity, and during other times that such releases will be needed for another beneficial purpose.

As indicated, the WMP is built upon the concept of two basic types of water, “uninterruptible” and “interruptible,” and these two types of water now constitute LCRA's entire authorization for using water from Lakes Buchanan and Travis. Descriptions of uninterruptible (firm) and interruptible water and the conditions relating to their use by LCRA and others in the lower basin are described in the following sections.

WMP Uninterruptible (Firm) Water

Generally, uninterruptible water refers to LCRA's dependable or firm supply of water based on the firm yield of the Buchanan/Travis reservoir system. In the WMP, the firm yield of the Buchanan/Travis reservoir system is stated as 536,312 acre-feet per year. This quantity of firm water supply was determined based on a reservoir system operation simulation using 1940-1965 hydrology and current “WAM type” assumptions, with the exception of the protection of conservation storage on a priority basis. Information in the WMP document indicates that in the firm yield analysis, water use by junior rights upstream of senior rights with reservoirs was not curtailed when downstream senior reservoirs were below their conservation storage levels. Instead, upstream junior water rights were curtailed only when the downstream senior reservoirs would have otherwise experienced a shortage in their respective authorized diversion amounts.

The Buchanan/Travis firm yield amount of 536,312 acre-feet per year as stated in the WMP includes a commitment of 90,546 acre-feet per year to O. H. Ivie Reservoir (formerly Stacy Reservoir) upstream as required under the terms of a 1985 “Settlement Agreement” between the LCRA and the Colorado River Municipal Water District (CRMWD), the owner of the water right for Ivie Reservoir (Permit No. 3676). Pursuant to this agreement, the water right for Ivie Reservoir was issued on May 14, 1985 (with a priority date of February 21, 1978) authorizing the diversion and use of up to 88,000 acre-feet per year of domestic and municipal water and up to 25,000 acre-feet per year of industrial water (later amended to be 103,000 municipal and

10,000 industrial), subject to certain release requirements for providing inflows and stored water to Lakes Buchanan and Travis. Concurrently, one of LCRA's water rights relating to Lakes Buchanan and Travis (Permit No. 1259) was amended to allow the Ivie Reservoir diversions (Amendment B). A subsequent amendment of the Ivie Reservoir water right (Amendment D) in 1998, with LCRA's concurrence, removed the requirements for releases of stored water from Ivie Reservoir to provide water for Lakes Buchanan and Travis. In effect, this latest amendment makes the more senior authorizations for storing water in Lakes Buchanan and Travis subordinate to storing water in Ivie Reservoir under its water right.

The WMP sets forth the current commitments for uninterruptible (firm) water from the Buchanan/Travis reservoir system by dividing the commitments into six distinct groups. These groups and their respective shares of the firm yield from the reservoir system are listed in Table 4-9. It should be noted that the four large irrigation districts with senior water rights (Garwood, Lakeside, Pierce Ranch, and Gulf Coast) that are located on the lower Colorado River below the Highland Lakes (and which are now owned by the LCRA) are not included in this list as their run-of-the-river water supplies now are backed-up with interruptible water pursuant to the provisions of the WMP.

WMP Interruptible Water

Interruptible water is the amount of water in storage in Lakes Buchanan and Travis under LCRA's water rights that is determined to be available for water supply purposes on an annual or semi-annual basis depending on the level of storage in the reservoir. Interruptible water is conceptually divided into two accounts.

1. The first account, which is considered the more senior of the two, provides stored water as backup to the four large irrigation water rights in the lower part of the basin (Garwood, Lakeside, Pierce Ranch, and Gulf Coast). The amount of stored water that is available to supplement the needs of these water rights is based on the amount of system storage in Lakes Buchanan and Travis at the beginning of each calendar year. The basic elements of this scheme include the following:

    a. When the system storage exceeds 1,100,000 acre-feet (52% of the system conservation storage capacity) on January 1 - The demands of the four irrigation rights are fully backed up with stored water for that year.

    b. When the system storage is between 1,100,000 acre-feet and 325,000 acre-feet on January 1 - The amount of water available to backup the four irrigation rights is decreased 4% for each 100,000 acre-feet of decrease in system storage below 1,100,000 acre-feet for that year.

    c. When the system storage is less than 325,000 acre-feet on January 1 - no stored water is made available as backup for the four irrigation rights for that year.

TABLE 4-9
FIRM ANNUAL COMMITMENTS FOR THE BUCHANAN/TRAVIS RESERVOIR SYSTEM
(per LCRA WMP)

	Entity or Contract	Acre-Feet/Year	
(1)	O. H. Ivie Reservoir	90,546	
(2)	Backup of City of Austin Water Rights	148,546	*
(3)	Highland Lakes Contracts	85,789	
(4)	LCRA Cooling Water	63,851	
(5)	South Texas Nuclear Project	5,680	**
(6)	Instream Flow Requirements	12,860	***
(7)	Bay and Estuary Freshwater Inflow Needs	3,090	****
	Total System Yield Commitment:	410,362	
	Uncommitted System Yield:	125,950	

* Contractual commitment is 290,156 acre-feet per year.
** This is stated in the WMP as the average impact. The maximum impact is 51,700 acre-feet per year, whereas the authorized amount is 102,000 acre-feet per year.
*** This is stated in the WMP as the average impact. The maximum impact is 36,720 acre-feet per year.
**** This is stated in the WMP as the average impact. The maximum impact is 11,200 acre-feet per year.
Source: LCRA Water Management Plan for the Lower Colorado River Basin

2. The second interruptible water account, which is the more junior, is used to provide stored system water, on a contract basis, to entities with the understanding that it is subject to curtailment in whole or in part. As noted above, all of the stored water assigned to this account is considered junior to the interruptible water demands of the four large irrigation water rights in the lower basin. The amount of stored water that is available for this account is determined in two stages; one for January through June of each year and one for July through December of each year. The amount allocated for January through June is based on the amount of system storage in Lakes Buchanan and Travis on January 1, whereas the maximum storage levels during April, May and June of each year dictate the amount of water allocated during July through December. 30,000 acre-feet of interruptible water can be supplied in any one year. The basic elements of this scheme include the following:

> For the January-through-June allocation, the amount of stored water that is available for contracting varies proportionally between zero when the system storage on January 1 is 94% of the full conservation capacity and 13,000 acre-feet per year when the system storage on January 1 is 100% of the full conservation capacity. No water is allocated when the system storage on January 1 is less than 94% of the full system conservation capacity.
>
> For the July-through-December allocation, the amount of stored water that is available for contracting varies proportionally between zero when a system storage indicator based on April-June storage levels is 94% of the full conservation capacity and 17,000 acre-feet per year when a system storage indicator based on April-June storage levels is 100% of the full conservation capacity. No water is allocated when the system storage indicator is less than 94% of the full system conservation capacity.

The effective priority date for both of the interruptible water accounts is November 1, 1987 since the COA's, as well as the WMP, indicate that LCRA cannot make a priority call on any water right senior to this date for any water in excess of the firm yield of the Buchanan/Travis reservoir system.

WMP Instream Flow Requirements

There are four streamflow gages located along the lower Colorado River that are identified in the WMP where minimum flow restrictions apply for the purpose of protecting instream uses. These are located at or near the cities of Austin, Bastrop, Eagle Lake (Columbus), and Egypt (Wharton). Two levels of minimum streamflows are specified in the WMP as being required to satisfy instream uses. One is referred to as a "Target" flow, and it applies at all times except during the most extreme drought conditions when the "Critical" flow applies. The Target flow level provides an optimal range of habitat complexity to support a well balanced, native aquatic community in the river, and it is intended to be maintained whenever adequate water resources are available in the lower basin. The Target instream flow criteria are considered to be interruptible and subject to curtailment when water resources become limited during drought periods. Under the provisions of the WMP, the Target instream flow criteria are to be satisfied at all times up to the limit of inflows to the Highland Lakes, except when the available storage in Lakes Buchanan and Travis is such that the interruptible water supplies for the four large irrigation districts (Garwood, Lakeside, Pierce Ranch, and Gulf Coast) have to be curtailed. As described above, this occurs when storage in the Buchanan/Travis reservoir system falls below 1,100,000 acre-feet, or 52% of the system conservation storage capacity on January 1 of each year. At this point, the lower Critical instream flow criteria come into effect.

Based on the current WMP, both Target and Critical instream flow criteria are stipulated for the Austin and Bastrop streamflow gages, while only Target instream flow criteria are specified at the Eagle Lake and Egypt gages. For the Austin gage, the Target instream flow criterion varies as a function of the combined storage in Lakes Buchanan and Travis, while all other Target streamflow thresholds appear to be fixed at particular values.

Target instream flow criteria are required to be maintained to the extent inflows are available to the Highland Lakes. Stored water in Lakes Buchanan and Travis is not subject to release to satisfy any of the Target streamflow thresholds. Maintenance of the Critical instream flow criteria, however, require the release of stored water from Lakes Buchanan and Travis, if needed. The lowest Critical instream flow threshold for the Austin gage (based on the bottom bracket of storage in the Buchanan/Travis reservoir system) is 46 cubic feet per second (cfs), which must be supported with the release of stored water from Lakes Buchanan and Travis.

WMP Bay and Estuary Freshwater Inflow Requirements

Just as the WMP organizes the instream flow criteria using a two stage concept, the WMP also addresses the freshwater inflow needs for bays and estuaries (B&E) relative to Target and Critical inflow requirements. The WMP states that freshwater inflows to Matagorda Bay from the Colorado River historically have been about 1,800,000 acre-feet per year as measured at the Bay City gage. The total Target inflow need for the Matagorda Bay system is specified in the WMP as 2,000,000 acre-feet per year, of which an annual inflow of 1,033,100 acre-feet is identified as the Target amount for the Colorado River (the remainder of the total Target inflow requirement is to come from the Lavaca Basin and other associated coastal basins). The Brazos-Colorado Coastal Basin does not contribute to the B&E requirement. The Critical freshwater inflow need for the Matagorda Bay system from the Colorado River is specified in the WMP as 171,000 acre-feet per year.

In the WMP, both the Target and the Critical B&E freshwater inflow requirements for the Colorado River are stipulated as monthly values (rather than daily flows in cfs as specified for the instream flow requirements). The Target monthly inflow requirements vary from 38,800 acre-feet in September to 162,200 acre-feet in May. The Critical monthly inflow requirements are specified as a constant 14,260 acre-feet each month.

The requirements for B&E freshwater inflows are not to be satisfied with stored water from the Buchanan/Travis reservoir system; only the inflows to the Buchanan/Travis reservoir system are to be passed downstream for satisfying B&E freshwater inflow requirements. When the combined storage in Lakes Buchanan and Travis on January 1 of a given year is greater than or equal to 80% of the total conservation storage capacity of these reservoirs (1,660,000 acre-feet), then inflows to the reservoirs are to be passed to the extent they are available to maintain the Target monthly B&E inflows. In all other years when the system storage is less than 80% of the total conservation storage capacity of Lakes Buchanan and Travis, the Critical monthly B&E inflows are to be maintained by passing a reduced quantity of reservoir inflows, to the extent that they are available.

REPRESENTATION OF LCRA WMP IN WAM

Based on analysis of the WMP document and discussions with TNRCC staff, certain representations are used in the WRAP model to describe the specific water rights that are impacted by the WMP. Generally, dummy reservoirs are used to make a "snap shot" of system storage during key months, and this quantity of water is held for eleven months, at which time it is emptied and another snap shot is taken. During the twelve-month cycle, DI cards associated with WMP-related WR and IF cards cause the quantities coded on the WR and IF cards to be adjusted so that features of the WMP are represented based on the appropriate system storage. It should be noted that, due to the monthly time step limitation of the WAM and the fact that DI cards are keyed to the beginning-of-month storage content, it is necessary to divert water to a dummy reservoir one month earlier than the WMP specifications. In addition, it must be recognized that the beginning of one month during the simulation period in the WAM is equivalent to the end of the previous month and that all WRAP output is related to end-of-month conditions. For example, in order to quantify the WMP's beginning-of-January system storage criteria (end of December in WRAP), a snap shot of system storage is taken at the beginning-of-December time step (which is actually the end-of-month storage for November).

