EXECUTIVE SUMMARY

The Texas Natural Resource Conservation Commission (TNRCC) was required by Senate Bill 1 (SB1) of the 75th Texas Legislature to develop new reservoir/river basin simulation models in order to determine water availability in accordance with the Texas Water Code. The objective of SB1 was to create fully documented reservoir/river basin models for 22 of the 23 river basins within Texas by December 2001. The models are to be used and maintained for each basin to facilitate the evaluation of existing permits, approval of permit applications, and development or review of overall management strategies. In December of 2000, the TNRCC authorized KSA Engineers, Inc. to estimate naturalized inflows and develop a water availability model for the Cypress Basin in Northeast Texas.

STUDY OBJECTIVES

The TNRCC, mandated by SB1, is to conduct a water availability analysis to determine the:

- Projected amount of water available for all water rights during extended dry periods.
- Projected amount of water that would be available if cancellation procedures were instigated under the provisions of Subchapter E, Chapter 11, of the Texas Water Code.
- Potential impact of reusing municipal and industrial effluent on existing water rights, instream uses, and freshwater inflows to bays and estuaries.

Nine different scenarios were analyzed in this study to simulate the effects of the above-described parameters. Scenarios 1 through 8 were legislatively mandated, while Scenario 9 is a firm yield analysis of the basin reservoirs. The eight mandated scenarios include: three reuse scenarios, four cancellation scenarios, and one current conditions scenario (which includes term permits). Scenario 9 is performed to determine the firm yield of all permitted reservoirs with capacities greater than 5,000 ac-ft/yr in the Cypress Basin.

CYPRESS BASIN

The Cypress Basin encompasses all or part of 12 counties in Northeast Texas with water flowing from the headwaters in Hopkins, Franklin, Titus, Wood, Morris, Cass, Panola, Upshur, Gregg, and Harrison Counties, through Camp and Marion Counties to the Red River in Louisiana. The basin has a drainage area of approximately 2,812 square miles and has one major stream, Cypress Creek. Cypress Creek has two (2) major tributaries, Black Cypress Bayou and Little Cypress Bayou.

The current population in the Cypress Basin is about 134,000. From 1996 to the year 2050, the population of the basin is projected to increase from 131,621 to 147,342, representing an increase of 15,721 persons, or 12%. Major population centers in the basin and the 1990 population estimates include all or portions of the cities of Marshall (25,316), Mount Pleasant (13,790), Atlanta (6,342), Gilmer (5,815), Pittsburg (4,454), Winnsboro (3,399), Daingerfield (2,881), Linden (2,465), Hughes

Springs (2,148), and Waskom (1,890). *Reference: North East Texas Regional Water Planning Group – Region D, "Adopted Water Plan", January 5, 2001.*

There are 81 separate existing water rights located within the Cypress Basin. Locations of individual water rights are identified on the map in Appendix K, and are listed with general descriptive information, including permittee name and authorized diversion amounts, in Appendix A. The total authorized diversion amount for these water rights is approximately 449,019 ac-ft/yr as shown below in Table I.

Table I Authorized Diversions

Use Category	Authorized Diversion ac-ft/yr
Municipal	114,247[a]
Industrial	331,877[b]
Irrigation	2,730.31
Mining	165.21
Recreational	0
Other	0
Total	449,019.52

[a] Includes all WR 5272 as municipal use (permit allows use to be municipal and/or industrial).
[b] Includes APP 4573 & APP 4349 as their full amount (modeled only consumptive amount).

There are nine (9) existing major reservoirs in the Cypress Basin with capacities ranging from 10,100 to 252,040 acre-feet. Locations of major reservoirs in the Cypress Basin are shown in Appendix K. The Cypress Basin's total permitted reservoir storage capacity is 708,960 acre-feet.

PROCEDURES

Procedures and criteria for undertaking the water availability analyses for all basins in Texas have been developed by the Water Availability Modeling (WAM) Management team, consisting of representatives from the TNRCC, Texas Parks and Wildlife Department (TPWD), and the Texas Water Development Board (TWDB). These procedures include the development of naturalized streamflows from historical hydrological information, utilization of the Water Rights Analysis Package (WRAP) program, and adhering to the Texas prior appropriation system, the Texas Water Code and water management and regulatory policies set by the TNRCC.

Naturalized streamflows are the flows that would have occurred in the absence of human activities such as reservoir development, diversions, and return flows. Naturalized flows are used so that historical diversions, impoundments, and returns do not affect the water availability analysis. Naturalized flows at primary control points are based on historical hydrologic records, adjusted to remove the impact of human activities. The flows are used as input to the water availability model, which simulates the operation of existing water rights considering their location, characteristics, and priority under Texas water law. Naturalized streamflows were developed for selected USGS gage locations as well as specific reservoir sites in the Cypress Basin for each month over a 51-year historical period of record. The locations where naturalized streamflows were developed are called primary control points, and basically describe the spatial configuration of the river basin. Section 4.2.1 of the report gives a more detailed explanation of primary and secondary control points in WRAP (VER 12/01).

Water availability calculations were performed using the WRAP (VER 12/01) model, developed by Dr. Ralph A. Wurbs at Texas A & M University. The WRAP (VER 12/01) model incorporates the Prior Appropriation Doctrine and was selected by TNRCC in 1998 to simulate the water availability in Texas. WRAP (VER 12/01) has been used in a wide variety of different types of water rights, including municipal, industrial, irrigation, and recreational use, throughout Texas. As of December 31, 2001, all basins, except for the Rio Grande, have been modeled using WRAP (VER 12/01). WRAP (VER 12/01) utilizes monthly time steps, historical hydrologic river basin characteristics, and the specific water right information to determine the available water. The model performs a sequential monthly water volume accounting computation by determining if TNRCC permitted water diversions can be made at a particular location during a specified hydrologic period of analysis under given historic hydrologic conditions. The model is set up to allow water rights that have seniority the first right at diversion ("first in time, first in right").

The specific steps taken to develop the Cypress Basin Water Availability Model were to collect, analyze and compile data needed for input into WRAP (VER 12/01). Data required for input into the model include primary and secondary control points, naturalized flows, classified stream segments, evaporation, water rights information, reservoir area-capacity curves, return flows for facilities permitted above one million gallons per day (MGD), locations of water rights and return flows, and water use demand patterns. Nine scenarios were analyzed using WRAP (VER 12/01) to determine the effects of the parameters as outlined in the study objectives.

The principal results from the water availability analyses are:

- Reliability of existing water rights
- Monthly estimates of unappropriated water that would be available for diversion and/or storage.

The results of the water availability analysis performed for varied cancellation and reuse policies satisfy the requirements of SB1. Results presented in this draft report are only a partial summary of the complete output generated by WRAP (VER 12/01). The complete water availability output for existing water rights in the Cypress Basin is available from the TNRCC.

Existing data on the Cypress Basin are limited prior to 1948; therefore, this study will use hydrologic data from January 1948 through December of 1998 as the period of record. This period of record was selected because sufficient data are available to make the modeling effort reliable and because it encompasses the droughts periods including 1951-1956, 1963-1964, 1965-1967, 1980, 1984, 1988, and 1996.

RESULTS

Reliability results from the water availability analysis, for the eight base scenarios for the Cypress Basin, are presented in Tables ES-1 through ES-3 at the end of this Executive Summary. These tables list all water rights in the Cypress Basin with authorized diversions and give a unique identification number for each water right. In many cases, a water right has multiple entries which result from the water right having multiple use types, multiple diversion locations with a specified diversion amount at each location, and/or multiple priority dates, all of which are used in the WRAP (VER 12/01) model to simulate the written permit. The result tables list the authorized diversion amount, the simulated mean annual shortage, and the period and volumetric reliability for the 51-year period of record. Period reliability, expressed in percent, is defined as the ratio of number of months for which no shortages occurred to the total number of months in the simulation period. Volumetric reliability, expressed as a percent, represents the ratio of the mean actual annual diversion to the corresponding authorized annual diversion amount. For Tables ES-2 and ES-3, an #N/A indicates that the diversion amount was not used for that identification number. The non-use of the diversion amount could be from a partial or total cancellation of that portion of the water right or due to a grouping of the total amount of the water right at one identification number.

There are nine existing permitted reservoir projects within the Cypress Basin with capacities over 5,000 acre-feet (ac-ft). These reservoirs are Lake Monticello, Lake Bob Sandlin, Johnson Creek Reservoir, Lake Cypress Springs, Lake O' the Pines, Ellison Creek Reservoir, Caddo Lake, Welsh Reservoir, and Lake Gilmer. Firm yield analyses were only performed on those permitted reservoirs with impoundments greater than 5,000 ac-ft. A detailed description of how the firm yield analysis was performed is given in Section 5.1.4. and the firm yield results are given in Table 17, Section 5.2.4.

CONCLUSIONS

The WRAP (VER 12/01) model was used to determine the water availability in the Cypress Basin in Texas. All of the 81 water rights in the basin were included in the model. Water availability was calculated in three basic scenarios: (1) Reuse Runs (full authorized diversions with varying return flow amounts), (2) Cancellation Runs (varying diversion and return flow amounts based on cancellation of water rights), and (3) Current Conditions Runs (maximum use diversions with return flows using year-2000 area-capacity reservoir relationships. A detailed description of these scenarios is given in Section 5.1. All scenarios utilized:

- 51-year period of naturalized flows (1948 thought 1998).
- Water rights information for all water rights issued by the TNRCC through February 1999.

The WR, WS, and OR records in WRAP (VER 12/01) characterize the written permit and other pertinent information required for input into the computer model. No system operations were modeled unless authorized in the written permit. Nine scenarios were performed: eight base scenarios and one basin specific scenario (firm yield). The primary conclusions of this water availability study of the Cypress Basin are as follows:

- The Cypress Basin watershed area is approximately 2,812 square miles. There are 81 water rights with approximately 449,019 ac-ft/yr authorized annual diversions.

- The majority of the reliabilities for the water rights in Scenario 1 were above 90%. However, the majority of these rights did have small amounts of shortages associated with these high percentages.

- Comparisons of the three reuse scenarios show that varying levels of wastewater reuse do impact water supply. The reliability of a water right generally decreases as the level of reuse increases. Reuse of wastewater decreases the amount of storage in the reservoirs as well (See Figures R-1 through R-4 in Appendix R).

- Hypothetical cancellation of water rights has a negligible effect on the reliability of water supply for most rights in the basin. The magnitude of simulated cancellations totaled 3,142 ac-ft/yr, and accounts for only 1 % of the full authorized diversion amount. The majority of the simulated cancellations occurred in water rights whose reliability was less than 100%.

- Scenarios that utilize the ten-year maximum use as the diversion amount can significantly affect the amount of unappropriated flow and reservoir storage because the actual historical diversions during the last ten years were substantially less than the fully appropriated amounts. The cumulative diversion amount used in these runs (Scenarios 5 and 7) was 90,569 ac-ft/yr. The cancellation runs with this large change in diversion amounts had a greater impact on the water availability than the cancellation runs with full authorized amounts (Scenarios 4 and 6).

- Simulated results from the WRAP (VER 12/01) model indicate that there are quantities of unappropriated and regulated flow on the main stem of the Cypress River during most of the period of record. The largest amounts of unappropriated and regulated flows in Scenarios 1, 3 and 8 are shown in Figures R-61 and R-62. In general, wastewater reuse has minimal effect on unappropriated and regulated flows because there are few significant return flows in the basin. Diversions in Scenario 8 (maximum ten year use) created the largest difference in unappropriated and regulated flows. Future appropriations will be subject to environmental flow restrictions pursuant to Chapter 11 of the Texas Water Code.

    - Out of the nine major reservoirs in the Cypress Basin, only Lake Bob Sandlin was able to meet the full authorized diversions and did not require a yield analysis. The "permitted firm yield" of Lake Bob Sandlin was simply the authorized diversion amount for that reservoir. A firm yield analysis was not performed on Caddo Lake since there are no water rights associated with the reservoir. Firm yields were calculated solely based on the flows from the watershed. No water contracts for additional water supply were included in the analysis. Firm yields calculated in this study are expected to be lower than those yields that were calculated in previous studies. The yields calculated in this study incorporate all water rights in the river basin and therefore must release inflows to fill senior downstream water rights and reservoir storage. Results of previous studies can be viewed in Appendix F.

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1.0 INTRODUCTION

1.1 Description of the Basin

The Cypress Basin is bounded on the north by the Sulphur River Basin, on the west and south by the Sabine River Basin, and on the east by the Texas-Arkansas and Texas-Louisiana borders. The basin encompasses all or part of 12 counties in Northeast Texas with water flowing from the headwaters in Hopkins, Franklin, Titus, Wood, Morris, Cass, Panola, Upshur, Gregg, and Harrison Counties, through Camp and Marion Counties to the Red River in Louisiana. The Cypress Basin has a drainage area of approximately 2,812 square miles and has one major stream, Cypress Creek. Cypress Creek has two major tributaries, Black Cypress Bayou and Little Cypress Bayou. Figure 1 is a map of the Cypress Basin.

Predominate sectors of the basin economy are manufacturing, retail and wholesale trade, mineral production, agriculture, and agribusiness. The current population in the Cypress Basin is about 134,000. From 1996 to the year 2050, the population of the basin is projected to increase from 131,621 to 147,342, representing an increase of 15,721 persons, or 12%. Major population centers in the basin and the 1990 population estimates include all or portions of the cities of Marshall (25,316), Mount Pleasant (13,790), Atlanta (6,342), Gilmer (5,815), Pittsburg (4,454), Winnsboro (3,399), Daingerfield (2,881), Linden (2,465), Hughes Springs (2,148), and Waskom (1,890). (North East Texas Regional Water Planning Group – Region D, "Adopted Water Plan", January 5, 2001.)

Surface water resources supply about 89% of the total basin water needs with ground-water resources supplying the remaining 11%. Manufacturing and stream-electric power generation are the major surface water uses in the basin. In 1990, water used for all purposes within the basin totaled 194,572 acre-feet (ac-ft). This represents a reduction in total basin water use of nearly 55,000 ac-ft below the 1980 total basin water use. This decline was due primarily to a reduction in manufacturing water use of more than 68,000 ac-ft over this same period of time. By far, the largest water use category in the basin is manufacturing, which accounts for nearly 67% of all water used, while municipal water use accounts for about 10%. In 1990, 10,762 ac-ft of water was exported to the Sabine River Basin and 596 ac-ft was exported to the Sulphur River Basin from the Cypress Basin for municipal and industrial purposes. (Water for Texas, 1997).

There are nine existing major reservoirs in the Cypress Basin with capacities ranging from 10,100 to 252,040 ac-ft. The Cypress Basin's total permitted conservation storage is 708,960 ac-ft.

Figure 1 Cypress Basin

Welsh Reservoir is authorized as a 23,590 ac-ft reservoir on Swauano Creek in Titus County. The reservoir is owned and operated by Southwestern Electric Power Company and is used for industrial and recreational purposes (CA04-4576). Impoundment of water began in 1976. Under this water right, Welsh Reservoir can store water diverted from Lake O' the Pines and Cypress Creek for subsequent diversion. Welsh Reservoir is also subject to the 1972 Cypress Basin Operation Agreement. The total permitted diversion from Welsh Reservoir is 11,000 ac-ft/yr.

Monticello Reservoir is authorized as a 40,100 ac-ft reservoir on Blundell Creek in Titus County. The reservoir is owned by the Texas Utilities Electric Company and is used for industrial purposes (CA 04-4563). The dam was completed in the Spring of 1973 and deliberate impoundment began on August 9, 1972. Monticello Reservoir impounds water from both Blundell Creek (not to exceed 25,360 ac-ft/yr) and Cypress Creek (not to exceed 18,000 ac-ft/yr). The total permitted diversion from Monticello Reservoir is 16,300 ac-ft/yr.

Johnson Creek Reservoir is authorized as a 10,100 ac-ft reservoir on Johnson Creek in Marion County. The reservoir is owned by Southwestern Electric Power Company and is used for industrial and recreational purposes (CA 04-4588). The dam was completed on August 4, 1961 and deliberate impoundment began on August 4, 1961. The owners' rights are subject to an agreement for reservoir operations between the Texas Water Development Board, Titus County Fresh Water Supply District No. 1, Franklin County Water District, Northeast Texas Municipal Water District, and Lone Star Steel Company, dated January 1, 1973. The total permitted diversion from Johnson Creek Reservoir is a specified amount of water with a consumptive use not to exceed 6,668 ac-ft/yr for industrial purposes.

Lake Cypress Springs is authorized as a 72,800 ac-ft reservoir on Big Cypress Creek in Franklin County. The Franklin County Water District and the Texas Water Development Board own the lake jointly. Franklin County Water District was created in 1965 and provides water to Franklin County from Lake Cypress Springs. The District also provides cooling water to Texas Utilities Electric Company. In 1968, TWDB invested over $1.9 million in this project and the District is now in the process of buying the state's share of the project. The dam was completed February 15, 1971, and deliberate impoundment began July 7, 1970. The owners hold a water right (CA 04-4560) for Lake Cypress Springs that allows for the use of the reservoir for municipal, irrigation, industrial, interbasin transfers, and recreational purposes. The owners' rights are subject to an agreement for reservoir operations between the Texas Water Development Board, Titus County Fresh Water Supply District No. 1, Franklin County Water District, Northeast Texas Municipal Water District, and Lone Star Steel Company, dated January 1, 1973. The total permitted diversion from Lake Cypress Springs is 18,000 ac-ft/yr.

Lake Bob Sandlin (previously known as Fort Sherman Dam and the Cherokee Trail Lake) is authorized as a 213,350 ac-ft reservoir on Big Cypress Creek in Titus, Camp, Wood, and Franklin Counties. In 1966, the Titus County Freshwater Supply District No. 1 (TCFSD) was created by the County to finance and construct Lake Bob Sandlin. The lake provides water for a number of cooling lakes and municipal water supplies for the City of Mount Pleasant. Lake Bob Sandlin was developed through the state participation program. TWDB purchased a 59% interest in the project for $14.992 million in 1974, and the District has since bought TWDB's share. The TCFSD holds water rights for Lake Bob Sandlin (CA 04-4564) and the reservoir is permitted for municipal, industrial, and recreational purposes. The owners' rights are subject to an agreement for reservoir operations between the Texas Water Development Board, Titus County Fresh Water Supply District No. 1, Franklin County Water District, Northeast Texas Municipal Water District, and Lone Star Steel Company, dated January 1, 1973. The total permitted diversion from Lake Bob Sandlin is 48,500 ac-ft/yr.

Ellison Creek Reservoir is authorized as a 24,700 acre-foot reservoir on Ellison Creek in Morris County. The reservoir is owned by Lone Star Steel and is used for municipal and industrial purposes (CA 04-4582). The dam was completed in April 1943 and deliberate impoundment began in January 1943. The owners' rights are subject to an agreement for reservoir operations between the Texas Water Development Board, Titus County Fresh Water Supply District No. 1, Franklin County Water District, Northeast Texas Municipal Water District, and Lone Star Steel Company, dated January 1, 1973. The total permitted diversion from Ellison Creek Reservoir is 49,000 ac-ft/yr.

Lake O' the Pines is authorized as a 252,040 ac-ft reservoir on Cypress Creek in Marion, Upshur, Morris, and Camp Counties. Lake O' the Pines is owned by the United States of America and is operated by the U.S. Corps of Engineers. The Northeast Texas Municipal Water District, created in 1953, has the right to storage in Lake O' the Pines Reservoir under an agreement with the U. S. Corp of Engineers and supplies water to its member cities, as well as municipal customers, industries, and steam-electric power plants in the Cypress and Sabine Basins. The District currently supplies water to the Brady Branch cooling lake, which is located in the Sabine River Basin and has contracted to supply up to 20,000 ac-ft to the City of Longview in the Sabine River Basin with an option for another 20,000 ac-ft. The dam was completed on June 25, 1958 and deliberate impoundment began on August 21, 1957. The owners' rights are subject to an agreement for reservoir operations between the Texas Water Development Board, Titus County Fresh Water Supply District No. 1, Franklin County Water District, Northeast Texas Municipal Water District, and Lone Star Steel Company, dated January 1, 1973. The total permitted diversion from Lake O' the Pines is 221,800 ac-ft/yr (CA 04-4590). The water right permits the owner to use the reservoir for municipal, industrial, trans-watershed diversions, and recreational purposes.

Lake Gilmer is authorized as a 12,720 ac-ft reservoir on Kelsey Creek in Upshur County. The reservoir is owned by the City of Gilmer and is used for municipal, industrial, and recreational purposes (Permit 04-5272). The total permitted diversion from Lake Gilmer is 6,180 ac-ft/yr.

Another major reservoir that is within the Cypress Basin, as well as the State of Louisiana, is Caddo Lake. The Caddo Levee District Board of Commissioners owns Caddo Lake. Caddo Lake has conservation storage of 59,560 acre-feet. The original Caddo Dam was completed in 1914 as a feature of the navigation project Cypress Bayou and waterway between Jefferson, Texas and Shreveport, Louisiana. The replacement of Caddo Dam was begun on August 7, 1968 and completed June 18, 1971. Impoundment of the water was maintained during the construction of the replacement dam. Texas does not have any water rights located on Caddo Lake.

The outlet of the Cypress Basin, specifically Caddo Lake, is part of the Red River Compact. The Red River Compact is an agreement between the States of Texas, Arkansas, Oklahoma, and Louisiana. There are five principal purposes of the Red River Compact:

1. To promote interstate comity and remove causes of controversy between each of the affected states by governing the use, control, and distribution of the interstate water of the Red River and its tributaries;
2. To provide an equitable apportionment among the Signatory States of the water of the Red River and its tributaries;
3. To promote an active program for the control and alleviation of natural deterioration and pollution of the water of the Red River Basin and to provide for enforcement of the laws related thereto;
4. To provide the means for an active program for the conservation of water, protection of lives and property from floods, improvement of water quality, development of navigation and regulation of flows in the Red River Basin; and
5. To provide a basis for state or joint state planning and action by ascertaining and identifying each state's share in the interstate water of the Red River Basin and the apportionment thereof.

The Red River Compact divides the Red River into five major subdivisions within the four states. The only portion of the Red River Compact that affects the Cypress Basin is Reach III. Article VI of the Compact further divides Reach III into four subbasins. In the state of Texas, the Cypress Basin is defined as Subbasin 1 and 3. Reach III of the Red River Compact is shown in Figure 2.

Figure 2 Reach III Red River Compact

Subbasin 1 includes the Texas portion of those streams crossing the Arkansas-Texas state boundary one or more times and flowing through Arkansas into Cypress Creek-Twelve Mile Bayou watershed in Louisiana. Texas is apportioned 60% of the runoff of this subbasin and shall have unrestricted use thereof; Arkansas is entitled to 40% of the runoff of this subbasin.

Subbasin 3 includes the Texas portion of all tributaries crossing the Texas-Louisiana state boundary one or more times and flowing into Caddo Lake, Cypress Creek-Twelve Mile Bayou or Cross Lake, as well as the Louisiana portion of such tributaries. Texas and Louisiana, within their respective boundaries, shall each have the unrestricted used of the water of Subbasin 3. Subbasin 3 was amended on April 25, 1989 and is subject to the following:

1) Texas shall have the unrestricted right to all water above Marshall, Lake O' the Pines, and Black Cypress damsites; however, Texas shall not cause runoff to be depleted to a quantity less than that which would have occurred with the full operation of Franklin County, Titus County, Ellison Creek, Johnson Creek, Lake O' the Pines, Marshall, and Black Cypress Reservoirs constructed, and those other impoundments and diversions existing on the effective date of May 12, 1978 of the Red River Compact. Any depletions described above shall be charged against Texas' apportionment of the water in Caddo Reservoir.
    a. Texas may use the bed and banks of the streams or tributaries available within this Subbasin to convey its developed water downstream from the aforesaid dam sites to specified authorized users. Such water would retain its identity and would not be subject to the Caddo Lake drawdown provisions of Section 5.b. of these rules until passing the designated point of diversion. Appropriate transportation losses will be approved by the Red River Compact Commission.
    b. Until both Marshall Reservoir (with an estimated capacity of 782,300 acre-feet and yield of 325,000 ac-ft annually) and Black Cypress Reservoir (with an estimated capacity of 824,000 ac-ft and yield of 220,000 ac-ft annually) have been constructed, it will be virtually impossible for Texas to deplete runoff in excess of that authorized. In the future, whenever potential Texas depletions above Marshall, Lake O' the Pines, and Black Cypress damsites become a concern to Louisiana, procedures to compute Texas depletion of runoff in excess of that authorized by Section 6.03 (b)(1) of the Compact should be developed by the Engineering Committee and presented for Commission consideration.

