FINAL TECHNICAL REPORT

Lake Whitney Comprehensive Water Quality Assessment

Phase IB- Physical and Biological Assessment (USDOE)

DOE Award DE-FG02-06ER64253

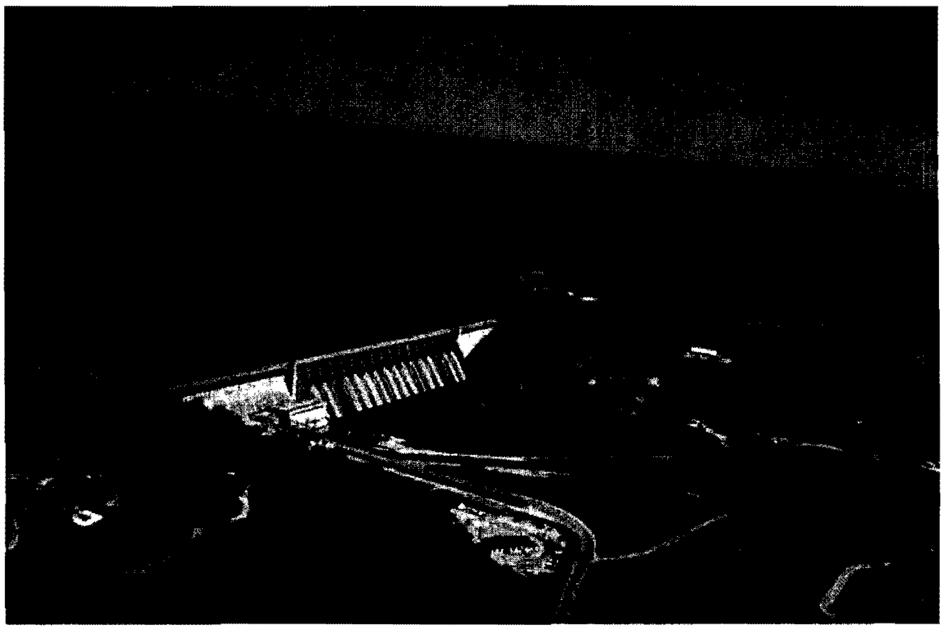

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Table of Contents

EXECUTIVE SUMMARY

Baylor University Center for Reservoir and Aquatic Systems Research (CRASR) has conducted a phased, comprehensive evaluation of Lake Whitney to determine its suitability for use as a regional water supply reservoir.

The area along the Interstate 35 corridor between Dallas / Fort Worth Metroplex and the Waco / Temple Centroplex represents one of the fastest growth areas in the State of Texas and reliable water supplies are critical to sustainable growth. Lake Whitney is situated mid-way between these two metropolitan areas. Currently, the City of Whitney as well as all of Bosque and Hill counties obtain their potable water from the Trinity Sands aquifer. Additionally, parts of the adjoining McLennan and Burleson counties utilize the Trinity sands aquifer system as a supplement to their surface water supplies. Population growth coupled with increasing demands on this aquifer system in both the Metroplex and Centroplex have resulted in a rapid depletion of groundwater in these rural areas. The Lake Whitney reservoir represents both a potentially local and regional solution for an area experiencing high levels of growth. Because of the large scope of this project as well as the local, regional and national implications, we have designed a multifaceted approach that will lead to the solution of numerous issues related to the feasibility of using Lake Whitney as a water resource to the region.

Phase IA (USEPA, QAPP Study Elements 1-4) of this research focused on the physical limnology of the reservoir (bathymetry and fine scale salinity determination) and develops hydrodynamic watershed and reservoir models to evaluate how salinity would be expected to change with varying hydrologic and climatic factors. To this end, we implemented a basic water quality modeling program in collaboration with the Texas Parks and Wildlife Department and the Texas Commission on Environmental Quality to add to the developing long-term database on Lake Whitney. Finally, we conducted an initial assessment of knowledge of watershed and water quality related issues by local residents and stakeholders of Lake Whitney and design an intervention educational program to address any deficiencies discovered. Phase IA was funded primarily from EPA Cooperative Agreement X7-9769 8901-0.

Phase IC (USEPA, QAPP Study Element 5) of this research focused on the ambient toxicity of the reservoir with respect to periodic blooms of golden algae. Phase IC was funded primarily from Cooperative Agreement EM-96638001.

Phase 1B (USDOE, Study Elements 6-11) complemented work being done via EPA funding on study elements 1-5 and added five new study elements: 6) Salinity Transport in the Brazos Watershed to Lake Whitney; 7) Bacterial Assessment; 8) Organic Contaminant Analysis on Lake Whitney; 9) Plankton Photosynthesis; 10) Lake Whitney Resident Knowledge Assessment; and 11) Engineering Scoping Perspective: Recommendations for Use.

INTRODUCTION

PROBLEM STATEMENT

Situated in both Bosque and Hill counties, Lake Whitney is one of the largest reservoirs in the state of Texas with a surface area of 23,500 acres and a volume of 627,000 acre feet of water. The population around the Lake Whitney area varies seasonally and at times can swell to 50,000+. Such flux in population as well as economic development puts an enormous strain on groundwater resources that currently feed the region. Thus, reliable surface water sources should be investigated for development as public water supply.

Physically, Lake Whitney is approximately 25 river miles (= 41 km) in length and averages approximately 40 feet (12 m) in depth. This depth value can be deceiving however, since the lake is constructed in a meandering river valley of the Brazos River, giving it a long-slender profile with a narrow (one mile) average width. The result of this valley construction is a very steep bathymetry that reaches a depth of just over 100 feet (30 m) at the dam (fig. 1).

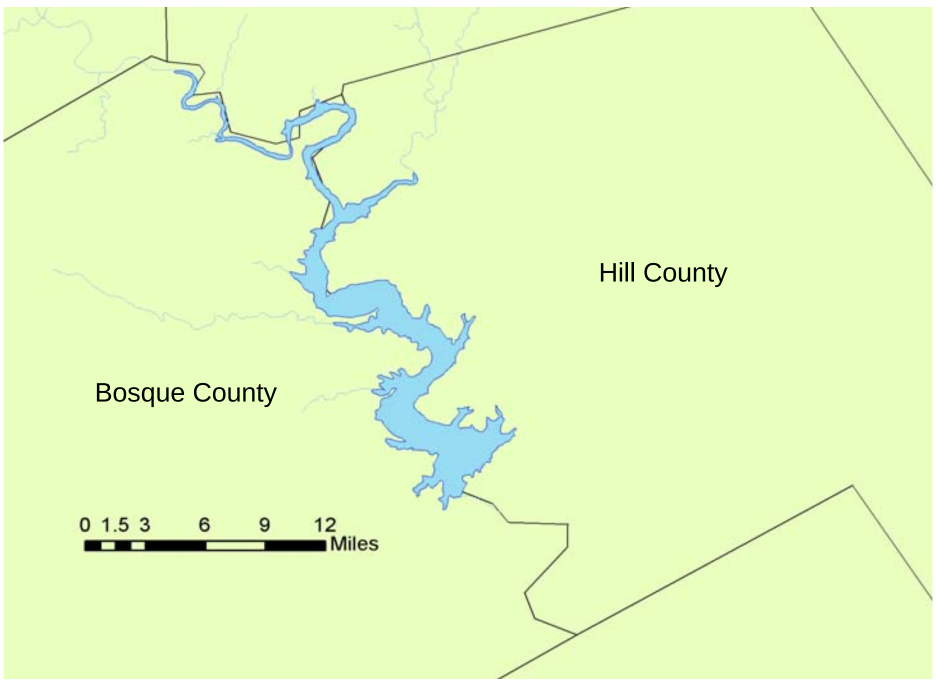

Figure 1 – Lake Whitney, TX is a run-of-the-river reservoir on the Brazos River. It is located between Hill and Bosque Counties, in Central TX.

Given the climatology of central Texas, such a deep reservoir can exhibit a slow response to climatologically factors that induce in-reservoir circulation. Such variables as temperature and temperature induced circulation (“turnovers”) impact water quality including salinity, algal productivity and overall reservoir ecology. One unique physical feature of Lake Whitney is that the linear nature of the reservoir lines up with the dominant wind direction for the region, both in the summer, from the southeast, and in the winter, from the northwest. Thus, wind driven circulation mechanics likely play a significant role in the circulation of the reservoir.

The main issue regarding utilization of Lake Whitney as a water supply resource is its salinity.   Past work by the USGS, Corps of Engineers, and the State of Texas have pointed to the elevated salinity levels in the reservoir. These elevated salinity levels have been traced to specific geologic units within the watershed itself. Specifically, the geology of the Salt Fork is partially made up of high salinity sandstone, which results in increased salinity of return flow into main tributaries. These higher salinity waters eventually find their way into Lake Whitney. Even though the drainage area of the watershed is nearly 25,000 square miles, the proximity of Lake Whitney to the high salinity inflow waters does not allow sufficient stream dilution distance to affect the elevated levels (fig. 2).

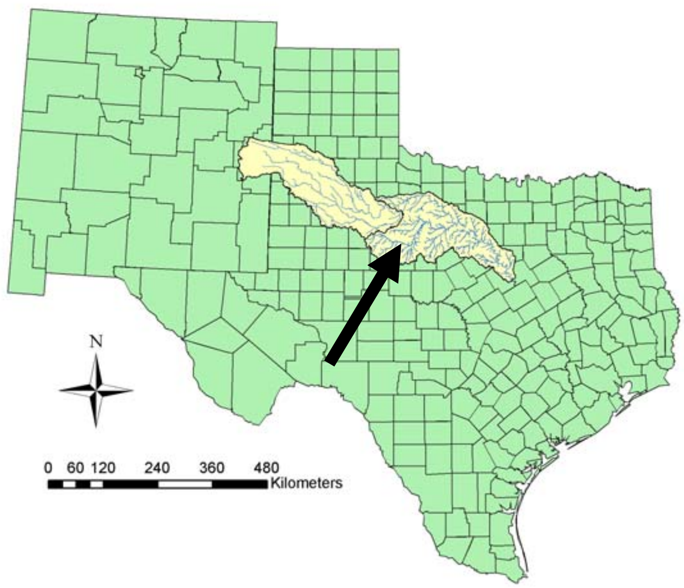

Figure 2 – Spatial extent of the Brazos River watershed that drains into Lake Whitney. The arrow indicates the approximate location of the Salt Fork drainage, which is the primary source of salinity to the river.

Within the reservoir itself, initial data gathered by the Brazos River Authority shows concentrations of salinity during much of the year exceeds the EPA's 300 ppm standard for drinking water by 20-30% (fig. 3). However, inflow data also shows that there are periods when inflow salinity is well below 300 ppm, and therefore potentially available for use with much less expensive technologies (fig. 4). Periods when the water exceeds the drinking water standard by more than 50% are rare. These single point measurements, however, do not give insight into the spatial variability and mixing of high salinity waters with lower salinity waters within the reservoir itself. The existing point data shows that there are periods of time when inflow as well as reservoir salinity values are within the acceptable ranges for public drinking water. However, the spatial extent of salinity as well as the mixing dynamics within the reservoir is unknown.

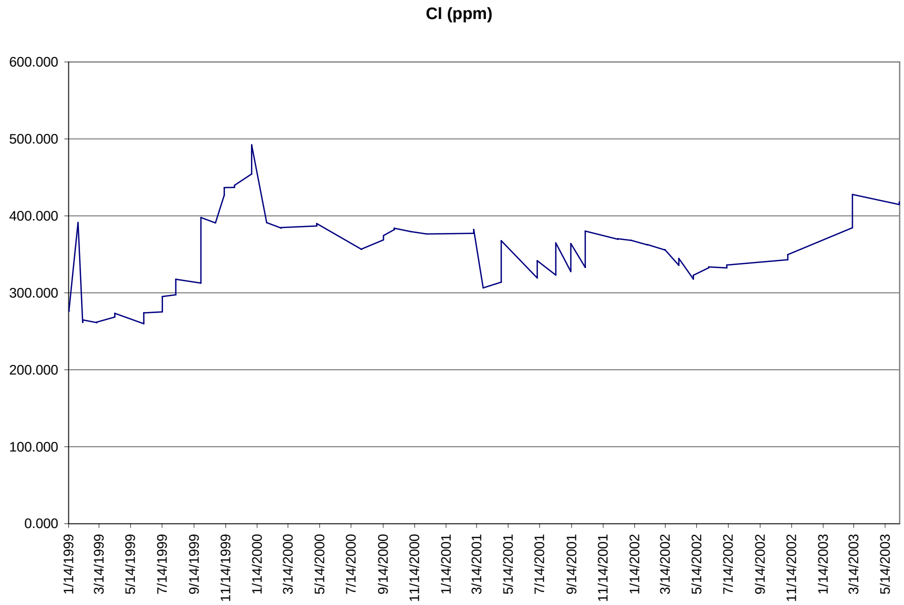

Figure 3 – Graph of salinity values over time for Lake Whitney at the Dam.

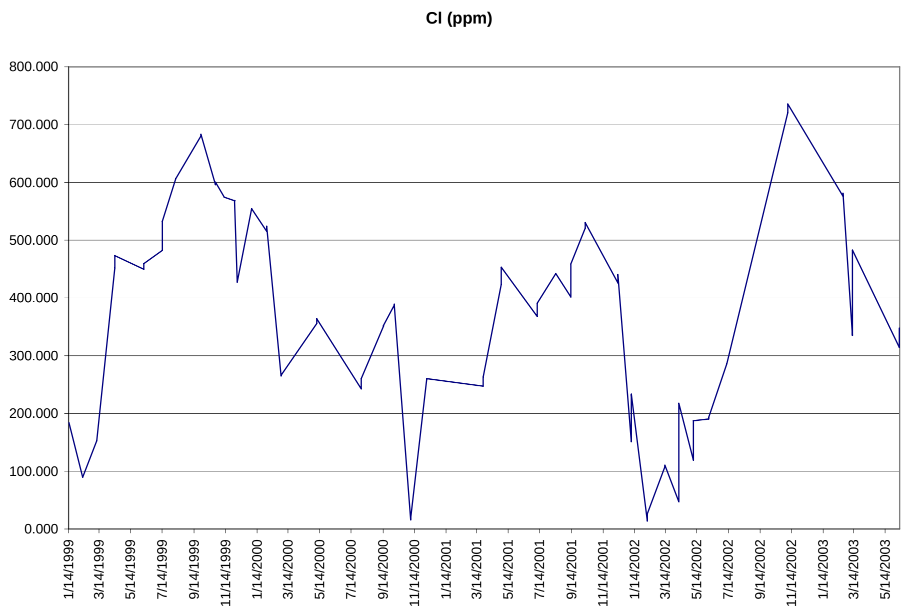

Figure 4 – Inflow salinity into Lake Whitney at the Nolan River confluence.

One additional issue that has been identified as a critical component of water quality in Lake Whitey is the presence of the toxin-producing harmful algae *Prymnesium parvum*, also called golden algae. This species occurs worldwide and is responsible for large fish kills in coastal and inland water environments, especially in those exhibiting elevated salinities. The occurrences of the blooms and resulting fish kills have diminished local community revenues from tourism, fishing, and hatchery production. In 1985, the state of Texas officially confirmed a *P. parvum* bloom along the Pecos River (see Texas Parks and Wildlife, 2003).

PROJECT OBJECTIVES AND METHODS

There are eleven major elements which compose this research of the Lake Whitney reservoir including a comprehensive physical, and baseline chemical and ambient toxicity assessment of the reservoir and its watershed. This assessment followed the general guidelines being developed by the State of Texas for the Source Water Assessment Protection (SWAP) program. Since salinity has been identified as the major issue in utilizing the reservoir for human use, the primary component of the initial research was an assessment of salinity. To this end, we performed field data gathering and spatial modeling to determine the seasonal variability of saline concentrations in the reservoir. The first five elements were detailed and approved by EPA in a QAPP (QTRAK #08-002). Reports on Study Elements 1-5 were submitted to EPA on 6/1/2009 and are available upon request. Study Elements 6-11 were conducted with funding from the US DOE and are the subject of the current report.

Summary of Study Elements, Associated Tasks and Technical Lead

Element/Task No.	Study Element/Task Description	Technical Lead
Phase IA (US EPA)		
No. 1	**Develop Geophysics-Based Bathymetric and Seasonal Salinity Distribution Maps**	Dunbar, Allen
Task 1	Geophysical Bathymetric Mapping	
Task 2	Geophysical Salinity Assessment	
No. 2	**Develop a GIS-Based Watershed and Reservoir Water Quality Model to provide Predictive Capability for Water Quality Changes in Response to Climatological, Land Use Change and Management Methods**	Byars, Prochnow, White
No. 3	**Perform Nutrient Analysis for Lake Whitney**	Doyle
No. 4	**Stakeholder Outreach: Provide Web Access for the Public to Reports, Maps, and Other Educational Displays Arising from this Project**	Doyle, Byars
Phase IC (US EPA)		
No. 5	**Ambient Toxicity Study**	Brooks
Phase 1B (US DOE)		
No. 6	**Salinity Budget for the Brazos River/Reservoir System: PK to Whitney**	Allen (Lee & Wurbs, TAMU)
No. 7	**Bacterial Assessment**	Doyle (Massengale)
No. 8	**Organic Contaminant Analysis**	Belden
No. 9	**Plankton Photosynthesis Assessment**	Doyle
No. 10	**Lake Whitney Outreach and Education**	Doyle (ver Duin & Ruggiere, UNT)
No. 11	**Engineering Scoping Perspective**	Byars (Yu, SMU)

Salinity Budget Study for the Brazos River/Reservoir System From Above Possum Kingdom to below Whitney DRAFT Final Report

Phase IB

Study Element No. 6:

Prepared for:
USDOE

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Zachry Department of Civil Engineering
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*Baylor University Subcontract Agreement

CRASR

Salinity Budget Study for the Brazos River/Reservoir System From Above Lake Possum Kingdom to Below Lake Whitney

Prepared by

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under

Baylor University Subcontract Agreement 032-75BL
with the Texas Engineering Experiment Station

for the

TAMU Lake Whitney Salinity Project Component
of the
Lake Whitney Comprehensive Assessment
Conducted at Baylor University

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Introduction

The Lake Whitney Salinity Project is being conducted at Texas A&M University (TAMU) as a component part of the Lake Whitney Comprehensive Assessment being conducted at Baylor University, sponsored by the U.S. Department of Energy. The TAMU sub-project focuses on improvement and application of salinity simulation features that are being developed for the Water Rights Analysis Package (WRAP) modeling system to incorporate consideration of natural salt pollution in assessments of water supply capabilities. The salinity budget studies described here are part of the work being performed at TAMU.

This report documents the development and analysis of salinity budgets for four sub-reaches of a 244-mile reach of the Brazos River extending from upstream of Possum Kingdom Reservoir to downstream of Whitney Reservoir. Flow and storage volume and total dissolved solids (TDS) load budgets and associated TDS concentrations are developed for a 1964-1986 period-of-analysis and monthly time step, which are adopted based on the availability of salinity data. Stream flow, reservoir storage, and salinity data collected by the USGS along with TCEQ WAM System data are supplemented with additional data synthesized as necessary in this study to develop complete balanced volume and load budgets. The objectives of the salinity budget study are to develop:

- a better understanding of the salinity characteristics of the Brazos river/reservoir system
- a dataset for developing and testing salinity routing methods in the WRAP model
- salinity routing parameters for WRAP for use in water availability and supply reliability assessments for Lake Whitney and the Brazos River Authority reservoir system

TCEQ WAM System Dataset

The Texas Commission on Environmental Quality (TCEQ) Water Availability Modeling (WAM) System (http://www.tceq.state.tx.us/permitting/water_supply/water_rights/wam.html) consists of the generalized WRAP river/reservoir system simulation model (Wurbs 2006 and 2007, http://ceprofs.civil.tamu.edu/rwurbs/wrap.htm) and input datasets for the 23 river basins of Texas. The WAM System is routinely applied in regional and statewide planning studies and administration of the water rights permit system, but without consideration of salinity. A major objective of the research being performed at TAMU is to improve capabilities for incorporating salinity and measures for dealing with salinity in assessments of water availability for municipal, industrial, agricultural, and other water uses.

WRAP input datasets for the Brazos River Basin for alternative water management/use scenarios are available from the TCEQ WAM System. Consulting firms developed the original Brazos WAM System dataset under contract with the TCEQ. The Brazos River Basin WAM dataset was developed and documented in two phases. The first phase focused on converting observed stream flows to 1940-1997 sequences of monthly naturalized stream flows representing natural hydrology without human water resources development and use (Freese and Nichols, Inc. 2001). The second phase consisted of developing a complete WRAP input dataset for the river basin and simulating specified water management scenarios (HDR, Inc. 2001). The Brazos River Basin WAM dataset is being used in the WRAP water supply reliability studies being performed for the current research project. Water quantities from the TCEQ WAM System WRAP input dataset and backup files were also used in the water and salinity balance studies presented here.

Dataset from USACE/USGS Natural Salt Pollution Studies

Natural salt pollution severely constrains the water supply capabilities of the Brazos River and other neighboring rivers shown in Figure 1 (Wurbs 2002). Geologic formations in the Permian Basin geologic region are the primary source of the salinity. Salt springs and seeps and salt flats in the upper watersheds of the Brazos, Colorado, Pecos, Red, Canadian, and Arkansas Rivers contribute large salt loads to these rivers. The salinity drastically limits the municipal, industrial, and agricultural use of water that could otherwise be supplied by a number of existing large reservoirs located on these rivers.

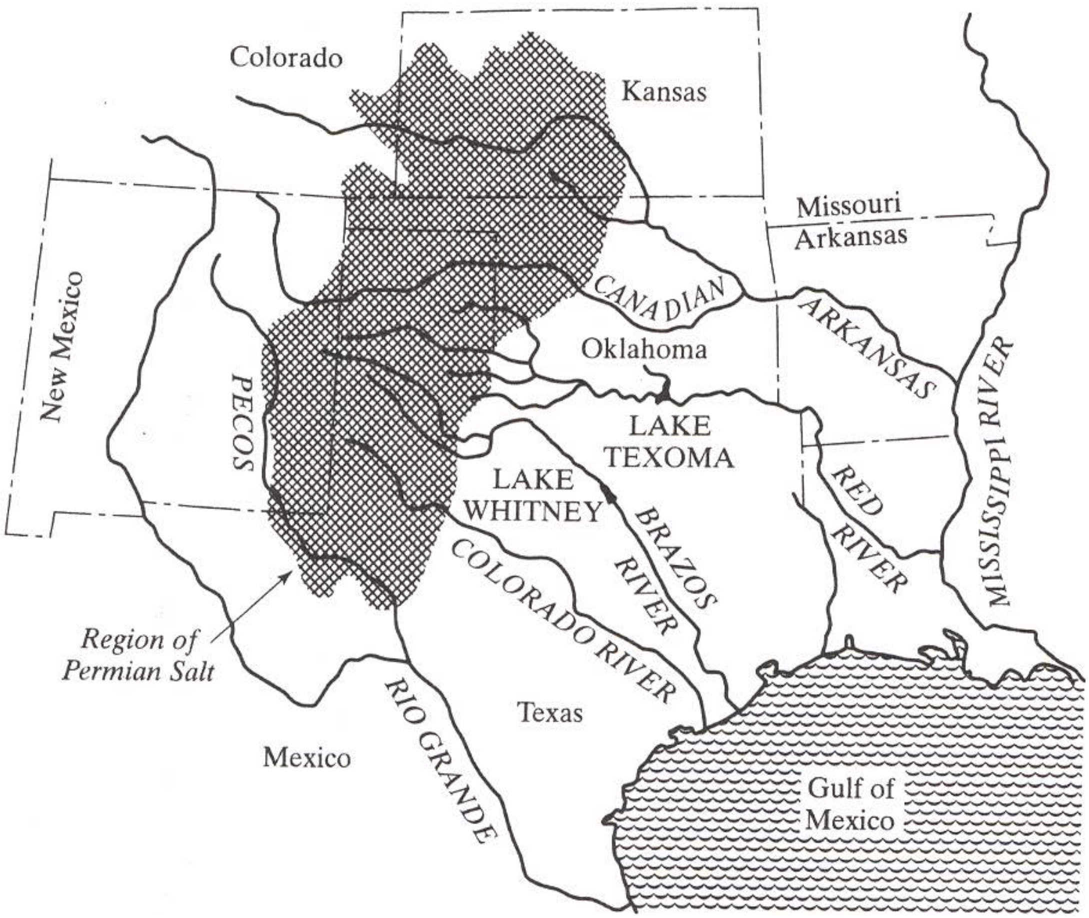

Figure 1. Major Rivers Affected by Permian Basin Salt

Water quality in Possum Kingdom, Granbury, and Whitney Reservoirs on the Brazos River is seriously degraded by natural contamination by salts consisting largely of sodium chloride with moderate amounts of calcium sulfate and other dissolved solids. The primary source of the salinity is groundwater emissions in an area of about 1,500 square miles in the upper basin consisting of the Salt Fork Brazos River watershed and portions of the adjacent Double Mountain Fork Brazos River and North Croton Creek watersheds. The salinity concentrations in the Brazos River decrease significantly in the lower basin with dilution from low-salinity tributaries (Wurbs et al. 1993).

The Fort Worth District (FWD) of the U.S. Army Corps of Engineers (USACE) in collaboration with the U.S. Geological Survey (USGS), U.S. Environmental Protection Agency (USEPA), and other agencies conducted extensive Brazos River Basin natural salt pollution studies during the 1970's-1980's (Wurbs 2002). The USGS conducted an extensive water quality data collection program during October 1963 – September 1986 in support of the USACE salt pollution control studies. The USACE-sponsored USGS salinity measurement program was discontinued in 1986. The USACE later contracted with Texas A&M University to compile the USGS salinity data into a more conveniently usable format and to perform various analyses (Wurbs et al. 1993).

The water (Oct-Sep) years 1964-1986 USGS/USACE observed data described by Wurbs et al. (1993) being used to develop the basin-wide salinity input required for the WRAP modeling studies. The salinity component of WRAP requires specification of time sequences of monthly loads entering the river system covering the 1940-1997 WAM simulation period throughout the river basin, which are developed based on the 1964-1986 USGS data. The 1964-1986 USGS data are also used to develop the volume and load budgets presented here in this report. Analyses of the volume and load budgets also contribute to development of WRAP salinity input data.

USGS water quality sampling activities in the Brazos River Basin date back to 1906 and continue through the present. However, the salinity data collection program during October 1963 through September 1986 was much more extensive than salinity measurement activities before or since. A total of 39 stations in the basin have monthly salinity data for at least three years during 1964-1986. The 26 stations listed in Tables 1 and 2 with locations shown in Figure 2 were selected for the compilation and analyses of Wurbs et al. (1993) because of their record length and pertinent locations. The water quality measurements occurred at or near stream flow gaging stations included in the regular USGS stream flow data collection program. The USGS continues to measure flow rates at most of the gaging stations even though the water quality measurements ended in 1986.

The USGS aggregated daily flow and concentration observations into mean monthly flows and monthly concentrations and loads of total dissolved solids (TDS), chloride, and sulfate. Chloride and sulfate are major constituents of total dissolved solids (salinity) in the Brazos River. Discharges and salt loads are cited by the USGS in units of cubic feet per second (cfs) and tons/day, respectively. Salt concentrations are cited in units of milligrams of salt solute per liter of water (mg/l). Assuming a liter of water has a mass of one kilogram, the units mg/l and parts of salt solute per million parts of water (ppm) are equivalent.

The main stream of the Brazos River begins at the confluence of the Salt Fork and Double Mountain Fork, which is 923 river miles above the Brazos River mouth at the Gulf of Mexico. The Aspermont and Peacock gages (Figure 2 map numbers 1 and 2) are located on the Salt Fork and Double Mountain Fork of the Brazos River, respectively, 35 and 54 river miles above their confluence. The Seymour, Possum Kingdom, Whitney, College Station, and Richmond gages (map numbers 7, 13, 15, 21, and 15) are located at river miles 847, 687, 442, 281, and 92, respectively, above the Gulf of Mexico. The Seymour gage is downstream of the primary salt source areas and upstream of Possum Kingdom, Granbury, and Whitney Reservoirs, which are the only reservoirs on the main-stem of the Brazos River. The Graford gage is just downstream of Morris Sheppard Dam and Possum Kingdom Reservoir. The gaging station near the town of Whitney is just below Whitney Dam and Reservoir.

The period-of-record for the monthly data is listed in Table 1. Since the period-of-record varies between stations, the mean flows, loads, and concentrations in Table 2 are not strictly comparable but still provide a good representation of the great spatial variability of salinity in the Brazos River Basin. Salinity levels at stations 2, 3, 4, 5, and 6 are very high, representing runoff from the primary salt source areas. Tributaries entering the Brazos River downstream of Possum Kingdom Reservoir have relatively low salinity concentrations. Salt concentrations in the Brazos River decrease in a downstream direction with tributary inflows. The 1964-1986 mean TDS concentrations shown in Table 2 at the Seymour, Graford, Whitney, and Richmond gages (Figure 2 map numbers 7, 13, 15, and 25) are 3,590 mg/l, 1,510 mg/l, 928 mg/l, and 339 mg/l, respectively. The 1964-1986 mean salinity (TDS) concentration of 263 mg/l at the Cameron gage (20) on the Little River is representative of the water quality of tributaries entering the Brazos River below Possum Kingdom Reservoir.

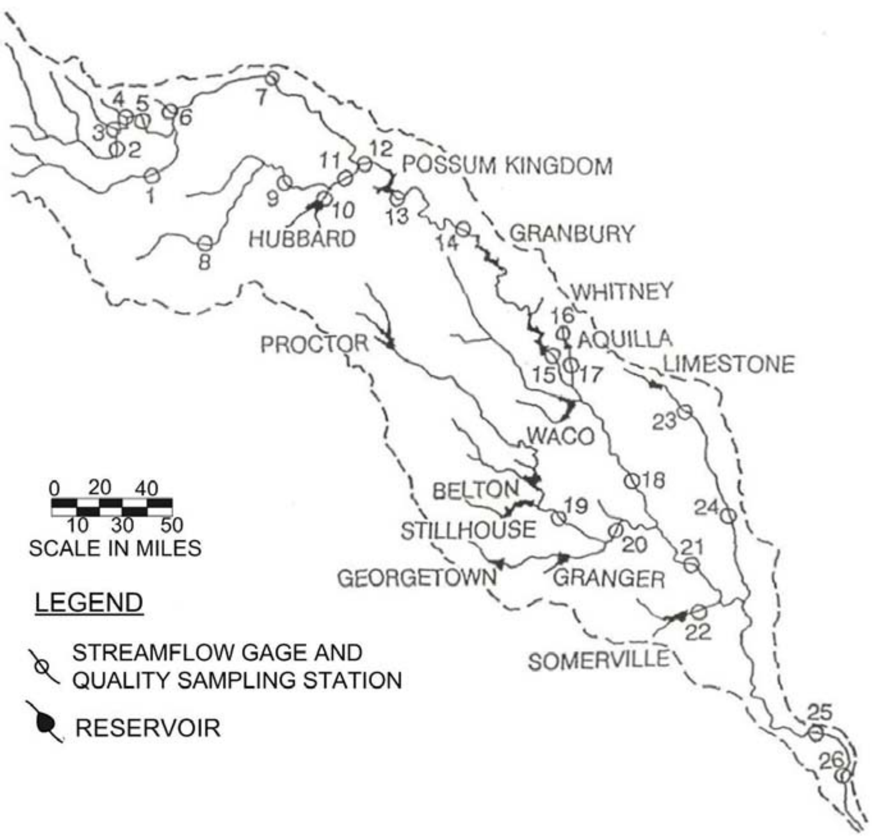

Figure 2. USGS Stream Flow and Water Quality Stations (Wurbs et al. 1993)

Wurbs et al. (1993) document various analyses of spatial and temporal distributions of flows and salt loads and concentrations. Characteristics of variability are also displayed by the presentation of the volume and load budgets and associated concentrations in the following sections of this report. The 1964-1986 USGS data are characterized by tremendous apparently random variations over time. Reservoirs have the effect of smoothing out the variations in concentrations somewhat. A seasonal pattern of concentration variations is more pronounced for the Seymour gage and other upper basin gages than for the gages located downstream of reservoirs which exhibit essentially no seasonal patterns. Trends or long-term changes in salt loads and concentrations that may have occurred during 1964-1986 are very small relative to the tremendous random variability. No clearly defined trends were detected by various trend analyses (Wurbs et al. 1993).

Table 1. USGS Stream Flow Gaging and Water Quality Sampling Stations (Wurbs et al. 1993)

Map No.	Station Number	Station Name (nearest town)	Stream	Drainage Area (sq miles)	Period-of Record
1	08080500	Aspermont	Double Mountain Fork	8,796	1964-86
2	08081000	Peacock	Salt Fork of Brazos	4,619	1965-86
3	08081200	Jayton	Croton Creek	290	1966-86
4	08081500	Aspermont	Salt Croton Creek	64	1969-77
5	08082000	Aspermont	Salt Fork of Brazos	5,130	1964-82
6	08082180	Knox City	North Croton Creek	251	1966-86
7	08082500	Seymour	Brazos River	15,538	1964-86
8	08083240	Hawley	Clear Fork of Brazos	1,416	1968-79,82-84
9	08085500	Fort Griffin	Clear Fork of Brazos	3,988	1968-76,79,82-84
10	08086500	Breckenridge	Hubbard Creek	1,089	1968-75
11	08087300	Eliasville	Clear Fork of Brazos	5,697	1964-82
12	08088000	South Bend	Brazos River	22,673	1978-81
13	08088600	Graford	Brazos River	23,596	1964-86
14	08090800	Dennis	Brazos River	25,237	1971-86
15	08092600	Whitney	Brazos River	27,189	1964-86
16	08093360	Aquilla	Aquilla Creek	255	1980-82
17	08093500	Aquilla	Aquilla Creek	308	1968-81
18	08098290	Highbank	Brazos River	30,436	1968-79,81-86
19	08104500	Little River	Little River	5,228	1965-73,80-86
20	08106500	Cameron	Little River	7,065	1964-86
21	08109500	College Station	Brazos River	39,599	1967-83
22	08110000	Somerville	Yegua Creek	1,009	1964-66
23	08110325	Groesbeck	Navasota River	239	1968-86
24	08111000	Bryan	Navasota River	1,454	1964-81
25	08114000	Richmond	Brazos River	45,007	1964-86
26	08116650	Rosharon	Brazos River	45,339	1969-80

Table 2. Period-of-Record Mean Discharge and Salt Loads and Concentrations

	USGS Gauging Station (nearest town, stream)	Flow (cfs)	Load (tons/day) TDS	Load (tons/day) Chloride	Load (tons/day) Sulfate	Concentration (mg/l) TDS	Concentration (mg/l) Chloride	Concentration (mg/l) Sulfate
1	Aspermont, Double Mountain	126	580	153	209	1,540	416	548
2	Peacock, Salt Fork Brazos	40	684	339	81	5,782	2,830	698
3	Jayton, Croton Creek	13	225	93	53	6,391	2,541	1,591
4	Aspermont, Salt Croton Cr	4	676	425	33	56,923	32,856	2,273
5	Aspermont, Salt Fork	60	1,660	1,094	219	12,407	6,066	1,235
6	Knox City, North Croton Cr	17	211	80	58	4,723	1,786	1,323
7	Seymour, Brazos River	269	2,601	1,074	504	3,591	1,482	696
8	Hawley, Clear Fork Brazos	46	235	51	94	1,893	411	759
9	Fort Griffin, Clear Fork	151	391	105	116	961	258	286
10	Breckenridge, Hubbard Cr	93	73	25	4	268	91	20
11	Eliasville, Clear Fork	319	614	201	148	715	234	172
12	South Bend, Brazos River	760	2,601	996	561	1,261	486	274
13	Graford, Brazos River	712	2,947	1,127	571	1,534	601	309
14	Dennis, Brazos River	892	3,103	1,205	622	1,291	501	259
15	Whitney, Brazos River	1,230	3,075	1,134	591	928	342	30
16	Aquilla, Aquilla Creek	55	35	2	10	236	14	69
17	Aquilla, Aquilla Creek	147	102	6	29	257	14	73
18	Highbank, Brazos River	2,530	4,154	1,287	772	609	189	113
19	Little River, Little River	912	768	79	61	313	32	25
20	Cameron, Little River	1,544	1,094	129	126	263	31	30
21	College Station, Brazos	4,529	5,348	1,368	938	438	112	77
22	Somerville, Yequa Creek	252	114	20	33	167	30	48
23	Groesbeck, Navasota River	161	56	9	6	131	22	13
24	Bryan, Brazos River	600	232	61	38	144	38	23
25	Richmond, Brazos River	6,868	6,267	1,466	1,030	339	79	56
26	Rosharon, Brazos River	7,305	6,462	1,491	1,004	328	76	51

River/Reservoir System Reaches for the Salinity Budget Study

The reach of the Brazos River containing Lakes Whitney, Granbury, and Possum Kingdom is divided into four sub-reaches for purposes of the water and salinity budget study. The four river reaches are defined by the USGS stream flow gaging and/or water quality stations listed in Table 3 with locations shown in Figure 3.

The five USGS gaging stations defining the four volume and load balance reaches are listed in Table 3. The USGS salinity dataset includes monthly flows as well as monthly loads and concentrations. The monthly flows from the salinity dataset are used in the analyses. Although the salinity data collection program was terminated in 1986, stream flow data continues to be collected at four of the gages. The flow gaging stations near the towns of South Bend, Graford, and Dennis also served as water quality stations during the USACE-sponsored USGS salinity data collection program. The flow gage near Glen Rose was not included in the salinity data collection program. Although another stream flow gage is located nearby, gage 08092600 near the City of Whitney below Whitney Dam was used to collect flow and salinity data during the 1964-1986 salinity program but was not continued as a regular flow gage. The Whitney and Graford gages have complete flow and salinity data covering the entire 1964-1986 period. The Glen Rose gage has complete flow data but no salinity data. The South Bend gage has complete flow data and salinity data for 1978-1981. The Dennis gage has flows for 1968-1986 and salinity data for 1970-1986.

Table 3. Gaging Stations Defining Volume and Load Balance Reaches

Station	Fig. 2 Num	USGS Number	WAM CP ID	Flow-Only Gage Record	Salinity and Flow	River Mile	Drainage Area (mile^2) Total	Contrib	Increm
South Bend	12	08088000	BRSB23	1938-present	1978-81	686.5	22,673	13,107	13,107
Graford at PK	13	08088600	SHGR26	1976-present	1964-86	614.2	23,596	14,030	923
Dennis	14	08090800	BRDE29	1968-present	1971-86	571.0	25,237	15,671	1,641
Glen Rose	−	08091000	BRGR30	1923-present	none	523.6	25,818	16,252	581
Whitney	15	08092600	−	−	1964-86	442.4	27,189	17,623	1,371

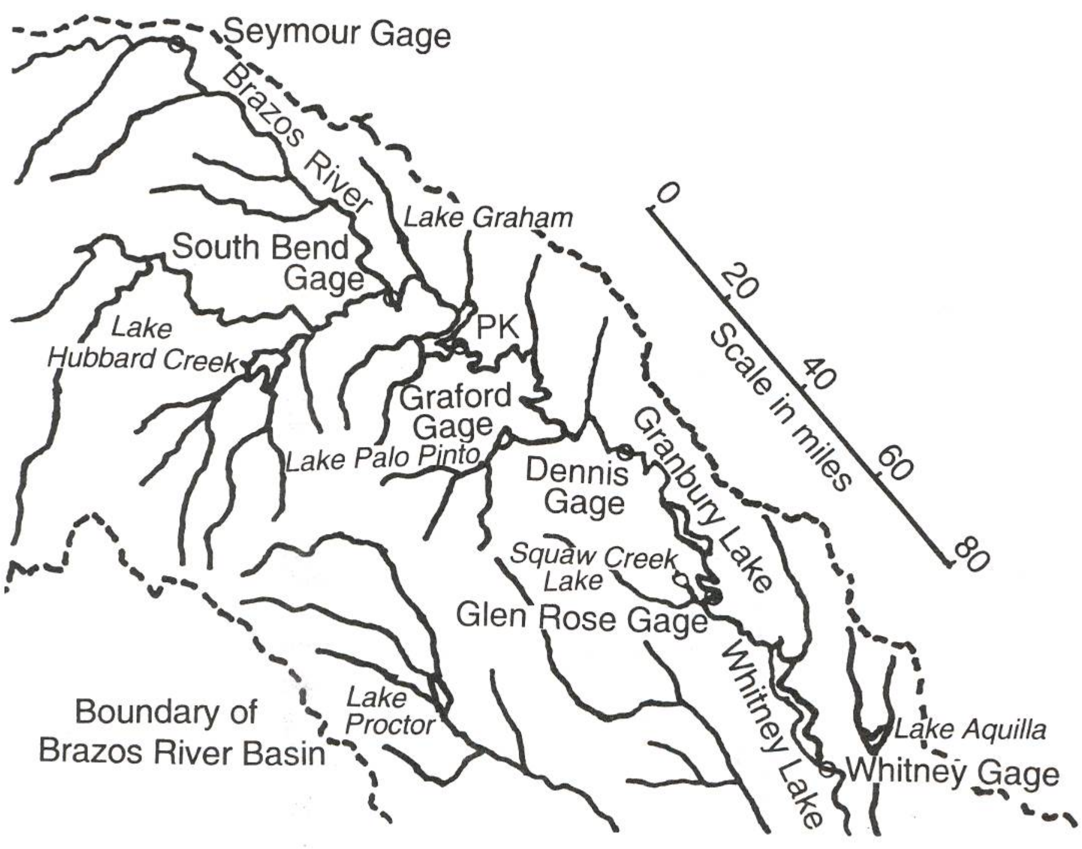

Figure 3. Map of Study Reach and Vicinity

The river miles in Table 3 are measured from the confluence of the Brazos River at the Gulf of Mexico. The river miles of the Whitney and Graford gages are from USGS studies. The river miles for the other three gages were estimated in the present study from GIS maps available from the WAM System dataset. The drainage areas are from published USGS data. A 9,566 square mile flat arid portion of the Brazos River Basin in and near New Mexico is considered by the USGS to not contribute to flows in the Brazos River.

The portion of the Brazos River Basin shown in Figure 3 includes the reach of the Brazos River extending from the Seymour gage at river mile 847 downstream to the Whitney gage at river mile 442. The Seymour gage is about 76 miles below the origin of the main-stem Brazos River at the confluence of the Salt Fork and Double Mountain Fork.

Lakes Possum Kingdom, Granbury, and Whitney

Texas has 196 major reservoirs with storage capacities of at least 5,000 acre-feet and about 3,500 other smaller reservoirs with storage capacities ranging between 200 and 5,000 acre-feet. The Brazos River Basin has 43 major reservoirs with storage capacities of at least 5,000 acre-feet and several hundred other smaller reservoirs with storage capacities ranging between 200 and 5,000 acre-feet. Possum Kingdom Lake has the largest conservation storage capacity in the Brazos River Basin, and Lake Whitney has the second largest conservation storage capacity. Considering the combined total of both flood control and conservation storage capacity, Lake Whitney is the largest reservoir in the Brazos River Basin and the seventh largest reservoir in Texas. Lakes Whitney, Granbury, and Possum Kingdom are the only major reservoirs on the main stream of the Brazos River. The 40 other major reservoirs in the Brazos River Basin are on tributaries.

The Fort Worth District (FWD) of the U.S. Army Corps of Engineers (USACE) operates a system of nine reservoirs in the Brazos River Basin that contain about half of the conservation storage capacity and all of the flood control storage capacity in the basin. The locations of the nine USACE reservoirs are shown in Figure 2. They include Whitney, Aquilla, Waco, Proctor, Belton, Stillhouse Hollow, Georgetown, Granger, and Somerville Reservoirs. The USACE FWD constructed, owns, and operates the federal multiple-purpose reservoirs. The USACE FWD is responsible for operating the nine-reservoir system for flood control. The Brazos River Authority (BRA) has contracted for most of the conservation storage capacity in the nine federal reservoirs, and owns four other non-federal reservoir projects: Lakes Possum Kingdom, Granbury, Limestone, and Allan Henry. The conservation storage in Lakes Waco, Proctor, and Allan Henry are dedicated to meeting local water supply needs in the vicinity of each individual reservoir. The BRA operates the ten other reservoirs as a system to meet water supply needs in the lower Brazos River Basin and adjoining coastal basins as well as in the vicinity of the reservoirs. Hydroelectric power is also generated at Whitney and Possum Kingdom Reservoirs. All of the reservoirs are also used for recreation.

Thus, the multiple-purpose Whitney Reservoir is a component of a federal nine-reservoir system operated by the USACE FWD for flood control. Whitney Reservoir is also a component of a multiple-reservoir system operated by the BRA for water supply that includes the nine USACE reservoirs and four other non-federal reservoirs. Possum Kingdom and Granbury Reservoirs are non-federal conservation storage projects owned and operated by the BRA.

Pertinent data for Lakes Possum Kingdom (PK), Granbury, and Whitney are tabulated in Tables 4, 5, and 6 and their locations are shown on the Figures 2 and 3 maps. The BRA holds water right permits to store and divert the amounts of water noted in Table 4 for municipal, industrial, and agricultural uses. The BRA water right permits provide flexibility for multiple-reservoir and multiple-purpose reservoir/river system operations. The majority of the water released from these three reservoirs for water supply purposes is diverted from the lower reaches of the Brazos River many miles below Whitney Dam for use in the lower Brazos Basin and adjoining San Jacinto-Brazos Coastal Basin. Actual water use is typically significantly less than permitted diversion amounts. The last column of Table 4 shows the diversion amounts associated with the water rights attached to each reservoir included in the TCEQ WAM System current use scenario dataset, which reflects the maximum actual use in any year during the ten-year period 1988-1997.

Table 4. Possum Kingdom, Granbury, and Whitney Reservoirs on Brazos River

Name of Reservoir	Name of Dam	Initial Impoundment Date	Permitted Storage (acre-feet)	Permitted Diversions (ac-ft/yr)	WAM 1988-1997 Diversions (acre-feet/year)
Possum Kingdom	Morris Sheppard	March 1941	724,739	230,750	57,483
Granbury	De Cordova Bend	September 1970	155,000	64,712	36,025
Whitney	Whitney	December 1951	50,000	18,336	18,336

Table 5. Reservoir Storage Capacity

Reservoir	Initial Storage Date	Sediment Survey Update	Inactive Pool (acre-feet)	Top of Conservation Pool			Flood Control (acre-feet)
				Original (acre-feet)	Surveyed (acre-feet)	WAM 2000 (acre-feet)	
PK	1941	1974	221,000	724,740	570,240	552,010	−0−
Granbury	1970	−	52,500	153,490	−	132,820	−0−
Whitney	1951	1959	379,100	642,180	627,100	549,790	1,372,400

Table 6. Additional Information for Lakes Possum Kingdom, Granbury, and Whitney

Name of Reservoir	Name of Dam	Drainage Area ($mile^2$)	Mean Lake Precipitation (inches/year)	Mean Lake Evaporation (inches/year)	WAM Net E-P (inches/year)
Possum Kingdom	Morris Sheppard	14,030	31	70	33.5
Granbury	De Cordova Bend	16,110	33	69	26.0
Whitney	Whitney	17,620	34	66	24.6

Hydroelectric power is generated at Whitney and Possum Kingdom Reservoirs. The Southwest Power Administration is responsible for marketing hydroelectric power generated at Lake Whitney, which it sells to the Brazos Electric Power Cooperative. The BRA sells the power generated at Possum Kingdom also to the Brazos Electric Power Cooperative. No water rights exist specifically for hydropower at the two Brazos River reservoir/hydropower projects. Hydropower is generated by excess flows (spills) and releases for downstream water supply diversions.

In addition to releases for water supply diversions from the lower Brazos River, Possum Kingdom and Granbury Reservoirs supply water as needed to maintain constant operating levels in Lakes Squaw Creek, Tradinghouse Creek and Lake Creek which are owned and operated by utility companies for steam-electric power plant cooling. The BRA operates a desalting water treatment plant that allows use of water from Lake Granbury to supplement the water supply for the City of Granbury. The BRA hold a water right permit to impound 50,000 acre-feet of storage in Lake Whitney between elevations 520 feet (387,024 acre-feet) and 533 feet (642,179 acre-feet) to supply a diversion of 18,336 acre-feet/year for municipal use. The BRA has a water supply contract with the USACE for the 50,000 acre-feet of storage capacity in Lake Whitney.

The Corps of Engineers operates the 1,372,400 acre-feet flood control pool of Lake Whitney as a component of the system of nine federal flood control reservoirs to reduce downstream flooding. The flood control pool is emptied as quickly as feasible after flood events while not contributing to flows exceeding specified non-damaging levels at downstream gaging stations. The bottom of the flood control pool is the top of the conservation pool. Flood control operations are in effect whenever the lake water surface rises above the top of conservation pool elevation.

Storage capacity data for Lakes Possum Kingdom, Granbury, and Whitney are shown in Table 5. Inactive pools at Lakes Whitney and Possum Kingdom provide dead storage for hydropower. The inactive pool at Lake Granbury is set to accommodate lakeside withdrawals of cooling water for a steam-electric power plant.

Reservoir storage capacity is lost over time due to sedimentation. The total storage capacity below the top of conservation pool elevation at the completion of construction (date of initial impoundment) is shown in the fifth column of Table 5. Sediment surveys of Lakes Possum Kingdom and Whitney in 1974 and 1959 resulted in the revised storage capacity estimates in the sixth column. The TCEQ WAM System current use dataset includes approximate estimates of storage capacities of all major reservoirs as of the year 2000. These estimates for the Brazos River reservoirs are also included in Table 5.

The 1971-2000 mean annual precipitation falling on the reservoir water surface and 1950-1979 mean annual reservoir surface evaporation rates in Table 6 are estimated from information provided by the Texas Water Development Board (2007). The 1940-1997 annual net evaporation less precipitation rates tabulated as the last column of Table 6 were obtained from monthly data in the TCEQ WAM System dataset. Texas Water Development Board (2007) data indicate that average annual stream flow runoff for the incremental watershed above Whitney Dam but below the dam at Possum Kingdom Lake is about 2.0 inches/year or a little more. The mean annual runoff for the watershed above Possum Kingdom Lake ranges from zero to 2 inches with most of the watershed contributing less than 1.0 inch of annual runoff.

Pertinent data for five other major reservoirs located upstream of Lakes Possum Kingdom, Granbury, and Whitney on tributaries are provided in Table 7. The five tributary lakes affect flows into Lakes Possum Kingdom, Granbury, and Whitney.

Table 7. Major Reservoirs on Tributaries

Name of Reservoir	Name of Dam	Stream	Drainage Area (mile^2)	Initial Impoundment Date	Storage Capacity (acre-feet)
Hubbard Creek	Hubbard Creek	Hubbard Creek	1,085	Dec 1962	314,280
Graham	Eddleman & Graham	Salt Creek	221	1929/1958	53,680
Palo Pinto	Palo Pinto	Palo Pinto	471	Apr 1964	44,100
Squaw Creek	Squaw Creek	Squaw Creek	64	1977	151,500
Pat Cleburne	Pat Cleburne	Nolan River	100	Aug 1964	25,560

Volume and Load Budget Procedures

The objectives for developing and analyzing flow and storage volume budgets, TDS load budgets, and associated TDS concentrations are to:

1. Develop an understanding of the magnitude, timing, variability, and other characteristics of salinity moving through the river/reservoir system.
2. Develop and test salinity routing methods for use in the WRAP modeling system.
3. Develop values for reservoir salinity routing parameters for use in applying WRAP in assessing water supply capabilities for Lake Whitney and the BRA reservoir system.

The studies support improvement and application of the WRAP modeling system. The volume and load balance analyses also directly provide insight regarding the physical processes of salinity being transported through the river/reservoir system.

For each of the four river reaches, the volume and TDS load budgets consist of Microsoft Excel spreadsheet tabulations for each month of the 1964-1986 period-of-analysis of:

- volumes and loads entering the reach during the month
- volumes and loads leaving the reach during the month
- volume and load in storage at the end of each month

Concentrations are computed given loads and volumes. Some components of the volume and load budget inflows and outflows consist of observed data. Estimates for other components are computed from available data based on formulating reasonable assumptions and premises.

A flow and storage volume budget and total dissolved solids (TDS) load budget are developed for each of the four river reaches defined by the USGS stream flow gaging and/or water quality stations shown in Figures 3 and 4 and Table 3. The budgets cover the period from

September 1963 through October 1986 using a time step of one month. The water year 1964-1986 period-of-analysis and monthly time step were adopted based on availability of data. This 23 year (276 month) period covers a wide range of variability in flows and salinity concentrations.

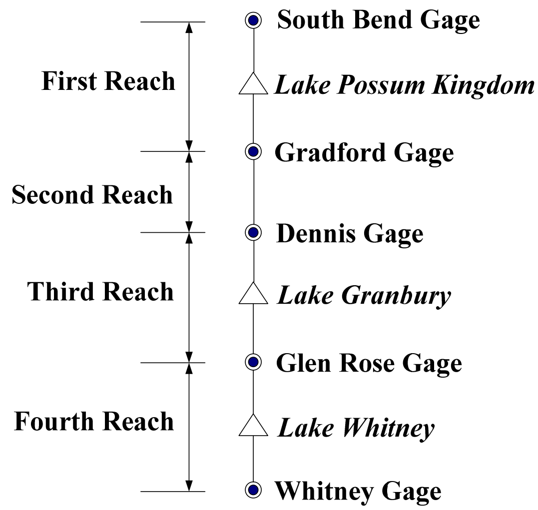

Figure 4. Volume and Load Balance Reaches

Table 8. Availability of Observed Monthly Stream Flow, Storage, and Salinity Data

Gage or Lake	Volume Observations	Salinity Observations
South Bend Gage above Lake Possum Kingdom	Oct 1963 − Sep 1986	Nov 1977 − Sep 1981
Graford Gage below Lake Possum Kingdom	Oct 1963 − Sep 1986	Oct 1963 − Sep 1986
Dennis Gage above Lake Granbury	Jun 1968 − Sep 1986	Oct 1970 − Sep 1986
Glen Rose Gage between Granbury & Whitney	Oct 1963 − Sep 1986	−
Whitney Gage below Lake Whitney	Oct 1963 − Sep 1986	Oct 1963 − Sep 1986
Lake Possum Kingdom	Oct 1963 − Sep 1986	−
Lake Granbury	Oct 1963 − Sep 1986	−
Lake Whitney	Oct 1963 − Sep 1986	−

The portions of the October 1963 through September 1986 period-of-analysis for which observed data have been published by the USGS are listed above in Table 8. Mean monthly flows are available for most of this period at the Dennis gage and for the complete period at the four other gages. End-of-month storage volumes are available for the complete period-of-analysis for the three reservoirs. The salinity observations cover the complete period-of-analysis at the Graford and Whitney gages and portions of the period-of-analysis at the South Bend gage. Observed data were used where available. Additional data were synthesized as required to develop complete sequences of flows and loads at all of the gages and end-of-month storage loads for the three reservoirs.

Water and Salinity Balance Relationships

The water and salt budgets are based on the following relationships which are valid for each of the 276 individual months or the overall 23 year period-of-analysis.

$$\sum \text{components of inflow volume} - \sum \text{components of outflow volume} = \Delta \text{ volume in storage}$$

$$\sum \text{components of inflow load} - \sum \text{components of outflow load} = \Delta \text{ load in storage}$$

$$\Delta \text{ volume in storage} = \text{end-of-period storage volume} - \text{beginning-of-period storage volume}$$

$$\Delta \text{ load in storage} = \text{end-of-period storage load} - \text{beginning-of-period storage load}$$

$$\text{concentration} = \frac{\text{load}}{\text{volume}} (\text{conversion factor})$$

With concentration in milligrams per liter (mg/l), load in tons, and volume in acre-feet, the conversion factor is 735.48 in the equation above. With concentration in mg/l, load in tons/day, and volumetric flow rate in ft^3/s, the conversion factor is 370.81.

The following notation is used to define the components of the volume and load budgets.

F − flow volume in acre-feet/month
L − TDS load in tons/month
C − TDS concentration in milligrams/liter (mg/l)

$$C = \frac{L}{V} (\text{conversion factor})$$

Subscripts:
- US − upstream gage representing river inflow to reach
- DS − downstream gage representing river outflow from reach
- WS − water supply diversions
- OI − other inflow volume and associated load entering reach
- OO − other outflow volume and associated load leaving reach
- X − other load required to balance load budget

EP − net evaporation less precipitation volume in acre-feet/month

S − storage volume in acre-feet
SL − TDS load in storage in tons
C − TDS concentration in milligrams/liter (mg/l)

$$C = \frac{SL}{S} (\text{conversion factor})$$

Subscripts B and E for storage at beginning and end of month or period-of-analysis

ΔS − change in storage volume during the month in acre-feet
ΔSL − change in TDS load in storage during the month in tons

Reach Inflows and Outflows

The following inflow and outflow components are included in the volume budgets for each of the 276 months of the water year 1964-1986 period-of-analysis.