Specific details regarding the modeling of each water right or water right component that is directly related to the WMP are described and discussed in the following paragraphs:

1. Lakes Buchanan and Travis are operated as a reservoir system. OR cards are used to enable demands (releases) to be met from the two reservoirs in a specified order down to specific trigger capacities of each reservoir based on operational rules given in the WMP. Generally, releases are made from Lake Travis first until it reaches a capacity of 850,000 acre-feet, then releases are made from Lake Buchanan until it reaches a capacity of 50,000 acre-feet, then releases are again made from Lake Travis until it is depleted, then Lake Buchanan until it is depleted.

2. O. H. Ivie Reservoir is operated as a standalone water right relative to the Buchanan/Travis reservoir system, but allowed to impound inflows at Lake Buchanan's priority date to the extent that Lake Buchanan could have impounded such inflows. This is accomplished by using TO records that calculate the open conservation space in each time step (drawdown) of each reservoir and enable O. H. Ivie Reservoir to divert the minimum quantity based on available inflows at a priority date of 3/6/1926 - 1 day senior to that of Lake Buchanan. These inflows are then routed to a control point off-network to be used later in the time step. The computations then proceed in standard priority order to simulate all junior water rights. When the Ivie Reservoir water right is encountered in this computational process, the water previously moved to the off-network location is transferred into Ivie Reservoir, and any remaining appropriation that Ivie Reservoir is entitled to, at its stated priority date, is simulated.

3. LCRA's uninterruptible (firm) water diversions from the Buchanan/Travis reservoir system is represented with an annual demand set equal to 211,739 acre-feet per year (85,789 acre-feet to represent the contractual commitments for diversions directly from the Highland Lakes and 125,950 to represent the remaining uncommitted firm yield as stated in the WMP), with the priority date for firm water diversions from the Buchanan/Travis reservoir system specified as March 7, 1938, with the priority date for storing water in the Buchanan/Travis reservoir system specified as March 7, 1926, and with the demand distribution for the firm water diversions based on actual historical use. (Note: In accordance with the provisions in the WMP, the balance of the firm water in the Buchanan/Travis reservoir system, excluding the 90,546 acre-feet per year committed to Ivie Reservoir, will be diverted as needed as backup supplies for the City of Austin and the South Texas Project water rights, used to supplement cooling water for LCRA's power plant cooling reservoirs at Bastrop, Fayette, and Ferguson, and releases as necessary for instream uses along the lower Colorado River).

4. LCRA's junior interruptible water right is represented using two WR cards totaling an annual demand of 30,000 acre-feet per year with a municipal demand distribution (13,000 acre-feet for January-June and 17,000 acre-feet for July-December). The priority date for the interruptible water diversion is specified as November 1, 1987 (the date specified in the COA and WMP for the priority of LCRA non-firm water with respect to upstream water rights), and DI cards and dummy reservoirs are used to curtail the interruptible water deliveries in accordance with the WMP provisions as described herein for the second (junior) of the two types of interruptible water accounts. These curtailments are accomplished by establishing dummy reservoirs which mirror system storage and allow the program to diminish the authorized amounts of these two WR cards based on the actual system storage at the beginning of January for the January through June interruptible diversions (13,000 acre-feet) and at the beginning of July for the July through December interruptible diversions (17,000 acre-feet).

5. The City of Austin water rights are represented as standalone water rights, with their respective stipulated priority dates with their run-of-the-river authorized diversion amounts backed by firm water from the Buchanan/Travis reservoir system up to the maximum contract amount of 290,156 acre-feet per year. The special condition in the latest amendment to COA 61405471 makes the City of Austin water rights (249,000 acre-feet/year) senior to all of LCRA's water rights with priority dates junior to November 15, 1900. This type of subordination condition between two water rights can not be precisely described with the WRAP program, and therefore, this subordination condition regarding the City of Austin and LCRA water rights is not represented in the Colorado/Brazos-Colorado WAM. One possibility for describing this special subordination condition would be to make the effective priority date for the appropriate LCRA water rights immediately junior to the City of Austin's stated water rights.

6. The South Texas Project water right is represented as a standalone water right, with its stipulated priority date and with its run-of-the-river authorized diversion backed by firm water from the Buchanan/Travis reservoir system up to the maximum contract amount of 102,000 acre-feet per year.

7. Garwood, Lakeside, Pierce Ranch, and Gulf Coast irrigation water rights are represented as standalone water rights, with their respective stipulated priority dates and run-of-the-river authorized diversion amounts backed by senior interruptible stored water from the Buchanan/Travis reservoir system subject to restrictions in accordance with the WMP provisions described above for the first (senior) type of interruptible water account. These curtailments prescribe full backup down to 52% of system storage, then increasing backup curtailments down to 325,000 acre-feet of system storage, and finally no backup when the system storage falls below 325,000 acre-feet. Similar to the junior interruptible diversions, these curtailments are accomplished with a dummy reservoir, which mirrors system storage and allows the program to diminish the amount of water available as backup based on the actual system storage at the beginning of each year. Per the WMP, the portion of the Garwood water right that has been sold to the City of Corpus Christi (35,000 AF/Y) does not have access to backup supply and thus has been simulated as run-of-the-river only.

8. Flow restrictions for instream uses are represented by using IF cards at each of the four gage locations specified in the WMP (Austin, Bastrop, Columbus [Eagle Lake], and Wharton [Egypt]). Per the WMP, target instream flow criteria is specified at all four locations while critical instream flow criteria is only specified at Austin and Bastrop. Target instream flow criteria are applied during times that the senior interruptible water rights are not curtailed (when system storage is greater than 52% on January 1). When system storage falls below 52% of the system conservation storage capacity on January 1, the Target instream flow criteria is replaced with the Critical instream flow criteria. Target instream flows are met with inflows only, and Critical instream flows are met with stored water from the Buchanan-Travis system without reservation. The priority dates for meeting both the Critical and Target instream flows are specified as immediately senior to the priority date associated with the right of storage in the Buchanan/Travis reservoir system (March 7, 1926).

9. Bay and estuary inflow criteria are represented by using two IF cards applied at the lower end of the basin, with the first having an annual B&E inflow amount of 1,003,000 acre-feet per year (Target criterion) and the second having an annual B&E inflow amount of 171,000 acre-feet per year (Critical criterion), and with both annual amounts distributed to monthly values in accordance with the WMP. Both IF cards are coded to establish the priority date for the B&E inflows as immediately senior to all of LCRA's water rights (March 6, 1926), and both IF cards are coded such that no stored water in Lakes

Buchanan or Travis is released for the purpose of satisfying the B&E inflow requirements. Similar to the interruptible water rights, a dummy reservoir is used to mirror system storage so that the Target IF card will be engaged during years in which the Buchanan/Travis reservoir system storage on January 1 is greater than 1,660,000 acre-feet (80% of the system conservation storage capacity) and the Critical IF card will be engaged, in place of the Target IF card, when the system storage is less than 1,660,000 acre-feet. As noted above, no stored water from Lakes Buchanan or Travis is released to supplement the B&E freshwater inflow needs.

Table 4-10 lists each of the water rights that are associated with the WMP and also contain the water right identifier used in the model, a brief description of the water right, how each is associated with the WMP, and whether they are considered in the firm annual yield, since the WMP considers yield. As detailed earlier, each of these water rights is either considered to be FIRM (uninterruptible), JUNIOR INTERRUPTIBLE or SENIOR INTERRUPTIBLE backup, or INDIRECT. The water rights associated as INDIRECT include the run-of-river portion of water rights related to the WMP, since these water rights' diversion success under their own water right priority governs the amount of backup the LCRA system provides.

4.2.3.5.3 CRMWD Water Rights in Upper Colorado River Basin

CRMWD WATER RIGHTS OVERVIEW

The Colorado River Municipal Water District (CRMWD) owns six water rights in the Colorado River Basin (Nos. 11403676, 11405457, 11405480, 61401002, 61401008, and 61401012)[1]. In addition, CRMWD partially owns and manages the City of Big Springs' water right (No. 61401018), which authorizes Moss Lake and Powell Lake. The six water rights owned by CRMWD are associated with 12 reservoirs and authorize the diversion of water for municipal, industrial, and mining uses. In addition, some of the water rights authorize the diversion of water for water quality purposes. Although CRMWD is authorized to impound water in 12 reservoirs, only three of these reservoirs are for water conservation purposes, with the remaining reservoirs being authorized and used for preventing poor quality water from entering the Colorado River and/or storing and disposing of poor quality water that would otherwise enter the Colorado River.

A summary of the basic authorizations and general features of the six water rights owned by the CRMWD is presented in Table 4-11.

[1] In accordance with TNRCC WAM Resolved Technical Issue No. 1 (1/1/99), these water right numbers reflect the identification scheme devised by RJBCO for purposes of the WAM, whereby the first digit signifies a permit (1) or a certificate of adjudication (6), the next two digits designate the river basin (14 for the Colorado Basin, 13 for the Brazos-Colorado Coastal Basin), and the last five digits correspond to either the permit number or the certificate of adjudication number for the water right.

TABLE 4-10
WATER RIGHTS ASSOCIATED WITH LCRA WATER MANAGEMENT PLAN

WRAP WRID	Description	Association with WMP	Included in Yield
61405482001C	Highland Lakes and uncommitted FIRM	Firm	Y
61405677001	Cedar Park firm water	Firm	Y
11403676990	OH Ivie depletions from old priority	Firm	Y
IFCA	Critical IF @ Austin	Firm	Y
IFCB	Critical IF @ Bastrop	Firm	Y
61405471005MBU	CO Austin Muni BU (large-old)	Firm	Y
61405489003MBU	CO Austin Muni BU (small-new)	Firm	Y
61405480001	LBJ Industrial Water	Firm	Y
61405473001	Bastrop Industrial Water	Firm	Y
61405474001	Fayette Industrial Water	Firm	Y
61405437001BU	South Texas Project BU	Firm	Y
61405482001A	Jan-Jun Inturuptible	Junior Interruptible	N
61405482001B	Jul-Dec Interruptible	Junior Interruptible	N
61405434201BU	Garwood LCRA BU	Senior Interruptible	N
61405477001BU	Pierce Ranch BU	Senior Interruptible	N
61405475001LBU	Lakeside BU	Senior Interruptible	N
61405475001WBU	Lakeside (old LW) BU	Senior Interruptible	N
61405476003BU	Gulf Coast BU	Senior Interruptible	N
61405434201RR	Garwood LCRA RR	Indirect	N
61405477001RR	Pierce Ranch RR	Indirect	N
61405475001LRR	Lakeside RR	Indirect	N
61405475001WRR	Lakeside (old LW) RR	Indirect	N
61405476003RR	Gulf Coast RR	Indirect	N
61405471005MRR	CO Austin Muni RR (large-old)	Indirect	N
61405489003M	CO Austin Muni RR (small-new)	Indirect	N
61405437001RR	South Texas Project RR	Indirect	N

TABLE 4-11
GENERAL DESCRIPTION OF CRMWD WATER RIGHTS

Water Right No.	Priority Date mm/dd/yy	Stream Name	Reservoir Name	Storage Ac-Ft	Diversion Ac-Ft/Yr	Purposes of Use
61401002	08/05/46	Colorado R	J. B. Thomas	204,000	30,000	Mun, Ind & Mining
"	08/05/46	Bull Creek	- -	- -	- -	Diversion Structure
61401008	08/17/64	Colorado R	E. V. Spence	488,760	41,573	Mun, Ind & Mining
"	03/06/84	Beals Ck	Beals Ck Sump	3.4	- -	- -
"	08/17/64	Off-Channel	Barber Lake	2,500		
"	03/06/84	Red Draw	Red Draw	8,538	8,427	Mining
"	02/14/90	U N T of Beals Ck	Mitchell Cty	27,266		
"	- -	Colo R/Beals Ck	- -	- -	14,692	Water Quality
11403676	02/21/78	Colorado R	O. H. Ivie	554,340	113,000	Mun & Ind
61401012	07/23/73	Beals Creek	- -	- -	2,200	Water Quality
"	07/23/73	Beals Creek	Three Mile Lk	n/a	2,000	Mining
"	07/23/73	Beals Creek	Four Mile Lk	n/a		
11405457	04/01/93	Sulphur Spgs Dr	Sulphur Draw	7,997	2,500	Ind & Mining
"	04/01/93	Off-Channel	Red Lake	9,150		
11405480	03/21/94	Sulphur Spgs Dr	Natural Dam Lk	54,560	2,500	Mining

Note: As discussed below, many of these water rights are interrelated and subject to common diversion limitations and/or system operations.