2. Texas and Louisiana shall each have the unrestricted right to use 50% of the

conservation storage capacity in the present Caddo Lake for the impoundment of water for state use, subject to the provision that supplies for existing uses of water from Caddo Lake, on the date of May 12, 1978 of the Red River Compact, are not reduced.

   a. Whenever water is spilling over the existing spillway at 168.5 feet above mean sea level, each state may withdraw or divert water from Caddo Lake without restriction.
   b. Whenever Caddo Lake is not spilling over the existing spillway at 168.5 feet above mean sea level, the total consumptive use by each state shall not exceed 8,400 ac-ft during the drawdown period, provided that neither state shall divert more than 3,600 ac-ft during any one month or 4,800 ac-ft during any two consecutive months.

3. Texas and Louisiana shall each have the unrestricted right to 50% of the conservation storage capacity of any future enlargement of Caddo Lake, provided the two states may negotiate for the release of each state's share of the storage space on terms mutually agreed upon by the two states after the effective date of May 12, 1978 of the Red River Compact.
   a. This Compact provision requires no separate computation procedures, but other rules may be changed if enlargement of Caddo Lake occurs. If enlargement of Caddo Lake is authorized in the future, the Engineering Committee should review and modify as necessary Rule 5 (b) and Rule 6.

4. Inflow to Caddo Lake from its drainage area downstream from Marshall, Lake O' the Pines, and Black Cypress damsites, and downstream from other last downstream dams in existence on the date of May 12, 1978, the signing of the Compact document by the Compact Commissioners, will be allowed to continue flowing into Caddo Lake except that any manmade depletions to this inflow by Texas will be subtracted from the Texas share of the water in Caddo Lake.
   a. As indicated in Paragraph 5a. (2) above, it is virtually impossible for Texas at the present time to reduce inflow to Caddo Lake below that which would occur with both Marshall and Black Cypress Reservoirs constructed and operating. However, if potential Texas depletions become a concern to Louisiana, procedures to compute excess depletion by Texas of inflow to Caddo Lake should be developed by the Engineering Committee and presented for Commission consideration.

In regard to the water of interstate streams, which do not contribute to the inflow to Cross Lake or Caddo Lake, Texas shall have the unrestricted right to divert and use this water on the basis of a diversion of runoff above the state boundary of 60% to Black Bayou. The Compact also states that Texas and Louisiana will not construct improvements on the Cross Lake watershed in either state that will affect the yield of Cross Lake. Appendix D, Water Rights and Assumptions, provides a detailed description of the modeling of the Red River Compact in the Cypress Basin WAM.

Total water use in the basin is projected to increase by about 4% over the 1990-2050 planning horizon resulting in a year 2050 water use of about 202,000 million ac-ft. This relatively slow growth in water use is attributable to a projected decline in manufacturing water use of about 8% over the same period of time. Manufacturing water use is projected to remain the largest water-using sector in the basin, accounting for approximately 59% of the total basin water use by the year 2050, even with the anticipated decline. Continued implementation of municipal, manufacturing, and irrigated agriculture conservations practices and programs is anticipated to reduce annual water use by 4,200 ac-ft in the year 2020 and 6,200 ac-ft by the year 2050. These saving are actually a reduction in increased water use that would occur without conservation practices.

Approximately 56,000 acre-feet per year of future water needs will be met through (wastewater) reuse by the year 2050. Reuse can provide a source of water for some of the steam-electric power generation and industrial water needs in the basin. The City of Shreveport, Louisiana has indicated a desire to use Caddo Lake as a water supply source. However, the Board's forecasts suggest that environmental impacts from the potential significant lowering of Caddo Lake levels through expanded water supply use, especially during dry weather periods, should preclude it from being a viable site for additional future water supplies. Further, potential industrial needs in Harrison County could also be met with water from Lake O' the Pines. (Water for Texas, 1997).

The Northeast Texas Municipal Water District's contract with the City of Longview for up to 20,000 ac-ft should meet Longview's long-term water needs. It is anticipated that the City would need to construct a pipeline from Lake O' the Pines by 2005. (Water for Texas, 1997).

1.2 Study Objectives

The objective of this study is to meet the requirements placed on the TNRCC by SB1. SB1, passed by the 75th Texas Legislature, requires that the TNRCC develop or acquire new reservoir/river basin simulation models in order to determine water availability in twenty-two river basins within Texas. In December of 2000, the TNRCC authorized KSA Engineers, Inc. to estimate naturalized inflows and develop a water availability model for the Cypress Basin in Northeast Texas. PBS&J, Inc., Espey Consultants, Inc., and CivilTech Engineering, Inc. served as sub-consultants to KSA Engineers, Inc. on this project.
In order to meet the study objectives for the Cypress Basin WAM Assessment two tasks had to be performed:

- Calculation of naturalized flows.
- Development of a water availability model using Texas A&M's Water Rights Analysis Package (WRAP (VER 12/01)).

As mandated by SB1, the TNRCC is to determine, through the water availability analysis, the:

- Projected amount of water available for all water rights during extended dry periods.
- Projected amount of water *that would be* available if cancellation procedures were instigated under the provisions of Subchapter E, Chapter 11, of the Texas Water Code.
- Potential impact of reusing municipal and industrial effluent on existing water rights and instream uses.

1.3 Study Approach

The WAM Management team, consisting of representatives from the TNRCC, Texas Parks and Wildlife Department (TPWD), and the Texas Water Development Board (TWDB), has developed procedures and criteria for undertaking the water availability analyses for all basins in Texas. These procedures include the development of naturalized streamflows from historical hydrological information, utilization of the Water Rights Analysis Package program, and adhering to the Texas prior appropriation system, the Texas Water Code, and water management and regulatory policies set by the TNRCC.

The model selected for use in this study by the TNRCC was WRAP (VER 12/01). The WRAP (VER 12/01) program, developed by Dr. Ralph A. Wurbs at Texas A & M University, simulates a basin using monthly time steps, historical hydrologic river basin characteristics, and the Texas prior appropriation system. The model performs a sequential monthly water volume accounting computation by determining if TNRCC permitted water diversions can be made at a particular location during a specified hydrologic period of analysis given historic hydrologic conditions. The model is set up to allow water rights that have seniority the first right of diversion ("first in time, first in right").

The steps taken to develop the Cypress Basin Water Availability Model were to collect, analyze, and compile data for a period from 1948 through 1998. Data required for input into the model include control points, naturalized flows, evaporation rates, water right data, reservoir area-capacity curves, return flows, and water use demand patterns. Once the data were obtained, nine model scenarios were analyzed using WRAP (VER 12/01) to determine the water availability for the 1948-1998 hydrologic period for the Cypress Basin.

Naturalized streamflows are the flows that would have occurred in the absence of human activities such as reservoir development, diversions, and return flows. Naturalized flows are used so that historical diversions, impoundments, and returns do not affect the water availability analysis. Naturalized flows at primary control points are based on historical hydrologic records, adjusted to remove the impact of human activities. They are used as input to the water availability model, which simulates the operation of existing water rights considering their location, characteristics, and priority under Texas water law. Naturalized flows at secondary control points are estimated from nearby primary control points.

The principal results from the water availability analyses are:

1. *Reliability of existing water rights*

   The results of the water availability analysis under varied cancellation and reuse policies satisfies the requirements of SB1. Results presented in this draft report are only a partial summary of the complete output generated by WRAP (VER 12/01). The complete water availability output for existing water rights in the Cypress Basin are available from the TNRCC.

2. *Monthly estimates of unappropriated water that would be available for diversion and/or storage.*

Existing data on the Cypress Basin are limited prior to 1948; therefore, this study will use hydrologic data from January 1948 through December of 1998 as the period of record. This period of record was selected because sufficient data are available to make the modeling effort reliable and because it encompasses the droughts of 1951-1956, 1963-1964, 1965-1967, 1980, 1984, 1988, and 1996.

2.0 EXISTING WATER AVAILABILITY INFORMATION

Key data for water availability modeling include water rights, historical water use, historical return flows, historical streamflow, reservoir data, and evaporation rates. This section discusses available information for the key data as well as previous water availability and planning studies.

2.1 Water Rights

There are 81 water rights in the Cypress Basin. Table 1 provides a summary of the combined water rights within the six sub-watersheds. Information regarding water rights was obtained from the TNRCC master water rights database and from hard copies of the water rights. Appendix A lists water rights in the Cypress Basin sorted by river order number and sequenced from downstream to upstream. Appendix B is the same database sorted by priority date from the most senior water right to the most junior water right. A map of the Cypress Basin including the six sub-watersheds is located in Appendix K. Current water rights documents (all Certificates of Adjudication and Permits issued by the TNRCC through February 1999) were reviewed and compared to the TNRCC database and the database was revised when appropriate. A memorandum was prepared and submitted to the TNRCC with suggested corrections to the master water rights database. This memorandum is shown in Appendix C.

Table 1 Summary of Water Rights by Sub-Watershed (ac-ft/yr)

Sub-Watershed	Upstream Control Points	Downstream Control Points	Municipal	Industrial	Irrigation	Mining	Total
BC_PB		Big Cypress Creek near Jefferson	23,724	75,024	300		99,047.95
BC_JF	Big Cypress Creek nr Pittsburg	Ungaged primary control point just upstream of Caddo Lake	64,000	218,468	412.46		282,880
LC_OC		Little Cypress Creek near Jefferson	6,180		7.03		6,187.03
LC_JF	Little Cypress Creek nr Ore City	Ungaged primary control point just upstream of Caddo Lake		1,195	174.20		1,369.20
BK_JF		Ungaged primary control point just upstream of Caddo Lake		10	72		82
DN_CL	Big Cypress Creek nr Pittsburg Big Cypress Creek nr Jefferson Black Cypress Bayou at Jefferson Little Cypress Creek nr Ore City Little Cypress Creek nr Jefferson	Ungaged primary control point just downstream of the discharge of Caddo Lake in Louisiana	20,343	37,180	1,764.67	165.21	59,452.88
TOTAL			114,247	331,877	2,730.31	165.21	449,019.5

2.2 Historical Water Use

Surface water resources supply about 89% of the total basin water needs with ground-water resources supplying the remaining 11%. Surface water is supplied by the nine major reservoirs in the basin. Manufacturing and steam-electric power generation are the major surface water uses in the basin. In 1990, water used for all purposes within the basin totaled 194,572 ac-ft. This represents a reduction in total basin water use of nearly 55,000 ac-ft below the 1980 total basin water use. This decline was due primarily to a reduction in manufacturing water use of more than 68,000 ac-ft over this same period of time. By far, the largest water use category in the basin is manufacturing, which accounts for nearly 67% of all water used, while municipal water use accounts for about 10%. In 1990, 10,762 ac-ft of water was exported to the Sabine River Basin and 596 ac-ft was exported to the Sulphur River Basin from the Cypress Basin for municipal and industrial purposes (Water for Texas, 1997).

Water use data were collected for the naturalization process. Surface water use records were obtained in a digital format for the study period from 1948 through 1998 from the TNRCC. The permit files were also reviewed to obtain water use data for water rights with large diversion amounts, as well as to identify water rights with missing data. Holders of water rights with incomplete records were contacted to obtain additional information to fill in the missing data. If no data were available, water use data were estimated on a per capita basis for municipal water rights. Per capita water use estimations were determined by dividing the water use in a given year by the population of the community using the water in that same year. These per capita values were then multiplied by the population of the community during the period of missing data. Estimates for water use for industrial and irrigation water rights were based on historical use patterns of those water rights or rights with similar uses and diversion amounts. When a good estimate could not be formed, the historical use was estimated to be zero. This estimation provided a conservatively low estimate in the naturalized streamflow calculations.

In accordance with TNRCC requirements, surface water use records for all water rights in the Cypress Basin were summarized for the thirteen-year period from 1984 through 1997 from the TNRCC permit files. This period of record was selected because data records were readily available and comprehensive. The water use data obtained from the TNRCC is data provided to the TNRCC by all permittees. This data set included the county in which the diversion occurred, the amount diverted, the amount returned, and the use type. A summary of water use by county for a thirteen-year use period of 1984 through 1997 is shown in Appendix E.

Groundwater was represented by the City of Pittsburg Sparks Branch Waste Water Treatment Plant and the City of Gilmer East Waste Water Treatment Plant and was input through the CI card for each of those facilities. Historical groundwater use records from

1984 to 1997 were obtained from the TWDB. The groundwater data are presented by county, defined by use type, and summarized by year in Appendix E.

2.3 Historical Return Flows and Treated Wastewater Effluent Discharge

Available records for return flows of treated municipal and industrial wastewater effluent discharges were obtained from TNRCC for the time period of 1978 through 1998. Prior to 1978, return flow records were generally not available. The following techniques were used to estimate return flows where records were not available:

- Return flows entity was contacted to determine whether any records or estimates of flows existed for the time frame not covered by the TNRCC database.
- For cities without such records, return flows were estimated on the basis of water use or a per capita value.
- For industries without such records, return flows were estimated on the basis of water use.
- Agricultural return flows were neglected.

Estimates of return flow were then calculated for all return flow locations from the date on which the discharge began up through 1978. All return flows in the Cypress Basin were utilized in the calculation of naturalized flows.

Return flows were located using the GIS coverage provided by the TNRCC. These locations are shown in the Cypress Basin map located in Appendix K. The return flow points on the map are denoted by green circles.

Smaller treatment plant return flows were not included in the Cypress Basin model. A detailed description of the modeling of return flow is included in Section 4.2.3.3.

2.4 Previous Firm Yield and Planning Studies

There are nine existing major reservoirs in the Cypress Basin: Lake Monticello, Lake Bob Sandlin, Johnson Creek Reservoir, Lake Cypress Springs, Lake O' the Pines, Ellison Creek Reservoir, Caddo Lake, Welsh Reservoir, and Lake Gilmer. A brief summary of firm yield studies that have been performed in the Cypress Basin of these reservoirs and the associated bibliography is presented in Appendix F. According to these studies, the total yield from the nine major reservoirs in the Cypress Basin is 363,877 acre-feet per year. The combined water supply depends on the definition of water supply yield (i.e. how much reserve content remained in the reservoir at the end of the critical period), assumed basin development, and other factors.

2.5 Significant Considerations Affecting Water Availability in the Basin

Assumptions made in this study which may affect water availability include:

- Filling of downstream reservoirs with senior water rights take precedence over diversion by upstream junior water rights. The firm yield analysis of this study maximizes the amount of diversions that could be made from the reservoir under their respective priority dates up to the authorized diversion amount. Lake Bob Sandlin is senior to Lake Cypress Springs; therefore, water is passed through Lake Cypress Springs to fill Lake Bob Sandlin.
- The watershed parameters received from the TNRCC, used in this study to distribute naturalized flows between control points, are assumed to be correct.
- All water rights and currently permitted reservoirs, as of January 1999, are modeled.
- Reservoirs less than 5,000 ac-ft are modeled using a regression relationship to relate reservoir storage to surface area (described in Section 3.4.2).
- Channel losses are assumed to be negligible and are not included in the model. Louisiana's diversion from Caddo Lake was modeled as 40,000 ac-ft/yr (Summary of 1996 diversions provided by the State of Louisiana).
- In general, the amounts of appropriated water covered by existing rights are determined by the permitted diversion for each water right and are not based on firm yields, geographical location, or other practical limits. Thus, the remaining unappropriated water at any point in the basin is based on the assumption that all rights are taking their full paper values of diversions whenever that much water is available.
- For water rights with off-channel storage, WRAP (VER 12/01) limits the streamflow depletions, which are made to meet diversions and refill storage on a monthly and annual basis.

3.0 HYDROLOGIC DATA REFINEMENT

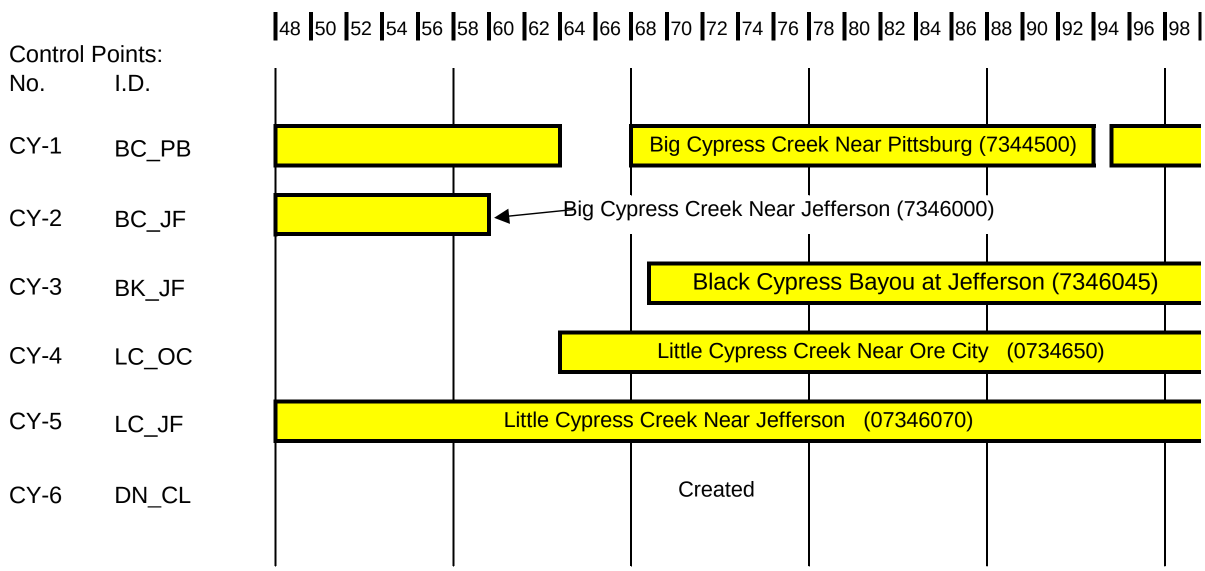
3.1 Natural Streamflow at Gaged Locations

USGS Gage locations served as primary control points for the water availability model. Primary control points were developed using the following general criteria:

- Streamflow gages with over 20 years of record and drainage areas over 100 square miles;
- Spatial distribution of primary control points throughout the basin; and
- Reservoir control points were avoided if possible due to the difficulty in obtaining accurate information on reservoir discharges.

Naturalized flows were estimated at primary control points in the Cypress Basin. The location of these control points corresponds to USGS streamflow gages with relatively extensive historic records as shown in Figure 3. To estimate naturalized flows, the gage records were adjusted to account for upstream diversions, return flows, changes in reservoir content, and net reservoir evaporation.

Figure 3 Hydrological Records for Primary Control Points



One primary control point did not meet the above gage criteria. This control point was developed to define the watershed of Caddo Lake. This control point was created at a location where there was no USGS gage. The primary control point is located just downstream of Caddo Lake. Naturalized flows were estimated for this control point using naturalized flows from other gages in the basin. A description of the naturalized flow estimating procedure for this ungaged primary control point is defined in Deliverable 2.

3.1.1 Streamflow Naturalization Methodology

Whenever possible, naturalized streamflows at the primary control points are based on available streamflow records using the methodology described herein. Naturalized flow data is based on historical flows, adjusted to remove the effects of human activity. A general equation for naturalized flow is as follows:

Naturalized Flow = Historical Flow + Upstream Diversions – Upstream Return Flows + Changes in Upstream Reservoir Contents + Upstream Reservoir Evaporation

The elements of the equation are determined as follows:

- ***Historical Flow*** – Flows at primary control points were determined based on recorded USGS streamflow gage data. Five primary control points were assigned at USGS gaging stations and one primary control point was assigned downstream of Caddo Lake, as described above. Figure 3 shows the control points assigned to the Cypress Basin and the historical period of record associated with each control point. Figure 1, located on page 6, shows the location of the water rights and the six primary control points in the Cypress Basin.

- ***Upstream Diversions*** – Upstream diversions as recorded in TNRCC records (or as estimated when records are missing) for all water right permits in the basin. A detailed description of the estimation procedure used to fill in missing data is given in the Final Naturalized Streamflow Report submitted to TNRCC in November 2001.

- ***Upstream Return Flows*** – Upstream return flows are based on TNRCC wastewater discharge permit records, or as estimated when records are not available. A detailed description of the return flow estimating procedures is also given in the Final Naturalized Streamflow Report submitted to TNRCC in November 2001. All return flows were used in calculated naturalized flows, but only those return flows over 1.0 million gallons per day (MGD) were included in the model. Return flows greater than 1.0 MGD that were used for once through cooling purposes, or storm water flows, were also not included in the model.

- ***Changes in Upstream Reservoir Contents*** – Changes in contents for major upstream reservoirs are based on USGS records, records kept by others, or estimates of content changes if records were not available. The sources of data utilized for reservoir content changes are listed in Table 2. Content changes for reservoirs with less than 5,000 ac-ft of conservation storage were neglected. Summaries of all reservoirs with greater than 5,000 ac-ft of conservation storage in the Cypress Basin can be found in Table 3.

Table 2 Sources of Data Utilized for Reservoir Content Changes

Reservoir	**Period**	**Method**
Lake Monticello	1/73 6/98	Monthly average of available data
Ellison Lake	1/48-1/86 & 10/89-12/98	Monthly average of available data

- ***Upstream Reservoir Evaporation*** – Monthly evaporation from upstream reservoirs is estimated by multiplying the net reservoir evaporation rate by the average reservoir surface area. Evaporation from reservoirs with less than 5,000 ac-ft of conservation storage is neglected. Section 3.3 includes a discussion of the development of net reservoir evaporation rates.

Table 3 Major Reservoirs in the Cypress Basin (over 5,000 ac-ft Conservation Storage)

Reservoir	Drainage Area (Square Miles)	Stream	Date of Impoundment	Owner or Operator	Conservation Storage (Ac-ft)	
					Permitted	Original
Bob Sandlin Reservoir	239	Big Cypress Creek	1975	Titus County Fresh Water Supply District No.1	213,350	213,350
Caddo Lake	2,700	Cypress Bayou	1914	Board of Commissioners, Caddo Levee District	Flood Control Act	59,560
Cypress Springs Reservoir	75	Big Cypress Creek	1970	Franklin County Water District, TX Water Development Board	72,800	72,800
Ellison Creek Reservoir (Lone Star Lake)	37	Ellison Creek	1943	Lone Star Steel Co.	24,700	24,700
Lake Gilmer	35.6	Kelsey Creek	1998	City of Gilmer	12,720	12,720
Johnson Creek Lake	11	Johnson Creek	1961	Southwestern Electric Power Co.	10,100	10,100
Lake O' the Pines	880	Cypress Creek	1957	Northeast Texas Municipal Water District	250,000	250,000
Monticello Reservoir	36	Blundell Creek	1972	TX Power & Light,TX Electric Co,Dallas Power & Light Co, TX Utilities Generating Co	40,100	40,100
Peacock Reservoir	1.8	Peacock Creek	1983	Lone Star Steel Co.	11,248	11,248
Welsh Reservoir	21.2	Swauano Creek	1976	Southwest Electric Power Co.	23,590	23,590

3.1.2 Streamflow Data Sources

Streamflow data in the Cypress Basin were obtained from U.S. Geological Survey gage flows. The U.S. Geological Survey maintains a network of streamflow gages throughout the United States. USGS gage measurements are the most reliable source of historical streamflow data. Table 4 lists USGS streamflow gages in the Cypress Basin. Figure 3 shows the length of record for each USGS streamflow gage used as a primary control point in the basin. Refer to Figure 1 on Page 6 for the location of the primary control points selected in this study.

Table 4 USGS Streamflow Gages in the Cypress Basin

Gage	USGS Number	Drainage Area (Square Miles)	Period of Record
Big Cypress Creek near Pittsburg	44500	366	4/43-12/62 & 10/67-9/93 & 10/94-9/96 & 10/97-9/98
Big Cypress Creek near Jefferson	46000	850	8/24-12/59 & 10/79-9/99
Black Cypress Bayou at Jefferson	46045	365	10/68-9/99
Little Cypress Creek near Ore City	46050	383	1/63-9/99
Little Cypress Creek near Jefferson	46070	675	6/46-9/99
Brushy Creek at Scroggins	44486	23.4	1/78-9/99
Big Cypress Creek near Winnsboro	44482	27.2	4/74-9/91
Boggy Creek near Daingerfield	45000	72	4/43-9/77
Frazier Creek near Linden	46140	48	12/64-9/91

3.1.3 Delivery Factors and Channel Loss Rates

Channel losses and groundwater interaction were examined using maps from the TWDB publication Water for Texas A Consensus-Based Update to the State Based Update to the State Water Plan. The TWDB was contacted to determine if any studies for channel losses or groundwater interaction had been completed in the Cypress Basin. According to the TWDB, no studies had been completed in the Cypress Basin. The Bureau of Economic Geology (BEG) was also contacted to determine if any channel loss studies had been performed. No studies had been performed by the BEG.

