Caddo Parish Regional Water/Utility District
Master Plan
FINAL REPORT
Phase IV - Feasibility Watershed Analysis
Caddo Parish
Shreveport, Louisiana

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1.0 Phase IV Introduction

As discussed in previous phases, the purpose of this Regional Water/Utility District Master Plan (Master Plan) is to provide Caddo and Bossier Parish officials with a comprehensive planning document. The Plan is composed of different phases, three of which have previously been completed by Shaw and listed below.

- Phase I - Identify and Define Existing Water Resources
- Phase II - Identify and Evaluate Existing Water Supply Infrastructure
- Phase III - Development and Evaluation of Future Growth Scenarios

As the next phase of the Master Plan, Phase IV - Feasibility Watershed Analysis will examine and determine surface water resources in Caddo and Bossier Parishes. Phase IV efforts will define and present surface resources including potential surface water availability and surface water yields and the amounts of surface water available to meet the current and future drinking water needs of the region.

Shaw reviewed and analyzed existing information from various sources, including the Louisiana Department of Transportation (DOTD), United States Geological Survey (USGS) and the United States Army Corp of Engineers (USACE) to ascertain yield amounts previously studied.

Safe Yield is generally defined as the reliable withdrawal rate of water with acceptable quality that can be provided by a combination of stream/river flows and reservoir storage through a defined critical drought period. Safe yield is dependent upon the storage and hydrologic (rainfall/runoff/evaporation) characteristics of the source, the source facilities, the selected critical drought, upstream and downstream withdrawals and minimum in-stream flow (MIF) requirements.

Ending Storage = Beginning Storage + Inflow – Water Supply Demand – Evaporation - MIF

The necessary storage and hydrologic data needed to perform a safe yield study for Bossier and Caddo Parishes was collected and analyzed by Shaw and is presented in this Phase of the Master Plan.

2.0 Phase IV Scope

The scope of this Phase, as previously defined, was to identify the surface water resources in Caddo and Bossier Parishes and perform a feasibility level watershed analysis of the Red River and other potential raw surface water sources within the Red River basin to determine the most optimal source and method for satisfying the region's needs. Phase IV of the Master Plan discusses the river basins, watersheds, historical runoff and stream flow data, surface water use, current and future water demand and the available yields of surface water sources in the Caddo/Bossier Region.

Determining surface water yields are vital to the long term planning and conservation of water resources in the Caddo and Bossier Region. In addition, water supply and storage are crucial to assuring the long-term economic viability of the region. In order to project the amount of water available, this water yield analysis considered stream/river flow, water depletions, existing water storage, existing water usage and projected water usage determined in previous phases of the Master Plan.

The purpose of this analysis is to determine the available raw surface water yield of existing surface water sources for Caddo and Bossier Parishes. Specifically, the objective of this phase is to:

- Evaluate options for raw surface water supplies to meet long term needs on a regional basis
- Determine viable raw water sources and initiate planning for long term water needs
- Review past yield investigations and develop feasibility level yields

This analysis will determine and evaluate raw surface water sources and the yields available to Caddo and Bossier Parishes. This analysis will include the following potential surface water sources:

- Red River
- Cross Lake
- Caddo Lake/Twelve Mile Bayou
- Toledo Bend Reservoir
- Lake Bistineau
- Cypress Bayou Reservoir
- Black Bayou Reservoir (Bossier Parish)
- Bodcau Bayou Reservoir

The results of the above evaluations and analysis are presented in the final section of this report.

3.0 Background

3.1 General

Water supply in the northwest region of the state is primarily controlled by the Red River and the Red River Watershed, groundwater recharge rates, seasonal patterns of storm systems, as well as highly variable annual precipitation. Recognition of these temporal and geographic variations plays an integral part in water supply planning and helps facilitate the orderly use of the region's surface water resources, so as to avoid a negative impact on its groundwater resources. In recent years, Caddo and Bossier Parishes have experienced severe droughts due to periods of abnormally dry weather, where the available supply of water from precipitation, surface runoff, reservoir storage and/or groundwater has declined to levels that may not reliably meet system demands.

River, lake, and reservoir yields are the rate of flow which can be drawn while still maintaining proper operating conditions. Although current surface water users in the Caddo/Bossier region have the production capabilities to meet current demands, there are many systems throughout the region that face water supply problems. For many of these systems, excessive withdrawals from groundwater aquifers and diminishing groundwater supply have emphasized the importance of looking to surface water as a long term solution. The analysis in this phase will fully discuss and present the yield analysis, historical flows, water usage, watershed characteristics, drainage areas and climatic information of the region.

3.2 Study Limitations

The following limitations and assumptions were made for this study:

- This study is limited to evaluating the yields of the surface water sources identified in this study; other potential raw surface water sources were not analyzed such as Black Bayou Lake (Caddo Parish), Wallace Lake, and Bayou Pierre.
- The yield analysis performed for this study is dependent upon estimates of reservoir yield volumes prepared by others.
- It was assumed that there are no transmission capacity limitations between raw water sources and water treatment facilities.
- Capacity evaluation of existing raw water treatment facilities was not performed. It is assumed that the treatment capacity and transmission capacity would not limit or negatively impact the yields.
- Monthly demands were based upon historical use records.
- Sedimentation effects on available supply were not considered.

4.0 Methodology

4.1 General

For many of the existing lakes, reservoirs, rivers and streams, yield determinations have been previously determined and published by the Louisiana Department of Transportation (DOTD) and the United States Army Corp of Engineers (USACE). The objective of Phase IV is to obtain a feasibility level estimate of water yield available that will serve as a foundation for future analysis and planning. A simplified method of water yield analysis was used to estimate yield for the Red River. This method and the results are discussed in Section 6.0.

4.2 Assessment of Available Information

Direct precipitation, stream flow, river flow and lake levels are accurately gauged and quantified from information obtained from the United States Geological Survey (USGS) and the USACE. Stream gage flow information is typically used as the primary source of reservoir inflow data. Where upstream gages exist with adequate periods of record, monthly mean flow records are typically used to determine the dependable yield.

Water demand is not a constant value and varies throughout the year. Consumers tend to use more water in the summer and less in the winter. Historical water use for the region was obtained from surveys conducted by Shaw with the local public water providers and USGS water use reports. This information was used as the basis for establishing outflows from the water sources identified in this study.

4.3 Critical Drought Periods

The drought period of record may vary depending upon local hydrology, reservoir and diversion capacities and other factors. A drought is a creeping phenomenon, making it hard to monitor and define. Droughts impact many sectors of the economy and operate on many different time scales. As a result, the climatological community has defined four types of droughts: meteorological drought, agricultural drought, socioeconomic drought and hydrological drought. Meteorological drought occurs when dry weather patterns dominate an area. Agricultural drought happens when crops become affected and a socioeconomic drought relates the supply and demand of various commodities to drought. Hydrological drought occurs when low water supply becomes evident, especially in streams, reservoirs, and groundwater levels, usually after many months of meteorological drought. Meteorological drought can begin and end rapidly, while hydrological drought takes much longer to develop and then recover. There are several climate indicators used to measure drought. The Palmer drought indices measure the balance between moisture demand (evapotranspiration driven by temperature) and moisture supply (precipitation). The Palmer Z Index depicts moisture conditions for the current month, while the Palmer Hydrological Drought

Index (PHDI) and Palmer Drought Severity Index (PDSI) depict the current month's cumulative moisture conditions integrated over the last several months. The Palmer Hydrological Drought Index measures hydrological impacts of drought (e.g., reservoir levels, groundwater levels, etc). This long term drought index was developed to quantify these hydrological effects, and it responds more slowly to changing conditions than the Palmer Drought Severity Index (NCDC).

According the National Oceanic and Atmospheric Administration (NOAA), the PHDI categories are defined as the following:

Table 4-1, Palmer Hydrological Drought Index

+4.00 and above	Extremely Moist
+3.00 to +3.99	Very Moist
+2.00 to +2.99	Moderately Moist
-1.99 to +1.99	Mid-Range
-2.00 to -2.99	Moderate Drought
-3.00 to -3.99	Severe Drought
-4.00 and below	Extreme Drought

PHDI data dating from January 1955 to July 2012 was collected for Bossier and Caddo Parishes. Over the past 57 years, moderate drought conditions occurred frequently within each decade lasting 1 to 2 years on average. Severe drought conditions occurred less frequently over the time period. The parishes experienced extreme drought conditions from March 2011 to December 2011, severe drought conditions during January and February of 2012, and have experienced moderate drought conditions from March 2012 to July 2012 (NCDC). Historical drought information is shown in Appendix A.

5.0 Watershed Analysis

5.1 General

Although recorded gage stream flow information will be used in this study, the general characteristics of each watershed will be discussed in this section. With the exception of Toledo Bend, all of the sources evaluated in this study are part of the Red River Watershed.

5.2 Watershed Characteristics

The determination of water yields generally requires the analysis of watersheds to determine the principal drainage basin characteristics that affect the amount and distribution of runoff. These characteristics are location, size, shape, physiography, geology, soils, vegetative cover and man-made developments. The general characteristics of the local watersheds are discussed below.

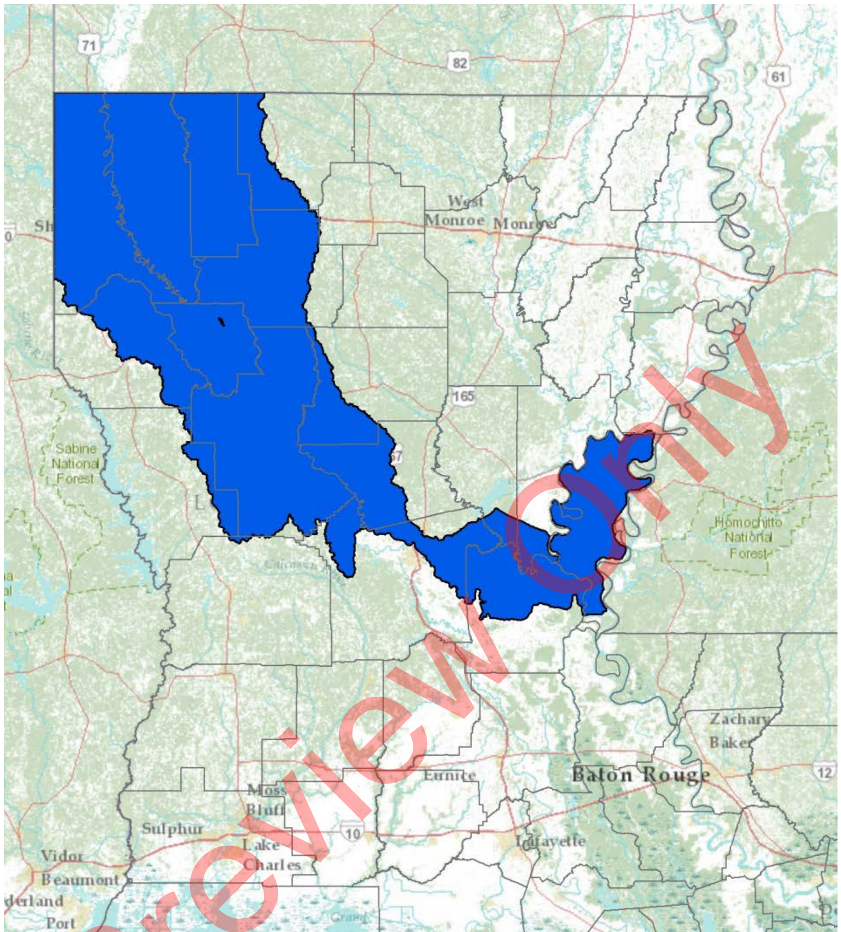
5.2.1 Red River Basin

Red River is one of Louisiana's major river systems and is located in the Mississippi River Drainage Basin. The headwaters of the Red River are located in Curry County, New Mexico and the river ends 1,360 miles downstream at the Mississippi River. The Red River Watershed is 69,200 square miles and receives drainage from 5 states including New Mexico, Texas, Oklahoma, Arkansas, and Louisiana. Red River enters Louisiana from Arkansas in the northwest portion of the state and follows a southeasterly course, passing through or forming the boundary of 10 parishes, until it reaches its mouth at the Mississippi River. Shreveport and Alexandria are the principle cities located along the river.

The Red River in Louisiana is located in the northwestern portion of the state. The basin has an area of 6,358 square miles within the state of Louisiana and is bound by the Arkansas-Louisiana State line to the north, the Texas-Louisiana State line to the west, the Sabine River, Calcasieu-Mermentau and Atchafalaya-Teche-Vermillion basins to the south and the Ouachita River Basin to the east. The main watercourses draining the Red River Basin are the Red River, Loggy Bayou, Saline Bayou and Bayou Dorcheat.

The Red River Basin in Louisiana is dominated by the undulating pine and hardwood-forested hills of the Pine Hills physiographic division. These uplands are dissected by the Red River valley, which opens into a broad, flat plain in the southeastern basin and is part of the Alluvial Plains physiographic region. The lowest elevation in the Red River Basin is 38 feet above mean sea level (msl), located on the Red River plain at the southeastern basin boundary. The highest point, 536 feet above msl, is located in Bienville Parish on the northeastern basin boundary. Geologic faults are located along the western and northeastern margins of the Red River Basin. Upland areas are dominated by loamy, clayey soils formed on shale marine bedrock, alluvial plains are characterized by loamy and clayey low terraces and flood plains. (Red River Basin Characterization Report, 2009).

Figure 5-1, Red River Drainage Basin Louisiana



5.2.2 Cross Lake

Cross Lake is located in the Red River Basin and is part of the Cross Bayou sub-basin. Cross Lake receives inflow from a 253 square mile watershed that includes eight major tributaries and supplemental flow through a pipeline from nearby Twelve Mile Bayou during low water levels. Most of the tributary inflow enters at the western end of the lake. The three largest tributaries and watershed areas are Paw Paw Bayou (82.02 square miles), Cross Bayou (62.43 square miles) and Shettleworth Bayou (19.54 square miles). Much of the shoreline is urbanized, particularly along the eastern and southern shores. The major types of land use surrounding Cross Lake and within its watershed are forest land, forested wetlands, residential and to a lesser degree, cropland and pastures. See Figure 5-2, Cross Bayou Watershed.

Figure 5-2, Cross Bayou Watershed

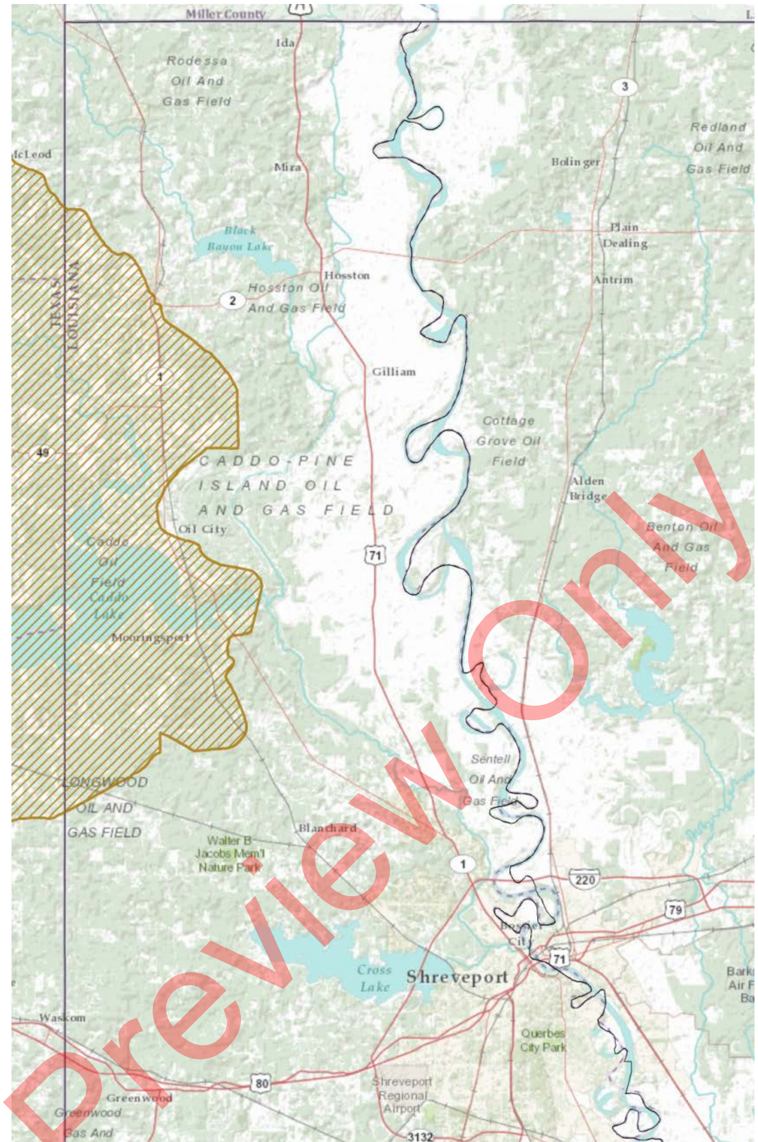
5.2.3 Caddo Lake/Twelve Mile Bayou

Caddo Lake is located in the Red River Basin and extends from northwestern Caddo Parish into Marion County, Texas. The lake has a drainage area of 2,744 square miles. Major tributaries are Big Cypress Bayou in Texas and James Bayou in Louisiana, which enter at the western and northern ends of the lake. There are also numerous smaller tributaries. Caddo Lake is a wide, shallow lake and the shallow areas of the lake are densely vegetated.

Caddo Lake is part of the Caddo Lake Watershed and consists of four major sub-basins drained by Big Cypress Creek in Texas, Little Cypress Creek Segment in Texas, Black Cypress Bayou in Texas and James Bayou in Louisiana; all sub-basins of the Red River Basin. The first three of these watersheds have USGS stream flow gauging stations located near Caddo Lake. James Bayou, which enters Caddo Lake through a large embayment on the northern shore in Louisiana, does not. These four watersheds provide most of the inflows to the lake, but three smaller creeks (e.g., Kitchen Creek, Haggerty Creek, Harrison Bayou) also enter the main body of the lake directly. Big Cypress Creek alone accounts for 953 square miles (35.4%) of the 2,694 square mile Caddo Lake Watershed, while the three gauged streams together drain 2,092 square miles, about 77.6% of Caddo Lake's drainage area. James Bayou and the minor drainage areas respectively account for 338 and 264 square miles (12.6% and 9.8%) of the total drainage area (Texas Water Development Board). See Figure 5-3, Caddo Lake Watershed.