F_{US} – Observed or synthesized flows at the upstream gage are the river flows into the reach.

F_{DS} – Observed or synthesized flows at the downstream gage are the river flows leaving the reach.

EP – Net evaporation from the water surface less precipitation falling on the water surface at Lakes Possum Kingdom, Granbury, and Whitney are taken from TCEQ WAM data.

F_{WS} – Water supply diversions at Lake Granbury are the only recorded data adopted for lakeside withdrawals of water.

F_{OI} – Other inflows represent rainfall runoff from the local incremental watershed entering the reach between the upstream and downstream gages. These inflows are estimated as the positive values computed from a volume balance. Both F_{OO} and F_{OI} are computed together as the amounts required to balance volumes each month, with positive results in a particular month being adopted as F_{OI} and negative results as F_{OO}.

F_{OO} – Other outflows are the negative values from a volume balance. These outflows represent water supply diversions, seepage, and other losses. As noted above, a volume difference is computed by summing all other components of the volume budget each month, with a positive difference in a particular month being adopted as F_{OI} and negative results as F_{OO}.

The following inflow and outflow components are included in the TDS load budgets for each of the 276 months of the water year 1964-1986 period-of-analysis.

L_{US} – Observed or synthesized loads at the upstream gage are the river flows into the reach.

L_{DS} – Observed or synthesized flows at the downstream gage are the river flows leaving the reach.

L_{WS} – Loads of water supply diversions at Lake Granbury. The Lake Granbury diversion loads are estimated based on estimated storage concentrations.

L_{OI} – Loads associated with other inflow volumes F_{OI} represent rainfall runoff loads from the local incremental watershed entering the reach between the upstream and downstream gages. These inflows are estimated based on the assumption that incremental flows F_{OI} have a concentration of 270 mg/l which is representative of observed concentrations for other watersheds in the vicinity.

L_{OO} – Loads associated with other outflow volumes F_{OO} are estimated based on the assumption that the other outflow volumes F_{OO} have the same concentration as the downstream river flows F_{DS}.

L_X – L_X is the load required to balance the long-term 1964-1986 load budget. These other loads (L_X) represent inaccuracies in the other load budget terms and additional inflows and outflows not otherwise reflected in the other load budget terms.

Lakes Possum Kingdom, Granbury, and Whitney

The end-of-month TDS load and volume-weighted mean concentration for each of the 276 months of the water in storage in Possum Kingdom, Granbury, and Whitney Reservoirs are key computed amounts to result from the water and salinity balances. The computations for Lake Granbury are very different than for Lakes Possum Kingdom and Whitney. The storage loads for Lakes Possum Kingdom and Whitney are computed given known load inflows and outflows. For Lake Granbury, storage and outflow loads are computed concurrently. Construction of the Possum Kingdom and Whitney projects were completed long before the 1964-1986 period-of-analysis, with impoundment beginning in 1941 and 1951. Construction of De Cordova Bend Dam impounding Lake Granbury occurred during the 1964-1986 period-of-analysis with impoundment of Lake Granbury beginning in September 1970. As indicated by Table 4, Lake Granbury is also much smaller than Lakes Possum Kingdom and Whitney. Lake Granbury is the only reservoir with a desalination plant and water supply diversion data.

Two alternative sets of storage loads were developed for Lake Possum Kingdom and Lake Whitney. Both alternative sets of loads were computed based on balancing the storage budget. However, two alternative approaches were compared for setting the initial storage concentration. The storage loads adopted for the final load budget are computed based on setting the initial storage concentration equal to the 1964-1986-year mean concentration of the outflows at the downstream gage. The alternative approach was based on iteratively changing the beginning storage concentration to find the initial concentration that results in the 1964-1986 volume-weighted mean concentration of the water in storage being equal to the 1964-1986-year mean concentration of the outflows at the downstream gage.

The storage concentrations computed in this study are volume-weighted mean monthly concentrations. In reality, concentrations vary spatially throughout the reservoir at any point in time. The outflow concentration at a point in time is the concentration of water stored in the reservoir near the outlet structure, which is different than the volume-weighted storage concentration reflected in the load budget computations. A lag time of perhaps many months may be required for the salt entering the reservoir to be mixed and transported to the reservoir outlet. The 1964-1986 mean outflow concentration should be representation of long-term volume-weighed storage concentrations but variations in individual months may be large.

Reach from the South Bend Gage to the Graford Gage below Possum Kingdom Reservoir

The most upstream of the four reaches of the Brazos River considered in the water and salinity balance analyses extends from the USGS gaging station near South Bend to the USGS gaging station near Graford which is just downstream of Possum Kingdom Reservoir. The volume and load balances were developed as follows.

South Bend−Graford Volume Budget

The volume budget is represented by the following equation which is applicable to each of the individual 276 months as well as to the overall 1964-1986 period-of-analysis.

$$\Delta \text{ Possum Kingdom storage} = \text{South Bend flow} - \text{Graford flow} + \text{other inflow}$$
$$- \text{other outflow} - \text{net reservoir evaporation-precipitation}$$

$$\Delta S = F_{US} - F_{DS} + F_{OI} - F_{OO} - EP$$

Monthly volumes are available from existing datasets for ΔS, F_{US}, F_{DS}, and EP. Other inflows (F_{OI}) and outflows (F_{OO}) are assigned based on balancing the above equation. The other flow required to balance the volume budget in individual months may be either positive (F_{OI}) or negative (F_{OO}). The volume budget is based on the following considerations.

- A complete 1964-1986 record of monthly flows at both the South Bend and Graford gages available from the USGS was adopted. The regular USGS flow data for the Graford gage begins in 1976, but the flows included in the special salinity dataset cover 1964-1986.

- A complete 1964-1986 record of end-of-month storage volume of Possum Kingdom Reservoir is available from the USGS. However, the storage volume data are significantly affected by the 1974 sediment survey. Published observed storage volumes are derived by combining water surface measurements with an elevation versus storage volume relationship, which as indicated in Table 5 changed significantly for Possum Kingdom Lake in 1974. For purposes of the volume budget, the capacity of Possum Kingdom Lake was assumed to decrease linearly from 724,700 acre-feet in March 1941 to 570,240 acre-feet in October 1973 to obtain a 14.8 percent decrease by September 1963. The Possum Kingdom storage volumes for October 1963 through September 1973 were adjusted by multiplying by a factor of 0.852.

- Net evaporation-precipitation volumes consist of evaporation losses from the Possum Kingdom Reservoir water surface less precipitation falling on the reservoir water surface. Net evaporation-precipitation volumes were obtained from the HDR work files associated with the WAM dataset. HDR computed the volumes as an average water surface area during the month multiplied by a monthly net evaporation-precipitation depth from a dataset maintained by the Texas Water Development Board. These monthly net evaporation-precipitation depths are also found in the TCEQ WAM System WRAP input dataset.

- The other inflows (F_{OI}) and outflows (F_{OO}) represent volumes of all other inflows and outflows entering or leaving the reach between the South Bend and Graford gages along with any inaccuracies in the other terms. These additional incremental flows were computed based on balancing the volume budget equation.

$$\text{other inflow or outflow} = \Delta S - F_{US} + F_{DS} + EP$$

$$F_{OI} = \text{other inflow if positive}$$

$$F_{OO} = \text{other outflow if negative}$$

Thus, the water balance equation is automatically balanced in each month. These computations completed the volume budget, with inflows, outflows, and storage changes summing to zero in each month. The other inflows (F_{OI}) may include rainfall runoff from the 923 square mile incremental watershed, stream underflow not measured by the upstream gage, water supply diversions, and water supply return flows. The other outflows (F_{OO}) may be stream underflow not measured by the downstream gage, seepage from the river and reservoir into the ground, evapotranspiration not accounted for by the reservoir surface evaporation term, and water supply diversions. Other flows may also reflect timing effects of flows passing through the reach and inaccuracies in the other components of the water budget.

South Bend−Graford Load Budget

The TDS load budget for the South Bend to Graford reach was developed after completion of the volume budget. Upon completion of the load budget, computed Possum Kingdom Reservoir storage loads are combined with storage volumes from the volume budget to compute storage concentrations. The load budget is represented by the following equation which is applicable to each of the individual 276 months and to the overall 1964-1986 period-of-analysis.

$$\text{South Bend load} + \text{other inflow load} - \text{other outflow load}$$
$$+ \text{other load} - \text{Graford load} - \Delta \text{ storage load} = \text{zero}$$

$$L_{US} + L_{LI} + L_{OI} - L_{OO} + L_X - L_{DS} - \Delta SL = 0$$

Incremental flow volumes from the volume budget are used in estimating the incremental loads for the load budget. The other load term L_X in the load balance is the loads required to make the water budget balance. The other load L_X represents the net total of all other inflow and outflow loads not otherwise accounted for in the load budget and any inaccuracies in the other terms. The components of the load budget were developed as follows.

- The USGS salinity data includes loads for November 1978 through September 1981 at the South Bend gage. The loads for the missing portions of the 1964-1986 period-of-analysis were computed for the load budget by regression analyses as a function of South Bend flows and loads at the Seymour (Figure 2 map number 7) and Eliasville (11) gages. The 1964-1986 flow record at South Bend is complete. The 1964-1986 load record at Seymour is complete. Loads are available at Eliasville for September 1963 through September 1982.

  Missing loads in the Eliasville load (L_{11}) record were synthesized by regression with flows at Eliasville. The South Bend loads (L_{12}) for September 1963 through November 1978 are computed as a function of South Bend flows (F_{12}) and the summation of Seymour loads (L_7) and Eliasville loads (L_{11}), as follows. The subscripts refer to the map numbers in Figure 2.

$$L_{12} = 15.10\, F_{12}^{0.5022} \left(L_{11} + L_7\right)^{0.3094}$$

  The correlation coefficient (R) is 0.968. This equation was adopted as after investigating several alternative forms of regression equations and alternative variables (flows and loads at different gages).

- The USGS salinity data includes loads for the complete 1964-1986 period-of-analysis at the Graford gage which were adopted for the load budget.

- The other inflow loads L_{OI} were determined by combining the F_{OI} from the volume budget with a constant concentration of 270 mg/l, adopted based on concentrations at gages with similar neighboring watersheds. Mean TDS concentrations at the Breckenridge (Fig. 2 map number 10), Little River (19), and Aquilla (17) gages are 268 mg/l, 313 mg/l, and 257 mg/l.

- The other outflow loads L_{OO} associated with the other outflows F_{OO} from the volume budget were determined by combining the F_{OO} with the concentration of the downstream flows at the Graford gage each month.

- The other load term L_X makes the load balance to sum to zero. L_X represents all loads not reflected in the other load budget terms and inaccuracies in the other terms.

  The 1964-1986 mean load difference is computed based on the following equation.

$$\text{1964-1986 mean load difference} = \text{1964-1986 mean } L_{DS} - \text{1964-1986 mean } L_{US}$$
$$- \text{1964-1986 mean } L_{LIF} + \text{1964-1986 mean } L_{LOF} + \text{1964-1986 mean } \Delta SL$$

$$\text{1964-1986 mean load difference} = \text{1964-1986 mean of Graford loads}$$
$$- \text{1964-1986 mean of South Bend loads} - \text{1964-1986 mean of other inflow loads}$$
$$+ \text{1964-1986 mean of other outflow loads} + \text{1964-1986 mean difference in storage load}$$

  The 1964-1986 mean difference in storage load was estimated based on the difference between the October 1963 beginning and September 1986 ending storage volumes with corresponding beginning and ending storage concentrations assumed to be the 1964-1986 mean outflow concentration at the Graford gage.

  The 1964-1986 mean load difference was computed to be −137 tons/month, with the negative sign indicating a loss in load. The monthly other outflow loads L_X were computed by distributing the 1964-1986 mean load loss of −137 tons/month over the 276 months in proportion to the summation of South Bend loads (L_{US}) and other inflow loads (L_{OI}). Thus, the other losses required to balance the load budget are distributed over time in proportion to load inflows to the reach.

- Storage loads are computed based on the following equation.

$$SL_E = SL_B + L_{US} + L_{OI} - L_{OO} + L_X - L_{DS}$$

$$\text{end-of-month storage load} = \text{beginning-of-month storage load}$$
$$+ \text{South Bend load} + \text{other inflow load} - \text{other outflow load} + \text{other load} - \text{Graford load}$$

  The September 1963 beginning storage concentration was combined with the corresponding Possum Kingdom Reservoir storage volume to set the load in storage at the beginning of the 1964-1986 period-of-analysis. The October 1986 ending concentration is automatically equal to the September 1963 beginning storage concentration since the total net 1964-1986 load balance is maintained in the computations.

  The September 1963 beginning storage concentration was set equal to the 1964-1986 mean outflow concentration at the Graford gage. As an alternative comparative analysis, the September 1963 beginning storage concentration was set by iteratively repeating the computation of storage loads until the 1964-1986 mean storage concentration equaled the 1964-1986 mean concentration of flows at the Graford gage. Thus, with this alternative approach, the long-term mean concentration of reservoir outflows equal the mean concentration of reservoir storage, but the beginning and ending concentrations were found to be relatively low.

- Upon completion of the load budget, the end-of-month concentration of the water in storage in Possum Kingdom Reservoir was computed by combining the storage loads computed in the load budget with the observed storage volumes.
-

Reach from the Graford Gage to the Dennis Gage

The Graford to Dennis reach is the only reach of the four that has no reservoir on the Brazos River. The volume and load balances were developed as follows.

Graford−Dennis Volume Budget

The volume budget is represented by the following equation which is applied to each of the 276 months of the 1964-1986 period-of-analysis.

$$F_{US} + F_{OI} - F_{OO} - F_{DS} = 0$$

Graford flow + other inflow − other outflow − Dennis flow = zero

Additional positive and negative flows (F_{OI} and F_{OO}) were computed based on the equation above. Thus, the water balance equation is automatically balanced in each month. These local incremental flows representing all inflows (F_{OI}) entering and outflows (F_{OO}) leaving the reach between the South Bend and Graford gages. The local incremental flows include rainfall runoff from the 1,641 square mile incremental watershed, stream underflow not measured by the gages, channel seepage, evapotranspiration, water supply diversions, return flows, and inaccuracies in the flow values adopted at the Graford and Dennis gages. The volume budget was developed as follows.

- The complete 1964-1986 record of monthly flows at the Graford gage are outflows from the South Bend-to-Graford reach and inflows to the Graford-to-Dennis reach.

- Observed monthly flows at the Dennis gage are available for the period June 1968 through October 1986. Incremental flows during this period were computed as the observed flows at the Dennis gage minus the observed flows at the Graford gage.

- Incremental flows for September 1963 through April 1968 were computed as the naturalized flows from the WAM dataset at the Dennis gage minus naturalized flows at the Graford gage adjusted for Lake Palo Pinto. In any month during September 1963 through April 1968 in which the storage in Lake Palo Pinto increased, the storage increase was subtracted from the incremental naturalized flows. If Lake Palo Pinto was full to capacity at the end of the month, the net evaporation-precipitation volume was subtracted from the incremental naturalized flows.

- The observed monthly flows at the Dennis gage available for the period June 1968 through October 1986 were adopted as the Dennis outflows. The flows at Dennis during the period from September 1963 through April 1968 were computed as the flows at Graford plus the incremental flows.

Graford−Dennis Load Budget

The TDS load budget for the Graford to Dennis reach was developed after completion of the volume budget. Incremental flow volumes from the volume budget are used in estimating the incremental loads for the load budget. The load budget is represented by the following equation.

$$L_{US} + L_{OI} - L_{OO} - L_{DS} = 0$$

Graford load + other inflow load − other outflow load − Dennis load = zero

The components of the load budget were developed as follows.

- The USGS salinity data includes loads for the complete 1964-1986 period-of-analysis at the Graford gage which were adopted for the load budget.
- The USGS salinity data includes loads for October 1970 through October 1986 at the Dennis gage. These loads were adopted as the Dennis outflows for this period.
- The incremental loads for the period from October 1970 through October 1986 were computed by subtracting Graford loads from Dennis loads.
- The incremental loads for the period from September 1963 through September 1970 were computed by multiplying incremental volumes by the mean concentration computed for the October 1970 through October 1986 incremental flows and loads.
- The loads at the Dennis gage during September 1963 through September 1970 were computed as the summation of the Graford loads plus incremental loads.

Reach from the Dennis Gage to the Glen Rose Gage

The Dennis to Glen Rose reach contains Lake Granbury, which was constructed during the first several years of the 1964-1986 period-of-analysis. The load budget computations are different than for the other three reaches largely because there are no salinity data at the Glen Rose gage defining the downstream limit of the reach. This is also the only reach with data for water supply diversions. The volume and load balances were developed as follows.

Dennis−Glen Rose Volume Budget

The volume budget is represented by the following equation.

$$F_{US} - F_{DS} + F_{OI} - F_{OO} - F_{WS} - EP - \Delta S = 0$$

Dennis flow − Glen Rose flow+ Dennis-to-Granbury incremental flow
+ Granbury-to-Glen Rose other inflow − Granbury-to-Glen Rose other outflow
− water supply diversions − Granbury evaporation-precipitation − Δ Granbury storage
= zero

The volume budget was developed as follows.

- The complete record of observed storage volumes in Lake Granbury are available, but the dam and reservoir project was constructed during the early years of the 1964-1986 period-of-analysis. An initial small non-zero volume of 270 acre-feet was stored during October 1968 but the total storage volume did not exceed inflows each month until November 1969. September 1970 has been cited as the official initial impoundment date for the completed project.

- Net reservoir evaporation-precipitation volumes were taken from the data files prepared by HDR, Inc. for the TCEQ during development of the WAM System dataset for the Brazos.

- Water supply diversions from Lake Granbury were also obtained from the HDR WAM files.

- The flows at Dennis were previously developed in conjunction with the Graford-to-Dennis volume budget.

- USGS flows at Glen Rose are available for the complete 1964-1986 period-of-analysis.

- Local incremental flows were computed as follows.

$$F_{OI} = F_{DS} - F_{US} + F_{OO} + F_{WS} + \Delta S + EP + \Delta S$$

Other inflow = Glen Rose flow − Dennis flow + other outflow
+ water supply diversion + Granbury evaporation-precipitation + Δ Granbury storage

The incremental flows were divided between the two sub-reaches upstream and downstream of the dam in proportion to drainage area. Of the total incremental drainage area between the Dennis and Glen Rose gages of 581 square miles, 442 square miles (76.1 percent) is above De Cordova Bend Dam (Lake Granbury) and the remaining 139 square miles (23.9 percent) is below. The incremental flows were divided 76.1 and 23.9 percent.

<u>*Dennis−Glen Rose Load Budget*</u>

- The loads at Dennis were previously developed with the Graford-to-Dennis load budget.

- Incremental loads were determined by combining the incremental flows (F_{OI}) from the volume budget with a constant concentration of 270 mg/l. The estimated 270 mg/l was adopted based on concentrations of gages with similar neighboring watersheds. As previously noted, mean TDS concentrations at the Breckenridge, Little River, and Aquilla gages are 268 mg/l, 313 mg/l, and 257 mg/l, respectively.

  Incremental loads entering Lake Granbury were assumed to be 76.1 percent of the total, with the remaining 23.9 percent entering the Brazos River between the dam and Glen Rose gage.

- During the period from October 1963 through September 1968, construction of Lake Granbury had not been completed and reservoir storage was zero. The loads at Glen Rose were computed as the summation of Dennis loads plus total incremental loads.

- Non-zero ponding occurred during the period from October 1968 through early 1969. Prior to November 1969, the storage volume was much smaller than monthly inflows. The storage volume was greater than the monthly inflow for the first time in November 1969. From October 1968 through September 1986, the load budget computations were performed following an algorithm that combines the following premises.

  Flow volumes at the Glen Rose gage are the Lake Granbury outflow volume plus 23.9 percent of incremental flows. Lake Granbury outflow volumes are computed as observed flow at the Glen Rose gage less 23.9 percent of incremental flows.

  Water supply diversion loads are estimated based on assuming the diversion concentration during a month is equal to the storage concentration at the beginning of the month.

  A net inflow load to Lake Granbury is defined as consisting of the load at the Dennis gage plus 76.1 percent of incremental load less the diversion load. In each month, this net inflow load is divided between Granbury change-in-storage load and Granbury outflow load in direct proportion to the change-in-storage volume and outflow volume.

  Lake Granbury storage loads are computed based on the following relationships.

$$SL_E = [SL_B + L_{US} + L_{OI} - L_{OO} - L_{WS}] \left[\frac{F_{DS}}{F_{DS} + S_{DS}} \right]$$

end-of-month storage load = [beginning-of-month storage load + Dennis load + 76.1 percent of other inflow load − 76.1 percent of other outflow load − diversion load] [assigned proportion]

- For the period October 1968 through October 1986, loads at the Glen Rose gage were computed as the summation of Lake Granbury outflow loads and 23.9 percent of incremental loads.

Reach from the Glen Rose Gage to the Whitney Gage

The most downstream of the four reaches contains Lake Whitney. The volume and load balances were developed as follows, which is similar to the procedure applied to the South Bend to Graford reach which contains Possum Kingdom Lake.

Glen Rose Gage−Whitney Gage Volume Budget

The volume budget is represented by the following equation which is applicable to each of the individual 276 months and to the overall 1964-1986 period-of-analysis.

Δ Lake Whitney storage = Glen Rose gage flow − Whitney gage flow + other inflow − other outflow − net reservoir evaporation-precipitation

$$\Delta S = F_{US} - F_{DS} + F_{OI} - F_{OO} - EP$$

Monthly volumes are available from existing datasets for ΔS, F_{US}, F_{DS}, and EP. Other inflows (F_{OI}) and outflows (F_{OO}) are assigned based on balancing the above equation. The other flow required to balance the volume budget in individual months may be either a positive F_{OI} with zero F_{OO} or a negative F_{OO} with F_{OI}. The water balance equation is automatically balanced in each month.

The other flows (F_{OI} and F_{OO}) represent all other inflows and outflows entering or leaving the reach between the Glen Rose and Whitney gages. The other flows include rainfall runoff from the 1,370 square mile incremental watershed, stream underflow not measured by the gages, seepage from the river and reservoir into the ground, evapotranspiration not accounted for by the reservoir surface evaporation term, water supply diversions, return flows, and inaccuracies in the other components of the water budget.

The volume budget is based on the following considerations.

- A complete 1964-1986 record of monthly flows at both the Glen Rose and Whitney gages available from the USGS was adopted.

- A complete record of end-of-month storage volume of Whitney Reservoir available from the USGS was adopted. These data were taken from files compiled by HDR Engineering, Inc. in developing the TCEQ WAM System dataset.

- Net evaporation-precipitation volumes consist of evaporation losses from the Lake Whitney water surface less precipitation falling on the water surface. Net evaporation-precipitation volumes were also obtained from the HDR work files associated with the WAM dataset. HDR computed the volumes as an average water surface area during the month multiplied by a monthly net evaporation-precipitation depth from a dataset maintained by the Texas Water Development Board.

- Other inflows F_{OI} and outflows F_{OO} represent all other flows entering or leaving the reach between the Glen Rose and Whitney gages that are not already reflected in the other terms of the volume budget. The other flows were computed based on balancing the volume budget equation.

Glen Rose−Whitney Load Budget

The TDS load budget for the Glen Rose gage to Whitney gage reach was developed after completion of the volume budget. Upon completion of the load budget, computed Lake Whitney storage loads are combined with storage volumes from the volume budget to compute storage concentrations. The load budget is represented by the following equation which is applicable to each of the individual 276 months and to the overall 1964-1986 period-of-analysis.

$$L_{US} + L_{OI} - L_{OO} + L_X - L_{DS} - \Delta SL = 0$$

Glen Rose load + other inflow load − other outflow load + other load
− Whitney gage load − Δ storage load = zero

Other flow volumes (F_{OI} and F_{OO}) from the volume budget are used in estimating the other loads (L_{OI} and L_{OO}) for the load budget. The other load term L_X in the load balance are the additional loads required to maintain the 1964-1986 load budget. The other load L_X represents the net total of all other inflow and outflow loads not otherwise accounted for in the load budget and any inaccuracies in the other terms. The components of the load budget were developed as follows.

- The loads at Glen Rose were computed in the Dennis-to-Glen Rose load budget computations.

- The USGS salinity data includes loads for the complete 1964-1986 period-of-analysis at the Whitney gage which were adopted for the load budget.

- Other inflow loads L_{OI} were determined by combining the incremental flows from the volume budget with a constant concentration of 270 mg/l. As previously discussed, the estimated 270 mg/l was adopted based on concentrations of gages with similar neighboring watersheds.

- The other outflow loads L_{OO} associated with the other outflows F_{OO} from the volume budget were determined by combining the F_{OO} with the concentration of the downstream flows at the Whitney gage each month.

- The other load term L_X makes the load balance to sum to zero. L_X represents all loads not reflected in the other load budget terms and inaccuracies in the other terms. The monthly L_X amounts were determined as follows in the same manner previously applied to the South Bend–Graford reach.

  The 1964-1986 mean load difference is computed based on the following equation.

  $$\text{1964-1986 mean load difference} = \text{1964-1986 mean } L_{DS} - \text{1964-1986 mean } L_{US} - \text{1964-1986 mean } L_{LIF} + \text{1964-1986 mean } L_{LOF} + \text{1964-1986 mean } \Delta SL$$

  1964-1986 mean load difference = 1964-1986 mean of Whitney gage loads
  − 1964-1986 mean of Glen Rose loads − 1964-1986 mean of other inflow loads
  + 1964-1986 mean of other outflow loads + 1964-1986 mean difference in storage load

  The 1964-1986 mean difference in storage load was estimated based on the difference between the October 1963 beginning and September 1986 ending storage volumes with corresponding beginning and ending storage concentrations assumed to be the 1964-1986 mean outflow concentration at the Graford gage.

  The 1964-1986 mean load difference was computed to be −1,031 tons/month, with the negative sign indicating a loss in load. The monthly other outflow loads L_X were computed by distributing the 1964-1986 mean load loss of −1,031 tons/month over the 276 months in proportion to the summation of South Bend loads (L_{US}) and other inflow loads (L_{OI}). Thus, the other losses required to balance the load budget are distributed over time in proportion to load inflows to the reach.

- Storage loads are computed based on the following equation.

  $$SL_E = SL_B + L_{US} + L_{OIF} - L_{OOF} + L_X - L_{DS}$$

  end-of-month storage load = beginning-of-month storage load
  + Glen Rose load + other inflow load − other outflow load + other load − Whitney load

The computational algorithm is the same for both the Possum Kingdom Lake and Whitney Lake reaches. The September 1963 beginning storage concentration was combined with the corresponding Possum Kingdom Reservoir storage volume to set the load in storage at the beginning of the 1964-1986 period-of-analysis. The September 1986 ending concentration is automatically equal to the October 1963 beginning storage concentration since the total net 1964-1986 load balance is maintained in the computations.

The October 1963 beginning storage concentration was set equal to the 1964-1986 mean outflow concentration at the Whitney gage. As an alternative comparative analysis, the October 1963 beginning storage concentration was set by iteratively repeating the computation of storage loads until the 1964-1986 mean storage concentration equaled the 1964-1986 mean concentration of flows at the Whitney gage. Thus, with this alternative approach, the long-term mean concentration of reservoir outflows equal the mean concentration of reservoir storage, but the beginning and ending concentrations were found to be relatively low.

- Upon completion of the load budget, the end-of-month concentration of the water in storage in Lake Whitney was computed by combining the storage loads computed in the load budget with the observed storage volumes.

Volume and Load Budget Results

The four volume budgets and four load budgets consist of Microsoft Excel spreadsheet tabulations of pertinent amounts for each of the 276 months of the October 1963 through September 1986 period-of-analysis (water years 1964-1986). Concentrations are determined by applying a conversion factor to load divided by volume. The 1964-1986 means of the components of the volume budgets and load budgets are tabulated in Tables 9 and 10. Mean concentrations corresponding to the Tables 9 and 10 load and flow means are shown in Table 11. The 1964-1986 means of storage volumes and loads and 1964-1986 mean concentrations for Possum Kingdom, Granbury, and Whitney Reservoirs are summarized in Tables 12 and 13. The storage volume, load and concentration at the beginning of October 1963 and end of September 1986 are also included in Tables 12 and 13.

Storage loads in Lakes Possum Kingdom and Whitney were computed for the end of each of the 276 months based on summing inflow and outflow loads for each month starting with a specified load in storage at the beginning of October 1963. The load at the beginning of October 1963 was estimated by combining the observed beginning storage volume with an assumed beginning concentration. The storage concentration at the end of September 1986 automatically equals the October 1963 beginning concentration in the load balance computations. Tables 12 and 13 compare load budget results for the following two different premises.

- The results in Table 12 were obtained based on assuming that the concentration at the beginning of October 1963 equaled the long-term 1964-1986 mean outflow concentration at the Graford gage for Lake Possum Kingdom and Whitney gage for Lake Whitney.
- The results in Table 13 reflect the premise that the 1964-1986 mean storage concentration equaled the 1964-1986 mean outflow concentration. The October 1963 beginning concentration was adjusted until the long-term mean storage and outflow concentrations were the same.

Table 9. 1964-1986 Mean Monthly Flow Volumes (acre-feet/month)

Components of Volume Balance	South Bend to Graford (ac-ft/month)	Graford to Dennis (ac-ft/month)	Dennis to Glen Rose (ac-ft/month)	Glen Rose to Whitney (ac-ft/month)
Upstream river flow (F_{US}, +)	38,712	42,999	57,077	61,670
Downstream river flow (F_{DS}, −)	42,998	57,077	61,670	74,193
Other inflow (F_{OI}, +)	9,874	15,280	8,350	18,938
Other outflow (F_{OO}, −)	1,164	1,202	1,020	2,124
Water supply diversions (F_{WS}, −)	−0−	−0−	923	−0−
Net evaporation-precipitation (EP, −)	3,731	−0−	1,272	3,603
Change in storage volume (ΔS, −)	255	−0−	541	1,088
Upstream naturalized flows	44,178	53,868	68,376	75,682
Downstream naturalized flows	53,868	68,376	75,682	93,761

Table 10. 1964-1986 Mean Monthly Loads (tons/month)

Components of Load Balance	South Bend to Graford (tons/month)	Graford to Dennis (tons/month)	Dennis to Glen Rose (tons/month)	Glen Rose to Whitney (tons/month)
Upstream river flow (L_{US}, +)	83,395	89,712	93,409	91,892
Downstream river flow (L_{DS}, −)	89,712	93,409	91,892	93,538
Other inflow load (L_{OI}, +)	3,624	9,235	3,065	6,952
Other outflow load (L_{OO}, −)	2,638	5,538	1,577	2,938
Water supply diversions (L_{WS}, −)	−0−	−0−	1,859	−0−
Other load to balance budget (L_X, −)	137	−0−	−0−	996
Change in load in storage (ΔSL, −)	533	−0−	1,149	1,371

Table 11. 1964-1986 Mean Concentrations (milligrams/liter)

Components of Load Balance	South Bend to Graford (mg/l)	Graford to Dennis (mg/l)	Dennis to Glen Rose (mg/l)	Glen Rose to Whitney (mg/l)
Upstream river flow	1,698	1,534	1,204	1,096
Downstream river flow	1,534	1,204	1,096	927
Other inflows	270	444	270	270
Other outflows	1,667	3,389	1,237	1,017
Water supply diversions	−0−	−0−	1,480	−0−
Reservoir storage change	1,537	−0−	1562	927

Table 12. Reservoir Volumes, Loads, and Concentrations for Scenario with Beginning Concentration = 1964-1986 Mean Outflow Concentration

	Possum Kingdom	Granbury Reservoir	Whitney Reservoir
276-month mean storage volume (acre-feet)	517,008	107,420	475,928
276-month mean storage TDS load (tons)	1,298,779	191,864	859,429
276-month mean storage TDS concentration (mg/l)	1,716	1,314	1,328
276-month mean outflow TDS concentration (mg/l)	1,534	1,096	927
Storage volume at beginning of October 1963 (ac-ft)	477,802	−0−	332,300
Storage volume at end of September 1986 (acre-feet)	548,300	149,200	632,500
TDS load at the beginning of October 1963 (tons)	996,875	−0−	418,944
TDS load at the end of September 1986 (tons)	1,143,962	317,040	797,419
TDS concentration beginning October 1963 (mg/l)	1,534	−0−	927
TDS concentration end of September 1986 (mg/l)	1,534	1,563	927

Table 13. Reservoir Volumes, Loads, and Concentrations for Scenario with 1964-1986 Mean Storage Concentration = 1964-1986 Mean Outflow Concentration

	Possum Kingdom	Granbury Reservoir	Whitney Reservoir
276-month mean storage volume (acre-feet)	516,482	107,420	475,928
276-month mean storage TDS load (tons)	1,097,527	191,864	600,021
276-month mean storage TDS concentration (mg/l)	1,534	1,314	927
276-month mean outflow TDS concentration (mg/l)	1,534	1,096	927
Storage volume at beginning of October 1963 (ac-ft)	477,802	−0−	332,300
Storage volume at end of September 1986 (acre-feet)	548,300	149,200	632,500
TDS load at the beginning of October 1963 (tons)	868,772	−0−	240,162
TDS load at the end of September 1986 (tons)	996,957	317,040	457,124
TDS concentration beginning October 1963 (mg/l)	1,337	−0−	532
TDS concentration end of September 1986 (mg/l)	1,337	1,563	532

The means of flows, loads, and concentrations at the five gaging stations and an additional upstream gage (Seymour) and two other downstream gages (College Station and Richmond) are tabulated in Table 14 along with the means expressed as a percentage of the means at the Whitney gage. The flows, TDS loads, and concentrations at the five gaging stations are plotted in Figures 5−19. The volumes, TDS loads, and concentrations of water stored in Possum Kingdom, Granbury, and Whitney Reservoirs are plotted in Figures 20−27. Storage and outflow concentrations for Possum Kingdom, Granbury, and Whitney Reservoirs are compared in Figures 28−32.

Table 14. 1964-1986 Mean Flows, Loads, and Concentrations at Gages on the Brazos River

Gage	Fig. 2 No.	River Mile	Mean Flow (ac-ft/yr)	Mean Load (tons/yr)	Mean Conc (mg/l)	Mean Flow	Mean Load	Mean Conc
						Percentage of Whitney Gage		
Seymour	7	847.4	194,700	949,400	3,590	21.9%	84.6%	387%
South Bend	12	686.5	464,500	1,072,700	1,700	52.2%	95.6%	183%
Graford	13	614.2	516,000	1,076,500	1,530	58.0%	95.9%	165%
Dennis	14	571.0	684,900	1,120,900	1,200	76.9%	99.9%	130%
Glen Rose	–	523.6	740,000	1,102,700	1,100	83.1%	98.2%	118%
Whitney	15	442.4	890,300	1,122,500	927	100%	100%	100%
College Station	21	281.1	3,279,000	1,952,000	438	368%	174%	47%
Richmond	25	92.0	4,972,000	2,287,000	339	558%	204%	37%

Table 15. Other Inflow Volumes as a Watershed Runoff Depth Equivalent

Reach	Watershed Area (square miles)	Other Inflow (F_{OI}) (acre-feet/month)	Other Inflow Depth (inches/year)
South Bend to Graford	923	9,874	2.4
Graford to Dennis	1,641	15,280	2.1
Dennis to Glen Rose	581	8,350	3.2
Glen Rose to Whitney	1,371	18,938	3.1

The means of the other inflow volumes (F_{OI}) from Table 9 are expressed as an equivalent depth of runoff from the local incremental watershed with drainage areas shown in Table 15 as a check on the reasonableness of the computed amounts. The 1964-1986 mean inflow volume as an equivalent depth over the watershed is computed by dividing the mean other inflow (F_{OI}) in acre-feet/month by the watershed area and applying appropriate conversion factors. The F_{OI} volume equivalents of 2.4, 2.1, 3.2, and 3.1 inches/year listed in the last column of Table 15 appear to be reasonable amounts when viewed as rainfall runoff from the local incremental watersheds above the gages. For comparison, the Aquilla Creek at Aquilla and Little River at Little River gages (gages 17 and 19 in Figure 2 and Tables 2 and 3) have mean flows of 147 and 912 cfs and drainage areas of 308 and 5,228 mile^2, which translate to 6.5 and 2.4 inches/year, respectively. Texas Water Development Board (2007) data indicate that average annual stream flow runoff for the incremental watershed above Whitney Dam but below the dam at Possum Kingdom Lake is about 2.0 inches/year or a little more.