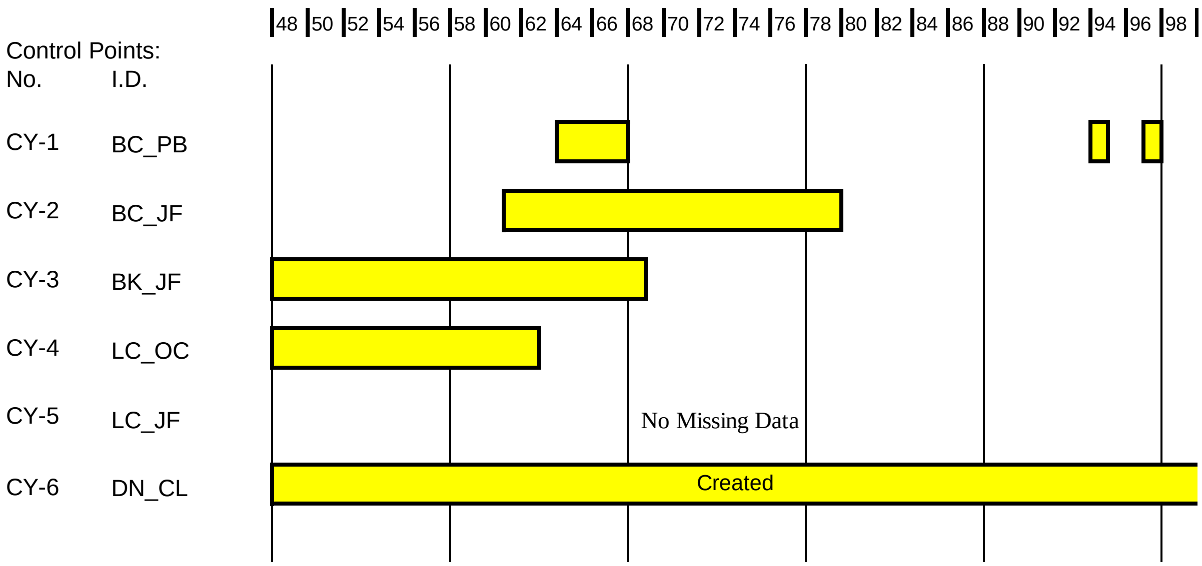
Major water right holders and other parties with water related concerns in the Cypress Basin were contacted to determine if any groundwater studies had been completed. These water right holders and interested parties included Northeast Texas Municipal Water District, Texas Utilities, Titus County Fresh Water Supply District, Franklin County Water District, Lone Star Steel, KSA Engineers, Inc., Freese & Nichols, Inc., and TWDB. The entities were also asked if they had channel losses in their delivery systems (when they used the bed and banks for delivery). None of the parties contacted knew of any channel loss studies and none had experienced channel losses in their conveyance systems. Finally, streamflow records for several gages were evaluated to determine if any significant channel losses could be determined. There are only two USGS gages that are on the same stream in the Cypress Basin, the gage located on the Big Cypress River near Pittsburg and the gage located at the Big Cypress River near Jefferson. The analysis of these gage records in association with the intervening drainage area flow and Lake O' the Pines impoundments yielded no conclusive evidence of channel losses.

The Cypress Basin is located over the upper portion of the Carrizo-Wilcox (major aquifer) and the upper portion of the Queen City (minor aquifer). The Carrizo-Wilcox Aquifer is predominantly composed of sand, locally interbedded with gravel, silt, clay, and lignite deposited during the Tertiary Period. The aquifer is stratified with silt and clay and is not overly productive in the Cypress Basin. The Queen City Aquifer is also predominantly composed of sand, loosely cemented sandstone, and interbedded clay units of the Queen City Formation of the Tertiary Claiborne Group. These rocks dip gently to the south and southeast toward the Gulf Coast. Although total aquifer thickness is usually less than 500 feet, it can approach 700 feet in some areas of northeast Texas. In the outcrop area, water occurs under water-table conditions while in the downdip subsurface, where the Queen City is covered by younger, non water-bearing rocks, the water is under artesian conditions. There was no stream reach in the Cypress Basin that had an upstream and downstream gage (with minimal inflows from tributaries or influence from reservoirs) that could be used for a channel loss analysis. Therefore, due to low permeability of the outcrops of the Carrizo-Wilcox and no reported losses in the area, channel losses in the Cypress Basin are assumed to be minimal and not included in the water availability model. There were no adjustments necessary to account for channel losses during the development of naturalized flows. A discussion of channel losses and groundwater interaction modeling assumptions is included as Appendix H.

3.1.4 Completion of Streamflow Records

Most of the primary control points in the Cypress Basin do not have a complete flow record for 1948 through 1998. The periods of missing data for the primary control points are shown in Figure 4. Historical USGS gaged flow data was used as a basis for the flow at a given control point based on the drainage area ratio. Control points with missing data were filled by correlating the overlapping data period with nearby gages and using the gage with the highest correlation value. Appendix G gives a complete list of the options considered to fill in missing data. A detailed description of the filling procedure is found in Deliverable 2. Appendix I shows the Cypress Basin naturalized flows for the primary control points.

Figure 4 Missing Hydrological Records for PrimaryControl Points



Naturalized flows were calculated at the gaged locations using the methodology described in Section 3.1.1. Negative incremental flows occur when the upstream naturalized flow is greater than the naturalized flow calculated for the downstream control point. In normal conditions, it is assumed that the flow from the incremental watershed area, when naturalized and added to the upstream naturalized flow, will be greater than the naturalized flow calculated upstream. However, during computation of naturalized flow for this study, negative incremental flows were calculated for some months at some of the primary control points. Negative incremental flows between control points are generally explained by the following reasons:

- Timing problems created by large flows, which pass different points during different months;
- Incorrect data; and/or
- Errors in the estimation of hydrologic data.

Negative incremental streamflow adjustments were made for those gages that had negative incremental flows. These adjustments were made to the data to eliminate the negative flows.

Negative incremental streamflow adjustments were made by setting the negative flow value to zero. Then the amount of flow that was added to the negative number to make it zero was subtracted from the surrounding months.

3.1.5 Comparison with Other Naturalized Streamflow

Comparison of Naturalized Flows to TNRCC Legacy WAM

A water availability model previously developed by the TNRCC is referred to as a Legacy WAM. There is no Legacy WAM for the Cypress Basin. Therefore, no comparison was performed with the results of this study.

3.1.6 Statistical Assessment of Trends in Streamflow

Trends in streamflow were analyzed by comparing historical to naturalized flows at the USGS gage control points. The minimum, 90% exceedance, 75% exceedance, median, 25% exceedance, 10% exceedance, maximum, and average flows were calculated for each month. Complete tables for each of these control points are in Appendix J, along with the double mass curve comparing the gage flow to the naturalized flow. Table 5 lists the control points along with the comparison periods, the median annual flows for both the gaged and naturalized flows, and the ratio of the cumulative naturalized flow to the cumulative gaged flow.

Table 5 Naturalized Streamflow Comparison Summary Cypress Basin Control Points

No.	I.D.	Gage	USGS Number	Drainage Area (Square Miles)	Comparison Period	Median Annual Gage Flow (acre-ft)	Median Annual Naturalized Flow (acre-ft)	Cumulative Naturalized Flow/Gage Flow Ratio
CY-1	BC_PB	Big Cypress Creek near Pittsburg	7344500	366	4/43-12/62, 10/67-9/93, 10/94-9/96	178,257	202,608	1.137
CY-2	BC_JF	Big Cypress Creek near Jefferson	7346000	850	8/24-12/59, 10/79-9/99	413,951	460,081	1.111
CY-3	BK_JF	Black Cypress Bayou at Jefferson	7346045	365	10/68-9/99	256,560	256,561	1.000
CY-4	LC_OC	Little Cypress Creek near Ore City	7346050	383	1/63-9/99	226,429	226,423	1.000
CY-5	LC_JF	Little Cypress Creek near Jefferson	7346070	675	6/46-9/99	387,477	387,483	1.000

Naturalized flow for BC_JF exceeds gaged flow starting in about 1980, reflecting the gradual increase in diversions over time, although the data was highly variable during this period as well. BC_PB exhibited the same trend, reflecting the effects of the three reservoirs above this control point beginning in the mid to late 70's and a gradual increase in diversions since the 80's.

The annual statistics are shown in Figure 5, Figure 6 and Figure 7 for BC_PB, BC_JF and

LC_JF, respectively. The 90% exceedance, median and 10% exceedance flows for control points BC_PB, BC_JF and LC_JF are displayed graphically in Figure 8, Figure 9, and Figure 10, respectively. The figures for BC_JF are generally representative of control points affected by the combination of upstream reservoirs and diversion. The figures for LC_JF are generally representative of areas minimally affected by changes to flow. The figures for BC_PB are generally representative of an area with high return flows.