Twelve Mile Bayou is a low flow stream downstream of Caddo Lake, located below the Caddo Lake dam. Twelve Mile Bayou is 23 miles long, 250 to 300 feet wide, with an average depth of 16 feet. It is 8,800 feet upstream the confluence of Cross Bayou and Red River. Completion of Lock and Dam No.5 on the Red River by the USACE raised the Red River pool 5 feet above the low head structure on Twelve Mile Bayou and led to a reported decrease in water quality.

Figure 5-3, Caddo Lake Watershed

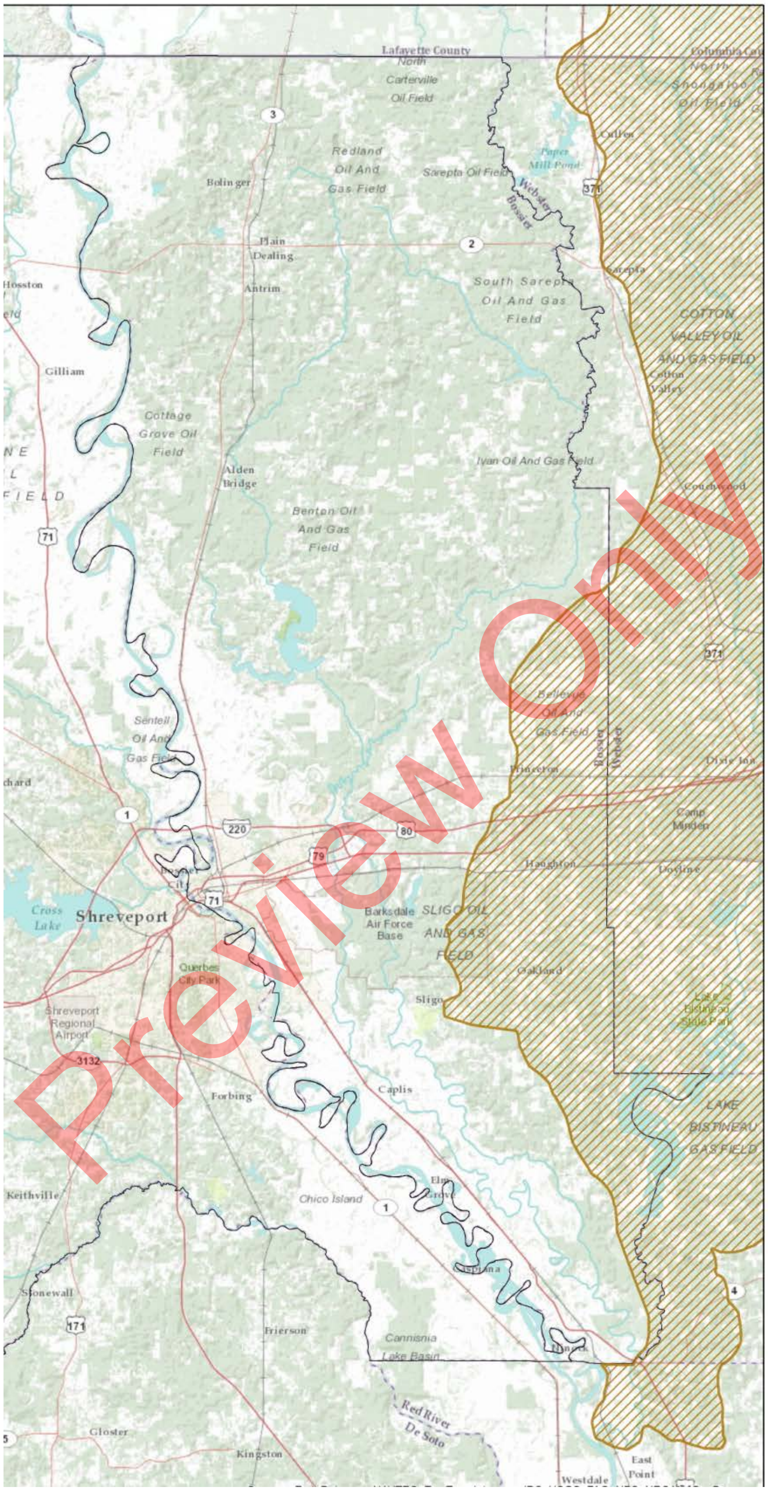


Source: EPA

5.2.4 *Lake Bistineau*

Lake Bistineau is a 26.9 square mile (17,200 acre) reservoir located in the Red River Basin extending to parts of southeast Bossier, southwest Webster and northwest Bienville Parishes. Bayou Dorcheat is the primary tributary. Lake Bistineau is part of the Loggy Bayou sub-basin and has a drainage area of approximately 1,443 square miles and is primarily used for flood control and conservation. See Figure 5-4, Loggy Bayou Watershed.

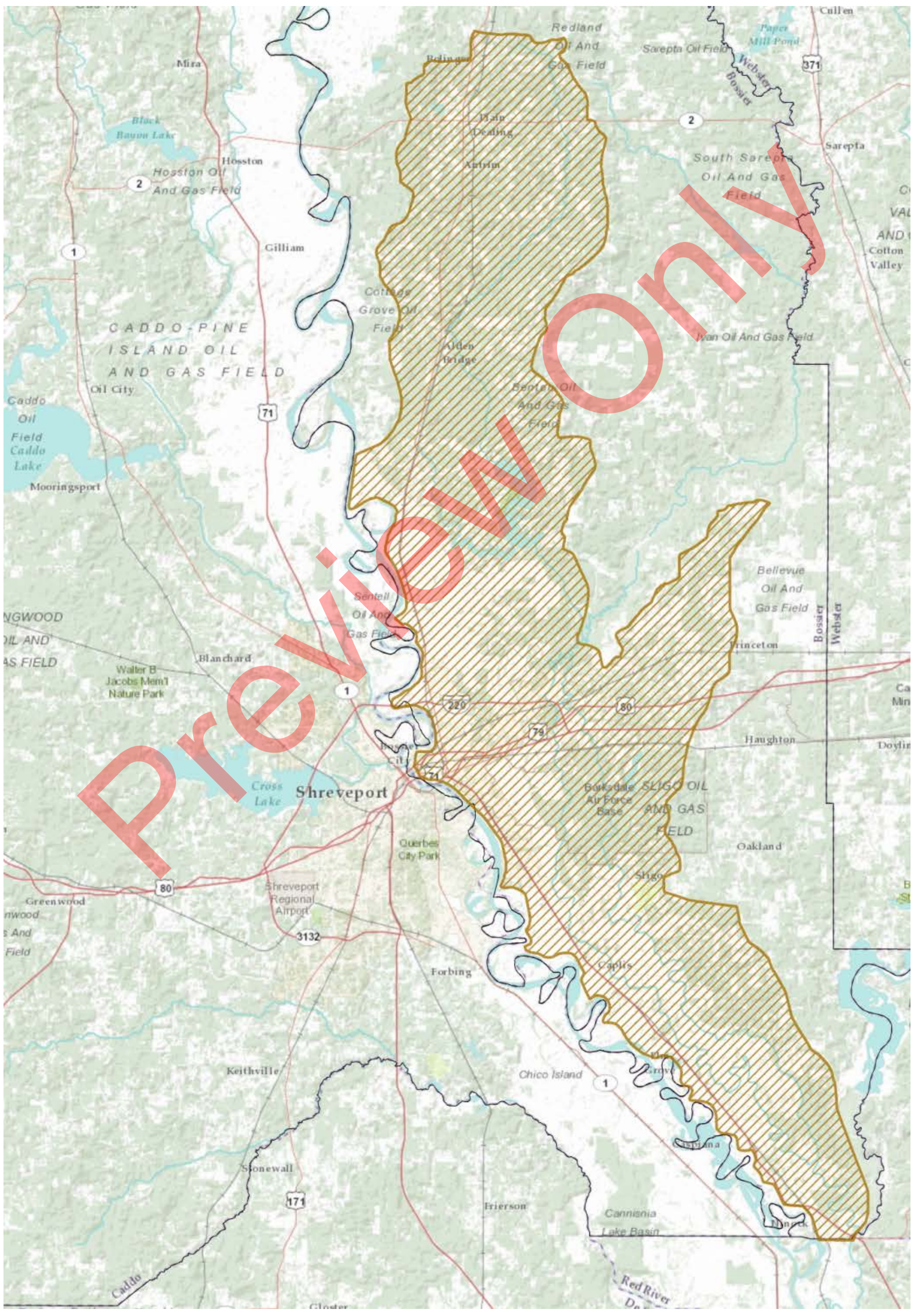
Figure 5-4, Loggy Bayou Watershed



5.2.5 *Cypress Bayou Reservoir*

Cypress Bayou Reservoir is located in the Red River Basin, within the Red Chute Watershed, and has a drainage area of 155 square miles. Cypress Bayou Reservoir receives inflows from Cypress Bayou, Little Caney Bayou and White Oak Bayou. The Cypress Bayou Reservoir, located about 10 miles north of Bossier City, was completed in 1975. See Figure 5-5, Red Chute Watershed.

Figure 5-5, Red Chute Watershed



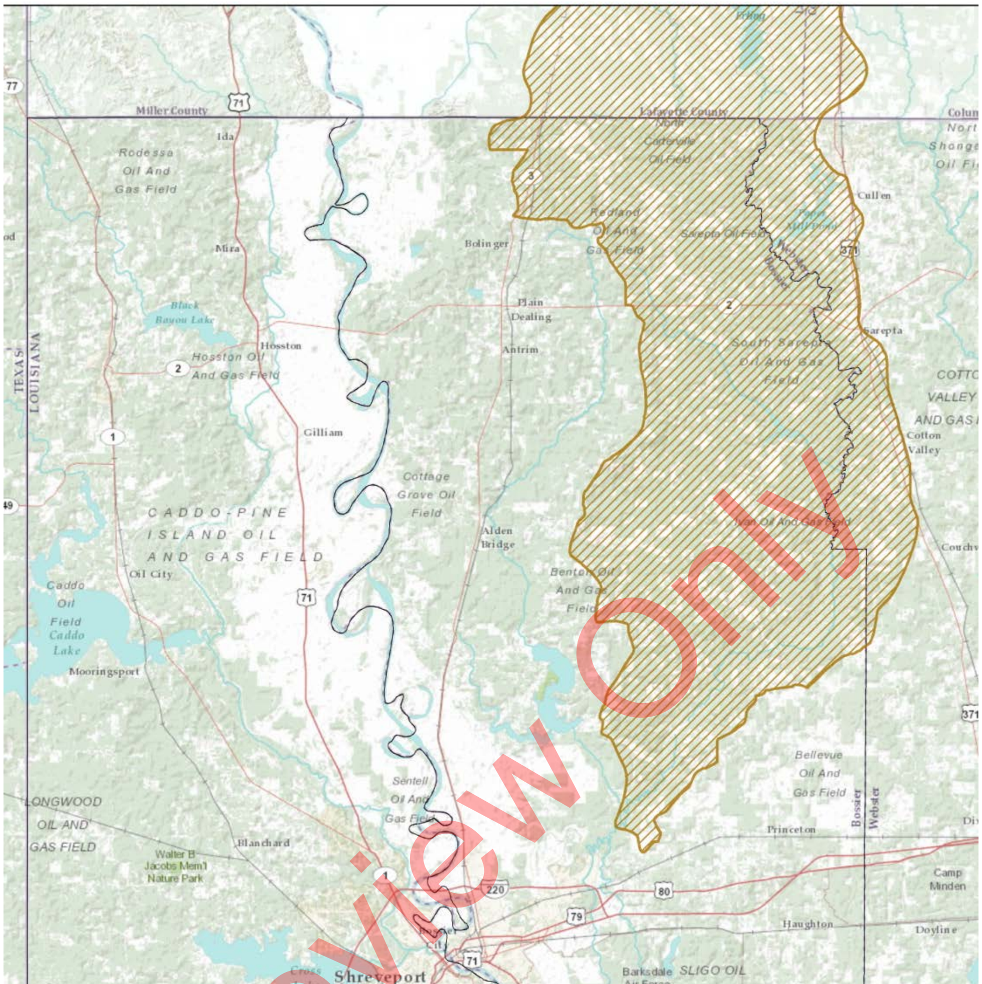
5.2.6 Black Bayou Reservoir (Bossier Parish)

Cypress Black Bayou Reservoir is located in Bossier Parish, about 8 miles north of Bossier City, Louisiana, and 3 miles southeast of Benton, Louisiana. The reservoir, formed from an earthen dam built in 1975 on Black Bayou, is used for water-based activities such as water skiing, fishing, boating, and swimming. Black Bayou Reservoir has a drainage area of 26 square miles and receives inflow from Black Bayou. The earthen dam is 4,800 feet in length and the reservoir level is controlled by a spillway 150 feet in length with a crest elevation of 185 feet msl. The maximum discharge for the spillway structure is 13,680 cubic feet per second (Ray Elifami, Louisiana Department of Transportation and Development, 1998). Bathymetric information for Black Bayou Reservoir is contained in Phase I of this study. The Red Chute Watershed is shown in Figure 5-5.

5.2.7 Bodcau Bayou

Bodcau Bayou is part of the Red River Basin and lies within the Bodcau Bayou sub-basin. The Bodcau Bayou sub-basin is part of the Red River Basin, beginning in southwest Arkansas and crossing into Louisiana. Bodcau Bayou forms the northeastern parish line before draining southwest through central Bossier Parish. The sub-basin is 454 square miles and land use is approximately 72.7% Forest, 12.3% Grassland, 10.9% Transitional, 2.9% Water, 0.9% Suburban, 0.1% Cropland and 0.1% Urban. See Figure 5-6, Bodcau Bayou Watershed.

Figure 5-6, Bodcau Bayou Watershed



5.2.8 Toledo Bend Reservoir

The Toledo Bend Reservoir is located within the Sabine River Basin on the Texas and Louisiana border. The Sabine River Basin has an area of 2,560 square miles and is surrounded by the Red River Basin to the north and east, the Texas-Louisiana state line on the west, the Calcasieu-Mermentau Basin to the east and the coast of the Gulf of Mexico to the south. The basin includes the areas drained by the Sabine River in Louisiana. It extends 190 miles north to south, and is 25 miles wide at its widest point. The southern tip of the Sabine River Basin is in the Coastal Zone, as delineated by the Louisiana Department of Natural Resources.

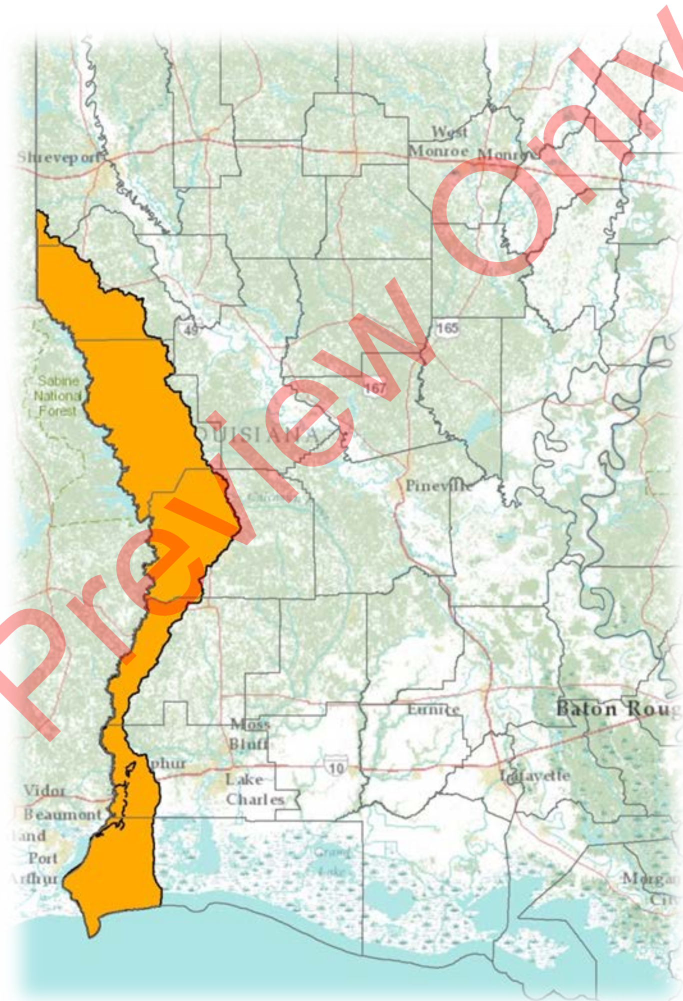
The principal land use in the Sabine River Basin is forest with wetlands dominating the southern end of the basin. There is little urban development in the Sabine River Basin.

The Sabine River Basin extends across multiple physiographic regions and climates. The northern Sabine River Basin is dominated by the Pine Hills physiographic region, which is characterized by undulating hills covered by pine and hardwood forests. In the southern Sabine

River Basin, prairies transition to coastal marshes. The lowest elevation within the Sabine River Basin is at msl in Cameron Parish and the highest point is 487 feet above msl in Sabine Parish on the eastern boundary. Geologic faults are found throughout Sabine Parish. Soils in the Pine Hills area of the northern Sabine River Basin are dominated by brackish organic and mineral coastal deposits, while the southern Sabine River Basin has loamy, silty and fluvial (river) deposited soils. (Sabine River Basin Characterization Report, 2009).

Toledo Bend Reservoir is one of the largest man-made reservoirs in the United States and covers an area of approximately 185,000 surface acres, with a storage capacity of 4, 477,000 acre-feet at a reservoir level of 172 feet in elevation (msl). See Figure 5-7, Sabine River Basin.