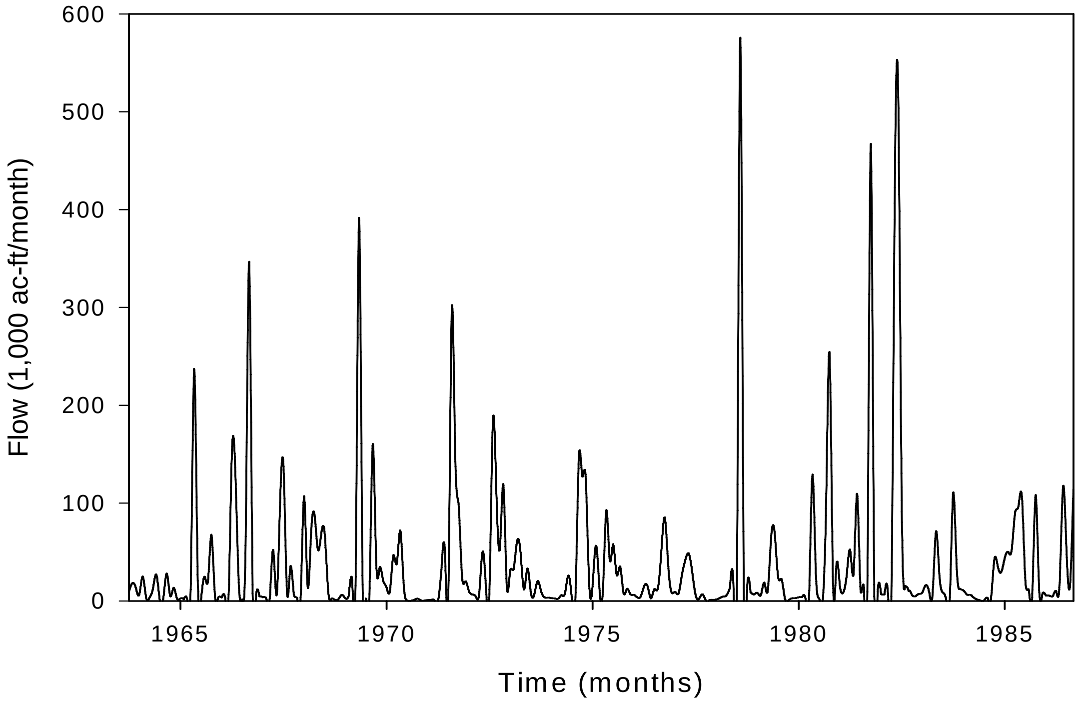

Figure 5. Monthly Flows at the South Bend Gage

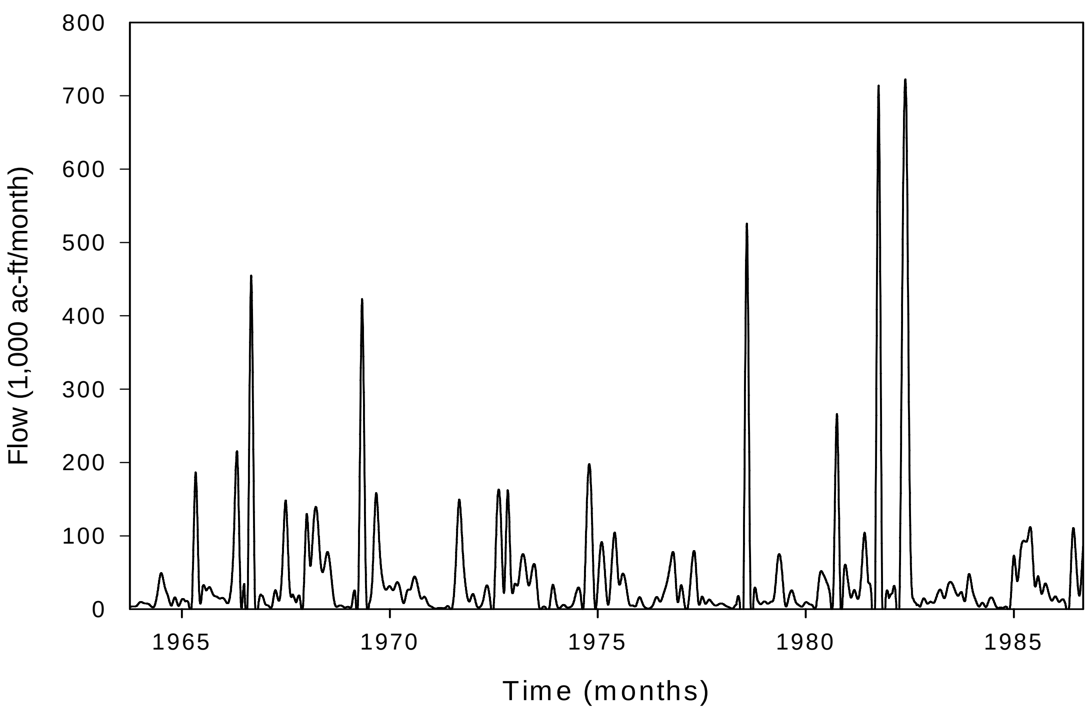

Figure 6. Monthly Flows at the Graford Gage

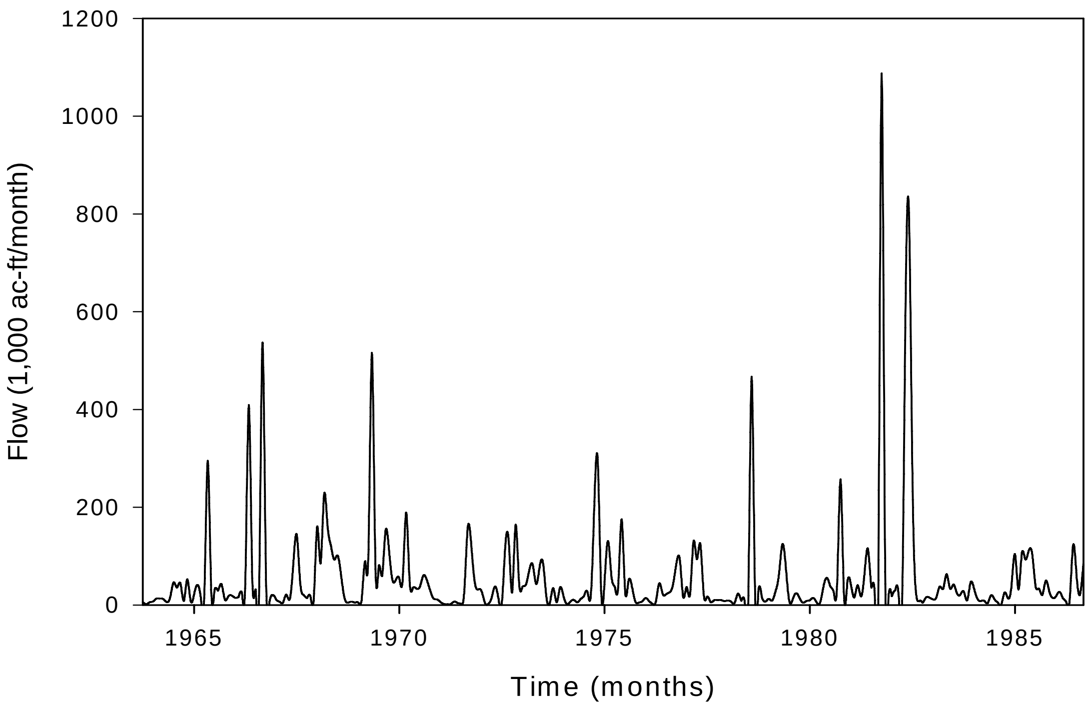

Figure 7. Monthly Flows at the Dennis Gage

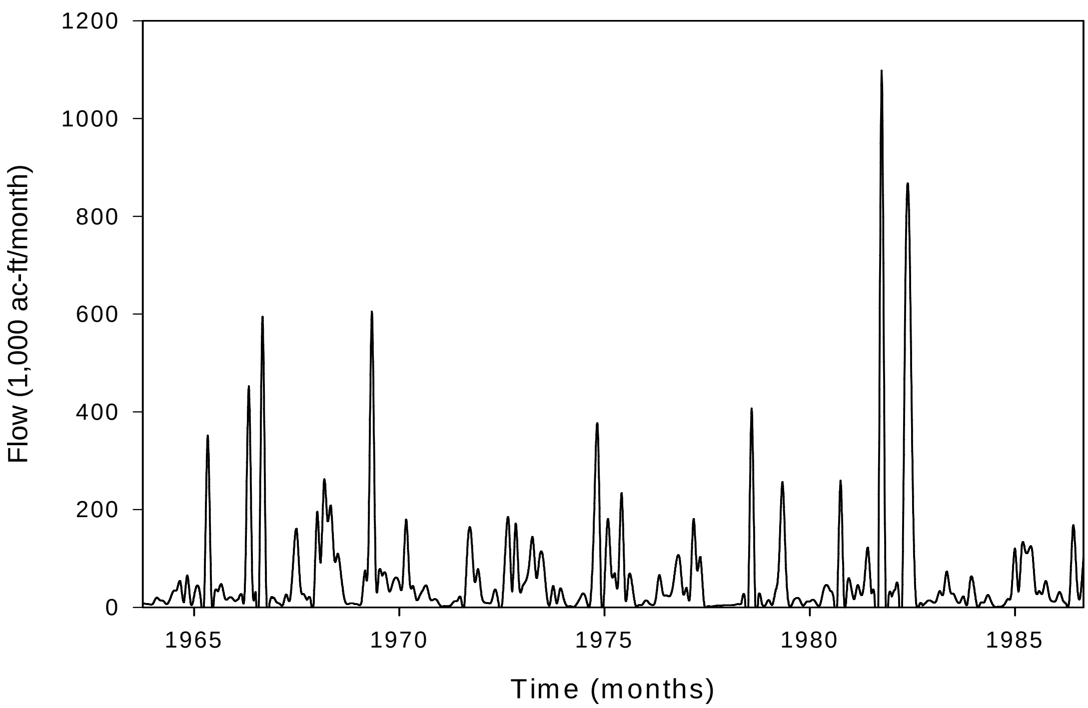

Figure 8. Monthly Flows at the Glen Rose Gage

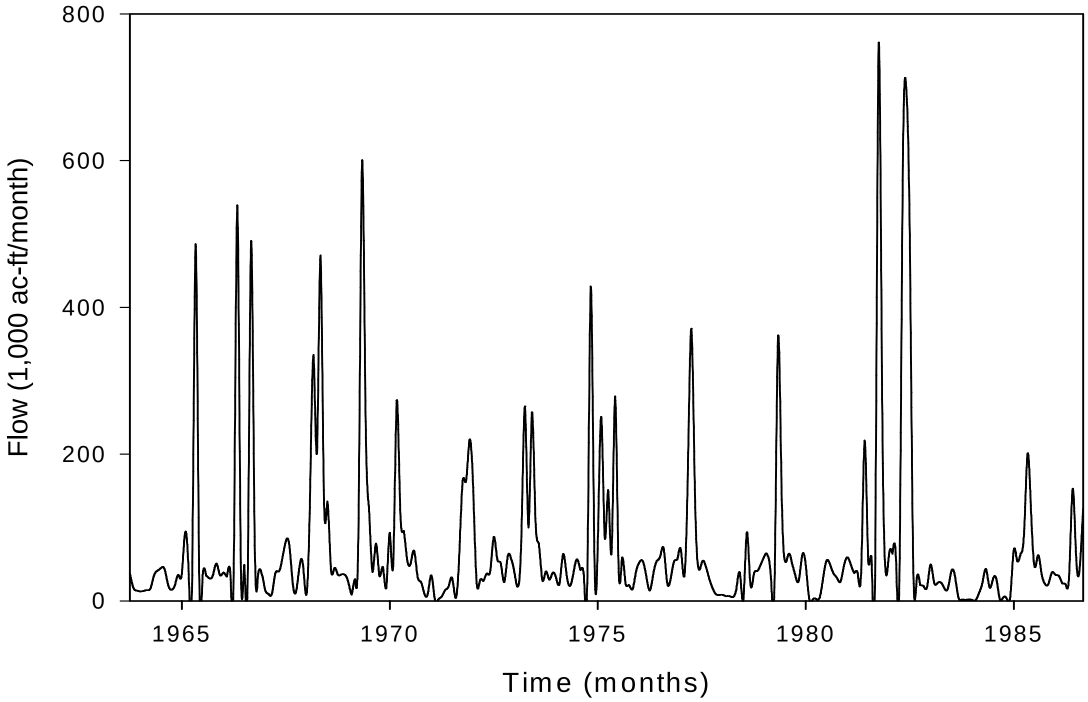

Figure 9. Monthly Flows at the Whitney Gage

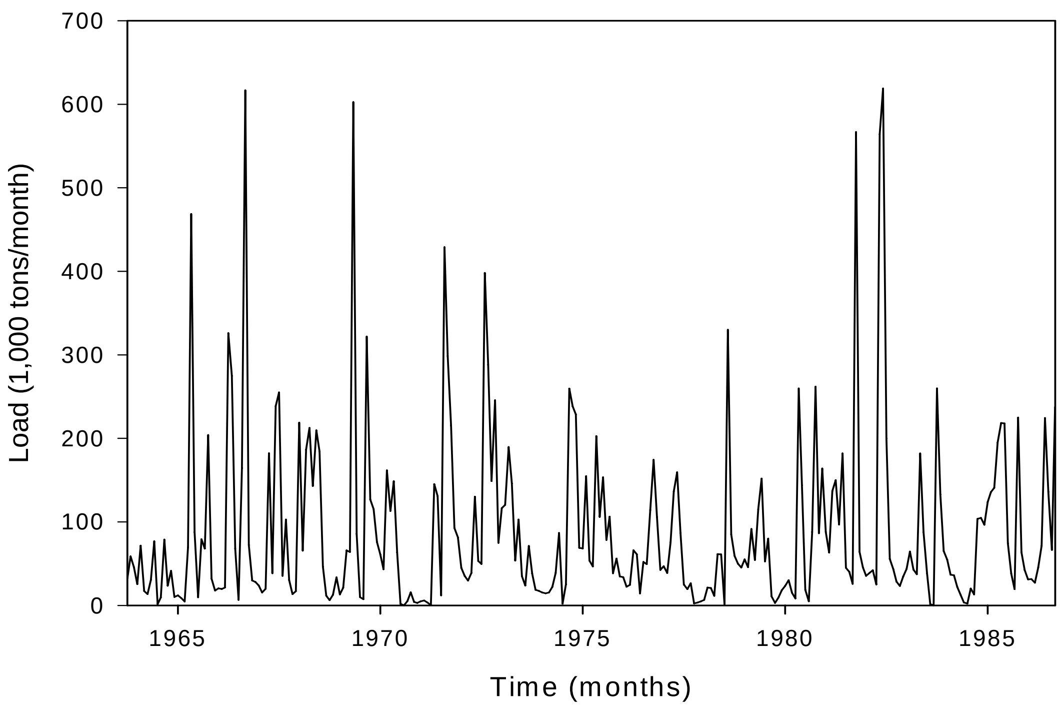

Figure 10. Monthly TDS Loads at the South Bend Gage

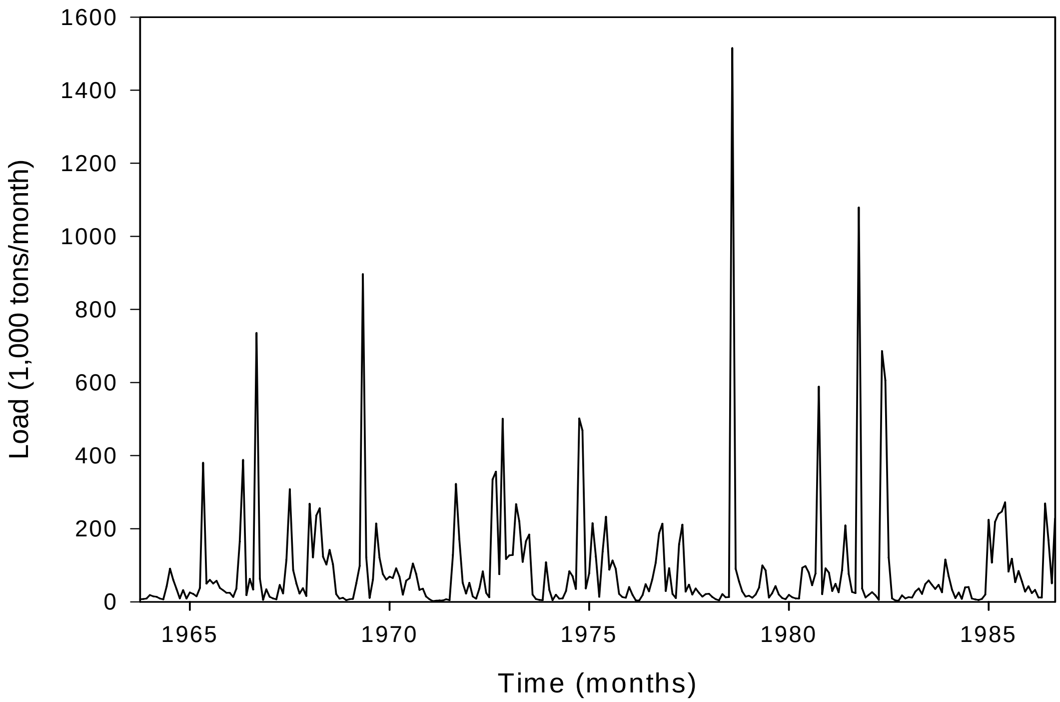

Figure 11. Monthly TDS Loads at the Graford Gage

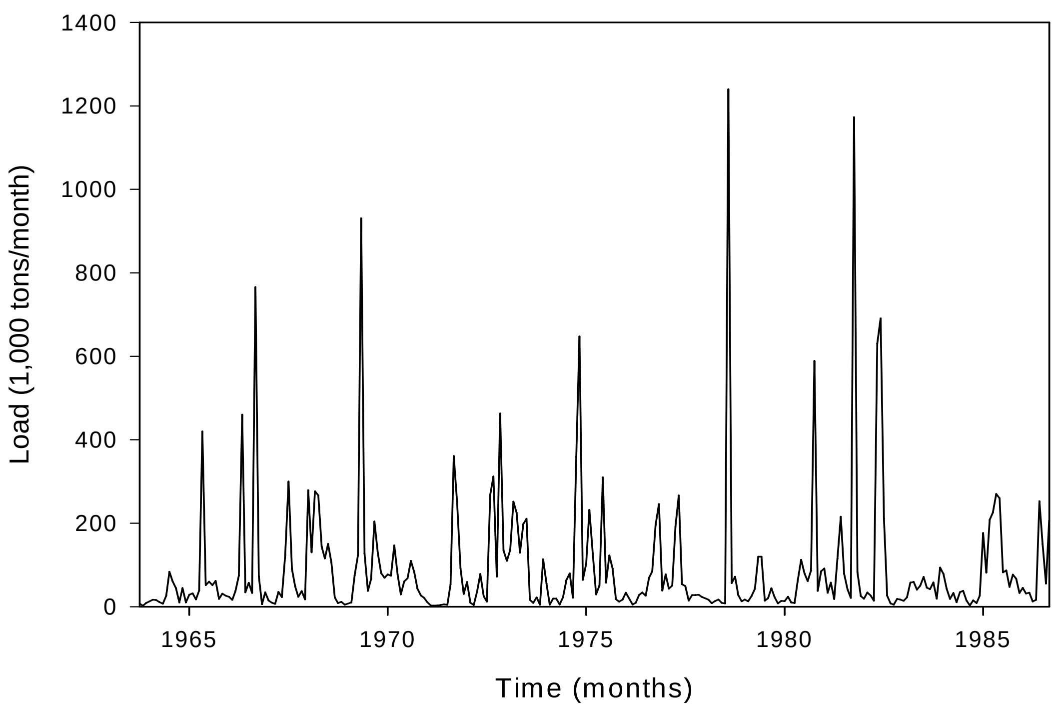

Figure 12. Monthly TDS Loads at the Dennis Gage

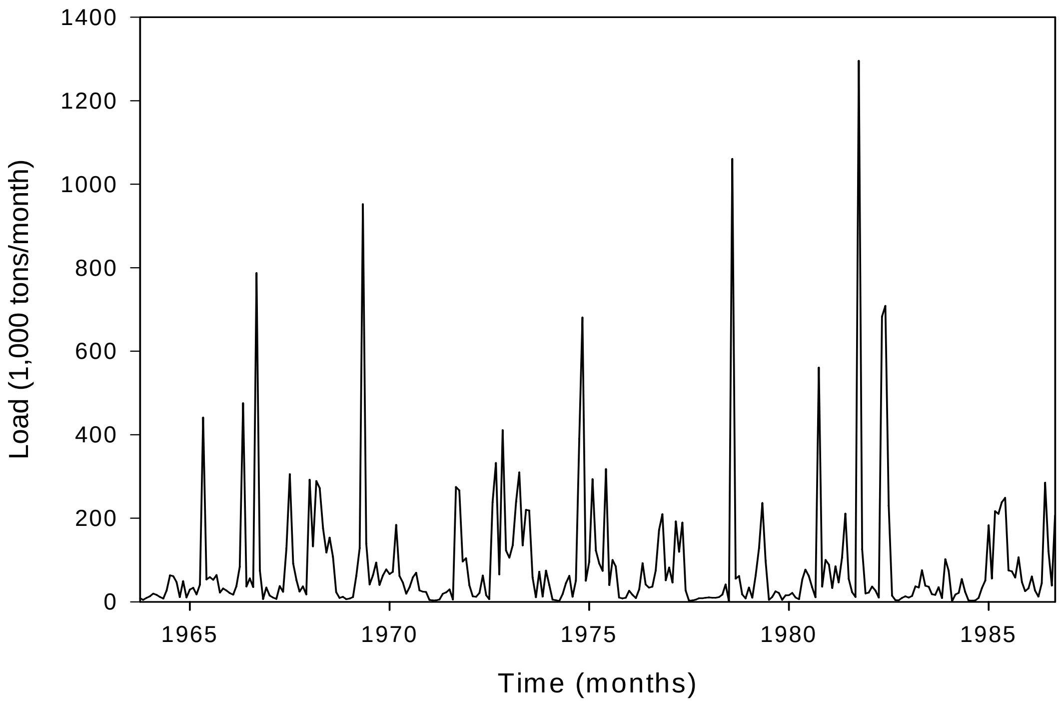

Figure 13. Monthly TDS Loads at the Glen Rose Gage

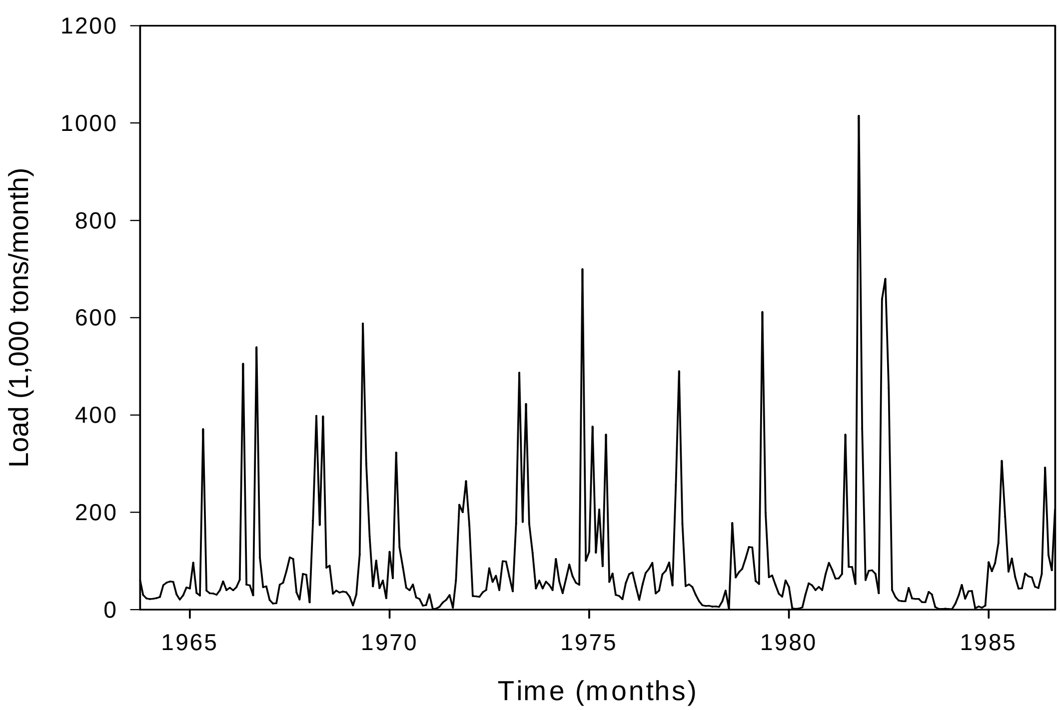

Figure 14. Monthly TDS Loads at the Whitney Gage

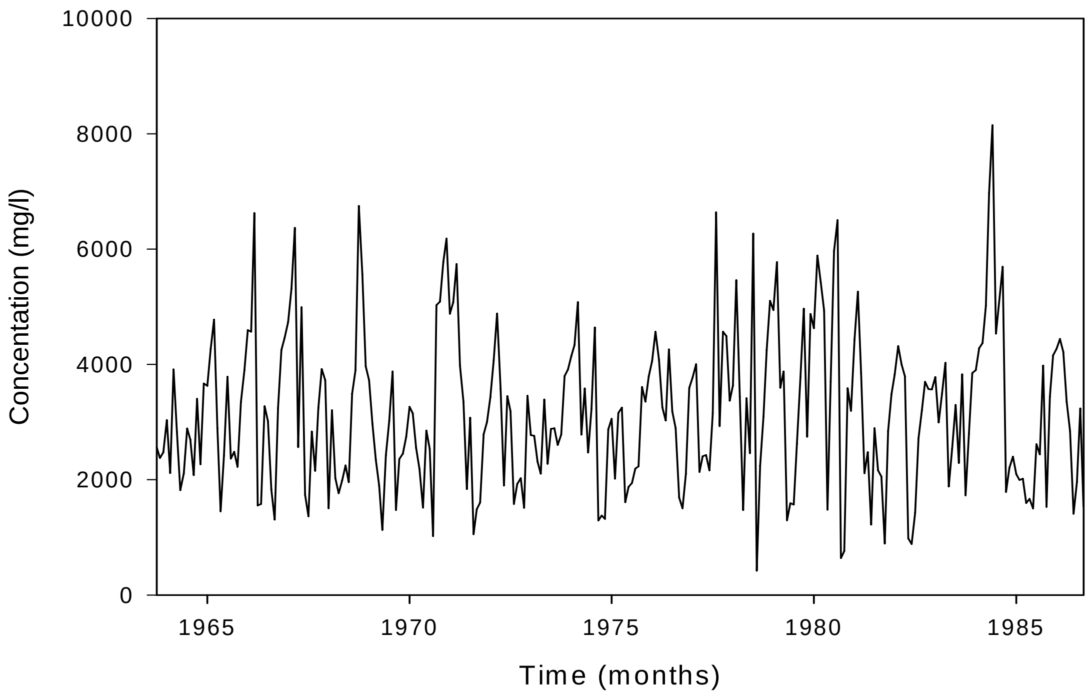

Figure 15. TDS Concentrations at the South Bend Gage

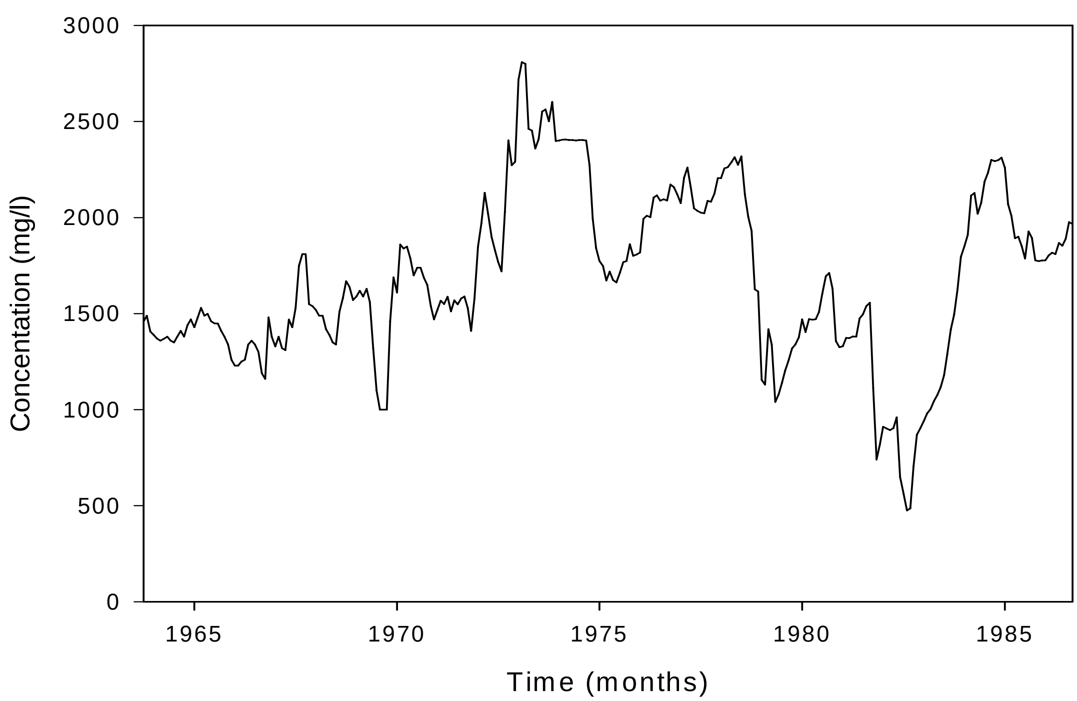

Figure 16. TDS Concentrations at the Graford Gage

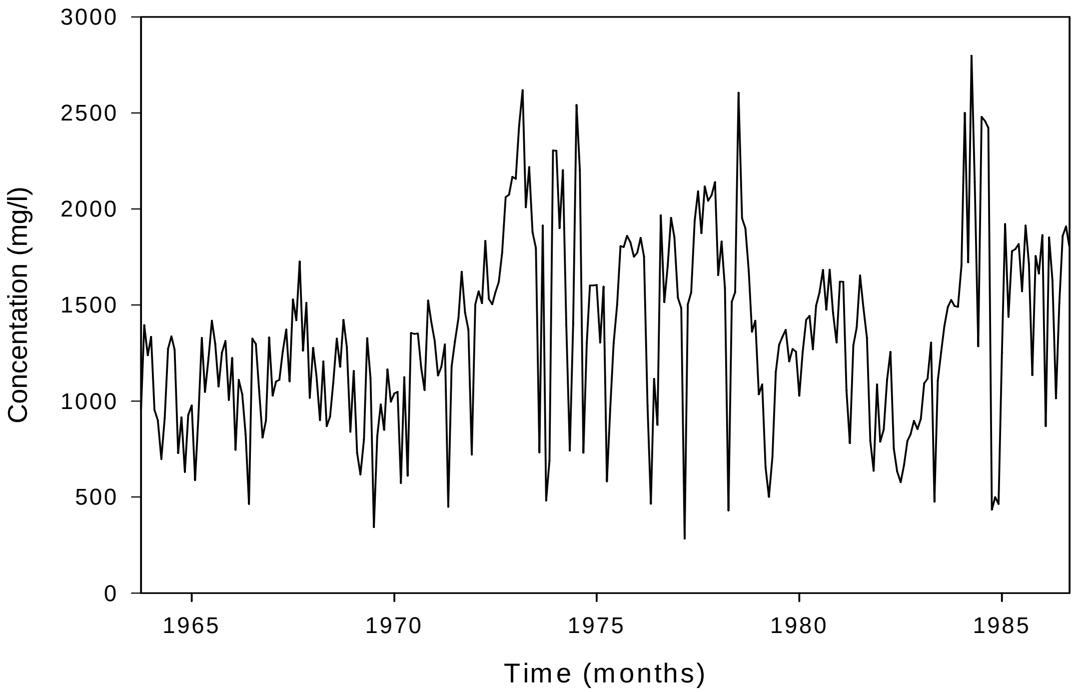

Figure 17. TDS Concentrations at the Dennis Gage

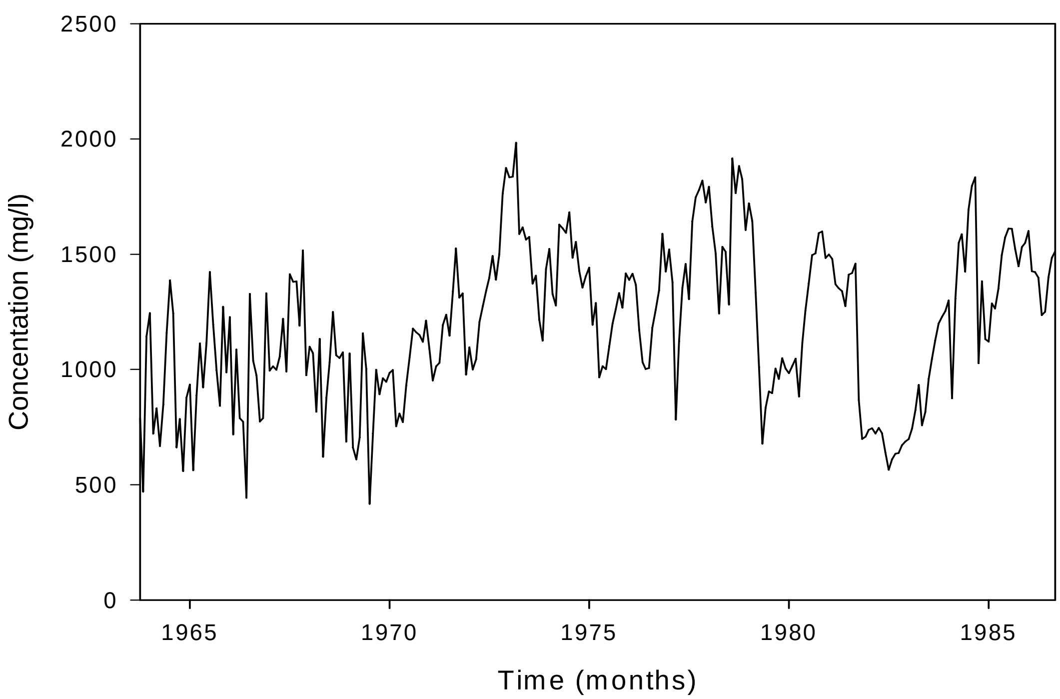

Figure 18. TDS Concentrations at the Glen Rose Gage

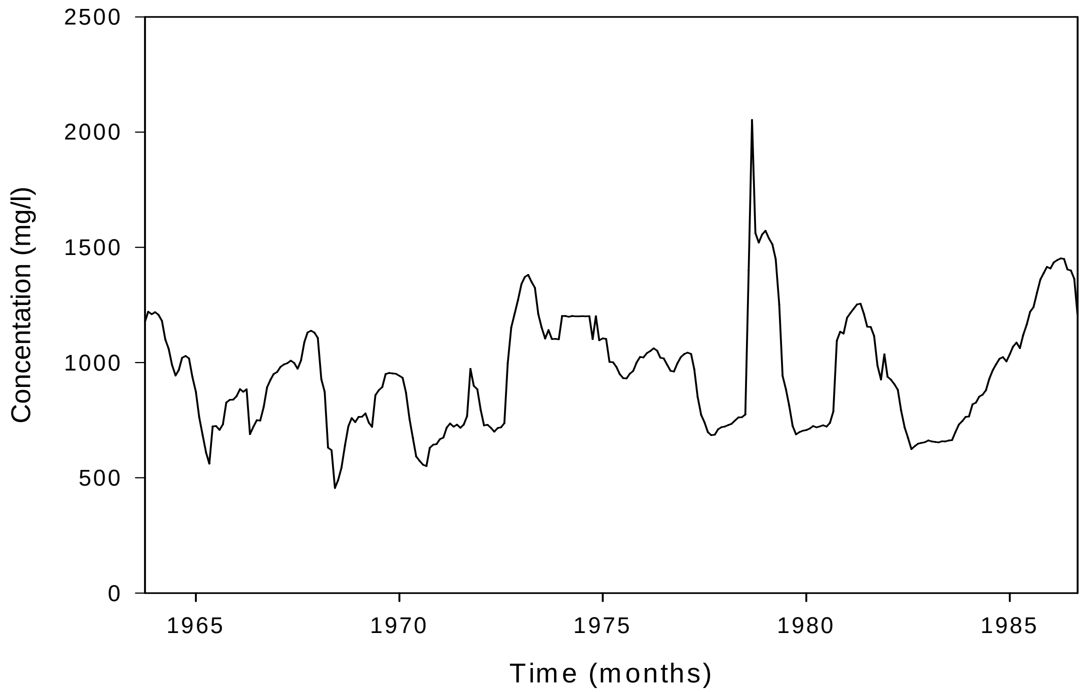

Figure 19. TDS Concentrations at the Whitney Gage

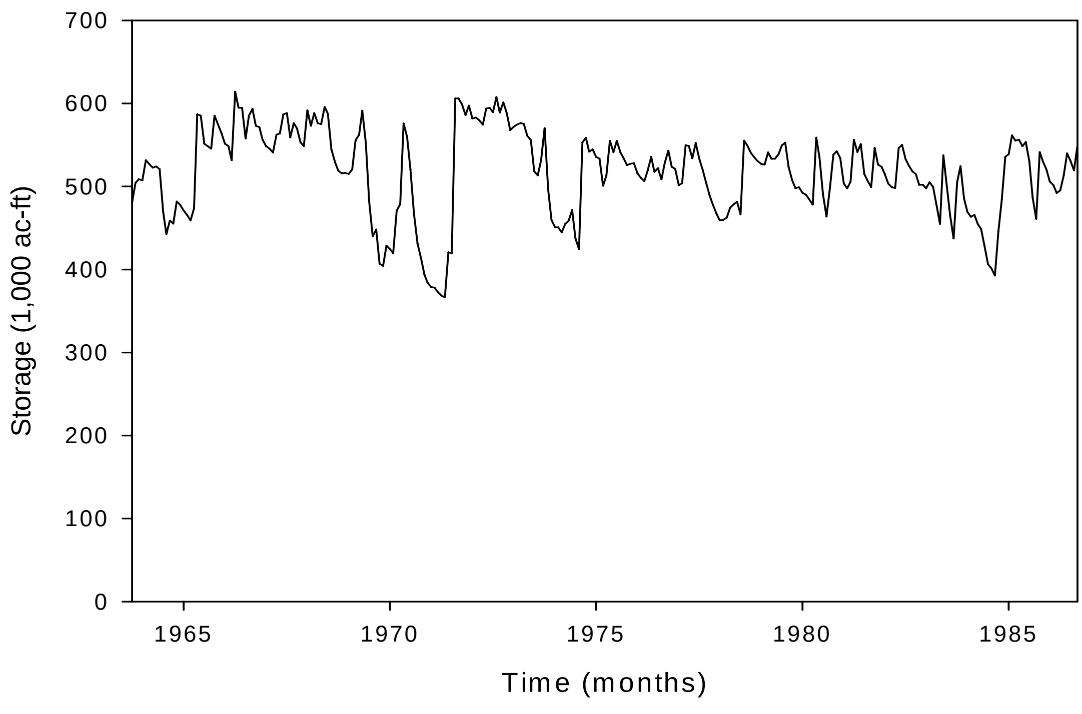

Figure 20. Storage Volumes in Possum Kingdom Reservoir

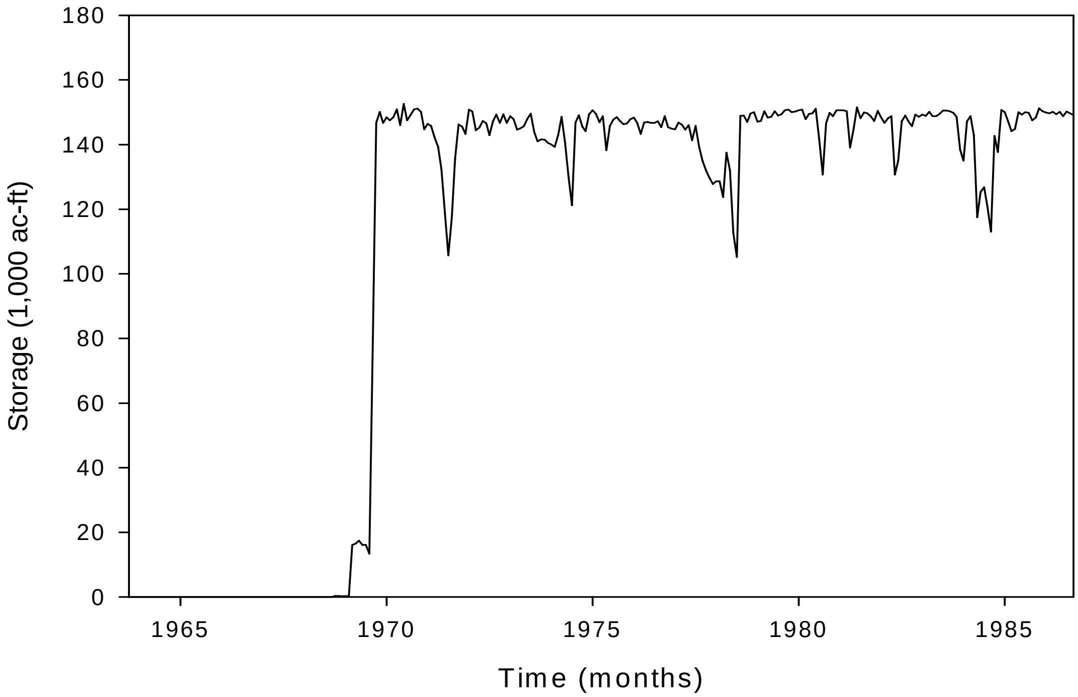

Figure 21. Storage Volumes in Granbury Reservoir

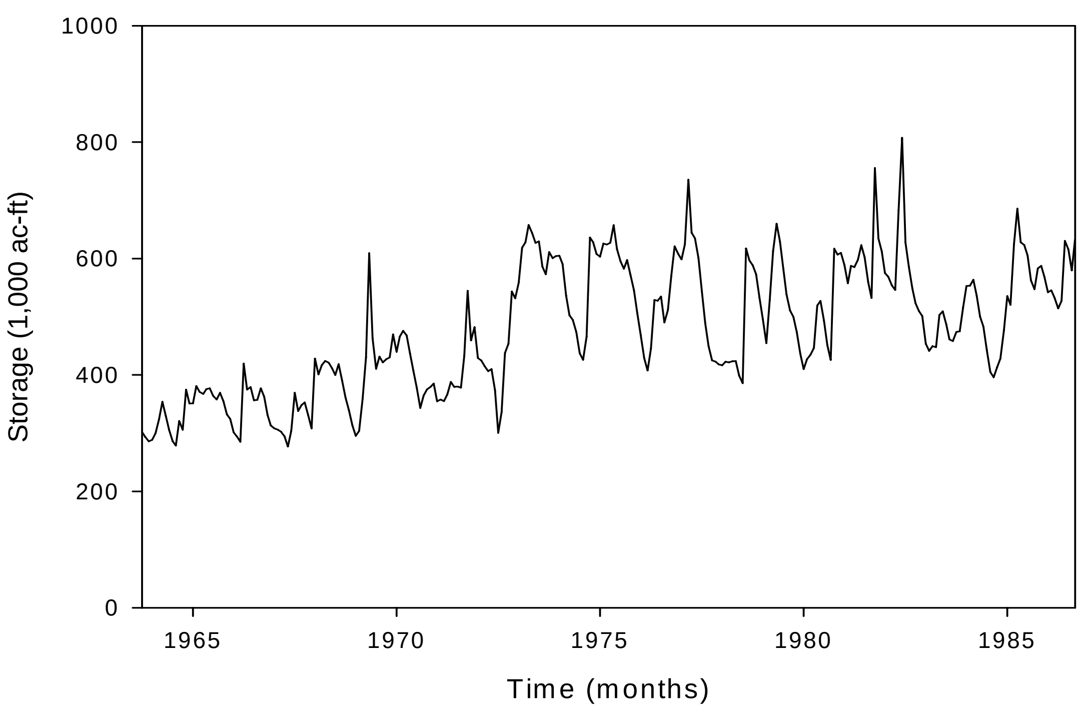

Figure 22. Storage Volumes in Whitney Reservoir

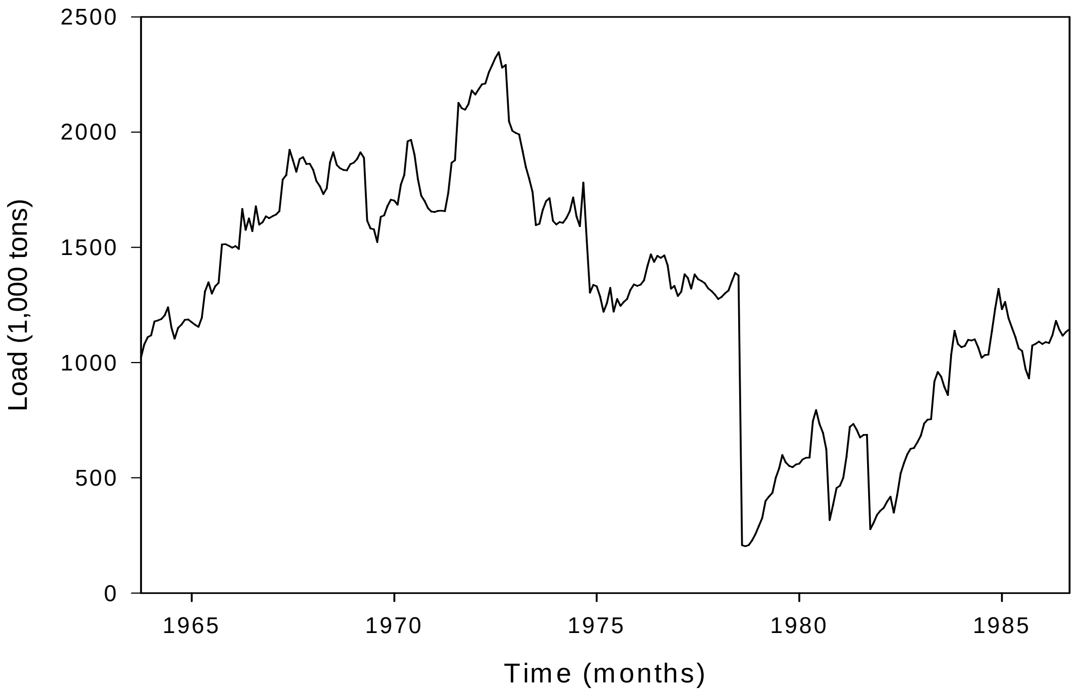

Figure 23. Storage Load in Possum Kingdom Reservoir
(Beginning Concentration = 1964-1986 Mean Outflow Concentration)

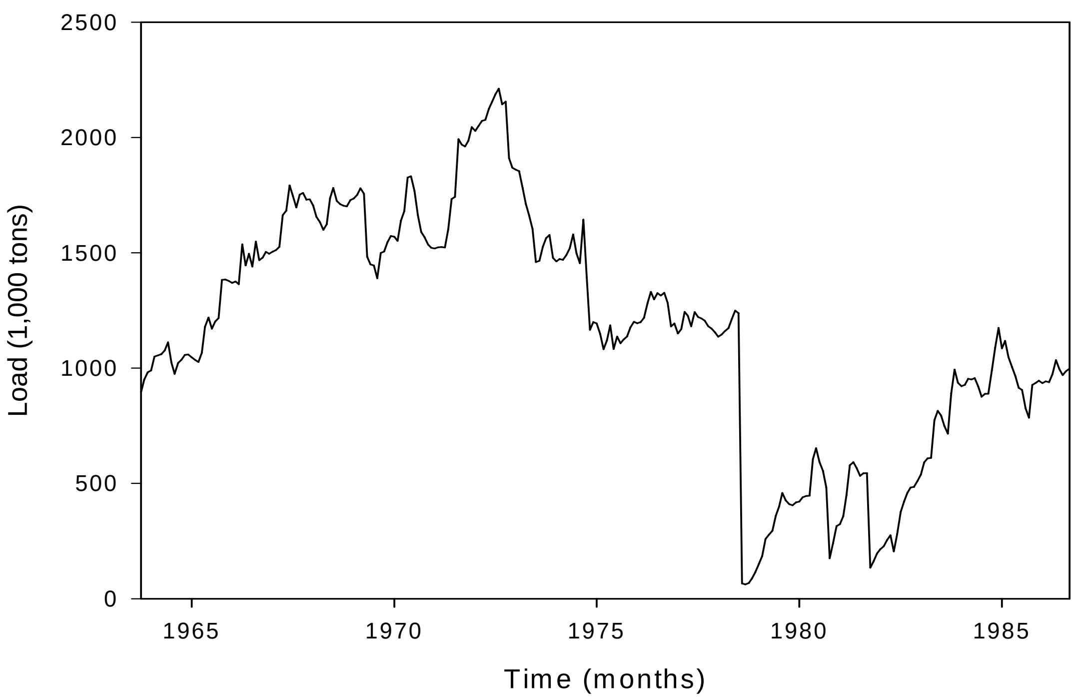

Figure 24. Storage Load in Possum Kingdom Reservoir
(1964-86 Mean Storage Concentration = 1964-86 Mean Outflow Concentration)

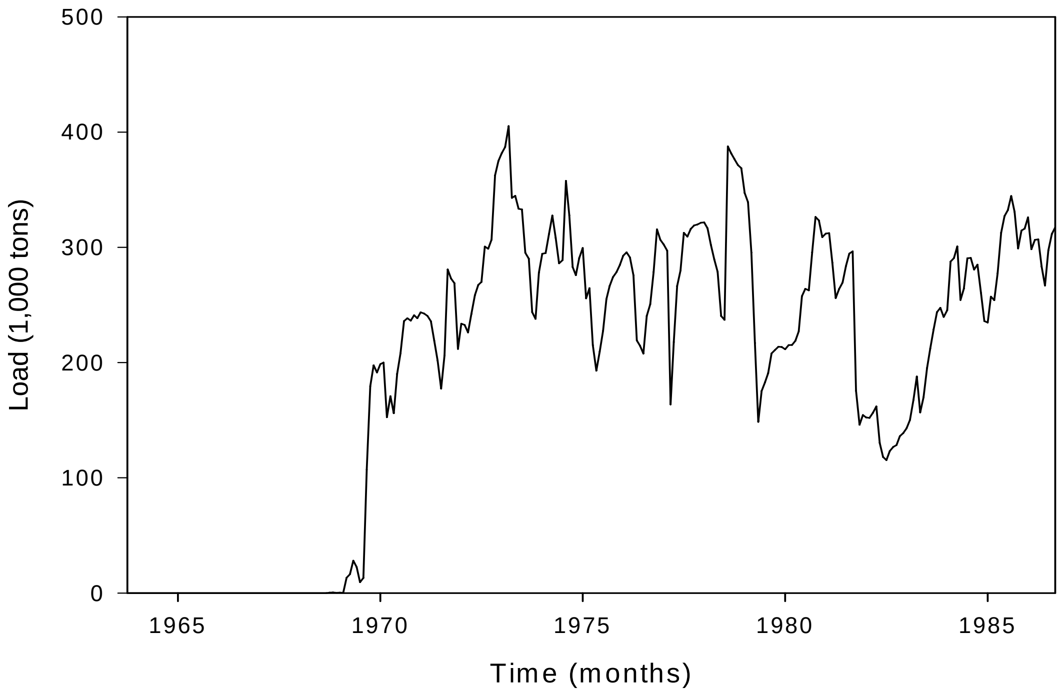

Figure 25. Storage Load in Granbury Reservoir

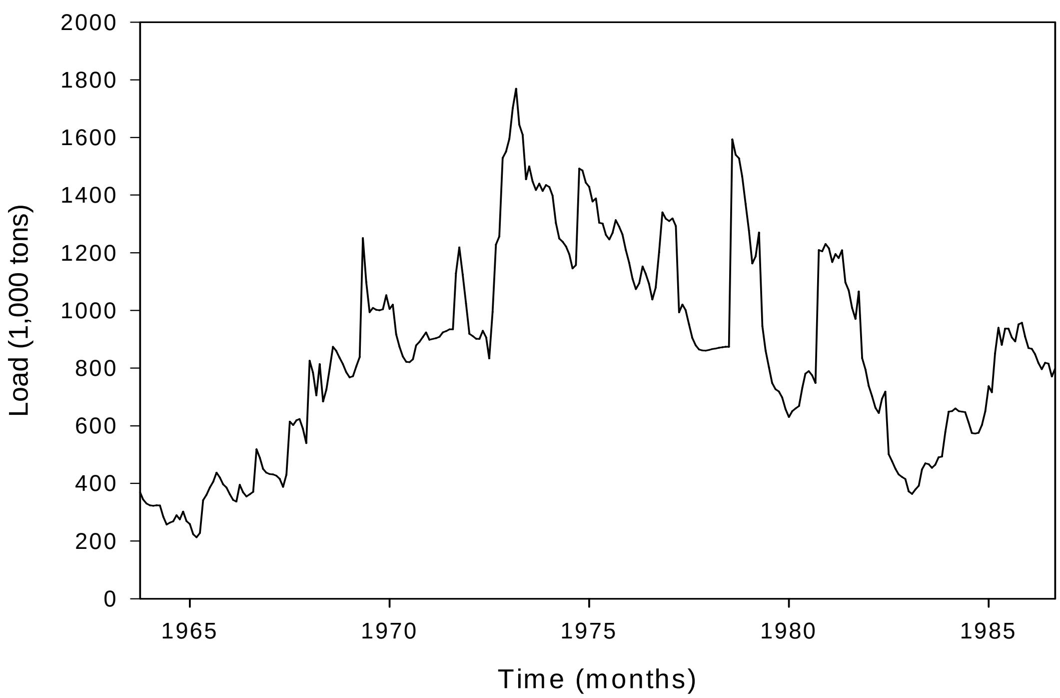

Figure 26. Storage Load in Whitney Reservoir
(Beginning Concentration = 1964-1986 Mean Outflow Concentration)

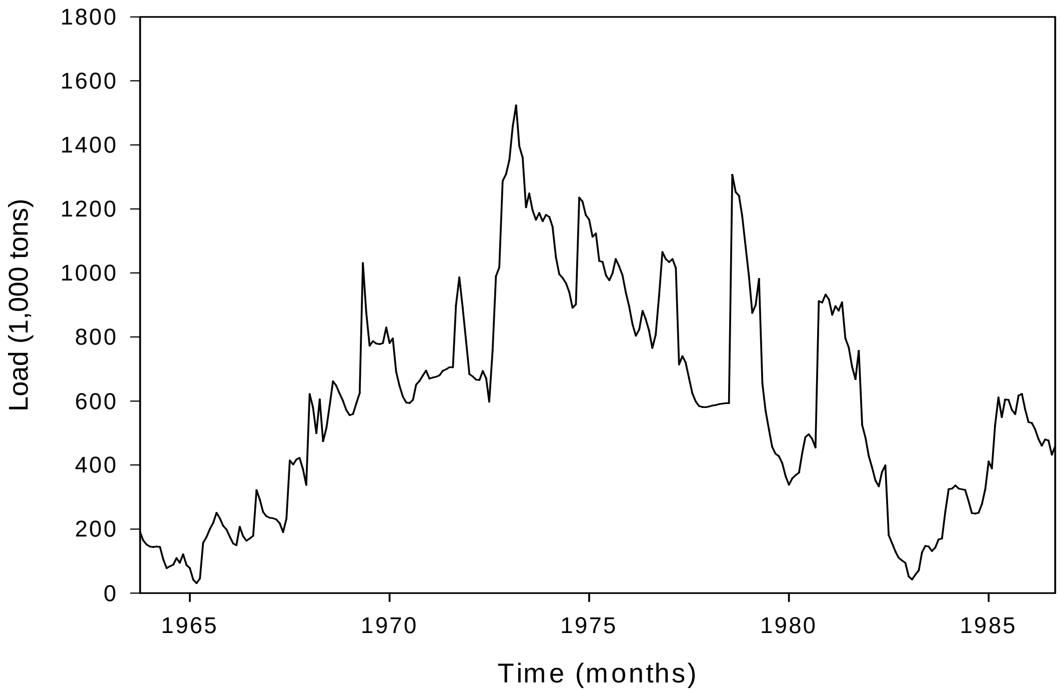

Figure 27. Storage Load in Whitney Reservoir
(1964-86 Mean Storage Concentration = 1964-86 Mean Outflow Concentration)

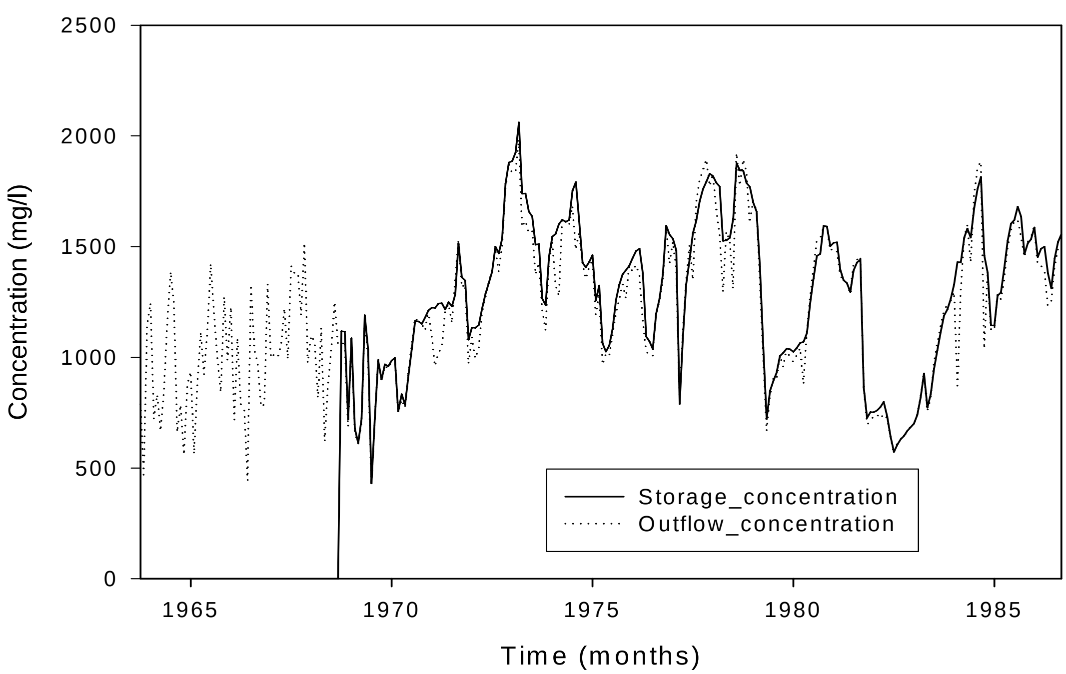

Figure 28. Comparison of Granbury Storage and Outflow Concentrations

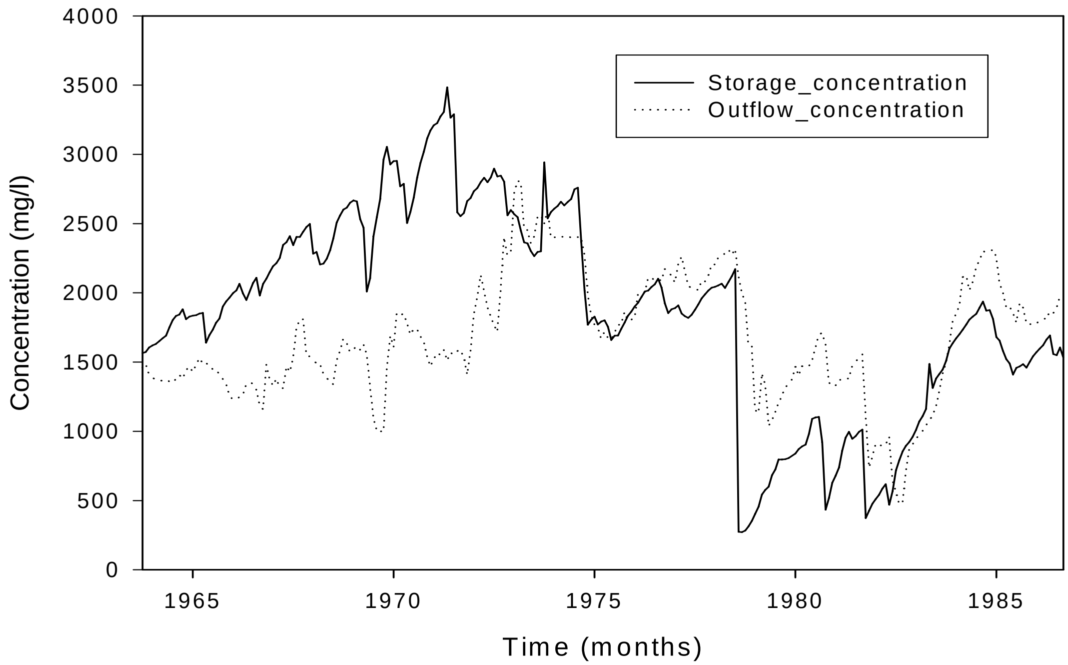

Figure 29. Comparison of Possum Kingdom Storage and Outflow Concentrations (Beginning Concentration = 1964-1986 Mean Outflow Concentration)

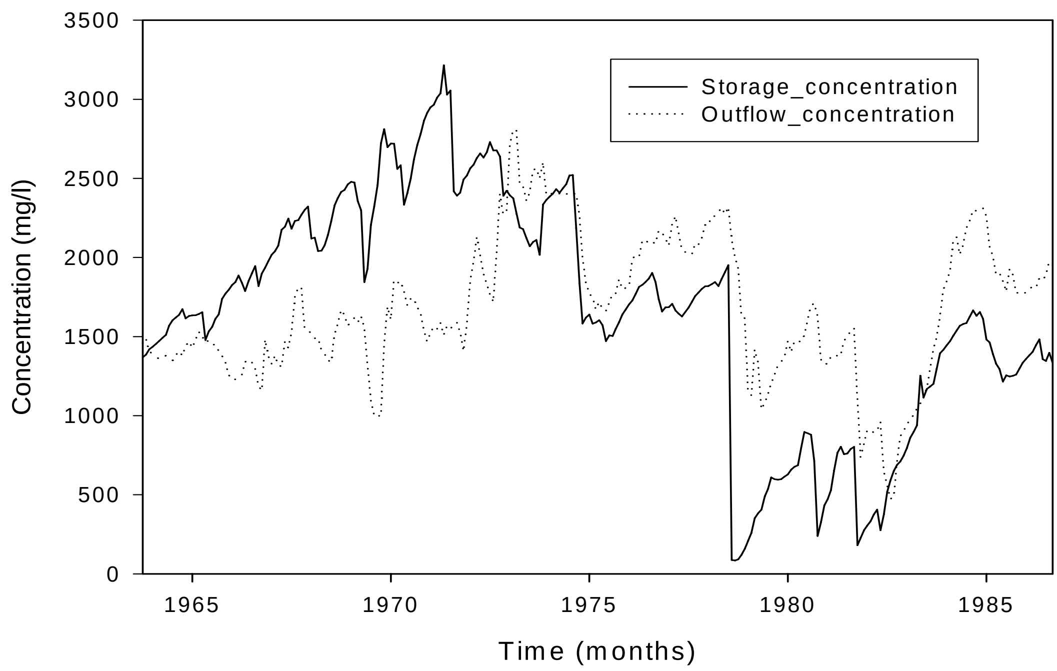

Figure 30. Comparison of Possum Kingdom Storage and Outflow Concentrations (1964-86 Mean Storage Concentration = 1964-86 Mean Outflow Concentration)

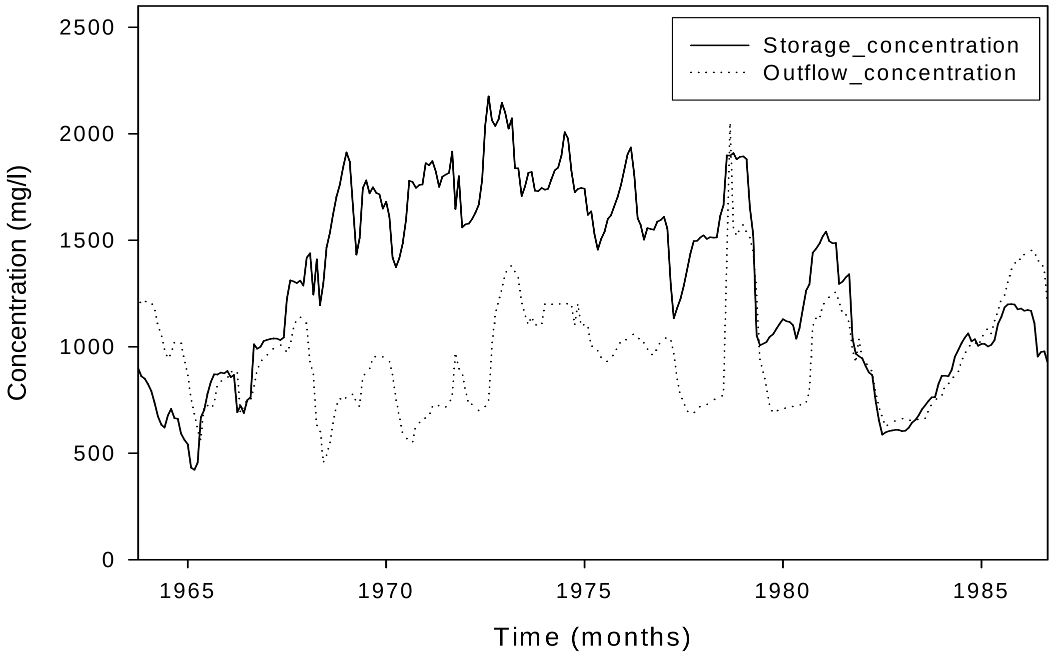

Figure 31. Comparison of Whitney Storage and Outflow Concentrations
(Beginning Concentration = 1964-1986 Mean Outflow Concentration)

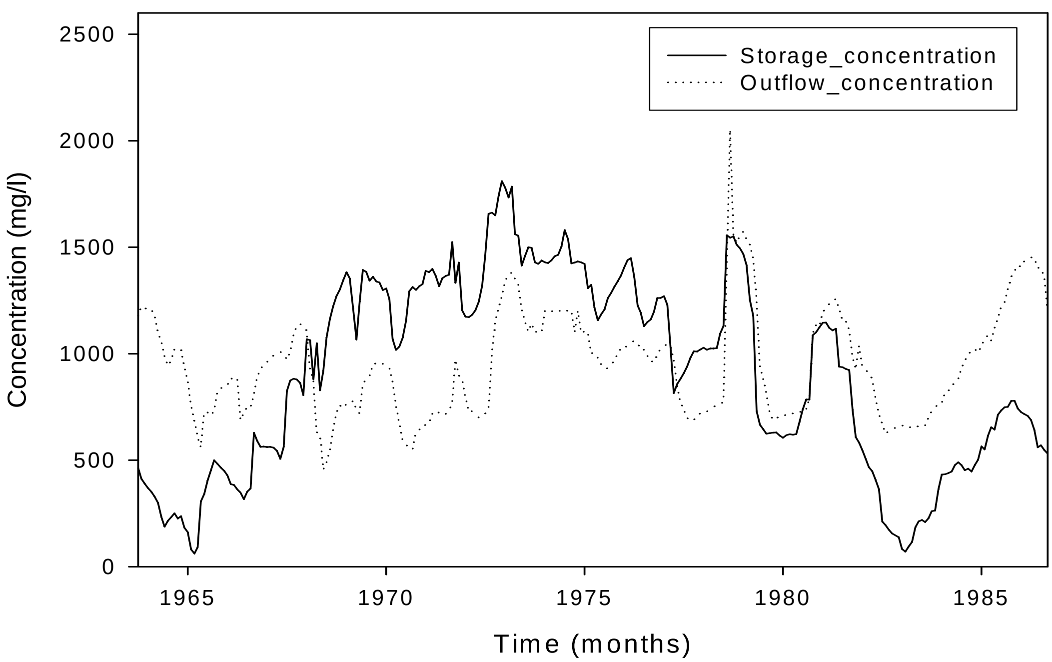

Figure 32. Comparison of Whitney Storage and Outflow Concentrations
(1964-86 Mean Storage Concentration = 1964-86 Mean Outflow Concentration)

Summary and Conclusions

The results of the water and salinity budget study may be viewed from the following two perspectives.

1. The investigation provides insight into the characteristics of flow and storage volumes and salinity loads and concentrations in the river/reservoir system independently of any other further studies.
2. The water and salinity budget study results also provide a database to support development and application of salinity features of the Water Rights Analysis Package (WRAP) modeling system for use in assessments of the water supply capabilities of the river/reservoir system.

Components of the Volume and Load Budgets

The 1964-1986 mean volumes and TDS loads for the components of the volume and load budgets for the four river reaches are tabulated in Tables 9 and 10. The component amounts sum to zero, balancing each budget. The corresponding concentrations determined by dividing the mean loads by the corresponding mean flow volumes are shown in Table 11. Reservoir storage volumes, loads, and concentrations are summarized in Tables 12 and 13.

Most of the inflow and outflow for each reach is reflected in the river flows at the upstream and downstream gages defining the upper and lower ends of the reach. The 1964-1986 mean flow at the Glen Rose gage (upstream of Lake Whitney) and Whitney gage (downstream of Lake Whitney) are 61,670 acre-feet/month and 74,193 acre-feet/month (Table 9). The mean TDS load at the upstream and downstream ends of the Glen Rose to Whitney reach are 91,927 and 93,538 tons/month (Table 10). The corresponding concentrations are 1,096 mg/l and 927 mg/l (Table 11).

The naturalized flows from the TCEQ WAM System dataset are shown as the last two lines of Table 9 though not a part of the actual volume budget. Naturalized flows were developed for the WAM System by adjusting gaged flows to remove the effects of water resources development and use. Naturalized flows represent natural river basin conditions without reservoirs and human water use. A comparison of the actual river flows in the first two lines of Table 9 with the naturalized flows in the last two lines provides a measure of the reduction in flows due to reservoir storage and water supply diversions in the river system upstream of the gages.

The net reservoir water surface evaporation less precipitation falling on the water surface at Lake Whitney is 3,603 acre-feet/month (Table 9). The volume in storage in Lake Whitney at the beginning of October 1963 was 332,300 ac-ft and at the end of September 1986 was 632,500 ac-ft (Table 12) resulting in a net increase in storage of 1,088 ac-ft/month (Table 9) when averaged over 276 months. The 1964-1986 mean storage volume of Lake Whitney of 475,928 acre-feet (Table 12) is equivalent to 6.4 months of outflow at the downstream mean flow rate of 74,193 acre-feet/month (Table 9). The Lake Whitney conservation pool storage capacity of 627,100 ac-ft (Table 5) is equivalent to 8.5 months of outflow at the rate of 74,193 acre-feet/month. The 570,240 acre-feet capacity of Possum Kingdom Lake is equivalent to 13.3 months of outflow at the mean rate of 42,998 acre-feet/month. The storage capacity of Granbury Lake is 2.5 months of its mean outflow.

Recorded water supply diversion data were available for Lake Granbury. The diversions averaged 923 acre-feet/month over the 1964-1986 period-of-analysis. Concentrations of the water diverted each month were assumed equal to the storage concentration at the beginning of the month in the load budget calculations.

The other inflow volume (F_{OI}) and other outflow volume (F_{OO}) are monthly amounts required to balance the volume budget each month. The other flows volume differences are the summation of all other components of the volume budget and are positive in some months and negative in other months. This volume difference was assigned to the variable F_{OI} if positive in a particular month and F_{OO} if negative. Of course, the volume difference required to balance the volume budget in a particular month is probably the net of both other inflows and outflows. Thus, the procedure adopted here of assigning the monthly volume differences as being either totally inflow (F_{OI}) or totally outflow (F_{OO}) is an approximation. The other inflows (F_{OI}) may include rainfall runoff from the incremental watersheds, stream underflow not measured by the upstream gage, water supply diversions, and water supply return flows. The other outflows (F_{OO}) may be stream underflow not measured by the downstream gage, seepage from the river and reservoir into the ground, evapotranspiration not accounted for by the reservoir surface evaporation term, and water supply diversions. The other flows (F_{OI} and F_{OO}) terms may also reflect timing effects of flows passing through the reach and inaccuracies in the other components of the water budget.

The 1964-1986 means of the other inflow volume (F_{OI}) and other outflow volume (F_{OO}) for the Glen Rose to Whitney reach are 18,938 and 2,124 acre-feet/month, respectively (Table 9). The other inflow volume (F_{OI}) should consist largely of rainfall runoff from the local incremental watersheds draining to the reaches between their upstream and downstream gages. The mean other inflow volume (F_{OI}) of 18,938 acre-feet/month is equivalent to a depth of 3.1 inches (Table 15) for the 1,371 square mile incremental watershed, which is a reasonable rainfall runoff depth for this region. The other outflow volumes (F_{OO}) reflecting diversions and losses are a relatively small component of the volume budget.

The other inflow load (L_{OI}) was estimated by applying a concentration of 270 mg/l to the other inflow volume (F_{OI}). This concentration is representative of other similar watersheds in the vicinity for which salinity measurements are available. The other outflow load (L_{OO}) was estimated by applying the monthly concentration at the downstream gage each month. The 1964-1986 means of the other inflow load (L_{OI}) and other outflow load (L_{OO}) for the Glen Rose to Whitney reach are 6,952 and 2,938 tons/month (Table 10).

The other load (L_X) term is the additional load difference required to balance the load budget for the South Bend to Graford (Lake Possum Kingdom) and Glen Rose to Whitney (Lake Whitney) reaches. The 1964-1986 mean load difference was calculated by summing the 1964-1986 means of the other components and then distributed to the 276 individual months in proportion to inflow loads for each month. The load balances are achieved automatically in the computational algorithms for the other two reaches. The other loads (L_X) required to balance the load budgets for the South Bend to Graford and Glen Rose to Whitney reaches are additional outflows of 137 and 996 tons/month, respectively (Table 10). Ideally L_X should be zero. The total mean 1964-1986 L_X values of 137 and 996 tons/month are close enough to zero to not be of concern. The L_X term represents inaccuracies in the other terms or additional flows not reflected in the other terms.

Spatial and Temporal Variations in River Flows, Loads, and Concentrations

Much of the salinity of the Brazos River originates from salt seeps and springs in sub-watersheds of the Salt Fork and Double Mountain Fork some distance upstream of the Seymour gage. Salt concentrations are extremely high on several of the small streams originating in these primary salt source sub-watersheds. Salinity concentrations of the Brazos River decrease in a downstream direction with inflows from low-salinity tributaries.

Mean flows and TDS loads and concentrations during water years 1964-1986 at the five gages included in the volume and load budgets plus three other gages are shown in Table 14 expressed as a percentage of the amounts at the Whitney gage. Locations of the gages are shown in Figure 2, and their river mile distances above the mouth of the Brazos River are included in Table 14. The Seymour gage on the Brazos River is located 405 miles upstream mean of the Whitney gage which is just downstream of Whitney Dam. The mean flow at the Seymour gage is 21.9 percent of the mean flow at the Whitney gage. However, the mean TDS load at the Seymour gage is 84.6 percent of the mean TDS load at the Whitney gage. The mean TDS concentration of the flow at the Seymour gage is 387 percent of the mean TDS concentration at the Whitney gage. Likewise, the mean flow at the Richmond gage 350 river miles below the Whitney gage is 558% of the mean flow at the Whitney gage. The mean TDS load and concentration at the Richmond gage are 204% and 37%, respectively, of the load and concentration at the Whitney gage.

Monthly river flows during the period October 1963 through September 1986 at the five gaging stations are plotted in Figures 5 through 9. The corresponding TDS loads are plotted in Figures 10−14. The mean monthly TDS concentrations are shown in Figures 15−19. The monthly flows, loads, and concentrations fluctuate greatly during the 23-year period-of-analysis. The monthly flow volumes show tremendous variability including the extremes of floods and droughts. TDS loads fluctuate along with the flow volumes. The TDS concentrations also exhibit dramatic variability. The fluctuations in concentrations are dampened somewhat by reservoir storage at the gages located below the dams.