The CRMWD reservoirs that are authorized and used solely for water supply (conservation) purposes are J. B. Thomas, E. V. Spence, and O. H. Ivie, all of which are located on the mainstem of the Colorado River. The CRMWD reservoirs that are authorized and used for water quality purposes (either to facilitate the diversion of poor quality water from the Colorado River and Beals Creek or to serve as terminal storage of highly mineralized water) are:

1. Sulphur Draw Reservoir
2. Red Lake Reservoir
3. Natural Dam Lake
4. Barber Reservoir
5. Mitchell County Reservoir
6. Red Draw Reservoir
7. Beals Creek Sump
8. Three Mile Lake
9. Four Mile Lake

Several of the CRMWD reservoirs are associated with each other through several different authorizations, usually involving diverting or pumping water from one reservoir to another. Following are groupings of the reservoirs as they are associated for operational purposes:

1. Group 1 – COA 14-1002 and COA 14-1008

- J. B. Thomas Reservoir

- Bull Creek Diversion Dam
- E. V. Spence Reservoir
- Barber Reservoir (Off-Channel)
- Beals Creek Sump
- Red Draw Reservoir
- Mitchell County Reservoir

2. Group 2 – Permit 5480, Permit 5457, and COA 14-1012

- Three Mile Lake
- Four Mile Lake
- Sulphur Draw Reservoir
- Red Lake Reservoir
- Natural Dam Lake

3. Group 3 – Permit 3676

- O. H. Ivie Reservoir

CRMWD WATER RIGHTS OPERATIONS

CRMWD Group 1 Reservoirs – Water Supply

The water right for J. B. Thomas Reservoir (COA 14-1002) authorizes the diversion of 30,000 acre-feet per year for "municipal, industrial, recreational and mining purposes," with no specific allocations to these different types of use. The water right for E. V. Spence Reservoir (COA 14-1008, Amendment B) authorizes the diversion from the reservoir of a total of 41,573 acre-feet of water per year, with 38,573 acre-feet per year for municipal use, 2,000 acre-feet per year for industrial use, and 1,000 acre-feet per year for mining purposes.

The Spence water right (COA 14-1008, Amendment B) also authorizes the diversion of up to 14,692 acre-feet per year of poor quality water either from the Colorado River (Barber diversion point) or from Beals Creek (Red Draw diversion point) for subsequent storage in Barber, Red Draw and/or Mitchell County Reservoirs. A total of 8,427 acre-feet per year of the water stored in Barber, Red Draw and/or Mitchell County Reservoirs can be diverted and used for mining purposes. Additionally, the Spence water right (COA 14-1008, Amendment B) allows all or part of the 2,000 acre-feet per year of industrial diversions and 1,000 acre-feet per year of mining diversions referenced above for Spence Reservoir to be withdrawn from Barber, Red Draw and/or Mitchell County Reservoirs.

Paragraph 5(a) in the original Spence water right (COA 14-1008) limits the combined diversions of water under COA 14-1008 and COA 14-1002 to no more than 73,000 acre-feet in any one year, of which not more than 20,000 acre-feet per year can be used for mining and industrial purposes. For purposes of developing the WAM, these combined diversion limitations apply to the combined diversions from E. V. Spence and J. B. Thomas Reservoirs on the Colorado River and from Barber, Red Draw and Mitchell County Reservoirs either off-channel or on tributaries. The combined total authorized diversion amount for all of these reservoirs is 80,000 acre-feet per year (which is the same as that authorized in the original Spence and Thomas water rights), whereas their combined industrial and mining authorized diversion amount is 41,427 acre-feet per year (assuming that all of the 30,000 acre-feet per year of authorized diversion amount for J. B. Thomas Reservoir is used for mining and industrial purposes). The combined diversion limitations on these reservoirs as stipulated in COA 14-1008, as amended, require them to be modeled together as a system in the WAM.

For purposes of describing these reservoirs and their respective water supply diversions in the WAM, the following specifications are made:

1. For J. B. Thomas Reservoir, a diversion of 23,000 acre-feet per year for mixed uses, with the monthly demand distribution based on historical diversions, is specified with a priority date of August 5, 1946.

2. Another 7,000 acre-feet per year of mixed-use diversions is specified for J. B. Thomas Reservoir with a priority date of August 5, 1946, backed up, as necessary, with storage in E. V. Spence Reservoir.

3. For E. V. Spence Reservoir, a total diversion of 34,573 acre-feet per year for municipal and industrial uses, with the monthly demand distribution based on historical diversions, is specified with a priority date of August 17, 1964.

4. A total diversion of 8,427 acre-feet per year of the water stored in Barber, Red Draw and/or Mitchell County Reservoirs is specified for mining use with a priority date of August 17, 1964.

Hence, the total diversions associated with J. B. Thomas and E. V. Spence Reservoirs in the WAM is limited to 73,000 acre-feet per year in accordance with Paragraph 5(a) in the original Spence water right (COA 14-1008).

CRMWD Group 1 Reservoirs – Water Quality Control

As noted above, a total of 14,692 acre-feet per year of poor quality water is authorized under COA 14-1008 (Amendment B) to be diverted either from the Colorado River (Barber diversion point) or from Beals Creek (Red Draw diversion point) for subsequent storage in Barber, Red Draw and/or Mitchell County Reservoirs. Paragraph 5(b) in COA 14-1008 stipulates that diversions from the Colorado River into Barber Reservoir can be made only when the chloride content of the river water equals or exceeds 500 parts per million. Based on discussions with CRMWD staff, it appears that the diversions from both the Colorado River and Beals Creek are made whenever routine monitoring indicates that poor quality water is flowing in these streams. The primary purpose of these diversions, of course, is to prevent the poor quality water from flowing downstream and entering E. V. Spence Reservoir; however, the removal of this highly mineralized water from the system also improves water quality for all downstream users.

Historical data describing the quantity and quality of the flow in the Colorado River and Beals Creek have been statistically analyzed to determine if mathematical relationships could be developed for use in the WAM for describing when the diversions of the poor quality water should be made. This effort has not proved to be successful, and the fact that such general relationships do not exist has been confirmed through discussions with CRMWD staff. Apparently, the occurrence of poor quality water in the Colorado River and Beals Creek is more a function of where rainfall occurs within the upstream watersheds, rather than how much rainfall or streamflow occurs. Some watersheds, because of their inherent geologic and soil conditions, contribute more highly mineralized runoff than others. When rainfall occurs on these watersheds, the resulting runoff results in the occurrence of poor quality water in the Colorado River and Beals Creek, and these are the conditions under which diversions into Barber and Red Draw Reservoirs are made.

Since part of the diversions for industrial and mining uses authorized under COA 14-1008, as amended, i. e., those from water stored in Barber, Red Draw and/or Mitchell County Reservoirs, are dependent upon the diversions of poor quality water from the Colorado River into Barber Reservoir and from Beals Creek into Red Draw Reservoir, it is essential that these water quality diversions be accounted for in the WAM. For this purpose, the full diversion amount of 14,692 acre-feet per year has been apportioned between the Colorado River diversion and the Beals Creek diversion based on their historical average annual diversion amounts and the monthly patterns of these diversions has been described in the WAM in accordance with their historical average monthly diversion amounts. Also, the BACKUP option in WRAP has been used to assure that the full authorized diversion amount can be diverted between the two different diversion points, i. e., from the Colorado River and from Beals Creek.

The priority date that should be assigned to the 14,692 acre-feet per year of water quality diversions from the Colorado River and Beals Creek is somewhat in question. The authorized priority date for these diversions, based on language in Paragraph 6 of Amendment B of COA 14-1008, appears to be the same as the priority date for the authorized storage in Barber Reservoir, the Beals Creek Sump, and Red Draw Reservoir as specified in Amendment A of COA 14-1008, i.e., March 6, 1984. However, since these diversions are related to the quality of the water flowing in the Colorado River and Beals Creek, it could also be rationalized that this water should be diverted all of the time under the oldest priority date in the basin in order to conservatively limit the availability of the highly mineralized water for downstream users. Subsequent discussions with the TNRCC have resulted in the follow resolution. For Runs 1 through 7, the referenced water quality diversions have been simulated with the priority date as specified in Amendment A, March 6, 1984. For Run 8, these same diversions have been modeled as the last ten years maximum diversion, but with the "oldest" priority date in the basin.

As noted above, the poor quality water diverted from the Colorado River and Beals Creek is authorized to be stored in Barber, Red Draw and/or Mitchell County Reservoirs for subsequent use for mining purposes. The amount authorized for diversion from these reservoirs for mining use is 8,427 acre-feet per year (Amendment B of COA 14-1008), while these reservoirs are operated as a system, there is no authorized allocation of this diversion among the three reservoirs. For this reason, for modeling purposes, the three reservoirs have been combined into a single reservoir with an authorized storage capacity equal to the sum of the individual authorized storage amounts (38,304 acre-feet), and the entire authorized amount of 8,427 acre-feet per year has been specified in the WAM for diversion from this single reservoir. Additionally, Mitchell County Reservoir has a small drainage area which contributes some runoff; however, any spills that occur from this reservoir are routed outside the WRAP model and do not contribute flow to downstream control points on Beals Creek or the Colorado River. The priority date for this diversion is the same as that for the original Spence Reservoir water right (COA 14-1008), i. e., August 17, 1964.

CRMWD Group 2 Reservoirs

All of the reservoirs in this group are operated by the CRMWD essentially for water quality improvement purposes. Natural Dam Lake, the largest with an authorized storage capacity of 54,560 acre-feet, is designed to capture and hold all of the runoff from its approximately 550 square miles of drainage area. Because of the highly mineralized nature of this runoff, none of this runoff that is stored in Natural Dam Lake is discharged downstream into Sulphur Springs Draw or Beals Creek for subsequent use by other water rights. Instead, this poor quality water either is disposed of in Natural Dam Lake by evaporation or used for saltwater injection in the petroleum industry (mining). Consequently, for modeling purposes, it has been assumed that all of the drainage area above Natural Dam Lake is non-contributing, and, in effect, the inflows to the overall system from this drainage area have been ignored with respect to downstream water availability.

It should be noted that the CRMWD did not acquire a water right for Natural Dam Lake until the early 1990's, thus this reservoir (the oldest of all of the CRMWD's reservoirs) has the latest and most junior priority date (March 21, 1994). However, since the water stored in Natural Dam Lake is poor quality water and essentially not wanted by downstream water users, it seems appropriate to model Natural Dam Lake as if it has the most senior priority date in the basin and allow all of the inflows to the reservoir, which are totally disposed of through evaporation, to be ignored with regard to availability for downstream water rights. This is the approach used for handling Natural Dam Lake in the WAM.