Figure 5 BC_PB Statistical Comparison of Annual Historical and Naturalized Flows

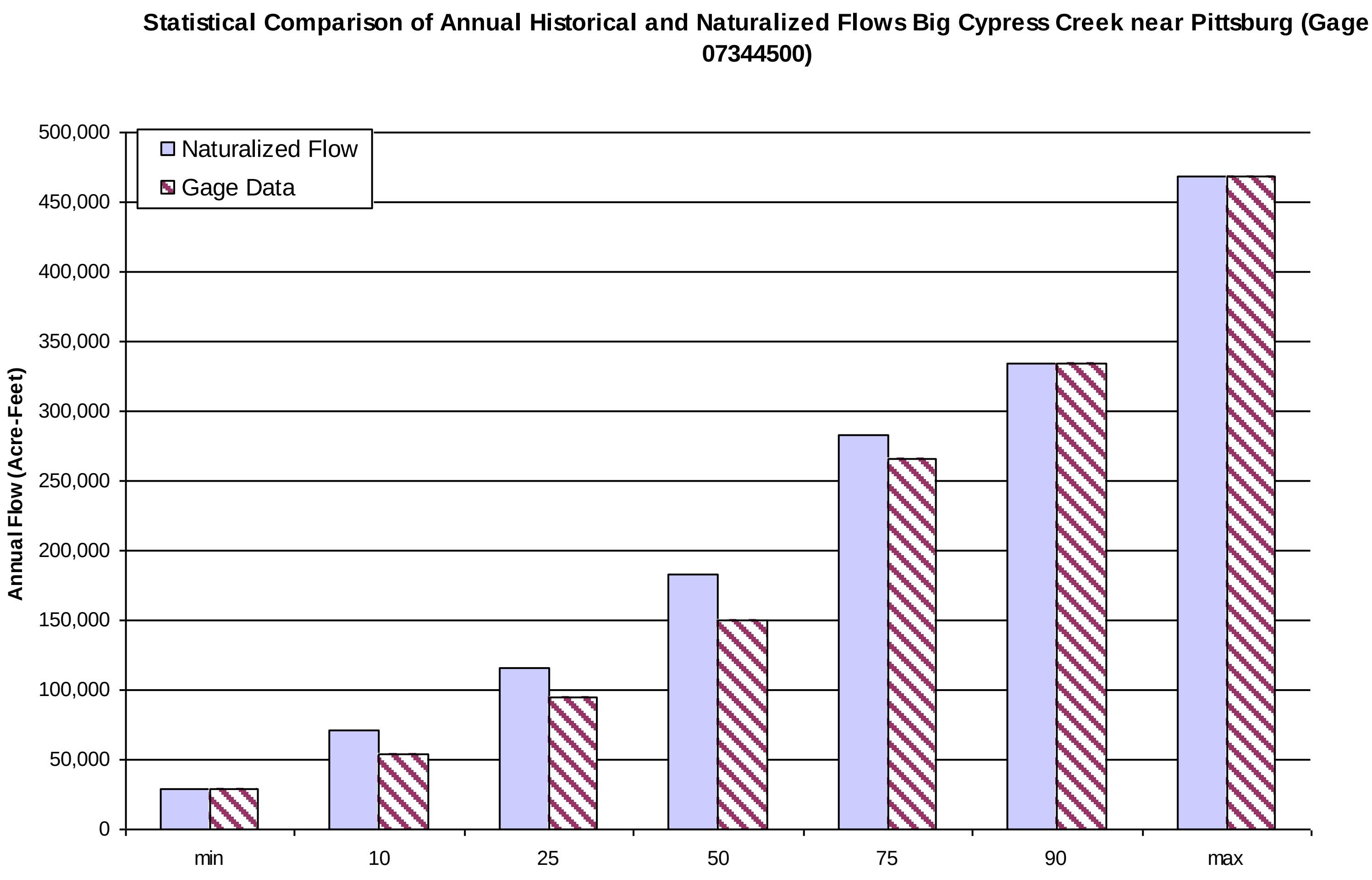


Figure 6 BC_JF Statistical Comparison of Annual Historical and Naturalized Flows

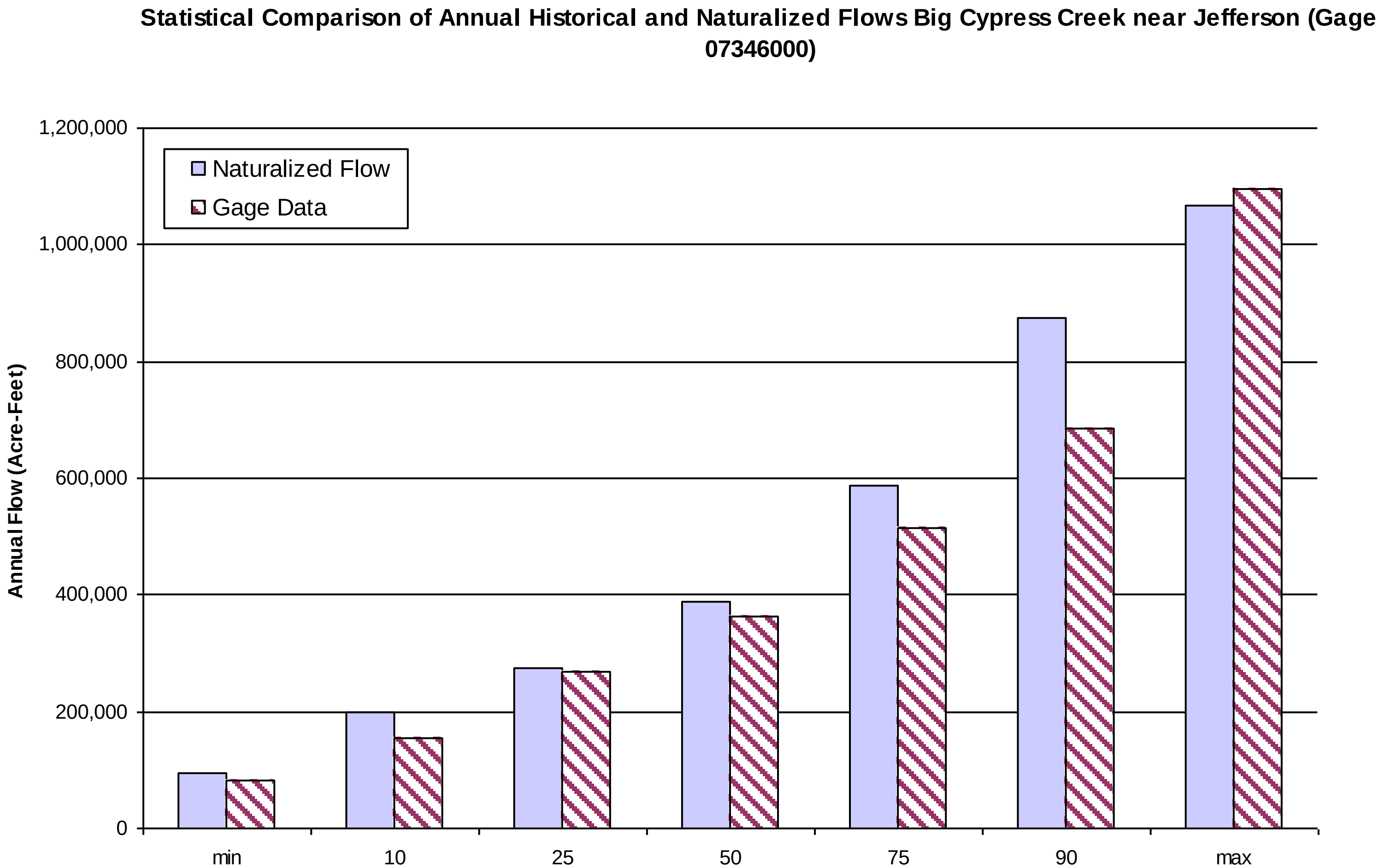


Figure 7 LC_JF Statistical Comparison of Annual Historical and Naturalized Flows

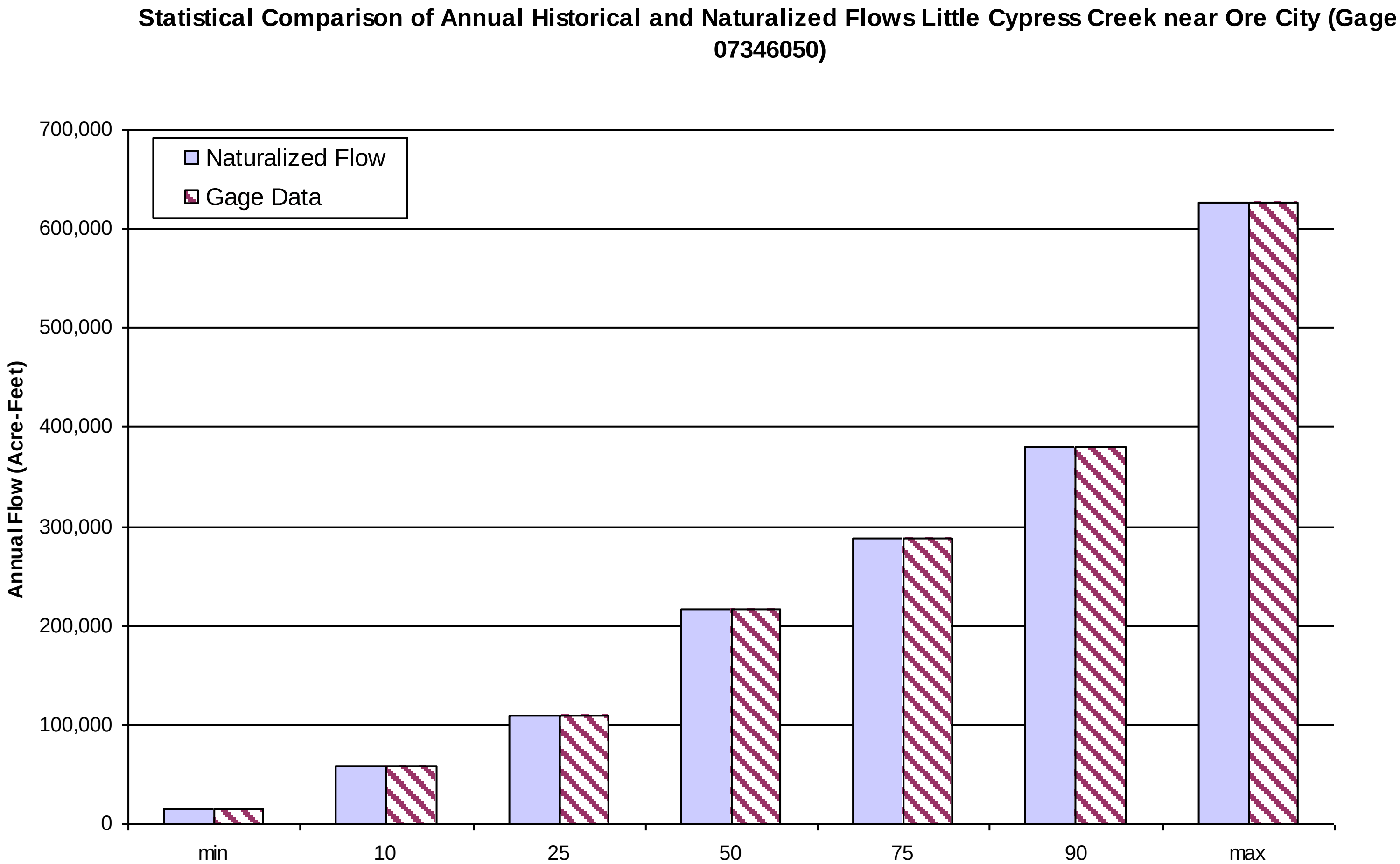


Figure 8 Monthly Statistics for BC_PB

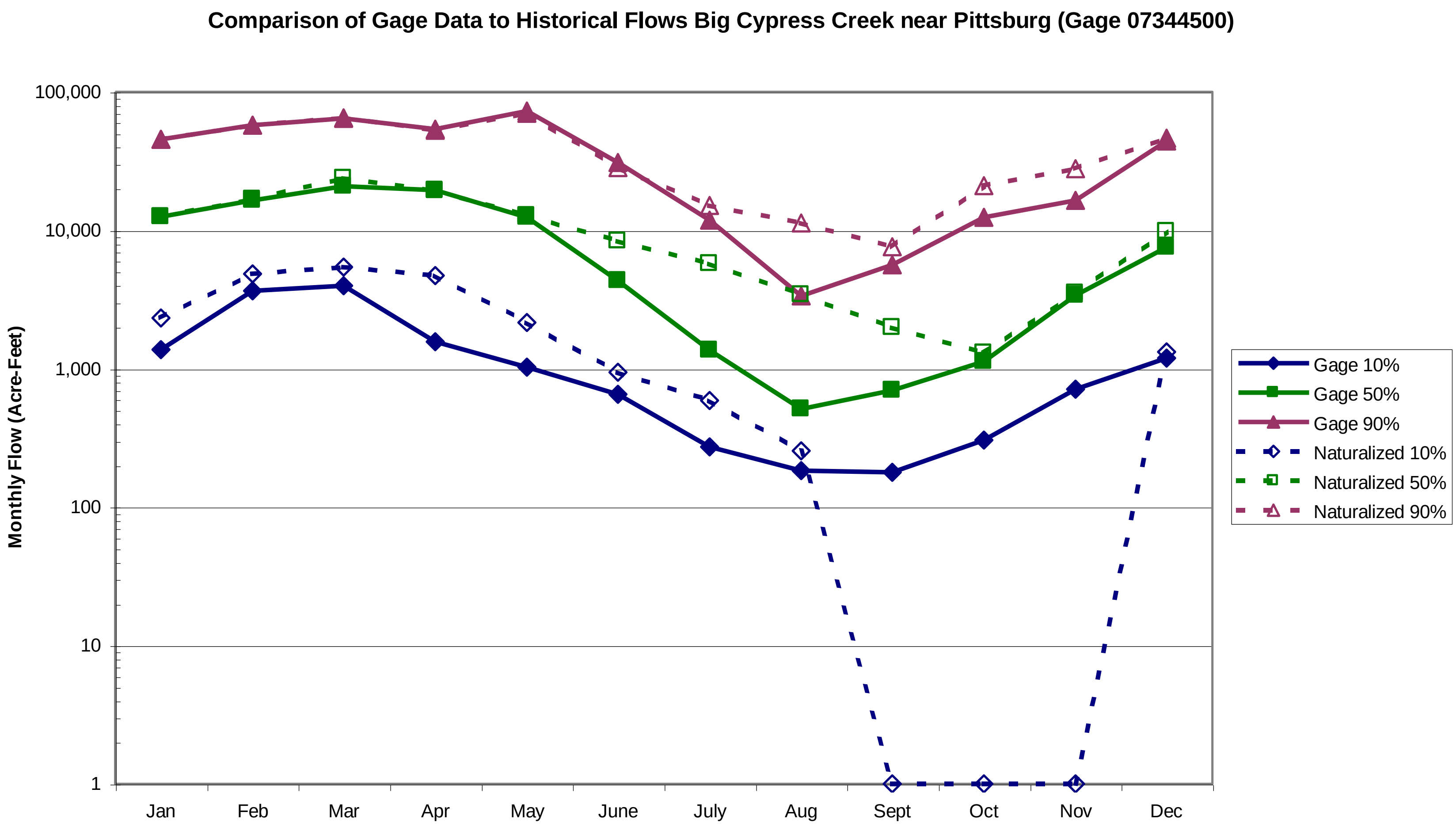


Figure 9 Monthly Statistics for BC_JF

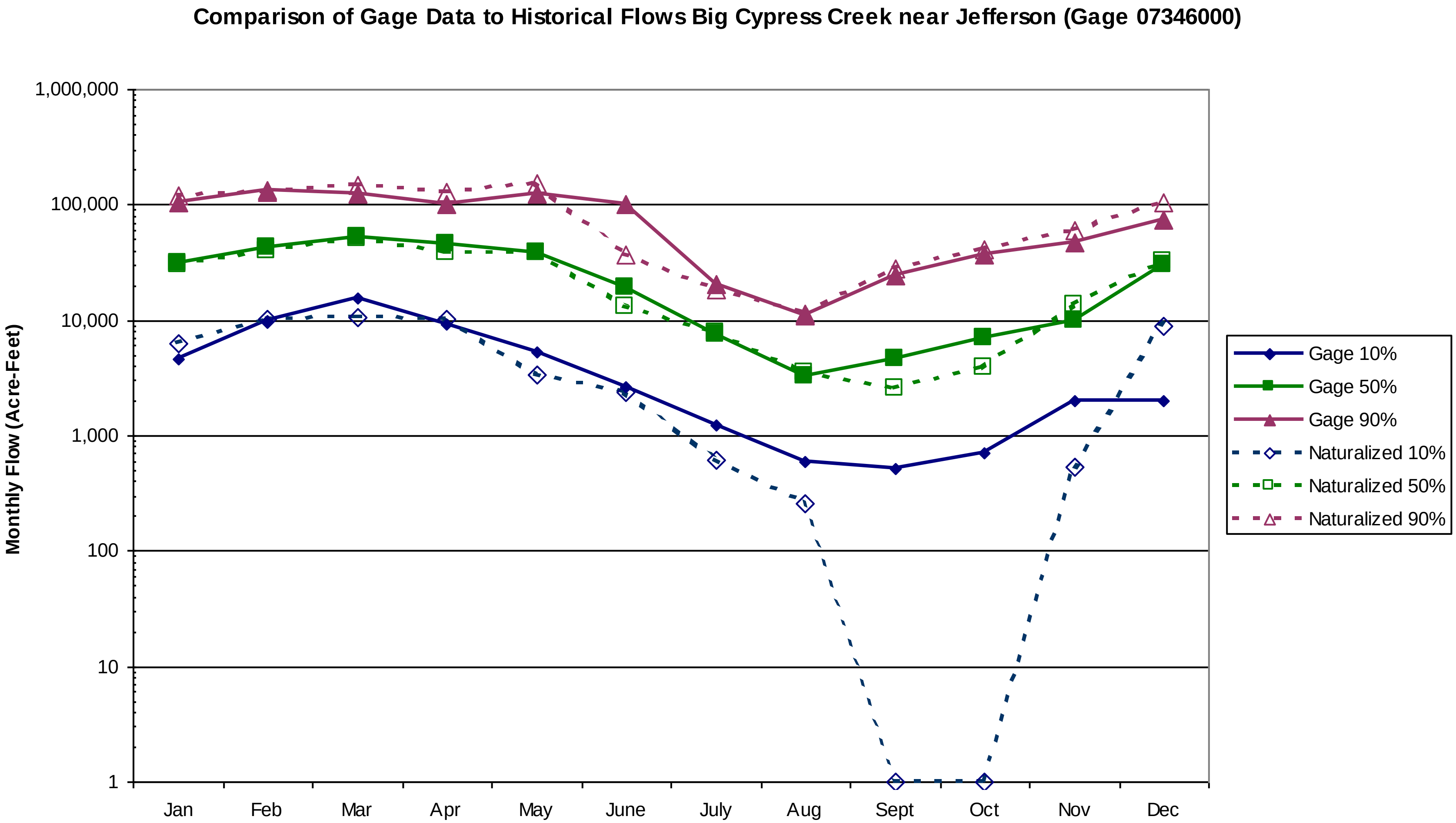
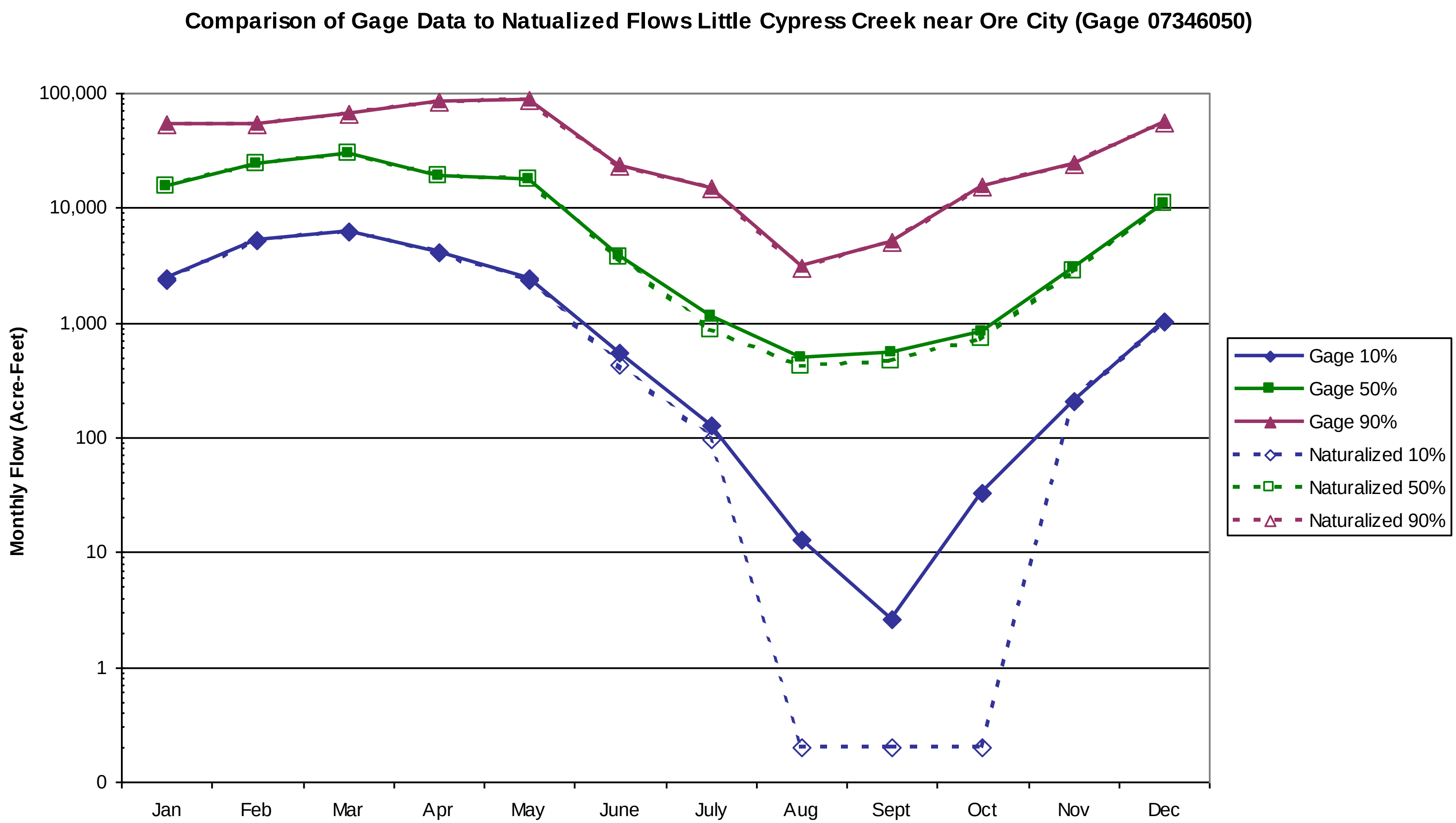


Figure 10 Monthly Statistics for LC_JF



3.2 Natural Streamflow at Ungaged Locations

Naturalized streamflow was derived ungaged locations in the Cypress Basin utilizing naturalized flow data from gaged sites and watershed parameters for both gaged and ungaged sites. Ungaged sites, or secondary control points, include any ungaged location within the basin where water availability calculations need to be performed including diversion locations for water rights, the ends of classified stream segments, and return flow or groundwater inflow locations. The map attached in Appendix K provides the locations of all primary (gaged) and secondary (ungaged) control points.

WRAP (VER 12/01), developed by Dr. Ralph A. Wurbs at Texas A & M University, has the capability to compute naturalized flows at ungaged sites by utilizing the drainage area method. Specifically, naturalized flows or inflows at gaged sites are input into the program along with total drainage areas of gaged and ungaged points. Watershed parameters were obtained from the University of Texas Center for Research Water Resources (CRWR). The specific methods used in this program are described in the WRAP (VER 12/01) user's manual. Table 6 provides the watershed parameters at all control points.

Table 6 Control Points and Corresponding Watershed Parameters

Control Point Name	CRWR Number	Downstream Control Point	Drainage Area (Sq. Mi.)	CN	Avg Precip (in.)
A10370	60404558301	A10360	6.8736	72.93	43.42
A10360	435	A10340	30.9307	69.24	43.53
A10350	60404559301	A10340	0.705	32.78	44.21
A10340	60404560301	A10320	74.0257	65.96	43.92
A10330	60404560501	A10300	74.0394	65.96	43.92
A10320	436	A10300	74.0394	65.96	43.92
A10310	441	A10300	46.2773	69.91	43.32
A10300	60404561001	A10220	165.7761	68.53	43.83
A10290	60404562002	A10220	3.8945	68.95	45.12
A10280	10405167301	A10250	0.8391	69.57	45.12
A10270	10405456301	A10260	0.0121	70	45.43
A10260	10405529301	A10250	2.4997	62.95	45.24
A10250	2697.003	A10240	32.6004	69.97	45.25
A10240	60404563001	A10220	36.26	71.65	45.28
A10230	60404563501	A10220	36.26	71.65	45.28
A10220	433	A10200	239.7953	70.22	44.26
A10200	60404590002	A10000	240.042	70.22	44.26
A10200	60404564301	A10000	240.042	70.22	44.26
A10200	442	A10000	240.042	70.22	44.26
A10180	10405284302	A10170	0.4987	67.5	46.27
A10170	10405461301	A10120	0.9109	66.05	46.25
A10160	10405518301	A10120	0.9028	68.62	46.52
A10150	2697.002	A10140	0.2461	70.76	46.42
A10140	3174.002	A10120	0.2532	70.73	46.42
A10130	10405284303	A10120	0.5895	71.66	46.57
A10120	60404565301	A10110	8.6031	69.44	46.42
A10110	3017.001	A10000	26.4541	70.52	46.45
A10100	60404567301	A10000	0.149	65.79	46.3
A10090	60404566301	A10000	0.8048	69.67	46.51
A10080	10405284301	A10070	0.1024	69.94	46.46
A10070	60404569301	A10010	3.6154	62.41	46.49
A10060	60404570301	A10010	0.4779	70.53	46.57
A10050	60404568301	A10010	0.0784	79.65	46.54
A10040	60404571301	A10010	0.1014	66.97	46.46
A10030	60404572301	A10010	0.0324	75.87	46.38
A10020	10575.004	A10010	2.2135	80.55	46.59
A10010	60404573301	A10000	45.7152	71.79	46.44
A10000	BC_PB	B10150	365.1115	69.83	44.85

Table 6 Control Points and Corresponding Watershed Parameters (Continued)

Control Point Name	CRWR Number	Downstream Control Point	Drainage Area (Sq. Mi.)	CN	Avg Precip (in.)
B10320	60404574301	B10310	0.4166	75.42	44.22
B10310	10250.001	B10150	1.9709	76.83	44.12
B10300	10405212301	B10150	0.7986	70.32	44.01
B10290	60404575301	B10150	1.0226	75.7	44.72
B10280	60404576501	B10270	21.4777	75.31	45.96
B10270	60404576301	B10150	21.4879	75.3	45.96
B10260	10405251301	B10150	0.4502	77.15	43.63
B10250	10404199301	B10150	370.209	64.61	46.75
B10240	10239.001	B10230	0.5283	79.65	46.64
B10230	60404577304	B10210	58.2012	70.54	46.34
B10220	60404578301	B10230	2.7574	70.02	46.09
B10210	60404579001	B10150	63.3506	73.71	45.89
B10200	60404580301	B10150	0.6791	78.66	45.39
B10190	10499.001	B10170	11.0515	73.43	45.65
B10180	60404581301	B10170	0.7938	71.11	45.51
B10170	60404582301	B10150	44.3155	75.03	45.17
B10160	348.005	B10040	0.34	87.89	44.65
B10150	60404582302	B10130	682.2326	69.54	44.98
B10140	431	B10130	1.0338	57.9	44.72
B10130	434	B10020	684.8503	69.55	44.97
B10120	60404583001	B10020	2.4049	68.84	44.7
B10110	60404584301	B10020	0.1216	79.29	44.79
B10100	60404585301	B10020	0.2249	73.84	44.96
B10090	60404586301	B10020	0.4032	73.07	45.42
B10080	60404587301	B10020	3.1229	60.04	45.31
B10070	60404588301	B10020	10.7174	65.88	45.8
B10060	60404588502	B10020	10.7304	65.92	45.8
B10050	60404589301	B10020	0.3276	70.98	46.26
B10020	429	B10010	885.949	68.96	45.11
B10030	432	B10020	0.1602	72.03	46.45
B10020	60404590301	B10010	885.949	68.96	45.11
B10010	60404590501	B10000	885.9533	68.96	45.11
B10000	BC_JF	F10230	885.954	68.96	45.11
C10050	10405080301	C10010	1.4	70.82	46.3
C10040	60404597301	C10010	0.0096	78	46.68
C10030	60404598301	C10010	1.7329	68.53	46.57

Table 6 Control Points and Corresponding Watershed Parameters (Continued)

Control Point Name	CRWR Number	Downstream Control Point	Drainage Area (Sq. Mi.)	CN	Avg Precip (in.)
C10020	60404599002	C10000	0.0143	70	47.05
C10010	60404599001	C10000	86.8685	65.4	46.98
C10000	BK_JF	F10180	370.1999	64.61	46.75
D10200	443	D10000	0.0327	55	42.91
D10190	10403997307	D10000	0.0432	55	42.99
D10180	10403997301	D10000	0.0607	61.1	42.99
D10170	10403997305	D10160	0.0992	55	42.99
D10160	10403997302	D10150	0.1335	55	42.99
D10150	10403997306	D10130	0.1534	55	42.99
D10140	10403997304	D10130	0.1789	55	42.99
D10130	10403997303	D10000	0.5308	57.53	43.00
D10120	10405054301	D10000	0.9856	60.42	42.91
D10110	10405272301	D10100	34.7912	67.98	44.32
D10100	10405272501	D10000	34.8323	67.98	44.32
D10090	60404601301	D10000	0.8241	64.14	44.96
D10080	60404602301	D10000	9.4172	68.43	43.7
D10070	60404603301	D10000	2.2216	72.85	43.44
D10060	60404604301	D10000	1.3259	71.99	44.23
D10050	10457.001	D10000	7.1486	67.87	45.01
D10040	60404605302	D10000	0.7809	64.91	44.94
D10030	60404605301	D10000	0.3049	70.55	45.04
D10020	60404606301	D10000	0.0196	62.25	45.16
D10010	60404607301	D10000	0.1574	76.39	45.16
D10000	LC_OC	E10060	393.1653	67.27	44.21
E10090	10405608301	E10080	1.0889	57.31	46
E10080	10405537301	E10060	1.3468	57.94	46.01
E10070	60404608301	E10060	0.1079	76.25	46.38
E10060	60404609001	E10040	539.859	66.25	44.69
E10050	60404609301	E10040	0.4741	57.7	46.38
E10040	60404610001	E10000	594.0014	65.86	44.86
E10030	10404254501	E10010	0.4527	65.03	47.46
E10020	10404254301	E10010	0.4527	65.03	47.46
E10010	60404611301	E10000	9.9421	61.84	47.5
E10000	LC_LF	F10160	691.2837	65.25	45.16
F10250	60404591301	F10230	0.1139	68.6	46.67
F10240	60404593301	F10230	1.0911	58.52	46.67
F10230	60404592001	F10220	927.8624	68.58	45.18

Table 6 Control Points and Corresponding Watershed Parameters (Continued)

Control Point Name	CRWR Number	Downstream Control Point	Drainage Area (Sq. Mi.)	CN	Avg Precip (in.)
F10220	60404594002	F10210	940.3851	68.52	45.2
F10210	60404595001	F10200	941.3446	68.52	45.2
F10200	60404595501	F10190	941.8336	68.53	45.2
F10190	60404596001	F10130	947.3888	68.51	45.21
F10180	10404198101	F10170	371.1018	64.64	46.75
F10170	60404600001	F10130	388.0644	64.64	46.75
F10160	60404612001	F10150	709.1771	65.26	45.21
F10150	444	F10130	711.6171	65.28	45.22
F10140	60404613001	F10130	5.7082	64.03	47.1
F10135	60404614501	F10080	2080.1317	66.58	45.53
F10130	60404614001	F10080	2080.1317	66.58	45.53
F10120	60404615301	F10080	0.4119	55.16	47.76
F10110	60404616301	F10080	2.9505	63.56	47.78
F10100	10405112301	F10080	1.0985	61.45	47.81
F10090	10405302301	F10080	0.3736	55	47.8
F10080	10404005001	F10050	2158.502	66.53	45.62
F10070	427	F10050	0.4925	70	49.04
F10060	430	F10050	1.2759	100	48.62
F10050	428	F10005	2351.4406	66.77	45.84
F10040	439	F10030	1.152	61.6	47.74
F10030	60404617301	F10020	1.1542	61.58	47.74
F10020	60404618001	F10010	304.9603	61.15	47.59
F10010	440	F10005	329.274	60.61	47.58
F10005		F10000	2791.6004	66.21	46.08
F10000	DN_CL	OUT	2791.6004	66.21	46.08
10070	10378.001	OUT	0.5905	80.86	47.92
10060	438	10010	5.0801	62.34	47.09
10050	60404619301	10040	0.8384	75.04	47.24
10040	60404620301	10010	3.8182	74.8	47.25
10030	10338.001	10010	0.0037	86	46.97
10020	60404621301	10010	0.5407	67.2	47.12
10010	437	OUT	105.8047	34.29	47.2

The drainage area method distributes flow from a gaged to an ungaged location utilizing the following equation:

$$Q_{ungaged} = Q_{gaged}\left(\frac{A_{ungaged}}{A_{gaged}}\right)$$

where Q represents the naturalized flow at the gaged and ungaged sites and A represents the drainage area for the gaged and ungaged sites.

WRAP (VER 12/01) also allows the naturalized flow to be distributed to the secondary control points by utilizing the NRCS curve number and annual precipitation. The NRCS Curve Number method utilizes the watershed characteristics as follows:

$$Q = \left[\frac{(P-0.2S)^2}{(P+0.8S)}\right]$$

$$if\ \ P \geq 0.2S$$

$$Q = 0 \longrightarrow if\ \ P \leq 0.2S$$

$$where\ \ S = \left(\frac{1000}{CN}\right) - 10$$

In this equation S represents the potential maximum retention, an upper limit on the amount of water that can be removed through surface storage, infiltration, or other hydrologic methods by the watershed. The value for S is derived from the curve number. The CN is a dimensionless parameter ranging in value from 0 to 100 that represents the ability of the watershed to absorb water. A CN of zero represents a watershed that is capable of absorbing all rainfall regardless of amount while a CN of 100 represents an impervious watershed that is incapable of absorbing any rainfall.

WRAP (VER 12/01) utilizes the following algorithm to calculate flows at ungaged sites:

1. The runoff at the gage (Q) is computed by dividing streamflow at the gage by the drainage area of the gage and multiplying the product by a conversion factor to change the units of runoff from acre-feet per month to inches per month.

2. The precipitation depth (P) at the gage is calculated through an iterative solution of the above equation given the runoff computed in step 1 and the value of S.

3. The precipitation depth at the ungaged site is computed by adjusting the precipitation depth at the gaged site by the ratio of the mean precipitation depth (M) at the ungaged

and gaged sites.

$$P_{ungaged} = P_{gaged}\left(\frac{M_{ungaged}}{M_{gaged}}\right)$$

4. The runoff at the ungaged site is then computed by inputting the values for P and S at the ungaged site in the NRCS CN method equation. The computed value for the runoff is then converted to streamflow at the ungaged site by multiplying it by the drainage area of the ungaged site. Finally, a conversion factor is used to change the units of streamflow from inches per month to ac-ft per month.

In this study, the watershed parameters (the CN, mean precipitation, and drainage areas at gaged and ungaged sites) were derived by the CRWR using a geographic information system (GIS) grid basis. The CRWR used USGS digital elevation models (DEMs), Environmental Protection Agency (EPA) river reach segments, USGS gaging locations, U.S. Department of Agriculture-Parameter-Elevation Regressions on Independent Slopes Model (PRISM) for mean annual precipitation, TNRCC water right diversion locations, and curve numbers derived by the NRCS at the Blackland Research Center at Texas A & M to create a geospatial database and model of the basin. From this geospatial model, the CRWR delineated drainage areas, curve numbers and mean annual precipitation for each water right diversion location within the basin. Although WRAP (VER 12/01) allows for distribution of the naturalized streamflow using the curve number and annual precipitation, the decision was made by the TNRCC to only use the drainage area ratio to distribute the flows to the secondary control points.

3.2.1 Distribution of Natural Flows Considering Channel Losses

No specific channel losses were discovered in the Cypress Basin. Refer to the discussion in Section 3.1.3.

3.2.2 Impacts on Instream Flows

The impacts on instream flows were monitored by comparing unappropriated and regulated flows for the various model scenarios at key points in the watershed for each model scenario.

Key control points at which these comparisons were made include:

- Big Cypress at Jefferson (B10000)
- Black Cypress Bayou at Jefferson (C10000)
- Little Cypress Bayou at Jefferson (E10000)

- Just upstream of Caddo Lake (F10080)

A description of these appropriated and regulated flows is discussed in Section 5.0 of this report.

3.3 Adjusted Net Reservoir Evaporation

Adjusted Net Evaporation data are utilized in water availability modeling in two ways:

1. Computation of naturalized streamflows to remove the effects of reservoirs on flow.
2. Water availability computations at primary and secondary control points located at reservoirs.

Adjusted Net Evaporation for reservoirs, explained in Section 3.3.2, was derived from gross reservoir evaporation data and precipitation data obtained from the TWDB, and runoff data from available USGS gage data or available naturalized flow data. Table 7 summarizes the sources used to estimate the runoff for each of the four quadrangles in the Cypress Basin.

3.3.1 Evaporation Data Sources

The TWDB has developed historical evaporation rates for the State of Texas since the 1960s. Their most recent data set is for gross evaporation rates from 1950 through 1996 using an improved methodology not used in previous evaporation data sets. Evaporation data for the period from 1940 through 1953 are not available using the new method, so previously developed data was used. Precipitation data were also obtained from TWDB. The evaporation and precipitation data are available by 1 degree quadrangle. Runoff data were developed based on USGS gaged flows as shown in Table 7.

Table 7 Methods for Estimating Quadrangle Runoff

Quadrangle	Gage	County	USGS Number	Drainage Area (Sq. Mi.)	Period
412	North Sulphur River near Cooper, Texas	Lamar	7343000	276	1/50-Present
413	Big Cypress Creek near Pittsburg, Texas	Camp	7344500	366	4/46-12/62, 10/67-9/93, 10/94-9/96 & 10/97-9/98
512	Big Sandy Creek near Big Sandy, Texas	Upshur	8019500	231	1/39 - 9/62
513	Little Cypress Creek near Jefferson, Texas	Harrison	7346070	675	6/46-9/99

3.3.2 Procedures for Estimation of Adjusted Net Reservoir Evaporation

Adjusted Net Reservoir Evaporation is the rate at which water is lost to evaporation from the surface of a reservoir. It represents the net impact of evaporation and of rainfall directly on the reservoir surface. The equation for adjusted net reservoir evaporation used in this study is:

$$ANE = GE - R + xR$$

where *ANE* is the adjusted net reservoir evaporation rate, *GE* is the gross reservoir evaporation rate, *R* is the rate of precipitation, and *xR* is the fraction of rainfall that would have been in the runoff in the absence of a reservoir. Table 7 shows the quadrangles used for estimation and

Table 8 shows the methodology for derivation of *xR* for each quadrangle.