An evident abnormity in the data plots is the dramatic decrease in the computed TDS load and concentration in Possum Kingdom Lake occurring during August 1978 shown in Figures 23 and 29. The TDS load and concentration drop in Lake Whitney (Figures 26 and 31) during August 1978 is also large but not nearly as dramatic as Possum Kingdom. Major flooding occurred in central Texas during the first week of August 1978 as a result of Tropical Storm Amelia. Much of the Hubbard Creek watershed received 15 to 30 inches of rainfall during July 31 to August 5, 1978. Hubbard Creek flows into the Brazos River just above the South Bend gage. The monthly inflow volume at the South Bend and Graford gages during August 1978 were 575,700 and 525,700 acre-feet, respectively. The storage contents of Possum Kingdom Lake increased from 466,500 ac-ft at the beginning of August to a peak of 557,200 ac-ft on August 14 and ended the month at 555,300 ac-ft. The storage contents in Lake Whitney increased from 385,900 ac-ft at the beginning of August to 638,700 ac-ft on August 21 and 617,500 ac-ft on August 31. The mean monthly TDS concentration of the August 1978 flows at the South Bend gage was 420 mg/l, compared to the 1964-1986 mean of 1,700 mg/l. The flood greatly lowered TDS concentrations through the river/reservoir system downstream of the South Bend gage. The USGS reported a significant impact of the flood on water quality in streams throughout central Texas.

Reservoir Storage Volumes, Loads, and Concentrations

Observed storage volumes for Lakes Possum Kingdom, Granbury, and Whitney are plotted in Figures 20−22. The corresponding computed TDS loads in storage are plotted in Figures 23−27. Storage concentrations are plotted along with outflow concentrations in Figures 28−32. Means are tabulated in Tables 12 and 13. The computed storage concentrations are volume-weighted mean monthly concentrations. Impoundment of water Lakes Possum Kingdom, Granbury, and Whitney began in 1941, 1970, and 1951, respectively. A sediment survey in 1974 indicated that the storage capacity of Possum Kingdom Lake had decreased significantly since initial impoundment in 1941. The storage volumes for October 1963 through September 1973 at Possum Kingdom Lake plotted in Figure 20 were adjusted in the volume budget calculations to partially correct the USGS data for sediment accumulation not otherwise reflected in the published data.

End-of-month storage loads and volume-weighted storage concentrations were computed for the three reservoirs. The computations for Lake Granbury are very different than for Lake Possum Kingdom and Lake Whitney.

Storage loads in Lakes Possum Kingdom and Whitney were computed for the end of each of the 276 months based on summing inflow and outflow loads for each month starting with the specified load shown in Tables 12 and 13 in storage at the beginning of October 1963. The storage concentration at the end of September 1986 automatically equals the October 1963 beginning concentration in the load balance computations. The load at the beginning of October 1963 was estimated by combining the observed beginning storage volume with an assumed beginning concentration estimated based alternatively on the following two different premises.

1. The concentration at the beginning of October 1963 equals the 1964-1986 mean outflow concentration at the Graford gage for Lake Possum Kingdom and Whitney gage for Lake Whitney.
2. The 1964-1986 mean storage concentration equals the 1964-1986 mean outflow concentration. The October 1963 beginning concentration was adjusted until the long-term mean storage and outflow concentrations were the same.

The effects of the two alternative premises on the calculated storage loads and concentrations can be examined by comparing Figures 23 and 24, 26 and 27, and 29 through 32.

Water Supply Capabilities

Salinity is a major determinant of where and how the water resources of the Brazos River are used. Natural salt pollution is severely constraining the beneficial use of large amounts of water from the Brazos River and Lakes Possum Kingdom, Granbury, and Whitney. The U.S. Environmental Protection Agency secondary drinking water standards suggest a maximum TDS limit of 500 mg/l set on the basis of health effects and taste preferences and because conventional treatment processes do not remove salinity. Salts also damage pipelines, equipment, household appliances, and industrial facilities. Salinity is also a major consideration in irrigated agriculture. Acceptable salt concentrations for irrigation vary greatly depending on the type of crop, soil conditions, climate, and the relative amounts and timing of rainfall versus supplemental irrigation. TDS concentrations of less than 1,000 mg/l are usually preferred for irrigation.

Desalination is very energy intensive and much more expensive than conventional municipal and industrial water treatment processes. The Brazos River Authority operates a desalination plant that allows water withdrawn from Lake Granbury to supplement municipal water supplies for the City of Granbury. However, Brazos River salinity constraints are mitigated primarily by using the water resource through water supply diversions in the lower Brazos River after dilution from low-salinity tributary inflows.

The 1964-1986 mean TDS concentration at the Whitney gage is 927 mg/l, and mean concentrations are higher at all gages located on the Brazos River upstream of the Whitney gage (Table 9). The mean monthly concentrations at the Whitney gage plotted in Figure 19 are almost always significantly greater than 500 mg/l and exceed 1,000 mg/l during 39.5 percent of the time. Most of the water supplied by the Brazos River Authority to its customers from releases from Lakes Possum Kingdom, Granbury, and Whitney is diverted from the lower Brazos River at sites between the College Station gage (Table 14 and Figure 2) and the mouth of the river at the Gulf of Mexico. Lakes Possum Kingdom, Granbury, and Whitney are components of the 13-reservoir BRA system. Lake Whitney contains a large amount of storage capacity, but water use from lakeside diversions is severely constrained by salinity. Salinity is also a problem in the lower reaches of the Brazos River below the College Station gage but the concentrations are much lower due to dilution from tributary inflows that may include releases from BRA reservoirs as well as unregulated flows.

WRAP Model Development and Application

The Texas Commission on Environmental Quality (TCEQ) Water Availability Modeling (WAM) System consists of the generalized Water Rights Analysis Package (WRAP) river/reservoir system simulation model and input datasets for the 23 river basins of Texas. The WAM System is routinely applied by agencies and consulting firms in regional and statewide planning studies and administration of the water rights permit system, but without consideration of salinity. Previous research and development at Texas A&M University has included incorporation of salinity simulation features into WRAP. However, the salinity features of WRAP are still in a developmental stage and have not yet been applied in actual water availability modeling studies.

The continuing current research will improve capabilities for incorporating salinity and measures for dealing with salinity in assessments of water availability for municipal, industrial, agricultural, and other water uses. A WRAP modeling study will be performed for the Brazos River Authority reservoir system with a particular focus on evaluating the potential for enhancing the water supply capabilities of Lake Whitney. The water and salinity budgets documented by this report will provide a dataset for use in both improving the salinity modeling methods incorporated in WRAP and determining input parameters for the Lake Whitney and associated Brazos River Authority system-wide water availability assessment studies.

A WRAP input dataset will be developed using selected data from the volume and water budget time series data for purposes of experimenting with modeling methods. Computed storage and outflow concentrations from the WRAP simulation results will be compared with the data from the salinity budget study. The salinity budget data will also be used in developing salinity input for a WAM System water availability assessment for the Brazos River system.

The comparisons of storage and outflow concentrations in Figures 29 through 32 are particularly pertinent to the WRAP model development and application effort. Storage concentrations computed within WRAP are volume-weighted mean monthly concentrations just like those developed in the salinity budget study. In reality, concentrations vary spatially throughout the reservoir at any point in time. The upper end of the reservoir will contain water with concentrations similar to the concentrations of recent river inflows. The outflow concentration at a point in time is the concentration of water stored in the reservoir near the outlet structure, which is different than the volume-weighted storage concentration. The long-term mean outflow concentration will likely be representative of long-term volume-weighed storage concentrations but large variations in concentrations occur in individual months. A lag time of perhaps many months may be required for the salt entering the reservoir to be mixed and transported to the reservoir outlet. The salinity budget dataset will support further studies of methods for incorporating lag or retention time and other concepts in salinity routing methodologies.

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Lake Whitney Bacterial Assessment
DRAFT Final Report

Phase IB

Study Element No. 7: Bacterial Assessment

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USDOE

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION/BACKGROUND

The Safe Water Drinking Act of 1974 was created to help ensure the safety of drinking water in the United States. Amendments instituted in 1996 require the evaluation of public drinking water for the presence of potentially harmful contaminants. To fully implement this requirement, it is also necessary to conduct a thorough analysis of the surface waters and associated watershed that provide source waters for water treatment plants that produce drinking water. Surface waters are often contaminated with microbes from agricultural run off, sewage effluent, or from various wildlife. These contaminants commonly include *Escherichia coli* and other coliform bacteria.

People can be potentially exposed to these contaminants by drinking water from which the organisms have not been completely removed or through direct exposure to animals or their fecal material that is contaminated with the organisms. In addition, persons can be exposed to these organisms during recreational water activities through the accidental ingestion of raw water. Given the possibility of exposure to potential pathogens in surface waters and of transmission of these pathogens into drinking water, it is critical to evaluate lakes, surface waters, and associated watersheds for their presence. Once watersheds with elevated levels of the microorganisms are identified, preventive measures can be taken to reduce the health-risk to potentially exposed persons. The current study implements the U.S. Safe Water Drinking Act Amendments by assessing water quality in Lake Whitney and its immediate watershed by determining the levels of potential water contaminants including *E. coli* and total coliform bacteria that may adversely affect human health.

1.1. Bacteria in water supplies and surface waters

E. coli and other coliform bacteria can be found naturally in the environment and also inhabit the gut of warm-blooded animals. *E. coli* is always found in animal or human stool samples, and coliform bacteria are frequently isolated from this source as well. These organisms are usually isolated from feces or water polluted with feces and are associated with outbreaks of disease. Although these strains are not usually pathogenic, their presence in water samples indicates a likelihood of fecal contamination. Since there are some pathogenic strains of *E. coli* and *E. coli* is always found in fecal material, *E. coli* is an especially important indicator of possible fecal contamination and possible presence of other more pathogenic microbes.

The EPA has published a method for detecting *E. coli* and total coliform bacteria in water samples (EPA Publication #821/R-97/004, EPA 2000). This modified method consists of a membrane filter medium (MI agar) that allows the simultaneous detection and enumeration of the bacteria in 24 hours. The test distinguishes between *E. coli* and other coliform bacteria on the basis of their specific enzymatic activity. MI agar contains two enzyme substrates, the fluorogen 4-Methyumbelliferyl-β-D-galactopyranoside (MUGal), and the chromogen Indoxyl-β-D glucuronide (IBDG). These allow the detection of the enzymes β-galactosidase and β-glucuronidase produced by total coliform bacteria and *E.*

coli respectively. This test allows for a wide range of sample volumes to be tested and provides rapid results. Some limitations of the method are difficulties in enumeration due to occasional indistinguishable colonies and the occasional growth of non-*E. coli* or non-coliform isolates on the MI agar. In addition, the optimal volume for obtaining a good total coliform count may produce too few *E. coli* or vice versa.

1.2 Study Objectives

Monitoring and preservation of watersheds and source waters for water treatment facilities is critical to ensuring that public drinking water supplies are of the highest quality possible. These surface waters are often contaminated with microbes from a variety of sources including microbes from fecal contamination in particular. The amount of water treatment that is necessary to produce drinking water and the subsequent quality of that drinking water are directly proportional to the quality of the surface waters feeding into the reservoir and treatment facility. Therefore, to effectively improve drinking water quality, it is important to evaluate the levels of microbes in the watershed and identify potential sources of contamination so that these can subsequently be removed or improved.

The presence of the bacterium, *Escherichia coli*, and other total coliform bacteria in water are often indicators of water fecal contamination. The purpose of the current study is two-fold. First, the current research provides a comprehensive, longitudinal evaluation of potential pathogen levels in the waters of Lake Whitney. Second, the current study assesses *E. coli* and total coliform bacteria levels during wet weather conditions.

Specific objectives include:

1. Assess concentrations of *E. coli* and total coliform bacteria at approximately monthly time intervals at eight locations across the lake to determine spatial and temporal patterns of bacterial contamination.

2. Assess concentrations of *E. coli* and total coliform bacteria at the eight routine sampling sites plus an additional nine sites under wet-weather conditions to determine how bacterial contaminant patterns vary under storm conditions.

2.0 METHODS

2.1. Study Location

This bacterial assessment study was conducted on Lake Whitney, Texas. Eight routine (monthly baseline) and an additional nine storm-event sampling sites were selected for this study (Figure 1, Table 1).

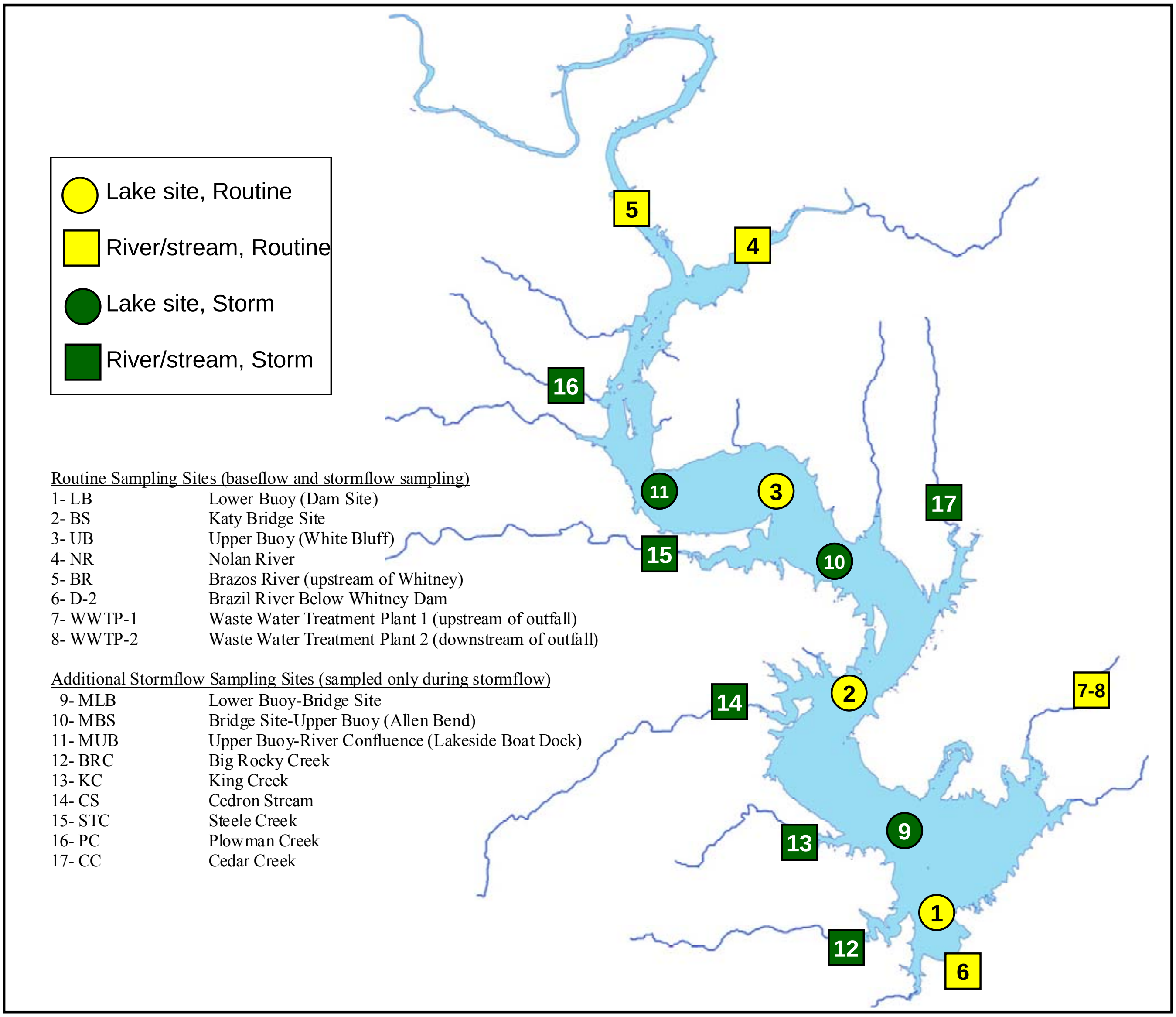

Figure 1. Sample sites for Longitudinal Analysis of Bacterial Pathogen Indicators in Lake Whitney, TX (2006-2008). The main lake sampling sites are shown as circles and the inflowing/outflowing rivers and streams are shown as squares. The eight routine sites are colored in yellow while the additional nine stormflow sampling sites are shown in green.

Table 1. Sampling sites on Lake Whitney (site numbers correspond to symbols on Figure 1)

Routine Sites	Abbreviation	UTM Zone 14 N	UTM Zone 14 E	When Sampled	Location Type	Sampling Protocol	YSI Data?
1- Lower Buoy (Dam Site)	LBS, LBM, LBB	3526700	0653903	All	Lake	3-depths	Yes
2- Katy Bridge Site	BSS, BSM, BSB	3536736	0651241	All	Lake	3-depths	Yes
3- Upper Buoy (White Bluff)	UBS, UBM, UBB	3543860	0649064	All	Lake	3-depths	Yes
4- Nolan River	NR	3558179	0650507	All	River/Stream	Sub-surface only	No
5- Brazos River	BR	3555086	0642011	All	River/Stream	Sub-surface only	No
6- Below Dam	D-2	3526772	0654410	All	River/Stream	Sub-surface only	No
7- Waste Water Treatment Plant 1	WWTP-1	3535811	0658494	All	River/Stream	Sub-surface only	No
8- Waste Water Treatment Plant 2	WWTP-2	3534772	0656722	All	River/Stream	Sub-surface only	No
Additional Storm Sampling Sites							
9- Lower Buoy-Bridge Site (Big Rocky Creek)	MLBS, MLBM, MLBB	3531528	0650371	Storm	Lake	3-depths	Yes
10- Bridge Site-Upper Buoy (Allen Bend)	MBSS, MBSM, MBSB	3540057	0650837	Storm	Lake	3-depths	Yes
11- Upper Buoy-River Confluence (Lakeside Boat Dock)	MUBS, MUBM, MUBB	3543995	0642896	Storm	Lake	3-depths	Yes
12- Big Rocky Creek	BRC	3527934	0648294	Storm	River/Stream	Sub-surface only	No
13- King Creek	KC	3532462	0644787	Storm	River/Stream	Sub-surface only	No
14- Cedron Stream	CS	3536057	0645871	Storm	River/Stream	Sub-surface only	No
15- Steele Creek	STC	3541747	0643232	Storm	River/Stream	Sub-surface only	No
16- Plowman Creek	PC	3548530	0642229	Storm	River/Stream	Sub-surface only	No
17- Cedar Creek	CC	3542936	0653772	Storm	River/Stream	Sub-surface only	No

2.2. Sampling

The lake was sampled 26 times between November 2006 and May 2008. The three primary in-lake sites (yellow circles on Figure 1) were selected that corresponded to the sites where long-term buoys were established for data collection for the salinity and hydrodynamic modeling tasks. Five river/stream sites (yellow squares on Figure 1) were added to the baseline sampling design beginning in January 2007.

The eight routine sampling sites (yellow markers in Figure 1) were sampled 26 times during for nineteen months between November 2006 and May 2008. Fifteen sampling dates were under baseflow conditions while 11 were immediately following significant rainfall events in the watershed and considered stormflow samples. The sites consisted of three main-lake sites (sites 1-3, Lower Bay, Bridge Site and Upper Bay respectively), two sites on the main rivers flowing into the lake (sites 4-5, Nolan River and Brazos River, respectively), one site below the Lake Whitney dam discharge (site 6) and sites above and below the City of Whitney waste water treatment plant outfall (sites 7-8).

During storm events, an additional nine sites [three additional lake sites (green circles) and six additional stream sites (green squares)] were sampled. The determination for storm sampling was made based on observed discharge increase of about 20% in stream flow for streams flowing into the lake. Only one stormflow sampling was conducted in any given month. Typically widespread rainfall of two or more inches was needed to increase stormflow sufficiently for storm sampling. There were 11 such sampling events during the study period.

Subsurface water samples were collected and maintained on ice until returned to the lab at Baylor University. Samples were analyzed for *Escherichia coli* (*E. coli*) and total coliform bacteria using modified EPA membrane filter methods. Duplicate samples were also collected at select locations for quality control (QC).

Water samples were tested for the presence of the following representative pathogens according to the approved protocols established by the EPA (Table 2).

Table 2. Methods for assessing target pathogens.

Organism(s)	*Method*
E. coli	EPA Modified Membrane Filter Method (EPA 821-R-97-004) or equivalent
Total coliform bacteria	EPA Modified Membrane Filter Method (EPA 821-R-97-004) or equivalent

2.3. Testing for Escherichia coli and total coliform bacteria

Method summary (Modified EPA Membrane Filter Method EPA # 600-R-00-013):

a. Water filtration: Water samples were collected and transported back to the laboratory. Water samples (100 ml) were filtered with a 0.45 *u*m filter. This sample was diluted as appropriate for obtaining optimum colony counts.
b. Incubation of filters: The filters were then placed on MI agar plates and incubated for 24 hours at 35°C. MI agar contains two substrates that allowed *E. coli* and non-*E. coli* coliform bacteria present in the sample to be detected on the basis of color change or fluorescence.
c. Analysis: The plates were analyzed for the presence and quantity of *E. coli* or other coliform bacteria
d. Confirmatory Analysis: We utilized the Biolog Microstation carbon utilization patterns for further confirmation of isolate identity. 10% of the total isolates that were counted on the filters (from all of the sample sites combined) were randomly selected and inoculated onto Biolog plates in order to get their carbon utilization profiles. The Biolog system was then used to confirm that these isolates did indeed belong to the *Escherichia* genus (based on their carbon profiles) – confirming the color change results from the media. The Biolog was used to confirm that the isolates on the filter paper that were thought to be *E. coli* actually were *E. coli* when their carbon utilization profiles were analyzed. All the isolates that were used for confirmation purposes were confirmed to be from the genus *Escherichia* or, when a genus could not be reasonably determined based on the Biolog's calculation, *Escherichia* was always one of the possible options that were included in the Biolog reading. This was still considered by the lab to be confirmation of the color change results from the media.
f. Quality control: Quality was assured through reproducible calibration and testing of the filtration, growth on MI agar, quantification, and detection methods.

Table 3. Expected reaction of target pathogens to different forms of light.

Organism	Reaction Under Ambient Light	Reaction Under Ultraviolet Light
E. coli	Blue colonies	Blue/green fluorescence Blue/green colony with fluorescent edge
Non-*E. coli* coliform bacteria		Blue/white fluorescent

Modification:

The confirmatory test was added to the protocol to ensure accurate detection of *E. coli* by means of strain typing through carbon utilization patterns. Quality-control testing for the Biolog Microstation Identification method was conducted to establish the accuracy and sensitivity of the method. Any necessary confirmation for this method involved the Biolog Microbial Identification System and standard biochemical testing.

Benefits of the modification:

1. Reduces detection problems due to bacterial overgrowth.

Turbid water samples may affect the detection of *E. coli* or other coliform bacteria and contain increased concentrations of these organisms. Water samples were serially diluted so that appropriate colony counts were obtained.

2. Reduce frequency of false negative or false positive results.

Including a Biolog confirmatory test in the protocol limits the possibility of false negative or false positive results from the method.

2.4. Data Analysis

The concentration of *E. coli* and total coliform bacteria in duplicate samples from each station were determined monthly. Geometric means were used to compare data at each station. A geometric mean is the average or mean of log transformed data which is then converted back to base 10. The log-transformation lessens the effect of a few extreme high values. Sample values of zero (0.0) were converted to 1.0 for estimation of the geometric mean since the log of zero is undefined.

3.0 RESULTS

3.1. E. coli concentrations: Spatial Variability

The long-term pattern of *E. coli* levels in Lake Whitney varied significantly among the 17 stations sampled (Figure 2). *E. coli* geometric means of the monthly samples for the main lake station were well below the State of Texas Water Quality Standards (WQS) long term geometric mean for contact recreation (126/100mL; TNRCC 2002) (Figure 2).

E. coli geometric means of the monthly samples for the inflowing streams and rivers were found to be significantly higher than in the main lake. Five of the ten sampled inflowing streams and rivers exceeded the TCEQ criteria. Only one stream on the west side of the lake exceeded the TCEQ criteria (#13, King Creek) while all of the streams on the eastern, more heavily populated side of the lake exceeded the contact recreation criteria (Nolan River- #4, Cedar Creek- #17 and both WWTP sites- #7 & #8).

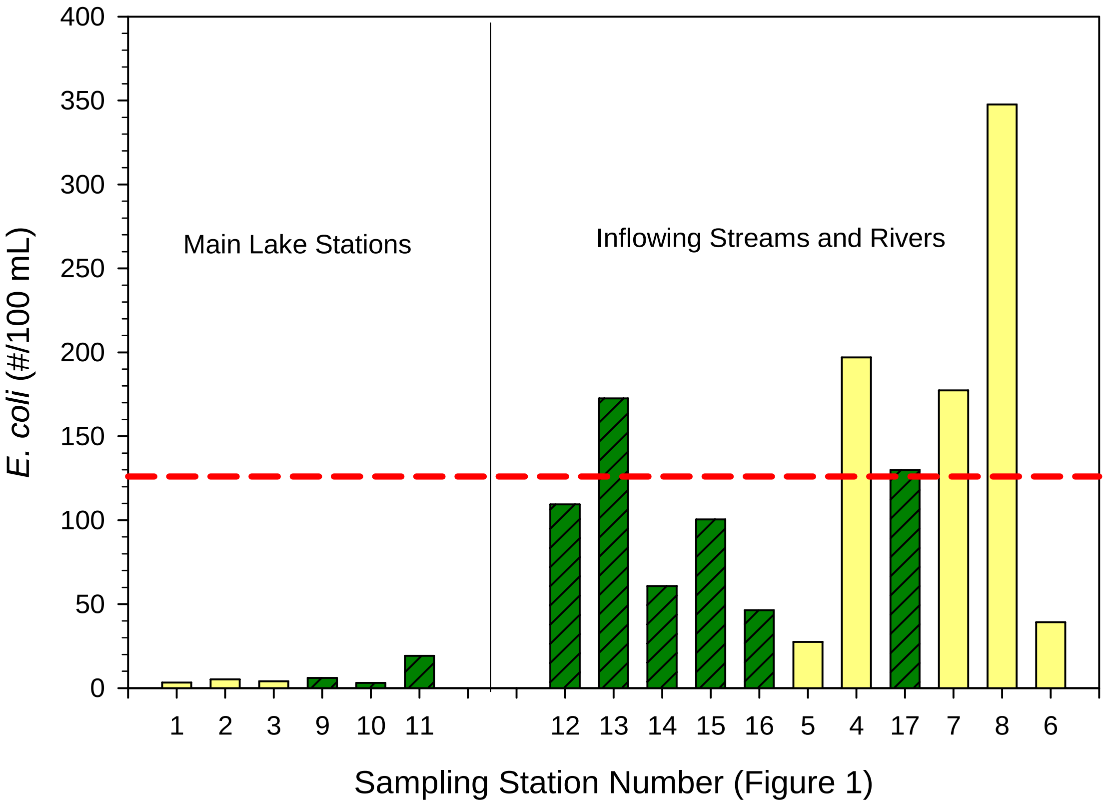

Figure 2. *E coli* geometric mean of samples collected at each station between November 2006 and May 2008. Yellow bars are the routine sampling stations sampled during all sampling events (n=26) while green hatched bars are stations sampled only during storm sampling (n=11). The horizontal dashed line represents the State of Texas (TCEQ) Long Term Geometric Mean Limit for Contact Recreation (126/mL).

3.2. E. coli concentrations: Temporal Variability

The levels of *E. coli* at the main lake sites were consistently low and never approached the Water Quality Standard Single Sample Criteria of 394/100 mL (Figures 3 and 4) except for the for the first storm flow sampling event when the levels at MUB and MBS were very high. Overall for the main lake sites, only two of the 108 samples collected (<2%) exceeded the single sample criteria, and both of these occurred during the first significant storm event in the winter of 2007.

E. coli levels were considerably higher in the Brazos and Noland Rivers. The Brazos and Noland River sites exceeded the single sample criteria several times, especially during storm-flow sampling (Figure 3). *E coli* levels in the minor inflowing streams (sampled only during wet-weather) also showed some high values, especially between January and May 2007 after which time the levels remained below the criteria. Overall the inflowing rivers and streams exceeded the single sample criteria in 20 of the 116 (17%) samples collected.

E. coli levels downstream of Lake Whitney (Site #6, D-2) exceeded the single sample criteria only twice in the spring of 2007. In contrast, the sites upstream and downstream of the City of Whitney Waste Water Treatment Plant (Sites 7-8, WWTP-1,2) about half the time (Figure 3).

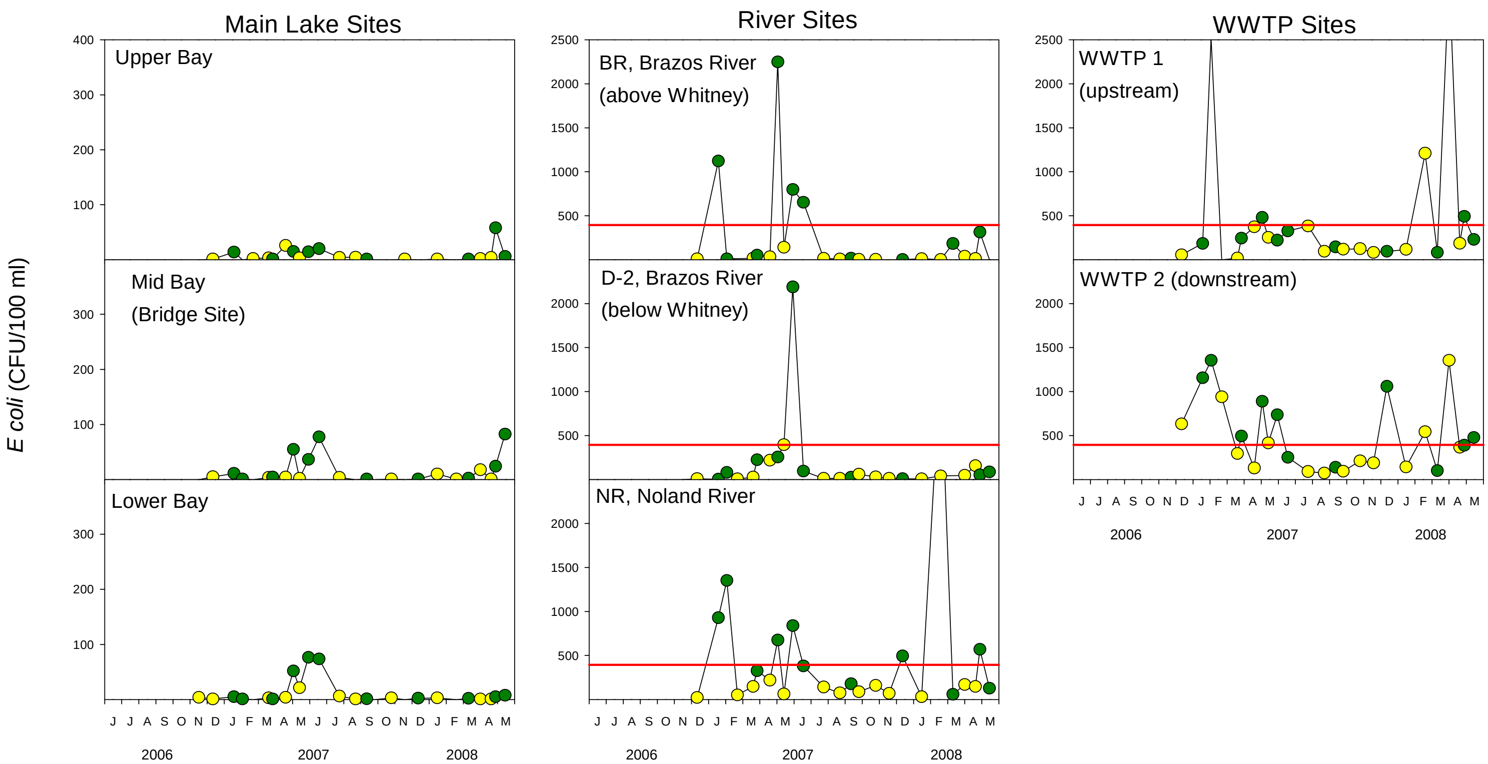

Figure 3. Monthly *E coli* levels in surface waters at the eight routine sampling sites on Lake Whitney, TX (see Fig 1 for locations). Horizontal red line shows the EPA contact recreational water limit (394 E. coli/100 ml). Yellow circles indicate samples collected under baseflow conditions while green circles show samples collected under stormflow conditions.

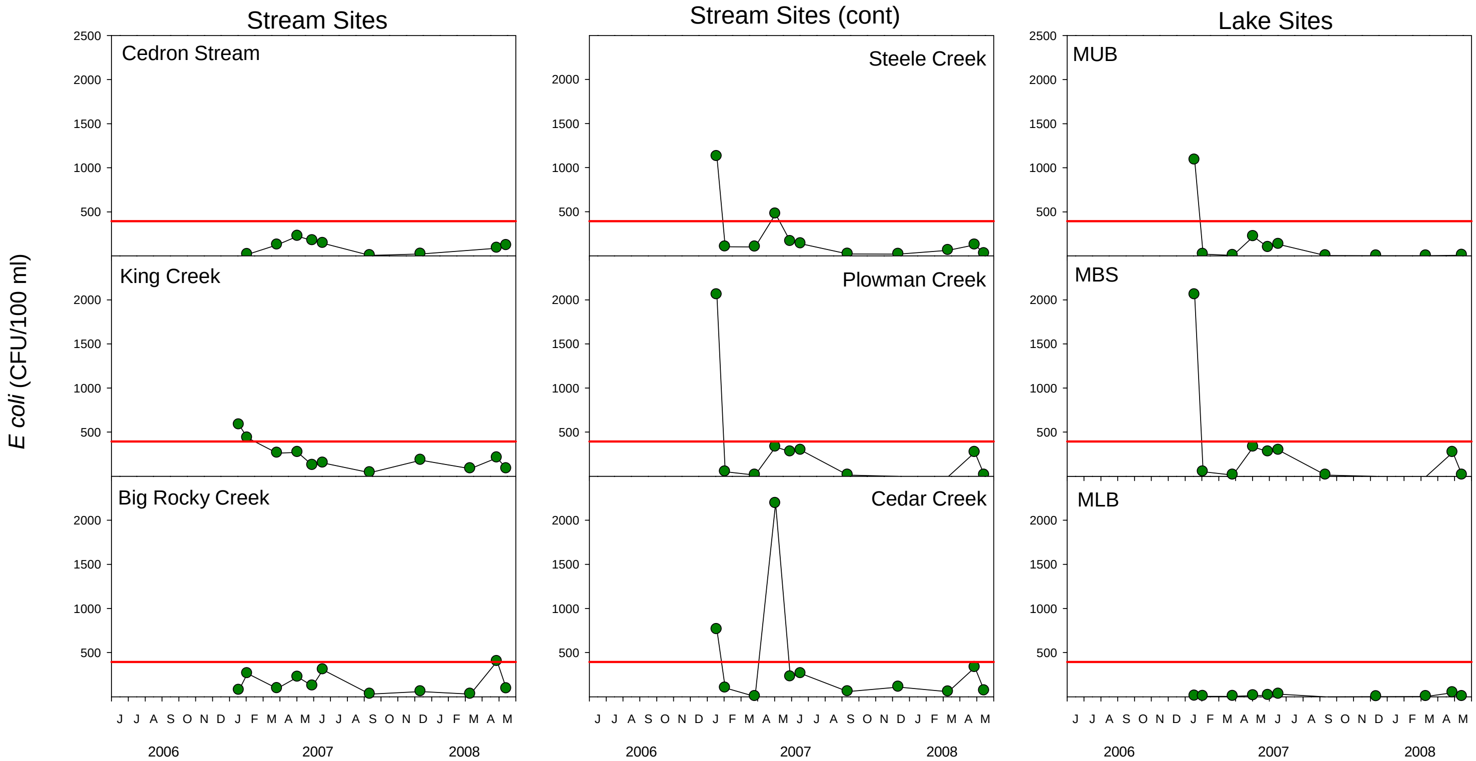

Figure 4. *E coli* levels in surface waters at the nine storm-flow sampling sites on Lake Whitney, TX (see Fig 1 for locations). Horizontal red line shows the EPA contact recreational water limit (394 E. coli/100 ml).

3.3. E. coli Concentrations: Baseflow vs. Stormflow Samples

Not surprisingly, average *E. coli* levels under stormflow conditions exceeded those of samples collected under baseflow conditions (Figure 5). Under baseflow conditions, the three main reservoir stations (stations 1-2) had an overall geometric mean of just over 2/100 mL (n-15) while under stormflow sampling conditions the average increased by a factor of 2-5X. Even so, at these stations the levels of *E. coli* were very low and fully supportive of contact recreation.

E. coli levels in the Noland River were much higher than those found in the main lake stations. Under baseflow conditions the geometric mean of the samples collected was 115/100 mL, a value not much under the long-term criteria. Under stormflow conditions, the geometric mean spiked to 390/100 mL.

While levels of *E. coli* increased in the Brazos River upstream and downstream of Lake Whitney (sites 5 & 6, respectively), the geometric means were well below the long-term contact recreation criteria under both baseflow and stormflow conditions.

At the stations above and below the City of Whitney Waste Water Treatment site (sites 7-8), the levels of *E. coli* exceeded the long-term criteria under both baseflow and stormflow conditions.

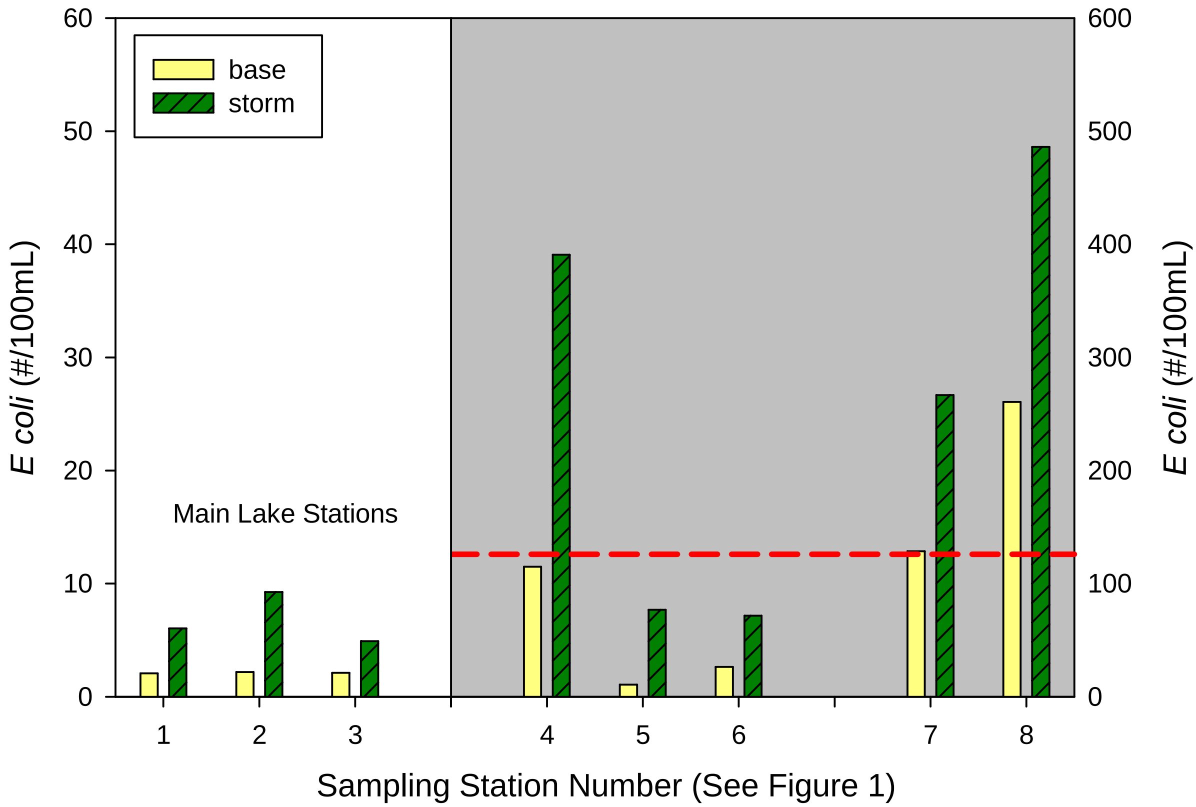

Figure 5. Comparison of *E coli* levels under baseflow vs. stormflow conditions. Yellow bars are geometric means of samples collected during baseflow conditions (n=15) while green bars are geomeans of samples collected under storm sampling (n=11). The horizontal dashed line represents the State of Texas (TCEQ) Long Term Geometric Mean Limit for Contact Recreation (126/mL). Note 10X scale change between main lake stations (1-3) and other stations (4-8).

3.3. Total Coliform Bacteria

Total coliform bacteria levels were also tested at the 17 sampling sites (Table 4).

Table 4. Geometric means of Total Coliform bacteria (#/100 mL) at each sampling station under baseflow and stormflow conditions.

Location Type	Station #	All Samples (n=26)	Baseflow Samples (n=15)	Stormflow Samples (n=11)
Main Lake	1 (Lower Bay)	602	830	400
	2 (Katy Bridge)	666	568	818
	3 (Upper Bay)	631	517	797
	9			507
	10			690
	11			1349
Rivers	4 (Noland R)	6,695	5,249	9,776
	5 (Brazos Upstream)	3,914	2,751	9,776
	6 (D-2 Brazos Downstream)	5,148	4,399	5,156
Inlfowing Streams (shown counterclockwise)	7 (Above WWTP)	14,743	11,895	20,587
	8 (Below WWTP)	15,138	14,540	16,315
	17 (Cedar Creek)			10,727
	16 (Plowman Creek)			4,238
	15 (Steele Creek)			4,292
	14 (Cedron Stream)			3,208
	13 (King Creek)			8,581
	12 (Big Rocky Creek)			3,478

Although the absolute value of Total Coliforms (TC) exceeded that of *E. coli*, the distribution patterns were quite similar. TC levels at the main lake stations were low under both baseflow and stormflow conditions. Levels of TC in the inflowing rivers and streams were considerably higher, and tended to be higher under stormflow conditions.

4.0 DISCUSSION/CONCLUSION

Monitoring and preservation of watersheds and source waters for water treatment facilities is critical to ensuring that drinking water supplies are of the highest quality. Surface waters are often contaminated with microbes from a variety of sources including microbes from fecal contamination. Contaminated surface waters raise two significant concerns. First, the potential for human health risks associated with recreational contact of surface waters. Second, the amount of water treatment that is necessary to produce drinking water and the subsequent quality of that drinking water are directly proportional to the quality of the surface waters feeding into the reservoir and treatment facility. Therefore, to effectively protect human health and improve drinking water quality, it is important to evaluate the levels of microbes in the watershed and identify potential sources of contamination so that these can subsequently be removed or improved.

The current study provided a comprehensive, longitudinal evaluation of *E. coli* and total coliform (TC) bacteria levels in the waters of Lake Whitney. Eight routine sampling stations were sampled approximately monthly under baseflow conditions during this period (n=15). In addition to the routine baseflow samplings, eleven stormflow events were sampled. Under stormflow conditions, we collected samples from the eight routine sites and an additional nine inflowing river and stream sites around the reservoir.

The eight routine sites consisted of three main reservoir sites distributed along the longitudinal axis of the reservoir, two sites on the main inflowing rivers (Brazos River and Noland River), one site on the Brazos river below the Lake Whitney dam discharge, and two sites located above and below the waste water treatment plant discharge of the City of Whitney. Under stormflow conditions nine additional sites were sampled. Three sites were located along the main axis of the reservoir and the remaining six sites were smaller streams flowing into the reservoir.

The main-reservoir sites had very low levels of *E. coli* and never approached the US EPA criteria for contact recreation. The long-term geometric mean of the three routine stations ranged between 2-3 *E coli*/100 ml under baseflow conditions (n=15) and only 5-9 *E coli*/100 ml under stormflow conditions (n=11), both well below the established long-term criteria of 126 *E coli*/100 ml. The highest observed single sample value at these sites under baseflow and stormflow conditions was only 21.4 and 82.4 *E coli*/100 ml, respectively, far below the single sample criteria of 394 *E. coli*/100 ml. The three additional sites along the main axis of the reservoir were sampled only during stormflow conditions. However, even these sites showed no excedances of either the single sample of long-term geometric means. The geometric means of these sites ranged from 5.2-19.2 *E. coli*/100 ml (n=11).

The levels of *E. coli* on the inflowing Brazos and Noland Rivers were below the long-term and single sample criteria under baseflow conditions. However, the levels in the Noland River were considerably higher than in the Brazos river, and the long-term geometric mean under baseflow conditions on the Noland (n=15) was 115 *E. coli*/100 ml, very near the 126 *E. coli*/100 ml criteria. Under stormflow conditions both river sites had numerous periods that exceeded the single sample criteria. When data from baseflow and stormflow conditions were combined, the Noland River exceeded the US EPA long-term criteria with a geometric mean of 196.9 *E. coli*/100 ml (n=26) while the Brazos River site did not (27.5 *E. coli*/100 ml, n=26).

Water in the Brazos River below Whitney exceeded the US EPA single sample criteria only twice and had an overall long-term geometric mean of 39.3 *E. coli*/100 ml (26.4 and 76.9 *E. coli*/100 ml under baseflow and stormflow conditions, respectively).

Not surprisingly, the sites above and below the waste water treatment plant outfall showed elevated *E. coli* values several times under baseflow and stormflow conditions. These sites exceeded the long-term USEPA criteria under both baseflow and stormflow conditions.

The six minor streams flowing into the reservoir were sampled only during stormflow conditions. Only two of these streams exceeded the USEPA long-term geometric mean criteria. King Creek, located on the western side of Lake Whitney had a long-term geometric mean of 172.5 *E. coli*/100 ml while Cedar Creek on the eastern side had 129.8 *E. coli*/100 ml (n=11).

Overall, under baseflow conditions only the two sites located in the vicinity of the City of Whitney waste water treatment plant exceeded the USEPA long-term geometric mean criteria. However, under stormflow conditions five of the seventeen sites exceeded the criteria (the two sites near the WWTP outfall, Noland River, Big Rocky Creek and Cedar Creek).

5.0 ACKNOWLEDGEMENTS

The study was designed, coordinated and implemented by Dr. Rene Massengale. Laboratory assistance from Ms. Stacey Pfluger and Ms. Bryn Cooper was greatly appreciated. Dr. Michelle Nemec assisted with data analysis and interpretation. Field assistance from Ms. Sara Seagraves was essential and much appreciated.

6.0 REFERENCES & TECHNICAL BACKGROUND

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Organic Contaminant Analysis on Lake Whitney
DRAFT Final Report

Phase IB

Study Element No. 8:

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CRASR

Background and Objectives

Two potential sources of direct anthropogenic contamination for Lake Whitney include agricultural related runoff and sewage effluent from municipal and on-site treatment. In order to evaluate the contamination level from each of these sources, related organic chemicals were measured. In the case of agricultural runoff, a series of moderately polar herbicides were selected for analysis. Atrazine, an herbicide used on maize and sorghum, is a regulated contaminate in drinking water due to human health concerns (USEPA, 2005). In addition, atrazine and its dealkyl-metabolites were of specific interest due to the history of the product contaminating drinking water supplies across the country and specifically at nearby Aquila Reservoir (Hackett et al. 2005; TCEQ 2005). The other herbicides, alachlor, metolachlor and acetochlor, have similar usage patterns to atrazine and have been documented as contaminants in surface water (Hackett et al. 2005).

In the case of sewage effluent, caffeine and two personal care products, galaxolide and tonalide, were monitored as indicators. Several previous studies have suggested caffeine as a useful indicator of microbial and nutrient contamination that is the result of human sewage (Seiler et al. 1999, Buerge et al. 2003a). Galaxolide and tonalide are used as musk fragrances, are commonly found in streams receiving municipal effluent (Kolpin et al. 2002), and have also been suggested as a chemical indicator of human waste (Buerge et al. 2003b, Cimenti et al. 2007).

The objectives of this study include:

1. To determine if atrazine or other herbicides are exceeding maximum contamination levels (MCL) for drinking water within the lake.
2. To determine if contamination related to row-crop agriculture is entering the lake, using herbicide contamination as an indicator of pollution source.
3. To determine if human waste sources, such as municipal sewage and on-site treatment, are contributing factors to contamination of the lake by using caffeine, galaxolide, and tonalide as an indicator of pollution.

Methods

Base-flow samples were collected from three in-lake sites on a monthly basis from January 2007 to June 2007. During the same time period, five high flow events were sampled. During high flow events, two additional in-lake sites were sampled. Tributaries were also sampled during the same duration and during both high flow and base flow events. Sampling occurred at the same time and sites as described for nutrients and microbial work.

Grab samples, 1 L, were collected from each site and stored in glass bottles with teflon lined lids. They were kept in the dark and at 4° C for less than 96 hours prior to extraction. Immediately prior to extraction, samples were filtered using Whatman GF/C 4.7 cm glass fiber filters and were acidified to pH 3.0 using a solution of HCl:water (1:1). Samples were extracted using a solid phase extraction technique with Oasis® HLB Cartridges (Waters, Milford, CN) at a flow rate of 10 ml/min. Analytes were eluted from the cartridges using 8 ml ethyl acetate. The extract was dried with anhydrous ~500mg Na_2SO_4, and then evaporated under N_2 gas and heating to 35°C. The volume has reduced to less than 0.5 mL and then brought to a 0.5 mL final volume. Standards, obtained from Sigma-Aldrich (St Louis, MO), were greater than 98% purity. All solvents were GC/MS grade.

Analysis was performed on a Varian Saturn 2100T (ion trap) GC/MS interfaced with a Varian CP8410 autoinjector and a split-splitless inlet. Peak separation was attained using a 1 µL injection volume and a Varian Factor Four Capillary Column (0.25 mm x 0.25 µm x 30 m). The inlet was held at 260° C and the oven started at 45°C, was held for 0.75 min., followed by a 8°C ramp to 290°C. Column flow rate was 1.8 ml/min throughout the run. The MS detector was in electron ionization mode with an emission current of 80 µamps and in full scan mode (70-650 m/z). Internal calibration was used and spectral identification confirmed qualitative identification.

Method accuracy and precision was characterized by analyzing eight spiked laboratory samples (reconstituted water) at a spiking concentration of 250 ng/L and calculating percent recovery and relative standard deviations. In addition, surrogate standards were added to each sample (p-terphenyl) to monitor recovery during the extraction process. Detection limits were determined by analyzing seven lower-level replicates (50 ng/L). Field duplicates were also performed at a 5% frequency to evaluate sampling and process precision.

Results

Quality Control

Method detection limits, method reporting limits, accuracy and precision of the technique, and results of field duplicates are shown in Table 1. Reporting limits were below 0.07 ug/L, except for alachlor, which had an elevated RL due to matrix interferences. Method accuracy for the herbicides ranged from 90-114% (mean recoveries) and the human sewage indicators were slightly lower ranging from 59-72% (mean recoveries). Method precision was adequate with laboratory spikes (n=8) recoveries having standard deviations of less than 26% and field duplicates (n=9) had relative percent differences of less than 40%. Surrogate recovery for the samples (n=132) was 109.88 ± 37.64 % (mean ± standard deviation).

Herbicide contamination within the lake

Within the lake, 40 samples were collected and analyzed. Extremely consistent, yet very low concentrations of atrazine and atrazine metabolites were found throughout the months of sampling (Figure 1). All samples were well below the 3.0μg/L maximum contaminant guideline (calculated as sum of atrazine and metabolites) set by the US EPA. Other than a single detection of metolachlor at 0.25 μg/L, no other herbicides were detected within the lake.

Herbicide contamination in the tributaries

Atrazine and/or its metabolites were detected in almost all of the samples collected from the tributaries; however, on only two occasions did the sum concentration exceed the 3.0 μg/L maximum contaminant guideline (Figure 2). Both of these samples were also collected early in the year and during high-flow events from Cedar Creek.

Table 1. Reporting limits, quality control parameters, and drinking water guidelines for the list of target compounds.

Analyte	Method Detection Limit (ug/L)[1,2]	Reporting Limit[1,3] (ug/L)	Field Duplicates RPD[5]	Lab Spike Percent Recoveries[6]	Drinking Water Guidelines (ug/L)
Acetochlor	0.028	0.043	--	89.71±16.47	*
Alachlor	0.063	0.390[4]	--	107.75±25.24	2.0[7]
Atrazine	0.018	0.027	31.16%	92.38±20.15	3.0[7,8]
Caffeine	0.018	0.027	40.36%	71.59±26.45	NA
Desethyl Atrazine	0.045	0.067	--	96.79±20.24	3.0[7,8]
Desisopropyl Atrazine	0.032	0.048	--	114.14±20.93	3.0[7,8]
Galaxolide	0.023	0.034	--	60.92±20.59	NA
Metolachlor	0.026	0.039	22.22%	94.63±19.03	*
Tonalide	0.031	0.047	--	58.81±19.67	NA

[1]Samples assume a 1 L volume extracted to 0.5 mL; [2]Std Dev x Student T-value, n=10; [3]RL reported as 3X(MDL); [4] Significant background matrix interference resulted in a higher RL; [5]Relative percent difference between duplicate field samples; [6]Mean ± Std Dev, n=8; [7]US EPA; [8]Atrazine guidelines are for the sum of atrazine and the two listed degradation products; NA indicates not available. * no guideline set from the US EPA, however the compound is included in the US EPA's Unregulated Contaminant Monitoring Regulation (UCMR) for Public Water Systems Program;

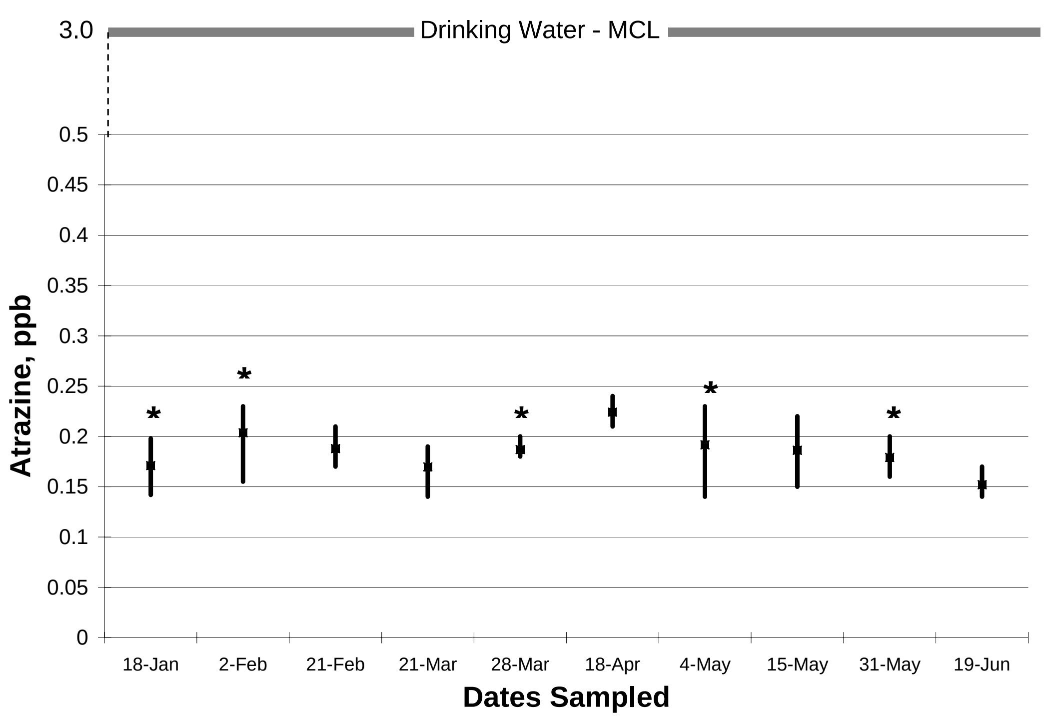

Figure 1. Concentration of atrazine (µg/L) in Lake Whitney during the six month study. Bars indicate the range of values measured (n=3 for base flow and n=5 for high flow). Squares indicate mean value. * indicates high flow events, while unmarked indicates base flow events.