Figure 5-7, Sabine River Basin

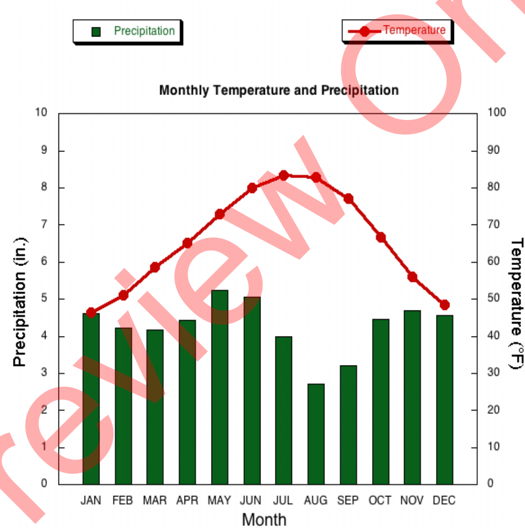


5.3 Climate

Northern Louisiana is located between 32 and 33 degrees latitude, the border between the Subtropics and Mid-latitudes. Köppen's Climatic Classification System categorizes Louisiana as

"Cfa". "C" represents an area having a moist climate with mild winters, "f" represents an area wet through all seasons and "a" represents long and hot summers where the average temperature of the warmest month is above 72° F and at least 4 months out of the year average temperatures above 50°F (Ahrens, 2007). Because of its latitudinal location, the climatology of Shreveport is transitional between the subtropical humid regime prevalent in the south to the continental climates of the Great Plains and Midwest to the north. During winter, cold Canadian air masses periodically move through the area. Spring and fall are usually mild and pleasant, but occasionally stormy. Summer is consistently hot and humid, dominated by high pressure and a moist, southerly surface flow (NCDC, 2006). Shreveport is located in southern Caddo Parish on the Red River, near the Caddo-Bossier Parish border. Due to its location, climatic data was obtained for Shreveport. Average monthly temperature and precipitation data from NCDC's Annual Climatology Data for Shreveport is represented in Figure 5-8.

Figure 5-8, Annual Climatology: Shreveport, LA (SHV)



Source: Average Temperatures and Precipitation 1971-2000. (NCDC Data)

In Shreveport, average temperatures range from upper 40's to mid-80's, but daily temperatures have been recorded to reach as low as -2°F and as high as 109°F. The precipitation presented by NCDC shows a minimum average of 2.8 inches falling in August and a maximum average of 5.3 inches falling in May. Extreme precipitation events range from a minimum of 0 inches recorded in August of 2000 and maximum 21.84 inches recorded in April 1991 (see Appendix B).

Average annual temperature in the Red River Basin generally increases from 63°F in the north to 83°F in the south. Average annual temperature in the Sabine River Basin generally increases from 65°F in the north to 69°F in the south.

5.4 Precipitation Data

Precipitation data is available from climatological stations maintained by the National Oceanic and Atmospheric Administration-National Weather Service (NOAA-NWS).

Average annual rainfall throughout the Red River Basin varies geographically from 30 to 65 inches per year, increasing from north to south. Historical annual precipitation in Shreveport varies between about 30 and 85 inches per year with a historical average of 48 inches per year. Although rainfall and the resulting runoff is plentiful in the Red River Basin, the historical record shows that extended dry periods can occur, such as in the 1960's and recent past years.

Annual rainfall throughout the Sabine River Basin varies from 50 to 60 inches per year, increasing from north to south. In Logansport, located in the northern Sabine River Basin, and DeRidder, located in the southern portion, total annual precipitation varies between 30 and 90 inches per year, with a historical annual average of about 52 inches in Logansport and 59 inches in DeRidder. Although rainfall and resulting runoff are plentiful in the Sabine River Basin, historical records show that extended dry periods can occur (e.g.., 1961 to 1966), stressing water supplies. Historical precipitation data for the City of Shreveport are included Appendix A.

5.5 Evaporation

Evaporation loss is an important factor when determining available yields from lakes and reservoirs. Lakes and reservoirs are renewable resources because they are replenished through the hydrologic cycle, making them reliable water sources.

Monthly lake evaporation information from 1954 through 2011 was taken from the Texas Water Development Board (TWDB). The TWBD uses the Pan Evaporation Method for obtaining evaporation data. Pan evaporation allows large-scale water bodies to be measured on a controlled, smaller scale. There are many factors that can influence pan evaporation rates (i.e. pan material, size, and water level) and all of these are accounted for in the National Weather Service Instruction 10-1302 "Requirements and Standards for the NWS Climate Observations" (NWS, 2010). The rates measured from the evaporation pan are multiplied by a pan-to-lake coefficient to get an accurate measurement. The pan-to-lake coefficient reflects previous data based on a seasonal and spatial distribution (TWDB, 2012).

TWDB prepares monthly and annual datasets for all stations for further computation on year by year basis by a geographic information system based program called ThEvap, developed by using ARC Macro Language (AML) by TWDB in 1998. ThEvap computes pan evaporation for an area of Thiessen polygon then transforms that Thiessen polygon data to a corresponding quadrangle. ThEvap then converts the pan evaporation rate to a reservoir surface evaporation rate for each quadrangle by applying the pan-to-lake coefficients (TWDB, 2012). The Monthly Lake

Surface Evaporation rates were obtained for quadrangle 514 from TWBD and are included in Appendix C.

6.0 Runoff and Stream Flow Data

6.1 General

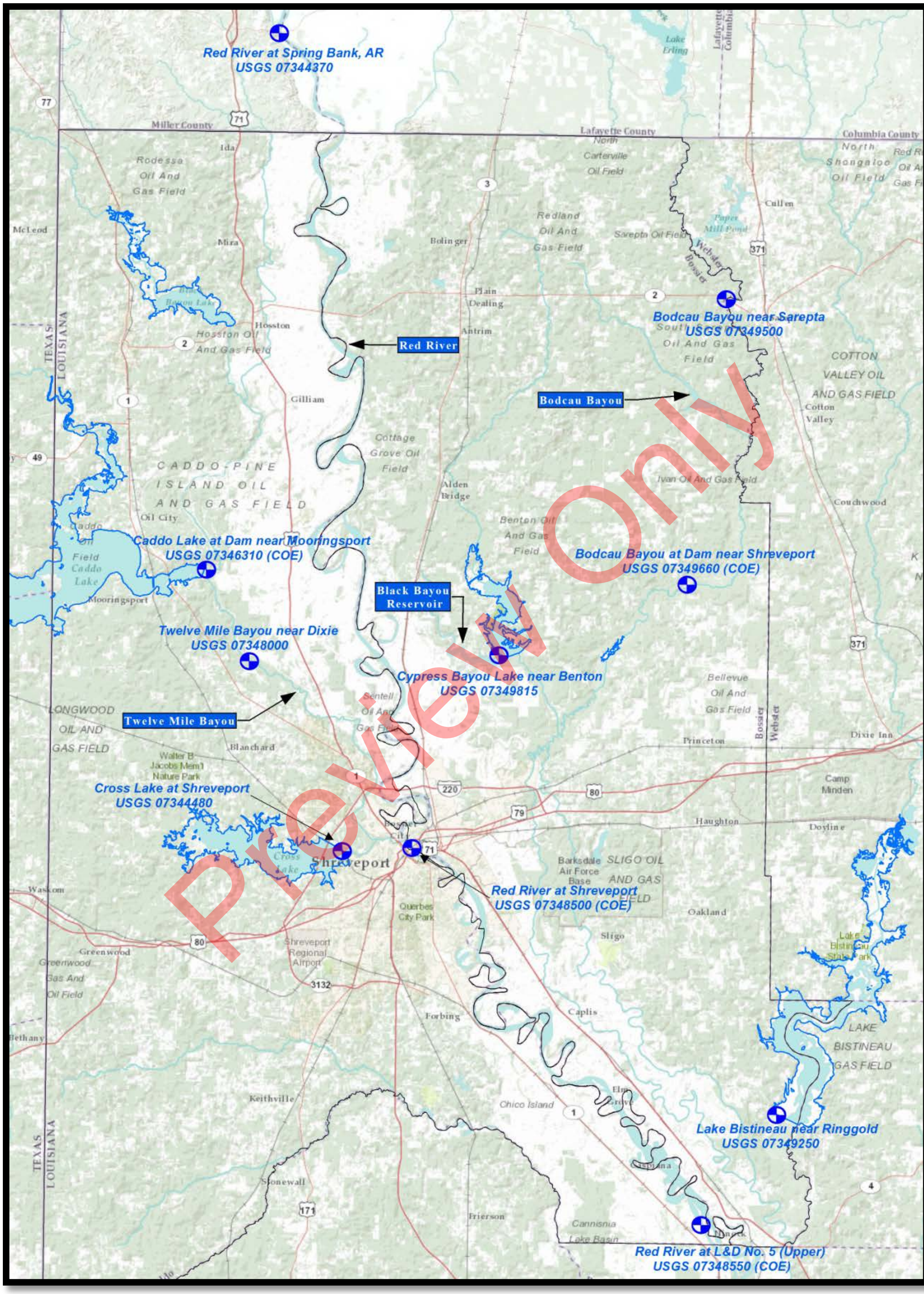
This section will discuss the dependable yield analysis of the surface water sources. DOTD and the USACE have determined the yield for several water sources and the results of those yields are presented in this study. From evaluating the yield data obtained from the DOTD and the USACE, some water sources were found to be unfeasible. A small overall yield was determined for the reservoirs, making them impractical water supply sources. Many streams draining upland areas of Caddo and Bossier Parishes are not dependable sources of supply because they do not have well-sustained flows during dry seasons. Other surface water bodies in Caddo and Bossier Parishes including Black Bayou Lake (Caddo Parish) and Wallace Lake are also not addressed in this study due to their low potential yields. Runoff and stream flow data for feasible surface water sources are discussed in the following sub- sections.

6.1 Runoff and Stream Flow Data

The stream flow from a drainage basin depends upon the climate and the physical characteristics of the basin. The principal drainage basin characteristics that affect the amount and distribution of runoff are location, size, shape, physiography, geology, soils, vegetative cover and man-made developments. Evaluating how basin characteristics affect stream flow and comparing the stream flow of multiple basins, based on basin characteristics, is not needed for a dependable yield analysis. Determining dependable yield requires extensive stream flow data to identity critical drought periods and to determine the availability of water at each source. This complex interrelationship between climate and drainage basin characteristics is integrated in the flow of the stream and the aggregate effect is measured directly at the stream gaging station. The primary objective of analyzing stream flow records is to develop a continuous daily stream flow record into each reservoir and at each river intake from the present time to a time prior to the drought of record. The measured stream flow from drainage basins therefore furnishes the best method for comparing runoff characteristics.

Runoff and stream flow data for the raw water surfaces are discussed in this section. USGS stream gages will be the primary source of reservoir inflow data for this analysis. USGS stream flow data for each of the water sources was presented in Phase I, but summaries containing mean gage heights and flows are presented and discussed in this section. Gage locations are shown in Figure 6-1.

Figure 6-1, Red River Basin Gages



Source: ESRI, Delorme, NAVTEQ, TomTom, Intermap, iPC, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, ESRO Japan, METI, ESRI China (Hong Kong) and the GIS User Community.

6.1.1 Red River

Bossier and Caddo Parish are located at River Mile 277 of the Red River, where the Red River has a drainage area of 60,614 square miles. The average discharge of the river was 19,500 cubic feet per second (CFS) during 1998-2008 at Spring Bank, Arkansas (station number 07344370; U.S. Geological Survey, 2008), about 4.5 miles upstream from Bossier and Caddo Parish. The highest mean daily discharge of the Red River recorded during this 10-year period was 138,000 CFS on March 14, 2001 and the lowest was 1,100 CFS on October 11, 2006.

The Red River enters the State of Louisiana from the State of Arkansas. In accordance with the Red River Compact, all waters entering the State of Louisiana can be utilized within the state without restrictions. Phase I of the Master Plan identified the major users of the Red River in Caddo and Bossier Parishes. The only municipality that utilizes the Red River as their primary drinking water source is Bossier City, who supplies several smaller utilities. The Red River is monitored by the Vicksburg Office of the USACE and the USGS through river level gages and flow measurements. For this effort, Shaw and our sub-consultants used the following gage locations for Red River water levels and flows:

Table 6-1, Red River Gages

	Location	Time Period	Data Type	Source
Upstream	Spring Bank, AR (USGS 07344370)	1995-2012 1995-2012	Discharge Gage	USGS
Caddo/Bossier	Shreveport, LA (USGS 07348500 (COE))	1928-1983 2000-2012	Discharge Discharge, gage, width, velocity, cross section area	USGS USACE
Downstream	L&D No.5 (Upper) (USGS 07348550 (COE))	1995-2011	Pool Level	USGS

Shaw and our sub-consultants found that the Shreveport gage data provided the most useful information for the hydraulic analysis and water yield. This data set provided historical river levels as early as 1928. The zero level of this Station is 131.48' NGVD29. In reviewing this data, levels as low as 0.2' were measured in the Red River. In 1995, the USACE completed construction of a lock and dam system to enhance navigation on the Red River. The presence of this lock and dam has a significant influence on Red River water levels in the Shreveport area. Use of data prior to 1995 would be inappropriate since the lock and dam prevents water levels from dropping to previous levels. The data set from 1996 through 2012 was used to develop minimum and mean water levels and available flows. Table 6-2 presents the data for the Shreveport Gage.

Table 6-2, Red River Mean Gage Heights

Year	Gage Heights	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
1996	MIN	14.20	14.00	14.00	14.10	14.10	13.90	13.90	14.40	14.60	14.30	18.40	18.30
	MAX	15.20	15.40	14.40	16.00	16.10	14.80	16.40	15.60	19.60	20.30	27.00	27.10
	MEAN	14.74	15.03	14.15	14.85	14.73	14.39	14.72	14.83	15.81	16.95	22.15	23.39
1997	MIN	16.10	15.70	21.00	18.10	18.30	16.30	14.60	14.20	14.10	14.20	14.10	14.10
	MAX	18.90	27.20	28.80	26.40	26.70	19.30	16.60	15.50	14.50	14.70	15.10	22.40
	MEAN	17.43	20.89	25.22	21.54	21.15	18.07	15.08	14.49	14.25	14.45	14.65	16.98
1998	MIN	21.30	18.60	18.60	15.30	14.20	14.10	14.20	14.00	14.10	14.20	14.30	14.40
	MAX	28.30	24.30	26.10	24.20	16.10	16.10	14.40	14.40	15.40	19.00	15.80	20.70
	MEAN	25.69	21.74	22.63	18.50	14.84	14.56	14.27	14.25	14.56	16.06	14.90	18.09
1999	MIN	15.50	15.70	14.70	15.30	15.20	15.00	14.10	13.90	13.90	14.20	14.30	13.90
	MAX	20.10	22.00	21.10	22.40	20.10	16.80	17.40	14.60	14.60	14.60	14.60	15.30
	MEAN	17.25	18.30	17.53	18.50	17.74	15.70	15.75	14.19	14.35	14.48	14.47	14.61
2000	MIN	14.30	14.10	14.60	14.60	14.30	15.80	14.30	14.30	14.10	14.10	14.10	17.20
	MAX	15.20	14.60	15.10	17.10	18.50	20.50	19.50	14.80	14.80	14.40	23.60	27.30
	MEAN	14.58	14.38	14.84	15.86	16.74	17.78	15.83	14.56	14.54	14.20	18.65	20.53
2001	MIN	20.50	19.50	24.30	17.30	16.10	15.30	14.00	13.80	14.00	13.90	13.80	14.90
	MAX	26.80	29.20	29.80	23.30	17.80	22.70	16.40	14.40	15.00	20.10	14.80	28.00
	MEAN	22.98	23.41	27.74	19.62	16.93	18.14	14.83	14.06	14.36	16.03	14.27	20.28
2002	MIN	16.70	18.20	15.70	22.90	14.90	14.20	14.10	14.10	14.00	14.20	14.20	13.90
	MAX	22.80	24.20	27.40	27.70	21.70	15.70	14.70	14.80	14.70	15.70	15.20	19.70
	MEAN	18.80	20.54	20.03	25.68	17.56	14.75	14.42	14.40	14.31	14.59	14.61	15.06
2003	MIN	14.40	14.30	15.80	14.10	13.90	13.30	14.00	13.81	13.77	13.70	13.60	13.70
	MAX	20.80	21.70	21.80	15.60	15.00	14.40	14.80	14.50	14.70	14.38	14.50	14.30
	MEAN	17.29	16.21	17.93	14.62	14.43	13.93	14.21	14.16	14.19	14.05	14.05	14.01
2004	MIN	13.63	13.89	14.05	13.95	13.94	14.26	13.96	13.96	14.16	14.09	14.27	14.70
	MAX	15.06	18.02	17.64	15.45	17.05	20.59	20.34	14.83	14.53	14.82	21.30	22.89
	MEAN	14.23	15.80	15.58	14.29	15.05	16.40	15.88	14.26	14.31	14.41	15.95	18.08
2005	MIN	14.55	15.76	14.37	14.29	13.93	13.97	14.16	13.94	13.24	13.08	13.02	14.16
	MAX	24.38	19.06	16.84	18.20	14.52	14.47	14.61	14.60	15.13	15.17	18.76	17.25
	MEAN	20.63	17.20	15.38	15.75	14.31	14.29	14.35	14.29	14.25	14.19	14.05	14.44
2006	MIN	14.13	14.05	14.16	13.80	13.86	13.78	14.05	14.00	13.99	13.97	14.06	13.87
	MAX	14.93	14.64	21.10	16.43	17.03	14.38	14.45	14.45	14.50	14.50	14.92	15.68
	MEAN	14.40	14.38	15.95	14.64	14.99	14.10	14.24	14.20	14.19	14.15	14.44	14.74
2007	MIN	14.73	14.95	14.00	14.51	15.64	15.54	2.41	20.36	14.69	14.15	13.92	14.20
	MAX	25.75	21.00	15.12	17.91	21.73	23.56	26.87	24.92	20.46	15.16	15.30	15.94
	MEAN	21.27	16.94	14.39	15.43	18.73	20.08	24.15	22.39	17.20	14.57	14.36	14.88
2008	MIN	14.03	14.14	18.89	23.14	17.03	14.48	14.08	14.15	14.21	14.12	14.02	13.72
	MAX	14.94	21.97	26.10	25.84	23.99	17.13	14.84	15.06	16.26	15.72	14.54	14.90
	MEAN	14.51	16.72	22.57	24.49	20.51	15.88	14.45	14.43	15.25	14.64	14.31	14.34
2009	MIN	14.14	14.13	13.88	14.32	14.93	15.80	14.05	14.08	14.22	17.95	19.87	17.13
	MAX	14.84	15.09	18.05	17.84	28.43	26.01	17.69	18.94	21.64	29.21	29.36	25.27
	MEAN	14.49	14.60	15.82	16.00	25.62	21.85	15.05	16.46	16.75	25.03	24.18	19.55
2010	MIN	18.64	21.89	17.72	14.93	14.22	14.44	14.42	14.16	14.00	14.11	13.89	13.91
	MAX	23.22	26.98	23.31	22.90	17.12	16.19	15.91	15.07	14.60	14.44	14.59	14.47

	MEAN	20.22	23.99	20.49	17.26	15.34	14.81	14.89	14.44	14.32	14.26	14.25	14.29
2011	MIN	14.09	14.14	14.04	13.98	15.62	14.00	14.01	14.02	14.02	14.00	13.97	14.39
	MAX	14.74	14.74	14.49	20.16	24.25	15.14	14.91	14.47	14.36	14.24	15.36	16.96
	MEAN	14.43	14.37	14.32	14.88	19.36	14.35	14.29	14.23	14.23	14.12	14.34	15.49
2012	MIN	13.93	15.30	13.99	14.34	13.94	13.86	13.81					
	MAX	22.17	22.29	25.72	24.01	14.52	14.42	14.26					
	MEAN	15.24	18.08	18.46	18.78	14.20	14.14	14.03					

The USACE has developed flow data which corresponds to the river level gage reading to estimate the flow in the Red River at that point. Table 6-3 shows the relationship of River Gage Level to Flow. This table was developed using the historical measured flows in the Red River and correlating this flows to river gage levels.