Table 8 Sources of Data for Deriving Net Evaporation Rates

Reservoir	Quadrangle Factors
Bob Sandlin Reservoir	0.2966(412) + 0.2943(413) + 0.2055(512) + 0.2036(513)
Caddo lake	0.0000(412) + 0.1316(413) + 0.0000(512) + 0.8684(513)
Cypress Springs Reservoir	0.3765(412) + 0.1944(413) + 0.2958(512) + 0.1332(513)
Ellison Creek Reservoir (Lone Star Lake)	0.0294(412) + 0.3578(413) + 0.1135(512) + 0.4992(513)
Gilmer Reservoir	0.1007(412) + 0.1122(413) + 0.3846(512) + 0.4025(513)
Johnson Creek Lake	0.0000(412) + 0.3400(413) + 0.0000(512) + 0.6600(513)
Lake O' the Pines	0.0000(412) + 0.2650(413) + 0.0000(512) + 0.7350(513)
Monticello Reservoir	0.3272(412) + 0.2701(413) + 0.2257(512) + 0.1770(513)
Peacock Reservoir	0.0219(412) + 0.4348(413) + 0.0526(512) + 0.4906(513)
Welsh Reservoir	0.1699(412) + 0.3849(413) + 0.1240(512) + 0.3212(513)

(**) Numbers in parentheses indicate evaporation quadrangles.

The sources of the data needed to determine reservoir evaporation rates are as follows:

Gross Reservoir Evaporation – The TWDB recently revised its estimate of gross reservoir evaporation rates for 1954-1996. Previous TWDB data, computed by slightly different methods, are available for 1940-1953. The TWDB gross evaporation data are available by quadrangle for the entire state, and monthly values for a specific location are derived by taking a weighted average for up to four nearby quadrangles.

Precipitation – Precipitation data by quadrangle are available from the TWDB for 1940 through 1996.

The Portion of Rainfall That Would Have Run Off in the Absence of a Reservoir – Runoff (expressed as inches) is generally obtained from a nearby USGS gage or gages. Table 7 shows the source of runoff data for each quadrangle bordering the Cypress Basin.

Following TNRCC recommended guidelines, reservoirs under 5,000 ac-ft were not included in the naturalized flow calculations. Adjusted net evaporation rates were calculated for each quadrangle in the Cypress Basin to be included in the model. For those reservoirs under 5,000 ac-ft, the adjusted net reservoir evaporation was taken from the quadrangle in which each reservoir was located. These adjusted net evaporations were input into the model for each quadrangle to be utilized for evaporation allocation to each reservoir under 5,000 acre-feet. In the Cypress Basin, the majority of the reservoirs were under 2,700 ac-ft. There were five reservoirs between 1,000 and 2,700 ac-ft but no change in content data was available. Therefore, the evaporation for these reservoirs could not be determined without estimating reservoir operations. The remainder of the reservoirs in the basin were under 1,000 ac-ft and therefore were not included in the naturalized flow calculation.

3.3.3 Comparison of Evaporation Data Sets

Monthly values of adjusted net evaporation for each of the nine major reservoirs were used as input to the 51-year period WRAP (VER 12/01) model of the Cypress Basin. Adjusted net evaporation records were consistent for the majority of the major reservoirs, primarily because the Cypress Basin is one of the smaller basins in Texas and the climate and rainfall patterns are the same throughout the basin. Adjusted net evaporation data for each 1-degree quadrangle were input for simulation of the minor reservoirs. This data was also relatively consistent for the quadrangles used in the study. Evaporation input for the major and minor reservoirs is found in Appendix S.

3.4 Reservoir Elevation-Area-Capacity Relationships

Area-capacity relationships in this study were derived from two primary sources: original area-capacities were used for reservoirs with capacities over 5,000 acre-feet and a standard area-capacity relationship was developed for reservoirs with capacities less than 5,000 acre-feet. Table 9 is a list of major reservoirs in the Cypress Basin (over 5,000 acre-feet of conservation storage) and the area-capacity data source used for each.

Table 9 Major Reservoirs in the Cypress Basin Area Capacity Source Information

Reservoir	Date of Impoundment	Conservation Storage Original (acre-feet)	Original Area-Capacity Source	Conservation Storage Surveyed (acre-feet)
Welsh	1976	23,590	Southwestern Electric Power Company	N/A
Monticello	1973	40,100	Texas Water Development Board (TWDB) Report 126, Part I, Oct 1974	34,740
Johnson Creek	1961	10,100	Texas Water Development Board (TWDB) Report 126, Part I, Oct 1974	N/A
Lake Cypress Springs	1971	72,800	Texas Water Development Board (TWDB) Report 126, Part I, Oct 1974	67,690
Lake Bob Sandlin	1975	213,350	Texas Water Development Board (TWDB) Report 126, Part I, Oct 1974	228,138
Ellison Creek	1943	24,700	Texas Water Development Board (TWDB) Report 126, Part I, Oct 1974	N/A
Lake O' the Pines	1958	251,000	Texas Water Development Board (TWDB) Report 126, Part I, Oct 1974	241,061
Lake Gilmer	1998	12,720	NRS Consulting Engineers	12,720
Caddo Lake	1914	59,560	Texas Water Development Board (TWDB) Report 126, Part I, Oct 1974	N/A

The elevation-area-capacity relationship for a reservoir is necessary to describe the storage capacities of the reservoir along with the evaporation potential. This relationship, which is also referred as the area-capacity curve, is typically developed during the reservoir design phase from the topography of the inundated area of the reservoir. The original capacity at the normal operating pool of a reservoir generally complies with the authorized capacity of the water use permit. Once impoundment of a reservoir begins, the reservoir accumulates sediment carried by the upstream inflow. The sediment successively deposited within the reservoir reduces the capacity and water surface area of the reservoir at various storage stages, thereby reducing the yield and changing evaporative characteristics of the reservoir.

3.4.1 Large Reservoirs

The Cypress Basin has nine major reservoirs, Lake Monticello, Lake Bob Sandlin, Johnson Creek Reservoir, Lake Cypress Springs, Lake O' the Pines, Ellison Creek Reservoir, Caddo Lake, Welsh Reservoir, and Lake Gilmer. The storage capacity data for these reservoirs, obtained from the sources listed in Table 9, were further reviewed for consistency with other available information, such as the "water resource" data published by U.S. Geological Survey. All the area-capacity data, including those of year 2000 condition, were plotted and fitted to power-type equations. A number of twelve or less data points (depending on data availability) were selected as input to the WRAP (VER 12/01) model to define the area-capacity curve.

The method for developing the year-2000 area-capacity curve or relationship for each of the major reservoirs can be described as follows:

- The conservation storage capacity of each reservoir for year-2000 is to be reduced by the accumulated amount of sediment entering the reservoir between the date of the latest survey and year-2000. The amount of accumulated sediments is equal to the product of annual sedimentation rate, drainage area of the reservoir, and number of years between the latest survey and year-2000. The sedimentation rate can be obtained from data of the latest survey and the original design (see Table 10).

Table 10 Sedimentation Rates for Major Reservoirs in the Cypress Basin

Reservoir	Original Capacity (Acre-Feet)	Date of Impoundment	Surveyed Capacity (Acre-Feet)	Date of Survey	Period (Years)	Drainage Area (Square Miles)	Sedimentation Rate (Ac-Ft per Square Mile Per year)
Welsh	23,590	1976	Not Available	Unknown	-	21.2	0.18
Monticello	40,100	1972	34,740	Feb 1998	2	36	0.18
Johnson Creek	10,100	1961	Not Available	Unknown	-	11	0.18
Lake Cypress Springs	72,800	1970	67,690	Apr 1998	2	75	0.13
Lake Bob Sandlin	213,350	1975	228,138	Feb 1998	2	239	0.36
Ellison Creek	24,700	1943	Not Available	1952	-	37	0.18
Lake O' the Pines	251,000	1957	241,061	Feb 1998	2	880	0.11
Lake Gilmer	12,720	1998	12,720	1998	2	35.6	0.00
Caddo Lake	59,560	1914	Not Available	1952	-	2,700	0.11

Note:Surveyed capacities are from TWDB surveys

- It is assumed that the sediment accumulated within a reservoir is distributed at all elevations of the reservoir. The surface area of the reservoir at each elevation is then reduced due to sediment accumulation. The reductions of surface area at all elevations are assumed to be equal. This assumption constitutes the basis of the "area increment" method.

- This "area increment" method is an empirical procedure that reduces the water surface area from the area-capacity curve of the latest survey by a constant area until the new calculated storage capacity is reduced by the total volume of accumulated sediment.

3.4.2 Small Reservoirs

Standard elevation-area-capacity relationships have been used in the water availability analyses for small reservoirs with less than 5,000 ac-ft of storage. The Natural Resource Conservation Service was involved in the design and construction of many similar impoundments within the Cypress Basin, and area-capacity curves for these impoundments were obtained from the NRCS office in Temple, Texas. The TNRCC Dam Safety files and water rights files were examined to locate additional area-capacity curves for small impoundments within the Cypress Basin.

For small reservoirs, standardized area-capacity curves have been generated using an equation of the form:

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

This form of equation, known as a power function, is the only equation form available to represent area-capacity relationships in WRAP (VER 12/01). To obtain the coefficients a, b, and c, regression analyses of available area-capacity data for existing small reservoirs have been performed. All available area-capacity curves for the small reservoirs in the Cypress Basin were plotted, and power function regression analyses were performed to obtain the best-fit equation. The coefficient of determination, or R^2 value, is an indicator that ranges in value from 0 to 1 and reveals how closely the best-fit equation corresponds to the data. Separate regression analyses were performed on the reservoirs greater than 600 ac-ft, reservoirs less than 600 ac-ft, and the reservoir data combined. The R^2 value for the reservoirs less than 600 ac-ft was lower than the R^2 value for the reservoir data combined. In addition, the data only contained one reservoir greater than 600 ac-ft. Therefore, the results of the regression analyses performed on the combined reservoir data were used to generate the area-capacity relationship for the small reservoirs in the Cypress Basin. The best-fit equation for all the data resulted in the following coefficients. The R^2 for the best-fit line is also shown below.

$$a = 0.9788 \quad b = 0.5841 \quad c = 0 \quad R^2 = 0.7806$$

The graphs for the equation shown above and the original data points are shown in Figure 11. The area capacity relationship developed for small reservoirs with capacities less than 5,000 acre-feet is:

$$Area = 0.9788(Capacity)^{0.5841} + 0.00$$

The reservoir coefficients that were calculated were then input into WRAP (VER 12/01) to allow the surface area to be determined based on the storage in the reservoir during each month of the simulation, therefore, allowing WRAP (VER 12/01) to remove the correct amount of evaporation from each of the minor reservoirs each month. The evaporation amount is determined by WRAP (VER 12/01) by multiplying the surface area by the amount of evaporative loss for the quadrangle that the minor reservoir is located. The net adjusted evaporation losses for each quadrangle are input in the evaporation records card.

3.5 Aquifer Recharge

Aquifer recharge was not analyzed in this study (see section 3.1.3).

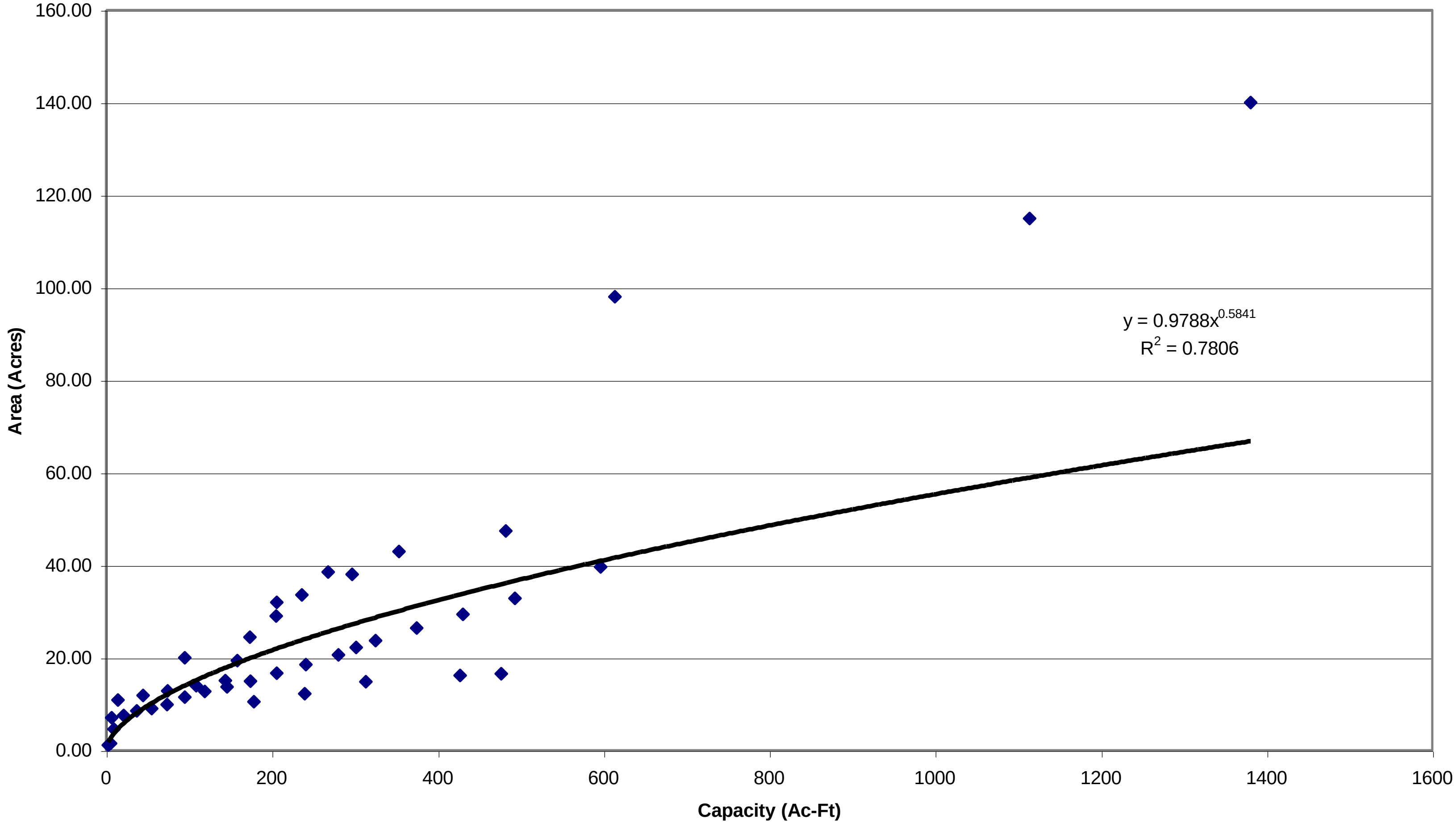
3.5.1 Historical Recharge

Not Applicable

3.5.2 Enhanced Recharge

Not Applicable

Figure 11 Cypress Basin Standard Area-Capacity Curve Reservoirs Less Than 5,000 acre-feet



4.0 WATER AVAILABILITY MODEL OF THE BASIN

WRAP (VER 12/01) was used to model the water availability of the Cypress Basin, utilizing input data specific to the Cypress Basin including water rights, reservoir information, and naturalized streamflows. The WRAP (VER 12/01) program was originally developed by Dr. Ralph Wurbs at the Texas A & M University in March 1986. Throughout the evolution of the WAM process and completion of six river basins, WRAP (VER 12/01) has undergone numerous improvements and upgrades. WRAP was selected by the WAM Management Team as the best model available to model the Texas prior appropriation system, as well as meet the requirements set forth by SB1. Specific parameters utilized in WRAP (VER 12/01) will be described in the following sections.

4.1 Description of WRAP Model

The WRAP (VER 12/01) program was designed to simulate management and use of the streamflow and reservoir storage resources of one or more river basins under the prior appropriation system. The WRAP (VER 12/01) program is capable of evaluating river basins that have numerous diversions and use types (including hydropower), systems with multiple reservoirs, complex allocation systems, and reservoirs with multiple users. The model may be applied to various types of planning and management situations to evaluate alternative management strategies.

WRAP (VER 12/01) simulates a river basin by performing water accounting computations at each water right and control point based on the prior appropriation system in monthly time steps. This water accounting system tracks the effects of reservoir storage, instream flow, diversions, and return flows on streamflow data. Simulations using the model are typically based on the following assumptions:

1. Basin hydrology is represented by an assumed repetition of historical period of record naturalized streamflows and reservoir evaporation rates.
2. The full amounts of all permitted water rights requirements are met as long as water is available from streamflow and/or specified reservoir storage.

Characteristics of specific water rights are incorporated as assumptions in the input data, such as in the WR record, WS record, and the OR record. These input cards describe how a water right will be simulated (from run of river, reservoir storage, or both), how the water rights will be divided (into use types and priority), and how multiple-reservoir operations will be defined.

4.1.1 Base WRAP Model

The WRAP (VER 12/01) model works by performing a water accounting simulation utilizing a series of loops. Specifically, the WRAP (VER 12/01) simulation is composed of the following loops:

1. **Loop 1:** The input data including water rights, storage-area tables, basin configuration, use types, return flow factors, and gains and losses in the basin are read into the program and water rights are then ranked in priority order.
2. **Loop 2:** The hydrology records, inflow and evaporation, are read and adjustments for negative incremental flows and December return flows (made to January flows) are performed in an annual loop.
3. **Loop 3:** A monthly loop is performed in which net-evaporation-precipitation adjustments are made, spills are computed based on monthly varying storage capacities, flow adjustments for constant inflow/outflow are computed, a water right loop is performed, and then control point and reservoir records are developed. The water rights loop is run for each water right in priority order and is composed of determining the amount of water available for each water right; checking unappropriated and regulated flows; making diversions, reservoir releases, and return flows; adjusting available streamflows at all control points; and creating output records for each water right.

4.1.2 Basin Specific WRAP Model

No basin specific changes were made to the WRAP (VER 12/01) program for modeling the Cypress Basin.

4.2 Development of WRAP Water Rights Input File

Water rights, input files, and a river basin control point schematic were created using the revised TNRCC master water rights list, the written certificates of adjudication and water rights permits, TNRCC adjudication maps, and geo-referenced data from the TNRCC (obtained from the CRWR). The basic steps included in creating the water right input card include:

- Identifying primary and secondary control points.
- Obtaining all water right diversion locations from TNRCC.
- Determining diversion amounts, use types, and priority dates for all water rights within the basin.
- Determining impoundment amounts for water rights, storage, and reservoir information (input in the WS card).
- Compiling and computing return flows for all industrial and municipal water right diversions, including interbasin transfers.

- Computing monthly distribution factors to distribute annual diversion amounts.
- Creating a control point schematic.
- Input naturalized streamflow and evaporation data.

Each task methodology is described in the following sections.

4.2.1 Control Points

Control points are used in the WRAP (VER 12/01) program as a means of spatially referencing the position of all inflow and outflow in a river basin. The actual formulation of the basin schematic used for the WRAP (VER 12/01) program is done in the control point (CP) records. The CP records list control points from upstream to downstream. The river layout is reproduced in the CP records by listing each control point and following it with the next downstream control point. In the Cypress Basin Water Availability Model, control points were segregated into two distinct types:

- Primary control points – five points located at USGS streamflow gage locations and one control point located downstream of Caddo Lake.
- Secondary control points – points located at water right diversions or impoundments, water import locations, groundwater return flow sites, return flow sites, and classified stream segments that are not primary control points. Naturalized streamflow is distributed by WRAP (VER 12/01) to these secondary control points based on drainage area ratio.

Figure 1 shows the primary control point locations and their relationship to the secondary control points. The period of record for the primary control points is shown in Figure 3. These primary control points were developed using the following general criteria:

- Streamflow gages with over 20 years of record and drainage areas over 100 square miles.
- Spatial distribution of primary control points throughout the basins
- Reservoir control points were avoided if possible due to the difficulty in obtaining accurate information on reservoir discharges

There was one exception to the above criteria. One primary control point was developed to define the watershed of Caddo Lake. This control point was created at a location where there was no USGS gage. Therefore, historical records were defined as follows:

- Downstream of Caddo Lake – flow for the Caddo Lake watershed was determined using a drainage area ratio for the drainage area of Caddo Lake with USGS gage 8019000 (Lake Fork Creek near Quitman, Texas).

The control points with calculated flows (primary) are easily discernable from control points with estimated flows at ungaged sites (secondary). Both primary and secondary control points utilize an alphanumeric six-digit code in the form of AXXXXX. The six-digit code for primary control points is defined below:

- A represents the letter assigned to the primary control point.
- XXXXX is equal to 10000.

Each primary control point in the Cypress Basin was assigned a letter of the alphabet. The alphanumeric six-digit code for the primary control points is the letter assigned to that control point followed by the number 10000. For example, the primary control point Big Cypress Creek near Pittsburg (BC_PB) was labeled as A10000, and Big Cypress Creek near Jefferson (BC_JF) was labeled B10000 in the model.

The six-digit code for the secondary control points is defined below:

- A represents which primary control point subwatershed the secondary control point is located within.
- XXXXX represents the relative location to the primary control point.

The secondary control points are numbered in increasing order from downstream to upstream in each primary control point subwatershed. For example, in the subwatershed of A10000, the first secondary control point upstream from A10000 was labeled A10010.

The water quality stream segment control points were identified as part of the CRWR dataset and used as secondary control points with no diversions at the points. The water quality stream segments were also numbered with the six-digit code. Again, the letter in the first character of the name identifies which primary control point subwatershed in which the the water quality stream segment is located.

4.2.2 Monthly Demand Distribution Factors

Diversion amounts associated with each water right were input into the WR record in WRAP (VER 12/01) as an annual amount in acre-feet per year (ac-ft/yr). The annual values are then distributed by the monthly distribution factors for each use type as specified in the UC record in WRAP (VER 12/01). Seasonal use (demand) patterns were determined for municipal, industrial, irrigation, mining, and other water uses. Historical water consumption data was used to derive the seasonal pattern for each type of water use. The historical consumption data were derived from water use records submitted annually to the TNRCC by the water right holders. Table 11 shows the corresponding distributions for the different categories of water use.

For each individual water right corresponding to a specific type of water use, averages were computed for water consumption for each of the twelve months per primary control point. The monthly average was then divided by the annual average to produce a percent value to represent monthly consumption for the entire basin.

No significant trend of water demand pattern was indicated from one region to another in the Cypress Basin. Therefore, only one set of use data for each type of water use for the entire basin was used.