Poor quality water also is pumped from Three Mile Lake and Four Mile Lake into Natural Dam Lake for subsequent disposal through evaporation or use for mining purposes. Again, once this water is stored in Natural Dam Lake, none of it is ever discharged downstream into Sulphur Springs Draw or Beals Creek for subsequent use by other downstream water rights.

For modeling purposes, the combined diversion from Three Mile Lake and Four Mile Lake on Beals Creek into Natural Dam Lake has been specified in two parts; one at 2,000 acre-feet per year (the amount authorized in COA 14-1012 for mining use) and the other at 200 acre-feet per year (the balance of the total diversion amount authorized in COA 14-1012 for diversion from Beals Creek). Both have a priority date of July 23, 1973, as stipulated in COA 14-1012. Since both Sulphur Draw Reservoir and Red Lake Reservoir are located within the Natural Dam Lake watershed, the water stored in these impoundments is of poor quality and essentially not wanted by downstream water users; therefore, again, it seems appropriate to assume that all of the drainage area above these impoundments is non-contributing. In effect, the inflows to the overall system upstream of Natural Dam has been ignored with respect to contributing water for downstream use as part of the overall water availability modeling.

CRMWD Group 3 Reservoirs

O. H. Ivie Reservoir, as authorized under Permit No. 3676 and the amendments to Permit No. 1259 (the original water right for Lake Buchanan held by the Lower Colorado River Authority), is represented as a standalone reservoir with no specific authorization to operate as a system with any of CRMWD’s other reservoirs. The only mention of some type of system operation in the permit is in Paragraph 6(g) where it is stated that the CRMWD shall meet as much of its water requirements “as feasible and consistent with reasonable operating requirements” from J. B. Thomas and E. V. Spence Reservoirs, rather than O. H. Ivie Reservoir. Specifically, this paragraph stipulates that the CRMWD shall take no less than 20,000 acre-feet of water per year from J. B. Thomas Reservoir to supply the CRMWD's users, provided that the storage in J. B. Thomas Reservoir is greater than or equal to 100,000 acre-feet.

For purposes of the WAM, the above stipulation regarding the minimum diversion of 20,000 acre-feet of water per year from J. B. Thomas Reservoir has no meaning since the fully authorized diversion amounts for both J. B. Thomas Reservoir and O. H. Ivie Reservoir are specified as demands in the WAM. See the earlier section for more specific details on the WAM representation of O. H. Ivie Reservoir.

4.2.4 Water Rights Cancellation

To address the issue of water rights cancellation and its potential impact on water availability, the TNRCC has requested that the WRAP model be operated under the fully authorized water rights diversions, but with zero diversion amounts specified for those water rights that have reported zero use during the last ten years. These water rights are indicated in Table 4-12.

TABLE 4-12
WATER RIGHTS WITH ZERO REPORTED USE DURING LAST TEN YEARS

11303795	61401003	61401136	61401391	61401499
11303810	61401007	61401138	61401392	61401507
11303846	61401010	61401186	61401393	61401512
11303957	61401017	61401187	61401395	61401516
11303967	61401020	61401193	61401403	61401525
11303996	61401022	61401197	61401406	61401529
11304006	61401030	61401198	61401408	61401539
11304122	61401036	61401200	61401410	61401540
11304162	61401040	61401201	61401412	61401542
11304229	61401041	61401203	61401413	61401543
11305067	61401048	61401204	61401414	61401545
11305156	61401051	61401205	61401415	61401546
11305244	61401052	61401211	61401418	61401547
11305446	61401060	61401221	61401419	61401548
11305645	61401061	61401226	61401420	61401549
11403010	61401062	61401233	61401422	61401551
11403030	61401064	61401234	61401425	61401553
11403061	61401067	61401236	61401429	61401555
11403158	61401070	61401237	61401430	61401557
11403284	61401073	61401242	61401435	61401559
11403343	61401074	61401247	61401436	61401574
11403344	61401075	61401256	61401437	61401577
11403411	61401080	61401257	61401439	61401585
11403512	61401084	61401265	61401440	61401586
11403837	61401085	61401269	61401441	61401588
11403883	61401091	61401278	61401442	61401589
11404025	61401093	61401279	61401443	61401597
11404138	61401094	61401283	61401447	61401601
11405179	61401096	61401287	61401448	61401602
11405193	61401097	61401288	61401449	61401605
11405216	61401098	61401291	61401451	61401606
11405273	61401099	61401293	61401453	61401609
11405335	61401101	61401301	61401454	61401618
11405341	61401102	61401309	61401456	61401622
11405457	61401103	61401312	61401459	61401629
11405480	61401104	61401314	61401460	61401630
61303416	61401105	61401315	61401463	61401634
61303417	61401106	61401324	61401464	61401636
61303424	61401108	61401326	61401467	61401638
61303426	61401110	61401334	61401469	61401640
61303428	61401114	61401336	61401470	61401641
61303431	61401115	61401339	61401471	61401643
61303432	61401121	61401350	61401472	61401647

61303434	61401124	61401362	61401473	61401648
61303435	61401125	61401363	61401474	61401649
61303436	61401126	61401369	61401476	61401655
61400993	61401127	61401370	61401477	61401657
61400994	61401129	61401371	61401478	61401658
61400995	61401130	61401372	61401482	61401661
61401000	61401133	61401389	61401485	61401662
61401001	61401135	61401390	61401496	61401663

TABLE 4-12, cont'd.
WATER RIGHTS WITH ZERO REPORTED USE DURING LAST TEN YEARS

61401664	61401772	61402477	61402582	61405398
61401667	61401776	61402478	61402584	61405399
61401669	61401779	61402481	61402585	61405400
61401670	61401780	61402484	61402591	61405401
61401671	61401783	61402485	61402593	61405402
61401672	61401784	61402486	61402595	61405403
61401673	61401790	61402487	61402596	61405405
61401679	61401792	61402490	61402597	61405406
61401680	61401797	61402491	61402601	61405407
61401681	61401798	61402492	61402602	61405411
61401684	61401800	61402493	61402603	61405418
61401685	61401801	61402494	61402608	61405420
61401690	61401805	61402497	61402609	61405424
61401691	61401807	61402503	61402611	61405428
61401694	61401812	61402504	61402613	61405431
61401695	61401813	61402506	61402622	
61401697	61401814	61402508	61402623	
61401699	61401820	61402511	61402624	
61401701	61401821	61402512	61402625	
61401706	61401824	61402513	61402626	
61401708	61401831	61402514	61402627	
61401709	61401846	61402515	61402628	
61401710	61401848	61402519	61402630	
61401711	61401849	61402520	61402633	
61401712	61401850	61402523	61402635	
61401713	61401851	61402525	61402636	
61401725	61401863	61402526	61402637	
61401727	61401866	61402527	61402638	
61401729	61401873	61402528	61402639	
61401730	61401882	61402530	61402640	
61401731	61401883	61402532	61402642	
61401733	61401885	61402534	61402643	
61401739	61401886	61402536	61402644	
61401743	61401888	61402537	61402646	
61401744	61401889	61402538	61402647	
61401747	61401894	61402539	61402648	
61401751	61401896	61402541	61402649	
61401752	61401897	61402542	61402650	
61401753	61401909	61402544	61402651	
61401754	61401912	61402545	61405369	
61401755	61401915	61402552	61405373	
61401756	61401918	61402555	61405382	
61401758	61401919	61402559	61405384	

61401759	61401920	61402562	61405385	
61401761	61401922	61402564	61405389	
61401762	61401923	61402568	61405390	
61401763	61401925	61402570	61405391	
61401764	61401926	61402571	61405392	
61401765	61402470	61402572	61405393	
61401766	61402471	61402577	61405394	
61401770	61402476	61402578	61405396	

4.2.5 Term Permits

In accordance with TNRCC instructions, terms permits are to be excluded from all of the water availability analyses, except for Run 8. There are seven active term permits in the Colorado/Brazos-Colorado Basin. Table 4-13 lists the active term permits modeled in Run 8.

TABLE 4-13
TERM PERMITS MODELED IN RUN 8

WATER RIGHT NAME	WATER RIGHT NUMBER	AUTHORIZED AMOUNT AC-FT/YR	DATE ISSUED	EXPIRATION DATE
OEHMIG Land & Cattle Co.	11403830B	450	9-11-1991	12-30-2001
Bertha L. Barth, et al	11403837A	0.4	6-24-1992	12-31-2001
Lower Colorado River Authority	11404137A	10	3-17-1995	12-31-2004
Lower Colorado River Authority	11404138A	5	3-10-1995	12-31-2004
Steven R. Sprinkel, et ux	11404143A	25	4-19-1995	12-31-2014
Brother’s Cattle Co. Inc.	11405364	62.5	9-11-1991	12-31-2001
Weirich Bros., Inc.	11405569	180	5-5-1997	3-31-2004

4.2.6 Data for Basin-Specific Features Added to *WRAP*

No basin-specific modifications have been made to the WRAP program as part of this water availability modeling study for the Colorado/Brazos-Colorado Basin; consequently, no special data are required for basin-specific features.

4.3 SIGNIFICANT ASSUMPTIONS AFFECTING WATER AVAILABILITY MODELING

4.3.1 Streamflow Assignments

In some instances, in the streamflow naturalization process, historical streamflow data have not been readily available to describe actual streamflow conditions for a particular tributary watershed or at a particular location within the basin. Consequently, data from the nearest gage for a similar watershed have been used, and these data may not accurately reflect actual streamflow conditions as they occurred historically in the affected watersheds. This could result in some misstatement of the reliability of affected water rights.

4.3.2 Historical Diversions and Return Flows

Complete data are not available for describing historical diversion amounts and the associated quantities of return flows for all water rights in the Colorado/Brazos-Colorado Basin. Various fill-in and estimation procedures have been employed to develop as complete and accurate data as possible for use in the streamflow naturalization process. Still, there are likely to be errors in these estimates that could translate to corresponding errors in the associated naturalized streamflows and the corresponding results from the water availability simulations.

4.3.3 Historical Springflows

Numerous springs are known to occur on creeks and streams in the middle Colorado Basin; however, very little specific data are available to quantify these springflows for purposes of the water availability modeling. As part of the streamflow naturalization process, discharges from known springs with limited historical flow data have been estimated based on correlations with other springs with more complete data. Some of these estimated spring discharges may not accurately reflect actual historical conditions and may introduce some uncertainties in the results from the water availability simulations.

4.3.4 Rice Irrigation Return Flows

Specific records of historical return flow quantities associated with rice irrigation in the lower basin are not available. Information compiled from literature sources, from discussions with LCRA personnel and farmers, and from other water availability modeling efforts has been used to develop estimates of these quantities as functions of the amount of water diverted. Water balance analyses performed during the streamflow naturalization process have provided checks on assumed quantities. Inaccuracies inherent in the values used for return flow factors for rice irrigation in the lower basin may result in incorrect estimates of water availability with respect to lower basin demands.

4.3.5 Return Flow Simulations

In the WAM, all return flows that are quantified based on return flow factors utilize the simulated diversions from the previous month to calculate the return flow amounts for the next month. This assures that the calculated return flows contributed by upstream junior water rights will be available for use by all downstream senior water rights during the WAM simulation process.

4.3.6 Combined Multiple Diversion Points

In the WAM, water rights with multiple diversion points located on the same stream segment have been modeled with a single diversion located at a control point coincident with the most downstream diversion point.