Table 6-3, Red River Gage Level to Flow

Gage Height, ft	Flow, CFS
12	0
12.5	333
13.5	1,000
14	2,500
15	12,000
16	23,000
17	31,000
18	38,000
19	46,000
20	54,000
21	60,000
22	67,000
23	74,000
24	83,000
25	91,000
26	99,000
27	107,000
28	117,000
29	127,000
30	136,000
31	145,000
32	155,000
33	165,000

Again, the USACE has established 12.0 feet as the zero discharge for measurement. This gage reading is not zero water elevation in the Red River. In order to maintain flow above the discharge level, 12.5 feet was selected as the minimum water level for withdrawal. Shaw and its sub-consultants developed the yield analysis based on lowering the Red River to a level of 12.5 feet gage height, or 333 CFS of river flow.

6.1.2 Cross Lake

Cross lake is oriented east to west, is approximately 9 miles in length, and has an average depth of 7.7 feet. The lake has approximately 13.4 square miles in surface area and is 65,807 acre-feet in volume at spillway crest, which is 171.19 feet NGVD 29. Bathymetric information for Cross Lake is contained in Phase I of this study.

The monthly average gage height of Cross Lake at USGS 07344480 Cross Lake at Shreveport, LA is shown in Table 6-4. Based on the data, a maximum mean gage height of 171.44 feet was recorded in December 2009 and a minimum gage height of 167.12 feet was recorded in October 2011.

Table 6-4, Cross Lake Monthly Mean Gage Height

Monthly mean in ft (Calculation Period: 1996-10-01 -> 2011-10-31)												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1996										170.5	170.4	170.7
1997	170.7	171.0	170.9	170.6	170.9	170.9	170.4	169.6	169.3	169.7	169.9	
1998	170.9	170.9	170.8	170.6	169.8	169.0	168.3	168.2	169.0	170.2	170.6	170.9
1999	170.9	170.7	170.6	170.8	170.1	170.3	170.9	170.2	169.2	168.7	168.1	167.8
2000	167.6	168.1	169.5	171.0	171.0	170.9	170.8	170.3	169.0	168.2	168.6	170.7
2001	170.9	171.0	170.9	170.7	170.0	170.8	170.7	169.9	169.9	170.4	170.4	170.9
2002	170.9	171.0	171.1	171.1	170.7	170.5	170.7	170.2	169.5	168.6	168.6	169.8
2003	170.8	170.8	170.9	170.7	170.6	170.9	171.1	170.7	170.1	169.3	168.7	168.2
2004	168.2	169.6	171.0	170.9	171.3	171.4	171.1	170.7	170.4	170.8	171.0	171.2
2005	171.2	171.2	171.1	171.1	170.4	170.3	170.5	170.2	169.3	169.1	168.4	167.8
2006	167.5	168.9	170.4	171.2	171.1	171.1	170.8	170.5	169.9	169.3	169.2	168.8
2007	170.6	171.2	171.1	171.0	171.3	171.3	171.4	171.0	170.8	170.9	171.0	170.9
2008	170.8	170.9	171.2	171.1	171.2	171.1	171.1	171.1	170.4	170.0	170.4	170.5
2009	170.5	170.3	170.7	171.3	171.2	170.7	170.4	171.3	170.6	171.4	171.1	171.4
2010	171.4	171.4	171.3	171.2	170.6	170.4	170.5	170.3	169.9	169.1	169.4	169.4
2011	169.7	170.1	169.8	170.1	170.3	170.2	169.9	168.9	167.7	167.1		
Mean of monthly gage height	170.2	170.5	170.8	170.9	170.7	170.7	170.6	170.2	169.7	169.6	169.7	169.9

6.1.3 Caddo Lake

Information obtained from the Northeast Texas Municipal Water District (NTMWD) reported that Caddo Lake has a conservation pool elevation of 168.5 feet msl and a conservation storage volume of 129,000 acre-feet. According to NTMWD, Caddo Lake has a dead zone elevation of 166 feet msl and a total volume of 69,200 acre-feet. Because of this dead zone, the actual storage capacity of Caddo Lake is reported to be 59,800 acre-feet by NTMWD.

Lake water level is controlled by a spillway located at the eastern end and spillway water discharges into Willow Pass, which eventually becomes Twelve Mile Bayou. The crest elevation of the spillway is 168.5 feet NGVD 29 and the maximum design discharge of the spillway is 36,000 CFS. Caddo Lake is a wide, shallow lake and the shallow areas of the lake are densely vegetated. The lake has a surface area of about 26 square miles, an average depth of 4.6 feet and a depth of 4.6 feet or greater in more than 50 percent of the lake area. The largest depths are located in the eastern part of the lake. East of the bridge on State Highway 538 (near Mooringsport), the water depth is approximately 27 feet. The Caddo Lake dam consists of 2,400 linear feet of concrete wall, with the central 860 feet of crest at 168.5 feet NGVD and the remaining 1,540 feet at 170.5 feet NGVD. A 1,200 foot earthen embankment levee ties the concrete dam to the hill line at one end. At the opposite end, the dam abuts the hill line. Bathymetric information for Caddo Lake is contained in Phase I of the Master Plan.

The monthly average gage height of Caddo Lake at USGS 07346310, Mooringsport, LA is shown in Table 6-5. Based on the data, a maximum mean gage height of 173.59 feet was observed in April 2004 and a minimum gage height of 166.75 feet was observed in October 2011.

Table 6-5, Caddo Lake Monthly Mean Gage Height

Monthly mean in ft (Calculation Period: 2001-10-01 -> 2011-10-31)												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2001										169.5	169.2	170.8
2002	170.1	170	170.4	170.9	169.6	168.9	168.8	168.6	168.5	168.7	168.9	169.4
2003	169.6	169.8	170.3	169.2	169.1	169	168.7	168.5	168.4	168.3	168.1	168.4
2004	168.8	169.6	170	173.6	169.3	169.9	169.1	168.5	168.4	168.9	169.3	169.5
2005	169.6	169.7	169.3	169.3	168.7	168.5	168.1	168.1	168.7	168.3	167.2	167.2
2006	167.4	168.4	169.3	169	168.7	168.4	168.1	167.8	167.5	167.3	167.5	167.7
2007	169.9	169.4	169	169.2	169	169	170.4	169.3	168.7	168.5	168.5	168.8
2008	168.9	169.4	170.1	169.9	169.9	169.2	167.8	168.1	168.9	169	169	169.1
2009	169.2	169.1	169.7	172.2	170.5	169.5	168.9	170.1	169.5	172.5	171.5	170.5
2010	170.5	170.7	170.4	169.5	169	169	169	168.6	168.2	167.8	168	168.3
2011	169	169	168.9	168.8	168.8	168.4	167.8	167.2	166.9	166.8	167	167.8
Mean of Monthly Gage Height	169.3	169.5	169.7	170.2	169.3	169.0	168.7	168.5	168.3	168.7	168.6	168.9

6.1.4 Twelve Mile Bayou

Twelve Mile Bayou is located below the Caddo Lake dam. Twelve Mile Bayou is 23 miles long and 250 to 300 feet wide with an average depth of 16 feet. It is 8,800 feet upstream of the Cross Bayou and Red River confluence. The gage station is located 17.3 miles upstream of the mouth of the bayou.

The monthly average gage height of Twelve Mile Bayou at USGS 07348000, Twelve Mile Bayou near Dixie, LA is shown in Table 6-6. Based on the data, a maximum mean gage height of 29.08 feet was observed in October 2009 and a minimum gage height of 9.732 feet was observed in December 2003.

Table 6-6, Twelve Mile Bayou Monthly Mean Gage Height

00065, Gage height, feet,												
Monthly mean in ft (Calculation Period: 2001-10-01 -> 2011-10-31)												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2001										15.76	11.75	22.61
2002										10.14	10.27	13.3
2003	14.76	16.34	19.36	11.07	11.25	10.45	9.945	9.872	9.902	9.771	9.783	9.732
2004	10.14	13.42	15.45	10.52	12.45	16.19	13.06	9.947	9.983	10.33	12.4	15.4
2005	17.72	15.55	12.21	12.58	9.997	9.964	9.959	10.03	9.969	9.995	9.966	9.946
2006	10.03	10.05	13.72	11	10.92	9.943	9.964	9.878	9.875	9.85	10.16	10.51
2007	20.59	13.89	10.76	12.08	14.6	16.15	25.09	18.63	13.01	10.26	10.09	10.67
2008	10.41	14.02	20.56	21.56	18.95	11.71	10.19	10.14	11.02	10.44	10.21	10.39
2009	10.71	10.61	13.91	13.51	25.1	18.13	12.67	16.68	14.51	29.08	24.39	20.59
2010	20.86	23.84	20.02	13.92	11.15	10.69	10.8	10.09	9.941	9.884	9.905	9.99
2011	10.61	10.43	10.15	10.7	15.19	10.07	10.01	9.945	9.917	9.75		
Mean of Monthly Gage Height	13.98	14.24	15.13	12.99	14.4	12.59	12.41	11.69	10.9	12.3	11.89	13.31

6.1.5 Toledo Bend Reservoir

The Toledo Bend Reservoir is located within the Sabine River Basin on the Texas-Louisiana border. Toledo Bend Reservoir is one of the largest man-made reservoirs in the United States. The reservoir covers an area of approximately 185,000 surface acres and has a storage capacity of 4,477,000 acre-feet at a reservoir level of 172 feet in elevation (msl). Extensive yield modeling has been performed by the Sabine River Authority and USGS gage data is not included in this analysis.

6.1.6 Lake Bistineau

Lake Bistineau is a 26.9 square mile (17,200 acres) reservoir encompassing areas of southeast Bossier, southwest Webster and northwest Bienville Parishes. The reservoir has a volume of 120,000 acre-feet (39,102 Mgal) at spillway crest, an average depth of 7 feet and a maximum depth of 25 feet. Lake Bistineau is primarily used for flood control and conservation. USGS mean gage height is available for Lake Bistineau near Ringgold, LA (Station Number 07349250) from 2001 to 2012. The spillway crest elevation is 130 feet NGVD 29.

The monthly average gage height of Lake Bistineau at USGS 07349250, Lake Bistineau near Ringgold, LA is shown in Table 6-7. Based on the data, a maximum mean gage height of 13.1 feet was observed in October 2009 and a minimum gage height of 2.59 feet was observed in October 2010.

Table 6-7, Lake Bistineau Monthly Mean Gage Height

Monthly mean in ft (Calculation Period: 2001-10-01 -> 2011-09-30)												
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2001										11.53	11.16	12.41
2002	11.61	11.69	12.02	12.08	11.44	11.09	10.98	10.77	10.5	10.57	11.04	11.43
2003	11.49	11.77	11.95	11.5	11.58	11.2	11.08	10.96	10.99	10.87	10.93	11.07
2004	11.19	11.75	12.04	11.44	11.51	11.86	10.77	5.231	3.844	6.159	7.756	11.3
2005	11.38	11.89	11.45	11.74	11.02	11.01	9.606	5.083	3.769	3.551	3.259	3.275
2006	3.523	6.42	10.07	11.33	11.18	10.81	10.38	10.05	9.786	9.805	10.27	10.65
2007	12.09	11.49	11.36	11.51	11.35	11.33	11.93	11	10.58	10.4	10.31	10.84
2008	11.21	11.59	11.58	11.34	10.92	10.5	9.382	5.932	5.032	4.147	4.162	5.229
2009	5.78	6.348	9.325	11.63	12.17	11.14	10.86	11.21	10.68	13.1	11.83	9.695
2010	9.811	10.97	8.352	5.948	4.369	3.679	3.496	3.299	2.967	2.587	3.308	3.941
2011	4.626	6.327	7.007	7.229	9.251	9.34	8.905	8.382	8.075			
Mean of Monthly Gage Height	9.27	10.03	10.52	10.58	10.48	10.19	9.74	8.19	7.62	8.27	8.4	8.98

6.1.7 Cypress Bayou Reservoir

The Cypress Bayou Reservoir is a 3,400 acre reservoir located in Bossier Parish and receives inflows from Cypress Bayou, Little Caney Bayou and White Oak Bayou. The reservoir dam has a 250 foot concrete spillway with a crest elevation of about 180 feet NGVD 29. When the elevation of the water surface in the reservoir is near the crest elevation, the surface area of the reservoir is about 3,400 acres, the maximum depth is about 20 feet, the average depth is about 6.7 feet and the water volume is about 22,700 acre-feet. The reservoir's main uses are flood control, conservation and recreation, and is maintained and operated by the Cypress Black Bayou

Recreation and Water Conservation. Cypress Bayou Reservoir currently has no reported potable surface water users in Bossier Parish.

The monthly average gage height of Cypress Bayou Reservoir at USGS 07349815,Cypress Bayou Lake near Benton, LA is shown in Table 6-8 below. Based on the data, a maximum mean gage height of 10.54 feet was observed in March 2001 and a minimum gage height of 2.13 feet was observed in October 2010.

Table 6-8, Cypress Bayou Reservoir Monthly Mean Gage Height

00065, Gage height, feet, Monthly mean in ft (Calculation Period: 1996-10-01 -> 2011-10-31)												
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1996										9.65		
1997							9.418	9.03	8.7	8.66	9.44	9.841
1998	10.13	10.14	10.12	9.668	9.456	8.95	8.303	7.93	7.97	8.38	9.14	10
1999	10.16	9.993	9.946	10.03	9.604	9.67	9.519	8.85	8.44	4.93	3.11	3.15
2000	3.454	3.918	6.458	9.952	10	9.66	9.368	8.68	8.12	8.06	9.26	10.15
2001	10.27	10.34	10.54	9.786	9.553	9.68	9.187	8.85	9.09	9.37	9.53	10.09
2002	9.82	9.911	10.1	9.967	9.515	9.32	9.157	8.74	8.34	8.26	8.6	9.569
2003	9.796	10.14	9.935	9.748	9.785	9.51	9.256	9.13	8.93	8.68	8.5	8.552
2004	8.912	9.767	10.08	9.784	9.832	9.93	9.599	9.04	8.76	9.34	9.79	9.98
2005	9.968	9.97	9.725	9.9	9.393	9.03	8.652	8.29	8.01	8.08	7.87	7.761
2006	7.945	9.289	9.974	9.591	9.454	9.12	8.774	8.5	8.15	8.1	8.44	8.543
2007	10.06	9.801	9.697	9.664	9.592	9.54	10.09	9.3	9.04	8.72	8.56	8.829
2008	9.262	9.804	9.801	9.655	9.675	9.55	9.218	8.86	9.38	9.19	9.27	9.625
2009	9.627	9.656	9.829	9.774	9.921	9.52	9.24	9.59	9.03	9.96	9.97	10.08
2010	10.06	10.11	9.952	9.656	9.349	9.1	8.882	7.5	2.92	2.13	2.38	2.542
2011	3.35	5.268	5.895	5.937	6.04	5.69	5.114	4.45	3.96	3.75		
Mean of monthly Gage height	8.77	9.15	9.43	9.51	9.37	9.16	8.92	8.45	7.92	7.83	8.13	8.48

6.1.8 Black Bayou Reservoir (Bossier Parish)

Black Bayou Reservoir is located in Bossier Parish, approximately 8 miles north of Bossier City, Louisiana, and 3 miles southeast of Benton, Louisiana. The reservoir, formed from an earthen dam built in 1975 on Black Bayou, is used for water-based activities such as water skiing, fishing, boating, and swimming. The earthen dam is 4,800 feet in length and the reservoir level is controlled by a spillway 150 feet in length with a crest elevation of 185 feet msl. The maximum discharge for the spillway structure is 13,680 CFS (Ray Elifami, Louisiana Department of Transportation and Development, 1998). Bathymetric information for Black Bayou Reservoir is contained in Phase I. USGS gage information is not provided for Black Bayou Reservoir.

6.1.9 Bodcau Bayou Reservoir

Bodcau Bayou forms the northeastern parish line before draining southwest through central Bossier Parish. The reservoir is subject to extreme fluctuations and when the water level is near 157.0 feet msl, water is retained only in the stream proper.