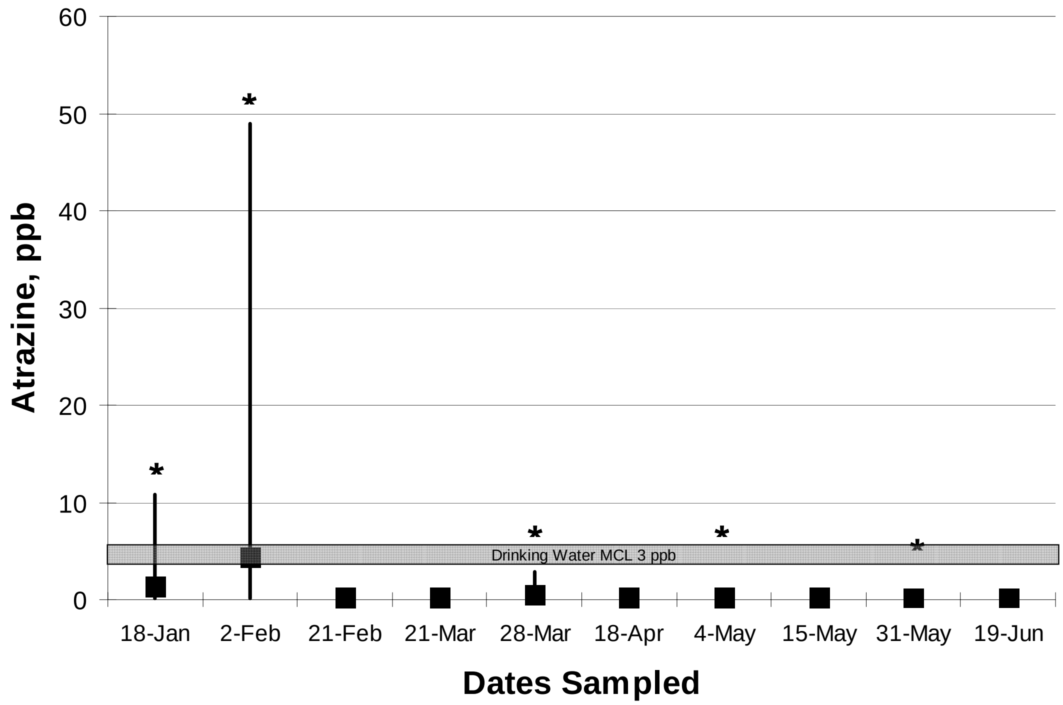

Figure 2. Concentration of atrazine (μg/L) in Lake Whitney tributaries during the six month study. Bars indicate the range of values measured (n=3 for base flow and n=5 for high flow). Squares indicate mean value. * indicates high flow events, while unmarked indicates base flow events.

Indicators of human sewage within the Lake

Caffeine was detected in 42 of 124 samples (above 0.027 μg/L) for the entire project. In the lake, 16% of samples had detectable levels of caffeine and 3% of samples had concentrations greater than 0.10 μg/L. Although caffeine was detected at least once at every lake site, the highest three concentrations were found at the upper buoy. The highest detected concentration was 0.15 μg/L. Frequency and maximum detections for caffeine for the three primary lake sites is shown in Table 2. Neither tonalide nor galaxolide were found in lake samples.

Indicators of human sewage in tributaries

In the tributaries, 35% of samples had detectable levels of caffeine and 13% of samples had a concentration of greater than 0.10 μg/L. The maximum detection was 0.34 μg/L in the Brazos River. Three out of the 10 sample collected form the Brazos contained caffeine, two of which above 0.100 μg/L. The Nolan River and Whitney Creek also had frequent caffeine detections (Table 2). Tonalide was not found within the Lake and tonalide was only detected twice.

Table 2. Caffeine recovery in primary sampling sites for the project. The top three sites were within the lake and the later sites are tributaries.

Location	**GPS**	**Samples**	**Frequency of Detection, %**	**Maximum Concentration Detected, μg/L**
Upper Water Quality Buoy (lake)	In Lake	10	50	0.15
Lower Water Quality Buoy (lake)	In Lake	10	30	0.061
Katy Bridge (lake)	In Lake	10	20	0.045
Big Rocky Creek @ SH 56	31º52.657' N 97º25.936' W	10	30	0.34
Brazos River (road) @ TEX 174	32º07.527' N 97º29.474' W	10	30	0.34
Plowman Creek @ SH 56	32º03.854' N 97º29.610' W	5	40	0.32
Whitney Creek upstream from WWTP @ San Marcos St	31º56.845' N 97º19.388' W	10	40	0.28
King Creek @ SH 56	32º54.399' N 97º27.710' W	5	40	0.19
Nolan River @ FM 933 (road)	32º09.004' N 97º24.224' W	10	50	0.134
Whitney Creek downstream from WWTP @ FM 1244	31º56.272' N 97º20.524' W	10	80	0.13
Cedar Creek @ FM 2604	32º00.723' N 97º22.301' W	5	20	0.034
Cedron Creek @ SH 56	32º57.063' N 97º27.396' W	5	0	<0.027
Steele Creek @ SH 56	32º00.159' N 97º29.038' W	5	0	<0.027

Discussion and Recommendations

Atrazine Contamination

Although atrazine was present in Lake Whitney at nearly every sampling, the concentrations were always 10 times lower than the maximum contaminant level. Interestingly, these levels were quite consistent throughout the year. Other studies have reported similar trends in lakes and reservoirs, where the half-life for atrazine can be over 200 days when at low concentrations (Ma and Sparling, 1997). From this data, it would appear that herbicide contamination would have little impact on the potential use of Lake Whitney as a source for drinking water. However, some concern would be warranted if water is collected on the southeastern portion of the lake.

During two early sampling events, (January and February) samples from a tributary, Cedar Creek, feeding into the southeastern portion of the lake had levels of atrazine contamination well above the maximum contaminant level. This area of the watershed has the highest intensity of row crop agriculture (Figure 3). The tributary only had significant contamination in January and February, which correlates to the pre-planting application of atrazine (Aatrex 4L Label, Syngenta; http://www.syngentacropprotection.com/prodrender/index.aspx?prodid=640). Planting of corn in Texas usually begins in late February (USDA, 1997). Although Lake Whitney appears to mix rapidly in regard to atrazine concentrations, additional herbicide testing should be conducted if this area of the Lake is chosen for the intake site. In addition, the presence of atrazine can also be interpreted as a general indicator of potential contamination from row-crop agriculture. Thus, beyond atrazine, this area of the lake is at greater risk of contamination by other pesticides and nutrients.

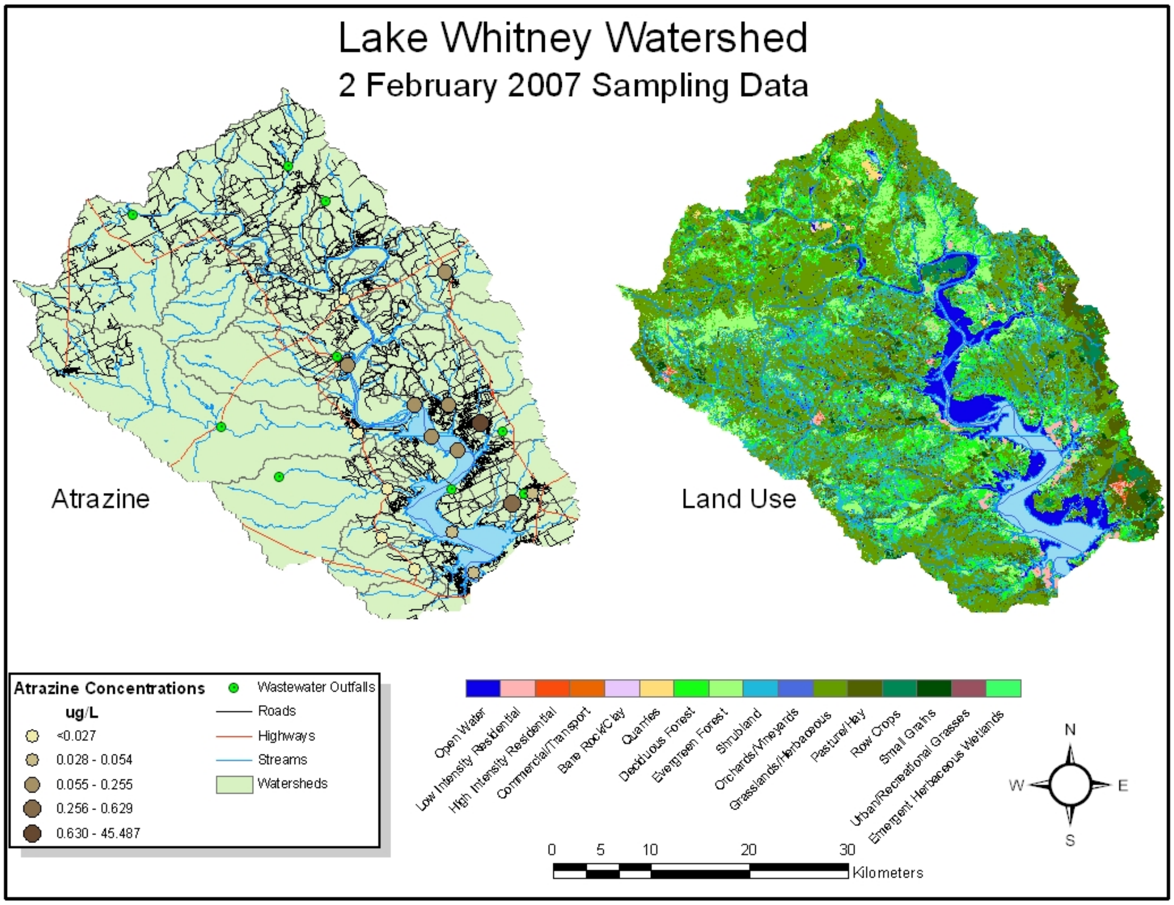

Figure 3. Atrazine concentrations are compared to land use across sampling sites in the Lake Whitney watershed during a high flow event which recorded the maximum concentration (45 ug/L) for atrazine for the 2007 sampling period. Row crops and small grain agriculture is primarily concentrated in the southeastern corner of the watershed, which is also where the highest concentrations of atrazine were observed.

Human Sewage Contamination

Although caffeine was found throughout the lake, it was most frequently found in areas that have inputs from municipal sewage such as below the WWTP on Whitney Creek and the Nolan River. This trend suggests that the primary source of caffeine, and thus potentially sewage contaminated water, was from municipal sewage effluent released to the tributaries and that onsite treatment of waste in areas immediately surrounding the lake is of secondary importance. The most frequent caffeine detection in the lake was on the upper buoy. As the

Nolan River is a major tributary entering the lake in that region and was found to have frequent caffeine hits, this was not unexpected. Similarly, the lowest frequency of detection is from some smaller tributaries that are not near populated areas, such as Cedar Creek.

The presence of caffeine strongly indicates that sources of human waste, including on-site treatment and municipal treatment are presence in the watershed. However, it should be noted that caffeine was generally not detected or detected at low concentrations. The majority of samples were below the reporting limit of 0.027 μg/L. In a sampling of US streams, Kolpin et al. (2002) found caffeine in 62% of samples, with a median of 0.08 μg/L and a maximum of 6.0 μg/L. Although the Kolpin study was targeted at areas that may be impacted, it still illustrates the relatively low concentrations found in this study. Similarly, galaxolide and tonalide were not detected in the vast majority of samples in this study, despite there wide spread occurrence in municipal waste water. For example, in one study concentrations in streams near wastewater treatment plants exceed 0.31 μg/L (Buerge et al. 2003). Based on these results, no evidence of excessive contamination from human waste was found in Lake Whitney.

Conclusions

Based on measurement of herbicides and organic indicators of human waste, neither row crop agriculture nor sources of human waste were found to be problematic for Lake Whitney. However, herbicide input into the southeastern region of the Lake should be monitored. Likewise, as Lake Whitney is further developed, appropriate management of wastewater will be necessary to prevent future contamination.

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Spatial and Temporal Patterns of Potential Phytoplankton Productivity and Respiration of Lake Whitney, TX
DRAFT Final Report

Phase IB

Study Element No. 9: Phytoplankton Assessment

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ABSTRACT

Potential phytoplankton productivity of Lake Whitney was measured 14 times over a 16-month period (February 2007 – May 2008) at three stations along the longitudinal axis of the reservoir. Rates were measures as *in vitro* changes in dissolved oxygen and converted to carbon units. Maximum potential gross daily areal productivity under cloud-free conditions was estimated and averaged 2.04, 1.94 and 1.88 g $C \cdot m^{2} \cdot d^{-1}$ at the lower bay (LB), mid-bay bridge site (BS) and upper bay (UB), respectively. Although significant differences were seen in chlorophyll-a and water column clarity among the stations (lower cholorphyll-a and higher water clarity in the down reservoir direction) there was no significant difference in maxium potential productivity among the three stations. Maximum potential gross areal productivity showed distinct seasonal variation with maxima at all stations occurring in the late summer (August-October) 2007. Mean values of the photosynthetic parameters ranged between 1.2 - 24.4 mg C mg Chl^{-1} hr^{-1} for P^{B}_{max} and 3.2 - 45.9 mg C mg Chl^{-1} E^{-1} m^{2} for α^{B}. These values were in the range to be expected for a turbid, temperate reservoir. During the study period the water column was never thermally stratified and total water column respiration usually exceeded production. Estimates of net ecosystem metabolism showed the production to respiration ratio (P:R) averaged only 0.33, 0.35 and 0.53 at the LB, BS and UB sites, indicating the reservoir to be a significant net source of CO_2 during the study period.

Key Words: phytoplankton, primary productivity, respiration, net ecosystem metabolism

Introduction

Productivity of plankton forms the base upon which aquatic food chains culminating in the natural fish populations exploited by man are founded (Reynolds, 1984). Excessive algal production in lakes and reservoirs, however, can interfere with aesthetic quality and uses such as drinking water supply, irrigation, recreation, and industrial uses (Ryding and Rast, 1989). Algal or phytoplankton productivity studies generate valuable data for lake and reservoir managers because these studies provide information regarding the degree of synthesis of a large portion of the new organic matter in the system and thus, the system's ability to sustain higher trophic levels.

Plankton productivity studies can also determine trophic status. Goldman (1988) states that the measurement of primary productivity supplies a photosynthetic integration of physical, chemical, and biological conditions, and when conducted over time, it is an excellent measure of change in the trophic state of an aquatic system. Wetzel (1983) maintains, however, that primary productivity measurement is only a valid criterion for such determination if organic matter inputs from the littoral and allochthonous sources are small in relation to those of the phytoplankton. These conditions appear to be met for the very large Lake Whitney.

Excessive plankton productivity may result in high levels of total and/or dissolved organic carbon (TOC, DOC). High levels of TOC and DOC are of concern in drinking water reservoirs because they are disinfection by-product precursors for systems that utilize chlorine disinfection.

Reservoirs typically have three distinguishable zones along their longitudinal axis. Uplake, there is riverine zone characterized by higher levels of available nutrients and light extinction relative to downstream portions. In the middle, there is a transition zone characterized by higher phytoplankton productivity and biomass because of available light and nutrients. Nearest the dam is the lacustrine zone which has lower concentrations of dissolved nutrients, transparency, and a deeper photic layer. Volumetric phytoplankton productivity can be reduced in this zone, however, by nutrient limitation (Kimmel et al, 1990). This heterogeneity of reservoirs along their longitudinal axis requires that a spatial component be added to productivity studies involving such waterbodies.

A phytoplankton productivity study of Lake Whitney is important because the reservoir provides a number of uses such as flood control, streamflow regulation, and recreation. The reservoir is well known for its striped bass, bass and catfish. In addition, the waters of the reservoir are increasingly being considered for potential use as a regional water supply, despite the elevated levels of salinity characteristic of this portion of the Brazos River system. The Lake Whitney Comprehensive Assessment Study was conducted to evaluate the potential problems associated with utilization of the reservoir as a drinking water supply. Phytoplankton productivity and possible generation of total and dissolved forms of organic carbon are of potential concerns because organic carbon is a disinfection by-product precursor.

Materials and Methods

Study Site

This phytoplankton productivity study was conducted on Lake Whitney, Texas. Three main lake sites along the longitudinal axis of the reservoir were selected for this study (Figure 1).

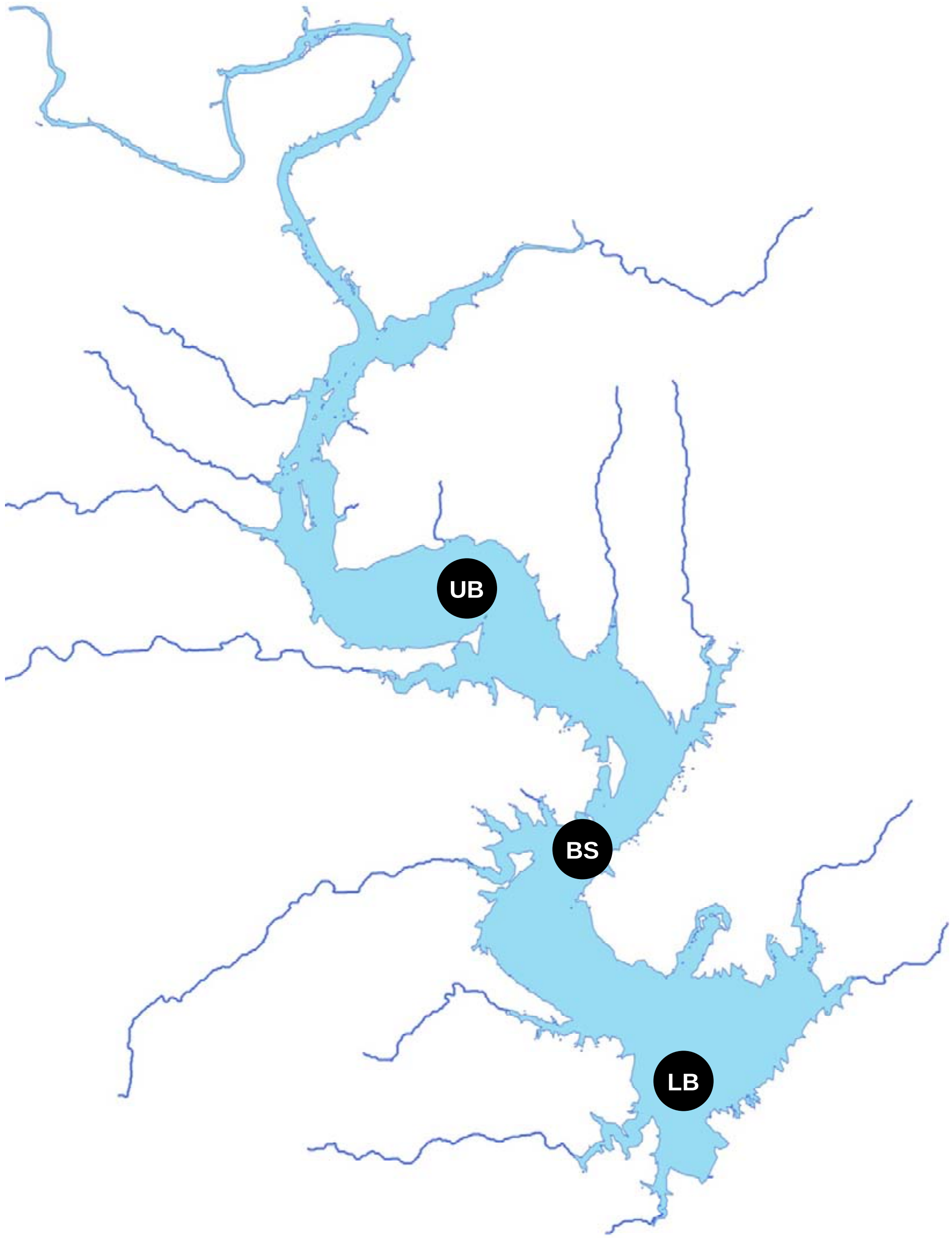

Figure 1. Sample sites for photosynthesis study in Lake Whitney, TX (2007-2008).
LB= Lower Bay, BS= Mid Bay Bridge Site, and UB= Upper Bay.

All three sites would be classified as part of the “lacustrine” (lake-like) zone of the reservoir. The stations varied in depth as well as other physical, biological and chemical characteristics (Table 1). This study is part of a larger, multi-investigator study of Lake Whitney funded by both USEPA and DOE.

Field Data Collection

Subsurface water samples were collected from a depth of 0.1 m for plankton metabolism, Chlorophyll-a and nutrient analyses. Samples were stored in acid-rinsed containers and kept on ice (Chlorophyll-a) or in the dark within a larger container filled with reservoir water to maintain ambient temperature (plankton metabolism & turbidity). Samples were transported immediately to the laboratory at Baylor University.

Secchi depth and vertical profiles of light, temperature, dissolved oxygen and pH were determined at each sampling station. Secchi depth in meters was determined by lowering a Secchi disk into the water from the shaded side of the boat, and averaging depths when it disappeared and when it reappeared after being raised. Light profiles were collected with a LiCor spherical quantum sensor and temperature, dissolved oxygen and pH were determined with a calibrated YSI multiparameter datasonde. The light extinction coefficient was calculated from the vertical profile of light (Lind,1979a). This total extinction coefficient is a composite of the components of water, suspended particles, and dissolved, colored components in the water column (Wetzel, 1983).

Table 2. Mean ± SE of major factors influencing phytoplankton productivity at each station (n=16) or for all stations (n=48) during the study period. The p value beneath each factor represents the significance of the station factor in a 2-way ANOVA (station x sample date). Factors with preceding asterisks did not meet normality assumptions and ANOVAS were made with log-transformed data. Significant ANOVAS were followed by mean comparison tests (LSD) among station means. Means exhibiting the same superscripted letter are not significantly different from each other (p>0.05).

Factor (ANOVA p value)	*Sampling Station*			
	All	Lower Bay	Bridge Site	Upper Bay
Depth	21.18 ± 0.93	[c]27.60 ± 0.54	[b]22.77 ± 0.54	[a]13.17 ± 0.54
*Chl-a ($p= 0.01$)	21.18 ± 2.60	[a]15.54 ± 3.75	[b]23.96 ± 5.20	[b]23.30 ± 4.35
*Turbidity ($p< 0.01$)	7.78 ± 1.00	[a]3.89 ± 0.53	[b]6.99 ± 1.05	[c]12.15 ± 2.22
Secchi Depth ($p< 0.01$)	0.97 ± 0.04	[c]1.20 ± 0.06	[b]0.93 ± 0.05	[a]0.79 ± 0.07
Ext. Coef ($p< 0.01$)	1.38 ± 0.05	[a]1.18 ± 0.08	[a]1.35 ± 0.06	[b]1.63 ± 0.08
*Z_{eu} ($p< 0.01$)	3.55 ± 0.13	[c]4.17 ± 0.26	[b]3.55 ± 0.18	[a]2.93 ± 0.13
*P^B_{max} ($p= 0.13$)	6.58 ± 0.89	[a]8.66 ± 1.96	[a]5.11 ± 0.99	[a]6.13 ± 1.52
*VOL P_{max} ($p< 0.01$)	94.4 ± 10.0	[a]81.7 ± 14.6	[a]90.9 ± 17.1	[b]109.8 ± 19.8
*α^B ($p= 0.13$)	13.5 ± 1.6	[a]18.0 ± 4.1	[a]10.6 ± 1.6	[a]12.0 ± 2.1
*R^B ($p= 0.20$)	0.80 ± 0.11	[a]1.08 ± 0.29	[a]0.73 ± 0.14	[a]0.62 ± 0.07
*VOL R ($p= 0.03$)	11.12 ± 0.88	[a]9.33 ± 1.11	[b]11.69 ± 1.60	[b]12.21 ± 1.75
*I_k ($p= 0.64$)	136.4 ± 10.0	[a]137.9 ± 18.5	[a]133.4 ± 16.3	[a]137.7 ± 18.4
*Z_{comp} ($p= 0.18$)	7.98 ± 0.75	[a]9.68 ± 1.92	[a]7.52 ± 1.00	[a]6.86 ± 0.76
GP ($p= 0.72$)	1.95 ± 0.16	[a]2.04 ± 0.32	[a]1.94 ± 0.26	[a]1.88 ± 0.25
*P:R ($p< 0.01$)	0.40 ± 0.04	[a]0.35 ± 0.07	[a]0.33 ± 0.05	[b]0.53 ± 0.06

Depth (m); Chl-a (mg m^{-3}); Turbidity (NTU); Secchi depth (m); Ext. Coeficient; Z_{eu} (m); P^B_{max} [(mgC $mgChl^{-1}$ h^{-1})]; VOL P_{max} (mgC m^{-3} h^{-1}); $\boldsymbol{\alpha^B}$ [(mg C $mgChl^{-1}$ h^{-1}) (E m^{-2} h^{-1})$^{-1}$]; R^B (mgC $mgChl^{-1}$ h^{-1}); VOL R(mg C m^{-3} h^{-1}); I_k (uE m^{-2} s^{-1}); Z_{comp} (m); GP Gross Production (mgC m^{-2} d^{-1}); P:R (Ratio of areal gross production to respiration).

Laboratory Analyses

Turbidity was measured with a Hach Company (Loveland, Colorado) 2100N bench top turbidimeter. Seston was trapped onto a filter and chlorophyll *a* was extracted with acetone and determined spectrophotometrically after correction for pheophytin-a (Wetzel and Likens 2000).

Planktonic photosynthetic paramenters of P^{B}_{max}, $alpha^{B}$ and R^{B} were determined by measuring changes in dissolved oxygen (DO) in light-dark bottle incubations under artificial light incubations (Fee 1973). All photosynthetic parameters were normalized to plankton biomass as chlorophyll-a. Oxygen data was converted to carbon equivalents by multiplying by 0.375 (mass ratio of C to O_2 assuming a photosynthetic quotient of 1.0, Wetzel and Likens 2000). P^{B}_{max} is the maximum biomass-specific rate of photosynthesis under light-saturating conditions (P^{B}_{max}, mg C mg Chl-a^{-1} hr^{-1}); $alpha^{B}$ is the slope of the production vs. irradiance curve under low-light conditions ($alpha^{B}$, mg C mg Chl-a^{-1} hr^{-1} mol m^{-2} h^{-1}); and R^{B} is the biomass specific rate of plankton respiration (mg C mg Chl-a^{-1} hr^{-1}).

Prior to incubation, each sample was bubbled with a mixture of gases containing atmospheric levels of CO_2 (~350 ppm CO_2) and the balance of N_2 to lower the oxygen level of the sample. High oxygen concentrations cause photorespiration in the algae and this would lead to true net photosynthesis being underestimated. The oxygen level of the samples was adjusted so that there was little danger of photorespiration occurring and affecting the measurement of the rate of photosynthesis (typically 40-50% DO saturation). Sample incubations were typically initiated within 6 hours of sample collection in the field.

Three subsamples were incubated under light-saturating artificial lighting (photosynthetically active radiation [PAR] = 375–550 µmol s^{-1} m^{-2}); three under low light (PAR = 30–75 µmol s^{-1} m^{-2}); and three in darkness (foil wrapped). Incubations lasted 4-16 hrs and were maintained at ambient reservoir temperature. R^B (mg C mg Chl-a^{-1} hr^{-1}) was calculated as the decrease in DO in dark bottles and was assumed to be constant in the dark and light. The light-saturated rate of gross production (P^B_{max}) was estimated as the average net production in the high-light bottles plus the respiration rate computed from the dark bottles. α^B was computed as the slope of the line between respiration and the rate of net production under low-light conditions. Control bottles of deionized water were routinely assayed along with the phytoplankton samples to ensure proper operation of the oxygen probe and account for minor instrument drift. Oxygen concentrations typically changed between 0.50 to 2.00 mg/l in bottles for dark and high light, respectively. Deionized control bottles typically showed less than 0.05 mg/l difference over the course of the incubation.

Calculation of Daily Areal Productivity

Potential areal daily gross primary production under cloud-free conditions (GP, mg C m^{-2} d^{-1}) was calculated using the Walsby (1997) method, which integrates production over time (sunlight hours) and photic depth (Z_{eu}, = depth of 1% light). The input variables included light extinction, chlorophyll *a*, P^B_{max}, α^B, beta (coefficient of photoinhibition), R^B, temperature, and irradiance. Beta was assumed to be zero because of the turbid nature of the water in the reservoirs sampled. Light energy data (W m^{-2}) at 5 minute intervals was obtained from the Texas Solar Radiation Database (University of Texas, Austin, Texas). Data are available from 1998-2002. For each month we selected the day with the highest total radiation on the assumption that it represents a near cloud-free day with maximum solar irradiation for that month. These data were used as an estimate of maximum potential solar input for that month in any given year. Light energy data was converted to PAR based on the empirical conversion factors of 2.07 umol m^{-2} s^{-1} per J m^{-2} s^{-1} (Fisher et. al. 2003). The estimated GP values should be considered the potential daily production under full sunlight conditions.

Statistical Analysis

We evaluated differences in production and respiration rates as well as parameters impacting these rates among stations using two-factor analyses of variance (ANOVA) followed by Tukey-Kramer least squares multiple comparison test (α=0.05, Statgraphics, INC). Variables that were not normally distributed were analyzed after log transformation. The two factors were sampling station and date.

Results

Water level, temperature and dissolved oxygen

The study period was one of profound hydrologic contrast on the reservoir. At the beginning of the study period the reservoir was in the midst of a significant drought and the lake level was 8-10 feet below the normal pool level of 533 ft MSL (Figure 2a). This dry period was followed by significant rainfall beginning in late spring 2007 and a resulting pool rise back to above the conservation level. During the fall and winter 2008 the reservoir levels again dropped, but not to the very low levels seen at the beginning of the study.

Water temperature showed the expected variability with season for reservoirs at this latitude (Figure 2b). The temperature at each of the sampling stations showed similar seasonal trends. Surface water temperatures mirrored each other closely at all stations throughout the duration of the study with maxima in the summer of 2007, a steady decline in the fall and winter,

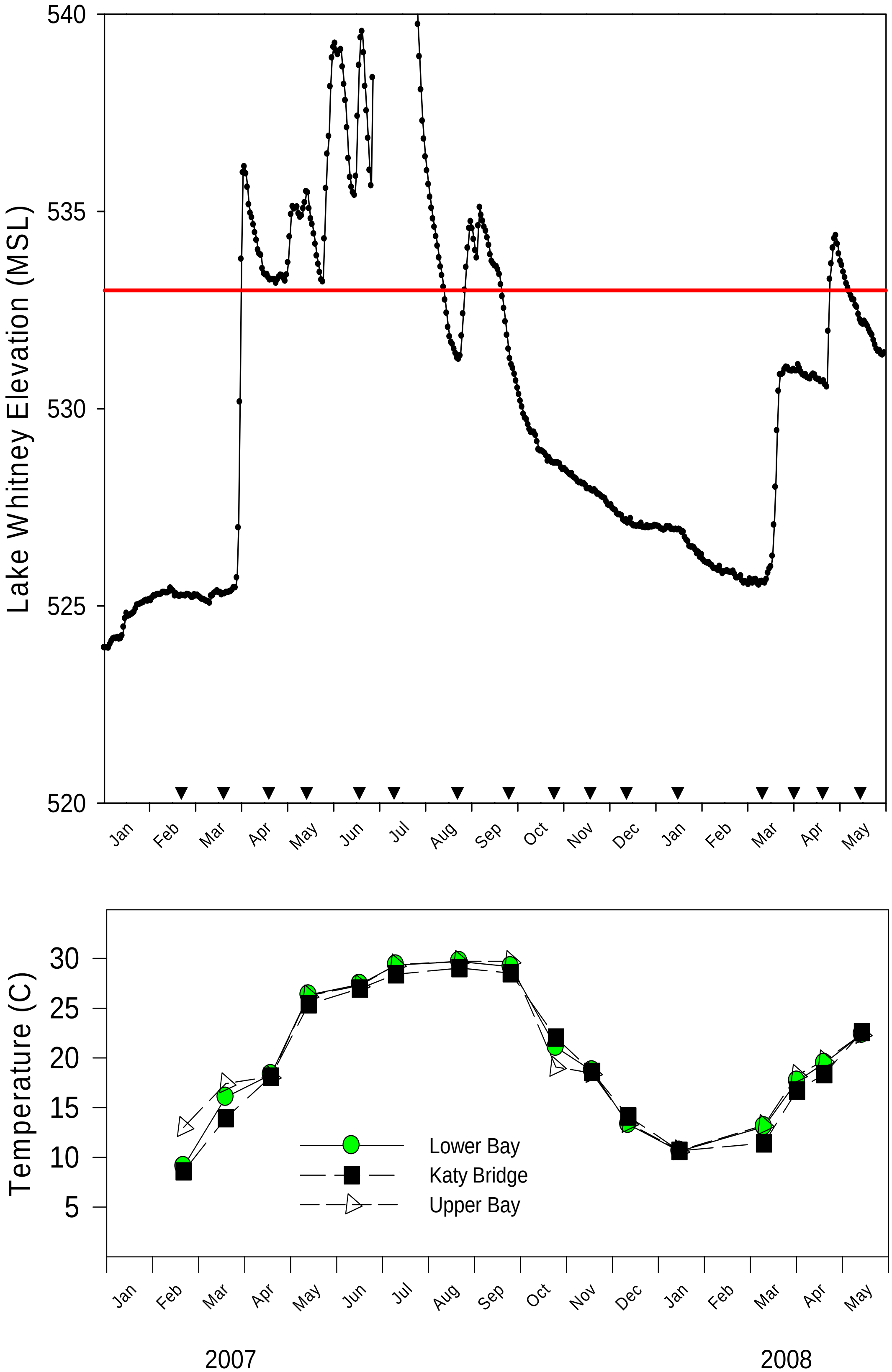

Figure 2. A) Water level (feet above mean sea level) of Lake Whitney, TX (2007-2008). Line= Conservation Pool Elevation. Sampling periods for photosynthesis measurements are indicated along the X-axis. B) Surface water temperature during the study period at the three main-lake stations sampled for photosynthesis.

followed by a steady rise through spring to 2008 (Figure 2b). The mean temperature for all the stations was 18.54 ^{o}C but ranged from 7.01 ^{o}C to 32.11 ^{o}C.

When sampling began in February 2007, the lake water column at all sampling sites was not thermally stratified (Figures 3). Lack of thermal stratification during winter months is typical for warm monomictic reservoirs at this latitude. However, persistent thermal stratification did not re-establish in Lake Whitney during the remainder of the study. Persistent summer thermal stratification is expected in deeper lakes in Texas and has generally been observed on Lake Whitney during summer sampling periods. Perhaps the unusually high rainfall and high flows during the summer of 2007 (Figure 1) prevented establishment of thermal stratification.

Despite lack of persistent thermal stratification, the lake showed significant vertical variability in dissolved oxygen (Figure 4). Surface values of dissolved oxygen were usually at or above saturation, while significant declines with depth were often observed indicating a significant benthic oxygen demand.

Chlorophyll-a and water column light quality

Chlorophyll-a concentrations ranged from 1.5 to 74.2 mg m^{-3} for all stations with a mean and median of 21.2 and 15.3 mg m^{-3}, respectively. Concentrations started out relatively high in February 2007 and generally declined until throughout the remainder of the study (Figure 5a). Chlorophyll-a was significantly different among the three stations (Table 1, two-way ANOVA p = 0.01). A multiple range test (LSD, $\alpha < 0.05$) showed that the levels at the lower bay (LB) was significantly lower than those at BS and UB which were not different from each other.

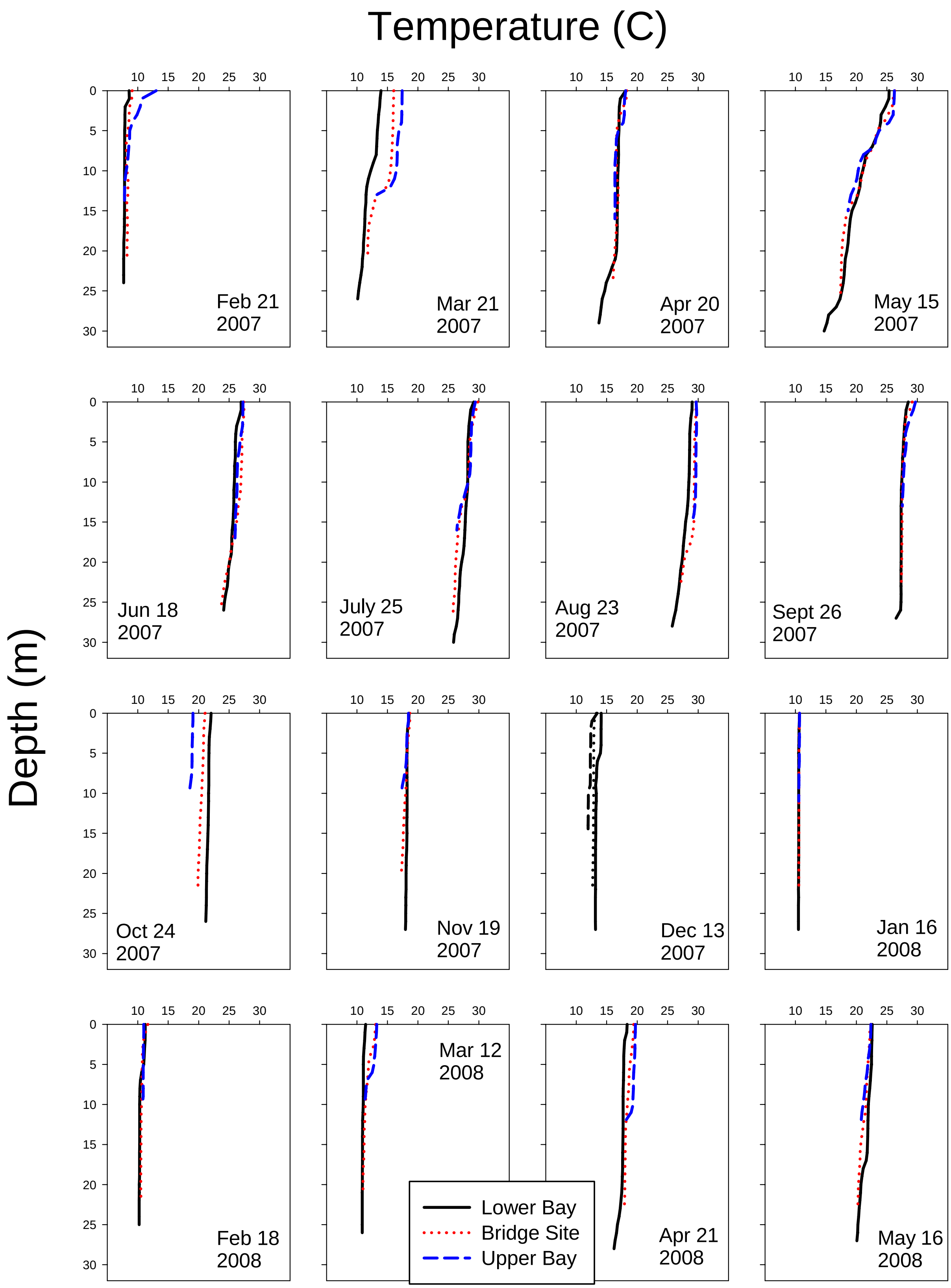

Figure 3. Vertical temperature profiles of three study sites on Lake Whitney, TX (2007-2008).

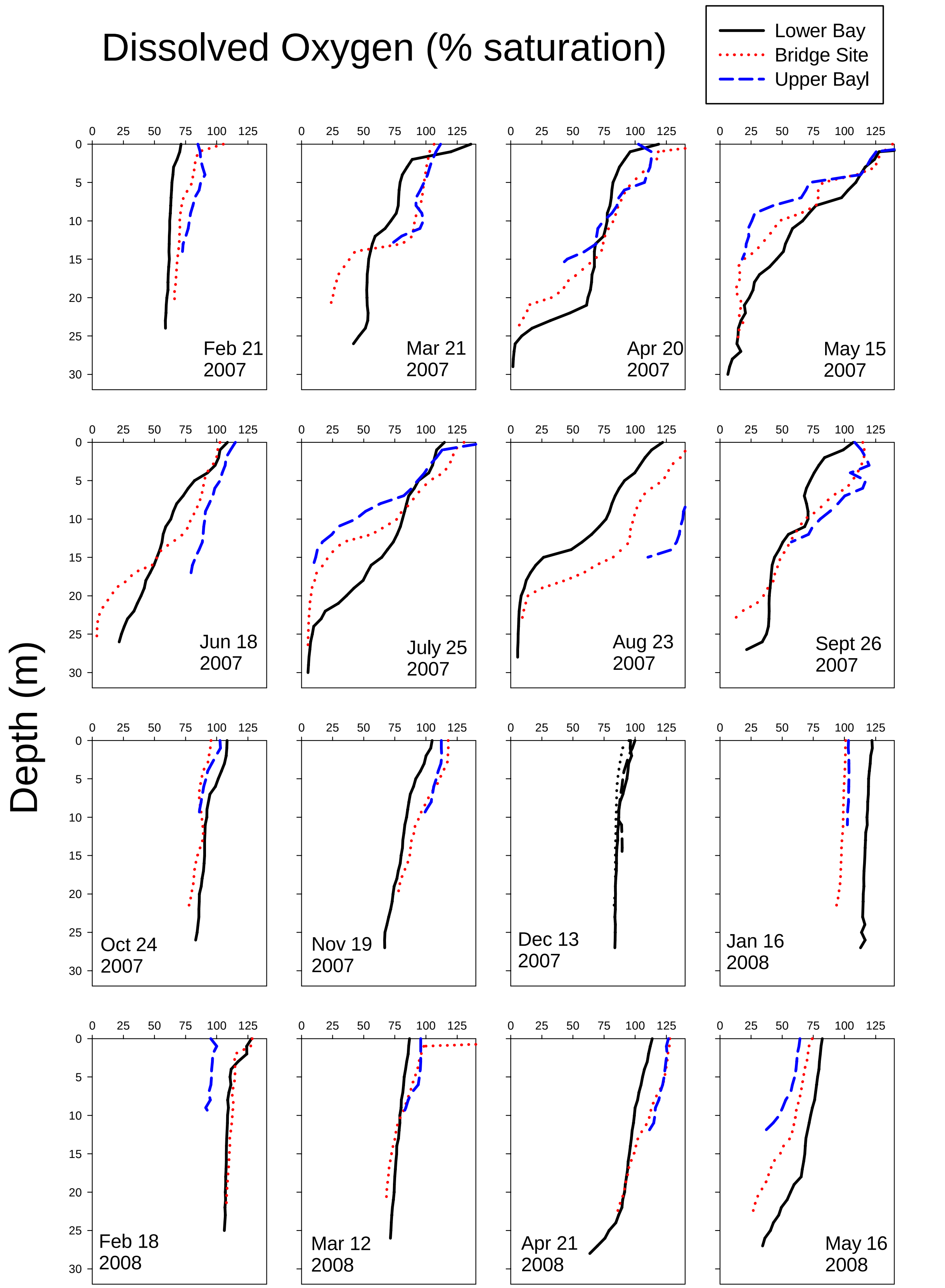

Figure 4. Vertical profiles of dissolved oxygen (% saturation) during the study period in Lake Whitney, TX (2007-2008).

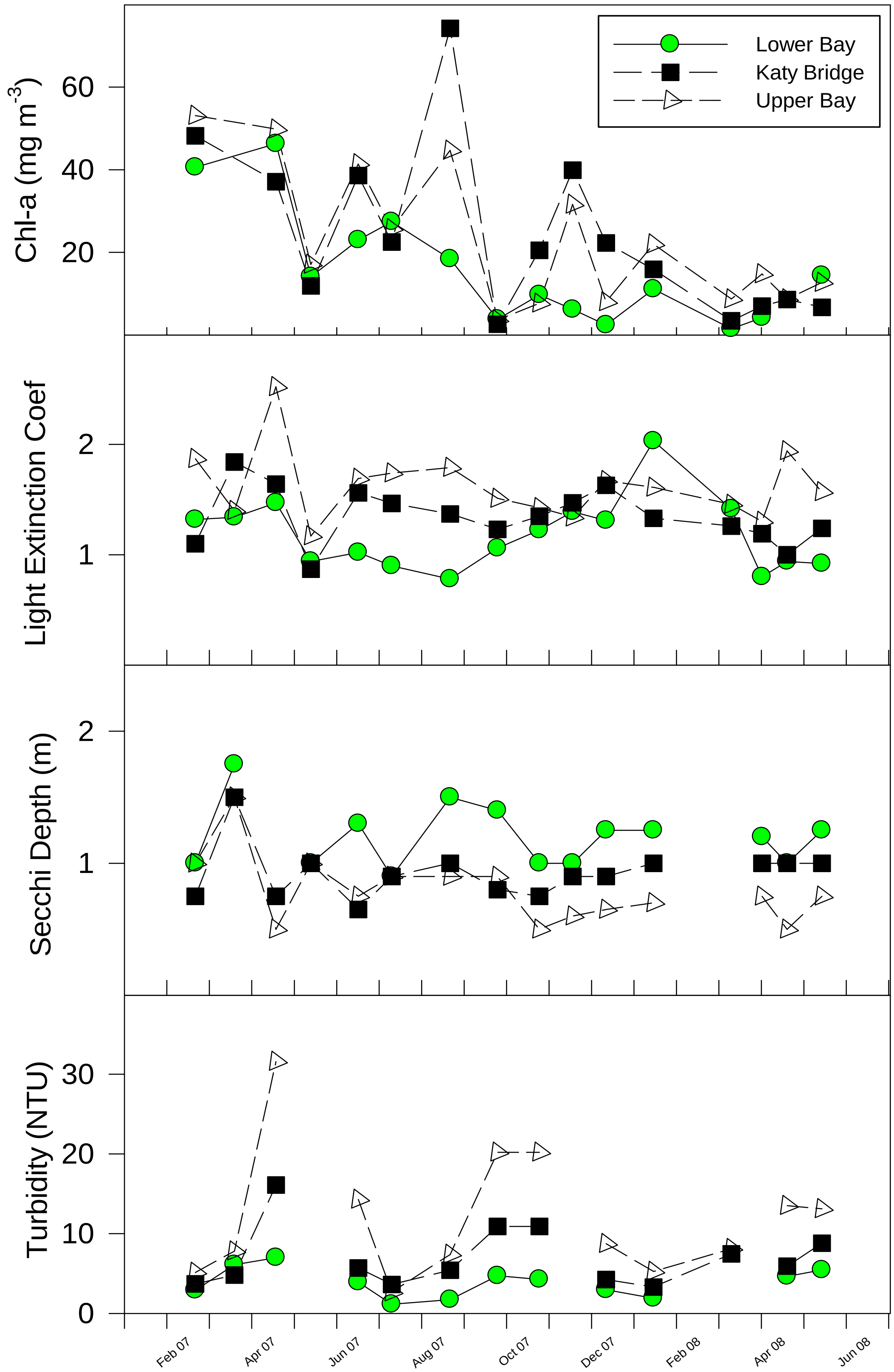

Figure 5. Seasonal pattern of chlorophyll-a (mg m^{-3}), light extinction coefficient, Secchi depth (m) and turbidity (NTU) in the surface waters of the three sampling stations of Lake Whitney.

Data for light extinction, Secchi depth and turbidity showed relatively little seasonal pattern but strong spatial variability. Values for all parameters showed a strong decline in turbidity and increasing water clarity as the water flowed through the reservoir, with significantly higher water clarity at the LB site (Figure 5 b, c, d, Table 1). Turbidity values at the LB showed little temporal variability and was always below 7.0 NTU and had an overall mean value of only 3.9 NTU. In contrast, the UB site showed pronounced fluctuations in time related to periods of high inflow. This station had an overall average turbidity of 12.2 NTU but values ranged up to 31.6 NTU during high inflow conditions. The BS station showed intermediate turbidity levels. The same pattern observed for turbidity was also true of light extinction coefficients and Secchi Depth. Euphotic zone depth (Z_{eu}) was consistently greatest at the LB Station and lowest at the UB station throughout the study period (Table 1).

Phytoplankton Productivity vs. Irradiance Assays

Biomass-specific rates of plankton respiration (R^B) ranged from 0.15 to 4.00 mg C mg Chl-a^{-1} hr^{-1} (Figure 6a). Higher values of respiration were observed during the period from November 2007-March 2008. R^B did not vary significantly among stations (Table 1, p=0.20) and showed an overall average and median rates of 0.80 and 0.58 mg C mg Chl-a^{-1} hr^{-1}. These values are equivalent to volumetric rates of 11.1 mg C m^{-3} hr^{-1} (range 4.7-28.9) which are very similar to rates reported by plankton in the Chesapeake Bay (Smith and Kemp 1995).

The light-saturated rate of photosynthesis per unit chlorophyll-a (P^B_{max}) ranged from 1.2 to 24.4 mg C mg Chl^{-1} hr^{-1} with a mean and median for all stations of 6.6 and 3.9 mg C mg Chl^{-1} hr^{-1}. P^B_{max} showed the same trend at all stations with peak values during the summer of 2007 and winter of 2008 (Figure 6b). Although The P^B_{max} levels at the LB tended to be higher than

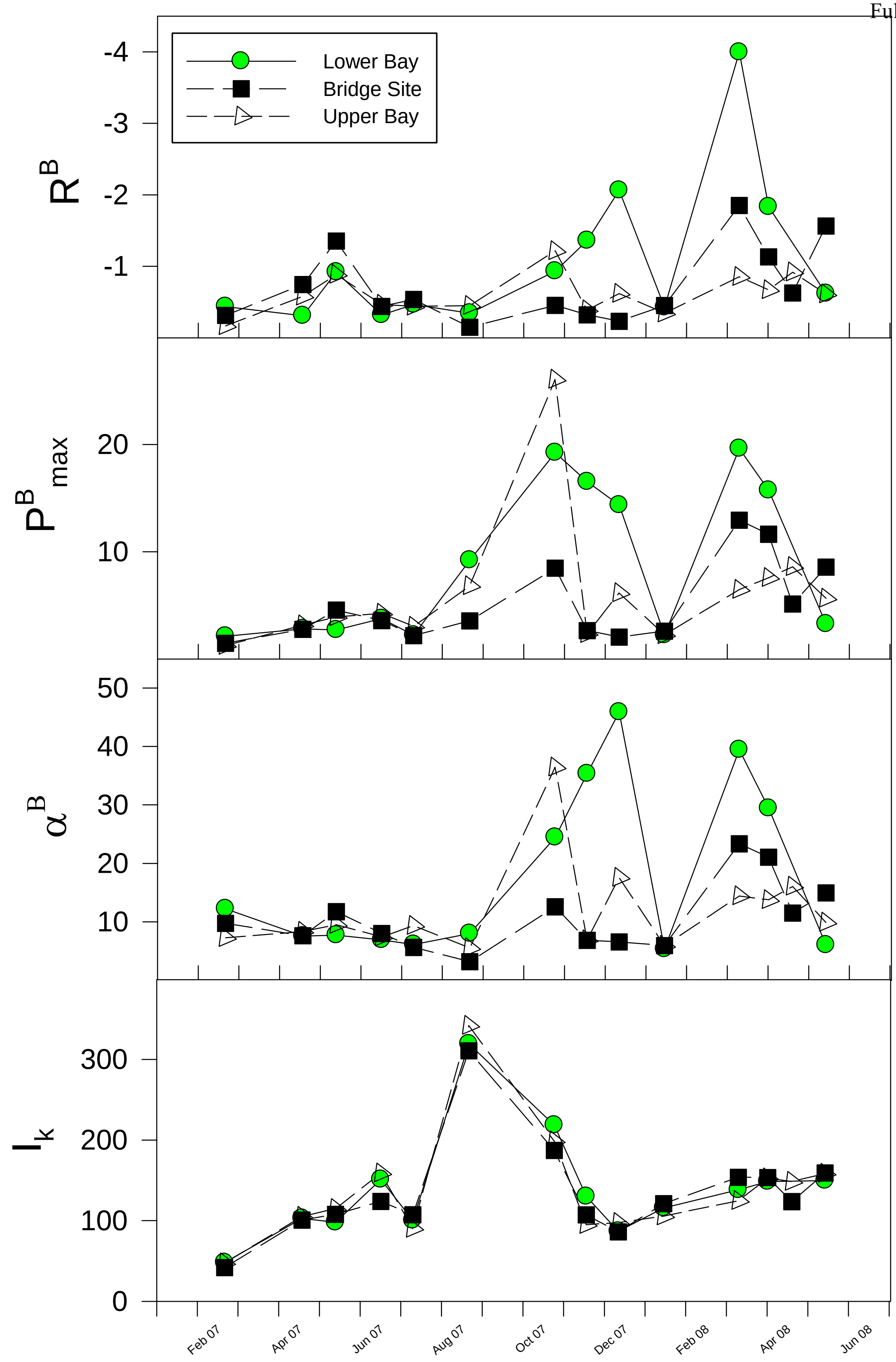

Figure 6. Temporal pattern of R^B, P^B_{max}, α^B, and I_k during the study period. R^B = (mg C mg Chl-a^{-1} h^{-1}). P^B_{max} = (mg C mg Chl^{-1} h^{-1}), α^B = [(mg C mg Chl^{-1} h^{-1}) (E m^{-2} h^{-1})$^{-1}$]

those at the upper stations they were not significantly different among the three stations (two-way ANOVA $p = 0.13$, Table 1).

The initial slope of the photosynthesis-irradiance curve at low light (α^B) ranged from 3.2 to 45.9 [(mg C mg Chl^{-1} h^{-1}) (E m^{-2} h^{-1})$^{-1}$] with a mean and median for all stations of 13.45 and 9.35, respectively. α^B was highly significantly correlated to P^B_{max} ($r = 0.88$, $p < 0.001$) and showed a similar temporal trend with the higher values occurring during the summer of 2007 and winter 2008 (Figure 6c). Like P^B_{max}, α^B was usually higher at the LB station that at the other stations but was not significantly different from that at the other stations due to the high variability of the data (Table 2, p=0.13). P^Bmax and α^B values during this study were found to be within the general range of data collected from water bodies in North America (Table 2).

The light saturation parameter I_k (P^B_{max}/ α^B) determines the onset of light saturation, which is often considered the minimum amount of light needed for optimal photosynthesis to take place. I_k had a strong maxima during the late summer of 2007 (Figure 6d). There was no significant difference among stations and the mean I_k for all stations was 136 μE m^{-2} s^{-1}. These values are similar to those found for phytoplankton in the Chesapeake Bay (Harding et. al. 1985, 2002; Smith and Kemp 1995).

Areal Phytoplankton Productivity and Respiration

Rates of potential gross areal daily production (GP) showed the expected seasonal variability with higher rates being found during the summer of 2007 (Figure 7). Rates during the winter (December-January) were the lowest, and spring (Feb-May) had intermediate values. Despite significant differences in Chlorophyll a and water column clarity, the rates of GP were not significantly different among stations (p=0.72, Table 2). Although Chlorophyll a levels near

Table 2. Observed values of plankton photosynthetic parameters P^B_{max} and α^B (expressed in C units) in various waterbodies. In some cases original data have been converted from oxygen to carbon units assuming a photosynthetic quotient of 1.0.

Location	**Year**	**P^B_{max}**	**α^B**	**Comment**	**Reference**
Bedford Basin, Nova Scotia	1975	2.04-8.37	9.7-31.4	Spring/Summer (May-July) day-to-day variations in photosynthetic parameters measured over a 70 day period	Cote and Platt (1983)
Northfrisian Wadden Sea, Germany	1995-1996	0.8-9.9	1.9-10.8	Primary production measured March 1995 to December 1996	Tillmann, Hesse and Colijn (2000)
Lake Ontario, Canada	1987-1992	0.4-7.5	0.6-13.5	May through late October, two stations	Milard et. al. (1996)
Shield Lakes, Canada	1997	3.5	9.2	Median value for 12 lakes; production and respiration measured May-Oct 1997	Carignan et. al. (2000)
Tomhannock Reservoir, NY	1991-1992	0.6-20.9	0.7-20.2	Mean for three stations: measurements May 1991 – October 1992.	Melcher (1994)
Lake Texoma, TX/OK	1999-2000	1.5-14.5	6.3-30.9	Range for four stations, measurements from August 1999 – August 2000	Baugher (2001)
Lake Ray Roberts, TX	1994	2.8-7.8	8.7-19.1	Single station, spring and summer	Doyle (unpublished)
Chesapeake Bay, MD	1982	1.0-12.0 (4.4)	2.8-52.8 (11.8)	Range and median values for three cuises (March, July, October)	Harding et. al. 1985
Ohio Reservoirs	2000	1.0-3.0	0.5-3.0	Range for 3 reservoirs sampled April-October 2000	Knoll et. al. 2003
Lake Whitney, TX	2007-2008	1.2-24.4 (3.9)	3.2-45.9 (9.3)	Range and median for three lacustrine stations along the main reservoir axis	Present study

$\mathbf{P^B_{max}}$ = (mg C mgChl^{-1} h^{-1}); $\boldsymbol{\alpha^B}$ = [(mg C mgChl^{-1} h^{-1}) (E m^{-2} h^{-1})$^{-1}$]

Table 3. Summary of phytoplankton productivity estimates in various reservoirs or estuaries. Productivity values represent the mean daily production for the entire year or growing season, unless noted otherwise. Asterisks indicate average values for two or more annual production estimates. Lake Whitney data reflect the annual mean. Trophic state categories, as indicated by ^{14}C method estimates, are those of Likens (1975) and Wetzel (1983).