4.3.7 Combined Multiple Small Reservoirs

Water rights authorized to store water in several small reservoirs on the same stream segment or tributary system have been represented in the WAM with a single reservoir with its storage capacity equal to the sum of the authorized storage amounts of the individual reservoirs. The single reservoir has been located at the site of the most downstream of the individual reservoirs.

4.3.8 Negative Incremental Flows

Although efforts were made during the streamflow naturalization process to eliminate all negative incremental flows to the extent possible and reasonable, some negative incremental flows still exist in the naturalized streamflow data base, particularly where significant natural streamflow losses occur, such as across the Edwards-Balcones Fault Zone. The WRAP program provides several options for dealing with negative incremental flows, but there is no clear direction as to the best approach to use. For all of the WAM simulations of the Colorado/Brazos-Colorado Basin that have been made to produce the results reported herein, the “-4” option in the WRAP program has been used based on professional judgment. This is a relatively conservative option where adjustments are added to downstream primary control points, but not at the control point of the water right being considered, to eliminate negative incremental flows at the control point being considered by the model. Other test simulations have been made using other options, including “1,” “4,”and “5.” Option “4” is a variation of “-4”, but resulted in an unacceptably long computation time. Results from all of these simulations in terms of water rights diversion reliabilities and the available supply of water from the Highland Lakes system have been different to varying degrees. It appears that the results with the “-4” and “5” options are generally similar and reasonable; however, it is important to recognize that significantly different results can be obtained simply by changing the negative incremental inflow option.

5.0 WATER AVAILABILITY IN THE BASIN

5.1 DESCRIPTIONS OF SCENARIOS MODELED

The TNRCC has defined eight specific scenarios that have been evaluated with respect to water availability in the Colorado/Brazos-Colorado Basin. These various scenarios, referred to as "Runs," are described in the following sections. The output from these runs is intended to address directly the requirements for water availability information specified in Senate Bill 1 as described in Section 1.2 of this report. Basically, the eight different runs are characterized by different combinations of input conditions for: (1) the diversion amounts specified for water rights; (2) the area-capacity relationships specified for reservoirs; (3) the quantities specified for return flows corresponding to assumed levels of reuse; and (4) diversions and/or storage associated with term water rights permits. The various combinations of these parameters for each of the eight runs are indicated in the matrix in Table 5-1.

It should be noted that the simulated water availability results from the WRAP model for each of these runs are described and summarized only in general terms in this report. Results for specific water rights and specific locations are presented as examples to demonstrate the general condition of the Colorado/Brazos-Colorado Basin with regard to overall water availability and to illustrate the types of water rights output that has been generated with the WRAP model. More detailed results from the WRAP water availability analyses for individual water rights, including plots of water availability and reliability, are available from the TNRCC.

5.1.1 Reuse Runs

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

Although the results from Run 1 provide the standard against which the results from the other seven runs have been compared, note that this run is not used by TNRCC to assess water availability for permit applications. For permitting purposes, TNRCC uses Runs 3 and 8 (see below).

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

TABLE 5-1, Matrix describing WRAP Runs

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

5.1.2 Cancellation Runs

Various simulations have been made with the WRAP model to provide information regarding the potential water availability impacts of canceling water rights pursuant to the provisions of Subchapter E, Chapter 11 of the Texas Water Code. Under this section of the Water Code, the TNRCC has the authority to cancel a permit, certified filing, or certificate of adjudication if the water authorized to be appropriated has not been beneficially used during the last ten years. This excludes municipal water rights, which cannot be cancelled even if there has been no use. Hence, as described previously, those water rights in the Colorado/Brazos-Colorado Basin that have not been used in the last ten years according to TNRCC and TWDB records have been identified and assumed to be cancelled for purposes of these analyses. The water rights with no reported usage in the last ten years are identified in Table 4-12.

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

5.1.3 Current Conditions Runs

Run 8 is the final simulation that has been made with the WRAP model for purposes of evaluating water availability in the Colorado/Brazos-Colorado Basin and corresponds to current conditions. This means that the annual diversion amounts for all water rights have been set equal to the maximum annual use reported during the last ten years, the area-capacity relationships for all reservoirs have been assumed to correspond to year-2000 sedimentation conditions, all return flows have been based on current conditions without any additional reuse, and all unexpired term water rights permits have been fully accounted for.

5.1.4 Firm Yield Analysis

As set forth in the "WAM Resolved Technical Issues No. 10 – Model Runs" document dated October 22, 1999, the firm annual yield for all major reservoirs, or reservoir systems, in the

Colorado/Brazos-Colorado Basin has also been determined using the WAM. The firm yield has been determined only for those reservoirs that experienced shortages in the Run 3 simulation. Diversions for the reservoirs exhibiting shortages were reduced until no shortages were experienced (the minimum volume remaining at the critical period was virtually zero), while maintaining all other water rights at their authorized amounts.

5.2 RESULTS OF WATER AVAILABILITY MODEL RUNS

The simulated results from the WRAP model for the various input conditions corresponding to the eight runs provide an indication of water availability for each water right in the Colorado/Brazos-Colorado Basin. All of these simulations have encompassed monthly hydrologic conditions for the 1940 through 1998 period. The basic results from the different runs with regard to water availability consist of monthly values of simulated diversions and simulated end-of-month reservoir storage for each of the water rights in the basin. Also of importance are the simulated quantities of monthly unappropriated streamflows and monthly regulated streamflows at various locations throughout the Colorado/Brazos-Colorado Basin. The unappropriated streamflows, of course, provide an indication of the water available for future water resource development projects, while the regulated streamflows reflect the actual levels of flow that can be expected in the streams under the various scenarios of diversions, reservoir storage, return flows, and term permits.

To illustrate the variations in water availability among major water rights in the Colorado/Brazos-Colorado Basin for the different simulation runs, several individual water rights (reservoirs) have been selected for graphically displaying the model results.

For describing the simulated quantities of unappropriated water and regulated flows corresponding to the different runs, model results have been plotted for all primary control points defined in this study. In accordance with the TNRCC Scope of Work for the Colorado/Brazos-Colorado WAM, results from the modeling for each of the 45 primary control points used in the model plus the downstream-most control points in each of the Colorado and Brazos-Colorado basins (representing inflows to the Matagorda Bay system) are presented in the following appendices:

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

A summary of the results from the eight runs with regard to the amount and reliability of simulated diversions is presented in tables in Appendix P. These tables list the water rights with authorized diversions in the Colorado/Brazos-Colorado Basin, and indicate their respective water right numbers and types of use, i.e., municipal, industrial, irrigation, or other. For each of the eight runs, the authorized annual diversion amount for each water right and type of use is listed, along with the simulated mean annual shortage amount, the percent of the total months analyzed (59 years x 12 = 708 months) for which the authorized diversion was satisfied, and the percent of the total authorized diversion amount over the entire 1940-1998 analysis period that was actually diverted. Although these results do not provide a complete picture of when and how much water is available for each water right, the two percentage quantities in the table do provide an indication of the reliability with which water can be diverted. At 100 percent, the fully authorized annual diversion of a particular water right is satisfied in every month. A zero value means water is never available.

The reliability results summarized in Appendix P do identify several problems with regard to water availability for some water rights. In particular, the western part of the Colorado Basin has very low reliabilities for many water rights and some of the major reservoirs are frequently dry. This is attributable to two major factors. The first is that this part of the state is very dry and there is little naturalized flow most of the time. The second is that Lakes O.H. Ivie, Buchanan, and Travis are located downstream and have relatively senior priority dates, as modeled in accordance with the LCRA Water Management Plan for Lower Colorado River Basin. These reservoirs are seldom full at the same time, so when naturalized flow does occur in the upper basin, it is required to be passed to satisfy these water rights.

5.2.1 Reuse Runs

5.2.1.1 Specific Large Water Rights

Because of the great number of water rights in the Colorado/Brazos-Colorado Basin, no plots are presented detailing the diversions for any specific individual water rights.

The effects on reservoir storage of the varying levels of reuse specified in the WRAP model for Runs 1, 2, and 3 for the reservoirs with conservation capacity greater than 100,000 acre-feet are illustrated in Figures Q-1 through Q-8 in Appendix Q. Lake LBJ has been omitted, as it is a constant level lake. On these graphs, the simulated end-of-month storage is plotted for the entire 1940-1998 analysis period for Lake J.B. Thomas (Figure Q-1), E.V. Spence (Q-2), Twin Buttes (Q-3), O.C. Fisher (Q-4), O.H. Ivie (Q-5), Lake Brownwood (Q-6), Lake Buchanan (Q-7), and Lake Travis (Q-8). As illustrated, there are some occasional significant differences in reservoir storage conditions for the three reuse levels. Lake Travis in particular, and Lake Buchanan to a lesser extent, show some significant drops in storage under full reuse conditions (Run 3) during drought periods, such as during the droughts of the 1950s and 1960s. This is primarily attributable to the City of Austin’s return flows being fully reused and therefore unavailable to downstream rice irrigators. These irrigation rights are backed up by Lakes Travis and Buchanan, and therefore they make large calls on stored water when the return flows are eliminated. The City of Austin’s rights are also backed up by Travis and Buchanan, and therefore the City is making significant calls on stored water during this drought period as well.

Lakes in the upper basin are dry a significant portion of the time, as discussed above. The critical drought for most of the other lakes occurs during the 1950s, although for Lake Brownwood it occurs in 1978.

Figure 5-1 illustrates the variation of storage in the Buchanan-Travis reservoir system for Run 1 (100 percent of assumed return flows, no reuse) and Run 3 (no return flows, full reuse). Note that the critical drought for the system (lowest storage condition) occurs during the 1950s drought, with the minimum system storage occurring in 1952 for Run 1 and in 1957 for Run 3. As shown, other severe low storage conditions occur during the 1960s and 1980s.

5.2.1.2 Unappropriated Flows at Selected Locations

Five control points were chosen to illustrate the WRAP simulation results. Table 5-2 lists the control points and their description. Annual quantities of the simulated unappropriated streamflows for the analysis period 1940-1998 for each of the three reuse conditions specified in Runs 1, 2, and 3 are plotted in Figures Q-9 through Q-13 at locations corresponding to the control points listed in Table 5-2.

TABLE 5-2

SELECTED CONTROL POINTS FOR WRAP RESULTS PRESENTATION

CONTROL POINT		CONTROL POINT LOCATION
NO.	ID	
B20000	**CR-SI**	Colorado River above Silver
D20000	CR-ST	Colorado River near Stacy
I10000	CR-AU	Colorado River at Austin
M10000	OUT	Most Downstream Point on Colorado River
N10060	OUT	Most Downstream Point on San Bernard River

The effects of the different levels of return flows associated with the three reuse conditions are apparent, although these effects do not appear to be significant. The greatest effect is in the San Bernard River (Figure Q-13), where return flows from rice irrigation compose a significant portion of the total flows. Table 5-3 presents the annual unappropriated flows for Run 1 (permitted conditions with existing return flows) and Run 3 (permitted conditions with no return flows, i.e. 100% reuse) at the selected control points.

Note that there are virtually no unappropriated flows in the extreme upper basin (Control Point B20000, Colorado River above Silver, Figure Q-9), and frequent years with no unappropriated flows at the next selected downstream point (Control Point D20000, Colorado River near Stacy,

FIGURE 5-1
Monthly Reservoir Storage Lake Buchanan and Lake Travis System

TABLE 5-3
UNAPPROPRIATED FLOWS AT SELECTED CONTROL POINTS

Figure Q-10). There are a few years with no unappropriated flows at the downstream locations (I10000 and M10000), particularly under full reuse conditions.