The monthly average gage height of Bodcau Bayou Reservoir at USGS 07349500, Bodcau Bayou near Sarepta, LA is shown in Table 6-9 below. Based on the data, a maximum mean gage height of 24.3 feet was recorded in November 2009 and a minimum gage height of 1.96 feet was observed to be in August 2011.

Table 6-9, Bodcau Bayou Reservoir Monthly Mean Gage Height

00065, Gage height, feet,												
Monthly mean in ft (Calculation Period: 1996-10-01 -> 2011-10-31)												
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1996										7.012	10.28	12.8
1997	12.14	14.59	13.88	12.79	11.35	8.487				2.831	5.132	7.477
1998	13.47	13.99	13.42	6.326	4.191	7.131	3.05	2.48	3.27	3.859	5.842	11.09
1999	12.6	13.13	10.77	10.72	5.602	5.683	3.91	3.14	3.2	5.624	3.405	3.569
2000	3.368	3.712	5.685	5.904	12.02	6.179	4.67	3.12	3.22	3.277	7.331	12.39
2001	15.17	15.14	22.51	17.56	9.341	7.057	4.96	3.6	4.3	11.15	6.396	13.4
2002	9.945	10.21	12.84	12.18	10.36	5.544	2.96	2.84	4.27	5.127	4.812	6.771
2003	7.688	9.959	16.73	6.46	7.74	4.745	4.76	3.11	2.65	2.613	2.901	2.897
2004	3.151	6.859	10.89	5.465	6.264	10.92	7.86	5.09	5.39	6.027	7.244	8.365
2005	11.03	9.791	6.778	8.266	4.166	3.341	2.4	2.14	2.46	2.87	2.706	2.593
2006	3.164	4.462	8.009	4.976	3.087	2.051	1.98	1.97	1.97	2.314	3.269	3.762
2007	11.37	7.557	6.48	7.939	5.501	3.878	9.66	2.74	2.12	2.161	2.865	3.337
2008	3.09	7.899	9.96	10.96	6.623	4.055	2.96	2.93	6.57	7.528	7.136	6.369
2009	6.237	6.032	6.24	8.114	15.24	5.486	3.66	3.54	5.08	19.8	24.3	16.74
2010	14.42	13.53	9.363	5.103	2.608	2.351	2.28	2.05	2.05	2.331	2.974	2.748
2011	3.985	3.456	2.731	3.08	8.302	2.695	1.99	1.96	2.09	4.207		
Mean of Monthly Gage Height	8.72	9.35	10.42	8.39	7.49	5.31	4.08	2.91	3.47	5.55	6.44	7.62

7.0 Surface Water Use & Treatment Capacity

7.1 Surface Water Use

Historically, surface water is used as a water source by larger systems and communities within close proximity to that body of water. The total surface water used by each water source from 1990 to 2010 is listed in Table 7-1. This information was compiled from USGS *Water Use in Louisiana Reports*.

Table 7-1, USGS Surface Water Use

USGS Reported Surface Water Use		MGD
1990	Caddo Lake	45.24
1990	Cross Lake	36.75
1990	Red River	15.03
1990	Toledo Bend Reservoir	15.34
1995	Caddo Lake	52.22
1995	Cross Lake	30.36
1995	Red River	16.73
1995	Toledo Bend Reservoir	13.28
2000	Caddo Lake	94.54
2000	Cross Lake	44.96
2000	Red River	21.18
2000	Toledo Bend Reservoir	20.86
2005	Caddo Lake	2.16
2005	Cross Lake	47.92
2005	Red River	23.56
2005	Toledo Bend Reservoir	21.6
2010	Caddo Lake	91.05
2010	Cross Lake	43.56
2010	Red River	22.24
2010	Toledo Bend Reservoir	29.09
2010	Twelve Mile Bayou*	0.1

*No Data Provided for 1990-2005.

It should be noted that the Caddo Lake water usage in Table 7-1 includes water used for power generation. Detailed use of each water source is discussed in this section.

7.1.1 Red River

Currently, Bossier City is the only municipality that depends on the Red River for water supply. Other uses of Red River include irrigation, industrial, power generation and hydraulic fracturing for oil and gas wells. Red River is an important navigable waterway. Navigation improvements along the Red River in Louisiana have been ongoing since the early 1800's. More recently, the Red River Waterway Project, completed in 1994, enables year-round navigation on the Red River from the Mississippi River to Shreveport, Louisiana. The project straightened the river, stabilized banks and added a series of five lock and dam complexes to prevent flooding. Three of the locks are located in the Red River Basin. The navigable depth of the Red River from the Mississippi River is 9 feet. Upstream of Shreveport, the Red River is currently not suitable for commercial navigation. However, the USACE is currently studying the feasibility of making channel improvements to allow commercial navigation into Arkansas.

7.1.1.1 City of Bossier City

Bossier City's water use information from 2011 was collected in Phase II and is presented in Table 7-2. Currently, the Bossier City Water system is rated to withdraw 25 MGD from the Red River.

Table 7-2, Red River 2011 Water Use (Shaw)

Surface Water Source:	**Red River**
Water System:	**Bossier City (Gals)**
January	291,314,000
February	269,778,000
March	305,181,000
April	313,356,000
May	432,424,000
June	471,658,000
July	558,900,000
August	642,600,000
September	501,800,000
October	450,700,000
November	343,200,000
December	316,700,000
Annual Total	**4,897,800,000**
Annual Total (MGD)	**13.42**

7.1.1.2 Agricultural Uses

Historically, the USGS has estimated approximately 1.0 million gallons per day (MGD) consumption of Red River water for irrigation uses. In 2010, USGS reported 1.44 MGD of surface water was used for general irrigation purposes in Caddo Parish and 0.77 MGD in Bossier Parish. The water source for these estimates was not given.

More recently, the "Red Bayou Irrigation Feasibility Study Hydraulic Analysis" performed by USDA-NRCS estimated that approximately 333 CFS (215 MGD) of Red River water could be used for irrigation purposes for Red Bayou. The Red Bayou Irrigation Project that will transfer water from the Red River to Red Bayou is currently under construction.

7.1.1.3 Other Users

The QEP Energy Company (QEP) currently withdraws water from the Red River for hydro-fracking. QEP has a Cooperative Endeavor Agreement (CEA) with the State of Louisiana which specifies the yearly amount of water an entity can withdraw from the Red River. The following shows the total annual withdrawal requested by QEP Energy Company.

Agreement Number	Withdrawal Amount (Gallons)	Withdrawal Amount (MGD)
CUA-2011-0021	158,400,000	0.434
CUA-2011-0025	153,400,000	0.420
Total	**311,800,000**	**0.854**

Chesapeake Energy is also part of the Louisiana Cooperative Endeavor. The following annual amounts have been identified.

Agreement Number	Withdrawal Amount (Gallons)	Withdrawal Amount (MGD)
CUA-2011-0022	30,240,000	0.083
CUA-2011-0033	30,240,000	0.083
Total	**60,480,000**	**0.166**

The information reported above was obtained as part of Phase I of the Master Plan. Combined, the users are allowed to pull approximately 1.02 MGD of water from the Red River for gas production.

7.2 Cross Lake

Cross Lake is used by the City of Shreveport as the city's main raw water source. When the demand during summer months exceeds the available water in Cross Lake, Shreveport supplements its water supply with water from Twelve Mile Bayou. In Phase II, Shaw collected the City of Shreveport's recorded water production for 2011, which is presented in Table 7-3.

Table 7-3, Cross Lake/Twelve Mile Bayou 2011 Water Use (Shaw)

Surface Water Source:	**Cross Lake**
Water System:	**City of Shreveport W.S.**
January	1,075,000,000
February	961,000,000
March	1,065,000,000
April	1,107,000,000
May	1,239,000,000
June	1,347,000,000
July	1,428,000,000
August	1,524,000,000
September	1,324,000,000
October	1,230,000,000
November	1,023,000,000
December	1,075,000,000
Annual Total	**14,398,000,000**
Annual Total (MGD)	**39.45**

7.3 Caddo Lake

Caddo Lake is a critical source of drinking water for a substantial portion of Caddo Parish residents. Table 7-4 displays DOTD's records of Caddo Lake's raw water use for 2011. In addition, Shaw conducted surveys of surface water users and those results can be found in Phase II. Caddo Lake is also a major source of water for power generation.

Table 7-4, Caddo Lake 2011 Water Use (DOTD)

2011 LOUISIANA WATER USAGE FROM CADDO LAKE IN MILLIONS OF GALLONS (MG)									
	Blanchard Utilities	Caddo Parish Water Dist. #1	Greenwood WS	E. Mooringsport WS	Town of E. Mooringsport	SW Electric Power Co.	Universal Oil Products	Town of Vivian	TOTAL
Jan	34.98	7.56	15.92	0.51	1.24	7.14	2.09	12.44	81.88
Feb	31.90	7.01	15.41	0.43	1.10	7.14	2.94	11.82	77.75
Mar	29.47	5.27	15.54	0.42	1.48	0.00	1.97	11.68	65.83
Apr	32.71	5.86	16.72	0.49	1.52	0.11	0.91	11.83	70.15
May	39.74	6.01	17.87	0.54	1.53	8.46	2.65	13.70	90.50
Jun	52.98	7.18	18.27	0.80	1.68	12.12	8.15	15.53	116.71
Jul	53.01	8.28	19.03	0.73	1.33	16.21	11.00	16.31	125.90
Aug	57.01	8.33	17.56	0.89	1.52	18.80	9.75	15.50	129.36
Sept	40.24	6.52	16.01	0.54	1.44	11.24	9.07	12.82	97.88
Oct	38.56	5.64	16.78	0.58	1.27	0.00	6.02	12.40	81.25
Nov	29.92	5.07	17.06	0.43	1.35	0.00	11.68	11.37	76.88
Dec	31.20	5.59	18.64	0.34	1.26	4.22	2.90	12.66	76.81
Total (MG)	471.72	78.32	204.81	6.70	16.72	85.44	69.13	158.06	1090.90
Total (MGD)	1.29	0.12	0.56	0.02	0.05	0.23	0.19	0.43	2.99

The USGS water use for Caddo Lake (Table 7-1) reports 91.05 MGD for 2010 and DOTD water use (Table 7-4) for 2011 reports 2.99 MGD. USGS indicates a significantly higher use of water for power generation than DOTD. A more detailed study exploring the water rights and usage agreements of power generation companies should be conducted to determine any surplus availability and clarify the water use discrepancies between USGS and DOTD.

7.4 Surface Water Treatment Capacity

There are currently nine public water utilities that treat surface water for municipal use. The source, current capacities and any known future capacities of these systems are shown in Table 7-5.

Table 7-5, Surface Water Providers

Caddo Parish			
Surface Water Utility	**Source**	**Current Capacity (MGD)**	**Future Capacity (MGD)**
Blanchard Utilities	Caddo Lake	1.75	5
Caddo Parish Water Dist. #1 (Formerly Oil City Water Works)	Caddo Lake	1.1	1.1
Greenwood WS	Caddo Lake	0.8	0.8
E. Mooringsport WS	Caddo Lake	0.11	Blanchard
Town of E. Mooringsport	Caddo Lake	0.07	Blanchard
Town of Vivian	Caddo Lake	0.45	
City of Shreveport	Cross Lake/Caddo Lake	90	90
East Cove	Caddo Lake	0.13	Blanchard
Total Caddo Capacity		**94.41**	**96.9**
Bossier Parish			
Surface Water Utility	**Source**	**Current Capacity (MGD)**	**Future Capacity (MGD)**
City of Bossier City	Red River	25	45
Total Bossier Capacity		**25**	**45**
Total Capacity		**119.41**	**141.9**

1. Town of Vivian Capacity estimated from USGS 2010 Water Use Report
2. Confirm additional existing producers that will connect to Blanchard
3. Only known future expansions are included in Future Capacity

The City of Shreveport, Bossier City and the City of Blanchard are the three primary suppliers of potable water to the residents of Caddo and Bossier Parishes. The Amiss Water Treatment Plant located in the City of Shreveport, primarily depends on surface water from Cross Lake and Twelve Mile Bayou for raw water sources. Including recent expansions, the City of Shreveport's average daily capacity is approximately 90 MGD. However, the raw water yield is limited to 43 MGD. In addition to the existing capacities and expansions, ongoing studies of possible sources, including a 20 MGD plant using water from the Red River, are being conducted.

Bossier City's surface water treatment plant draws raw water exclusively from the Red River at a rate of 25 MGD. The treatment plant is currently under expansion, which will increase Bossier City's average daily capacity to 45 MGD.

The City of Blanchard has a surface water treatment plant with the current capacity to draw water from Caddo Lake at a rate of 1.75 MGD. The City of Blanchard's water treatment plant is also under expansion with plans to increase the average daily capacity to 5 MGD, allowing water to be provided to Mooringsport, East Mooringsport, East Cove, and Lakeview. Combined, the City of Shreveport, Bossier City, and the City of Blanchard has the capacity to produce 117 to 140 MGD.

8.0 Water Demand

8.1 Current Demand

Current demand and water use were compiled from 3 sources: reported USGS water use, survey of water systems and per capita use estimations. This was to provide a representation of current water demand for both Caddo and Bossier Parishes. Historical water use in Caddo and Bossier Parishes obtained from USGS information is summarized in Table 8-1 and Table 8-2. Public Water Usage was updated from Phase I to include figures from the USGS 2010 Water Use Report.

Table 8-1, Caddo Public Water Usage (USGS)

CADDO PARISH (MGD)			
YEAR	**PUBLIC SUPPLIES**		**TOTAL**
	GROUND	SURFACE	
1960	0.57	18.1	**18.67**
1965	1.52	22.1	**23.62**
1970	1.3	24.9	**26.2**
1975	0.98	30.6	**31.58**
1980	1.23	35.9	**37.13**
1985	1.33	36.4	**37.73**
1990	0.99	38.12	**39.11**
1995	1.48	31.85	**33.33**
2000	1.13	46.89	**48.02**
2005	1.56	50.04	**51.6**
2010	1.77	45.56	**47.33**

Source: USGS Water Use Reports

Table 8-2, Bossier Public Water Usage (USGS)

BOSSIER PARISH (MGD)			
YEAR	PUBLIC SUPPLIES		TOTAL
	GROUND	SURFACE	
1960	0.24	3.5	**3.74**
1965	0.34	4.00	**4.34**
1970	0.43	4.02	**4.45**
1975	0.99	6.00	**6.99**
1980	0.97	6.24	**7.21**
1985	1.2	6.27	**7.47**
1990	1.32	7.49	**8.81**
1995	1.57	8.66	**10.23**
2000	2.04	9.69	**11.73**
2005	1.73	10.67	**12.4**
2010	2.15	10.24	**12.39**

Source: USGS Water Use Reports

In addition to the USGS water use information for each parish, Shaw conducted a survey of water use as part of Phase II of the Master Plan. Shaw surveyed water use by all of the public water systems in Caddo and Bossier Parishes for the year 2011. The summary results of that survey are shown in Table 8-3 and Table 8-4.

Table 8-3, 2011 Caddo Parish Water Survey (Shaw)

Caddo Parish 2011 Water Production	
Water Type	Annual Total (MGD)
Surface Water	40.88
Ground Water	2.44
Total	43.32

Notes:
1. Purchased water systems not included in water totals, assumed included with provider total.
2. Deepwoods Utilities, Hosston-Mira, Waterworks District #7, Forcht Wade Correctional Center and Vivian Water System estimated from average monthly volumes provided.
3. Vivian Water System estimated volume included in Ground Water Total
4. Bella Vista MHP, Country Living Estates, Silent Cedars MHP and South Shreveport Mobile Villa estimated from number of connections.

Table 8-4, 2011 Bossier Parish Water Survey (Shaw)

Bossier Parish 2011 Water Production	
Water Type	Annual Total (MGD)
Surface Water	13.42
Ground Water	3.25
Total	16.66

Notes:
1. Purchased water systems not included in water totals, assumed included with provider total.
2. Bellevue Water System taken from 2010 USGS Water Use Report
3. Oak Haven MHP, Hillcrest MHP, J&N MHP, Peaceful Pines MHP, River Point and Shady Park MHP Water Systems estimated from number of connections.

Lastly, the water demand for Bossier and Caddo Parishes were calculated from United States Census population information and are shown in Table 8-5.

Table 8-5, Domestic Water Use Estimate (Per Capita)

Year (2010)	Population	Annual Average Day (MGD)	Maximum Day (MGD)	Maximum Hour (MGD)
CADDO	254,969	48.4	87.2	140.5
BOSSIER	116,979	16.4	29.5	47.5

USGS water use figures (Table 8-1 and Table 8-2) for Caddo Parish and the annual average day water demand (Table 8-5) calculated from population are reasonably close. For this study and for planning purposes, the per capita demand of 48.4 MGD will be used as the current demand for Caddo Parish. For Bossier Parish, the per capita demand of 16.4 MGD will be used as the current demand.

8.2 Future Demand

Future demand estimates for Caddo and Bossier Parishes were prepared in Phase III of this Master Plan and are shown in Table 8-6. These demands were used to determine the required additional yields that would be required for Caddo and Bossier Parishes.

Table 8-6, Projected Water Demands

Year	Adjusted Population		Per Capita*		Annual Average Day		Maximum Day		Maximum Hour	
			(gal/day)		(MGD)		(MGD)		(MGD)	
	Caddo	Bossier	Caddo	Bossier	Caddo	Bossier	Caddo	Bossier	Caddo	Bossier
2015	270,700	128,050	190	140	51.3	17.9	102.7	35.9	148.9	52.0
2020	285,530	138,990	190	140	54.2	19.5	108.3	38.9	157.0	56.4
2025	299,150	150,190	190	140	56.7	21.0	113.5	42.1	164.5	61.0
2030	311,650	161,960	190	140	59.1	22.7	118.2	45.3	171.4	65.8
2035	323,640	174,560	190	140	61.4	24.4	122.8	48.9	178.0	70.9

* Based on *Water Use in Louisiana,* average water usage for each parish from 1990 to 2010

9.0 Water Yield Determinations

9.1 General

Yield determinations and results for each of the raw water sources are presented in this section. Yield analyses for all water sources were not feasible for this study and previously reported yields have been included.