Table 11 Seasonal Distribution Factors for the Cypress Basin

		Monthly Average for period of record (acre-feet)												
		JAN	**FEB**	**MAR**	**APR**	**MAY**	**JUNE**	**JULY**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**ANNUAL**
Irrigation	BCPB	0.00	0.26	0.39	2.14	3.16	17.13	19.59	23.59	5.55	1.97	0.55	0.00	74.33
	BKJF	0.00	0.00	0.00	0.00	0.00	0.02	0.22	0.29	0.00	0.00	0.00	0.00	0.53
	DNCL	0.04	0.16	0.39	1.32	12.41	31.16	36.77	43.05	32.97	20.88	16.30	12.67	208.13
	LCJF													0.00
	LCOC													0.00
	BCJF	0.00	0.00	0.39	0.80	1.39	5.21	8.97	12.60	8.20	9.06	0.53	0.00	47.15
	Average	0.01	0.10	0.29	1.07	4.24	13.38	16.39	19.88	11.68	7.98	4.35	3.17	82.53
	Distribution	**0.01**	**0.13**	**0.35**	**1.29**	**5.14**	**16.21**	**19.85**	**24.09**	**14.15**	**9.67**	**5.27**	**3.84**	**100.00**
Municipal	BCPB	241.44	220.15	229.93	236.14	272.68	299.46	344.74	344.77	305.56	277.41	250.85	253.30	3276.44
	BKJF													
	DNCL	456.13	411.23	455.57	455.18	494.36	530.01	566.88	571.42	511.14	498.02	442.95	463.33	5856.21
	LCJF													
	LCOC													
	BCJF	111.03	100.95	108.48	107.74	119.01	124.71	135.52	135.29	120.92	114.51	107.53	108.49	1394.16
	Average	269.53	244.11	264.66	266.35	295.35	318.06	349.05	350.49	312.54	296.64	267.11	275.04	3508.94
	Distribution	**7.68**	**6.96**	**7.54**	**7.59**	**8.42**	**9.06**	**9.95**	**9.99**	**8.91**	**8.45**	**7.61**	**7.84**	**100.00**
Industrial	BCPB	582.42	606.54	605.42	610.89	669.58	1110.46	1261.34	1185.32	842.57	883.20	758.03	701.89	9817.68
	BKJF	0.00	0.00	0.00	0.00	0.00	0.10	0.10	0.06	0.04	0.00	0.00	0.00	0.29
	DNCL	61.93	58.39	64.72	60.88	61.80	74.74	61.29	64.24	66.19	58.67	59.35	66.65	758.85
	LCJF	1.55	1.57	2.51	1.63	1.12	0.88	0.84	0.90	0.53	0.41	0.37	0.16	12.47
	LCOC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	BCJF	15030.18	13969.23	15441.61	16659.74	18437.85	19403.55	23909.59	24114.04	23305.42	18445.10	15915.47	16771.66	221403.45
	Average	2612.68	2439.29	2685.71	2888.86	3195.06	3431.62	4205.53	4227.43	4035.79	3231.23	2788.87	2923.39	38665.46
	Distribution	**6.76**	**6.31**	**6.95**	**7.47**	**8.26**	**8.88**	**10.88**	**10.93**	**10.44**	**8.36**	**7.21**	**7.56**	**100.00**
Mining	DNCL	1.73	1.75	1.84	1.75	1.76	1.69	1.75	1.84	1.92	1.96	1.96	1.90	21.84
	Distribution	**7.90**	**7.99**	**8.44**	**7.99**	**8.08**	**7.72**	**7.99**	**8.44**	**8.80**	**8.98**	**8.98**	**8.71**	**100.00**

4.2.3 Water Rights

Water rights are defined in the WRAP (VER 12/01) model with parameters for permitted diversions, priority, reservoir storage, and diversion location. This is accomplished in the water right (WR) records of WRAP (VER 12/01), which formulates the manner in which a particular water right is configured. A single written water right may be segmented into several WR records based on the language of the Permit or Certificate of Adjudication (CA). For example, a water right with more than one diversion point, or having multiple uses, will have more than one WR record to represent the permit in the model.

Water rights are identified using an eleven digit numeric code in the form of XXYAAAAABBB, as defined below:

- XX represents the Basin Number.
- Y represents the type of water right, where:
    - 6 is for Certificate of Adjudication.
    - 1 is for a Permit.
- AAAAA represents the Water Right Number
- BBB represents the Type of Feature, where:
    - 001-100 water right location (regular diversion point)
    - 101-200 downstream boundary of diversion area
    - 201-300 upstream boundary of diversion area
    - 301-400 on-channel reservoir
    - 401-500 off-channel reservoir
    - 501-600 return flow points
    - 601-700 off-channel diversion point
    - 901-999 other

Water rights in the Cypress Basin for Scenario 1 are listed in Table 12. This table gives each water right location, permitted diversion amount, use type, priority date, and how each water right permit was segregated into multiple parts. The specific locations of the water right control points can be referenced on the map of the Cypress Basin attached as Appendix K.

Table 12 Water Right Information

RECORD (WR/IF)	WATER RIGHT NUMBER	CONTROL POINT	ANNUAL DIVERSION / INSTREAM FLOW	USE TYPE	PRIORITY DATE
WR	10403997301	D10130	0	REC	19830222
WR	10403997302	D10160	0	REC	19830222
WR	10403997303	D10140	0	REC	19830222
WR	10403997304	D10180	0	REC	19830222
WR	10403997305	D10170	0	REC	19830222
WR	10403997306	D10150	0	REC	19830222
WR	10403997307	D10190	0	REC	19830222
WR	10404005001	F10080	2,343	MUN	19830418
WR	10404005002	F10080	1,281	IND	19830418
WR	10404198101	F10180	202.5	IRR	19841218
WR	10404199301	B10250	0	REC	19841127
WR	10404253301	E10020	25.3	IND	19850604
WR	60404558301	A10370	0	REC	19750106
WR	60404559301	A10350	0	REC	19751215
WR	60404560301	A10340	4,315	MUN	19700720
WR	60404560302	A10340	1,000	MUN	19660131
WR	60404560303	A10340	210	IRR	19700720
WR	60404560304	A10340	3,590	IND	19700720
WR	60404560305	A10340	2,012	OTHER	19801006
WR	60404560306	A10340	3,385	OTHER	19700720
WR	60404560307	A10340	788	OTHER	19700720
WR	60404560308	A10340	0	REC	19660131
WR	60404561001	A10300	11.61	IRR	19630831
WR	60404562002	A10290	24	IRR	19630801
WR	60404563301	A10240	16,300	IND	19700406
WR	60404564301	A10200	7,000	MUN	19711220
WR	60404564302	A10200	3,000	MUN	19711220
WR	60404564303	A10200	8,000	IND	19711220
WR	60404564304	A10200	10,900	IND	19711220
WR	60404564305	A10200	19,600	IND	19780313
WR	60404564306	A10200	0	REC	19711220
WR	60404565301	A10120	1,680	MUN	19550822
WR	60404565302	A10120	550	IND	19550822
WR	60404565303	A10120	0	REC	19550822
WR	60404566301	A10090	21.44	IRR	19591231
WR	60404567301	A10100	6	IRR	19561231
WR	60404568301	A10050	7.5	IRR	19631231
WR	60404569301	A10070	400	MUN	19380317

Table 12 Water Right Information (Continued)

RECORD (WR/IF)	WATER RIGHT NUMBER	CONTROL POINT	ANNUAL DIVERSION / INSTREAM FLOW	USE TYPE	PRIORITY DATE
WR	60404569302	A10070	0	REC	19380317
WR	60404570301	A10060	144	MUN	19750120
WR	60404570302	A10060	0	REC	19750120
WR	60404571301	A10040	4	IRR	19631231
WR	60404572301	A10030	4.4	IRR	19631231
WR	60404573001	A10010	11	IRR	19551231
WR	60404574301	B10320	1.4	IRR	19511231
WR	60404575301	B10290	0	REC	19730430
WR	60404576301	B10270	11000	IND	19730910
WR	60404576302	B10270	0	REC	19730910
WR	60404577301	B10230	124	IRR	19500930
WR	60404578301	B10220	6	IRR	19521231
WR	60404579301	B10210	75	IRR	19531231
WR	60404580301	B10200	2	IRR	19581231
WR	60404581301	B10180	0	REC	19690922
WR	60404582301	B10170	2,000	MUN	19720508
WR	60404582302	B10170	21,000	IND	19421130
WR	60404582303	B10150	0	OTHER	19421130
WR	60404583301	B10120	38.3	IRR	19620731
WR	60404584301	B10110	14.2	IRR	19480930
WR	60404585301	B10100	0.56	IRR	19550331
WR	60404586301	B10090	1	IRR	19641231
WR	60404587301	B10080	150	IRR	19561231
WR	60404588301	B10070	6,700	IND	19600504
WR	60404588302	B10070	0	REC	19600504
WR	60404589301	B10050	0	REC	19751208
WR	60404590301	B10020	40,070	MUN	19570916
WR	60404590302	B10020	32,400	IND	19570916
WR	60404590303	B10020	6,700	IND	19570916
WR	60404590304	B10020	16,500	IND	19570916
WR	60404590305	B10020	18,000	IND	19570916
WR	60404590306	A10200	1,930	MUN	19530911
WR	60404590307	B10020	0	REC	19570916
WR	60404590308	B10020	20,000	MUN	19950822
WR	60404590309	A10200	10,000	IND	19570916
WR	60404590310	B10020	96,200	IND	19570916

Table 12 Water Right Information (Continued)

RECORD (WR/IF)	WATER RIGHT NUMBER	CONTROL POINT	ANNUAL DIVERSION / INSTREAM FLOW	USE TYPE	PRIORITY DATE
WR	60404591301	F10250	8	IRR	19670430
WR	60404592001	F10230	96.88	IRR	19690930
WR	60404593301	F10240	85	IRR	19620531
WR	60404594001	F10220	1,080	IRR	19550103
WR	60404595001	F10210	2,000	MUN	19630218
WR	60404596001	F10190	80.21	IRR	19570319
WR	60404597301	C10040	25	IRR	19760621
WR	60404598301	C10030	10	IND	19700126
WR	60404599001	C10010	47	IRR	19530731
WR	60404600001	F10170	62.5	IRR	19660630
WR	60404601301	D10090	0	REC	19461121
WR	60404602301	D10080	0	REC	19600211
WR	60404603301	D10070	0	REC	19730312
WR	60404604301	D10060	7.03	IRR	19670630
WR	60404605301	D10030	0	REC	19741209
WR	60404605302	D10040	0	REC	19741209
WR	60404606301	D10020	0	REC	19740812
WR	60404607301	D10010	0	REC	19740812
WR	60404608301	E10070	18.2	IRR	19520630
WR	60404609001	E10060	15	IND	19680318
WR	60404609301	E10050	225	IND	19821206
WR	60404610001	E10040	122	IRR	19551010
WR	60404611301	E10010	955	IND	19430701
WR	60404612001	F10160	46.58	IRR	19550323
WR	60404613001	F10140	165.21	MIN	19690224
WR	60404614001	F10130	7,558	MUN	19470418
WR	60404614002	F10130	8,442	MUN	19561127
WR	60404615301	F10120	10	IRR	19751215
WR	60404616301	F10110	0	REC	19690811
WR	60404617301	F10030	0	REC	19720207
WR	60404618301	F10020	42	IRR	19790221
WR	60404618302	F10020	51	IRR	19810413
WR	60404619301	10050	0	REC	19760524
WR	60404620301	10040	0	REC	19781016
WR	60404621301	10020	0	REC	19470922
WR	10405054301	D10120	0	REC	19860404
WR	10405080301	C10050	0	REC	19860729

Table 12 Water Right Information (Continued)

RECORD (WR/IF)	WATER RIGHT NUMBER	CONTROL POINT	ANNUAL DIVERSION / INSTREAM FLOW	USE TYPE	PRIORITY DATE
WR	10405112301	F10100	0	REC	19861125
WR	10405167301	A10280	0	IND	19880121
WR	10405212301	B10300	0	IRR	19890112
WR	10405251301	B10260	0	IRR	19890810
WR	10405272301	D10110	6,180	MUN	19891214
WR	10405272302	D10110	0	REC	19891214
WR	10405284301	A10080	0	IND	19900220
WR	10405284302	A10180	0	IND	19900220
WR	10405284303	A10130	0	IND	19900220
WR	10405302301	F10090	0	REC	19900710
WR	10405456301	A10270	0	IND	19930330
WR	10405461301	A10170	0	IND	19930429
WR	10405518301	A10160	0	IND	19950210
WR	10405529301	A10260	0	IND	19950522
WR	10405537301	E10080	0	REC	19950801
WR	10405608301	E10090	34	IRR	19980320
WR	10405608302	E10090	0	REC	19980320
WR	60409999301	F10005	0	OTHER	20010101
WR	60409999302	F10005	40,000	MUN	20010201

4.2.3.1 Priority Dates

Priority dates were derived directly from hard copies of water rights obtained from the TNRCC. While most water rights have only one priority date, some have multiple priority dates. Multiple priority dates may be found on water rights with multiple diversions, with multiple reservoir impoundments, or in amended water rights.

Some water rights were characterized by multiple entries based on priority dates for storage, use types, as well as diversion locations. The priority date for each water right, as well as the instream flow requirements and the synthetic water rights utilized to distribute the return flows, is listed in Table 12. The format of the priority dates is YYYYMMDD, defined as:

- YYYY represents the four-digit year for Y2K compliance.
- MM represents the month by the two-digit code
- DD represents the day of the month in a two–digit code.

4.2.3.2 Treatment of Reservoir Storage

The maximum storage for a reservoir is specified in the TNRCC water right permit or certificate of adjudication. For reservoirs having multiple priority dates for storage, WRAP (VER 12/01) requires multiple WR and WS records to represent the different priority dates assigned to reservoir storage. Storage in a reservoir is filled only after meeting the needs of senior water rights. Incorporating these different reservoir storage levels by priority date allows the WRAP (VER 12/01) model to fill a reservoir only when flow is available based on the specific priority date.

4.2.3.3 Return Flows

Return flows in the Cypress Basin associated with water right diversions and groundwater use were input into WRAP (VER 12/01) as a constant monthly amount or as a percentage of the diversion amount of each water right. All groundwater return flows were modeled using the constant inflow (CI) record to provide continuous return flows throughout the simulation period. Information regarding the groundwater return flows included in the model as CI records is located in Appendix Q, and includes:

- Permit number, permit owner, facility name, CRWR number, WRAP ID, and
- Distribution of annual groundwater amount to monthly amounts for each return flow facility.

For this study, the CI records are used for wastewater discharge facilities that discharge groundwater only or with facilities that have combined surface and groundwater discharge. In the combined case, the CI record only represents the groundwater portion of the return flow. The groundwater return flow input into the CI record is the average return flow amount for each facility over the last five (5) years of the period of record (1994 to 1998). The underlying assumption used for the CI record is that municipal use will be continuous throughout the period of record and this water will always be returned. The values included in the CI records are adjusted (100%, 50%, 0%) according to the modeling scenarios.

The following example illustrates how the values for the CI record are calculated if the facility has a return flow of surface water and groundwater. The City of Pittsburg Sparks Branch Waste Water Treatment Plant (10250.001) discharges approximately 50% groundwater. The Sparks Branch WWTP is located upstream of control point BC_JF. The CI record was calculated based on the average discharge between 1994 and 1998 for each month. For example, an average value of 1.06 MGD was calculated for a combined surface and groundwater discharge for the month of January. Of this 1.06 MGD return flow, approximately 50%, or 0.53 MGD, is input as groundwater in the CI record. The 0.53 MGD is then converted to ac-ft for that month. The same process is continued for the remaining months.

Return flows of surface water associated with water rights are input into WRAP (VER 12/01) as a percentage of the diversion amount. As stated in an earlier section, return flow from irrigation water rights was not modeled. Industrial and municipal water rights were assigned return flow percentages as described in the following discussion.

Permit 4005
Longhorn Army Ammunition Plant is authorized to divert 2,343 ac-ft/yr for municipal use and 1,281 ac-ft/yr for consumptive industrial use. In Scenario 1, 60% of the municipal diversion was returned as return flow to the next downstream control point. In Scenario 2, 30% of the diversion was modeled as return flow, and in Scenario 3, no return flows were modeled. No water was returned as return flow from the consumptive industrial diversion.

CA 4560
Franklin County Water District and the Texas Water Development Board jointly own the authorization to impound Lake Cypress Springs (72,800 ac-ft) and divert 11,500 ac-ft/yr of water for municipal use, 3,590 ac-ft/yr for industrial use, and 210 for irrigation use. Interbasin transfers account for 7,185 ac-ft/yr of the 11,500 ac-ft/yr municipal diversion. The remaining 4,315 ac-ft/yr municipal diversion was modeled with a 60% return flow, in Scenario 1, to the next downstream control point. In Scenario 2, the diversion was modeled with a 30% return flow, and in Scenario 3, no return flow was modeled. In Scenario 1, the 3,590 ac-ft/yr industrial diversion was modeled with a 70% return flow to the City of Mount Pleasant's WWTP. In Scenario 2, the return flow was reduced to 35%, and in Scenario 3, no return flow was modeled. Return flow was not modeled for the irrigation diversion.

CA 4564
Titus County Fresh Water Supply District No. 1 is authorized to impound 213,350 ac-ft of water, known as Lake Bob Sandlin, and to divert 10,000 ac-ft/yr of water for municipal use and 38,500 ac-ft/yr for industrial use. In Scenario 1, the 10,000 ac-ft/yr municipal diversion was split into a 7,000 ac-ft/yr diversion modeled with a 60% return flow to the City of Mount Pleasant WWTP and a 3,000 ac-ft/yr diversion modeled with a 60% return flow to the next downstream control point. In Scenario 2, both return flows were reduced to 30%, and in Scenario 3, there were no return flows modeled. In Scenario 1, 30,500 ac-ft/yr of the industrial diversion was modeled with a 70% return flow to the next downstream control point. In Scenario 2, the return flow was reduced to 35%, and in Scenario 3, no return flow was modeled. The remaining industrial diversion of 8,000 ac-ft/yr was returned 100% to a dummy control point as part of a water supply contract; therefore, the return flow remained 100% in Scenarios 1, 2, and 3.

CA 4565
The City of Mount Pleasant is authorized to divert 1,680 ac-ft/yr of water for municipal use and 550 ac-ft/yr for industrial use. In Scenario 1, the municipal diversion was modeled with

a 60% return flow to the City of Mount Pleasant's WWTP and the industrial diversion was modeled with a 70% return flow to the next downstream control point in the Cypress Basin. In Scenario 2, the return flow was reduced to 30% and 35%, respectively, and in Scenario 3, there was no return flow modeled.

CA 4569

The City of Mount Pleasant is authorized to impound 1,176 ac-ft of water, known as the New City Lake, and to divert 400 ac-ft/yr of water for municipal use. In Scenario 1, the diversion was modeled with a return flow of 60% to the City of Mount Pleasant's WWTP. In Scenario 2, the return flow was reduced to 30%, and in Scenario 3, there was no return flow modeled.

CA 4570

The City of Mount Pleasant is authorized to impound 100 ac-ft of water, known as Old City Lake, and to divert 144 ac-ft/yr of water for municipal use. In Scenario 1, the diversion was modeled with a return flow of 60% to the City of Mount Pleasant's WWTP. In Scenario 2, the return flow was reduced to 30%, and in Scenario 3, there was no return flow modeled.

CA 4582

Lone Star Steel Company is authorized to impound 24,700 ac-ft of water, known as Ellison Creek Reservoir, and to divert 2,000 ac-ft/yr for municipal use and 21,000 ac-ft/yr for consumptive industrial use. In Scenario 1, the diversion was modeled with a return flow of 60% to the next downstream control point. In Scenario 2, the return flow was reduced to 30%, and in Scenario 3, there was no return flow modeled. The industrial diversion of 21,000 ac-ft/yr was modeled with no return flow since it is authorized for consumptive industrial use.

CA 4590

The Northeast Texas Municipal Water District is authorized to divert a total of 241,800 ac-ft/yr of water from Lake Bob Sandlin and Lake O' the Pines. Of the total 241,800 ac-ft/yr diversion, 62,000 ac-ft/yr of water is used for municipal purposes and 179,800 ac-ft/yr of water is used for industrial purposes. A municipal diversion of 40,070 ac-ft/yr from Lake O' the Pines is split between the City of Avenger, the City of Daingerfield, the City of Hughes Springs, the City of Jefferson, the City of Livingston, the City of Ore City, and the City of Pittsburg. In Scenario 1, each city's diversion was modeled with a return flow of 60%. In Scenario 2, the return flow was reduced to 30%, and in Scenario 3, there was no return flow modeled. A municipal diversion of 1,930 ac-ft/yr from Lake Bob Sandlin was modeled with a 60% return flow to the City of Pittsburg Wastewater Treatment Plant in Scenario 1. In Scenario 2, the return flow was reduced to 30%, and in Scenario 3, there was no return flow modeled. An industrial diversion of 32,400 ac-ft/yr from Lake O' the Pines was modeled with a return flow of 70% to the next downstream control point in Scenario 1. In Scenario 2, the return flow was reduced to 35%, and in Scenario 3, there was no return flow modeled. From Lake O' the Pines, 6,700 ac-ft/yr of water is used by CA 4588 and 16,500 ac-ft/yr of water is used by CA 4576 as backup to their water rights. From Lake Bob Sandlin, 10,000 ac-ft/yr of water is used by CA 4563 as backup to their water right. These diversions are for industrial purposes and are protected water supply contracts in Scenario 3. All water from this water right diverted for use by CA 4588, CA 4576, and CA 4563 is assumed to be consumed and not returned. Interbasin transfers to the Sabine River Basin account for 38,000 ac-ft/yr (18,000 ac-ft/yr industrial use, 20,000 ac-ft/yr municipal use) of the total authorized diversion from Lake O' the Pines. Currently, 96,200 ac-ft/yr of the total authorized diversion from Lake O' the Pines is not contracted; therefore, it is diverted and assumed to be consumed. Therefore, in all runs, this diversion has no return flow.

CA 4595

The City of Jefferson Water and Sewer District is authorized to divert 2,000 ac-ft/yr of water for municipal use. In Scenario 1, the diversion was modeled with a return flow of 60% to the next downstream control point. In Scenario 2, the return flow was reduced to 30%, and in Scenario 3, there was no return flow modeled.

CA 4609

T.S. Murrell is authorized to divert 240 ac-ft/yr of water for industrial use. In Scenario 1, the diversion was modeled with a return flow of 70% to the next downstream control point. In Scenario 2, the return flow was reduced to 35%, and in Scenario 3, there was no return flow modeled.

CA 4611

W. F. Palmer, B. G. Patterson, and the T & P Lake, Inc. are authorized to divert 955 ac-ft/yr of water for industrial use. In Scenario 1, the diversion was modeled with a return flow of 70% to the next downstream control point. In Scenario 2 the return flow was reduced to 35% and in Scenario 3 there was no return flow modeled.

CA 4614

The City of Marshall is authorized to divert 16,000 ac-ft/yr of water for municipal use. In Scenario 1, the diversion was modeled with a return flow of 60% to the next downstream control point. In Scenario 2, the return flow was reduced to 30%, and in Scenario 3, there was no return flow modeled. In Scenario 8, the return flow was returned to the Sabine River Basin (as it is currently operating).

Permit 5272

The City of Gilmer is authorized to divert a total of 6,180 ac-ft/yr of water for municipal or industrial use. In Scenario 1, the diversion was modeled with a return flow of 60% to the City of Gilmer's WWTP. In Scenario 2, the return flow was reduced to 30%, and in Scenario 3, there was no return flow modeled.

4.2.3.4 Multiple Diversion Locations

A large number of water rights contained in the Cypress Basin have multiple diversion points and/or multiple use types. Water rights issues and assumptions are described in Appendix D. Water rights with multiple diversion points include:

CA 4560	CA 4562	CA 4563	CA 4577
CA 4579	CA 4582	CA 4583	CA 4590
CA 4594	CA 4598	CA 4599	CA 4600
CA 4608	CA 4609	CA 4613	
Permit 4005	Permit 4198		

4.2.3.5 Saline Water Rights

There are no saline water rights in the Cypress Basin.

4.2.3.6 Rights Requiring Special Consideration

Appendix D contains a brief discussion of the assumptions utilized in representing selected water rights in WRAP (VER 12/01).

4.2.4 Data for Basin-Specific Features Added to WRAP (VER 12/01)

There were no basin specific modifications made to WRAP (VER 12/01) for the Cypress Basin WAM.

4.2.5 Red River Compact Issues

The Red River Compact was modeled as described in Appendix D. In general, the compact does not have any effect on the water right diversions in the Cypress Basin as it currently is permitted. In other words, there were no water rights in the Cypress Basin that had to curtail their diversion amounts because of restriction imposed by the Red River Compact. The model is set up to allow these curtailments to be modeled if additional water rights are added in the area downstream of Lake O' The Pines and the proposed dam sites on the Black and Little Cypress Rivers. The addition of water rights in this area in the future could require the water right curtailments based on the water level elevation in Caddo Lake. Future runs using this model will need to address the Red River Compact to determine if the curtailment feature (Drought Index) should be utilized.

4.3 Significant Assumptions Affecting Water Availability Modeling

The single most significant assumption in this study regarding water availability is the manner in which naturalized flows are distributed from gaged to ungaged sites. The key assumptions in this case are the parameters, which are used to distribute the flows, as described earlier in Section 2.5. Additional modeling assumptions, which have a significant impact on water availability, are described in the following sections.

4.3.1 Reuse

Wastewater reuse in the model was formulated for 100%, 50%, and 0% reuse of return flows. It was assumed that all existing reuse projects are included in the historical return flow data obtained from the TNRCC. These data were analyzed for the past five years for all water rights with permitted diversions. The manner in which reuse was calculated is described in section 4.2.3.3.

4.3.2 Return Flow/Constant Inflow Assumptions

The CI record can be utilized by the WRAP (VER 12/01) model to account for inflow of groundwater and/or surface water from other basins. In this study, the CI record was used to incorporate inflows from groundwater. There were no inflows associated with interbasin transfers to the Cypress Basin. Appendix Q lists which control points had constant inflows to represent groundwater sources.