Reservoir, Location	Mean daily production			Reference
	Year	($g C m^{-2} d^{-1}$)	Comments	
OLIGOTROPHIC 0.05-0.30 $g C m^{-2} d^{-1}$				
Tuttle Creek, Kansas	1970, 71	0.07	^{14}C; highly turbid, light-limited system	Marzolf and Osborne (1971)
Sam Rayburn, Texas	1977-78	0.10	^{14}C, very large reservoir	Lind (1979b)
Smallwood, Labrador, Canada	1974, 75	0.14*	^{14}C	Ostrofsky (1978), Ostrofsky and Duthie (1978)
Canyon, Texas	1976	0.18	^{14}C, very large, deep reservoir	Hannan et al. (1981)
Nickajack, Tennessee	1973	0.24	^{14}C, summer estimates	Placke and Poppe (1980)
MESOTROPHIC 0.25-1.00 $g C m^{-2} d^{-1}$				
Francis Case, South Dakota	1968	0.26	Net O_2 change, summer estimates	Martin and Novotny (1975)
Isabella, Michigan	1977-78	0.42	Net O_2 change, seasonal estimates	Groeger (1979)
North Lake, Texas	1976	0.52	^{14}C, small cooling reservoir	Stuart and Stanford (1979)
Cheat, West Virginia	1971	0.70	^{14}C	Volkmar (1972)
Waco, Texas	1968, 1977-78	0.81*	^{14}C	Kimmel and Lind (1972), Lind (1979b)
Pena Blanca, Arizona	1959-61	0.90	Gross pelagic production by O_2 change and estimates from chlorophyll data	McConnell (1963)
Texoma, Oklahoma-Texas	1979, 80	0.93	^{14}C, summer estimates	B.L. Kimmel (unpubl.data)
Douglas, Tennessee	1969	0.94	^{14}C	Taylor (1971)

EUTROPHIC >1.00 g C $m^{-2}d^{-1}$				
Texoma, Oklahoma-Texas	1978	2.63	^{14}C summer and fall estimates; midlake sample	Ellis (1980)
Texoma, Oklahoma-Texas	1999-2000	1.95	Gross production from O_2 change method. Average of 4 stations.	Baugher (2001)
Canyon Ferry, Montana	1958	1.13	Net O_2 change, April - September	Wright (1958, 1959, 1960)
Moss, Texas	1976	1.30	^{14}C	Silvey and Stanford (1978)
Long Lake, Washington	1972, 73	1.90	Estimated from chlorophyll and light data after Ryther and Yentsch (1957), July - March	Soltero et al. (1975)
Chesapeake Bay, MD	1990-1992	0.34, 1.96, 2.00	Annual mean GP for Upper Bay, Mid Bay and Lower Bay, respectively. Estimates for O_2 change method.	Kemp et. al. 1997
Stagecoach, Nebraska	1969, 70	3.98*	^{14}C summer estimates	Anderson and Hergenrader (1973)
Lake Whitney, TX	2007-2008	2.04	Annual mean *potential* GP (cloud-free days) from O_2 change method.	Present Study
		1.94	(Lower Bay) Annual mean *potential* GP (cloud-	Present Study
		1.88	free days) from O_2 change method.. (Bridge Site) Annual mean *potential* GP (cloud-free days) from O_2 change method. (Upper Bay)	Present Study

Modified from Wetzel (1983).

the dam (LB site) were significantly lower than upreservoir, the increased water clarity permitted production to a deeper depth at this station such that integrated areal production was equivalent throughout the reservoir. GP rates varied between 0.03 and 4.35 (average=1.95) mg C m^{-2} d^{-1}.

GP was found to be statistically related to Chlorophyll-a, temperature and underwater light climate. A multiple regression analysis yielded the following statistically significant ($F = 913.34$, $p < 0.001$, adjusted $r^2 = 0.48$) model for GP:

$$GP = 1.23 + [0.029(\text{chl-a}) + 0.061(\text{temp}) - 0.817(\text{ext})].$$

Net areal photosynthetic production is calculated by subtracting the daily plankton respiration for the surface mixed layer from the estimates of GP. This calculation was complicated for Lake Whitney because of the lack of thermal stratification throughout the study period. Under these conditions, the respiration rate of the total water column is subtracted from GP. Areal respiration almost always exceeded GP during the study period (Figure 7 a-c). Overall, the ratio of areal production to respiration (P:R) exceeded 1.0 only twice during the study (Figure 7d). P:R was significantly different among stations ($p<0.01$) being significantly higher at the upper bay station (0.53) than at the bridge site and lower bay sites (0.33 and 0.35, respectively, Table 1).

Another way to view the balance of production and respiration is to compute the respiratory compensation depth: the depth at which all autogenic production is consumed. The estimated compensation depth (Z_{comp}) was computed for each date and station by dividing the areal production rate by the volumetric rate of respiration. Z_{comp} was always less than the actual depth of the site and averaged 9.7, 7.5 and 6.9 m depth for sites LB, BS and UB respectively.

These data indicate that the water column of Lake Whitney was always an overall significant net source of atmospheric carbon with areal rates of respiration exceeding production by a factor of 2-4X on average.

Summary

The productivity data generated in this study should be considered *potential gross production* values since they are calculated for cloud-free periods. Therefore, it is not surprising that the average daily potential gross production of 1.88-2.04 g C m^{-2} d^{-1} is at the upper end of values reported for reservoirs (Table 3). Even so, numerous reservoirs show average daily rates equivalent or even higher than those reported here.

However, the fact that these data are potential production only strengthens the conclusion that the system is net heterotrophic during non-stratified periods. The respiration rates calculated are not influenced by the cloud-free nature of the estimates since we have assumed that dark rates remain constant during the 24 hour period. However, since actual GP values are likely lower than the potential rates estimated due to significant cloud-cover on most days, the difference between GP and respiration is likely underestimated by these calculations.

Finally, the observed levels of chlorophyll and phytoplankton production measured are unlikely to present undue problems with generation of dissolved organic carbon that would generate harmful compounds when disinfected with chlorine.

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Lake Whitney Educational Outreach
DRAFT Final Report

Phase IB

Study Element No. 10:

Prepared for:
USDOE

Prepared by:
Robert Doyle and Bruce Byars
Baylor University

CRASR

The Educational Outreach (Study Element 10) component of the Lake Whitney Assessment project was divided into three main efforts: 10a) Assessment of Resident Knowledge about Lake Whitney (sub-contract to UNT), 10b) Assistance with STEM curricula at the Whitney High School, and 10c) Development of a Lake Whitney Learning Laboratory Manual to facilitate ongoing educational opportunities for residents and students of Whitney.

Lake Whitney Educational Outreach
DRAFT Final Report

Phase IB

Study Element No. 10a:
Assessment of Resident Knowledge about Lake Whitney

Prepared for:
USDOE

Prepared by:
D'Arlene Ver Duin
&
Paul Ruggiere

University of North Texas
Survey Research Center

CRASR

Lake Whitney Survey 2007: Assessment of Resident Knowledge About Lake Whitney and the Lake Whitney Watershed

Prepared for:
Baylor University

By:

D'Arlene Ver Duin
Paul Ruggiere

Survey Research Center
University of North Texas

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

I. INTRODUCTION

During the months of March, April and May 2007, a water issues survey was administered to residents of the Lake Whitney area of Texas. This survey is part of the Lake Whitney Comprehensive Assessment conducted by the Center for Reservoir and Aquatic Systems Research at Baylor University and funded by the Department of Energy and the Department of Environmental Protection Agency to allow determination of its suitability for use as a regional water supply.

The water issues survey is designed to provide information that will be used to construct educational/outreach activities and measured local residents' and Lake Whitney stakeholders' knowledge of:

- Water usage and processing;
- Environmental conditions and behaviors impacting Lake Whitney, and;
- The feasibility of using Lake Whitney as a source of drinking water.

In order to allow meaningful and confident generalizations to the larger population, the number and characteristics of people interviewed must be sufficiently representative of adult residents of the target area. Two sampling methods were considered: Random Digit Dialing (RDD) and listed sample. The telephone exchanges surrounding Lake Whitney covered too many other areas for the RDD method to be economically feasible. Instead, phone numbers were drawn using up-to-date phone listings provided through Marketing Systems Group Genesys Sampling Systems. The listings database is updated each month and allows researchers to draw samples based on Census block definitions. Therefore, a listed sample provides greater geographic precision at a lower cost.

The survey provides a representative sample of households with listed telephone numbers within the Lake Whitney area. The survey does not include households without a listed telephone number or with no telephone. In many surveys, it is assumed that responses among households with listed and unlisted phone numbers would be similar. However, since the Lake Whitney area includes seasonal residences, it is reasonable to assume that many of the unlisted households may, in fact, be seasonal residences without landline telephone service. The survey may therefore under represent respondents living in seasonal housing units.

The Survey Research Center at the University of North Texas conducted the survey for the Center for Reservoir and Aquatic Systems Research at Baylor University.

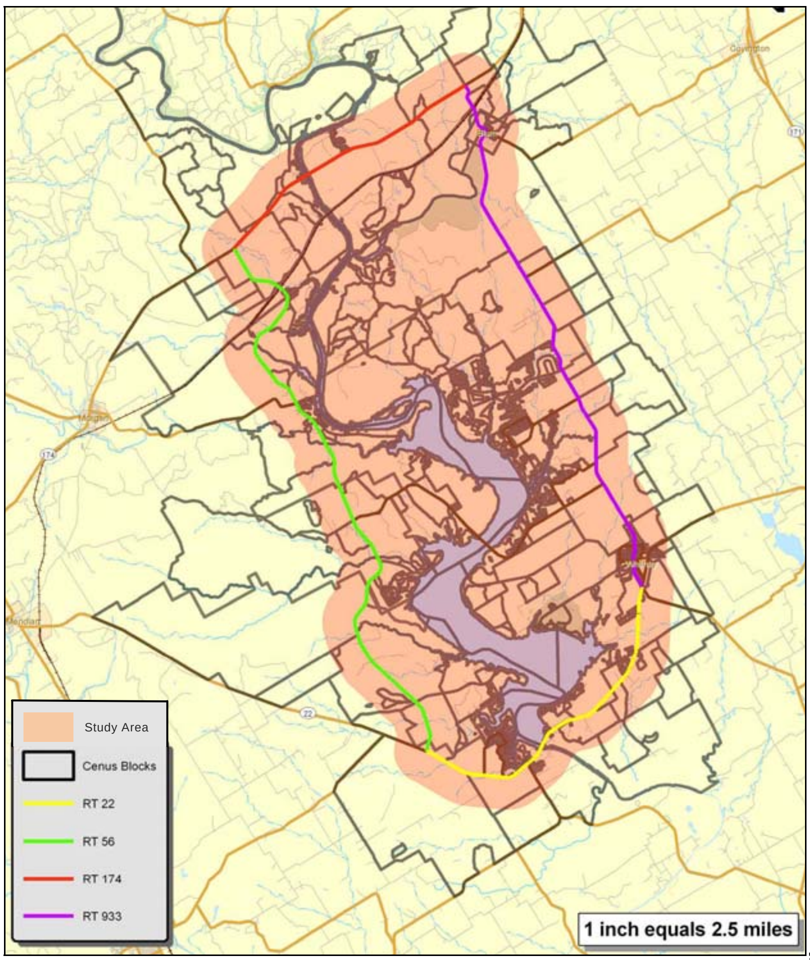
The data generated and information gathered by this survey will provide a robust basis for developing informational materials for the general public and educational information for the local school district.

II. METHODOLOGY

Sample

The conceptual population for the survey was all residents of the City of Whitney and respondents living in an area around Lake Whitney who were 18 years of age or older and who reside in households with listed telephone numbers. As a starting point for defining the area of interest, SRC defined a boundary using major roads: Rt. 22 to the south, Rt. 56 to the west, Rt. 174 to the north and Rt. 933 to the east (see the peach colored area in Map 1 below for an approximate boundary). Census blocks encompassing this area were used when preparing the sample.

Map 1:
Census Blocks Included in Sampling Frame



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A total of 600 usable interviews were conducted and analyzed. In a random sample, 600 interviews yield a margin of error of ± 4.0 percent. This means, for example, that if 40 percent of the respondents answered "yes" to a question, we can be 95 percent confident that the actual proportion of residents in the population who would answer "yes" to the same question is 4.0 percentage points higher or lower than 40 percent (36.0 percent to 44.0 percent).

Instrument

The survey instrument was provided to SRC by the research team at Baylor University. SRC worked with the research team after they drafted the initial survey instrument. A process of revision continued until a final survey instrument was agreed upon by all parties. The final instrument is available in Appendix A.

Data Collection

Trained telephone interviewers who had previous experience in telephone surveys were used to conduct the survey. Each interviewer completed an intensive general training session. The purposes of general training were to ensure that interviewers understood and practiced all of the basic skills needed to conduct interviews and that they were knowledgeable about standard interviewing conventions. The interviewers also attended a specific training session for the project. The project training session provided information on the background and goals of the study. Interviewers practiced administering the questionnaire to become familiar with the questions.

All interviewing was conducted from a centralized telephone bank in Denton, Texas. An experienced telephone supervisor was on duty at all times to supervise the administration of the sample, monitor for quality control, and handle any other problems. Data for the survey were collected from March 15 to May 23, 2007.

In an attempt to get as many respondents as possible who did not live in the City of Whitney, listed phone numbers from areas outside the city were sent a letter encouraging them to complete the survey when we called. These households were also invited to call SRC's 800 number to complete the survey. An additional U.S. Post Office data base was also utilized to produce a mailing list of all possible addresses in lake locations outside the City of Whitney. SRC mailed 827 letters encouraging unlisted potential households to call SRC's 800 number to complete the survey.

Analysis by Demographic Groups

Each question in the survey was cross-tabulated with the following 10 demographic categories:

- Years of education
- Race or ethnicity
- Age of respondent
- Gender of respondent
- Homeownership
- Employment status
- Work site
- Income
- Live in city or country
- Language spoken most in household

Whenever the responses to a single question are divided by demographic groups, the percentage distribution of responses within one group will rarely exactly match the percentage distribution of another group; there will often be some variation between groups.

The most important consideration in interpreting these differences is to determine if the differences in the sample are representative of differences between the same groups within the general population. This consideration can be fulfilled with a test of statistical significance. For categorical responses, SRC uses a Chi-square analysis and for comparisons of mean scores, an Analysis of Variance (ANOVA) test.

The Survey Research Center only reports those differences between demographic groups that are found to be statistically significant. Since the report already segments the responses of people living in the City of Whitney from “Others” in the study area, the tests of statistical significance are run on each segment independently. Therefore, a demographic breakdown that is statistically significant among the “City” respondents may not be statistically significant among the “Other” respondents.

In tables where demographic breakdowns are found to be statistically significant, differences are marked with one to three asterisks depending on the level of significance (*$p<.05$, **$p<.01$, ***$p<.001$). If the differences are not statistically significant for the City or Other segment, the percentages for that segment will not be presented and will be substituted with dashes (-).

Report Format

The remainder of the report is arranged in four sections beginning with Section III. This section, “Sample Characteristics,” presents the findings for all respondents except where it is otherwise noted. Section IV, “Findings,” presents findings for city and county respondents. These include environmental conditions and behaviors impacting Lake Whitney, water usage and processing, and the feasibility of using Lake Whitney as a source of drinking water. Section V is the report Conclusions.

III. SAMPLE CHARACTERISTICS

Table 1
Demographics

Demographics	Percentage	
	City of Whitney (n=510)	Others (n=90)
Age of respondent		
18 to 25	3.9	3.3
26 to 35	6.3	5.6
36 to 45	10.4	12.2
46 to 60	30.1	33.3
61 or older	49.3	45.6
Race/ethnicity		
White	94.1	94.4
Black	0.6	3.3
Hispanic/Latino	1.8	0.0
Asian	1.0	1.1
Native American	1.8	0.0
Other	0.8	1.1
Gender of respondent		
Female	57.1	61.1
Male	42.9	38.9
Language spoken most in home		
English	99.4	100.0
Spanish	0.0	0.0
Both equally	0.6	0.0
Other	0.0	0.0
Education		
Primary or middle school	3.9	4.4
High school	24.6	27.8
Some college or technical school	31.4	35.6
College	30.5	23.3
Masters degree or higher	9.6	8.9

- As seen in Table 1, 40.5 percent of the respondents who lived in the City of Whitney (“Whitney respondents”) were between ages 36 and 60 compared to 45.5 percent of respondents who lived throughout the rest of the Lake Whitney area (“Other respondents”).
- A large majority of respondents were white (94.1 percent-Whitney; 94.4 percent-Other).
- Fifty-seven percent of the Whitney respondents in the sample were female as were 61.1 percent of the Other respondents.
- English was the language spoken most in the home for both Whitney respondents (99.4 percent) and Other respondents (100.0 percent).
- Forty percent of Whitney respondents and 32.2 percent of other respondents had a college or advanced degree. Other respondents (32.2 percent) were more likely than Whitney respondents (28.5 percent) to have a high school education or less.

Demographics	Percentage	
	City of Whitney (n=510)	Others (n=90)
Employment status		
Employed full-time	32.7	40.0
Employed part-time	7.8	2.2
Unemployed	3.2	3.3
Retired	47.8	45.6
Student	1.4	2.2
Homemaker	7.2	6.7
Work site***	(n=200)	(n=37)
Work near the lake	51.0	18.9
Commute to another city	49.0	81.1
City of employment	(n=97)	(n=30)
Blum	1.0	3.3
Burleson	2.1	3.3
Cleburne	5.2	3.3
Clifton	4.1	16.7
Dallas	7.2	13.3
Fort Worth	10.4	13.3
Gatesville	0.0	6.7
Glen Rose	1.0	3.3
Hillsboro	17.5	0.0
Waco	21.6	16.7
Whitney	4.1	0.0
Single mention cities in Texas	11.3	6.7
Multiple mention cities in Texas	7.2	6.7
Multiple mention cities in US	4.1	6.7
International	3.1	0.0
Income		
Under $10,000	6.1	6.0
$10,001 to $25,000	20.0	19.0
$25,001 to $50,000	30.7	28.6
$50,001 to $75,000	19.8	22.6
$75,001 to $100,000	12.4	11.9
$100,001 to $150,000	7.6	4.8
Over $150,000	3.5	7.1

- Almost half of the Whitney respondents (47.8 percent) and Other respondents (45.6 percent) were retired.
- Half (51.0 percent) of employed Whitney respondents and 18.9 percent of employed Other respondents worked near the lake.
- Waco (21.6 percent for Whitney respondents and 16.7 percent for Other respondents) was the most common work site for employed respondents who commuted to work.
- Fifty-one percent of the Whitney respondents reported an annual household income of between $10,001 and $50,000 compared to 47.6 percent of the Other respondents.

*** The difference between Whitney and Other respondents for work site was statistically significant at the p<.001 level.

Demographics	Percentage	
	City of Whitney (n=510)	Others (n=90)
Length of residence		
0 to 5 years	23.9	34.4
6 to 10 years	21.0	22.2
11 to 20 years	24.5	21.1
21 to 35 years	19.0	14.4
36 years or more	11.6	7.8
Live in city or country		
City or town	19.6	17.2
In the country	80.4	82.8
Live on farm or ranch	(n=406)	(n=74)
Farm	12.6	9.5
Ranch	6.4	8.1
Neither	81.0	82.4
Rent apartment or house	(n=99)	(n=15)
House	78.8	93.3
Mobile home	10.1	6.7
Apartment	8.1	0.0
Condominium	2.0	0.0
Other	1.0	0.0
Primary or secondary home		
Primary home	98.0	96.7
Secondary home	1.8	3.3
Half here/half somewhere else	0.2	0.0

- Forty-five percent of Whitney respondents and 57.6 percent of Other respondents lived in the Whitney area for 10 years or less.
- About eighty percent of the Whitney respondents (80.4 percent) and Other respondents (82.8 percent) lived in the country.
- Respondents who lived in the country were asked if they lived on a farm or ranch. About 80 percent of Whitney respondents (81.0 percent) and Other respondents (82.4 percent) lived on neither a farm nor a ranch.
- Of the respondents who reported living in a city or town, over three-quarters (78.8 percent) of the Whitney respondents indicated they lived in a house while 93.3 percent of Other respondents did so.
- Nearly all of the Whitney (98.0 percent) and Other respondents (96.7 percent) reported that their Lake Whitney residence was their primary home.

IV. FINDINGS

Water Usage and Processing

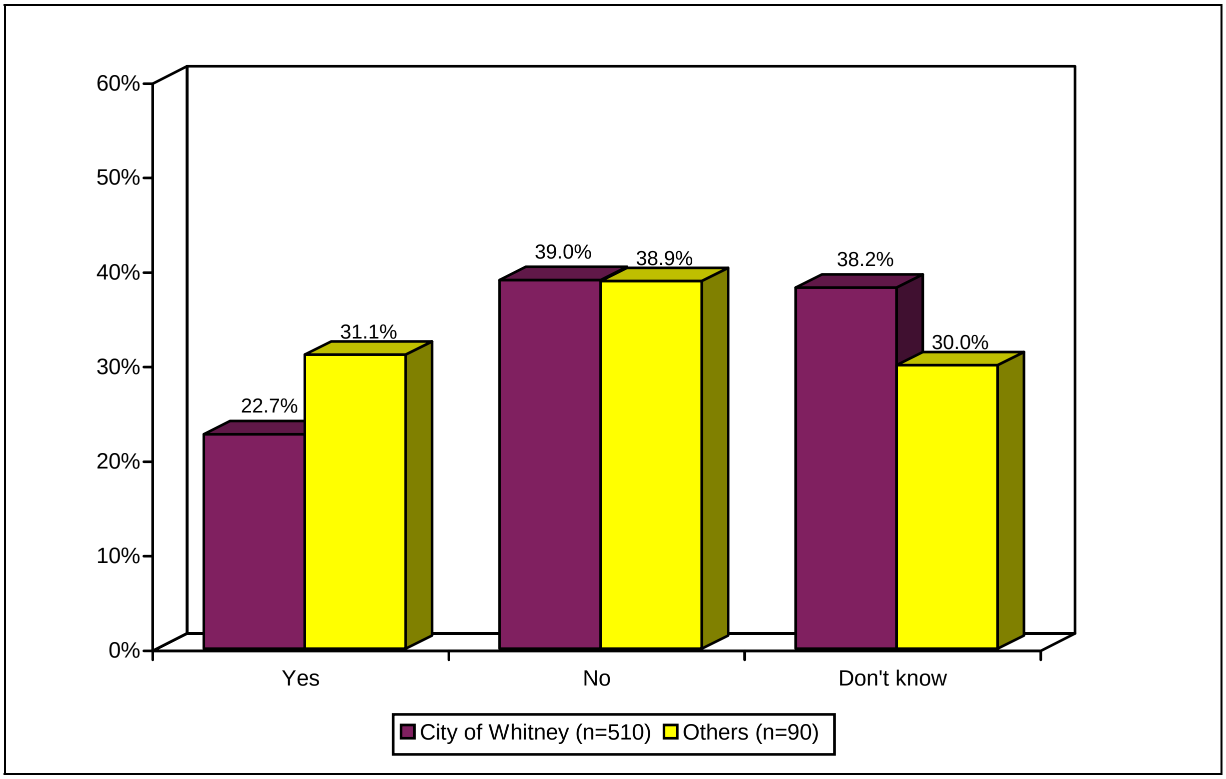
Table 2
Water in Your Community

	Percentage responding	
	City of Whitney (n=504)	Others (n=86)
Water for drinking (bottled or tap)	30.2	24.4
Need clean water supply	18.3	19.8
Necessary for life/living	7.2	9.2
Lack of water supply	6.4	3.5
Lake Whitney	4.8	5.8
Wet/cool/refreshing	4.0	1.2
Taste (good or bad)	3.2	7.0
Specific bodies of water (lakes/rivers)	3.0	2.3
Recreation	3.0	4.7
Bathing/cleaning	2.2	0.0
Water pollution	2.0	5.8
Availability/abundance of water	2.0	2.3
Cost	2.0	2.3
Supplier/city/service	2.0	5.8
Lake Whitney has a low water level	1.6	1.2
Rain	1.6	1.2
Conservation of water	1.0	0.0
Chemicals in the water	0.8	1.2
Watering yard/plants	0.6	0.0
Health	0.6	0.0
Well water	0.4	0.0
Water pressure	0.2	1.2
Other	3.0	1.2

- Respondents were asked the first thing that came to their mind when they thought of water in their community or rural area. As shown in Table 2, 30.2 percent of the Whitney respondents and 24.4 percent of the Other respondents answered "water for drinking." Smaller percentages of the Whitney respondents (18.3 percent) and the Other respondents (19.8 percent) mentioned need for a clean water supply. The open-ended comments can be found in Appendix B.

Watershed

Figure 1
Live in a Watershed



- Respondents were asked if they lived in a watershed. As shown in Figure 1, a larger percentage of other respondents (31.1 percent) than Whitney respondents (22.7 percent) indicated they did live in a watershed. Whitney respondents (38.2 percent) were more likely to report they did not know than other respondents (30.0 percent).
- Among Whitney respondents, a larger percentage of Other ethnic group respondents (63.3 percent) than White respondents (37.7 percent) indicated they did not live in a watershed (see Table 3a). Male respondents (38.4 percent) were more likely than female respondents (11.0 percent) to report living in a watershed. A smaller percentage of unemployed/student/ homemaker respondents (6.8 percent) reported living in a watershed compared to retired respondents (25.8 percent) and employed respondents (23.6 percent).
- Among Whitney respondents, males (52.2 percent) were more likely than females (20.8 percent) to report living in a watershed (see Table 3b). A smaller percentage of unemployed/student/ homemaker respondents (13.8 percent) reported living in a watershed compared to retired respondents (41.1 percent) and employed respondents (37.5 percent).

Table 3A
Live in a Watershed (includes "Don't Know" responses)
by Selected Demographics

	Group	Percentage responding		
		Yes	No	Don't know
Race/ethnicity				
White	City*	22.8	37.7	39.5
	Other	-	-	-
Other	City	20.0	63.3	16.7
	Other	-	-	-
Gender				
Female	City***	11.0	41.9	47.1
	Other	-	-	-
Male	City	38.4	35.2	26.5
	Other	-	-	-
Employment status				
Employed	City*	23.6	39.4	36.9
	Other	-	-	-
Unemployed/Student/Homemaker	City	6.8	42.4	50.8
	Other	-	-	-
Retired	City	25.8	37.1	37.1
	Other	-	-	-

Table 3B
Live in a Watershed
by Selected Demographics

	Group	Percentage responding	
		Yes	No
Gender			
Female	City***	20.8	79.2
	Other	-	-
Male	City	52.2	47.8
	Other	-	-
Employment status			
Employed	City*	37.5	62.5
	Other	-	-
Unemployed/Student/Homemaker	City	13.8	86.2
	Other	-	-
Retired	City	41.1	58.9
	Other	-	-

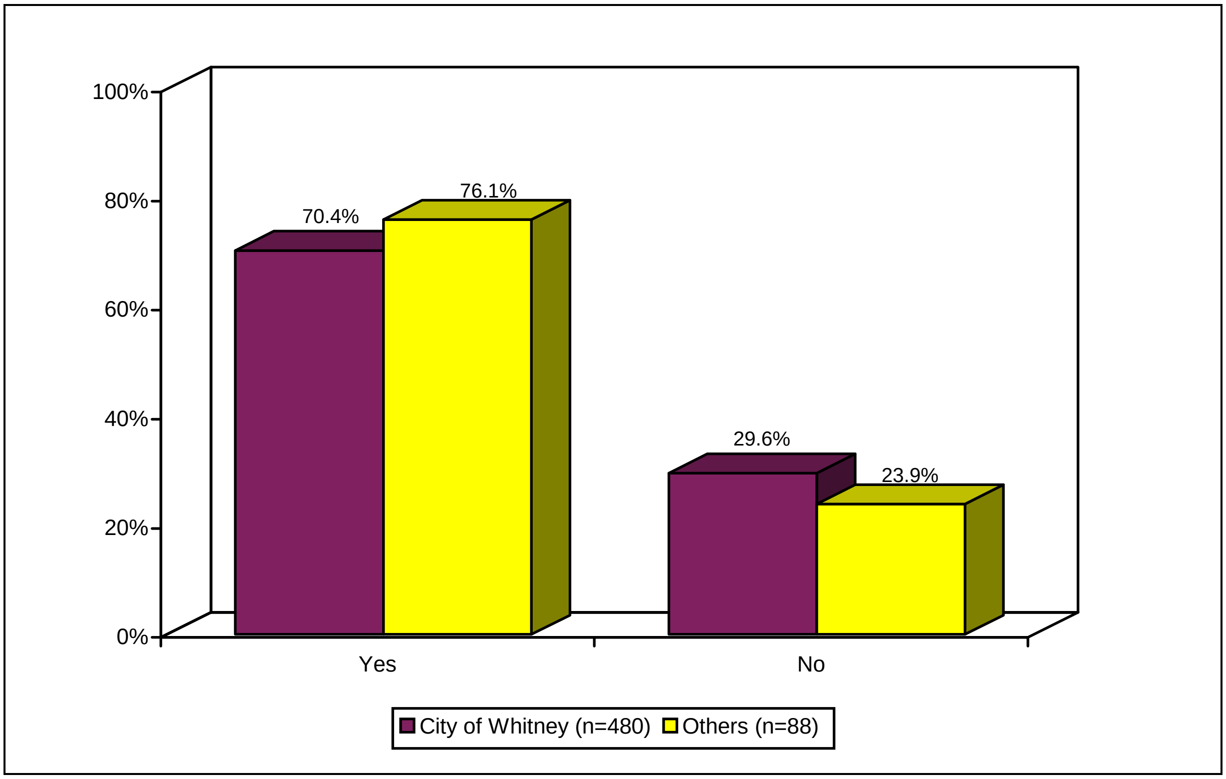
* The difference between demographic groups was statistically significant at the p<.05 level.
*** The difference between demographic groups was statistically significant at the p<.001 level.

Table 4
Name of Watershed

	Percentage responding	
	City of Whitney (n=79)	Others (n=21)
Lake Whitney	43.0	42.9
Brazos/Brazos River	32.9	33.3
Aquilla	10.1	0.0
Hilco/Hill County	5.1	0.0
Trinity	1.3	14.3
Edwards Aquifer	1.3	0.0
Other	6.3	9.5

- Respondents who indicated they lived in a watershed were asked if they could name the watershed. As shown in Table 4, Lake Whitney was the most common answer provided by both Whitney respondents (43.0 percent) and other respondents (42.9 percent) who gave an answer. Thirty-three percent of both groups of respondents answered Brazos or Brazos River.
- For Whitney respondents, other answers included County Coop System, Itasca Water Company, Pecos River and Crosstimbers, Hickory Creek, from the Rocky Mountains, Willow Creek Watershed – west of Richland Chambers.
- For Other respondents, the only other answer was Coon Creek.

Figure 2
Water Lawn during the Summer



- Respondents were asked if they watered their lawn during the summer. As shown in Figure 2, 70.4 percent of Whitney respondents and 76.1 percent of other respondents reported watering their lawn during the summer.
- The percentage of Whitney respondents who reported watering their lawn during the summer increased as the age of the respondent, education and income increased (see Table 5).
- Of the respondents who reported watering their lawn during the summer, Whitney respondents watered an average of 2.24 days a week while other respondents watered 2.08 days a week, on average.
- The average days per week that Whitney and other respondents watered generally decreased as the age of the respondent increased (see Table 6). Average watering days were higher among Whitney unemployed/student/homemaker respondents compared to respondents with other employment status. Average watering days per week were higher among Other respondents who commuted to another city for work (2.24 days) compared to those who worked near the lake (1.20 days).

Table 5
Water Lawn during the Summer
by Selected Demographics

	Group	Percentage responding	
		Yes	No
Age of respondent			
18 to 45	City	-	-
	Other*	52.6	47.4
46 to 60	City	-	-
	Other	76.7	23.3
61 or older	City	-	-
	Other	87.2	12.8
Education			
High school or less	City***	57.5	42.5
	Other	-	-
Some college/technical school	City	77.5	22.5
	Other	-	-
College or more	City	74.2	25.8
	Other	-	-
Income			
$25,000 or less	City***	55.6	44.4
	Other	-	-
$25,001 to $50,000	City	66.7	33.3
	Other	-	-
$50,001 to $75,000	City	74.2	25.8
	Other	-	-
Over $75,000	City	85.8	14.2
	Other	-	-

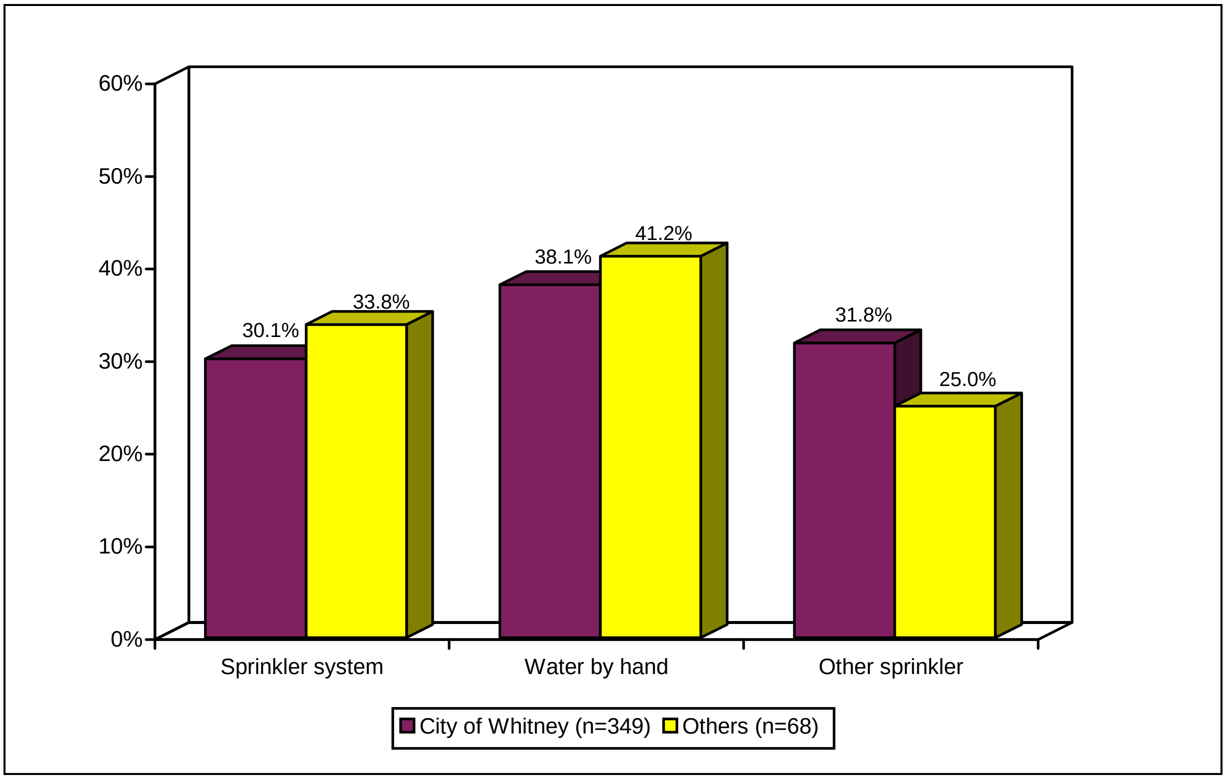
* The difference between demographic groups was statistically significant at the p<.05 level.
*** The difference between demographic groups was statistically significant at the p<.001 level.

Table 6
Average Days per Week Water Lawn during Summer
by Selected Demographics

	Group	Average Days/Week
Age of respondent		
18 to 45	City**	2.69
	Other*	2.30
46 to 60	City	2.19
	Other	2.45
61 or older	City	2.10
	Other	1.76
Employment status		
Employed	City*	2.32
	Other	-
Unemployed/Student/Homemaker	City	2.68
	Other	-
Retired	City	2.09
	Other	-
Work site		
Work near the lake	City	-
	Other**	1.20
Commute to another city	City	-
	Other	2.24

* The difference between demographic groups was statistically significant at the p<.05 level.
** The difference between demographic groups was statistically significant at the p<.01 level.

Figure 3
Type of Watering System Used



- Respondents who watered their lawn during the summer were asked if they had a sprinkler/irrigation system, watered by hand, or used another type of sprinkler. As shown in Figure 3, Whitney respondents (31.8 percent) were more likely than other respondents (25.0 percent) to use some other type of sprinkler. Usage of a sprinkler system was more common among other respondents (33.8 percent) than Whitney respondents (30.1 percent).
- Among Whitney respondents, the percentage who reported using a sprinkler/irrigation system to water their lawn increased as the age of the respondent increased, and generally increased as education and income increased (see Table 7).

Table 7
Have Sprinkler System, Other Type of Watering
by Selected Demographics

	Group	Percentage responding		
		Sprinkler/ irrigation system	Water by hand	Other sprinkler
Age of respondent				
18 to 45	City*	21.7	39.1	39.1
	Other	-	-	-
46 to 60	City	22.5	47.7	29.7
	Other	-	-	-
61 or older	City	38.1	31.5	30.4
	Other	-	-	-
Education				
High school or less	City*	24.4	40.2	35.4
	Other	-	-	-
Some college/technical school	City	23.1	43.8	33.1
	Other	-	-	-
College or more	City	39.0	32.2	28.8
	Other	-	-	-
Income				
$25,000 or less	City***	21.9	42.2	35.9
	Other	-	-	-
$25,001 to $50,000	City	19.8	50.5	29.7
	Other	-	-	-
$50,001 to $75,000	City	26.2	32.3	41.5
	Other	-	-	-
Over $75,000	City	46.7	26.1	27.2
	Other	-	-	-

* The difference between demographic groups was statistically significant at the p<.05 level.
*** The difference between demographic groups was statistically significant at the p<.001 level.

Table 8
Use Water Conservation Techniques

	Percentage responding	
	Yes	No
1.5 gallon toilets		
City of Whitney (n=446)	78.3	21.7
Others (n=78)	76.9	23.1
Low-flow shower heads		
City of Whitney (n=484)	72.7	27.3
Others (n=87)	75.9	24.1
Use of xeriscaping or low-water grasses and plants		
City of Whitney (n=480)	55.6	44.4
Others (n=85)	58.8	41.2
Collect and store rain water for outside watering		
City of Whitney (n=509)	32.8	67.2
Others (n=89)	34.8	65.2

- Respondents were asked if they used any of the four water conservation techniques listed in Table 8.

<u>1.5 Gallon toilets</u>

- Over three-quarters of Whitney respondents (78.3 percent) and Other respondents (76.9 percent) reported using 1.5 gallon toilets to conserve water (see Table 8).

<u>Low-flow shower heads</u>

- Seventy-three percent of Whitney respondents and 75.9 percent of Other respondents reported using low-flow shower heads to conserve water.
- As shown in Table 9, usage of low-flow shower heads was higher among Whitney male respondents (77.7 percent) than female respondents (68.9 percent). Usage of low-flow shower heads varied with education for Other respondents.

Table 9
Low-Flow Shower Heads
by Selected Demographics

	Group	Percentage responding	
		Yes	No
Gender			
Female	City*	68.9	31.1
	Other	-	-
Male	City	77.7	22.3
	Other	-	-

* The difference between demographic groups was statistically significant at the p<.05 level.

Table 9
Low-Flow Shower Heads
by Selected Demographics (continued)

	Group	Percentage responding	
		Yes	No
Education			
High school or less	City	-	-
	Other*	78.6	21.4
Some college/technical school	City	-	-
	Other	61.3	38.7
College or more	City	-	-
	Other	89.3	10.7

Use of xeriscaping or low-water grasses and plants

- Fifty-six percent of Whitney respondents and 58.8 percent of Other respondents reported using xeriscaping or low-water grasses and plants to conserve water.
- Whitney respondents age 46 to 60 were more likely than Whitney respondents of other age groups to report using xeriscaping or low-water grasses and plants (see Table 10).

Table 10
Use of Xeriscaping/Low-water Grasses/Plants
by Selected Demographics

	Group	Percentage responding	
		Yes	No
Age of respondent			
18 to 45	City*	45.0	55.0
	Other	-	-
46 to 60	City	62.6	37.4
	Other	-	-
61 or older	City	56.0	44.0
	Other	-	-

Collect and store rain water for outside watering

- Approximately one-third of Whitney respondents (32.8 percent) and Other respondents (34.8 percent) reported collecting and storing rain water for outside watering.
- Among Whitney respondents, collecting and storing rain water for outside watering varied with age and education, and was higher among respondents living in the country rather than in the city (see Table 11).
- Among Other respondents, collecting and storing rain water for outside watering generally decreased as income increased.

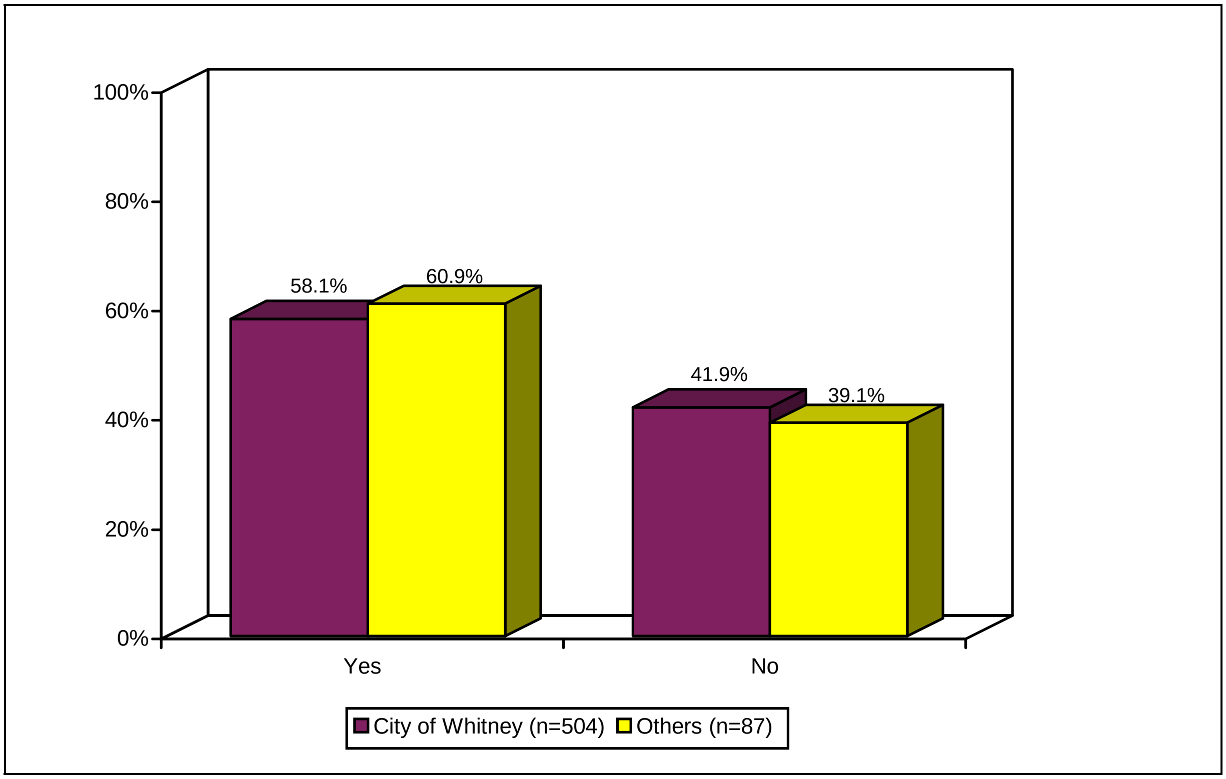
* The difference between demographic groups was statistically significant at the p<.05 level.

Table 11
Collect/Store Rain Water for Outside Watering
by Selected Demographics

	Group	Percentage responding	
		Yes	No
Age of respondent			
18 to 45	City**	27.6	72.4
	Other	-	-
46 to 60	City	45.1	54.9
	Other	-	-
61 or older	City	27.6	72.4
	Other	-	-
Gender			
Female	City**	38.8	61.2
	Other	-	-
Male	City	24.8	75.2
	Other	-	-
Education			
High school or less	City*	34.5	65.5
	Other	-	-
Some college/technical school	City	40.0	60.0
	Other	-	-
College or more	City	25.6	74.4
	Other	-	-
Income			
$25,000 or less	City	-	-
	Other*	23.8	76.2
$25,001 to $50,000	City	-	-
	Other	50.0	50.0
$50,001 to $75,000	City	-	-
	Other	47.4	52.6
Over $75,000	City	-	-
	Other	15.8	84.2
Live in city or country			
City or town	City*	24.2	75.8
	Other	-	-
In the country	City	35.1	64.9
	Other	-	-

* The difference between demographic groups was statistically significant at the p<.05 level.
** The difference between demographic groups was statistically significant at the p<.01 level.

Figure 4
Interest in Learning More about Water Conservation Techniques



- Respondents were asked if they would be interested in learning more about water conservation techniques. As shown in Figure 4, 58.1 percent of Whitney respondents and 60.9 percent of Other respondents indicated interest in learning more about these techniques.
- Among Whitney respondents, interest in learning more about water conservation techniques decreased as the age of the respondent increased, increased as education increased, and was lower among retired respondents (see Table 12).

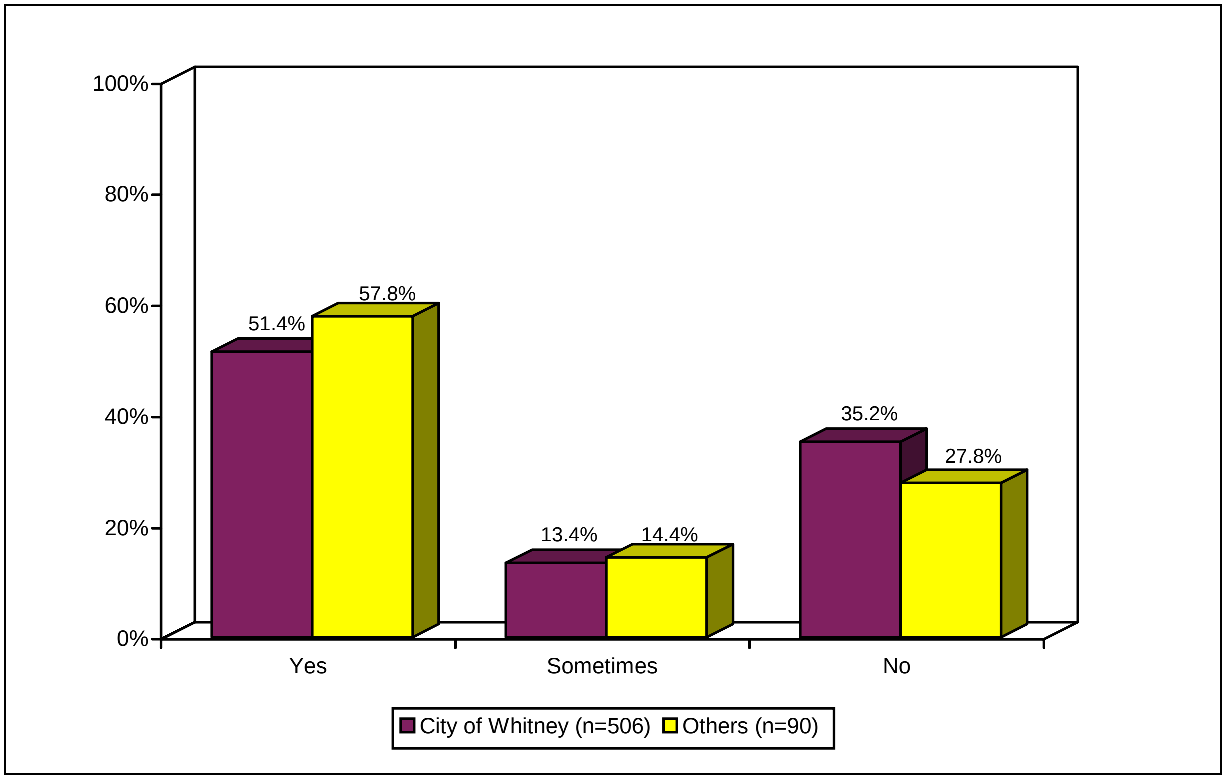
Table 12
Interested in Learning Water Conservation Techniques
by Selected Demographics

	Group	Percentage responding	
		Yes	No
Age of respondent			
18 to 45	City***	66.7	33.3
	Other	-	-
46 to 60	City	67.1	32.9
	Other	-	-
61 or older	City	49.2	50.8
	Other	-	-
Education			
High school or less	City*	49.7	50.3
	Other	-	-
Some college/technical school	City	60.4	39.6
	Other	-	-
College or more	City	62.7	37.3
	Other	-	-
Employment status			
Employed	City***	66.8	33.2
	Other	-	-
Unemployed/Student/Homemaker	City	69.0	31.0
	Other	-	-
Retired	City	47.7	52.3
	Other	-	-

* The difference between demographic groups was statistically significant at the p<.05 level.
*** The difference between demographic groups was statistically significant at the p<.001 level.

Landscaping

Figure 5
Use of Fertilizers and/or Pesticides



- Respondents were asked several questions about how they maintained the landscape outside around their property. In the first of these questions, they were asked if they used fertilizers and/or pesticides on their yard, garden, farm or ranch. As shown in Figure 5, over half (51.4 percent) of Whitney respondents and 57.8 percent of Other respondents reported using fertilizers and/or pesticides around their property.
- Among Whitney respondents, usage of fertilizers and/or pesticides increased as the age of the respondent and income increased, and was higher among White respondents, retired respondents, and respondents who live in the country (see Table 13).

Table 13
Use of Fertilizers and/or Pesticides
by Selected Demographics

	Group	Percentage responding		
		Yes	Sometimes	No
Age of respondent				
18 to 45	City*	41.9	10.5	47.6
	Other	-	-	-
46 to 60	City	49.0	13.7	37.3
	Other	-	-	-
61 or older	City	56.9	14.5	28.6
	Other	-	-	-
Race/ethnicity				
White	City*	52.7	13.7	33.5
	Other	-	-	-
Other	City	30.0	10.0	60.0
	Other	-	-	-
Employment status				
Employed	City*	45.5	12.4	42.1
	Other	-	-	-
Unemployed/Student/Homemaker	City	54.2	10.2	35.6
	Other	-	-	-
Retired	City	57.0	15.2	27.8
	Other	-	-	-
Income				
$25,000 or less	City*	45.8	15.8	38.3
	Other	-	-	-
$25,001 to $50,000	City	42.9	13.6	43.6
	Other	-	-	-
$50,001 to $75,000	City	59.3	8.8	31.9
	Other	-	-	-
Over $75,000	City	60.7	15.9	23.4
	Other	-	-	-
Live in city or country				
City or town	City*	38.8	13.3	48.0
	Other	-	-	-
In the country	City	54.5	13.2	32.3
	Other	-	-	-

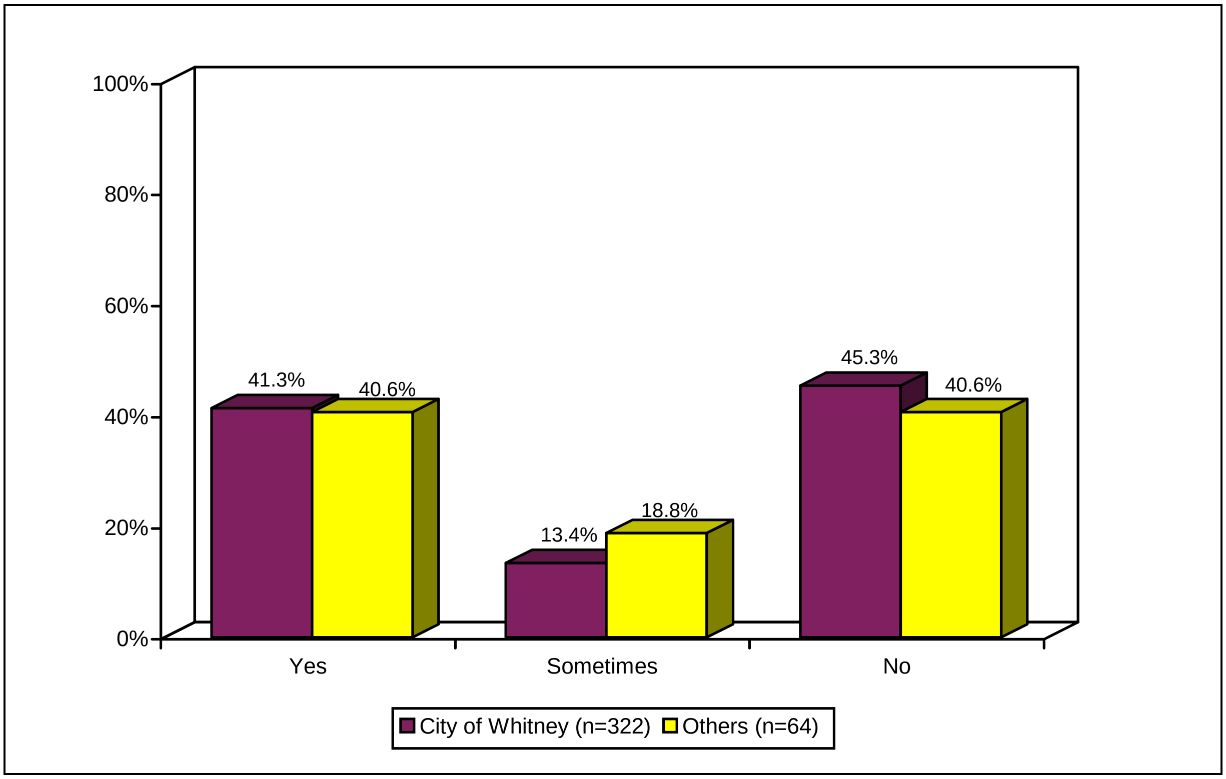
* The difference between demographic groups was statistically significant at the p<.05 level.

Table 14
Method to Get Rid of Chemicals and Containers

	Percentage responding	
	City of Whitney (n=285)	Others (n=52)
Throw away in the trash can	53.3	38.5
Bring to organized hazardous waste collection locations	18.9	21.2
Store in garage	7.7	7.7
No excess to dispose of	7.0	13.5
Burn it	4.6	3.8
Takes to city clean up day/city picks up	2.8	0.0
Someone else disposes of it	2.1	1.9
Pour outside (ex. driveway, storm water drain, curb, etc.)	1.1	5.8
Follow directions on container	1.1	1.9
Use organic chemicals	0.4	0.0
Recycle	0.4	3.8
Compost it	0.3	1.8
Pour into the toilet or sink	0.0	0.0
Other	0.4	0.0

- Respondents who used fertilizers and/or pesticides on their yard, garden, farm or ranch were asked how they got rid of excess lawn, garden or farm chemicals and their containers. As shown in Table 14, the most common disposal method for both Whitney respondents (53.3 percent) and Other respondents (38.5 percent) was throwing the chemicals and/or containers in the trash can.
- Approximately 20 percent of Whitney respondents (18.9 percent) and Other respondents (21.2 percent) reported bringing their chemicals and/or containers to the organized hazardous waste collection locations.
- Fourteen percent of Other respondents had no excess chemicals for disposal compared to 7.0 percent of Whitney respondents.