Since yield is a conservative measure of water supply, it is not uncommon for water use to exceed dependable yield. Dependable yield is a conservative measure of the ability of a water body or groundwater resource to provide specified minimum withdrawals. Most surface water bodies are evaluated according to the 95% exceedance criterion. According to this criterion, withdrawals or flows would be equaled or exceeded 95% of the time. Yields according to this standard were developed by the DOTD and USGS.

Dependable yield from the USACE for the Red River in Louisiana is based on different standards. Low flow or dependable yield on the Red River is estimated according to the 7-day 10-year standard, which represents the lowest flow that can be expected for 7 consecutive days during a 10-year period.

Dependable yields on lakes and reservoirs usually represent the amount of water that can be safely withdrawn from that water body. For a stream such as the Red River, the low flow or dependable yield merely indicates the lowest expected flows under adverse conditions.

9.2 Previous Yield Determinations

Yield determinations by the DOTD and the USACE for water sources in the region are shown in Table 9-1. Streams with low extended flow periods are not considered reliable water sources without construction of storage reservoirs. Due to small yields determined for some of these sources, further study is not recommended.

Table 9-1, Summary of Reported Yields

Name	Surface Area (Acres)	Volume (acre-feet)	Dependable Yield (MGD) (DOTD)	Dependable Yield (MGD) (USACE)
Red River				860 (430 Acceptable Source Yield)
Cross Lake	8,840	77,600	21	33
Caddo Lake	32,640	188,000		99.5
Black Bayou Lake (Caddo)	3,690	17,750	20	20
Twelve Mile Bayou				5.1
Toledo Bend Reservoir	181,600	4,500,000	814	925
Lake Bisteneau	17,220	120,000	5	5
Cypress Bayou Reservoir	3,400	22,700		13.8
Cypress Black Bayou Reservoir	590	5,850		4.9
Bodcau Bayou Reservoir	44,950	357,300	0	0
Wallace Lake	9,300	7,800	5	0

These reported yields are discussed in detail in the following sections. Black Bayou Lake (Caddo) and Wallace Lake yields are shown in Table 9-1, but these lakes were not considered viable options for water supply.

9.3 Red River

The Red River has a potential yield of 860 MGD. However, the USACE only considers 430 MGD as an acceptable source yield. This potential yield was developed by the USACE for the Red River reach near Shreveport/Bossier. Since it is unknown whether this potential yield takes into account the required navigation stages of the Red River, further study was conducted by Shaw and our sub-consultants to verify the potential yield reported by the USACE as part of Phase IV. In order to determine the maximum withdrawal from the Red River at minimum flow conditions, the minimum Red River levels from January 1996 through July 2012 were examined. This data is presented in Table 9-2.

Table 9-2, Red River Minimum Flows (USACE)

Table 3												
Year	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEPT**	**OCT**	**NOV**	**DEC**
1996	14.20	14.00	14.00	14.10	14.10	13.90	13.90	14.40	14.60	14.30	18.40	18.30
1997	16.10	15.70	21.00	18.10	18.30	16.30	14.60	14.20	14.10	14.20	14.10	14.10
1998	21.30	18.60	18.60	15.30	14.20	14.10	14.20	14.00	14.10	14.20	14.30	14.40
1999	15.50	15.70	14.70	15.30	15.20	15.00	14.10	13.90	13.90	14.20	14.30	13.90
2000	14.30	14.10	14.60	14.60	14.30	15.80	14.30	14.30	14.10	14.10	14.10	17.20
2001	20.50	19.50	24.30	17.30	16.10	15.30	14.00	13.80	14.00	13.90	13.80	14.90
2002	16.70	18.20	15.70	22.90	14.90	14.20	14.10	14.10	14.00	14.20	14.20	13.90
2003	14.40	14.30	15.80	14.10	13.90	13.30	14.00	13.81	13.77	13.70	13.60	13.70
2004	13.63	13.89	14.05	13.95	13.94	14.26	13.96	13.96	14.16	14.09	14.27	14.70
2005	14.55	15.76	14.37	14.29	13.93	13.97	14.16	13.94	13.24	13.08	13.02	14.16
2006	14.13	14.05	14.16	13.80	13.86	13.78	14.05	14.00	13.99	13.97	14.06	13.87
2007	14.73	14.95	14.00	14.51	15.64	15.54	2.41	20.36	14.69	14.15	13.92	14.20
2008	14.03	14.14	18.89	23.14	17.03	14.48	14.08	14.15	14.21	14.12	14.02	13.72
2009	14.14	14.13	13.88	14.32	14.93	15.80	14.05	14.08	14.22	17.95	19.87	17.13
2010	18.64	21.89	17.72	14.93	14.22	14.44	14.42	14.16	14.00	14.11	13.89	13.91
2011	14.09	14.14	14.04	13.98	15.62	14.00	14.01	14.02	14.02	14.00	13.97	14.39
2012	13.93	15.30	13.99	14.34	13.94	13.86	13.81					
Min	**13.63**	**13.89**	**13.88**	**13.80**	**13.86**	**13.30**	**13.81**	**13.80**	**13.24**	**13.08**	**13.02**	**13.70**

The minimum level recorded from 1996 to 2012 is 13.02 feet. Using Table 6-3 provided by the USACE, the flow at this level is equivalent to 680 CFS. Limiting the amount of water withdrawn from the Red River to a gage height of 12.5 feet, the available water at the minimum Red River level will be 347 CFS or 224 MGD. Table 9-3 shows the mean river levels.

Table 9-3, Red River Mean Levels (feet)

Table 4												
Year	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEPT**	**OCT**	**NOV**	**DEC**
1996	14.74	15.03	14.15	14.85	14.73	14.39	14.72	14.83	15.81	16.95	22.15	23.39
1997	17.43	20.89	25.22	21.54	21.15	18.07	15.08	14.49	14.25	14.45	14.65	16.98
1998	25.69	21.74	22.63	18.50	14.84	14.56	14.27	14.25	14.56	16.06	14.90	18.09
1999	17.25	18.30	17.53	18.50	17.74	15.70	15.75	14.19	14.35	14.48	14.47	14.61
2000	14.58	14.38	14.84	15.86	16.74	17.78	15.83	14.56	14.54	14.20	18.65	20.53
2001	22.98	23.41	27.74	19.62	16.93	18.14	14.83	14.06	14.36	16.03	14.27	20.28
2002	18.80	20.54	20.03	25.68	17.56	14.75	14.42	14.40	14.31	14.59	14.61	15.06
2003	17.29	16.21	17.93	14.62	14.43	13.93	14.21	14.16	14.19	14.05	14.05	14.01
2004	14.23	15.80	15.58	14.29	15.05	16.40	15.88	14.26	14.31	14.41	15.95	18.08
2005	20.63	17.20	15.38	15.75	14.31	14.29	14.35	14.29	14.25	14.19	14.05	14.44
2006	14.40	14.38	15.95	14.64	14.99	14.10	14.24	14.20	14.19	14.15	14.44	14.74
2007	21.27	16.94	14.39	15.43	18.73	20.08	24.15	22.39	17.20	14.57	14.36	14.88
2008	14.51	16.72	22.57	24.49	20.51	15.88	14.45	14.43	15.25	14.64	14.31	14.34
2009	14.49	14.60	15.82	16.00	25.62	21.85	15.05	16.46	16.75	25.03	24.18	19.55
2010	20.22	23.99	20.49	17.26	15.34	14.81	14.89	14.44	14.32	14.26	14.25	14.29
2011	14.43	14.37	14.32	14.88	19.36	14.35	14.29	14.23	14.23	14.12	14.34	15.49
2012	15.24	18.08	18.46	18.78	14.20	14.14	14.03					
Mean	**14.23**	**14.37**	**14.15**	**14.29**	**14.20**	**13.93**	**14.03**	**14.06**	**14.19**	**14.05**	**14.05**	**14.01**

The minimum mean level for the Red River is 13.93 feet. The minimum mean represents the average amount of water available in the Red River. Again, using Table 6-3 provided by USACE, the flow in the Red River is estimated to be 2,290 CFS. If the water was withdrawn to the minimum level of 12.5 feet, the available water is 1,957 CFS or 1,260 MGD.

9.4 Cross Lake

The City of Shreveport owns Cross Lake and utilizes the entire available yield. The Cross Lake dependable yield is occasionally exceeded during summer months of dry years. The City of Shreveport supplements its raw water supply by pumping from Twelve Mile Bayou and Caddo Lake (10.0 MGD).

According to the USACE reports, Cross Lake is reported to have a dependable yield of 33 MGD. According to the Red River Basin Characterization Report by DOTD, Cross Lake has a dependable yield of 21 MGD. In a report prepared for the City of Shreveport in 2001 by Black & Veatch, the estimated combined yield from both Cross Lake and Twelve Mile Bayou was estimated to be 50 MGD. Therefore, it is apparent that Cross Lake has no additional yield available to meet future regional demands.

9.5 Caddo Lake

The USACE estimates a dependable yield of 99.5 MGD from Caddo Lake for the state of Louisiana. However, a significant portion of that yield is used for hydroelectric power generation (USGS *Water Use in Louisiana, 2010*). It should be noted that once through the cooling for steam-electric usage, most of the water is returned to the source. USGS water use information reported a total use of 91.05 MGD for Caddo Lake for 2010, of which 89.12 MGD was reportedly used for power generation and DOTD reported a total use of 2.99 MGD for the year 2011. Caddo Lake is jointly owned by Louisiana and Texas. According to the Texas Water Development Board, Louisiana shares the water in Caddo Lake with Texas, each state receiving 50% of the water in the lake. North Texas Municipal Water District (NTMWD) estimates a firm yield of 10,000 acre-feet per year (8.9 MGD) for Caddo Lake for the State of Texas.

Seven public water utilities in Caddo Parish rely on Caddo Lake as a drinking water supply source and five of these seven systems rely on Caddo Lake as their sole water source. In addition, Caddo Lake water discharged into Twelve Mile Bayou provides a secondary source of water for the City of Shreveport. During periods of increased demand or when the available supply in Cross Lake is low, the City of Shreveport pumps water from Twelve Mile Bayou/Caddo Lake to supplement its raw water supply from Cross Lake.

Water use from Caddo Lake is regulated under the Red River Compact and there are several logistical and regulatory challenges that were identified in Phase I of this plan. A few are listed below:

- Caddo Lake is jointly owned by Louisiana and Texas. A specific water supply yield is not allocated, although some water is obviously used for domestic supply.
- Caddo Lake is located in an environmentally sensitive natural area. Environmental restrictions may restrict or limit future use.
- Existing surface water rights are minimally regulated and agreements for power generation and industrial use are not well documented.

An excerpt from the Caddo Lake Compact is provided below:

"In order to resolve current controversies regarding the use of Caddo Lake water, controversies not adequately dealt with in the Red River Compact, the States of Texas and Louisiana, acting through their authorized representatives, have agreed through the Caddo Lake Compact, to an equitable apportionment and use of the water of Caddo Lake and do hereby submit the Caddo Lake Compact to amplify the Red River Compact."

As discussed in Phase I of the Master Plan, the Caddo Lake Compact was intended to augment and amplify the Red River Compact and was not intended to amend, replace or supersede any provision of the Red River Compact. The Caddo Lake Compact was intended to preserve and project Caddo Lake as a valuable environmental, cultural and natural resource and enhance water resource and recreational potentials, while allowing its utilization for water needs of adjacent portions of Louisiana and Texas. A primary means of accomplishing these purposes was to raise the spillway elevation of Caddo Lake to an elevation of 170.5 feet above mean sea level. The Caddo Lake Compact also held that the minimum recreation and navigation pool elevation of 167.5 msl would be maintained. A copy of the Caddo Lake Compact is included in Phase I.

Pending further clarification on the above issues, Caddo Lake was precluded from consideration as a significant long term water supply source for the region. Also revisiting the provisions of the Caddo Lake Compact could add Caddo Lake as a potential water source to meet some immediate and long-term needs for the region. A more detailed study of Caddo Lake pertaining to these issues, in addition to a detailed yield analysis, should be conducted prior to Caddo Lake being considered as a potential long term source for future water needs.

9.6 Twelve Mile Bayou

According to the USACE, Twelve Mile Bayou has a reported dependable yield of 5.1 MGD (USACE Tulsa District, 2001). The City of Shreveport has the capability to pump 10 MGD of water from Twelve Mile Bayou/Caddo Lake to supplement its raw water supply from Cross Lake during periods of high demand or when there is insufficient water supply in Cross Lake. Use can exceed dependable yield since yield is a conservative measure of water supply that will be greater than the given figure. Twelve Mile Bayou is not considered a viable long term alternative for meeting water demand on a regional basis due to low yield and the uncertainty of increased water use from Caddo Lake.

9.7 Toledo Bend Reservoir

Toledo Bend is the fifth largest man-made body of water in the United States based on surface area and is owned and operated by the Sabine River Authority. Toledo Bend's annual water supply or firm yield is reported to be 2,086,600 acre-feet. The lake has a dependable yield of 1,851 MGD, which is equally shared by Texas and Louisiana. Reported available yield for Louisiana's share varied from 814 MGD to 925 MGD. Toledo Bend Reservoir also provides a significant amount of hydroelectric power to the region. Historically, the Sabine River Authority of Louisiana uses less than 3% of its annual water allocation with various municipal and independent water systems in Desoto and Sabine Parishes. (ToledoBend.com)

The Toledo Bend Reservoir currently has the available water supply to meet the future needs of Caddo and Bossier Parishes. Water is available for transport to the region but the portion of unallocated water should be researched and verified. In addition, the feasibility of transporting water to the region should be studied to understand costs and logistics. It is also noted that private companies from the State of Texas have made recent attempts (2010) to secure long term water usage agreements with the Sabine River Authority. The agreements were not approved by the State of Louisiana's authorities. Therefore, before consideration is given to the Toledo Bend Reservoir as a long term water source, a further evaluation of the State of Louisiana's statutes as well as current and planned commitments should be assessed.

9.8 Lake Bistineau

Lake Bistineau has a volume of 120,000 acre-feet (39,102 Mgal) at spillway crest, an average depth of 7 feet, and a maximum depth of 25 feet. Lake Bistineau has an estimated dependable yield of 5 MGD by the Red River Basin Characterization Report by DOTD. Because of this low dependable yield, Lake Bistineau is not considered a viable alternative for raw water supply.

9.9 Cypress Bayou Reservoir

The Cypress Bayou Reservoir, when the elevation of the water surface is near the crest elevation, has a surface area of about 3,400 acres, a maximum depth of about 20 feet, an average depth of about 6.7 feet and a water volume of about 22,700 acre-feet. Currently, Cypress Bayou Reservoir has no reported potable surface water users in Bossier Parish.

Cypress Bayou Reservoir has a dependable yield of 13.8 MGD. However, only 2.1 MGD is currently available for municipal use and 11.7 MGD is allocated to agricultural uses (USACE Tulsa District, 2001). Reallocation of the agricultural allotment may be possible to meet the anticipated demands of Bossier Parish, but because of the projected demands of Bossier City, Cypress Bayou Reservoir is not a considered a viable long term alternative for meeting water demand on a regional basis.

9.10 Black Bayou Reservoir (Bossier Parish)

Cypress Black Bayou Reservoir is located in Bossier Parish, about 8 miles north of Bossier City, Louisiana, and 3 miles southeast of Benton, Louisiana. The reservoir is formed from an earthen dam built in 1975 on Black Bayou. The earthen dam is 4,800 feet in length and the reservoir level is controlled by a spillway 150 feet in length with a crest elevation of 185 feet msl. The maximum discharge for the spillway structure is 13,680 CFS (Ray Elifami, Louisiana Department of Transportation and Development, 1998).

Black Bayou Reservoir (Bossier Parish) is also an agricultural water storage reservoir. The lake has a limited dependable yield of 4.9 MGD, with 3.7 MGD allocated to agricultural and 1.2 MGD available for municipal use (USACE Tulsa District, 2001). The small overall yield makes this reservoir impractical as a possible water supply source.

9.11 Bodcau Bayou Reservoir

The Bodcau Bayou Reservoir is a flood control reservoir with no maintained pool. Therefore, a yield analysis was not conducted. The reservoir is subject to extreme fluctuations and water is retained only in the stream proper when water level is near 157.0 feet msl. The Bodcau Bayou Reservoir is currently not a viable option for raw water supply.

10.0 Results and Conclusions

10.1 General

Determining and understanding yield estimates is critical to water supply planning at local and regional levels. In Phase IV of this Master Plan, raw water source yields were estimated for both Caddo and Bossier Parishes. The information obtained during this phase will serve as a basis for planning efforts to meet current and future water demands of the region. Further and more detailed analysis of each raw water source identified will be required prior to actual design and implementation.

In determining the adequacy of water supply facilities, the source of supply must be large enough to meet various demand conditions and reliable enough to meet at least a portion of normal demand during emergencies, such as power outages and disasters. At a minimum, the source of supply should be capable of meeting the maximum day system demand. Industry practices advise not to rely on storage reservoirs to compensate for any shortfall in supply at maximum day demand. It is common for systems to provide a source of supply that meets the maximum day demand, with the additional supply to meet peak hour demand coming from storage.

10.1.1 Available Yields

Development and analysis of existing information for this phase has demonstrated that there are raw water sources that can support current and future demands for both parishes and the northwest region of the state. Reviewing the existing literature, historical usage, and current trends have indicated an increased need for supply and especially a critical need for conservation and management. Using available data from the USACE and the USGS, the Red River has sufficient capacity to supply the estimated raw water withdrawal needs for the Caddo and Bossier Parish Region. Using the lowest mean water level for the Red River, there is approximately 1,260 MGD that is available for withdrawal. However, the dependable yield determined for this study is based upon flow at the minimum Red River water level of 347 CFS or 224 MGD. The raw water sources determined to have available yield to meet future needs of the region and the potential yields are listed in Table 10-1.