4.3.3 Off-channel reservoirs

There are numerous off-channel reservoirs in the Cypress Basin. Generally, for those water rights with multiple off-channel reservoirs, a single reservoir representing the sum total of all capacities was simulated. A total of 7 off-channel reservoirs were modeled in the Cypress Basin. WRAP (VER 12/01) simulates off-channel reservoirs by limiting the streamflow depletions which are made to meet diversions and refill storage. These constraints are defined as annual limits, which limits the cumulative annual streamflow depletion; and a monthly limit, which defines the maximum streamflow depletion for any given month. Water rights with off-channel impoundment and how they were modeled are described below:

CA 04-4574	5 ac-ft off-channel res.
CA 04-4598	5 ac-ft combined from seven off-channel res.
CA 04-4599	7 ac-ft off-channel res.
CA 04-4609	223 ac-ft off-channel res.
CA 04-4618	42 ac-ft off-channel res.
Permit 4005	8.29 ac-ft off-channel res.
Permit 5212	12 ac-ft off-channel res.

4.3.4 Term Permits

Term permits are issued primarily to industrial, mining, and agricultural enterprises, usually for ten years. The term can be renewed if, after ten years, water in the basin is still not being used by other water right holders. Other term permits, Term B permits, are based upon a lease agreement and expire with the termination of the lease. There are three water rights in the Cypress Basin which have term permits.

Permit 4253, is a Term B permit. The permit states that the permit shall expire and become null and void upon termination of the lease dated September 3, 1985, unless the permittee has acquired another right to use the tract of land which is the subject of the lease. This water right was modeled assuming the lease was still effective and was modeled in each scenario.

Permit 5212, is a term permit which expired on December 31, 1999. The permit states that the reservoir authorized in the permit shall be maintained for domestic and livestock purposes after the permit expires. Therefore, this water right was modeled in all scenarios as an impoundment with no diversions.

Permit 5251, is a term permit which expired on December 31, 1999. The permit states that the reservoir authorized in the permit shall be maintained for domestic and livestock purposes after the permit expires. Therefore, this water right was modeled in all scenarios as an impoundment with no diversions.

4.3.5 Interbasin Transfers

The TNRCC maintains a database of interbasin transfers in the State of Texas. According to the database, there are four permitted interbasin transfers in the Cypress Basin. Table 13 lists those water rights which are authorized to divert water from the Cypress River for subsequent use in other basins or import water into the Cypress Basin.

Table 13 Interbasin Transfers in the Cypress Basin

CA Number	Permittee	Authorization (Ac-Ft)	Basin of Origin	Watersheds of Use
03-4836	City of Texarkana	4,500	Sulphur	Red, Sulphur, Cypress
04-4560	Franklin Co. MWD	7,185	Cypress	Sabine, Sulphur
04-4590	Northeast Texas MWD	18,000 20,000	Cypress	Sabine

04-4614	City of Marshall	16,000	Cypress	Sabine, Cypress

CA 03-4836, authorizes the storage of water from the City of Texarkana to be imported into the Cypress Basin for municipal and industrial use. Discussions with the City of Texarkana indicated that this water right was not importing water into the Cypress Basin. There are also no plans to import this water into the basin. Therefore, the reliability of the water rights in the Cypress Basin should not be enhanced by the importation of this water. The interbasin transfer from 03-4839 was not modeled in the Cypress Basin WAM.

CA 04-4560, authorizes the Franklin County Municipal Water District to divert water from the Cypress Basin to the Sabine and Sulphur River Basins. The model includes a interbasin transfer of 2,800 ac-ft/yr is to the Sabine River Basin and 4,385 ac-ft/yr returned to the Sulphur River Basin.

CA 04-4590, authorizes the Northeast Texas Municipal Water District storage of water from the Cypress Basin in Lake O' the Pines for two diversions to the Sabine River Basin. The first, 18,000 ac-ft/yr, is returned to the Sabine River Basin (Southwestern Power Company, Brady Branch). The second, 20,000 ac-ft/yr, is returned to the Sabine River Basin (City of Longview).

CA 04-4614, authorizes the City of Marshall (Wastewater Treatment Plant) to discharge into the Sabine River Basin. The Certificate of Adjudication requires that all "excess" water be returned to the Cypress River. For Scenarios 1, 2, 4, and 5, the return flow from this water right was returned to the next downstream control point in the Cypress Basin. However, in Scenario 8, the return flow is modeled as an interbasin transfer to the Sabine River Basin (as it currently is operated).

5.0 WATER AVAILABILITY IN THE BASIN

5.1 Descriptions of Scenarios Modeled

The purpose of the TNRCC WAM effort is to determine the water availability and/or reliability of individual water rights in the Cypress Basin based on a number of different scenarios. A total of nine water availability scenarios were developed for the Cypress Basin: eight TNRCC "Base" scenarios and one basin specific scenario. The nine different scenarios include: three simulating various levels of reuse, four simulating partial/total cancellation, a current conditions scenario. The basin specific scenario a firm yield determination for all permitted reservoirs with capacities greater than 5,000 ac-ft per year.

A summary table containing all nine runs and the respective diversion amounts is shown in Table 14. Table 15 describes the simulation conditions in each of the nine model scenarios. Scenario 9 determines the firm yield of the major existing reservoirs in the basin based on the priority date of impoundment. There are three different annual diversion amounts entered into the modeling scenarios. The three categories include:

- full authorized diversions as defined in the water rights (excluding term permits).
- partial cancellation of water rights simulated by limiting the modeled diversion amount to the maximum use in the last 10 years.
- total cancellation simulated for those water rights reporting 0 use in the last 10 years.

Table 14 Summary of Diversions by Run

Count	Water Right ID Number	Control Point	Term	Maximum Reported Annual Use (ac-ft/yr)[1,2]	Authorized Annual Use (ac-ft/yr)[3]	Total Annual Diversions Included in Each Model Run (ac-ft/yr)								
						Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9
1	10403997301	D10130		0	0	0	0	0	0	0	0	0	0	0
2	10403997302	D10160		0	0	0	0	0	0	0	0	0	0	0
3	10403997303	D10140		0	0	0	0	0	0	0	0	0	0	0
4	10403997304	D10180		0	0	0	0	0	0	0	0	0	0	0
5	10403997305	D10170		0	0	0	0	0	0	0	0	0	0	0
6	10403997306	D10150		0	0	0	0	0	0	0	0	0	0	0
7	10403997307	D10190		0	0	0	0	0	0	0	0	0	0	0
8	10404005001	F10080		2,558	2,343	2,343	2,343	2,343	2,343	2,343	2,343	2,343	2,343	2,343
9	10404005002	F10080		3,246	1,281	1,281	1,281	1,281	1,281	1,281	1,281	1,281	1,281	1,281
10	10404198101	F10180		0	202.5	202.5	202.5	202.5	0	0	0	0	0	202.5
11	10404199301	B10250		0	0	0	0	0	0	0	0	0	0	
12	10404253301	E10020		25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3
13	60404558301	A10370		0	0	0	0	0	0	0	0	0	0	0
14	60404559301	A10350		0	0	0	0	0	0	0	0	0	0	0
15	60404560301	A10340		1,392	4,315	4,315	4,315	10,500	4,315	1,392	4,315	1,392	1,392	5,700
16	60404560302	A10340		1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
17	60404560303	A10340		130	210	210	210	210	210	130	210	130	130	210
18	60404560304	A10340		0	3,590	3,590	3,590	3,590	3,590	0	3,590	0	0	3,590
19	60404560305	A10340		0	2,012	2,012	2,012	N/A	2,012	N/A	2,012	N/A	N/A	0
20	60404560306	A10340		0	3,385	3,385	3,385	N/A	3,385	N/A	3,385	N/A	N/A	0
21	60404560307	A10340		0	788	788	788	N/A	788	N/A	788	N/A	N/A	0
22	60404560308	A10340		0	0	0	0	0	0	0	0	0	0	0
23	60404561001	A10300		0	11.61	11.61	11.61	11.61	0	0	0	0	0	11.61
24	60404562002	A10290		0	24	24	24	24	0	0	0	0	0	24
25	60404563301	A10240		16,300	16,300	16,300	16,300	16,300	16,300	16,300	16,300	16,300	16,300	2,750
26	60404564301	A10200		7,000	7,000	7,000	7,000	10,000	7,000	7,000	7,000	7,000	7,000	10,000
27	60404564302	A10200		0	3,000	3,000	3,000		3,000		3,000			0
28	60404564303	A10200		8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000
29	60404564304	A10200		4,693	10,900	10,900	10,900	10,900	10,900	4,693	10,900	4,693	4,693	10,900
30	60404564305	A10200		0	19,600	19,600	19,600	19,600	19,600	N/A	19,600	N/A	N/A	19,600
31	60404564306	A10200		0	0			N/A		N/A		N/A	N/A	0
32	60404565301	A10120		642	1,680	1,680	1,680	1,680	1,680	642	1,680	642	642	1,680
33	60404565302	A10120		0	550	550	550	550	550	0	550	0	0	550

Count	Water Right ID Number	Control Point	Term	Maximum Reported Annual Use (ac-ft/yr)[1,2]	Authorized Annual Use (ac-ft/yr)[3]	Total Annual Diversions Included in Each Model Run (ac-ft/yr)								
						Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9
34	60404565303	A10120		0	0	0	0	0	0	0	0	0	0	0
35	60404566301	A10090		21.44	21.44	21.44	21.44	21.44	21.44	21.44	21.44	21	21	21.44
36	60404567301	A10100		6	6	6	6	6	6	6	6	6	6	6
37	60404568301	A10050		0	7.5	7.5	7.5	7.5	0	0	0	0	0	7.5
38	60404569301	A10070		400	400	400	400	400	400	400	400	400	400	400
39	60404569302	A10070		0	0	0	0	0	0	0	0	0	0	0
40	60404570301	A10060		0	144	144	144	144	144	0	144	0	0	144
41	60404570302	A10060		0	0	0	0	0	0	0	0	0	0	0
42	60404571301	A10040		0	4	4	4	4	0	0	0	0	0	4
43	60404572301	A10030		0	4.4	4	4	4	0	0	0	0	0	4.4
44	60404573001	A10010	Yes	0	11	11	11	11	0	0	0	0	0	11
45	60404574301	B10320		1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
46	60404575301	B10290		0	0	0	0	0	0	0	0	0	0	0
47	60404576301	B10270		11,000	11,000	11,000	11,000	11,000	11,000	11,000	11,000	11,000	11,000	4,440
48	60404576302	B10270		0	0	0	0	0	0	0	0	0	0	0
49	60404577301	B10230		0	124	124	124	124	0	0	0	0	0	124
50	60404578301	B10220		0	6	6	6	6	0	0	0	0	0	6
51	60404579301	B10210		2	75	75	75	75	75	2	75	2	2	75
52	60404580301	B10200		0	2	2	2	2	0	0	0	0	0	2
53	60404581301	B10180		0	0	0	0	0	0	0	0	0	0	0
54	60404582301	B10170		996	2,000	2,000	2,000	2,000	2,000	996	2,000	996	996	2,000
55	60404582302	B10170		1,505	21,000	21,000	21,000	21,000	21,000	1,505	21,000	1,505	1,505	11,800
56	60404582303	B10150		0	0	0	0	0	0	0	0	0	0	0
57	60404583301	B10120		38.3	38.3	38.3	38.3	38.3	38.3	38.3	38.3	38.3	38.3	38.3
58	60404584301	B10110		0	14.2	14	14	14	0	0	0	0	0	14.2
59	60404585301	B10100		0	0.56	1	1	1	0	0	0	0	0	0.56
60	60404586301	B10090		0	1	1	1	1	0	0	0	0	0	1
61	60404587301	B10080		0	150	150	150	150	0	0	0	0	0	150
62	60404588301	B10070		3,318	6,668	6,668	6,668	6,668	6,668	3,318	6,668	3,318	3,318	1,925
63	60404588302	B10070		0	0	0	0	0	0	0	0	0	0	0
64	60404589301	B10050		0	0	0	0	0	0	0	0	0	0	0
65	60404590301	B10020		0	40,070	40,070	40,070	40,070	40,070	0	40,070	0	0	40,070
66	60404590302	B10020		0	32,400	32,400	32,400	32,400	32,400	0	32,400	0	0	32,400

Count	Water Right ID Number	Control Point	Term	Maximum Reported Annual Use (ac-ft/yr)[1,2]	Authorized Annual Use (ac-ft/yr)[3]	Total Annual Diversions Included in Each Model Run (ac-ft/yr)								
						Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9
67	60404590303	B10020		0	6,700	6,700	6,700	6,700	6,700	0	6,700	0	0	6,700
68	60404590304	B10020		0	16,500	16,500	16,500	16,500	16,500	0	16,500	0	0	16,500
69	60404590305	B10020		10,727	18,000	18,000	18,000	18,000	18,000	10,727	18,000	10,727	10,727	18,000
70	60404590306	A10200		1,449	1,930	1,930	1,930	1,930	1,930	1,449	1,930	1,449	1,449	1,930
71	60404590307	B10020		0	0	0	0	0	0	0	0	0	0	0
72	60404590308	B10020		0	20,000	20,000	20,000	20,000	20,000	0	20,000	0	0	20,000
73	60404590309	A10200		10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
74	60404590310	B10020		0	96,200	96,200	96,200	96,200	96,200	0	96,200	0	0	20,000
75	60404591301	F10250		0	8	8	8	8	0	0	0	0	0	8
76	60404592001	F10230		80	96.88	96.88	96.88	96.88	96.88	80	96.88	80	80	96.88
77	60404593301	F10240		44	85	85	85	85	85	44	85	44	44	85
78	60404594001	F10220		0	1,080	1,080	1,080	1,080	0	0	0	0	0	1,080
79	60404595001	F10210		659	2,000	2,000	2,000	2,000	2,000	659	2,000	659	659	2,000
80	60404596001	F10190		0	80.21	80	80	80	0	0	0	0	0	80.21
81	60404597301	C10040		0	25	25	25	25	0	0	0	0	0	25
82	60404598301	C10030		0	10	10	10	10	0	0	0	0	0	10
83	60404599001	C10010		2	47	47	47	47	47	2	47	2	2	47
84	60404600001	F10170		0	62.5	62	62	62.5	0	0	0	0	0	62.5
85	60404601301	D10090		0	0	0	0	0	0	0	0	0	0	0
86	60404602301	D10080		0	0	0	0	0	0	0	0	0	0	0
87	60404603301	D10070		0	0	0	0	0	0	0	0	0	0	0
88	60404604301	D10060		0	7.03	7	7	7.03	0	0	0	0	0	7.03
89	60404605301	D10030		0	0	0	0	0	0	0	0	0	0	0
90	60404605302	D10040		0	0	0	0	0	0	0	0	0	0	0
91	60404606301	D10020		0	0	0	0	0	0	0	0	0	0	0
92	60404607301	D10010		0	0	0	0	0	0	0	0	0	0	0
93	60404608301	E10070		0	18.2	18	18	18	0	0	0	0	0	18.2
94	60404609001	E10060		15	15	15	15	15	15	15	15	15	15	15
95	60404609301	E10050		31	225	225	225	225	225	31	225	31	31	225
96	60404610001	E10040		0	122	122	122	122	0	0	0	0	0	122
97	60404611301	E10010		0	955	955	955	955	0	0	0	0	0	955
98	60404612001	F10160		0	46.58	47	47	47	0	0	0	0	0	46.58
99	60404613001	F10140		0	165.21	165	165	165	0	0	0	0	0	165.21

Count	Water Right ID Number	Control Point	Term	Maximum Reported Annual Use (ac-ft/yr)[1,2]	Authorized Annual Use (ac-ft/yr)[3]	Total Annual Diversions Included in Each Model Run (ac-ft/yr)								
						Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9
100	60404614001	F10130		7,367	7,558	7,558	7,558	7,558	7,558	7,367	7,558	7,367	7,367	7,558
101	60404614002	F10130		0	8,442	8,442	8,442	8,442	8,442	0	8,442	0	0	8,442
102	60404615301	F10120		10	10	10	10	10	10	10	10	10	10	10
103	60404616301	F10110		0	0	0	0	0	0	0	0	0	0	0
104	60404617301	F10030		0	0	0	0	0	0	0	0	0	0	0
105	60404618301	F10020		42	42	42	42	42	42	42	42	42	42	42
106	60404618302	F10020		15	51	51	51	51	51	15	51	15	15	51
107	60404619301	10050		0	0	0	0	0	0	0	0	0	0	0
108	60404620301	10040		0	0	0	0	0	0	0	0	0	0	0
109	60404621301	10020		0	0	0	0	0	0	0	0	0	0	0
110	10405054301	D10120		0	0	0	0	0	0	0	0	0	0	0
111	10405080301	C10050		0	0	0	0	0	0	0	0	0	0	0
112	10405112301	F10100	Yes	0	0	0	0	0	0	0	0	0	0	0
113	10405167301	A10280		0	0	0	0	0	0	0	0	0	0	0
114	10405212301	B10300		0	0	0	0	0	0	0	0	0	0	0
115	10405251301	B10260	Yes	0	0	0	0	0	0	0	0	0	0	0
116	10405272301	D10110		6,180	6,180	6,180	6,180	6,180	6,180	0	6,180	0	0	4,325
117	10405272302	D10110		0	0	0	0	0	0	0	0	0	0	0
118	10405284301	A10080		0	0	0	0	0	0	0	0	0	0	0
119	10405284302	A10180		0	0	0	0	0	0	0	0	0	0	0
120	10405284303	A10130		0	0	0	0	0	0	0	0	0	0	0
121	10405302301	F10090		0	0	0	0	0	0	0	0	0	0	0
122	10405456301	A10270		0	0	0	0	0	0	0	0	0	0	0
123	10405461301	A10170		0	0	0	0	0	0	0	0	0	0	0
124	10405518301	A10160		0	0	0	0	0	0	0	0	0	0	0
125	10405529301	A10260		0	0	0	0	0	0	0	0	0	0	0
126	10405537301	E10080		0	0	0	0	0	0	0	0	0	0	0
127	10405608301	E10090		34	34	34	34	34	34	34	34	34	34	34
128	10405608302	E10090		0	0	0	0	0	0	0	0	0	0	0
129	60409999301	F10000		0	0	0	0	0	0	0	0	0	0	0
130	60409999302	F10000		40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000

[1] #N/A denotes no use reported in TNRCC historical use database for 1988-1998. Diversions set to zero for Runs 4 thru 8.

[2] When maximum use reported greater than permitted diversion amount, permitted diversion amount assumed.

[3] The authorized annual use includes all rights at their annual authorized diversion amounts.

Table 15 TNRCC Cypress Basin Water Availability Model

Scenario	Title	Diversion Amount	Area - Capacity	Return Flows	Term Water Rights
Re-Use					
1	0% Reuse	A	A	All	No
2	50% Reuse	A	A	50%	No
3	100% Reuse	A	A	None	No
Cancellation					
4	Total	M	A	All	No
5	Partial	MAX	A	All	No
6	Total	M	A	None	No
7	Partial	MAX	A	None	No
Current Conditions					
8	Current	MAX	Yr 2000	All	Yes
Alternative					
9	Firm Yield	A/Yld	A	None	No

Definition

A	Authorized area-capacities (original) and Authorized diversion amounts (full permitted)
M	Modified diversion amounts (10 years nonuse = 0)
MAX	Modified diversion amounts (Max use for last10 years)
Yr 2000	Year 2000 area-capacity curve
All	Return Flow factor determined based on minimum historical flows
50%	50% of computed return flow above
None	No return flow
No	No use to term water rights
Yes	Term water rights used
Yld	Diversions at reservoir set to firm yield amounts

A description of the reuse and cancellation scenarios is outlined in the following sections.

5.1.1 Reuse

Scenarios 1, 2, and 3 evaluate the impact of wastewater reuse on water availability in the basin. This is accomplished by varying the return flow percentage between each model scenario while using permitted diversion amounts and authorized reservoir area-capacity relationships.

Scenario 1 assumes existing levels of reuse based on the levels of return flow for the past five years. The full return flow factor was utilized to estimate return flows occurring from surface water diversions and no adjustment was made to return flows, which appear as a result of groundwater use, and/or interbasin transfers. Scenarios 2 and 3 assume 50% and 100% reuse, respectively. The 50% reuse in Scenario 2 was calculated by decreasing return flow factors and constant return flows originated by groundwater and/or interbasin transfer return flows to half the initial value as set in Scenario 1. In Scenario 3, all return flows were assumed to be zero to represent the full reuse of diverted water.

5.1.2 Cancellation

Scenarios 4, 5, 6, and 7 evaluate the impact of simulated cancellation of water rights, in addition to wastewater reuse on water availability in the basin. Water rights which have not been used within the last ten years (the statutory minimum) have been cancelled in the four model scenarios listed above. Water rights utilized, which reported a partial non-use of permitted diversions, were *not* cancelled in any of the scenarios. Table 16 lists the water rights authorized diversion amount, maximum ten-year-use, and whether the right was cancelled.

Scenario 4 simulates water availability if specific water rights were cancelled (no reported use in ten years). In this scenario, all remaining rights were set to permitted authorized diversions and return flows were based on no reuse. Scenario 5 is identical to Scenario 4, with the exception that the diversion amounts for those water rights which were not cancelled were set to the maximum reported use in the last ten years.

Scenarios 6 and 7 are similar to Scenarios 4 and 5 in terms of diversion amount, but no return flows were incorporated, in order to represent 100% wastewater reuse.

Appendix D lists specific assumptions made for selected water rights.

Table 16 Cancellation of Water Rights in the Cypress Basin (excluding recreational rights)

WATER RIGHT NUMBER	CONTROL POINT	USE TYPE	Authorized Diversion (Ac-Ft/Yr)	Max Use 10 Years (Ac-Ft/Yr)	Cancel
10404005001	F10080	MUN	2,343	2,343	No
10404005002	F10080	IND	1,281	1,281	No
10404198101	F10180	IRR	203	0	Yes
10404253301	E10020	IND	25.3	25.3	No
60404560301	A10340	MUN	11,500	2,392	No
60404560303	A10340	IRR	210	130	No
60404560304	A10340	IND	3,590	0	No
60404561001	A10300	IRR	12	0	Yes
60404562002	A10290	IRR	24	0	Yes
60404563301	A10240	IND	16,300	16,300	No
60404564301	A10200	MUN	10,000	7,000	No
60404564303	A10200	IND	38,500	12,693	No
60404565301	A10120	MUN	1,680	642	No
60404565302	A10120	IND	550	0	No
60404566301	A10090	IRR	21	21	No
60404567301	A10100	IRR	6	6	No
60404568301	A10050	IRR	8	0	Yes
60404569301	A10070	MUN	400	400	No
60404570301	A10060	MUN	144	0	No
60404571301	A10040	IRR	4	0	Yes
60404572301	A10030	IRR	4	0	Yes
60404573001	A10010	IRR	11	0	Yes
60404574301	B10320	IRR	1	1	No
60404576301	B10270	IND	11,000	11,000	No
60404577301	B10230	IRR	124	0	Yes
60404578301	B10220	IRR	6	0	Yes
60404579301	B10210	IRR	75	2	No
60404580301	B10200	IRR	2	0	Yes
60404582301	B10170	MUN	2,000	996	No
60404582302	B10150	IND	21,000	1,505	No
60404583301	B10120	IRR	38	38	No
60404584301	B10110	IRR	14	0	Yes
60404585301	B10100	IRR	1	0	Yes
60404586301	B10090	IRR	1	0	Yes
60404587301	B10080	IRR	150	0	Yes
60404588301	B10070	IND	6,668	3,318	No
60404590301	B10020	MUN	42,000	1,449	No
60404590302	B10020	IND	161,800	20,727	No

WATER RIGHT NUMBER	CONTROL POINT	USE TYPE	Authorized Diversion (Ac-Ft/Yr)	Max Use 10 Years (Ac-Ft/Yr)	Cancel
60404591301	F10250	IRR	8	0	Yes
60404592001	F10230	IRR	97	80	No
60404593301	F10240	IRR	85	44	No
60404594002	F10220	IRR	1,080	0	Yes
60404595001	F10210	MUN	2,000	659	No
60404596001	F10190	IRR	80.21	0	Yes
60404597301	C10040	IRR	25	0	Yes
60404598301	C10030	IND	10	0	Yes
60404599301	C10010	IRR	47	2	No
60404600001	F10170	IRR	63	0	Yes
60404604301	D10060	IRR	7.03	0	Yes
60404608301	E10070	IRR	18	0	Yes
60404609301	E10050	IND	240	46	No
60404610001	E10040	IRR	122	0	Yes
60404611301	E10010	IND	955	0	Yes
60404612001	F10160	IRR	47	0	Yes
60404613001	F10140	MIN	165	0	Yes
60404614001	F10130	MUN	16,000	7,367	No
60404615301	F10120	IRR	10	10	No
60404618301	F10020	IRR	93	57	No
10405167301	A10280	IND	0	0	Yes
10405212301	B10300	IRR	48	0	Yes
10405272301	D10110	MUN	6,180	0	No
10405284301	A10080	IND	0	0	Yes
10405284302	A10180	IND	0	0	Yes
10405284303	A10130	IND	0	0	Yes
10405456301	A10270	IND	0	0	Yes
10405518301	A10160	IND	0	0	Yes
10405529301	A10260	IND	0	0	Yes
10405608301	E10090	IRR	34	34	No

Note: Although some records indicate the maximum reported use the last 10 years as being zero, the water right was not canceled because another portion of the water right was used.