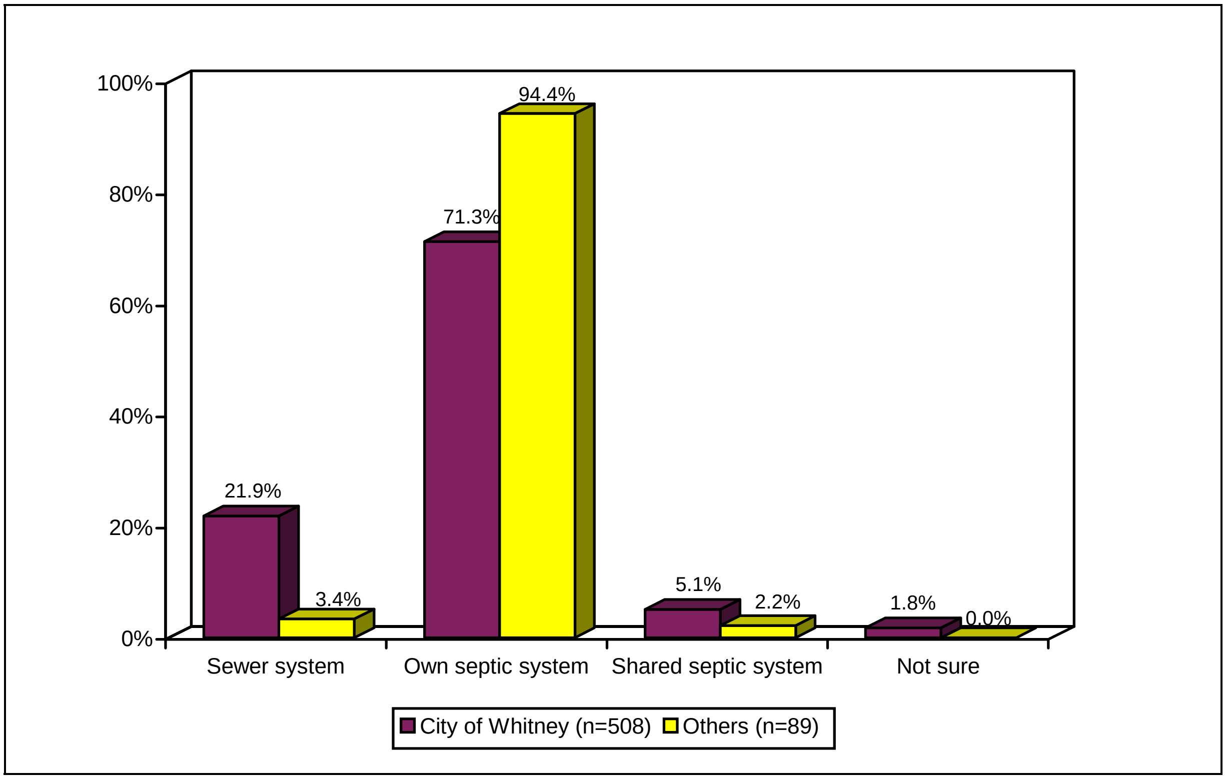
Figure 6
Apply Fertilizers and Chemicals to Lawn Before a Rain



- Respondents who used fertilizers/pesticides were asked if they used fertilizers and chemicals on their lawn or around their home just before it rained. As shown in Figure 6, 41 percent of Whitney respondents (41.3 percent) and Other respondents (40.6 percent) indicated they used fertilizers and chemicals just before it rained. Forty-five percent of Whitney respondents and 40.6 percent of Other respondents did not use these chemicals just prior to a rain.

Waste Water and Water Supply

Figure 7
Home Served by Municipal Sewer or Private Septic System



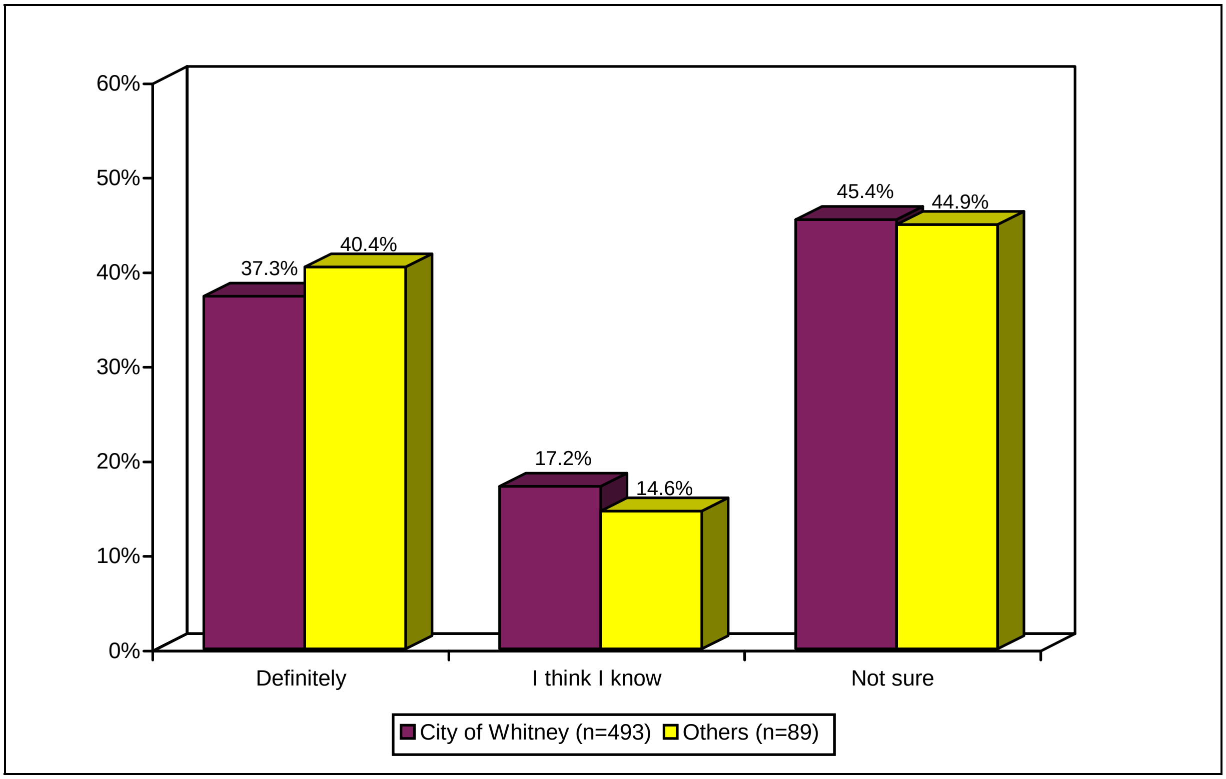
- Respondents were asked if their home was served by a municipal sewer system or they had their own septic system. As shown in Figure 7, 71.3 percent of Whitney respondents and 94.4 percent of Other respondents indicated their home was served by their own septic system.
- Eighty-three percent of Whitney respondents who live in the country and 21.4 percent of those who live in the city or town reported having their home served by their own septic system (see Table 15).

Table 15
Home Served by Municipal Sewer or Private Septic System
by Selected Demographics

	Group	Percentage responding			
		Sewer system	Own septic system	Shared septic system	Not sure
Live in city or country					
City or town	City***	73.5	21.4	5.1	0.0
	Other	-	-	-	-
In the country	City	9.2	83.4	5.2	2.2
	Other	-	-	-	-

*** The difference between demographic groups was statistically significant at the p<.001 level.

Figure 8
Know What Happens to Water after Treatment



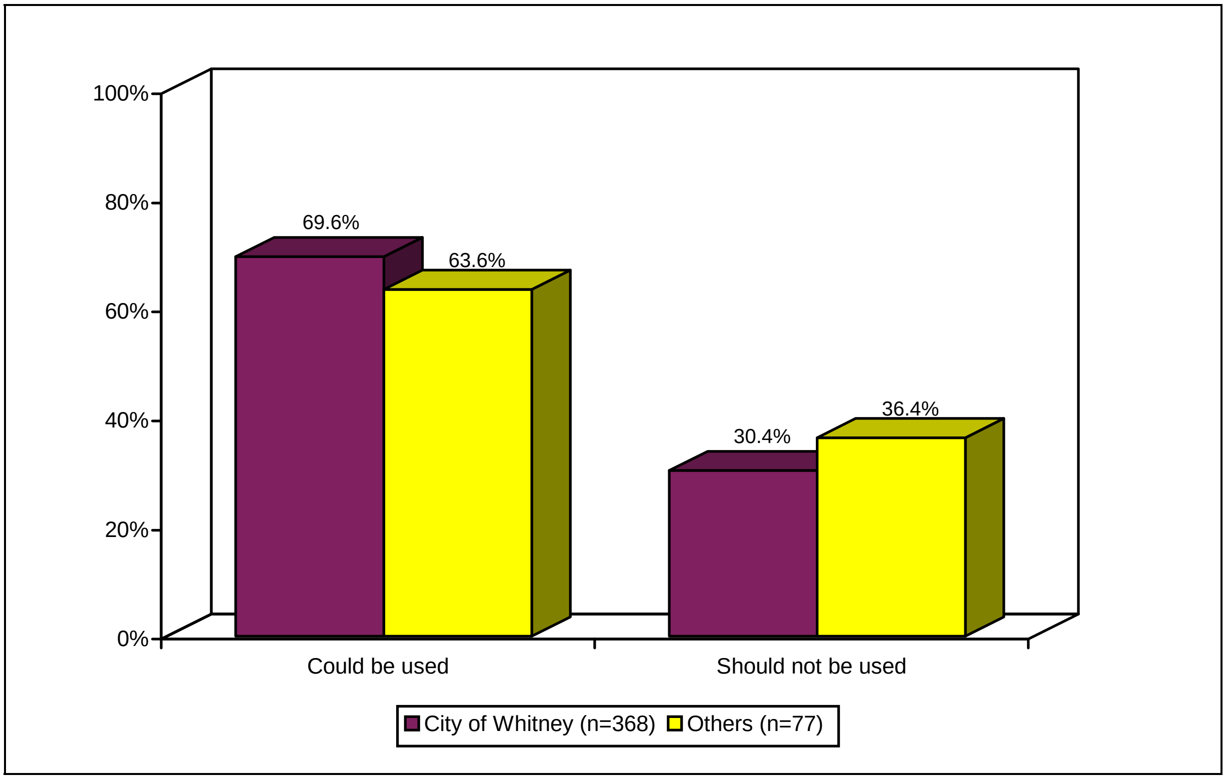
- Respondents were asked if they knew what happened to the water after it had been treated. As shown in Figure 8, 37.3 percent of Whitney respondents and 40.4 percent of Other respondents definitely knew what happened to the water after treatment. Forty-five percent of both Whitney and Other respondents were not sure.
- As shown in Table 16, the percentage of the Whitney respondents who definitely knew what happens to water after it has been treated increased as education and income increased, and was higher among male respondents, employed respondents, and respondents who live in the country.
- The percentage of Other respondents who definitely knew what happens to water after it has been treated was also higher among male respondents compared to female respondents (see Table 16).

Table 16
Know What Happens to Water after Treatment
by Selected Demographics

	Group	Percentage responding		
		Definitely	I think I know	Not sure
Gender				
Female	City***	26.0	18.8	55.2
	Other*	31.5	11.1	57.4
Male	City	51.9	15.3	32.9
	Other	54.3	20.0	25.7
Education				
High school or less	City*	26.6	18.0	55.4
	Other	-	-	-
Some college/technical school	City	37.6	17.8	44.6
	Other	-	-	-
College or more	City	44.4	16.3	39.3
	Other	-	-	-
Employment status				
Employed	City*	44.5	17.0	38.5
	Other	-	-	-
Unemployed/Student/Homemaker	City	24.5	20.8	54.7
	Other	-	-	-
Retired	City	33.9	17.2	48.9
	Other	-	-	-
Income				
$25,000 or less	City**	27.0	14.8	58.3
	Other	-	-	-
$25,001 to $50,000	City	34.3	22.6	43.1
	Other	-	-	-
$50,001 to $75,000	City	48.9	12.5	38.6
	Other	-	-	-
Over $75,000	City	44.8	16.2	39.0
	Other	-	-	-
Live in city or country				
City or town	City*	24.2	20.0	55.8
	Other	-	-	-
In the country	City	40.1	16.6	43.4
	Other	-	-	-

[*] The difference between demographic groups was statistically significant at the p<.05 level.
[**] The difference between demographic groups was statistically significant at the p<.01 level.
[***] The difference between demographic groups was statistically significant at the p<.001 level.

Figure 9
Use of Water Exiting Septic System for Landscape



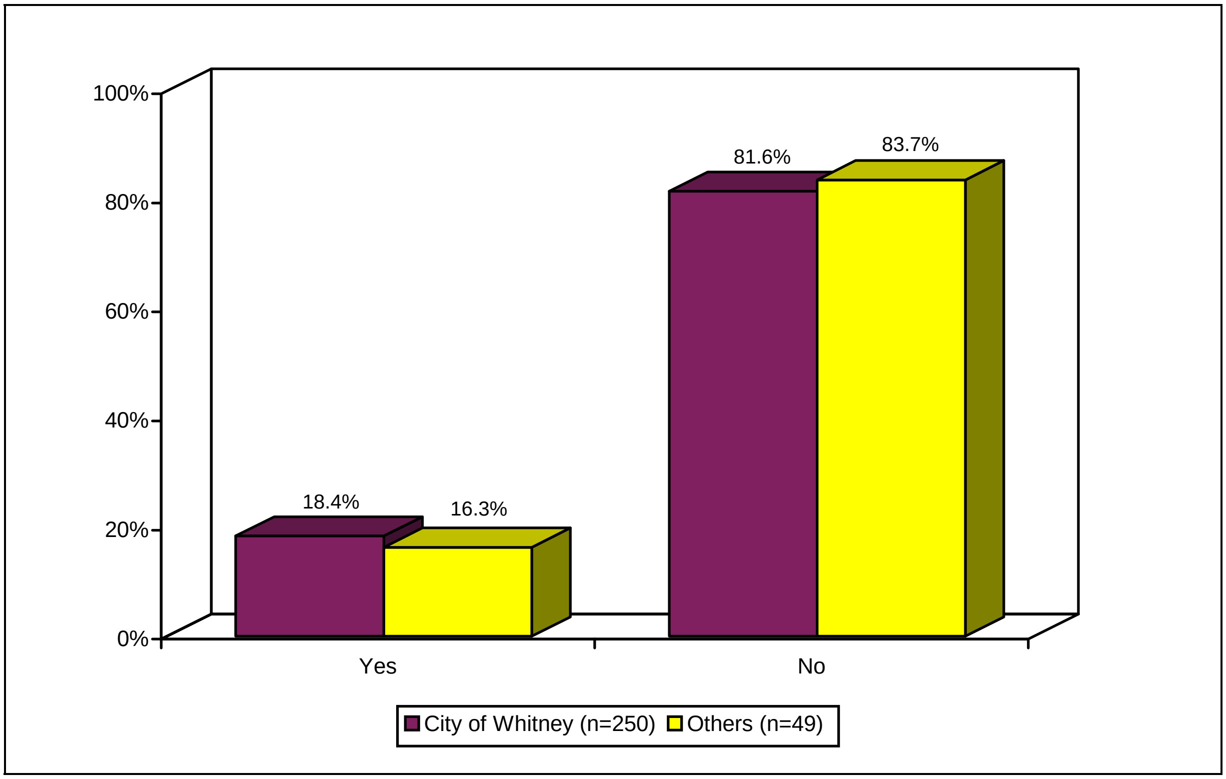
- Respondents whose home was served by a septic system were asked if they thought water exiting from their septic system could be used or should not be used for watering their landscape. As shown in Figure 9, approximately two-thirds of those Whitney respondents (69.6 percent) and Other respondents (63.6 percent) indicated that water exiting from their septic system could be used to water their landscape.
- Among Whitney respondents, the percentage of those who reported that water exiting from their septic system could be used to water their landscape decreased as the age of the respondent and length of residence increased, varied with income, and was greater among respondents who commute to another city for work (see Table 17).

Table 17
Use of Water Exiting Septic System for Landscape*
by Selected Demographics

	Group	Percentage responding	
		Could be used	Should not be used
Age of respondent			
18 to 45	City*	78.9	21.1
	Other	-	-
46 to 60	City	72.0	28.0
	Other	-	-
61 or older	City	63.8	36.2
	Other	-	-
Length of residence			
0 to 5 years	City*	68.9	31.1
	Other	-	-
6 to 10 years	City	76.7	23.3
	Other	-	-
11 to 20 years	City	74.3	25.7
	Other	-	-
21 to 35 years	City	69.2	30.8
	Other	-	-
36 years or more	City	47.6	52.4
	Other	-	-
Income			
$25,000 or less	City*	65.4	34.6
	Other	-	-
$25,001 to $50,000	City	62.3	37.7
	Other	-	-
$50,001 to $75,000	City	80.6	19.4
	Other	-	-
Over $75,000	City	77.5	22.5
	Other	-	-
Work site			
Work near the lake	City*	69.7	30.3
	Other	-	-
Commute to another city	City	83.5	16.5
	Other	-	-

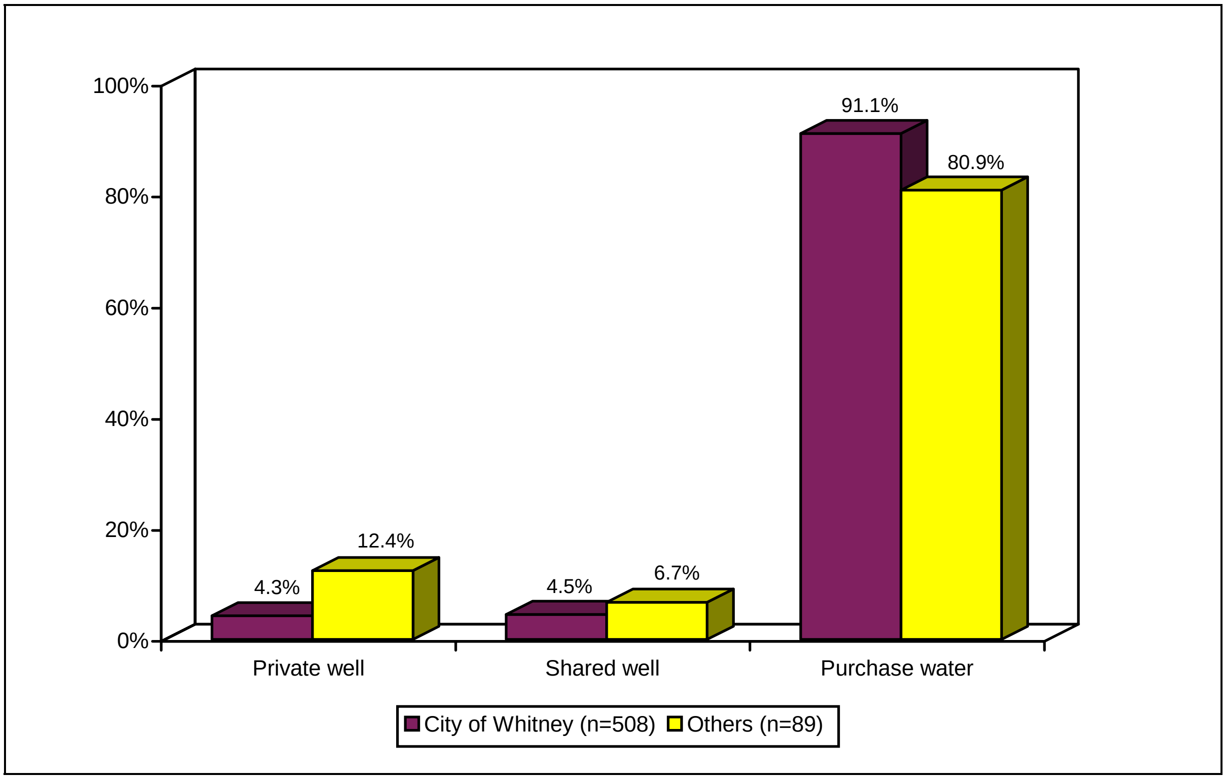
* The difference between demographic groups was statistically significant at the p<.05 level.

Figure 10
Use of Septic System Water to Water Landscape



- Respondents who thought that water exiting from their septic system could be used to water their landscape were asked if they used it for that purpose. Eighteen percent of those Whitney respondents and 16.3 percent of those Other respondents answered “yes” (see Figure 10).

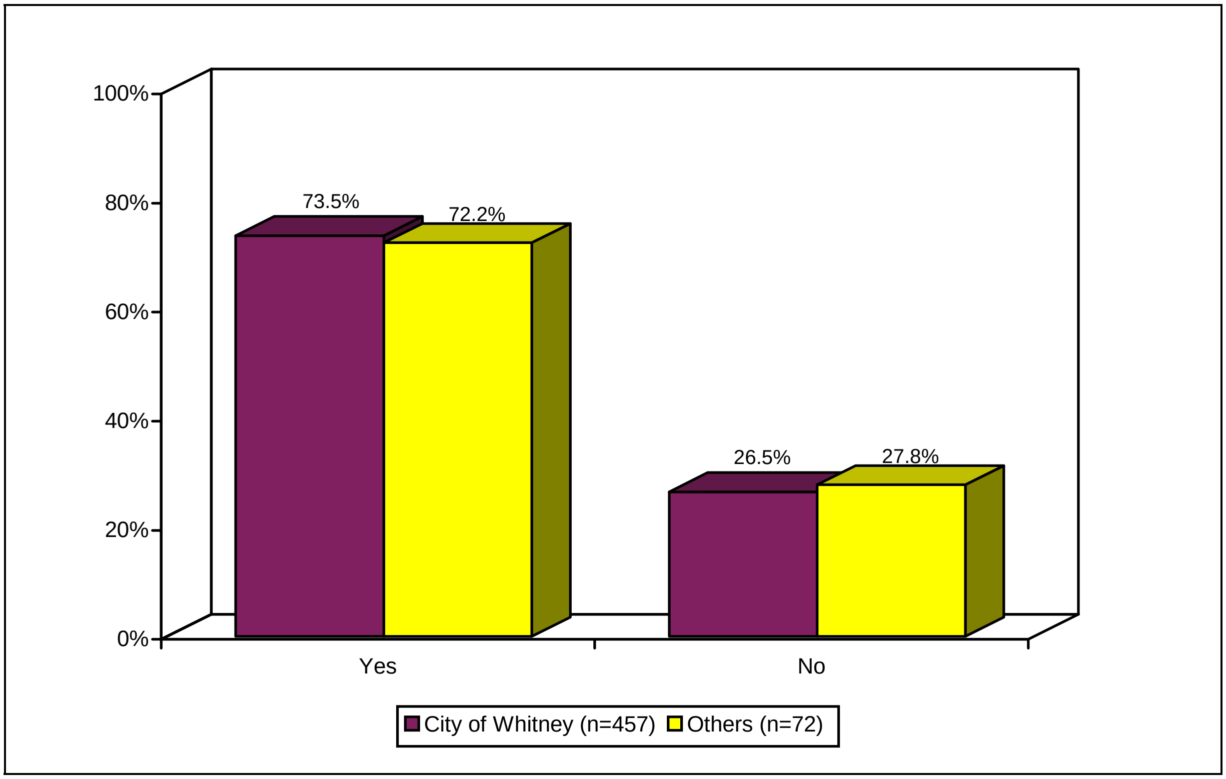
Figure 11
Water Comes from Private Well or Other Supplier**



- Respondents were asked if they had a private well or if they purchased water from a supplier. Ninety-one percent of Whitney respondents and 80.9 percent of Other respondents indicated their water was purchased from a supplier (see Figure 11).

** The difference between Whitney and Other respondents for this question was statistically significant at the p<.01 level.

Figure 12
Know Where Water Supplier Gets Your Water



- Respondents who purchased their water were asked if they knew where their supplier got their water. Seventy-four percent of Whitney respondents and 72.2 percent of Other respondents who purchased their water answered “yes” (see Figure 12).
- Among Whitney respondents, the percentage who knew where their supplier got their water increased as the age of the respondent, length of residence, and income increased and was greater among male respondents, employed and retired respondents (see Table 18).

Table 18
Know Where Water Supplier Gets Your Water
by Selected Demographics

	Group	Percentage responding	
		Yes	No
Age of respondent			
18 to 45	City**	60.8	39.2
	Other	-	-
46 to 60	City	72.7	27.3
	Other	-	-
61 or older	City	80.0	20.0
	Other	-	-
Gender			
Female	City***	67.0	33.0
	Other	-	-
Male	City	82.4	17.6
	Other	-	-
Length of residence			
0 to 5 years	City**	64.2	35.8
	Other	-	-
6 to 10 years	City	69.0	31.0
	Other	-	-
11 to 20 years	City	73.6	26.4
	Other	-	-
21 to 35 years	City	83.0	17.0
	Other	-	-
36 years or more	City	86.0	14.0
	Other	-	-
Employment status			
Employed	City**	76.1	23.9
	Other	-	-
Unemployed/Student/Homemaker	City	55.6	44.4
	Other	-	-
Retired	City	77.0	23.0
	Other	-	-
Income			
$25,000 or less	City*	66.3	33.7
	Other	-	-
$25,001 to $50,000	City	71.4	28.6
	Other	-	-
$50,001 to $75,000	City	76.2	23.8
	Other	-	-
Over $75,000	City	84.2	15.8
	Other	-	-

* The difference between demographic groups was statistically significant at the p<.05 level.
** The difference between demographic groups was statistically significant at the p<.01 level.
*** The difference between demographic groups was statistically significant at the p<.001 level.

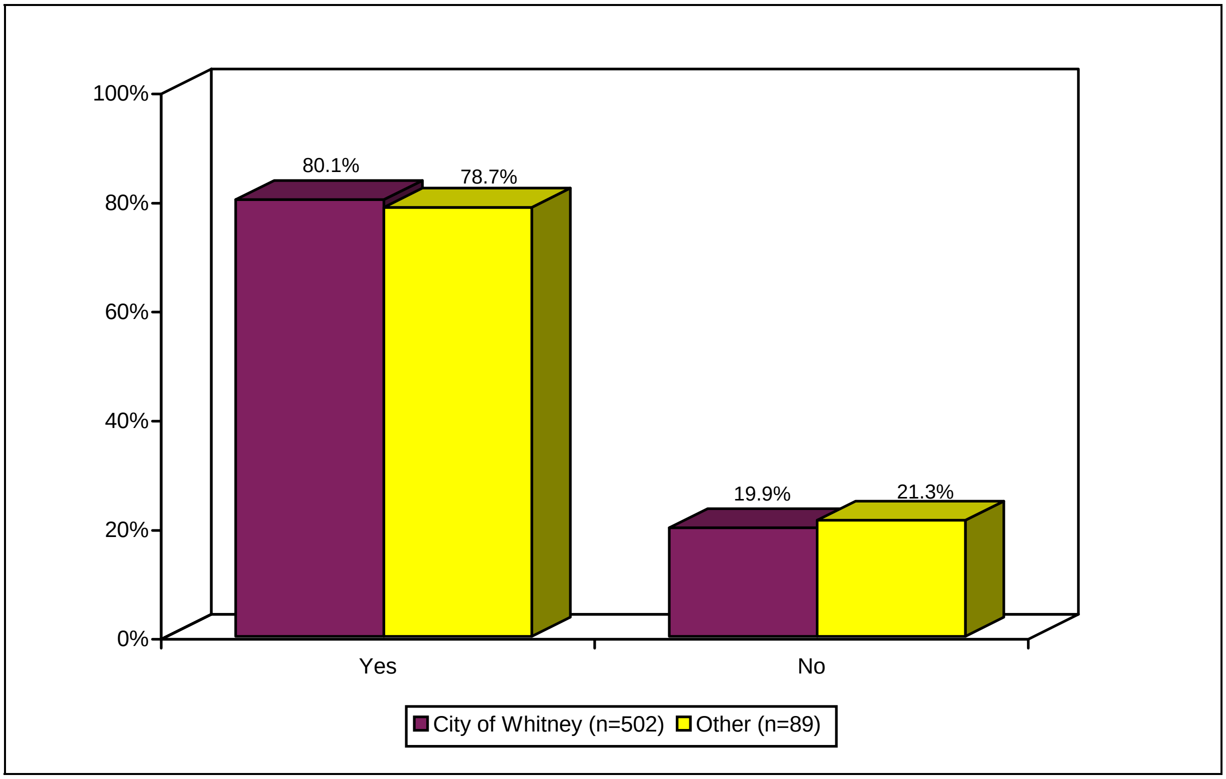
Table 19
Source of Purchased Water*

	Percentage responding	
	City of Whitney (n=331)	Others (n=50)
A well	65.6	74.0
Lake Whitney	16.9	8.0
Lake Aquilla	4.5	0.0
Aquifer	2.7	2.0
Trinity River/Reservoir	2.1	4.0
A city	2.1	2.0
Commercial enterprise	1.5	0.0
Hill County	1.2	2.0
Ground water	1.2	4.0
Unnamed rivers/lakes	0.9	0.0
Brazos River	0.0	4.0
Other	1.2	0.0

- Of those respondents who said they knew from where their supplier got their water, 65.6 percent of the Whitney respondents and 74.0 percent of the Other respondents said their supplier's water came from a well (see Table 19). Seventeen percent of Whitney respondents and 8.0 percent of Other respondents reported their supplier's water was Lake Whitney. Less than 5 percent gave any of the other responses listed in Table 19.

* The difference between Whitney and Other respondents for this question was statistically significant at the $p<.05$ level.

Figure 13
Know What Storm Water Runoff Is



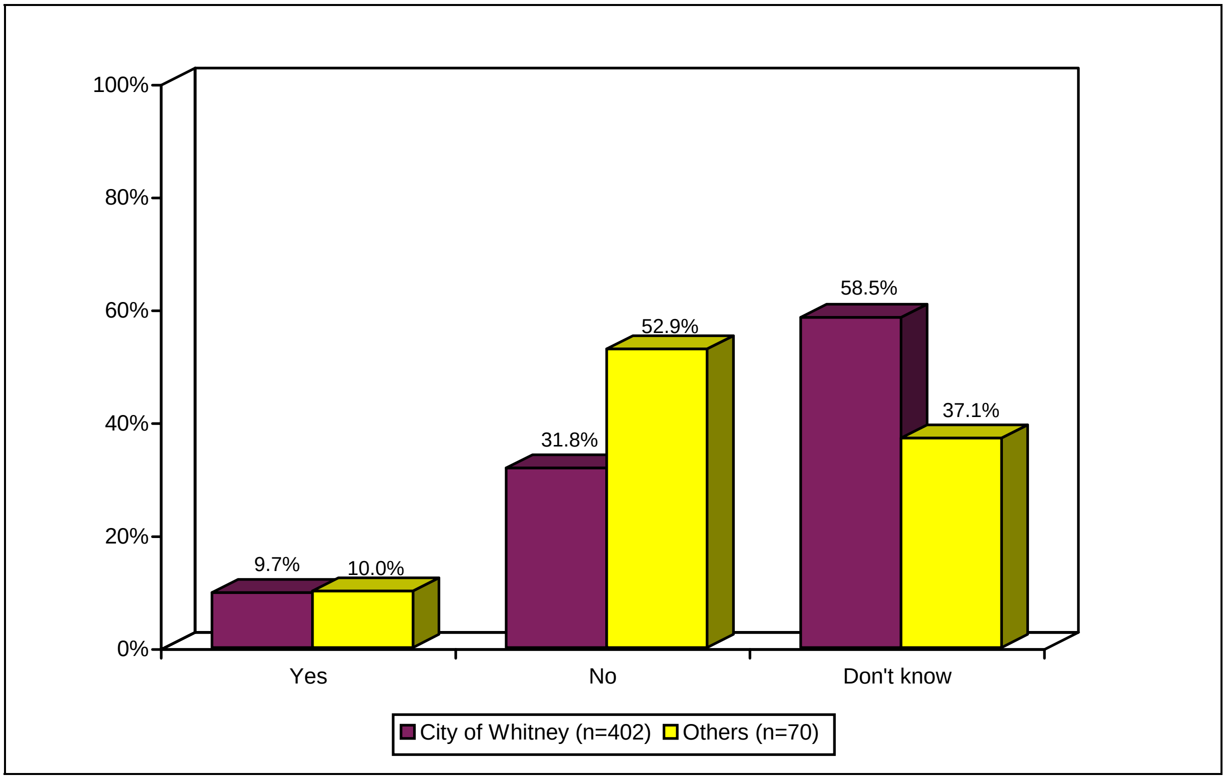
- All respondents were asked if they knew what storm water runoff is. As shown in Figure 13, 80.1 percent of Whitney respondents and 78.7 percent of Other respondents answered “yes.”
- Among Whitney respondents, the percentage of respondents who knew what storm water runoff was increased as education and income increased and was greater among male respondents and retired respondents (see Table 20).

Table 20
Know What Storm Water Runoff Is
by Selected Demographics

	Group	Percentage responding	
		Yes	No
Gender			
Female	City***	73.8	26.2
	Other	-	-
Male	City	88.4	11.6
	Other	-	-
Education			
High school or less	City**	70.4	29.6
	Other	-	-
Some college/technical school	City	81.6	18.4
	Other	-	-
College or more	City	86.1	13.9
	Other	-	-
Employment status			
Employed	City**	80.2	19.8
	Other	-	-
Unemployed/Student/Homemaker	City	63.2	36.8
	Other	-	-
Retired	City	83.8	16.2
	Other	-	-
Income			
$25,000 or less	City*	70.9	29.1
	Other	-	-
$25,001 to $50,000	City	82.3	17.7
	Other	-	-
$50,001 to $75,000	City	84.1	15.9
	Other	-	-
Over $75,000	City	86.9	13.1
	Other	-	-

* The difference between demographic groups was statistically significant at the p<.05 level.
** The difference between demographic groups was statistically significant at the p<.01 level.
*** The difference between demographic groups was statistically significant at the p<.001 level.

Figure 14
Area Wastewater Treatment Plant Treats Storm Water



- Respondents who understood storm water runoff, were asked if their area wastewater treatment plant treats storm water. Ten percent of both Whitney respondents (9.7 percent) and Other respondents (10.0 percent) reported that their area wastewater treatment plant does treat storm water (see Figure 14). Sixty percent of the Whitney respondents and 37.1 percent of Other respondents indicated they did not know.
- Among Whitney respondents, the percentage of respondents who did not know if their local wastewater treatment plant treats storm water was higher among White respondents, female respondents and unemployed/student/homemaker respondents (see Table 21A).
- Among Whitney respondents, the percentage who knew their area wastewater treatment plant treated storm water decreased as the age of the respondent increased, and was higher among female respondents (see Table 21B).

Table 21A
Area Wastewater Treatment Plant Treats Storm Water
(includes "Don't Know" responses)
by Selected Demographics

	Group	Percentage responding		
		Yes	No	Don't know
Race/ethnicity				
White	City*	8.8	31.5	59.7
	Other	-	-	-
Other	City	23.1	34.6	42.3
	Other	-	-	-
Gender				
Female	City***	11.4	20.9	67.8
	Other	-	-	-
Male	City	7.9	44.0	48.2
	Other	-	-	-
Employment status				
Employed	City**	14.2	34.6	51.2
	Other	-	-	-
Unemployed/Student/Homemaker	City	8.3	11.1	80.6
	Other	-	-	-
Retired	City	6.6	33.5	59.9
	Other	-	-	-

Table 21B
Area Wastewater Treatment Plant Treats Storm Water
by Selected Demographics

	Group	Percentage responding	
		Yes	No
Age of respondent			
18 to 45	City*	33.3	66.7
	Other	-	-
46 to 60	City	30.9	69.1
	Other	-	-
61 or older	City	13.9	86.1
	Other	-	-
Gender			
Female	City**	35.3	64.7
	Other	-	-
Male	City	15.2	84.8
	Other	-	-

* The difference between demographic groups was statistically significant at the p<.05 level.
** The difference between demographic groups was statistically significant at the p<.01 level.
*** The difference between demographic groups was statistically significant at the p<.001 level.

Environmental Conditions and Behaviors

Table 22
Concern about Environmental Issues

	Average Score (1-10)	Percentage responding: No concern (1-3)	Moderately concerned (4-7)	Extremely concerned (8-10)
Drought or lack of rain				
City of Whitney (n=509)	7.68	9.2	26.3	64.4
Others (n=90)	7.82	8.9	23.3	67.8
Drinking water quality				
City of Whitney (n=506)	6.68	23.7	22.5	53.8
Others (n=90)	7.10	21.1	18.9	60.0
Water pollution				
City of Whitney (n=500)	6.66	17.4	35.4	47.2
Others (n=90)	6.96	17.8	28.9	53.3
Trash or litter in your region				
City of Whitney (n=509)	6.15	23.2	38.1	38.7
Others (n=89)	6.27	21.3	36.0	42.7
Loss of trees				
City of Whitney (n=510)	5.89	28.8	32.5	38.6
Others (n=90)	5.70	33.3	25.6	41.1

- Respondents were read a list of 10 environmental issues and asked to rank, using a scale of 1 to 10, with 1 being no concern and 10 being extremely concerned, their level of concern about each as it pertains to the Lake Whitney area. An average score was computed using the 1 to 10 scale. The categories were then collapsed to compute percentages: no concern (1-3), moderately concerned (4-7), and extremely concerned (8-10). The first five issues are presented in Tables 22 and the next five are presented in Table 27.
- Based on the average scores, the Other respondents are more concerned than the Whitney respondents about drought or lack of rain, drinking water quality, water pollution, and trash or litter in their region. Whitney respondents were more concerned about loss of trees than Other respondents.

<u>Drought or lack of rain</u>

- Drought or lack of rain was of extreme concern to 64.4 percent (7.68 average score) of Whitney respondents and 67.8 percent (7.82 average score) of Other respondents.

<u>Drinking water quality</u>

- The quality of drinking water was of extreme concern to 53.8 percent of Whitney respondents and 60.0 percent of Other respondents. The average scores were 6.68 for Whitney respondents and 7.10 for Other respondents.
- Among Whitney respondents, the percentage of respondents who expressed no concern for drinking water quality increased as the age of the respondent increased. Extreme

concern was higher among Whitney respondents with some college or technical school education (see Table 23).

Table 23
Drinking Water Quality
by Selected Demographics

	Group	Percentage responding		
		No concern (1)	Moderately concerned (2)	Extremely concerned (3)
Age of respondent				
18 to 45	City*	15.4	31.7	52.9
	Other	-	-	-
46 to 60	City	23.7	19.7	56.6
	Other	-	-	-
61 or older	City	27.3	20.5	52.2
	Other	-	-	-
Education				
High school or less	City**	35.2	19.0	45.8
	Other	-	-	-
Some college/technical school	City	17.0	23.3	59.7
	Other	-	-	-
College or more	City	21.1	24.5	54.4
	Other	-	-	-

Water pollution

- Forty-seven percent of Whitney respondents (6.66 average score) and 53.3 percent of Other respondents (6.96 average score) were extremely concerned about water pollution in the Lake Whitney area.
- Among Whitney respondents, the percentage that was extremely concerned about water pollution generally increased as length of residence increased, and was greater among other ethnic group respondents (see Table 24).

Table 24
Water Pollution
by Selected Demographics

	Group	Percentage responding		
		No concern (1)	Moderately concerned (2)	Extremely concerned (3)
Race/ethnicity				
White	City**	17.7	36.7	45.6
	Other	-	-	-
Other	City	10.3	13.8	75.9
	Other	-	-	-

* The difference between demographic groups was statistically significant at the p<.05 level.
** The difference between demographic groups was statistically significant at the p<.01 level.

Table 24
Water Pollution
by Selected Demographics (continued)

	Group	Percentage responding		
		No concern (1)	Moderately concerned (2)	Extremely concerned (3)
Length of residence				
0 to 5 years	City*	21.0	36.1	42.9
	Other	-	-	-
6 to 10 years	City	17.0	38.7	44.3
	Other	-	-	-
11 to 20 years	City	8.3	40.5	51.2
	Other	-	-	-
21 to 35 years	City	24.7	32.0	43.3
	Other	-	-	-
36 years or more	City	17.5	22.8	59.6
	Other	-	-	-

Trash or litter in your region

- Trash or litter was of extreme concern to 38.7 percent of Whitney respondents (6.15 average score) and 42.7 percent of Other respondents (6.27 average score).
- Among Whitney respondents, extreme concern about trash or litter in the region was higher for respondents age 46 to 60, female respondents, and respondents who had lived in the Lake Whitney area for 11 to 20 years (see Table 25).

Table 25
Trash and Litter
by Selected Demographics

	Group	Percentage responding		
		No concern (1)	Moderately concerned (2)	Extremely concerned (3)
Age of respondent				
18 to 45	City*	18.1	48.6	33.3
	Other	-	-	-
46 to 60	City	17.6	37.9	44.4
	Other	-	-	-
61 or older	City	28.4	34.0	37.6
	Other	-	-	-
Gender				
Female	City*	21.0	35.2	43.8
	Other	-	-	-
Male	City	26.0	42.0	32.0
	Other	-	-	-

* The difference between demographic groups was statistically significant at the p<.05 level.

Table 25
Trash and Litter
by Selected Demographics (continued)

	Group	Percentage responding		
		No concern (1)	Moderately concerned (2)	Extremely concerned (3)
Length of residence				
0 to 5 years	City*	32.0	36.0	32.0
	Other	-	-	-
6 to 10 years	City	27.1	36.4	36.4
	Other	-	-	-
11 to 20 years	City	17.6	34.4	48.0
	Other	-	-	-
21 to 35 years	City	21.6	41.2	37.1
	Other	-	-	-
36 years or more	City	12.1	48.3	39.7
	Other	-	-	-

Loss of trees

- Thirty-nine percent of the Whitney respondents and 41.1 percent of the Other respondents were extremely concerned about the loss of trees in the Lake Whitney area. The average scores were 8.11 for city respondents and 7.51 for county respondents.
- Among Whitney respondents, the percentage that was extremely concerned about the loss of trees in the Lake Whitney area generally increased as length of residence increased, and was higher among respondents age 46 to 60 and female respondents (see Table 26).

Table 26
Loss of Trees
by Selected Demographics

	Group	Percentage responding		
		No concern (1)	Moderately concerned (2)	Extremely concerned (3)
Age of respondent				
18 to 45	City**	25.7	43.8	30.5
	Other	-	-	-
46 to 60	City	25.5	26.1	48.4
	Other	-	-	-
61 or older	City	31.9	31.9	36.3
	Other	-	-	-

* The difference between demographic groups was statistically significant at the p<.05 level.
** The difference between demographic groups was statistically significant at the p<.01 level.

Table 26
Loss of Trees
by Selected Demographics (continued)

	Group	Percentage responding		
		No concern (1)	Moderately concerned (2)	Extremely concerned (3)
Gender				
Female	City*	25.4	30.9	43.6
	Other	-	-	-
Male	City	33.3	34.7	32.0
	Other	-	-	-
Length of residence				
0 to 5 years	City*	33.6	35.2	31.1
	Other	-	-	-
6 to 10 years	City	28.0	40.2	31.8
	Other	-	-	-
11 to 20 years	City	28.0	29.6	42.4
	Other	-	-	-
21 to 35 years	City	33.0	28.9	38.1
	Other	-	-	-
36 years or more	City	15.3	25.4	59.3
	Other	-	-	-

* The difference between demographic groups was statistically significant at the p<.05 level.

Table 27
Concern about Environmental Issues

		Percentage responding		
	Average Score (1-10)	No concern (1-3)	Moderately concerned (4-7)	Extremely concerned (8-10)
Loss of wildlife habitat City of Whitney (n=506)	5.76	29.8	33.0	37.2
Others (n=90)	5.57	31.1	35.6	33.3
Loss of open land to housing or business development City of Whitney (n=506)	5.51	32.6	35.0	32.4
Others (n=90)	5.20	34.4	36.7	28.9
Traffic City of (n=510)	5.19	35.5	35.7	28.8
Other (n=89)	4.84	36.0	40.4	23.6
Urban sprawl City of Whitney (n=424)	4.40	43.9	37.3	18.9
Others (n=73)	4.75	38.4	38.4	23.3
Poor air quality City of Whitney (n=505)	4.27	51.9	27.1	21.0
Others (n=89)	4.16	55.1	25.8	19.1

- Respondents were read a list of 10 environmental issues and asked to rank their level of concern about each as it pertains to the Lake Whitney area using a scale of 1 to 10, with 1 being no concern and 10 being extremely concerned. An average score was computed using the 1 to 10 scale. The categories were then collapsed to compute percentages: no concern (1-3), moderately concerned (4-7), and extremely concerned (8-10). The first five issues were presented in Tables 22 and the next five are presented in Table 27 above.
- Based on the average scores, the Other respondents are more concerned than the Whitney respondents about urban sprawl. Whitney respondents were more concerned about loss of wildlife habitat, loss of open land to housing or business development, traffic and poor air quality than Other respondents.

<u>Loss of wildlife habitat</u>

- Loss of wildlife habitat was of extreme concern to 32.4 percent of Whitney respondents and 28.9 percent of Other respondents. The average scores were 5.51 for Whitney respondents and 5.20 for county respondents.
- The percentage of the Other respondents who were extremely concerned about the loss of wildlife habitat was higher among female respondents and respondents with income of $50,001 to $75,000 (see Table 28).

Table 28
Loss of Wildlife Habitat
by Selected Demographics

	Group	Percentage responding		
		No concern (1)	Moderately concerned (2)	Extremely concerned (3)
Gender				
Female	City	-	-	-
	Other*	21.8	36.4	41.8
Male	City	-	-	-
	Other	45.7	34.3	20.0
Income				
$25,000 or less	City	-	-	-
	Other*	57.1	19.0	23.8
$25,001 to $50,000	City	-	-	-
	Other	29.2	41.7	29.2
$50,001 to $75,000	City	-	-	-
	Other	5.3	47.4	47.4
Over $75,000	City	-	-	-
	Other	35.0	30.0	35.0

Loss of open land

- About one-third (32.4 percent) of Whitney respondents and 28.9 percent of Other respondents were extremely concerned about the loss of open land to housing or business development in the Lake Whitney area. The average scores were 5.51 for Whitney respondents and 5.20 for Other respondents.
- Whitney (42.8 percent) and Other respondents (50.0 percent) age 46 to 60 were more likely to report extreme concern for the loss of open land than Whitney and Other respondents of other ages (see Table 29).
- Among Whitney respondents, the percentage that was extremely concerned about loss of open land in the Lake Whitney area generally increased as length of residence increased.

* The difference between demographic groups was statistically significant at the p<.05 level.

Table 29
Loss of Open Land to Housing and Business Development by Selected Demographics

	Group	Percentage responding		
		No concern (1)	Moderately concerned (2)	Extremely concerned (3)
Age of respondent				
18 to 45	City*	33.3	35.2	31.4
	Other*	47.4	36.8	15.8
46 to 60	City	25.7	31.6	42.8
	Other	20.0	30.0	50.0
61 or older	City	36.7	36.7	26.6
	Other	39.0	41.5	19.5
Length of residence				
0 to 5 years	City***	44.2	29.2	26.7
	Other	-	-	-
6 to 10 years	City	33.6	44.9	21.5
	Other	-	-	-
11 to 20 years	City	23.2	40.8	36.0
	Other	-	-	-
21 to 35 years	City	34.7	30.5	34.7
	Other	-	-	-
36 years or more	City	23.7	23.7	52.5
	Other	-	-	-

Traffic

- Twenty-nine percent of the Whitney respondents and 23.6 percent of the Other respondents were extremely concerned about the poor air quality in the Lake Whitney area. The average scores were 5.19 for Whitney respondents and 4.84 for Other respondents.
- Among Other respondents, the percentage that was extremely concerned about traffic was higher among respondents age 46 to 60 (see Table 30).
- Among Whitney respondents, the percentage that was extremely concerned about traffic increased as length of residence increased (see Table 30).

* The difference between demographic groups was statistically significant at the p<.05 level.
*** The difference between demographic groups was statistically significant at the p<.001 level.

Table 30
Traffic
by Selected Demographics

	Group	Percentage responding		
		No concern (1)	Moderately concerned (2)	Extremely concerned (3)
Age of respondent				
18 to 45	City	-	-	-
	Other*	55.6	22.2	22.2
46 to 60	City	-	-	-
	Other	20.0	43.3	36.7
61 or older	City	-	-	-
	Other	39.0	46.3	14.6
Length of residence				
0 to 5 years	City***	45.9	31.1	23.0
	Other	-	-	-
6 to 10 years	City	51.4	29.0	19.6
	Other	-	-	-
11 to 20 years	City	27.2	42.4	30.4
	Other	-	-	-
21 to 35 years	City	28.9	39.2	32.0
	Other	-	-	-
36 years or more	City	13.6	37.3	49.2
	Other	-	-	-

<u>Urban sprawl</u>

- Nineteen percent of Whitney respondents and 23.3 percent of Other respondents were extremely concerned about urban sprawl in the Lake Whitney area. The average scores were 4.40 for Whitney respondents and 4.75 for Other respondents.
- Among Whitney respondents, the percentage that was extremely concerned about urban sprawl in the Lake Whitney area increased as length of residence increased (see Table 31).

* The difference between demographic groups was statistically significant at the p<.05 level.
*** The difference between demographic groups was statistically significant at the p<.001 level.

Table 31
Urban Sprawl
by Selected Demographics

	Group	Percentage responding		
		No concern (1)	Moderately concerned (2)	Extremely concerned (3)
Length of residence				
0 to 5 years	City**	56.9	30.4	12.7
	Other	-	-	-
6 to 10 years	City	51.6	33.3	15.1
	Other	-	-	-
11 to 20 years	City	30.5	50.5	19.0
	Other	-	-	-
21 to 35 years	City	42.9	35.1	22.1
	Other	-	-	-
36 years or more	City	31.9	34.0	34.0
	Other	-	-	-

Poor air quality

- Twenty-one percent of the Whitney respondents and 19.1 percent of the Other respondents were extremely concerned about the poor air quality in the Lake Whitney area. The average scores were 4.27 for Whitney respondents and 4.16 for Other respondents.

** The difference between demographic groups was statistically significant at the p<.01 level.

Table 32
Concern about Water Issues

	Average Score (1-10)	Percentage responding No concern (1-3)	Moderately concerned (4-7)	Extremely concerned (8-10)
Golden algae in Lake Whitney City of Whitney (n=490)	7.90	10.4	21.2	68.4
Others (n=89)	8.25	6.7	15.7	77.5
Clean water for fish and wildlife City of Whitney (n=506)	7.70	10.3	22.9	66.8
Others (n=90)	8.28	4.4	23.3	72.2
Water supplies to meet future needs of the region City of Whitney (n=499)	7.27	11.8	29.9	58.3
Others (n=89)	7.81	6.7	27.0	66.3
Taste and/or odor of your drinking water City of Whitney (n=505)	7.00	23.4	16.2	60.4
Others (n=88)	7.20	22.7	13.6	63.6
Personal health concerns about clean drinking water City of Whitney (n=506)	6.76	24.9	19.0	56.1
Others (n=90)	7.03	16.7	26.7	56.7
Swimming in Lake Whitney City of Whitney (n=506)	6.47	23.1	27.9	49.0
Others (n=90)	6.70	18.9	33.3	47.8
Eating fish from Lake Whitney City of Whitney (n=499)	6.17	28.5	24.2	47.3
Others (n=90)	7.01	20.0	22.2	57.8
Saltiness of the water in Lake Whitney City of Whitney (n=488)	5.64	30.5	33.2	36.3
Others (n=89)	5.96	30.3	25.8	43.8

- Respondents were read a list of 8 water issues and asked to rank using a scale of 1 to 10, with 1 being no concern and 10 being extremely concerned, their level of concern about each as it pertains to the Lake Whitney area. An average score was computed using the 1 to 10 scale. The categories were then collapsed to compute percentages: no concern (1-3), moderately concerned (4-7), and extremely concerned (8-10).

Golden algae in Lake Whitney

- Sixty-eight percent of Whitney respondents and 77.5 percent of Other respondents were extremely concerned about golden algae in Lake Whitney (see Table 32). The average scores were 7.90 for Whitney respondents and 8.25 for Other respondents.
- Among Whitney respondents, 74.9 percent of female respondents and 59.7 percent of male respondents were extremely concerned about golden algae in Lake Whitney (see Table 33).

Table 33
Golden Algae in Lake Whitney
by Selected Demographics

	Group	Percentage responding		
		No concern (1)	Moderately concerned (2)	Extremely concerned (3)
Gender				
Female	City***	6.5	18.6	74.9
	Other	-	-	-
Male	City	15.6	24.6	59.7
	Other	-	-	-

Clean water for fish and wildlife

- Sixty-seven percent of Whitney respondents and 72.2 percent of Other respondents were extremely concerned about clean water for fish and wildlife in the Lake Whitney area. The average scores were 7.90 for Whitney respondents and 8.25 for Other respondents.
- Among Whitney respondents, the percentage that was extremely concerned about clean water for fish and wildlife decreased as the age of the respondent increased, and was higher among female respondents (see Table 34).

Table 34
Clean Water for Fish and Wildlife
by Selected Demographics

	Group	Percentage responding		
		No concern (1)	Moderately concerned (2)	Extremely concerned (3)
Age of respondent				
18 to 45	City*	3.8	23.8	72.4
	Other	-	-	-
46 to 60	City	9.2	19.0	71.9
	Other	-	-	-
61 or older	City	13.8	24.7	61.5
	Other	-	-	-
Gender				
Female	City***	6.9	18.3	74.7
	Other	-	-	-
Male	City	14.7	29.0	56.2
	Other	-	-	-

* The difference between demographic groups was statistically significant at the p<.05 level.
*** The difference between demographic groups was statistically significant at the p<.001 level.

Water supplies to meet future needs of region

- Fifty-eight percent of Whitney respondents and 66.3 percent of Other respondents were extremely concerned about water supplies to meet future needs of the region. The average scores were 7.27 for Whitney respondents and 7.81 for Other respondents.
- Among Whitney respondents, the percentage that was extremely concerned about water supplies to meet future needs of the region was higher among female respondents compared to male respondents (see Table 35).

Table 35
Water Supplies to Meet Future Needs of the Region
by Selected Demographics

	Group	Percentage responding		
		No concern (1)	Moderately concerned (2)	Extremely concerned (3)
Gender				
Female	City***	7.4	27.1	65.5
	Other	-	-	-
Male	City	17.7	33.5	48.8
	Other	-	-	-

Taste and/or odor of drinking water

- Sixty percent of Whitney respondents and 63.6 percent of Other respondents were extremely concerned about the taste and/or odor of their drinking water. The average scores were 7.00 for Whitney respondents and 7.20 for Other respondents.
- Among Whitney respondents, the percentage that was extremely concerned about the taste and/or odor of their drinking water was higher among female respondents compared to male respondents (see Table 36).

Table 36
Taste or Odor of Your Drinking Water
by Selected Demographics

	Group	Percentage responding		
		No concern (1)	Moderately concerned (2)	Extremely concerned (3)
Gender				
Female	City*	19.0	15.5	65.5
	Other	-	-	-
Male	City	29.3	17.2	53.5
	Other	-	-	-

* The difference between demographic groups was statistically significant at the p<.05 level.
*** The difference between demographic groups was statistically significant at the p<.001 level.

Personal health concerns about clean drinking water

- Fifty-six percent of Whitney respondents and 56.7 percent of Other respondents were extremely concerned about their personal health with regards to clean drinking water. The average scores were 6.76 for Whitney respondents and 7.03 for Other respondents.
- Among Whitney respondents, the percentage that was extremely concerned about their personal health with regards to clean drinking water was higher among female respondents (see Table 37).
- Among Other respondents, male respondents were more likely than female respondents to report extreme concern about their personal health with regards to clean drinking water (see Table 37). Respondents with some college/technical school education were more likely than those with more or less education to express no concern about their personal health with regards to clean drinking water.

Table 37
Personal Health Concerns about Clean Drinking Water
by Selected Demographics

	Group	Percentage responding		
		No concern (1)	Moderately concerned (2)	Extremely concerned (3)
Gender				
Female	City***	17.9	19.3	62.8
	Other*	10.9	34.5	54.5
Male	City	34.3	18.5	47.2
	Other	25.7	14.3	60.0
Education				
High school or less	City	-	-	-
	Other*	10.3	31.0	58.6
Some college/technical school	City	-	-	-
	Other	31.3	12.5	56.3
College or more	City	-	-	-
	Other	6.9	37.9	55.2

Swimming in Lake Whitney

- Forty-nine percent of Whitney respondents and 47.8 percent of Other respondents were extremely concerned about swimming in Lake Whitney. The average scores were 6.47 for Whitney respondents and 6.70 for Other respondents.
- Among Whitney respondents, the percentage that was extremely concerned about swimming in Lake Whitney decreased as the age of the respondent increased, and was higher among female respondents and unemployed/student/homemaker respondents (see Table 38).

* The difference between demographic groups was statistically significant at the p<.05 level.
*** The difference between demographic groups was statistically significant at the p<.001 level.

Table 38
Swimming in Lake Whitney
by Selected Demographics

	Group	Percentage responding		
		No concern (1)	Moderately concerned (2)	Extremely concerned (3)
Age of respondent				
18 to 45	City*	16.2	28.6	55.2
	Other	-	-	-
46 to 60	City	18.3	27.5	54.2
	Other	-	-	-
61 or older	City	29.1	27.5	43.3
	Other	-	-	-
Gender				
Female	City**	18.3	28.0	53.6
	Other	-	-	-
Male	City	29.5	27.6	42.9
	Other	-	-	-
Employment status				
Employed	City*	20.2	30.0	49.8
	Other	-	-	-
Unemployed/Student/Homemaker	City	13.6	20.3	66.1
	Other	-	-	-
Retired	City	28.7	28.7	42.6
	Other	-	-	-

<u>Eating fish from Lake Whitney</u>

- Forty-seven percent of Whitney respondents and 57.8 percent of Other respondents were extremely concerned about eating fish from Lake Whitney. The average scores were 6.17 for Whitney respondents and 7.01 for Other respondents.
- Among Whitney respondents, the percentage that was extremely concerned about eating fish from Lake Whitney decreased as the age of the respondent increased (see Table 39). Male respondents were more likely than female respondents to express no concern about eating fish from Lake Whitney.

* The difference between demographic groups was statistically significant at the p<.05 level.
** The difference between demographic groups was statistically significant at the p<.01 level.