Table 10-1, Available Yields

Name	Dependable Yield (MGD) (DOTD)	Dependable Yield (MGD) (USACE)	Dependable Yield (MGD) Shaw and Sub-Consultants
Red River		860 (430 Acceptable Source Yield)	224
Toledo Bend Reservoir	814	715	

10.2 Caddo Parish Water Service Populations

The current and future raw water demand for Caddo Parish was presented in Section 8 of this phase. However, a regional analysis is required to comprehend the distribution of water demand and water yields within Caddo Parish. In an effort to accomplish this task, the water service populations for the City of Shreveport and Blanchard (the two largest providers) were separated from the total population of Caddo Parish. This allowed for the identification of the required water demand and any deficits for the remaining population of Caddo Parish. The water service populations for all of Caddo Parish, the City of Shreveport, and the City of Blanchard are shown in Table 10-2.

Table 10-2, Caddo Parish Water Service Population

Year	Caddo Parish Total	City of Shreveport	City of Blanchard	Remaining Caddo Parish Population
2010	254,969	199,311	10,500	45,158
2015	270,700	211,608	11,148	47,944
2020	285,530	223,201	11,759	50,571
2025	299,150	233,848	12,319	52,983
2030	311,650	243,619	12,834	55,197
2035	323,640	252,992	13,328	57,320

1. *For the Shaw Water Survey (Phase II), the City of Shreveport reported a population of 210,000 and Blanchard 10,500 for population served.*
2. *The 2010 Census Demographic Profile Data reported a population of 2,889 for the City of Blanchard.*
3. *Future population totals for City of Shreveport and City of Blanchard estimated from City of Shreveport and City of Blanchard's 2010 percentage parish population.*

10.3 Bossier Parish Water Service Populations

The current and future raw water demand for Bossier Parish was presented in Section 8 of this phase. In efforts to look at the distribution of water demand and water yields within Bossier Parish, the water service population of the City of Bossier City (the largest provider) was separated from and compared to the remaining portion of Bossier Parish. The water service populations of Bossier Parish, the City of Bossier City and the remaining Bossier Parish population are shown in Table 10-3.

Table 10-3, Bossier Parish Water Service Population

Year	Bossier Parish Total	City of Bossier City	Remaining Bossier Parish Population
2010	116,979	61,315	55,664
2015	128,050	67,118	60,932
2020	138,990	72,852	66,138
2025	150,190	78,723	71,467
2030	161,960	84,892	77,068
2035	174,560	91,496	83,064

1. *DHH Information showed a reported population served for the City of Bossier City of 59,611.*
2. *Future population totals for the City of Bossier City estimated from the City's percentage of current parish population.*

10.4 Caddo Parish Yield Deficits

Caddo Parish currently relies on three surface water sources for its drinking water supply: Caddo Lake, Cross Lake and Twelve Mile Bayou. Based on the information gathered in this analysis, those surface water sources have a combined estimated dependable yield of approximately 46.5 MGD. Estimating yield for Caddo Lake was difficult due to varying reports of yield and usage. For this report, Caddo Lake yield is estimated at approximately 8.5 MGD, based on an overall yield of 99.5 MGD by the USACE and reported usage for power generation in 2010 of 91.05 MGD by USGS (USACE dependable yield estimate minus reported USGS Power Generation Usage). Caddo Lake, Cross Lake and Twelve Mile Bayou have reached maximum capacity of raw water availability and additional raw water will be required as Caddo Parish population continues to increase. The surface water yield deficit found for Caddo Parish is shown in Table 10-4.

Table 10-4, Caddo Parish Yield Deficits

Year	Average Day Demand (MGD)	Maximum Day Demand (MGD)	Maximum Hour Demand (MGD)	Total Existing Dependable Yield (MGD)[1]	Yield Deficit/ Surplus Avg. Day (MGD)[2]	Yield Deficit/ Surplus Max. Day (MGD)[2]	Yield Deficit/ Surplus Max. Hour (MGD)[2]
2010	48.4	87.1	140.4	46.5	-1.90	-40.6	-93.9
2015	51.3	103	149	46.5	-4.84	-56.2	-102.4
2020	54.2	108	157	46.5	-7.65	-61.8	-110.5
2025	56.7	113	165	46.5	-10.24	-67.0	-118.0
2030	59.1	118	171	46.5	-12.61	-71.7	-124.9
2035	61.4	123	178	46.5	-14.88	-76.3	-131.5

1. *Total Existing Dependable Yield of 46.5 MGD for Caddo Parish based on existing yields for Caddo Lake (8.45 MGD), Cross Lake (33.0 MGD) and Twelve Mile Bayou (5.1 MGD).*
2. *Negative values designate water yield deficits and positive values designate water yield surpluses.*

Yield volumes for the City of Shreveport for current and future demands were separated from the Caddo Parish Yield Deficit and are shown in table 10-5 below. Dependable yield for the City of Shreveport is the combined dependable yield of Cross Lake and Twelve Mile Bayou. Population projections for the City of Shreveport were estimated as a percentage of the overall Caddo Parish population projections determined in Phase III.

Table 10-5, City of Shreveport Yield Deficits

Year	Per Capita[2] (gal/day)	Annual Average Day (MGD)	Maximum Day (MGD)	City of Shreveport Total Existing Dependable Yield* (MGD)	City of Shreveport Yield Deficit Avg. Day (MGD)	City of Shreveport Yield Deficit Max. Day (MGD)
2010	190	37.8	68.0	38.1	0.3	-29.9
2015	190	40.1	80.3	38.1	-2.0	-42.2
2020	190	42.3	84.7	38.1	-4.2	-46.6
2025	190	44.4	88.7	38.1	-6.3	-50.6
2030	190	46.2	92.4	38.1	-8.1	-54.3
2035	190	48.0	96.0	38.1	-9.9	-57.9

1. *Yield used for the City of Shreveport is the combined dependable yield of Cross Lake and Twelve Mile Bayou.*
2. *Based on Water Use in Louisiana 2010*

Yield volumes for the City of Blanchard for current and future demands were separated from the Caddo Parish Yield Deficit and are shown in table 10-6 below. Dependable yield for the City of Blanchard is the existing and future treatment capacity of the City of Blanchard's Water Treatment Facility which uses Caddo Lake as its water source. Population projections for the City of Blanchard were based on the population served and population projections were estimated as a percentage of the overall Caddo Parish population projections determined in Phase III.

Table 10-6, City of Blanchard Yield Deficits

Year	Per Capita[2] (gal/day)	Annual Average Day (MGD)	Maximum Day (MGD)	Blanchard Water Dependable Yield* (MGD)	Blanchard Water Yield Deficit Avg. Day (MGD)	Blanchard Water Yield Deficit Max. Day (MGD)
2010	190	2.0	3.6	1.75	-0.2	-1.8
2015	190	2.1	4.2	5	2.9	0.8
2020	190	2.2	4.5	5	2.8	0.5
2025	190	2.3	4.7	5	2.7	0.3
2030	190	2.4	4.9	5	2.6	0.1
2035	190	2.5	5.1	5	2.5	-0.1

1. *Yield used for Blanchard Water is the available treatment of capacity of the treatment facility.*
2. *Based on Water Use in Louisiana 2010.*

The required yield for the remaining portion of Caddo Parish's population not served by the City of Shreveport and the City of Blanchard are shown in Table 10-7 below. In addition, the remaining yield of Caddo Lake was used to determine the yield deficit. Only existing surface water sources were considered and the remaining dependable yield of Caddo Lake was used to determine the yield deficit for the remaining portion of Caddo's population.

Dependable yield for the remainder of Caddo Parish contains the existing and future treatment capacity of the City of Blanchard's Water Treatment Facility which uses Caddo Lake as its water source. Population projections for the City of Blanchard were based on the population served and population projections were estimated as a percentage of the overall Caddo Parish population projections determined in Phase III.

Table 10-7, Remaining Caddo Parish and Caddo Lake Yield Deficits

Year	Per Capita² (gal/day)	Annual Average Day (MGD)	Maximum Day (MGD)	Remaining Caddo Lake Existing Dependable Yield* (MGD)	Caddo Lake Yield Deficit Avg. Day (MGD)	Caddo Lake Yield Deficit Max. Day (MGD)
2010	190	8.6	15.4	6.7	-1.9	-8.7
2015	190	9.1	18.2	3.45	-5.6	-14.7
2020	190	9.6	19.2	3.45	-6.1	-15.7
2025	190	10.0	20.1	3.45	-6.6	-16.6
2030	190	10.5	20.9	3.45	-7.0	-17.5
2035	190	10.9	21.7	3.45	-7.4	-18.3

1. *Remaining Caddo Lake Yield is the Estimated Yield of 8.45 MGD minus the treatment capacity of Blanchard Water.*
2. *Based on Water Use in Louisiana 2010.*

The yield deficits shown in Table 10-4, 10-5, 10-6 and 10-7 are based on the use of existing surface water sources to meet existing and future water demands. Also, the water yields do not include existing or future ground water use to meet future demands or potential surface water sources addressed in Section 10.1. The yield deficits are shown for planning purposes under the assumption that surface water supply is the sole drinking water source for Caddo Parish.

10.5 Bossier Parish Yield Deficits

Currently, the Bossier City Water System is the only system in Bossier Parish that relies on the Red River for surface water. According to capacity information obtained for this analysis, Bossier City has capacity to provide water for a significant portion of Bossier Parish, but not the entire parish. Rural portions of Bossier Parish that are not within the City of Bossier City Water

System's existing or future service area currently rely on groundwater to meet current and future water needs. Further study is required to determine the feasibility and cost effectiveness of connecting these rural systems to the City of Bossier City or other systems. The existing surface water yield deficit found for Bossier Parish is shown in Table 10-8.

Table 10-8, Bossier Parish Yield Deficits

Year	Average Day Demand (MGD)	Maximum Day Demand (MGD)	Maximum Hour Demand (MGD)	Total Existing Dependable Yield (MGD)[1]	Yield Deficit/ Surplus Avg. Day (MGD)[2]	Yield Deficit/ Surplus Max. Day (MGD)[2]	Yield Deficit/ Surplus Max. Hour (MGD)[2]
2010	16.4	29.5	47.6	25	8.60	-4.5	-22.6
2015	18	36	52	45	27.07	9.1	-7.0
2020	19	39	56	45	25.54	6.1	-11.4
2025	21	42	61	45	23.97	2.9	-16.0
2030	23	45	66	45	22.33	-0.3	-20.8
2035	24	49	71	45	20.56	-3.9	-25.9

1. *Total Existing Dependable Surface Water Yield for Bossier Parish based on City of Bossier City's existing and future treatment capacity*
2. *Negative values designate water yield deficits and positive values designate water yield surpluses.*

Yield volume deficits for the City of Bossier City for current and future demands were separated from the Bossier Parish Yield Deficit and are shown in Table 10-9 below. Dependable yield volumes estimated for the City of Bossier City used in this analysis are the existing and future treatment capacity of the Bossier City Water Treatment Facility. Population projections for the City of Bossier City were estimated as a percentage of the overall Bossier Parish population projections determined in Phase III.

Table 10-9, City of Bossier City Yield Deficits

Year	Per Capita[2] (gal/day)	Annual Average Day (MGD)	Maximum Day (MGD)	Bossier City Dependable Yield (MGD)	Bossier City Yield Deficit Avg. Day (MGD)	Bossier City Yield Deficit Max. Day (MGD)
2010	140	8.6	15.5	25	16.4	9.5
2015	140	9.4	18.8	45	35.6	26.2
2020	140	10.2	20.4	45	34.8	24.6
2025	140	11.0	22.0	45	34.0	23.0
2030	140	11.9	23.8	45	33.1	21.2
2035	140	12.8	25.6	45	32.2	19.4

1. *Total Existing Dependable Surface Water Yield for Bossier Parish based on City of Bossier City's existing and future treatment capacity.*
2. *Based on Water Use in Louisiana 2010.*

Yield volume deficits for the remainder of Bossier Parish are shown in Table 10.10. Since Bossier Parish currently has no other surface water providers, the current available yield used for Bossier Parish is zero. Population projections for the remaining portion of Bossier Parish were estimated as a percentage of the overall Bossier Parish population projections determined in Phase III.

Table 10-10, Remaining Bossier Parish Yield Deficits

Year	Per Capita[2] (gal/day)	Annual Average Day (MGD)	Maximum Day (MGD)	Remaining Bossier Parish Excluding Bossier City Dependable Yield (MGD)	Remaining Bossier Parish Required Yield Avg. Day (MGD)	Remaining Bossier Parish Required Yield Max. Day (MGD)
2010	140	7.8	14.0	0	-7.8	-14.0
2015	140	8.5	17.1	0	-8.5	-17.1
2020	140	9.3	18.5	0	-9.3	-18.5
2025	140	10.0	20.0	0	-10.0	-20.0
2030	140	10.8	21.6	0	-10.8	-21.6
2035	140	11.6	23.3	0	-11.6	-23.3

1. *Total Existing Dependable Surface Water Yield for Bossier Parish based on City of Bossier City's existing and future treatment capacity*
2. *Based on Water Use in Louisiana 2010.*

The yield deficits shown in Table 10-8, 10-9 and 10-10 are based on the use of existing surface water sources to meet existing and future water demands. Also, the water yields do not include existing or future ground water use to meet future demands or potential surface water sources addressed in Section 10.1. The yield deficits are shown for planning purposes under the assumption that surface water supply is the sole drinking water source for Bossier Parish.

10.6 Regional Yield Deficits

Average and maximum day demands for Caddo and Bossier Parish were combined to determine regional water demands. Likewise, existing and future surface water yield availability was combined for both parishes. Yield deficits for the region are shown in Table 10-11.

Table 10-11, Regional Yield Deficits

Year	Average Day Demand (MGD)	Maximum Day Demand (MGD)	Total Existing Dependable Yield (MGD)1,2	Yield Deficit/Surplus Avg. Day (MGD)3	Yield Deficit/Surplus Max. Day (MGD)3
2010	64.8	116.6	71.5	6.7	-45.1
2015	69.3	138.5	91.5	22.2	-47.0
2020	73.6	147.2	91.5	17.9	-55.7
2025	77.8	155.5	91.5	13.7	-64.0
2030	81.8	163.6	91.5	9.7	-72.1
2035	85.8	171.6	91.5	5.7	-80.1

1. Total Existing Dependable Yield of 46.5 MGD for Caddo Parish based on existing yields for Caddo Lake (8.45 MGD), Cross Lake (33.0 MGD) and Twelve Mile Bayou (5.1 MGD).

2. Total Existing Dependable Surface Water Yield for Bossier Parish based on City of Bossier City existing and future treatment capacity.

3. Negative values designate water yield deficits and positive values designate water yield surpluses.

As stated previously, Caddo Lake was precluded from consideration as a significant long term water supply source for the region. Also revisiting the provisions of the Caddo Lake Compact could add Caddo Lake as a potential water source to meet some immediate and long-term needs for the region. A more detailed study of Caddo Lake pertaining to these issues, in addition to a detailed yield analysis, should be conducted prior to Caddo Lake being considered as a potential long term source for future water needs.

Based on this feasibility level analysis, the Red River as well as the Toledo Bend Reservoir appear to have the allowable yield to provide raw water to the Caddo/Bossier Region. As mentioned earlier, the Toledo Bend Reservoir should be further evaluated for legal clarification relative to use as a long term source of water. Likewise, further study of Red River is recommended to determine actual yield and/or storage requirements for use as a regional water source. However, this feasibility level analysis supports use of the Red River as a long term water source based on long term demand as projected in Phase III and dependable yield estimated from existing hydrographs.

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APPENDICES

APPENDIX A

Palmer Hydrological Drought Index for Bossier and Caddo Parishes									
Moderate Drought (-1.25 to -1.99)		Moderate Drought (-1.25 to -1.99)		Moderate Drought (-1.25 to -1.99)		Severe Drought (-2.00 to -2.74)		Extreme Drought (< -2.75)	
Month	Year	Month	Year	Month	Year	Month	Year	Month	Year
Feb	1955	May	1967	Feb	1996	Jan	1955	Mar	2011
Mar	1955	Jun	1967	Mar	1996	Dec	1956	Apr	2011
Apr	1955	Dec	1967	Apr	1996	Oct	1963	May	2011
Jan	1956	Aug	1969	May	1996	Jul	1964	Jun	2011
Sept	1956	Sept	1969	Jun	1998	Mar	1967	Jul	2011
Oct	1956	Apr	1971	Jan	2000	Apr	1967	Aug	2011
Nov	1956	Jun	1971	Oct	2000	Apr	1978	Sep	2011
Jan	1957	Apr	1972	Jul	2005	Dec	1980	Oct	2011
Feb	1957	May	1972	Aug	2005	Jan	1981	Nov	2011
Feb	1963	Jun	1972	Oct	2005	Feb	1981	Dec	2011
Mar	1963	Jul	1977	Nov	2005	Mar	1981		
Apr	1963	Oct	1977	Feb	2006	Apr	1981		
May	1963	Nov	1977	Apr	2006	Jul	1988		
Jun	1963	Dec	1977	May	2006	Aug	1998		
Jul	1963	Jan	1978	Jun	2006	Feb	2000		
Aug	1963	Feb	1978	Jul	2006	Dec	2005		
Sept	1963	Mar	1978	Sept	2006	Jan	2006		
Nov	1963	May	1978	Oct	2006	Aug	2006		
Dec	1963	Jun	1978	Nov	2006	Sept	2010		
Jan	1964	Jul	1978	Apr	2007	Oct	2010		
Feb	1964	Aug	1978	May	2007	Dec	2010		
Feb	1964	Sept	1978	May	2010	Jan	2011		
Mar	1964	Oct	1978	Jun	2010	Feb	2011		
May	1964	Nov	1978	Jul	2010				
Jun	1964	Sept	1980	Aug	2010				
Aug	1964	Oct	1980	Nov	2010				
Sept	1964	Nov	1980						
Oct	1964	May	1981						
Nov	1964	Mar	1982						
Dec	1964	May	1982						
Jan	1965	Jul	1982						
Apr	1965	Aug	1982						
May	1965	Sept	1982						
Jul	1965	Mar	1986						
Aug	1965	Apr	1986						
Nov	1965	Jul	1987						
Dec	1965	Aug	1987						
Mar	1966	Sept	1987						
Nov	1966	Oct	1987						
Jan	1967	Jun	1988						
Feb	1967	Sept	1988						
May	1967								