5.1.3 Current Conditions Scenario

Scenario 8, a TNRCC base scenario, was performed to estimate water availability under current conditions of water use and storage capacity. The current condition scenario consists of diverting the maximum amount used by a water right holder in the last ten years, using year-2000 area-capacity curves and return flows based on no reuse, and including term permits in the model. In the Cypress Basin, there were three term permits. However, one term permit was a Term B permit and the other two term permits had expired, except for the authorized reservoir impoundments. Therefore, these water rights were modeled in each scenario and not just Scenario 8. As a result, Scenario 8 is identical to Scenario 5 except with year 2000 capacities utilized. A detailed discussion of the term permits in the Cypress Basin and how each was modeled is located in Section 4.3.4. Conditions of this scenario for the Cypress Basin include:

- Setting the annual diversion amounts to the maximum reported use in the last ten years,
- Basing return flows on no wastewater reuse, and
- Developing area-capacity relationships for all major reservoirs to reflect year-2000 conditions, as a result of sedimentation.

Appendix N contains the tables showing the original and the estimated area-capacity relationship as of the year 2000 for each major reservoir in the Cypress Basin.

5.1.4 Firm Yield Scenario

The firm yield run (Scenario 9) is a basin specific scenario to identify the yield of any permitted reservoir, which goes dry under authorized diversions. The firm yield analysis was performed using Scenario 3 (full authorized diversions, no return flows). If the reservoir did not go dry during Scenario 3, then the firm yield of the reservoir is simply the diversion amount used in Scenario 3. If the reservoir did have a value of zero during any one month of the simulation, then the diversion amount was adjusted. Diversions from each reservoir were made such that the remaining volume left in storage was within 1% of the total original storage capacity. Diversions were adjusted up or down, maintaining the existing seasonal use patterns and existing priority dates until the reservoir went dry. The firm yields were developed using only the drainage area of the reservoir; no additional water was added to any reservoir from water supply contracts.

Results of the firm yield analysis are shown in the Section 5.2.4.

5.2 Results of Water Availability Model

Appendix R provides the results from the various WRAP (VER 12/01) scenarios and illustrates the reliability of individual water rights. The tables in Appendix R list all water rights in the Cypress Basin with permitted diversions along with their period and volume reliability. Period reliability, expressed as a percent, is defined as the ratio of number of months for which no shortages occurred to the total number of months in the simulation period. Volumetric reliability, expressed as a percent, represents the ratio of the mean volume of shortages divided by the corresponding annual diversion amount.

Also shown in Appendix R, are the results of the modeling simulations on four specific reservoirs. Results were reported for the following four reservoirs:

- Lake O' the Pines located on Cypress Creek.
- Lake Bob Sandlin located on Big Cypress Creek.
- Lake Cypress Springs.
- Welsh Reservoir.

These reservoirs were chosen to illustrate the results the modeling simulations had on the reservoirs in the Cypress Basin. Lake O' the Pines, Lake Bob Sandlin, and Lake Cypress Springs are all large reservoirs with sizeable diversions located on a major river in the Cypress Basin. Welsh Reservoir is representative of the smaller major reservoirs with smaller diversions located on minor tributaries. The monthly storage for these reservoirs, under Scenarios 2 through 8, are compared to the monthly storage for Scenario 1, considered here only as a baseline scenario.

Additional interest, in a water availability context, is the regulated and unappropriated flows at five primary control points and the inflow to Caddo Lake:

- USGS gage Big Cypress Creek near Pittsburg (BC_PB), Control Point (A10000).
- USGS gage Big Cypress at Jefferson (BC_JF), Control Point (B10000).
- USGS gage Black Cypress at Jefferson (BK_JF), Control Point (C10000).
- USGS gage Little Cypress Creek near Ore City (LC_OC), Control Point (D10000).
- USGS gage Little Cypress at Jefferson (LC_JF, Control Point (E10000).
- Inflow into Caddo Lake (WR-4349), Control Point (F10080).

Regulated flows are defined as the actual streamflows at that control point, including releases from upstream reservoirs for downstream water rights and instream flow requirements that are not available for appropriation. Unappropriated flows are those streamflows at a control point that remain after all water rights in the simulation have made their depletions. Unappropriated streamflows reflect that amount of water which may be available for future use. Unappropriated flows and regulated flows under Scenarios 2 through 8 are compared to those streamflows for Scenario 1. Future appropriations are subject to environmental flow restrictions pursuant to Chapter 11 of the Texas Water Code. Environmental flow needs will be considered when granting new water rights or amending existing water rights, thereby affecting the amount of water available for appropriation.

Appendix R contains the study results for selected reservoirs and control points in order to compare the impacts of various scenarios.

5.2.1 Reuse

Reliability for Scenarios 1, 2, and 3 are shown in Table R-1 in Appendix R. These reliabilities illustrate the effect of reuse for each of the water rights. Graphical plots of Scenarios 1, 2, and 3 for selected reservoirs and control points are presented in Appendix R, Figures R-1 through R-18. The effects of wastewater reuse on the selected reservoirs vary considerably, as shown in Figures R-1 through R-4. Figure R-1 indicates that there is an impact of reuse on Lake Cypress Springs. The maximum difference between Scenarios 1 and 3 is approximately 10,000 ac-ft/yr. Lake O' the Pines also is affected by reuse. The difference between Scenarios 1 and 3 is approximately 40,000 ac-ft/yr in 1965 and 1984. There is minimal impact from reuse on Lake Bob Sandlin. As shown in Figure R-3, no difference can be seen between the three scenarios except for 1968. There is an impact on the storage in Welsh Reservoir during the early 1980s. Monthly reservoir storage declined between Scenario 1 and Scenario 3 approximately 2,000 ac-ft/yr in 1985. The difference can be attributed to more inflow releases from Welsh Reservoir to make up for the amount of return flow that was not in the river that was filling senior water rights downstream (Lake O' the Pines).

These four reservoirs were analyzed to illustrate the effect of reuse on different reservoirs in the Cypress Basin. The other reservoirs in the basin were generally on smaller tributaries and were not affected by reuse.

5.2.1.1 Specific Large Rights

In general, most of the large water rights in the Cypress Basin have high reliability regardless of the reuse scenario. These reliabilities do not differ significantly because there are few large return flows in the Cypress Basin. When the reuse is set to 100%, Scenario 3, several large water rights drop by two to three percent. The reliability of Permit 4005 declines between Scenario 1 and 3 from 92.32% to 88.73% and from 99.74% to 90.76% for monthly and volume reliabilities, respectively. Likewise, the reliability of CA 4576 declines from 98.86% to 97.711% and from 95.52% to 92.53% for monthly and volume reliabilities, respectively. The most significant difference in reliabilities between Scenarios 1 and 3 is for CA 4595. This water right decreases from 99.18% to 79.25% and from 99.31% to 80.73%

for monthly and volume reliabilities, respectively. This water right is a run-of-river right and has no access to storage to make up for the loss of return flows.

5.2.1.2 Unappropriated Flows at Selected Locations

Annual unappropriated flows at the primary control points using varying levels of wastewater reuse are shown in Figures R-6, R-8, R-10, R-12, R-14, and R-18. Minimal effects on unappropriated flows from reuse scenarios for BK_JF, LC_OC, and LC_JF are shown in Figures R-10, R-12, and R-14, respectively. The difference in unappropriated flows is less than 200 ac-ft. Again, the differences in these three scenarios are minimal because there are few significant return flows in these parts of the Cypress Basin.

Reuse does have an impact on the unappropriated flows at control point BC_PB and BC_JF, as shown in Figures R-6 and R-8, respectively. The maximum difference between Scenario 1 and Scenario 3 is approximately 30,000 ac-ft/yr for BC_PB. Figure R-8 shows a difference of approximately 60,000 ac-ft/yr due to reuse for control point BC_JF.

5.2.1.3 Regulated Flows at Selected Locations

Annual regulated flows using varying levels of wastewater reuse are shown in Figures R-5, R-7, R-9, R-11, R-13, R-15, and R-17 for control points BC_PB, BC_JF, BK_JF, LC_OC, LC_JF, F10080, and DN_CL, respectively. The effects of wastewater reuse on regulated flows at the selected control points are consistent with those at unappropriated flows described in the previous section.

5.2.2 Cancellation Scenarios

There are 55 water rights with authorized diversion amounts of approximately 393,919 ac-ft/yr modeled in the cancellation Scenarios 4 and 6. The diversion amount for Scenario 5 and 7 is approximately 90,569 ac-ft/yr. The diversions used in Scenarios 4 and 6 were the full authorized amounts for those rights that were not cancelled, and Scenarios 5 and 7 diversion amounts were based on the maximum use in the last ten years for each of the water rights. Water rights that have been cancelled are shown in Table 16.

5.2.2.1 Specific Large Rights

The reliability of each water right in Scenarios 4, 5, 6, and 7 is shown in Table R-3. Reservoir storage, unappropriated and regulated flows for the cancellation scenarios are presented in Figures R-19 through R-54. The following discussion describes the effects of the cancellation scenarios on each of the four reservoirs selected for comparison purposes.

- Lake Cypress Springs – Figure R-19 illustrates that cancellation Scenarios 4 and 5 differ from Scenario 1. There is minimal difference between Scenario 1 and 4. Both scenarios utilize full return flows and full authorized amounts. The only difference between the two runs is amount of cancelled water rights, which is 3,142 ac-ft/yr. Scenario 5 utilizes full return flows and the maximum use demand (see Table for demand changes). This scenario drastically changes the reservoir storage during the critical period. The maximum change between Scenario 1 and 5 is in 1971 and is approximately 55,000 ac-ft/yr (See Figure R-19). Scenario 6 is equivalent to Scenario 3 (no return flow); again, the only difference between the scenarios is the 3,286 ac-ft of cancelled water rights. Scenario 7 is similar to Scenario 5 with a maximum change between Scenario 1 and 7 of approximately 55,000 ac/ft/yr in 1971. Scenarios 6 and 7 are shown in Figure R-37.

- Lake O' The Pines – Scenarios 4 and 5 are shown in Figure R-20 and Scenarios 6 and 7 in Figure R-38. There is minimal difference between Scenarios 1 and 4, and the two scenarios show the same trends in reservoir storage, primarily because there was only 3,142 ac-ft/yr of cancelled water rights. Likewise, Scenarios 5 and 7 show similar storage amounts that are significantly higher monthly storage values throughout the period of record. These storage values are higher because the total diversion amount for the entire Cypress Basin is only 90,568 ac-ft/yr (in comparison to the full authorized amount of 393,919 ac-ft/yr in Scenario 1).

- Lake Bob Sandlin – Scenarios 4 and 5 for the cancellation scenarios for Lake Bob Sandlin are illustrated in Figure R-21. Again, the Scenario 4 diversion amount is 3,142 ac-ft/yr less than that of Scenario 1. However, these cancelled diversions did not affect the storage of Lake Bob Sandlin, therefore Scenarios 1 and 4 are identical in relation to the withdrawal from Bob Sandlin. Scenarios 5 and 7 show significantly higher monthly storage values throughout the period of record. Monthly storage for Scenarios 6 and 7 for Bob Sandlin is shown in Figure R-39. These storage values are higher because the total diversion amount for the entire Cypress Basin is only 90,569 ac-ft/yr (in comparison to the full authorized amount of 393,919 ac-ft/yr in Scenario 1). Although the reservoir storage is higher in Scenarios 5 and 7, the reservoir still has a significant reduction in storage during the mid to late 1960s. This drawdown is caused by the reported maximum use diversion taken from Bob Sandlin.

- Welsh Reservoir – Scenarios 4 and 5 are shown in Figure R-22 and Scenarios 6 and 7 in Figure R-40. Scenarios 1, 4, and 6 are similar because the maximum reported use in the last 10 years was comparable to the full authorized diversion amount. Again, Scenarios 5 and 7 have higher reservoir storage for the entire period of record. Storage decreases appear larger in this reservoir due to the lower reservoir content. Scenario 6 creates the lowest amount of storage in Welsh Reservoir. The reason for the low storage volumes is that this run has full diversion amounts for those rights that have reported use and 100 % reuse.

5.2.2.2 Unappropriated Flows at Selected Locations

The effect on annual unappropriated flows differed in all four cancellation scenarios. The difference was from minimal to significant. The difference in magnitude is due to the varying levels of return flow, cancellation of water rights, and the maximum historical use being significantly less than the authorized diversion amount. Annual unappropriated flows at the primary control points with differing cancellation scenarios (Scenarios 4 and 5) are shown in Figures R-24, R-26, R-28, R-30, R-32, R-34, and R-36. Annual unappropriated flows for Scenarios 6 and 7 are shown in Figures R-42, R-44, R-46, R-48, R-50, R-52, and R-54. In general, reuse and maximum historical use had significant effect on unappropriated flows, while cancellation of individual water rights had a negligible effect (primarily because only 3,142 ac-ft/yr was cancelled).

5.2.2.3 Regulated Flows at Selected Locations

Annual regulated streamflow values for cancellation Scenarios 4 and 5 are illustrated in Figures R-23, R-25, R-27, R-29, R-31, R-33 and R-35. Results for regulated flow for Scenarios 6 and 7 are found in Figures R-41, R-43, R-45, R-47, R-49, R-51, and R-53. Patterns in the regulated flows were similar to those in the unappropriated flows.

5.2.3 Current Conditions Scenario

Reliabilities for water rights in the Cypress Basin for Scenario 8 are shown in Table R-3. Scenario 8 is the current conditions scenario including maximum use demands, current reservoir capacities, term permits and full return flows. Scenario 8 results for reservoir storage and unappropriated and regulated streamflow are shown in Figures R-55 through R-72. In general, the results of Scenario 8 were similar to those results from Scenario 5. The term permits that are in the Cypress Basin had not reported use in the last ten years so their diversion amounts were set to zero; therefore, mirroring the results of Scenario 5. The main difference between the two scenarios is the area-capacity curves (original area-capacity curves used in Scenario 1 and 5, while year 2000 capacity curves used in Scenario 8). Therefore, in Scenario 8, reservoir volumes will begin the simulation period with less storage due to sedimentation of the reservoir.

5.2.3.1 Specific Large Rights

There are significant differences in reservoir storage, and unappropriated and regulated flows between reuse Scenario 1, 3 and the current condition Scenario 8. Differences in reservoir storage are shown in Figure R-55 through R-58.

- Lake Cypress Springs –Reservoir storage is presented in Figure R-55. Reservoir storage begins the simulation period at lower levels in Scenario 8 because sedimentation has been accounted for in this reservoir. Scenarios 1 and 3 are similar: however, the only difference is the amount of return flow that is found in Scenario 1. The availability of these return flows allows the reservoir to have higher values of storage in Scenario 1. Reservoir storage in Lake Cypress Springs is significantly higher in Scenario 8 than in Scenario 1. In 1968, there is over 33,000 ac-ft more water in storage in Scenario 8. The major cause of these higher storage values is the smaller amount of diversions in Scenario 8 (maximum ten-year use).

- Lake O' The Pines – Reservoir storage information is shown in Figure R-56. As with Lake Cypress Springs, Lake O' the Pines has a significant difference in reservoir storage between Scenario 8 and Scenario 1. There is approximately 200,000 ac-ft difference in storage values during the drought conditions of 1955-1957. Scenario 3 has even lower values of reservoir storage (40,000 ac-ft less than Scenario 1). The actual use from Lake O' the Pines is minor compared to the authorized diversion amount; therefore, all three scenarios are similar during much of the period of record.

- Lake Bob Sandlin and Welsh Reservoir did not change significantly in capacity from the original to the current condition. Therefore, Scenario 8 closely matches Scenario 5 in both cases. Lake Bob Sandlin had over 120,000 ac-ft of additional storage in the mid to late 1960s between Scenario 1 and Scenario 8. Again, the main difference is the smaller amount of diversions from the reservoir in Scenario 8. Reservoir storage values for Bob Sandlin are presented in Figure R-57.

5.2.3.2 Unappropriated Flows at Selected Locations

Annual unappropriated flows for the primary control points are shown in Figures R-60, R-62, R-64, R-66, R-68 and R-72. Total unappropriated flows increases for BC_JF and F10080 from Scenario 8 to Scenario 1. The increase in streamflow is a direct result of the amount of water being diverted in Scenario 8. Diversions are based on maximum use and therefore are significantly less than the full authorized amount in Scenario 1. Control point BC_PB also has greater values of unappropriated flows for Scenario 8 that can be attributed to the smaller amount of water diverted. However, for control points BK_JF, LC_OC and LC_JF, the unappropriated flows are similar in Scenarios 1, 3, and 8. All of these control points are on smaller rivers than the Cypress River and have fewer water rights than the mainstem of the Cypress River. The maximum use reported for the water rights in there control points is closer to the full authorized diversion than those on the main stem.

5.2.3.3 Regulated Flows at Selected Locations

Regulated streamflow values are shown in Figures R-59, R-61, R-63, R-65, R-67, R-69, and R-71. Results are similar to those described in the previous section.

5.2.4 Firm Yield Scenario

Out of the nine major reservoirs in the Cypress Basin, only Lake Bob Sandlin was able to meet the full authorized diversions and did not require a yield analysis. The "permitted firm yield" of Lake Bob Sandlin was simply the authorized diversion amount for that reservoir. A firm yield analysis was not performed on Caddo Lake since there are no water rights associated with the reservoir. The firm yield results are listed in Table 17. As stated previously, the firm yields were calculated solely based on the flows from the watershed. No water contracts for additional water supply were included in the analysis.

Table 17 Firm Yield Results

Reservoir	Permitted Diversion (acre-feet)	Firm Yield (acre-feet)	Previous Firm Yields (See Appendix F)
Monticello Reservoir	16,300	2,750	7,700
Welsh Reservoir	11,000	4,400	18,000
Ellison Creek Reservoir	23,000	13,800	23,000 & 22,100
Johnson Creek Reservoir	6,668	1,925	6,700
Lake O' the Pines	229,870	153,670	163,400 & 130,600
Lake Gilmer	6,180	4,325	7,470
Lake Bob Sandlin	60,430	60,430 [1]	48,500 & 60,500
Lake Cypress Springs	15,300	5,700	15,300 & 16,200

[1] Firm yield represents the "permitted firm yield", maximum authorized diversion.

Firm yields calculated in this study are expected to be lower than those yields that were calculated in previous studies. The yields calculated in this study incorporate all water rights in the river basin and therefore must release inflows to fill senior downstream water rights and reservoir storage. The results of previous studies can be found in Appendix F.

5.3 Comparison to Existing River Basin Model

Not Applicable.

5.4 Factors Affecting Water Availability and Modeling Results

There are several factors that affect the water availability modeling. One of the most important issues with regard to the water availability analyses performed for the Cypress Basin and the results from the WRAP (VER 12/01) model relates to naturalized streamflow development.

Distribution of naturalized flows can also affect the results of the modeling process. The TNRCC has required that the calculated naturalized streamflow be distributed based only on the drainage areas. Curve numbers and mean annual precipitation were also generated by the TNRCC and may need to be incorporated in the distribution method. These watershed parameters are developed by the CRWR at the University of Texas and have a direct effect on the results of the WAM model. The accuracy of the drainage areas derived using GIS procedures must be manually checked and verified. For this study, refined digital elevation data (30 meter-square cells) were used to create the drainage areas. With regard to NRCS curve numbers assigned to the watersheds of individual control points in the model, the small watersheds may only have enough area to cover one curve number type. Therefore, it is extremely important to verify that the correct curve number is being used for these areas.

It was assumed that interbasin transfer from the Cypress Basin were 100% reliable.

5.5 Requirements for Model Re-run and/or Model Update

The model can be re-run with any standard computer equipment. Issues that might be evaluated in the future include the use of curve number and precipitation in the distribution process for naturalized streamflows.

6.0 SUMMARY AND CONCLUSIONS

The Texas A&M WRAP (VER 12/01) model has been applied to the Cypress Basin in Texas to determine water availability. All of the 81 water rights in the basin were included in the model. Water availability was calculated in three basic scenarios: (1) Reuse Runs (full authorized diversions with varying return flow amounts), (2) Cancellation Runs (varying diversion and return flow amounts based on cancellation of water rights), and (3) Current Conditions Runs (maximum use diversions with return flows using year-2000 area-capacity reservoir relationships. All scenarios utilized:

- 51-year period of naturalized flows from 1948 through 1998.
- Water rights information for all water rights issued by the TNRCC through February 1999.

The WR, WS, and OR records in WRAP (VER 12/01) characterize the written permit and other pertinent information required for input into the computer model. No system operations were modeled unless authorized in the written permit. Nine scenarios were performed: eight base scenarios and one basin specific scenario (firm yield). The primary conclusions of this water availability study of the Cypress Basin are as follows:

- The Cypress Basin watershed area is approximately 2,812 square miles. There are 81 water rights with approximately 449,019 ac-ft/yr authorized annual diversions.

- The majority of the reliabilities for the water rights in Scenario 1 were above 90%. However, the majority of these rights did have small amounts of shortages associated with these high percentages.

- Comparisons of the three reuse scenarios show that varying levels of wastewater reuse do impact water supply. The reliability of a water right generally decreases as the level of reuse increases. Reuse of wastewater decreases the amount of storage in the reservoirs as well (See Figures R-1 through R-4).

- Hypothetical cancellation of water rights has a negligible effect on the reliability of water supply for most rights in the basin. The magnitude of simulated cancellations totaled 3,142 ac-ft/yr, and accounts for only 1% of the full authorized diversion amount. The majority of the simulated cancellations occurred in water rights whose reliability was less than 100%.

- Scenarios that utilize the ten-year maximum use as the diversion amount can significantly affect the amount of unappropriated flow and reservoir storage because the actual historical diversions during the last ten years were substantially less than the fully appropriated amounts. The cumulative diversion amount used in these runs (Scenarios 5 and 7) was 90,569 ac-ft/yr. The cancellation runs with this large change in diversion amounts had a greater impact on the water availability than the cancellation runs with full authorized amounts (Scenarios 4 and 6).

- Simulated results from the WRAP (VER 12/01) model indicate that there are quantities of unappropriated and regulated flow on the mainstem of the Cypress River during most of the period of record. The largest amounts of unappropriated and regulated flows in Scenarios 1, 3, and 8 are shown in Figures R-61 and R-62. In general, wastewater reuse has minimal effect on unappropriated and regulated flows because there are few significant return flows in the basin. Diversions in Scenario 8 (maximum ten year use) created the largest difference in unappropriated and regulated flows. Future appropriations will be subject to environmental flow restrictions pursuant to Chapter 11 of the Texas Water Code.

- Out of the nine major reservoirs in the Cypress Basin, only Lake Bob Sandlin was able to meet the full authorized diversions and did not require a yield analysis. The "permitted firm yield" of Lake Bob Sandlin was simply the authorized diversion amount for that reservoir. A firm yield analysis was not performed on Caddo Lake since there are no water rights associated with the reservoir. Firm yields were calculated solely based on the flows from the watershed. No water contracts for additional water supply were included in the analysis. Firm yields calculated in this study are expected to be lower than those yields that were calculated in previous studies. The yields calculated in this study incorporate all water rights in the river basin and therefore must release inflows to fill senior downstream water rights and reservoir storage.

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This document was submitted to the Texas Water Digital Library by Grant J. Gibson, P.G., Water Availability Modeling Coordinator, Texas Commission on Environmental Quality, on April 1, 2014.