5.2.1.3 Regulated Flows at Selected Locations

Annual quantities of the simulated regulated streamflows for the analysis period 1940-1998 for each of the three reuse conditions specified in Runs 1, 2, and 3 are plotted in Figures Q-14 through Q-18 for the same locations used for presenting the unappropriated streamflows. The effects of the different levels of return flows associated with the three reuse conditions on the regulated streamflows are essentially the same as those indicated for the unappropriated flows.

5.2.2 Cancellation Runs

5.2.2.1 Specific Large Water Rights

The plots in Figures R-1 through R-16 in Appendix R illustrate the effects of water rights cancellation on storage in the large reservoirs. These plots present simulated monthly storage variations for selected reservoirs over the period 1940 through 1998 for the fully authorized water availability case (Run 1) and the different cancellation conditions (Runs 4, 5, 6, and 7). In general, the major deviations in the simulated reservoir storage levels from the fully authorized case (Run 1) result from the maximum 10-year use simulations (Runs 5 and 7). The diversion amounts specified in the model for these simulations are considerably less than the fully authorized diversions; consequently, more water generally is stored in the reservoirs. The greatest increase in storage levels occurs in the upper basin, from Lake Buchanan upstream.

5.2.2.2 Unappropriated Flows at Selected Locations

Annual quantities of the simulated unappropriated streamflows for the analysis period 1940-1998 for each of the four cancellation scenarios, i.e., Runs 4, 5, 6, and 7, are plotted in Figures R-17 through R-26. The Run 1 unappropriated streamflows also are shown on these plots. As expected, the general trend illustrated by these plots is that there is slightly more unappropriated water available throughout the basin with cancellation in effect, and there is even more water available for the 10-year maximum use case since the actual historical diversions have been substantially less than the fully appropriated diversion amounts.

5.2.2.3 Regulated Flows at Selected Locations

Annual quantities of the simulated regulated streamflows for the analysis period 1940-1998 for the fully authorized case (Run 1), the two cancellation conditions (Runs 4 and 6), and the two 10-year maximum use scenarios (Runs 5 and 7) are plotted in Figures R-27 through R-36 for the same locations used for presenting the unappropriated streamflows. The effects of the different cancellation and maximum water use scenarios on the regulated streamflows are essentially the same as those indicated for the unappropriated flows. The regulated streamflows, of course, are somewhat greater than the unappropriated flows because they do not reflect all of the streamflow depletions associated with all water rights.

5.2.3 Current Conditions Runs

5.2.3.1 Specific Large Water Rights

The differences in storage attributable to the changes in area-capacity curves between the authorized storage conditions and year-2000 storage conditions and to using the maximum diversions in the last 10 years are reflected on the reservoir storage plots in Figures S-1 through S-8 in Appendix S. These plots present simulated monthly storage variations for selected reservoirs over the period 1940 through 1998 for the fully authorized water availability case (Run 1) and the current conditions case (Run 8). One obvious difference between these two sets of results relates to the maximum available storage capacities that have been used for each of the reservoirs for the two conditions. Because of sedimentation, the year-2000 maximum reservoir storage capacities generally are somewhat less than the authorized storage amounts. In general, the major deviations in the Run 8 simulated reservoir storage levels from the Run 1 case occur because the diversion amounts specified in the model for these current conditions simulations are considerably less than the fully authorized diversions; consequently, more water is stored in the reservoirs. As with the cancellation runs, the greatest increase in storage levels occurs in the upper basin.

5.2.3.2 Unappropriated Flows at Selected Locations

Under current conditions, almost all water rights are not using their fully authorized amounts. Therefore, although there are currently unused flows, all of this water is technically not “unappropriated,” since some of it is subject to lawful claim by existing water rights holders. However, although all of the flows may not be available on a perpetual basis, they could possibly be available on a temporary basis. Annual quantities of the simulated unappropriated streamflows for the analysis period 1940-1998 for Run 1 and the current conditions (Run 8) scenarios are plotted in Figures S-9 through S-13. As expected, the general trend illustrated by these plots is that there is slightly more water available throughout the basin under current conditions. This occurs primarily because the actual 10-year maximum use diversions are substantially less than the fully appropriated diversion amounts.

5.2.3.3 Regulated Flows at Selected Locations

Annual quantities of the simulated regulated streamflows for the analysis period 1940-1998 for the fully authorized case (Run 1) and the current conditions scenario (Run 8) are plotted in Figures S-14 through S-18 for the same locations used for presenting the unappropriated streamflows. The differences between the two sets of simulated regulated streamflows are similar to those indicated for the unappropriated flows, and again, these deviations are the result primarily of the lower diversions associated with the 10-year maximum water use condition. The regulated streamflows, of course, are somewhat greater than the unappropriated flows because they do not reflect all of the streamflow depletions associated with all water rights.

5.2.4 Flow-Duration Curves

When a time series of hydrologic events, in this case annual streamflows at a location, are arranged in order of their magnitude, the percent of time that each annual streamflow value is equaled or exceeded can be computed. A plot of the annual streamflows versus the corresponding percentages of time is known as a flow-duration curve. Flow-duration curves have been computed for the control points listed in Table 5-2. These results are presented in Appendix W in Figures W-1 through W-5. Curves are shown for naturalized flows and for regulated flows as simulated with the WRAP model for Run 1 (fully authorized diversions with full return flows), Run 3 (fully authorized diversions with no return flows, i.e. 100% reuse), and Run 8 (maximum use for the last 10 years and existing return flows, i.e. current conditions).

Comparison of these curves can be used to assess the cumulative impact of appropriations on regulated streamflows. As can be seen from the curves, Run 3 generally results in the greatest reduction in streamflows from the naturalized conditions. This is to be expected because fully authorized diversions are modeled and return flows are eliminated. The Run 1 flows are greater than naturalized flows in Figure W-1 because of the effects of constant return flows that are specified in the WAM upstream of the Silver gage. These return flows reflect current conditions and were not in existence during the early part of the simulation period. Also, in Figure W-1, Run 8 flows are the lowest because the water quality diversions made by CRMWD above this point were given the most senior priority date in the basin for this run. In Figure W-5, the Run 1 and 8 flows exceed the naturalized flows because of the significant amount of rice irrigation return flows that are discharged into the San Bernard Basin from the Colorado Basin.

5.2.5 Reservoir Firm Yield Analyses

The firm annual yield for all major reservoirs, or reservoir systems, in the Colorado/Brazos-Colorado Basin has been determined consistent with the guidelines set forth in the "WAM Resolved Technical Issues No. 10 – Model Runs" (see Section 5.1.4). As directed, the firm yield has been determined only for those reservoirs that experienced shortages in the Run 3 simulation. For the reservoirs that do not exhibit shortages, the firm annual yield has been identified as the "permitted firm yield." Table 5-4 summarizes the results from the firm yield analyses for all major reservoirs, or reservoir systems, in the Colorado/Brazos-Colorado Basin. The yield of some of the reservoirs has not been determined because these reservoirs are operated solely for water quality control purposes.

When operating the WAM to calculate the firm annual yield of any one of the reservoirs, or reservoir systems, the specified demand(s) on the reservoir, or reservoir system, was reduced from its authorized amount until no shortages occurred. This amount of specified demand has been

TABLE 5-4
SUMMARY OF RESERVOIR FIRM YIELD ANALYSES

RESERVOIR	AUTHORIZED CONSERVATION STORAGE acre-feet	AUTHORIZED DIVERSION AMOUNT acre-feet/year	FIRM YIELD DIVERSION AMOUNT acre-feet/year	YEAR OF MINIMUM STORAGE	NOTE REF.
Lake J.B. Thomas & E.V. Spence Reservoir System	204,000/488,760	34,573	100	1957	
Lake Colorado City	29,934	5,500	0	1974	
Mitchell Co., Red Draw & Barber Reservoirs System	27,266/8,538/2,500	8,427	n/a	n/a	1
Natural Dam Lake, Sulphur Draw Reservoir & Red Lake Reservoir System	54,560/7,997/9,150	2,500/2,500	n/a	n/a	2
Champion Creek Reservoir	40,170	6,750	10	1957	
Twin Buttes Reservoir & Lake Nasworthy System	186,200/12,500	54,000	10	1957	
O.C. Fisher Lake	80,400	80,400	0	1957	
Oak Creek Reservoir	30,000	10,000	5	1957	
Lake Winters (Elm Creek)	8,374	1,360	0	1955	
Ballinger Municipal Lake	6,050	1,685	30	1954	
O.H. Ivie Reservoir	554,340	113,000	113,000	n/a	3
Lake Clyde	5,748	1,200	0	1951	
Hords Creek Lake	7,959	2,240	0	1957	
Lake Coleman	40,000	9,000	5	1957	
Lake Brownwood	114,000	29,712	29,712	n/a	3
Brady Creek Reservoir	30,000	3,500	0	1957	
Buchanan/Travis System	992,475/1,170,752	- -	560,313	1957	4
Inks Lake	17,545	0	n/a	n/a	5
Lake LBJ	138,500	15,700	15,700	n/a	6
Lake Marble Falls	8,760	0	n/a	n/a	5
Lake Austin (w/o B-T Backup)	21,000	271,403	22,000	n/a	
Lake Austin (w/ B-T Backup)	21,000	271,403	190,300	n/a	
Decker Lake	33,940	16,156	1,075	1957	
Lake Bastrop	16,590	10,750	10,750	n/a	6
Fayette (Cedar Creek) and	71,400/46,600	38,101	38,101	n/a	6

Baylor Creek Reservoirs					
Eagle Lake	9,600	0	n/a	n/a	7
STP Reservoir (w/o B-T Backup)	202,600	102,000	43,050	n/a	

NOTES:

1 Reservoirs are combined in the WAM and operated as a system for water quality control (see Section 4.2.3.5.3).

2 Reservoirs are operated only for water quality control and are not included in the WAM (see Section 4.2.3.5.3).

3 Authorized diversion amount is firm without shortages; therefore, the Firm Annual Yield is the "Permitted Firm Yield".

4 Firm Annual Yield has been calculated according to procedures in the Water Management Plan (see Section 5.2.5.1).

5 Reservoir has no direct consumptive demand and is operated as a constant-level reservoir.

6 Authorized diversion amount is firm without shortages due to backup from the Buchanan/Travis reservoir system; therefore, the Firm Annual Yield is the "Permitted Firm Yield", which is equal to the authorized diversion amount.

7 Reservoir has no direct consumptive demand and is operated only in conjunction with LCRA's Lakeside irrigation diversion.

taken to represent the firm annual yield of the reservoir, or reservoir system. With this amount of demand, virtually no storage remains in the reservoir, or reservoir system, at the end of one month during the critical drought period. The year during which this minimum storage condition occurs for each reservoir, or reservoir system, is indicated in Table 5-4. As shown, the critical drought period for most of the reservoirs occurs during the 1950's.

The yield values for some of the individual reservoirs reflect the availability of backup water from the Buchanan/Travis reservoir system. These reservoirs include Lakes LBJ, Marble Falls, Austin and Bastrop and Cedar Creek and Baylor Creek Reservoirs. The inclusion of the backup water in the yield of these reservoirs is considered to be appropriate because their respective demands, and in some cases their storage, are authorized to be supplemented with water from the Buchanan/ Travis reservoir system under the Water Management Plan for the Lower Colorado River Basin.