APPENDIX B

Monthly Precipitation for Shreveport in inches													
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Total Annual**
1955	3.44	4.43	3.00	4.78	9.64	2.67	6.17	6.83	1.09	1.93	0.82	2.42	47.22
1956	3.68	4.58	4.47	4.51	3.85	3.11	0.30	2.25	0.17	2.05	3.50	1.54	34.01
1957	5.07	4.05	6.55	11.19	3.45	8.37	3.26	1.75	4.17	6.78	9.49	3.10	67.23
1958	4.18	1.98	3.15	7.78	2.89	6.86	4.13	2.22	8.58	0.55	3.75	0.68	46.75
1959	1.17	4.79	2.82	3.58	3.23	3.35	3.29	2.13	1.64	3.90	2.94	6.18	39.02
1960	3.08	4.49	4.04	1.39	1.88	7.35	2.88	4.99	4.98	2.34	2.99	8.10	48.51
1961	3.79	3.88	6.15	1.70	1.46	12.39	3.95	2.26	5.75	3.51	5.16	7.50	57.50
1962	4.26	2.12	3.28	5.78	1.22	4.70	0.60	3.96	2.57	1.26	3.52	2.35	35.62
1963	1.46	2.42	0.91	3.53	2.25	2.65	1.00	3.74	2.36	0.00	6.72	2.99	30.03
1964	2.57	2.74	4.24	7.27	1.41	1.87	0.15	4.71	2.51	0.64	1.63	2.55	32.29
1965	3.77	6.51	3.39	1.16	5.40	3.18	1.49	1.82	6.55	0.36	1.20	6.29	41.12
1966	4.22	3.45	0.56	8.02	3.78	2.05	0.58	1.71	3.27	1.62	0.97	3.63	33.86
1967	1.36	2.91	1.02	2.11	11.78	0.89	6.15	4.67	1.27	1.34	0.71	3.92	38.13
1968	8.33	2.22	1.89	9.38	6.05	2.78	4.68	1.89	9.59	1.90	5.85	3.27	57.83
1969	1.14	4.32	7.23	6.63	5.18	1.16	1.06	0.50	0.97	3.16	7.50	3.95	42.80
1970	1.23	4.70	4.30	5.12	4.36	1.14	3.94	2.04	1.64	7.44	2.09	3.80	41.80
1971	0.27	4.13	2.11	1.06	5.26	0.97	6.15	2.99	1.30	3.86	3.75	3.65	35.50
1972	5.97	0.94	2.45	2.06	4.13	2.76	9.46	1.27	2.10	6.32	5.32	4.18	46.96
1973	5.65	1.52	5.01	6.44	2.00	5.84	7.63	0.77	6.39	5.38	5.16	6.37	58.16
1974	10.09	3.67	3.60	3.09	4.58	6.29	7.73	3.84	6.64	3.79	5.80	2.34	61.46
1975	4.55	4.51	5.84	3.91	5.31	3.48	3.45	1.65	0.98	3.87	4.44	1.88	43.87
1976	2.07	2.45	6.67	1.75	5.95	4.42	3.47	2.96	6.28	2.08	1.63	3.77	43.50
1977	3.00	3.68	4.94	2.05	2.40	2.41	3.89	4.28	0.53	0.31	2.11	2.58	32.18
1978	4.89	1.90	2.66	2.79	7.92	1.21	1.74	3.90	2.40	2.74	4.18	5.13	41.46
1979	9.22	4.98	5.74	7.42	7.99	3.04	7.50	1.86	4.35	3.96	4.76	3.12	63.94
1980	4.67	3.10	3.75	5.34	4.42	2.60	1.83	0.42	1.63	2.48	3.59	0.74	34.57
1981	1.43	3.83	3.33	1.97	9.96	6.45	2.36	0.94	3.32	5.63	1.49	0.59	41.30
1982	3.59	3.19	2.59	2.72	2.32	1.84	4.25	2.20	1.11	5.19	5.72	10.00	44.72
1983	2.45	8.57	3.68	1.47	8.22	6.60	1.18	1.67	3.12	0.79	4.90	7.18	49.83
1984	2.10	5.66	3.58	2.52	5.86	3.56	2.20	0.87	2.61	12.05	4.46	2.88	48.35
1985	2.38	4.42	4.28	3.05	1.96	4.57	8.40	0.35	4.40	9.87	4.25	3.37	51.30
1986	0.49	3.48	0.75	3.50	6.60	14.67	2.92	1.68	3.51	6.63	9.19	4.69	58.11
1987	2.26	7.80	1.48	0.43	6.67	5.43	1.21	3.50	0.94	5.49	10.81	8.12	54.14
1988	2.06	3.59	3.89	3.45	0.42	0.13	3.12	3.52	1.61	4.44	5.44	4.71	36.38
1989	7.20	4.06	3.41	2.41	10.07	17.11	4.46	3.94	1.08	1.50	2.32	3.34	60.90
1990	10.02	6.92	4.90	4.29	10.48	2.56	3.53	2.88	2.93	4.33	8.81	3.99	65.64
1991	7.70	5.13	2.89	21.84	10.71	2.53	3.47	9.23	3.45	3.59	3.94	7.51	81.99
1992	4.63	6.41	5.94	3.26	2.81	3.95	3.36	1.24	5.15	4.13	4.69	5.84	51.41
1993	4.63	4.80	5.94	4.19	3.30	15.73	0.27	4.09	3.51	4.43	4.85	1.44	57.18

Monthly Precipitation for Shreveport in inches													
1994	3.63	5.02	3.67	3.67	5.85	2.81	6.43	3.80	0.08	9.14	2.50	8.00	54.60
1995	5.44	3.75	4.05	7.80	3.26	1.09	5.68	0.83	3.36	1.65	1.92	5.11	43.94
1996	1.74	0.64	2.33	3.86	0.93	6.50	5.70	5.78	7.17	1.66	5.87	2.24	44.42
1997	4.47	8.09	8.72	11.93	3.19	6.14	1.73	5.48	2.41	7.50	3.44	6.10	69.20
1998	5.84	7.19	4.28	0.79	0.15	1.35	2.84	3.83	7.79	5.72	4.58	6.24	50.60
1999	12.96	0.42	5.10	7.88	3.96	7.98	2.80	1.47	4.90	3.21	0.52	3.82	55.02
2000	2.60	2.31	7.90	5.67	10.76	7.32	1.05	0.00	1.13	1.65	9.93	7.56	57.88
2001	5.76	6.52	6.47	0.86	4.31	7.33	1.75	4.10	6.84	5.17	4.16	6.10	59.37
2002	2.40	3.03	5.47	2.66	2.47	2.31	3.38	1.50	1.37	6.56	3.53	8.36	43.04
2003	0.44	7.66	2.19	2.12	2.04	4.61	3.07	3.19	2.93	1.92	2.81	3.61	36.59
2004	4.39	7.91	5.29	5.17	4.56	12.42	0.72	2.98	3.61	5.94	7.17	2.78	62.94
2005	4.37	3.76	1.91	4.59	0.73	0.38	4.60	3.27	5.66	1.41	1.06	1.24	32.98
2006	5.36	4.91	5.07	2.24	1.21	2.64	7.74	0.62	2.97	3.99	3.21	5.36	45.32
2007	7.64	3.32	2.09	1.64	4.26	6.00	10.64	0.61	1.32	2.36	3.06	4.58	47.52
2008	2.65	4.96	3.25	2.62	11.56	3.85	1.08	5.73	3.84	1.41	4.98	3.14	49.07
2009	2.13	1.63	6.48	3.97	7.44	1.22	6.49	1.69	2.58	20.35	1.42	4.64	60.04
2010	3.09	3.38	3.20	2.98	1.93	2.84	5.91	0.85	0.12	1.06	4.96	0.41	30.73
2011	4.37	2.82	1.84	2.85	2.47	1.62	1.85	0.51	1.05	1.56	4.25	7.88	33.07

Annual Average, Minimum and Maximum Precipitation for Shreveport in inches			
Year	**Avg Annual**	**Min**	**Max**
1955	3.94	0.82	9.64
1956	2.83	0.17	4.58
1957	5.60	1.75	11.19
1958	3.90	0.55	8.58
1959	3.25	1.17	6.18
1960	4.04	1.39	8.10
1961	4.79	1.46	12.39
1962	2.97	0.60	5.78
1963	2.50	0.00	6.72
1964	2.69	0.15	7.27
1965	3.43	0.36	6.55
1966	2.82	0.56	8.02
1967	3.18	0.71	11.78
1968	4.82	1.89	9.59
1969	3.57	0.50	7.50
1970	3.48	1.14	7.44
1971	2.96	0.27	6.15
1972	3.91	0.94	9.46
1973	4.85	0.77	7.63
1974	5.12	2.34	10.09
1975	3.66	0.98	5.84
1976	3.63	1.63	6.67
1977	2.68	0.31	4.94
1978	3.46	1.21	7.92
1979	5.33	1.86	9.22
1980	2.88	0.42	5.34
1981	3.44	0.59	9.96
1982	3.73	1.11	10.00
1983	4.15	0.79	8.57
1984	4.03	0.87	12.05
1985	4.28	0.35	9.87
1986	4.84	0.49	14.67
1987	4.51	0.43	10.81
1988	3.03	0.13	5.44
1989	5.08	1.08	17.11
1990	5.47	2.56	10.48
1991	6.83	2.53	21.84
1992	4.28	1.24	6.41
1993	4.77	0.27	15.73

Annual Average, Minimum and Maximum Precipitation for Shreveport in inches			
1994	4.55	0.08	9.14
1995	3.66	0.83	7.80
1996	3.70	0.64	7.17
1997	5.77	1.73	11.93
1998	4.22	0.15	7.79
1999	4.59	0.42	12.96
2000	4.82	0.00	10.76
2001	4.95	0.86	7.33
2002	3.59	1.37	8.36
2003	3.05	0.44	7.66
2004	5.25	0.72	12.42
2005	2.75	0.38	5.66
2006	3.78	0.62	7.74
2007	3.96	0.61	10.64
2008	4.09	1.08	11.56
2009	5.00	1.22	20.35
2010	2.56	0.12	5.91
2011	2.76	0.51	7.88

APPENDIX C

Regional Monthly Lake Surface Evaporation in inches													
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
1954	1.33	2.78	3.24	4.07	3.48	6.39	7.08	6.13	5.98	3.97	2.40	1.71	48.56
1955	1.23	1.97	4.12	3.99	5.12	4.92	5.37	4.70	4.27	3.62	2.64	1.90	43.85
1956	1.84	2.12	2.52	3.23	4.03	4.88	5.38	5.85	4.06	3.12	2.02	1.27	40.32
1957	1.46	1.22	2.20	2.32	3.53	3.86	4.34	4.58	3.30	2.42	1.54	1.58	32.37
1958	1.12	1.59	1.92	2.48	2.49	3.80	3.99	3.36	2.70	2.05	1.77	1.07	28.35
1959	1.23	1.48	3.51	3.10	4.19	5.57	5.54	5.93	5.20	4.09	2.65	2.22	44.71
1960	1.25	2.23	3.11	5.56	5.96	6.90	7.43	6.00	4.51	3.68	2.62	1.58	50.81
1961	1.49	1.81	3.61	5.04	5.83	3.66	5.41	5.58	5.64	3.13	1.98	1.92	45.10
1962	1.55	2.56	3.20	4.32	5.68	6.43	7.08	7.54	5.06	3.76	2.38	1.80	51.36
1963	1.41	2.39	4.72	3.67	4.72	6.39	5.60	6.50	5.17	5.11	3.30	1.64	50.61
1964	1.85	2.25	3.47	4.05	4.53	5.83	6.17	5.92	5.00	3.95	2.56	1.72	47.29
1965	2.03	2.02	2.83	4.80	4.11	5.17	7.25	6.44	5.02	3.81	2.26	1.87	47.62
1966	1.45	1.93	3.96	4.56	4.26	6.77	6.47	5.42	3.91	3.69	2.73	1.42	46.57
1967	2.03	2.19	4.40	3.61	4.40	4.99	5.72	6.65	4.05	4.54	2.40	2.10	47.08
1968	1.21	2.05	3.14	3.77	4.23	4.94	5.49	5.61	4.47	3.73	2.49	2.40	43.52
1969	1.69	2.15	3.08	3.89	4.08	5.94	6.90	6.64	4.84	4.19	2.31	1.71	47.43
1970	1.59	2.24	2.77	3.56	4.59	5.30	5.45	5.43	4.36	3.18	2.47	2.33	43.26
1971	2.15	3.09	3.97	4.52	4.74	6.47	5.73	4.57	4.57	3.47	2.64	2.61	48.54
1972	1.92	2.70	3.96	4.52	5.04	5.64	6.31	6.31	4.70	3.47	2.06	1.77	48.41
1973	1.58	2.02	4.54	2.74	4.90	4.90	6.12	5.92	3.92	3.10	2.79	2.01	44.54
1974	1.00	2.71	4.19	4.91	5.03	5.28	5.76	5.50	3.07	3.42	2.24	1.20	44.29
1975	1.90	1.50	3.05	3.81	4.23	5.13	6.06	5.68	4.56	3.84	2.71	1.96	44.43
1976	2.45	2.85	3.00	4.03	4.24	5.41	5.41	6.24	4.14	2.95	2.10	1.68	44.50
1977	1.64	2.34	3.58	4.34	5.23	6.00	6.20	4.82	4.37	3.52	2.20	2.71	46.95
1978	1.46	1.79	2.92	5.21	4.94	6.54	6.86	6.06	3.50	3.80	1.64	2.59	47.32
1979	1.57	1.73	3.29	3.37	3.91	5.69	4.85	5.37	4.04	4.22	2.13	2.24	42.41
1980	1.88	2.60	2.40	3.79	3.85	6.26	7.08	6.71	5.18	3.86	3.05	2.32	48.97
1981	2.19	2.04	3.33	4.04	4.33	5.62	5.97	5.33	4.23	2.76	1.99	2.41	44.24
1982	2.10	1.29	2.47	2.89	4.67	5.21	5.42	5.38	4.74	2.91	1.73	2.76	41.57
1983	1.27	1.79	3.11	3.23	4.04	4.65	5.23	5.58	4.61	3.32	2.11	2.09	41.04
1984	1.21	2.08	2.76	4.61	4.82	5.45	5.37	4.85	4.32	2.50	1.73	1.56	41.26
1985	1.39	1.25	2.80	4.46	4.52	6.19	5.78	5.95	4.74	2.54	1.66	1.84	43.12
1986	2.56	2.09	4.02	4.09	4.23	4.13	6.48	5.57	4.19	2.57	1.42	1.79	43.14
1987	2.20	1.22	3.19	4.93	4.14	5.10	5.40	6.10	4.35	3.99	2.02	1.98	44.63
1988	1.85	2.20	2.77	3.90	5.50	6.24	5.83	5.13	4.24	3.01	2.55	1.35	44.56
1989	1.11	2.40	2.64	4.30	4.38	4.71	4.80	3.90	3.63	2.49	2.68	2.08	39.50
1990	1.94	2.27	2.43	3.43	3.98	5.62	5.61	5.60	4.79	3.28	2.07	1.61	43.16
1991	1.75	1.69	3.15	3.04	3.72	5.18	6.50	5.08	4.41	4.10	2.55	1.53	42.70

Regional Monthly Lake Surface Evaporation in inches													
1992	1.29	1.77	2.87	3.77	3.68	4.70	5.87	5.39	4.74	3.64	2.06	1.17	40.95
1993	1.27	1.64	2.44	3.32	4.33	4.87	7.63	6.56	5.42	3.25	2.40	2.29	45.44
1994	2.24	1.90	2.74	3.78	4.02	5.56	6.58	6.24	5.79	3.21	2.52	2.28	46.87
1995	2.16	2.25	2.75	3.91	4.23	6.05	6.31	6.62	4.67	3.89	2.78	2.97	48.60
1996	2.46	3.57	4.44	4.86	5.82	5.07	5.53	4.78	4.20	3.27	1.94	2.58	48.52
1997	2.90	1.80	2.98	3.64	4.03	4.84	6.25	5.62	4.67	3.64	1.91	1.76	44.05
1998	1.48	2.21	3.98	4.57	5.35	8.13	8.14	6.16	5.54	3.26	1.57	1.69	52.09
1999	1.66	2.38	2.95	4.64	4.82	5.07	6.35	6.90	4.70	3.58	2.61	2.27	47.92
2000	2.32	2.72	3.23	3.97	5.28	5.18	6.62	7.19	5.40	3.65	1.92	1.07	48.55
2001	1.88	1.89	2.93	4.40	5.84	5.68	6.44	5.81	3.69	3.82	2.67	1.86	46.93
2002	1.92	2.52	3.05	4.38	5.37	5.82	6.11	5.95	4.66	2.52	2.10	1.77	46.18
2003	1.34	1.68	2.78	4.80	4.95	5.12	6.34	5.67	4.54	3.63	2.58	2.13	45.55
2004	1.39	1.69	3.53	4.48	5.29	4.45	5.92	5.40	5.21	3.26	2.13	1.84	44.58
2005	1.92	1.63	3.31	4.23	4.69	5.57	5.47	5.85	5.54	2.96	2.61	2.26	46.04
2006	2.92	2.30	3.75	5.14	5.60	5.98	7.00	6.48	5.48	3.58	2.45	1.35	52.03
2007	1.55	2.55	3.99	3.84	4.41	4.80	4.79	5.80	4.58	3.64	2.80	1.72	44.47
2008	1.74	2.58	3.42	4.40	5.24	6.37	7.08	5.18	4.08	4.02	2.51	1.98	48.63
2009	2.18	2.71	3.58	5.29	4.46	6.49	5.72	5.52	3.62	2.36	2.31	1.52	45.75
2010	2.33	2.18	3.07	4.62	5.22	5.97	5.42	6.70	5.05	6.03	3.57	2.44	52.61
2011	2.26	2.07	4.90	6.01	5.51	7.78	7.41	8.79	4.41	4.98	3.22	1.41	58.75