The yield for Lake Austin is specified in Table 5-4 both with and without backup water from the Buchanan/Travis reservoir system because Lake Austin does not appear to be authorized to use the system backup water for storage; hence, without the system backup water, the yield of Lake Austin is based only on the availability of run-of-the-river inflows. With the system backup water,
the yield of Lake Austin represents the available supply of water for the City of Austin water rights that withdraw from Lake Austin, i.e., Water Right Nos. 61405471 and 61405489.
The yield for the STP Reservoir as specified in Table 5-4 does not reflect the availability of any backup water from the Buchanan/Travis reservoir system. In accordance with the STP water right and as modeled in the WAM, run-of-the-river diversions from the Colorado River are used first to satisfy the STP demand (102,000 acre-feet/year) and to fill the STP Reservoir. When the available run-of-the-river flows are not sufficient to meet the STP demand, withdrawals are made from the STP Reservoir. When the available storage in the STP Reservoir is not sufficient to meet the STP demand, then backup water is available from the Buchanan/Travis reservoir system to satisfy the demand. No system backup water is used to fill the STP Reservoir. Hence, the yield value reported in Table 5-4 reflects only the supply of water available from run-of-the-river flows, since it represents the maximum amount of water that can be withdrawn from the STP without causing its storage to be reduced to zero.

The system yield for the Buchanan/Travis reservoir system has been calculated using the procedures set forth in the Water Management Plan for the Lower Colorado River Basin (WMP). These procedures are described in the following section.

5.2.5.1 Buchanan/Travis Reservoir System Yield

As stipulated in the WMP, the firm annual yield of the Buchanan/Travis reservoir system is based on the sum of the releases or diversions or other commitments made from the reservoirs for either providing backup water or supplying water directly to satisfy the specific demands of different entities and uses during the occurrence of the critical drought. These various entities and uses as identified in the WMP have been previously listed in Table 4-9, and the portions of the yield attributed to each of these individual entities and uses as determined with the WAM and as presented in the current version of the WMP are listed below in Table 5-5.

As previously described in Section 4.2.3.5.2, all of the elements of the WMP, including all of the commitments for backup water from the Buchanan/Travis reservoir system, have been described and modeled in the WAM to the extent possible based on interpretations of the provisions of the WMP and the associated water rights documents as agreed upon with TNRCC staff. The Buchanan/Travis reservoir system yield commitments determined with the WAM have not been constrained by the corresponding yield commitments specified in the WMP; instead, the criteria representing these commitments have been incorporated into the WAM, and new quantities for these commitments have been computed based on the Run 3 assumptions and simulations. The values of these commitments as presented in Table 5-5 represents annualized amounts based on the total quantities of water released or diverted from the Buchanan-Travis reservoir system for each of the entities or uses over the term of the critical drought period. The critical drought period for the Buchanan-Travis reservoir system as determined for Run 3 with the WAM extends over 14.5 years from November of 1942 to June of 1957 (spill to spill).

The final value for the total firm annual yield of the Buchanan-Travis reservoir system was established by adjusting the Uncommitted System Yield amount. Successive simulations with the WAM using Run 3 were made until no shortages occurred in any of the demands associated with the water supply commitments included in the WMP. As noted in Table 5-5, this resulted in the Uncommitted System Yield being reduced to a value of 57,168 acre-feet per year. With this level of demand, the storage remaining in the Buchanan-Travis reservoir system during the critical drought period was virtually zero.

There are several fundamental reasons that the firm annual yield values for the Buchanan/Travis reservoir system as derived with the WAM and as reported in the WMP are different. For one thing, the WAM is based on independently-derived naturalized streamflows at 45 primary control points located throughout the Colorado/Brazos-Colorado Basin, and these naturalized streamflows have been distributed by the WAM to provide local streamflows for every water right in the basin for purposes of the water availability simulations. The WAM takes into account the demands for all existing water rights in the Colorado/Brazos-Colorado Basin in the water availability analyses, including consideration of individual priority dates. It is not clear to what extent the demands of all senior water rights were accounted for in the yield analyses performed by the Lower Colorado River Authority (LCRA) pursuant to development of the WMP, but it is likely that different procedures were used. Another significant factor is that all return flows are assumed to be zero under the Run 3 conditions used for determining reservoir yields with the WAM. This apparently is not the case for the WMP yield determinations; although, without return flows, the WMP yield values would be even lower. Information in the

WMP indicates that 149,800 acre-feet per year of return flows from the City of Austin were included in the WMP yield analyses.

TABLE 5-5
COMPONENTS OF YIELD FOR THE BUCHANAN/TRAVIS RESERVOIR SYSTEM

ENTITY OR USE	FIRM YIELD COMMITMENT	
	BASED ON WAM Ac-Ft/Yr	BASED ON WMP Ac-Ft/Yr
O. H. Ivie Reservoir	165,000	90,546
Backup of City of Austin' Water Rights	138,133	148,546
Highland Lakes Contracts	85,789	85,789
LCRA Cooling Water	64,494	63,851
South Texas Nuclear Project	40,529	5,680
Instream Flow Requirements	9,201	12,860
Bay and Estuary Freshwater Inflow Needs	*	3,090
Total System Yield Commitment	503,146	410,362
Uncommitted System Yield	57,168	125,950
Total System Yield	560,313	536,312

* Releases from system storage are not made for Bay and Estuary Freshwater Inflow Needs according to
the provisions of the Water Management Plan for the Lower Colorado River Basin.

As indicated in Table 5-5, the effect of O. H. Ivie Reservoir on the yield of the Buchanan/Travis reservoir system also differs between the WAM results and those presented in the WMP. As described previously, O. H. Ivie Reservoir is modeled in the WAM using a series of TO cards which enable it to store water that Lake Buchanan would have otherwise been entitled to store. Therefore, two different Ivie Reservoir depletions are made in the WAM: one at an “old” priority date immediately senior to that of Lake Buchanan (3/6/1929) sized to equal the minimum of the drawdown of either Lake Buchanan or Ivie Reservoir, and the other at Ivie’s "normal" priority date that was based on the filing date of the application for O. H. Ivie Reservoir (2/21/1978). In an effort to determine the true effect that O .H. Ivie Reservoir has on the yield of the Buchanan/Travis reservoir system, the yield of the Buchanan/Travis reservoir system has been computed with and without the Ivie Reservoir "senior to Buchanan" depletion. In addition, in an effort to determine the increased firm yield that O. H. Ivie Reservoir realizes by being authorized the "senior to Buchanan" depletion, the firm yield of O. H. Ivie Reservoir also has been computed with and without the "senior to Buchanan" depletion.

Based on calculating the Buchanan-Travis reservoir system yield with and without the Ivie Reservoir "senior to Buchanan" depletion, the effect of O. H. Ivie Reservoir on the firm yield of the system is on the order of 165,000 acre-feet per year, and this is the amount of system yield commitment that has been assigned to O. H. Ivie Reservoir in Table 5-5. This amount differs considerably from that reported in the WMP, and the reasons for this difference are not clearly known. Certainly, the many different assumptions and procedures that characterize the different approaches used for determining system yield account for much of the difference in the two Ivie yield commitments. One point to note is that the demand associated with Ivie Reservoir (113,000 acre-feet/year), as simulated with the WAM based on Run 3 assumptions, is never shorted. Furthermore, during the critical drought period, 379,104 acre-feet of water remain in storage in Ivie Reservoir. It is not clear whether this stored water represents additional yield for Ivie Reservoir or yield that should be credited to the Buchanan-Travis reservoir system, but certainly it represents an additional supply of available water.

Results from the WAM with the Ivie Reservoir’s “old” priority date disabled indicate that the firm annual yield of Ivie Reservoir is 4,700 acre-feet. Hence, since the authorized diversion amount for Ivie Reservoir of 113,000 acre-feet per year is firm with the “old” priority date in effect, the additional yield realized by Ivie Reservoir as a result of the ability to store water senior in priority to the Buchanan-Travis reservoir system is 108,300 acre-feet per year. This, of course, does not include the amount of water left in storage in Ivie Reservoir during the critical drought period (379,400 acre-feet) with the “old” priority date in effect. Annualizing this amount of stored water over the 14.5-year duration of the critical drought increases the yield of Ivie Reservoir to about 140,000 acre-feet per year. It is also interesting to note that with the “old” priority date disabled, all of the WMP system demands were fully satisfied with no shortages, and with approximately 320,000 acre-feet of water left in storage in the Buchanan-Travis reservoir system.

5.2.5.2 Yield Comparisons With Other Studies

The most recent source of yield information for the major reservoirs in the Colorado-Brazos-Colorado Basin, other than the Buchanan-Travis reservoir system, is the Region F Regional Water Plan (2001), which encompasses 32 counties in West Texas, including the upper portion of the Colorado River Basin. Table 5-6 lists the firm annual yield amounts reported in the Region F Plan for specific reservoirs, or reservoir systems, in the upper Colorado River Basin for year-2000 conditions. Also included in the table are the yield values determined in this study based on the WAM Run 3 simulations.

As shown, there are significant differences in the yield figures from the Region F study and from the WAM simulations. All of the Region F yield values are considerably higher. Generally, none of these reservoirs, with the exception of Ivie and Brownwood, have been shown to have any significant amount of yield based on the WAM simulations. The reasons for these differences very likely relate to the assumptions made regarding reservoir inflows. As noted previously, the WAM accounts for the demands associated with all water rights in the Colorado River Basin, including consideration of priority dates. It is not clear from the Region F Plan what assumptions were made in this regard in determining the reported yield amounts, but it is noted in the Plan that thorough analyses of water availability, particularly with regard to run-of-the-river diversions, their respective critical drought periods. This suggests that the reservoirs are considerably oversized relative to their associated inflows.

The Texas Department of Water Resources (TDWR) also investigated water availability in the Colorado River Basin in the 1970’s and, as part of that study, analyzed the ability of the reservoirs in the upper basin to meet their projected demands. This work is published as TDWR Report LP-60 (1978). Although yields for these reservoirs were not determined in the LP-60 study, the results from reservoir analyses indicate significant shortages with respect to meeting year-2030 projected demands for J. B. Thomas, E. V. Spence, Twin Buttes, and O. C. Fisher Reservoirs (without O. H. Ivie Reservoir in operation). Simulated storage in the reservoirs also was indicated to be low most of the time.

5.3 COMPARISON TO EXISTING RIVER BASIN MODEL

The TNRCC Legacy model for the Colorado Basin is the only other river basin or water rights model for the Colorado/Brazos-Colorado Basin that is known to exist within the public domain. However, this model needs additional maintenance to bring it to the level of the new WRAP model, particularly with regard to the water rights accounted for and hydrologic conditions over the past 20 to 30 years. Consequently, no comparisons can be effectively made using the results generated with the WRAP model.

TABLE 5-6
COMPARISON OF RESERVOIR FIRM ANNUAL YIELD AMOUNTS

RESERVOIR	FIRM ANNUALYIELD AS REPORTED IN REGION F PLAN acre-feet/year	FIRM ANNUAL YIELD BASED ON WAM SIMULATIONS acre-feet/year
Lake J.B. Thomas	9,900	n/a
E.V. Spence Reservoir	38,776	n/a
O.H. Ivie Reservoir	96,169	113,000
Lake J.B. Thomas, E.V. Spence & O.H. Ivie Reservoir System	144,845	113,100
Lake Colorado City	4,550	0
Champion Creek Reservoir	4,081	10
Oak Creek Reservoir	5,684	5
Ballinger Municipal Lake	3,566	30
Lake Winters (Elm Creek)	1,407	0
O.C. Fisher Lake	2,973	0
Twin Buttes Reservoir	8,900	n/a
Lake Nasworthy	7,900	n/a
Twin Buttes Reservoir & Lakes Nasworthy and Fisher System	21,900	10
Lake Coleman	8,822	5
Hords Creek Lake	1,425	0
Lake Brownwood	41,800	29,712
Brady Creek Reservoir	2,252	0

5.4 FACTORS AFFECTING WATER AVAILABILITY AND MODELING RESULTS

As described in Section 2.5, the single issue of most concern with regard to the water availability analyses performed for the Colorado/Brazos-Colorado Basin and the results from the WRAP model relates to the accuracy of the naturalized streamflows that have been used in the calculations. This includes inaccuracies in the USGS streamflow gaging data, reservoir elevation or storage records and area-capacity data, estimation of drainage areas using GIS procedures, locations of control points on smaller tributaries, reported and estimated diversions and return flows, and channel losses.

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

Water quality diversions made by Colorado River Municipal Water District in the upper basin to control salinity in E.V. Spence Reservoir have been given their actual priority date in Runs 1-7. This results in that water being passed downstream frequently and being made available to senior water rights. But in Run 8, they were given a priority date senior to every water right in the basin. That was done because in practice, those diversions are made without regard to priority. The high salinity water that is diverted would be unwanted by downstream users. Because of this, Runs 1-7 result in more water being available downstream than would be the case in reality.

Other factors that may have an affect on the water availability results for the Colorado/Brazos-Colorado Basin are the various assumptions that are inherent in the WAM as listed and described in Section 4.3.

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

The following input records were used in the Colorado/Brazos-Colorado WRAP model and depending upon the change may or may not require updating:

<u>Records for defining control point connectivity and other related information</u>

CP - Control Point connectivity and references naturalized flows and evaporation data
FD - Flow Distribution specifications transferring flows from gaged to ungaged control points
WP - Watershed Parameters used in flow distribution

CI, FA-Constant Inflows or outflows and Flow Adjustments, entering or leaving system
RF - Return Flow factors

Records used for characterizing water rights information in WRAP

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

Records for defining reservoir-related information

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

The intent of this section is to assist the future modeler in modifying or updating the WRAP files in this report as a result of future changes to the Colorado/Brazos-Colorado River Basin. Any future water right application requires obtaining watershed parameters for the new water right and making changes to the WRAP data files. This section defines the required steps for updating the WRAP model, however the WRAP Users Manual should be consulted for a thorough understanding of each record and associated variables. This section assumes the future modeler has a general understanding of WAM issues and concepts. There are multiple versions of WRAP, and future modelers should reference the "Reference and Users Manual for the Water Rights Analysis Package (WRAP)," Third Edition, July 2001 when updating Colorado/Brazos-Colorado WAM files.

There are two fundamental steps in developing and executing a water availability model for the Colorado/Brazos-Colorado River Basin: 1) obtaining data necessary for simulating hydrology, and 2) obtaining and developing data representing water rights. WRAP has the capability to distribute flow from gaged to ungaged control points in addition to performing the water rights simulation. Using the example of an application for a new water right, the following sections outline those procedures to be followed when a Colorado/Brazos-Colorado WRAP model is to be updated with a single diversion location at a new secondary control point. The procedures describe the steps to update the model for Run 1. These procedures will need to be repeated for additional runs as necessary.

The hypothetical new water right will have a diversion point H11070, located immediately downstream of control point H20000 (PR-FR). The water right is for the diversion of 100 acre-feet per year for irrigation, with a priority date of December 31, 2001. The water right does not include the right to impound water. The watershed parameters for the new secondary control point have been obtained and they are: total drainage area of 370 square miles, a curve number of 61.2 and mean precipitation of 28.99 inches. The drainage area ratio method will be used to distribute flows to this control point, but the inclusion of the curve number and precipitation data will allow the NRCS Curve Number method to be used in the future.

5.5.1 Updating the Hydrology Data

WRAP develops the hydrology records (IN and EV) for secondary control points from given IN and EV records at primary control points as necessary to run the model simulation. All hydrology parameters are stored in the following files: CO1.DAT contains control point connectivity data, CO1.DIS contains watershed parameters and other data for distributing flow from gaged to ungaged control points, CO1.INF contains the naturalized streamflows for primary control points, CO1.EVA contains the evaporation data for selected control points. Because the new water right is at a secondary control point, additional hydrology will be simulated at this point, based on the existing primary control points. Thus the files to be updated are the *.DAT and *.DIS files, using the following procedures:

1. In the file CO1.DAT, locate within the CP records, the existing control point (H20000, PR-FR) which is upstream of the new control point. The next control point in the CP records is H11060. Thus insert a new CP record between H20000 and H11060. The variables in the new CP record should be set using the following values:

VARIABLE	VALUE	COMMENTS
CD	CD	Record identifier
CPID(cp,1)	H11070	Control point identifier
CPID(cp,2)	H11060	Downstream control point identifier
CPDT(cp,1)	blank	Default factor of 1.0 by which inflows are multiplied
CPDT(cp,2)	blank	Default factor of 1.0 by which evaporation rates are multiplied
INMETHOD	7	Naturalized flows at secondary control point are synthesized using drainage area ratio method
CPIN	blank	IN (inflow) records based on INMETHOD value
CPEV	G10010	Control point from which EV (evaporation) records are used
EWA	blank	Default net evaporation-precipitation adjustment set by JD record field 10 is used
CL	blank	Default channel loss factor of 0.0 is used for stream reach below point
INWS	blank	Parameters on the WP record represent the total watershed (not incremental watersheds)

2. For the CP record of H20000, change the downstream control point, CPID(cp,2) from H11060 to H11070, in order to reflect the change in model configuration (connectivity). If

there were additional control points that were located with H11060 as their downstream control points, those CP records would require changing as well.

3. In the CO1.DIS file, insert a new FD record at the same relative location as the new CP record was inserted (between the same two control points). Because H20000 is a primary control point, it will not be found in the FD records, thus insert the new record before H20020.

4. For the new FD record, enter the ID as H11070 and the DSG (downstream gaged (primary) control point) as H10000. The variable NG should be set to "1" as there is one primary control point upstream of H11070 that is also upstream of H10000. The UGID(I) variables are for identifying all primary control points upstream of H11070. Thus enter H20000 for UGID(1). The remaining UGID(I) variables should be left blank.

5. In the CO1.DIS file, insert a new WP record at the same relative location as the new CP record.

6. For the new WP record, enter the ID as H11070. For variable DA, the drainage area of 370 square miles should be entered. For the curve number variable, CN, enter the value 61.2. For the mean precipitation, MP, enter the value 28.99. Leave the drainage area factor, DAF, blank, as the value for drainage area is already in square miles.

5.5.2 Updating the Water Rights Data

WRAP performs the water rights simulation for the modeled configuration. The water rights data is stored in the CO1.DAT file. The following changes should be made to the *.DAT file:

1. Add a new set of UC records for the monthly use factors, to be referenced in the WR card. If an existing set of UC records is representative of the new water right, a new set of UC records is not required. For the example, the existing UC record “IRR-H” will be applied.

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

3. Add a new set of CI records to represent any new constant inflows at the new control point. For the example, no new CI records are necessary.

4. Add a new WR record to represent the new water right. The variable CP should be set to the new control point, H11070. The variable AMT is the authorized diversion amount 100 acre-feet per year for the new water right. For the variable USE, enter the value “IRR-H” to reference the monthly use coefficients for irrigation in subwatershed H. The variable WRNUM(wr,7) is the priority date of the new water right, 20011231. The variable WRNUM(wr,5) should be set to 1, as the water right may make diversions from streamflows. The variable WRID(wr) should be set as 114xxxxx001, a unique number for the diversion location and the water right, where 1 refers to water right type (permit), 14 is the basin number (14 for Colorado), xxxxx is the permit number (begins with 0, unless greater than 9999), and 001 is the TNRCC feature number or use type (typically 001, 002, etc., if there

are multiple features, such as diversion point and impoundment or multiple uses). Separate WR records should be created for each use type. The variable WRIDS(wr,1) should be the same value as WRID(wr) less the last three numbers. This is used to group water right features under one water right for output purposes. WRIDS(wr,2) should be set to the downstream primary control point, H10000 in this case, to be able to group output by primary control point. Consult the WRAP users manual for more information on using these features.

5. A new WS record may be added if there is a reservoir at the new control point location. The reservoir storage-area relationship may be described using coefficients in the WS record, or using a set of SA and SV records. For the example, no reservoir is included.

The executable WRAP-SIM program “SIM.EXE” must be run separately for each model scenario. The model output can be examined using the TABLES program, “TAB.EXE,” which will provide reliability information for the new water right.

6.0 SUMMARY AND CONCLUSIONS

The Texas A&M WRAP model has been applied to the Colorado/Brazos-Colorado Basin in Texas to determine water availability. All water rights in the basin have been modeled for a 59-year period of naturalized streamflows from 1940 through 1998 under eight different scenarios (referred to as "Runs"). The runs consist of three basic sets of conditions: (1) fully authorized diversion amounts and varied return flow amounts (Reuse Runs), (2) varied diversion amounts and varied return flow assumptions (Cancellation Runs), and (3) approximate current diversion and return flow conditions with year-2000 area-capacity relationships for reservoirs (Current Conditions Run). Special conditions reflecting environmental flow requirements have been included in all model runs where applicable.

The primary conclusions from this water availability investigation and modeling effort for the Colorado/Brazos-Colorado Basin are as follows:

1) The total drainage area of the Colorado River basin comprises 42,344 square miles, of which approximately 11,400 square miles are probably non-contributing. The Brazos-Colorado Coastal Basin borders the Colorado River Basin to the east and has a total drainage area of 1,850 square miles. Austin is the largest city in the Colorado/Brazos-Colorado Basin. The climate varies widely throughout the basin, with precipitation ranging from about 12 inches in the extreme western portion to 44 inches at the coast.

2) There are 1,287 water rights in the Colorado/Brazos-Colorado Basin. The total amount of authorized diversions for these water rights is approximately 3.3 million acre-feet per year. There are 31 major reservoirs in the basin, defined as having a conservation storage capacity of 5,000 acre-feet or greater.

3) Shortages occur frequently for many water rights, particularly in the upper basin where precipitation is much lower and drainage areas are smaller. In particular, relatively senior priority dates associated with Lakes Buchanan and Travis, and with O.H. Ivie Reservoir as modeled in accordance with the LCRA Water Management Plan for Lower Colorado River Basin, result in most water being required to be passed downstream to these reservoirs, since they are rarely full at the same time. Several lakes in the upper basin are frequently dry.

4) The drought of record at most locations is the drought of the 1950s, and it is significant to note that this drought extends over about 15 years for the Buchanan-Travis reservoir system.

5) Comparison of the WRAP results from the different runs indicates that the effects of varying levels of reuse have some significant impacts on existing

water rights and reservoir storage. This is primarily attributable to the City of Austin's and other dischargers' return flows being fully reused and therefore unavailable to downstream rice irrigators. These irrigation rights are backed up by Lakes Travis and Buchanan, and therefore they make large calls on stored water when the return flows are eliminated. This also causes further calls on upstream flows to refill storage in the lakes.

6) The effects of water rights cancellations under fully authorized conditions are not significant. However, when the use is limited to the maximum use in the last 10 years, there are significant improvements in water availability, particularly from Lake Buchanan upstream. This is because the maximum usages in the last 10 years are generally significantly less than fully authorized amounts. The effects of reservoir sedimentation do not appear to be great.

7) There are virtually no unappropriated flows in the extreme upper basin, and frequent years with no unappropriated flows in the middle basin. There are a few years with no unappropriated flows at the downstream locations, particularly under full reuse conditions. Cancellations increase unappropriated flows slightly. Restricting diversions to the maximum in the last 10 years makes a more significant difference, although there are still periods with none available at most locations.

8) The amount of regulated flows follows a similar pattern to unappropriated flows. The regulated streamflows, of course, are somewhat greater than the unappropriated flows because they do not reflect all of the streamflow depletions associated with all water rights.

9) The firm yield analysis shows that several reservoirs in the upper and middle basin have firm yields at or near zero. The demands on the Buchanan-Travis reservoir system, pursuant to the provisions of the Lower Colorado Water Management Plan, do not exceed the firm yield of the reservoir system.

Submitted to the Texas Water Digital Library on May 23, 2014, by Grant J. Gibson, P.G., Texas Commission on Environmental Quality.