Table 39
Eating Fish from Lake Whitney
by Selected Demographics

	Group	Percentage responding		
		No concern (1)	Moderately concerned (2)	Extremely concerned (3)
Age of respondent				
18 to 45	City*	26.7	18.1	55.2
	Other	-	-	-
46 to 60	City	22.1	28.2	49.7
	Other	-	-	-
61 or older	City	33.2	24.6	42.2
	Other	-	-	-
Gender				
Female	City**	23.2	28.4	48.4
	Other	-	-	-
Male	City	35.5	18.7	45.8
	Other	-	-	-

Saltiness of the water in Lake Whitney

- Thirty-six percent of Whitney respondents and 43.8 percent of Other respondents were extremely concerned about the saltiness of the water in Lake Whitney. The average scores were 6.17 for Whitney respondents and 7.01 for Other respondents.
- Among Whitney respondents, the percentage that was extremely concerned about the saltiness of the water in Lake Whitney was higher among female respondents and respondents with some college/technical school education (see Table 40).

* The difference between demographic groups was statistically significant at the p<.05 level.
** The difference between demographic groups was statistically significant at the p<.01 level.

Table 40
Saltiness of Water in Lake Whitney
by Selected Demographics

	Group	Percentage responding		
		No concern (1)	Moderately concerned (2)	Extremely concerned (3)
Gender				
Female	City*	27.4	31.4	41.2
	Other	-	-	-
Male	City	34.6	35.5	29.9
	Other	-	-	-
Education				
High school or less	City	-	-	-
	Other*	44.8	17.2	37.9
Some college/technical school	City	-	-	-
	Other	21.9	18.8	59.4
College or more	City	-	-	-
	Other	25.0	42.9	32.1

* The difference between demographic groups was statistically significant at the p<.05 level.

Water Pollution

Table 41
Contributing Factors to Local Water Pollution

Factor	Percentage responding			
	Major contributor	Moderate contributor	Minor contributor	Not at all a contributor
Agricultural use of pesticides and fertilizers				
City of Whitney (n=496)	43.8	34.9	17.3	4.0
Others (n=89)	41.6	39.3	12.4	6.7
Sanitary sewer overflows				
City of Whitney (n=484)	37.4	28.3	25.6	8.7
Others (n=84)	36.9	22.6	28.6	11.9
Waste from agriculture/dairy farms**				
City of Whitney (n=489)	33.5	29.7	28.2	8.6
Others (n=88)	37.5	29.5	14.8	18.2
Soil erosion off farm lands*				
City of Whitney (n=484)	21.5	37.0	34.1	7.4
Others (n=85)	23.5	40.0	21.2	15.3
Industrial waste				
City of Whitney (n=496)	29.0	21.0	35.5	14.5
Others (n=88)	34.1	26.1	21.6	18.2
Storm water runoff from city streets and parking lots				
City of Whitney (n=496)	17.1	33.3	36.1	13.5
Others (n=90)	14.4	35.6	32.2	17.8
Soil erosion from construction sites				
City of Whitney (n=495)	17.2	32.3	38.2	12.3
Others (n=88)	19.3	30.7	33.0	17.0

- Respondents were asked if any of the factors listed in Tables 41 and 48 contributed to local water pollution. Factors related to business and local government are shown in descending order of percentage (major plus moderate) for the Whitney respondents. As shown in Table 41, agricultural use of pesticides and fertilizers was reported by over three-quarters of the Whitney and Other respondents to be either a major or moderate contributor to local water pollution.
- A higher percentage of Other respondents reported all business and local government factors except sanitary sewer overflows and storm water runoff from city streets and parking lots either a major or minor contributor to local water pollution when compared to Whitney respondents.

** The difference between Whitney and Other respondents for this question was statistically significant at the $p<.01$ level.
* The difference between Whitney and Other respondents for this question was statistically significant at the $p<.05$ level.

Agricultural use of pesticides and fertilizers

- Agricultural use of pesticides and fertilizers was reported to be either a major or moderate contributor to local water pollution by 78.7 percent of Whitney respondents and 80.9 percent of Other respondents.
- Among Whitney respondents, the percentage who reported that agricultural use of pesticides and fertilizers was a major or moderate contributor to local water pollution generally decreased as length of residence increased (see Table 42).

Table 42
Agricultural Use of Pesticides and Fertilizers
by Selected Demographics

	Group	Percentage responding			
		Major	Moderate	Minor	Not at all
Length of residence					
0 to 5 years	City*	42.9	45.4	7.6	4.2
	Other	-	-	-	-
6 to 10 years	City	48.6	25.7	20.0	5.7
	Other	-	-	-	-
11 to 20 years	City	45.9	36.1	16.4	1.6
	Other	-	-	-	-
21 to 35 years	City	43.0	30.1	22.6	4.3
	Other	-	-	-	-
36 years or more	City	33.3	35.1	26.3	5.3
	Other	-	-	-	-

Sanitary sewer overflows

- Sanitary sewer overflows was reported to be either a major or moderate contributor to local water pollution by 65.7 percent of Whitney respondents and 59.5 percent of Other respondents.
- Among Whitney respondents, female respondents were more likely than male respondents to report that sanitary sewer overflows was either a major or moderate contributor to local water pollution (see Table 43).

Table 43
Sanitary Sewer Overflows
by Selected Demographics

	Group	Percentage responding			
		Major	Moderate	Minor	Not at all
Gender					
Female	City*	42.6	28.3	20.6	8.5
	Other	-	-	-	-
Male	City	30.7	28.3	32.1	9.0
	Other	-	-	-	-

* The difference between demographic groups was statistically significant at the p<.05 level.

Waste from agriculture/dairy farms

- Waste from agriculture/dairy farms was reported to be either a major or moderate contributor to local water pollution by 63.2 percent of Whitney respondents and 67.0 percent of Other respondents.
- Among Whitney respondents, the percentage who reported that waste from agriculture/dairy farms was either a major or moderate contributor to local water pollution decreased as income increased (see Table 44).

Table 44
Waste from Agriculture or Dairy Farms
by Selected Demographics

	Group	Percentage responding			
		Major	Moderate	Minor	Not at all
Income					
$25,000 or less	City*	31.9	30.1	26.5	11.5
	Other	-	-	-	-
$25,001 to $50,000	City	43.8	26.3	24.1	5.8
	Other	-	-	-	-
$50,001 to $75,000	City	31.9	33.0	33.0	2.2
	Other	-	-	-	-
Over $75,000	City	22.3	32.0	35.0	10.7
	Other	-	-	-	-

Soil erosion off farm lands

- Soil erosion off farm lands was reported to be either a major or moderate contributor to local water pollution by 58.5 percent of Whitney respondents and 63.5 percent of Other respondents.
- Among Other respondents, 68.0 percent of female respondents and 57.2 percent of male respondents reported that soil erosion off farm lands was either a major or moderate contributor to local water pollution (see Table 45).

Table 45
Soil Erosion off Farm Lands
by Selected Demographics

	Group	Percentage responding			
		Major	Moderate	Minor	Not at all
Gender					
Female	City	-	-	-	-
	Other*	30.0	38.0	26.0	6.0
Male	City	-	-	-	-
	Other	14.3	42.9	14.3	28.6

* The difference between demographic groups was statistically significant at the p<.05 level.

Industrial waste

- Half (50.0 percent) of Whitney respondents and 60.2 percent of Other respondents reported that industrial waste was either a major or moderate contributor to local water pollution.
- Among Whitney respondents, female respondents were more likely than male respondents to report that industrial waste was either a major or moderate contributor to local water pollution (see Table 46).

Table 46
Industrial Waste
by Selected Demographics

	Group	Percentage responding			
		Major	Moderate	Minor	Not at all
Gender					
Female	City**	32.4	21.9	29.1	16.5
	Other	-	-	-	-
Male	City	24.8	19.7	43.6	11.9
	Other	-	-	-	-

Storm water runoff from city streets and parking lots

- Half of both Whitney (50.4 percent) and Other (50.0 percent) respondents indicated that storm water runoff from city streets and parking lots was either a major or moderate contributor to local water pollution.
- There were no significant differences among demographic groups.

Soil erosion from construction sites

- Thirty-seven percent of Whitney respondents and 50.0 percent of Other respondents indicated that soil erosion from construction sites was either a major or moderate contributor to local water pollution.
- Among Whitney respondents, the percentage who reported that soil erosion from construction sites was either a major or moderate contributor to local water pollution decreased as income increased and was higher among female respondents (see Table 47).

** The difference between demographic groups was statistically significant at the p<.01 level.

Table 47
Soil Erosion from Construction Sites
by Selected Demographics

	Group	Percentage responding			
		Major	Moderate	Minor	Not at all
Gender					
Female	City**	18.6	38.6	32.1	10.7
	Other	-	-	-	-
Male	City	15.3	24.2	46.0	14.4
	Other	-	-	-	-
Income					
$25,000 or less	City*	19.0	28.4	34.5	18.1
	Other	-	-	-	-
$25,001 to $50,000	City	16.7	41.3	34.8	7.2
	Other	-	-	-	-
$50,001 to $75,000	City	17.8	30.0	47.8	4.4
	Other	-	-	-	-
Over $75,000	City	13.2	29.2	41.5	16.0
	Other	-	-	-	-

* The difference between demographic groups was statistically significant at the p<.05 level.
** The difference between demographic groups was statistically significant at the p<.01 level.

Table 48
Contributing Factors to Local Water Pollution

Factor	Percentage responding			
	Major contributor	Moderate contributor	Minor contributor	Not at all a contributor
Litter and trash City of Whitney (n=507)	42.6	36.1	17.6	3.7
Others (n=89)	39.3	38.2	14.6	7.9
Improper disposal of household hazardous waste City of Whitney (n=501)	35.9	32.9	24.8	6.4
Others (n=87)	33.3	28.7	25.3	12.6
Improper disposal of automobile oil and antifreeze City of Whitney (n=485)	38.6	29.7	24.1	7.6
Others (n=85)	35.3	36.5	21.2	7.1
Use of fertilizers and pesticides for lawns in residences City of Whitney (n=498)	28.9	39.8	25.5	5.8
Others (n=90)	25.6	37.8	26.7	10.0
Not picking up after pets** City of Whitney (n=498)	20.9	24.9	40.6	13.7
Others (n=88)	12.5	26.1	34.1	27.3

- Respondents were asked if any of the factors listed in Tables 41 and 48 contributed to local water pollution. Factors related to individual activities are shown in descending order of percentage (major plus moderate contribution) for the city respondents.
- A higher percentage of Whitney respondents compared to Other respondents reported all individual activity factors were either a major or minor contributor to local water pollution.

<u>Litter and trash</u>

- Seventy-nine percent of Whitney respondents and 77.5 percent of Other respondents indicated that litter and trash was either a major or moderate contributor to local water pollution.
- Among Whitney respondents, female respondents were more likely than male respondents to report that litter and trash was either a major or moderate contributor to local water pollution (see Table 49).

** The difference between Whitney and Other respondents for this question was statistically significant at the p<.01 level.

Table 49
Litter and Trash
by Selected Demographics

	Group	Percentage responding			
		Major	Moderate	Minor	Not at all
Gender					
Female	City**	48.1	36.3	12.1	3.5
	Other	-	-	-	-
Male	City	35.3	35.8	24.8	4.1
	Other	-	-	-	-

Improper disposal of household hazardous waste

- Improper disposal of household hazardous waste was reported to be either a major or moderate contributor to local water pollution by 68.8 percent of Whitney respondents and 62.0 percent of Other respondents.
- Among Whitney respondents, the percentage who indicated that improper disposal of household hazardous waste was either a major or moderate contributor to local water pollution decreased as income increased, and was higher among female respondents and respondents with some college/technical school education (see Table 50).

Table 50
Improper Disposal of Household Hazardous Waste
by Selected Demographics

	Group	Percentage responding			
		Major	Moderate	Minor	Not at all
Gender					
Female	City*	41.1	29.5	22.5	7.0
	Other	-	-	-	-
Male	City	29.2	37.5	27.8	5.6
	Other	-	-	-	-
Education					
High school or less	City*	40.0	25.7	24.3	10.0
	Other	-	-	-	-
Some college/technical school	City	40.9	33.3	21.4	4.4
	Other	-	-	-	-
College or more	City	29.4	37.8	27.4	5.5
	Other	-	-	-	-

* The difference between demographic groups was statistically significant at the p<.05 level.
** The difference between demographic groups was statistically significant at the p<.01 level.

Table 50
Improper Disposal of Household Hazardous Waste
by Selected Demographics (continued)

	Group	Percentage responding			
		Major	Moderate	Minor	Not at all
Income					
$25,000 or less	City*	42.7	27.4	17.9	12.0
	Other	-	-	-	-
$25,001 to $50,000	City	39.1	36.2	21.7	2.9
	Other	-	-	-	-
$50,001 to $75,000	City	29.7	37.4	27.5	5.5
	Other	-	-	-	-
Over $75,000	City	27.1	38.3	29.9	4.7
	Other	-	-	-	-

Improper disposal of automobile oil and antifreeze

- Improper disposal of automobile oil and antifreeze was reported to be either a major or moderate contributor to local water pollution by 68.3 percent of Whitney respondents and 71.8 percent of Other respondents.
- Among Whitney respondents, the percentage who indicated that improper disposal of automobile oil and antifreeze was either a major or moderate contributor to local water pollution decreased as length of residence increased (see Table 51).

Table 51
Improper Disposal of Auto Oil or Antifreeze
by Selected Demographics

	Group	Percentage responding			
		Major	Moderate	Minor	Not at all
Length of residence					
0 to 5 years	City**	33.6	42.2	19.8	4.3
	Other	-	-	-	-
6 to 10 years	City	49.5	22.3	22.3	5.8
	Other	-	-	-	-
11 to 20 years	City	45.8	22.9	25.4	5.9
	Other	-	-	-	-
21 to 35 years	City	31.2	29.0	26.9	12.9
	Other	-	-	-	-
36 years or more	City	25.5	32.7	29.1	12.7
	Other	-	-	-	-

* The difference between demographic groups was statistically significant at the p<.05 level.
** The difference between demographic groups was statistically significant at the p<.01 level.

Use of fertilizers and pesticides for lawns in residences

- Over two-thirds (68.7 percent) of Whitney and 63.4 percent of Other respondents reported that use of fertilizers and pesticides for lawns in residences was either a major or moderate contributor to local water pollution.
- Among Whitney respondents, the percentage who reported that use of fertilizers and pesticides for lawns in residences was either a major or moderate contributor to local water pollution decreased as income increased and was higher among female respondents (see Table 52).
- Among Other respondents, 70.9 percent of female respondents and 51.5 percent of male respondents reported that use of fertilizers and pesticides for lawns in residences was either a major or moderate contributor to local water pollution.

Table 52
Use of Fertilizers and Pesticides for Residential Lawns
by Selected Demographics

	Group	Percentage responding			
		Major	Moderate	Minor	Not at all
Gender					
Female	City*	32.4	42.3	20.3	5.0
	Other**	40.0	30.9	20.0	9.1
Male	City	24.4	36.4	32.3	6.9
	Other	2.9	48.6	37.1	11.4
Income					
$25,000 or less	City**	27.6	45.7	19.0	7.8
	Other	-	-	-	-
$25,001 to $50,000	City	34.3	43.1	16.8	5.8
	Other	-	-	-	-
$50,001 to $75,000	City	26.4	39.6	31.9	2.2
	Other	-	-	-	-
Over $75,000	City	22.4	34.6	39.3	3.7
	Other	-	-	-	-

Not picking up after pets

- Not picking up after pets was reported to be either a major or moderate contributor to local water pollution by 45.8 percent of Whitney respondents and 38.6 percent of Other respondents.
- Among Whitney respondents, the percentage who reported that not picking up after pets was either a major or moderate contributor to local water pollution decreased as income increased and was higher among female respondents compared to male respondents (see Table 53).

* The difference between demographic groups was statistically significant at the p<.05 level.
** The difference between demographic groups was statistically significant at the p<.01 level.

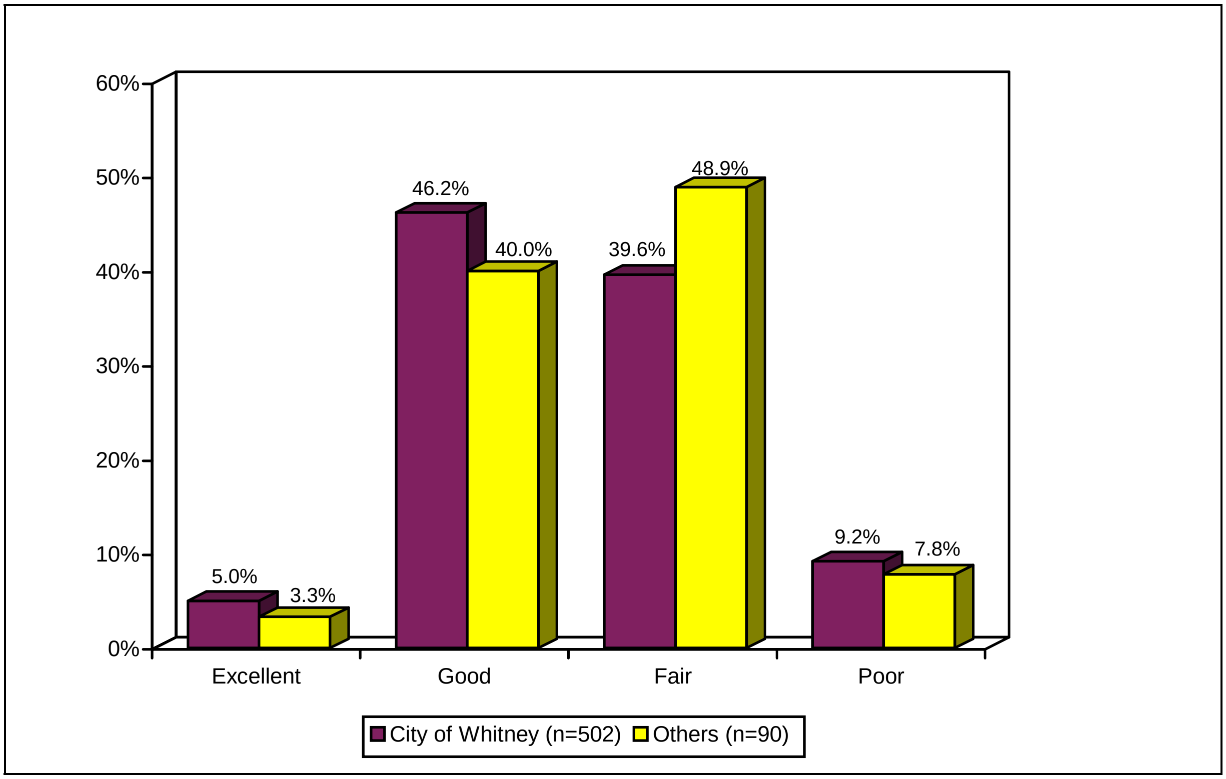
Table 53
Not Picking Up after Pets
by Selected Demographics

	Group	Percentage responding			
		Major	Moderate	Minor	Not at all
Gender					
Female	City**	26.1	26.9	36.0	11.0
	Other	-	-	-	-
Male	City	14.0	22.3	46.5	17.2
	Other	-	-	-	-
Income					
$25,000 or less	City*	25.4	26.3	33.1	15.3
	Other	-	-	-	-
$25,001 to $50,000	City	25.5	26.3	38.0	10.2
	Other	-	-	-	-
$50,001 to $75,000	City	17.8	24.4	46.7	11.1
	Other	-	-	-	-
Over $75,000	City	9.4	20.8	49.1	20.8
	Other	-	-	-	-

* The difference between demographic groups was statistically significant at the p<.05 level.
** The difference between demographic groups was statistically significant at the p<.01 level.

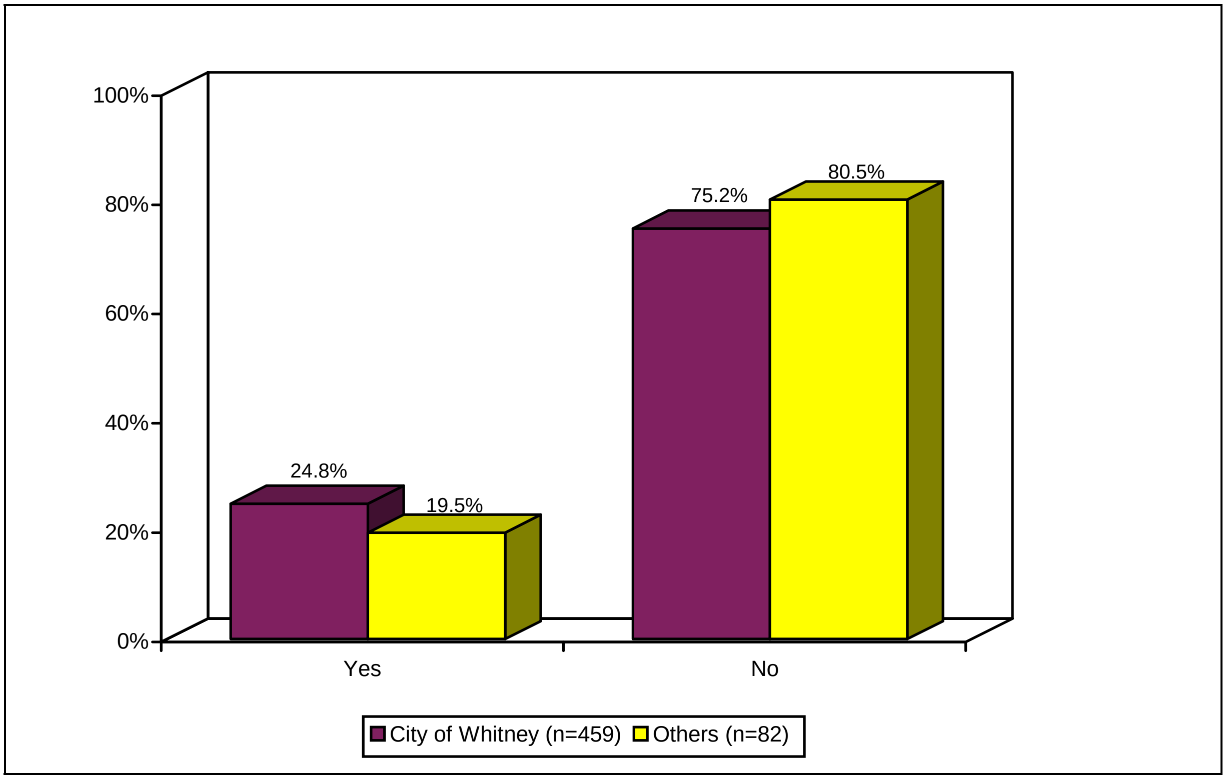
Water Quality

Figure 15
Quality of Lake Whitney Area Streams, Rivers and Reservoirs



- Respondents were asked to rate the water quality of the streams, rivers and reservoirs in and around Lake Whitney. As shown in Figure 15, 51.2 percent of Whitney respondents rated the water quality either excellent (5.0 percent) or good (46.2 percent). Forty-three percent of Other respondents rated the water quality either excellent (3.3 percent) or good (40.0 percent).
- Forty percent of Whitney respondents and 48.9 percent of Other respondents rated the quality of the water fair.

Figure 16
Water Quality Has Improved Over Past 5 Years



- Respondents were asked if the water quality in their area had improved over the past five years. One-quarter (24.8 percent) of Whitney respondents and 19.5 percent of Other respondents answered “yes” (see Figure 16).

Quality of Life

Table 54
Main Reason Live or Moved to Lake Whitney Area

	Percentage responding	
	City of Whitney (n=505)	Others (n=90)
Rural atmosphere/get out of city	24.2	27.8
Close to family/friends	14.1	7.8
Born here	11.3	7.8
Employment	10.7	6.7
Lake Whitney	7.5	13.3
Lake recreation	6.7	13.3
Retirement	5.8	6.7
Low population	4.6	4.4
Like the area/beautiful area	3.2	3.3
Land/homes/cost of living less expensive	2.4	3.3
Inherited/own property	2.0	0.0
Grew up here	1.4	0.0
Good place to live/raise children	1.2	2.2
Other types of recreation	1.2	0.0
Good schools	0.8	1.1
Expanse of land/agriculture and ranching	0.8	2.2
Other, specify	2.2	0.0

- Respondents were asked the main reason they lived or moved to the Lake Whitney area. As shown in Table 54, 24.2 percent of Whitney respondents and 27.8 percent of Other respondents lived in or moved to the Lake Whitney area because of the rural atmosphere or they wanted to get out of the city.
- For Whitney respondents, being close to family and friends (14.1 percent), they were born in the area (11.3 percent), and their employment (10.7 percent) were also reasons for living in the Lake Whitney area.
- For Other respondents, Lake Whitney itself (13.3 percent) and lake recreation (13.3 percent) were reasons for living in the Lake Whitney area.

Table 55
Important to Quality of Life

	Percentage responding			
	Very important	Somewhat important	Somewhat unimportant	Very unimportant
Wildlife				
City of Whitney (n=507)	69.6	24.1	3.9	2.4
Others (n=90)	70.0	24.4	5.6	0.0
Scenic views				
City of Whitney (n=505)	56.0	32.7	6.3	5.0
Others (n=90)	68.9	24.4	4.4	2.2
Impact on local businesses				
City of Whitney (n=504)	53.4	34.7	6.0	6.0
Others (n=86)	44.2	44.2	7.0	4.7
Lake-related businesses				
City of Whitney (n=501)	35.7	39.5	15.2	9.6
Others (n=90)	30.0	41.1	18.9	10.0
Tourism*				
City of Whitney (n=500)	35.6	35.0	16.0	13.4
Others (n=89)	20.2	40.4	22.5	16.9
Swimming				
City of Whitney (n=506)	28.3	36.6	14.2	20.9
Others (n=90)	35.6	37.8	13.3	13.3
Fishing				
City of Whitney (n=507)	33.5	29.8	17.0	19.7
Others (n=90)	38.9	31.1	15.6	14.4
Boating*				
City of Whitney (n=508)	24.2	30.7	17.3	27.8
Others (n=89)	28.1	38.2	21.3	12.4

- All respondents were asked to consider their own quality of life and then asked how important the aspects of Lake Whitney listed in Table 55 were to them. Aspects are shown in descending order of percentage (very important plus somewhat important) for the Whitney respondents. As shown in Table 55, wildlife was most important to respondents' quality of life, followed by scenic views, impact on local businesses, lake-related businesses, tourism, swimming, fishing and boating.
- A higher percentage of Other respondents reported all aspects except tourism and lake-related businesses either very important or somewhat important to their quality of life when compared to Whitney respondents.

Wildlife

- Ninety-four percent of Whitney (93.7 percent) and Other respondents (94.4 percent) reported that Lake Whitney wildlife was either very important or somewhat important to their quality of life.
- Among Whitney respondents, the percentage who reported that Lake Whitney wildlife was either very important or somewhat important to their quality of life decreased as the

* The difference between Whitney and Other respondents for the tourism and boating questions was statistically significant at the p<.05 level.

age of the respondent increased, and was higher among respondents who lived in a city or town when compared to those who lived in the country (see Table 56).

Table 56
Wildlife
by Selected Demographics

	Group	Percentage responding			
		Very important	Somewhat important	Somewhat unimportant	Very unimportant
Age of respondent					
18 to 45	City**	77.1	21.9	0.0	1.0
	Other	-	-	-	-
46 to 60	City	76.5	19.0	2.6	2.0
	Other	-	-	-	-
61 or older	City	62.5	28.2	6.5	2.8
	Other	-	-	-	-
Live in city or country					
City or town	City*	62.2	34.7	1.0	2.0
	Other	-	-	-	-
In the country	City	71.7	21.1	4.7	2.5
	Other	-	-	-	-

Scenic views

- Eighty-nine percent of Whitney respondents and 93.3 percent of Other respondents reported that Lake Whitney's scenic views were either very important or somewhat important to their quality of life.
- Among Whitney respondents, female respondents were more likely than male respondents to report that Lake Whitney's scenic views were very important to their quality of life (see Table 57).

Table 57
Scenic Views
by Selected Demographics

	Group	Percentage responding			
		Very important	Somewhat important	Somewhat unimportant	Very unimportant
Gender					
Female	City***	64.0	26.6	5.9	3.5
	Other	-	-	-	-
Male	City	45.4	40.7	6.9	6.9
	Other	-	-	-	-

* The difference between demographic groups was statistically significant at the p<.05 level.
** The difference between demographic groups was statistically significant at the p<.01 level.
*** The difference between demographic groups was statistically significant at the p<.001 level.

Impact on local businesses

- Eighty-eight percent of both Whitney (88.1 percent) respondents and Other respondents (88.4 percent) reported that Lake Whitney's impact on local businesses was either very important or somewhat important to their quality of life.
- There were no statistically significant differences among demographic groups.

Lake-related businesses

- Three-quarters (75.2 percent) of Whitney respondents and 71.1 percent of Other respondents reported that Lake Whitney's lake-related businesses were either very important or somewhat important to their quality of life.
- Among Whitney respondents, the percentage who reported that Lake Whitney's lake-related businesses were either very important or somewhat important to their quality of life increased as length of residence increased (see Table 58).

Table 58
Lake-related Businesses
by Selected Demographics

	Group	Percentage responding			
		Very important	Somewhat important	Somewhat unimportant	Very unimportant
Length of residence					
0 to 5 years	City*	28.3	46.7	16.7	8.3
	Other	-	-	-	-
6 to 10 years	City	25.5	42.5	18.9	13.2
	Other	-	-	-	-
11 to 20 years	City	36.4	38.0	14.9	10.7
	Other	-	-	-	-
21 to 35 years	City	48.5	29.9	13.4	8.2
	Other	-	-	-	-
36 years or more	City	47.4	38.6	8.8	5.3
	Other	-	-	-	-

Tourism

- Seventy percent of Whitney respondents and 60.6 percent of Other respondents reported that Lake Whitney tourism was either very important or somewhat important to their quality of life.
- Among Whitney respondents, the percentage who reported that Lake Whitney tourism was either very important or somewhat important to their quality of life varied with length of residence and education, and increased as income increased (see Table 59).

* The difference between demographic groups was statistically significant at the p<.05 level.

Table 59
Tourism
by Selected Demographics

	Group	Percentage responding			
		Very important	Somewhat important	Somewhat unimportant	Very unimportant
Length of residence					
0 to 5 years	City**	28.9	41.3	14.0	15.7
	Other	-	-	-	-
6 to 10 years	City	23.6	44.3	18.9	13.2
	Other	-	-	-	-
11 to 20 years	City	32.2	35.5	14.9	17.4
	Other	-	-	-	-
21 to 35 years	City	53.8	21.5	16.1	8.6
	Other	-	-	-	-
36 years or more	City	49.2	25.4	16.9	8.5
	Other	-	-	-	-
Education					
High school or less	City*	45.0	28.6	12.9	13.6
	Other	-	-	-	-
Some college/technical school	City	37.1	30.2	17.0	15.7
	Other	-	-	-	-
College or more	City	28.0	43.5	17.5	11.0
	Other	-	-	-	-
Income					
$25,000 or less	City*	39.3	24.8	18.8	17.1
	Other	-	-	-	-
$25,001 to $50,000	City	38.4	32.6	14.5	14.5
	Other	-	-	-	-
$50,001 to $75,000	City	36.3	44.0	12.1	7.7
	Other	-	-	-	-
Over $75,000	City	25.9	42.6	20.4	11.1
	Other	-	-	-	

<u>Swimming</u>

- Sixty-five percent of Whitney respondents and 73.4 percent of Other respondents reported that swimming in Lake Whitney was either very important or somewhat important to their quality of life.
- Among Whitney respondents, the percentage who reported that swimming in Lake Whitney was very important to their quality of life decreased as the age of the respondent increased, and was higher among female respondents and unemployed respondents (see Table 60).

* The difference between demographic groups was statistically significant at the p<.05 level.
** The difference between demographic groups was statistically significant at the p<.01 level.

Table 60
Swimming
by Selected Demographics

	Group	Percentage responding			
		Very important	Somewhat important	Somewhat unimportant	Very unimportant
Age of respondent					
18 to 45	City***	47.6	35.2	8.6	8.6
	Other	-	-	-	-
46 to 60	City	26.8	42.5	15.7	15.0
	Other	-	-	-	-
61 or older	City	21.1	33.6	15.8	29.6
	Other	-	-	-	-
Gender					
Female	City*	32.0	33.3	11.7	23.0
	Other	-	-	-	-
Male	City	23.3	40.9	17.7	18.1
	Other	-	-	-	-
Employment status					
Employed	City***	33.2	39.6	13.4	13.9
	Other	-	-	-	-
Unemployed/Student/Homemaker	City	39.0	32.2	20.3	8.5
	Other	-	-	-	-
Retired	City	21.1	35.9	13.9	29.1
	Other	-	-	-	-

<u>Fishing</u>

- Sixty-three percent of Whitney respondents and 70.0 percent of Other respondents reported that fishing in Lake Whitney was either very important or somewhat important to their quality of life.
- There were no statistically significant differences among demographic groups.

<u>Boating</u>

- Fifty-five percent of Whitney respondents and 66.3 percent of Other respondents reported that boating in Lake Whitney was either very important or somewhat important to their quality of life.
- There were no statistically significant differences among demographic groups.

* The difference between demographic groups was statistically significant at the p<.05 level.
*** The difference between demographic groups was statistically significant at the p<.001 level.

Responsibility for Water Quality

Table 61
Responsibility for Maintaining Water Quality
(Whitney n=965, 487, 461; Others n=161, 81, 79)

	Percentage responding		
	Overall (Most & 2nd most)	Most responsible	Least responsible
State government			
City of Whitney	30.3	29.8	4.6
Others	32.3	34.6	3.8
County and city governments			
City of Whitney	22.6	18.9	15.8
Others	17.4	14.8	10.1
Business and industry			
City of Whitney	22.6	3.5	6.5
Others	8.7	3.7	6.3
Individuals			
City of Whitney	20.6	26.5	23.0
Others	21.1	27.2	25.3
Federal government			
City of Whitney	15.8	18.1	39.5
Others	14.9	17.3	41.8
Farmers and ranchers			
City of Whitney	5.2	3.3	10.6
Others	5.6	2.5	12.7

- Respondents were asked who has the most, second most, and least responsibility for maintaining the water quality in the Lake Whitney area streams and reservoirs. The combined percentage of most and second most responsible is presented in the "Overall" column in Table 61.

Overall responsibility

- State government was reported to have the most overall responsibility for maintaining the water quality in area streams and reservoirs by 30.3 percent of the Whitney respondents and 32.3 percent of the Other respondents.

Most responsibility

- State government was reported to have the most responsibility for maintaining the water quality in area streams and reservoirs by 30.3 percent of the Whitney respondents and 32.3 percent of the Other respondents.
- Among Whitney respondents, 33.0 percent of male respondents and 27.3 percent of female respondents indicated that state government has the most responsibility for maintaining the water quality in area streams and reservoirs (see Table 62).

Table 62
Most Responsible for Water Quality
by Selected Demographics

	Group	Percentage responding					
		Federal govt.	State govt.	County/ city govts.	Business and industry	Farmers and ranchers	Individuals
Gender							
Female	City*	18.9	27.3	23.6	2.9	2.5	24.7
	Other	-	-	-	-	-	-
Male	City	17.0	33.0	12.7	4.2	4.2	28.8
	Other	-	-	-	-	-	-

Least responsibility

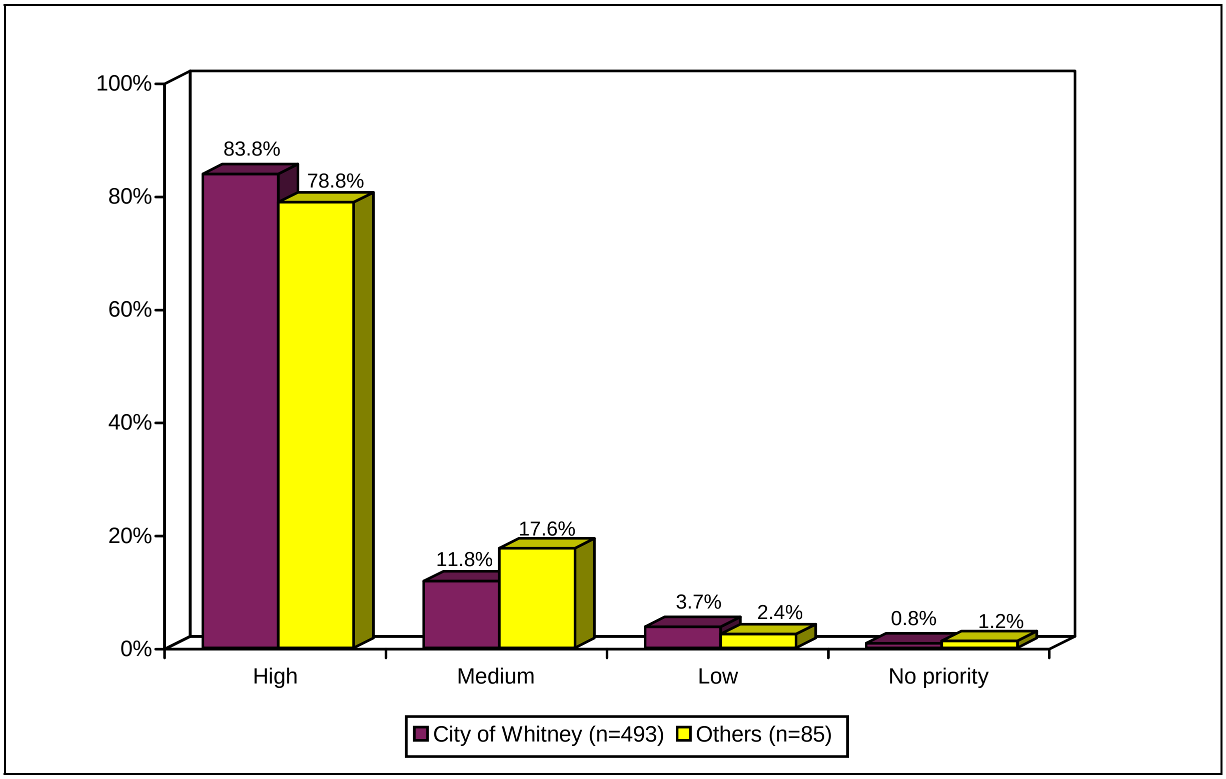
- The Federal government was reported by 39.5 percent of Whitney respondents and 41.8 percent of Other respondents to have the least responsibility for maintaining the water quality in area streams and reservoirs.
- Among Whitney respondents, the percentage who reported that the Federal government had the least responsibility for maintaining the water quality in area streams and reservoirs varied with the age of the respondent and employment status (see Table 63).

Table 63
Least Responsible for Water Quality
by Selected Demographics

	Group	Percentage responding					
		Federal govt.	State govt.	County/ city govts.	Business and industry	Farmers and ranchers	Individuals
Age of respondent							
18 to 45	City**	39.0	6.0	12.0	10.0	20.0	13.0
	Other	-	-	-	-	-	-
46 to 60	City	41.0	4.5	18.7	5.2	9.7	20.9
	Other	-	-	-	-	-	-
61 or older	City	38.5	4.0	15.9	5.8	7.1	28.8
	Other	-	-	-	-	-	-
Employment status							
Employed	City*	38.6	6.3	16.9	6.9	13.2	18.0
	Other						
Unemployed/Student/Homemaker	City	33.3	0.0	7.8	7.8	19.6	31.4
	Other						
Retired	City	41.7	4.2	17.1	6.0	6.0	25.0
	Other						

* The difference between demographic groups was statistically significant at the p<.05 level.
** The difference between demographic groups was statistically significant at the p<.01 level.

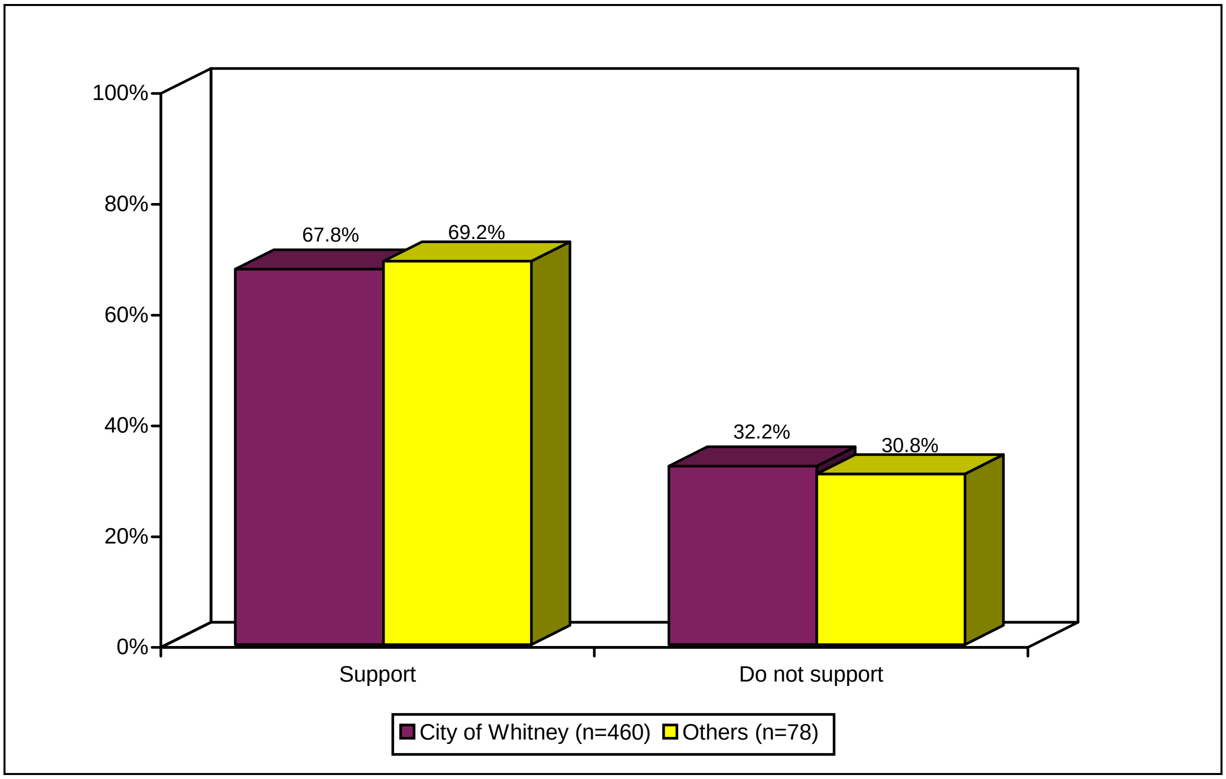
Figure 17
Priority on Protecting Lake Whitney



- Respondents were asked if their local and county governments should place a high, medium, low or no priority on protecting Lake Whitney. As shown in Figure 17, 83.8 percent of the Whitney respondents and 78.8 percent of the Other respondents indicated that their local and county governments should place a high priority on protecting Lake Whitney.

Lake Whitney as a Source of Drinking Water

Figure 18
Support Using Lake Whitney to Supply Drinking Water



- Respondents were read the following: "Some have considered treating the water in Lake Whitney to supply drinking water for the region. Would you support or not support using Lake Whitney to supply drinking water for the region?"
- As shown in Figure 18, over two-thirds of both Whitney respondents (67.8 percent) and Other respondents (69.2 percent) indicated they would support using Lake Whitney to supply drinking water for the region.
- Among Whitney respondents, support for using Lake Whitney to supply drinking water for the region increased as the age of the respondent increased (see Table 64).
- Among Other respondents, support for using Lake Whitney to supply drinking water was higher among respondents age 46 to 60.

Table 64
Support Using Lake Whitney to Supply Drinking Water by Selected Demographics

	Group	Percentage responding	
		Support	Do not support
Age of respondent			
18 to 45	City*	58.5	41.5
	Other*	43.8	56.3
46 to 60	City	64.6	35.4
	Other	80.8	19.2
61 or older	City	73.9	26.1
	Other	72.2	27.8

* The difference between demographic groups was statistically significant at the p<.05 level.

Table 65
Reason for Not Supporting Using Lake Whitney to Supply Drinking Water for Region

Reason	Percentage responding	
	City of Whitney (n=155)	Others (n=25)
Questionable water quality (pollution)	29.7	28.0
Need to maintain lake levels	19.4	20.0
Golden/black algae	11.0	16.0
Have a well/plenty of wells/do not need to use lake	9.7	8.0
Saltiness	7.7	8.0
Cost	4.5	4.0
Lake used to generate electricity, does not need to provide drinking water too	2.6	4.0
Want lake left the way it is	2.6	4.0
Do not think it should supply drinking water	2.6	4.0
Needs more information before making decision	2.6	0.0
Negatively impact recreation use	1.9	0.0
Would ruin ecosystem/hurt wildlife	1.3	4.0
Lake is too small	1.3	0.0
Other	3.2	0.0

- Respondents who were not supportive of using Lake Whitney as a source of drinking water were asked why they would not support it. As shown in Table 65, 29.7 percent of Whitney respondents and 28.0 percent of Other respondents who did not support using Lake Whitney to supply drinking water for the region said the water was of questionable quality/polluted.
- Approximately 20 percent of both Whitney (19.4 percent) and Other respondents (20.0 percent) did not support using Lake Whitney to supply drinking water because lake levels needed to be maintained.
- Eleven percent of Whitney respondents and 16.0 percent of Other respondents did not support using Lake Whitney to supply drinking water due to the golden/black algae.
- Other reasons, given by Whitney respondents, follow. “Because the state is too slow in testing the lake water to make sure that the water that goes to treatment plant would be sufficiently safe to drink. The government is too slow.” “Core engineers wants to control all the water and doesn’t want the people to use the lakes.” “Enough problems in the lake.” “Past experiences.” “We’re thirty miles from Comanche Peak, a nuclear plant.”

Table 66
Likely Outcome if Lake Whitney Used as Water Source

Outcome	Percentage responding			
	Very likely	Somewhat likely	Somewhat unlikely	Very unlikely
Negatively affect lake recreation usage				
City of Whitney (n=472)	22.5	30.7	22.7	24.2
Others (n=82)	24.4	28.0	24.4	23.2
Increase residential development around the lake				
City of Whitney (n=468)	21.2	28.8	25.6	24.4
Others (n=82)	29.3	26.8	20.7	23.2
Improve your quality of life				
City of Whitney (n=483)	10.6	20.5	25.1	43.9
Others (n=83)	14.5	20.5	27.7	37.3

- Respondents were asked to rate the likelihood of several outcomes if Lake Whitney were used as a regional source of drinking water.

Negatively affect lake recreation usage

- As shown in Table 66, 53 percent of both Whitney respondents (53.2 percent) and Other respondents (52.8 percent) reported it was either very likely or somewhat likely that using Lake Whitney as a regional source of drinking water would negatively affect lake recreation usage.
- Among Whitney respondents, 59.0 percent of female respondents and 46.0 percent of male respondents indicated it was either very likely or somewhat likely that using Lake Whitney as a regional source of drinking water would negatively affect lake recreation usage (see Table 67).
- Among Other respondents, the percentage who reported that it was either very likely or somewhat likely that using Lake Whitney as a regional source of drinking water would negatively affect lake recreation usage varied with education and was highest among respondents with college or more.

Table 67
Negatively Affect Lake Recreation Usage
by Selected Demographics

	Group	Percentage responding			
		Very likely	Somewhat likely	Somewhat unlikely	Very unlikely
Gender					
Female	City*	23.0	36.0	21.5	19.5
	Other	-	-	-	-
Male	City	21.8	24.2	24.2	29.9
	Other	-	-	-	-

* The difference between demographic groups was statistically significant at the p<.05 level.

Table 67
Negatively Affect Lake Recreation Usage
by Selected Demographics (continued)

	Group	Percentage responding			
		Very likely	Somewhat likely	Somewhat unlikely	Very unlikely
Education					
High school or less	City	-	-	-	-
	Other*	25.0	32.1	32.1	10.7
Some college/technical school	City	-	-	-	-
	Other	20.7	10.3	27.6	41.4
College or more	City	-	-	-	-
	Other	28.0	44.0	12.0	16.0

Increase residential development around the lake

- Fifty percent of Whitney respondents and 56.1 percent of Other respondents reported it was either very likely or somewhat likely that using Lake Whitney as a regional source of drinking water would increase residential development around the lake.

Improve your quality of life

- Approximately two-thirds of both Whitney respondents (69.0 percent) and Other respondents (65.0 percent) reported it was either very unlikely or somewhat unlikely that using Lake Whitney as a regional source of drinking water would improve their quality of life.
- Among Whitney respondents, the percentage who indicated it was either very unlikely or somewhat unlikely that using Lake Whitney as a regional source of drinking water would improve their quality of life varied with the age of the respondents and was higher among respondents age 46 to 60 (see Table 68).

Table 68
Improve Your Quality of Life
by Selected Demographics

	Group	Percentage responding			
		Very likely	Somewhat likely	Somewhat unlikely	Very unlikely
Age of respondent					
18 to 45	City*	9.8	24.5	34.3	31.4
	Other	-	-	-	-
46 to 60	City	11.7	16.6	18.6	53.1
	Other	-	-	-	-
61 or older	City	10.2	21.3	25.1	43.4
	Other	-	-	-	-

* The difference between demographic groups was statistically significant at the p<.05 level.

Table 69
Concern about Water Issues

	Average Score (1-10)	Percentage responding		
		No concern (1-3)	Moderately concerned (4-7)	Extremely concerned (8-10)
Golden algae				
City of Whitney (n=484)	7.78	12.2	20.0	67.8
Others (n=87)	8.07	10.3	16.1	73.6
Cost				
City of Whitney (n=487)	6.99	14.4	35.3	50.3
Others (n=85)	7.56	3.5	38.8	57.6
Pollution				
City of Whitney (n=499)	6.65	23.2	27.9	48.9
Others (n=89)	6.92	22.5	21.3	56.2
Safety of drinking water				
City of Whitney (n=504)	6.35	26.8	24.8	48.4
Others (n=87)	6.72	24.1	19.5	56.3
Saltiness of water				
City of Whitney (n=489)	5.83	30.5	28.4	41.1
Others (n=87)	6.49	23.0	26.4	50.6

- Respondents were read a list of five water issues and asked to rank their level of concern about each if treated water from Lake Whitney was offered to their household through a local utility company (using a scale of 1 to 10, with 1 being no concern and 10 being extremely concerned). An average score was computed using the 1 to 10 scale (see Table 69). The categories were then collapsed to compute percentages: no concern (1-3), (4-7), and extremely concerned (8-10).
- The average score for each issue was greater for Other respondents than for Whitney respondents.

<u>Golden algae</u>

- Sixty-eight percent of Whitney respondents and 73.6 percent of Other respondents reported that they would be extremely concerned about golden algae if treated water from Lake Whitney was offered to their household through a local utility company (see Table 69).
- Among Whitney respondents, extreme concern about golden algae was higher among female respondents and respondents with some college/technical school education (see Table 70).

Table 70
Golden Algae
by Selected Demographics

	Group	Percentage responding		
		No concern (1)	Moderately concerned (2)	Extremely concerned (3)
Gender				
Female	City***	7.6	15.8	76.6
	Other	-	-	-
Male	City	18.4	25.7	55.8
	Other	-	-	-
Education				
High school or less	City*	6.9	20.6	72.5
	Other	-	-	-
Some college/technical school	City	12.2	14.7	73.1
	Other	-	-	-
College or more	City	15.8	23.5	60.7
	Other	-	-	-

Cost

- Fifty percent of Whitney respondents and 57.6 percent of Other respondents reported that they would be extremely concerned about the cost if treated water from Lake Whitney was offered to their household through a local utility company.
- Among Whitney respondents, extreme concern about cost was higher among female respondents and respondents age 46 to 60 (see Table 71).

Table 71
Cost
by Selected Demographics

	Group	Percentage responding		
		No concern (1)	Moderately concerned (2)	Extremely concerned (3)
Age of respondent				
18 to 45	City*	17.6	42.2	40.2
	Other	-	-	-
46 to 60	City	10.0	29.3	60.7
	Other	-	-	-
61 or older	City	15.4	36.3	48.3
	Other	-	-	-
Gender				
Female	City**	11.8	30.7	57.5
	Other	-	-	-
Male	City	17.9	41.5	40.6
	Other	-	-	-

* The difference between demographic groups was statistically significant at the p<.05 level.
** The difference between demographic groups was statistically significant at the p<.01 level.
*** The difference between demographic groups was statistically significant at the p<.001 level.

Pollution

- Forty-nine percent of Whitney respondents and 56.2 percent of Other respondents reported that they would be extremely concerned about pollution if treated water from Lake Whitney was offered to their household through a local utility company.
- Among Whitney respondents, extreme concern about pollution was higher among female respondents and respondents who had lived in the City of Whitney 11 to 20 years (see Table 72).

Table 72
Pollution
by Selected Demographics

	Group	Percentage responding		
		No concern (1)	Moderately concerned (2)	Extremely concerned (3)
Gender				
Female	City***	16.8	29.5	53.7
	Other	-	-	-
Male	City	31.8	25.7	42.5
	Other	-	-	-
Length of residence				
0 to 5 years	City*	25.6	37.2	37.2
	Other	-	-	-
6 to 10 years	City	26.0	23.1	51.0
	Other	-	-	-
11 to 20 years	City	13.9	27.9	58.2
	Other	-	-	-
21 to 35 years	City	30.5	23.2	46.3
	Other	-	-	-
36 years or more	City	21.1	24.6	54.4
	Other	-	-	-

Safety of drinking water

- Forty-eight percent of Whitney respondents and 56.3 percent of Other respondents reported that they would be extremely concerned about the safety of the drinking water if treated water from Lake Whitney was offered to their household through a local utility company.
- Among Whitney respondents, extreme concern about the safety of the drinking water was higher among female respondents (see Table 73).

* The difference between demographic groups was statistically significant at the p<.05 level.
*** The difference between demographic groups was statistically significant at the p<.001 level.

Table 73
Safety of Drinking the Water
by Selected Demographics

	Group	Percentage responding		
		No concern (1)	Moderately concerned (2)	Extremely concerned (3)
Gender				
Female	City***	19.7	25.3	55.0
	Other	-	-	-
Male	City	36.3	24.2	39.5
	Other	-	-	-

Saltiness of the water

- Forty-one percent of Whitney respondents and 50.6 percent of Other respondents reported that they would be extremely concerned about the saltiness of the water if treated water from Lake Whitney was offered to their household through a local utility company.
- Among Whitney respondents, extreme concern about the saltiness of the water was higher among female respondents (see Table 74).

Table 74
Saltiness of the Water
by Selected Demographics

	Group	Percentage responding		
		No concern (1)	Moderately concerned (2)	Extremely concerned (3)
Gender				
Female	City*	26.3	27.7	46.0
	Other	-	-	-
Male	City	36.0	29.4	34.6
	Other	-	-	-

* The difference between demographic groups was statistically significant at the p<.05 level.
*** The difference between demographic groups was statistically significant at the p<.001 level.

Information

Table 75
News or Information Source for Information about Local Issues

Source	Percentage responding			
	Overall*		Top Choice	
	City of Whitney (n=1,470)	Others (n=254)	City of Whitney (n=506)	Others (n=90)
Newspaper	27.9	29.5	54.0	54.4
Television	19.1	19.3	20.4	18.9
Friends, neighbors or family	14.7	15.4	6.7	7.8
Internet	9.4	10.2	7.1	8.9
Local government cable TV, info inserts in bills, etc.	7.4	5.5	4.3	2.2
Radio	7.0	6.7	2.2	4.4
Local churches	6.4	5.9	2.2	3.3
Local schools	4.6	4.7	0.8	0.0
Magazines	3.5	2.8	2.4	0.0

- Respondents were read nine sources and asked what news or information source they were most likely to use to get important information about local issues. They ranked each source from 1 to 9 where 1 was the most important and 9 was the least important. Sources were rotated as each respondent was interviewed.
- Newspapers followed by television were the most common sources of information for both City of Whitney and Other respondents (see Table 75).

* The "n" is based on the number of total responses to the question.

Table 76
Trustworthiness of Information Sources

	Avg. Score (1-5)	Percentage responding		
		Untrust-worthy (1-2)	(3)	Trust-worthy (4-5)
Local newspapers				
News articles (n=590)	3.68	13.7	25.1	61.2
Advertising (n=586)	3.11	32.3	28.2	39.5
Television				
News features (n=586)	3.20	25.9	32.8	41.3
Advertising (n=586)	2.58	47.1	32.6	20.3
Radio				
News features (n=572)	3.07	27.6	37.4	35.0
Advertising (n=577)	2.64	45.1	32.1	22.9
Government				
County extension agents (n=580)	3.69	18.3	19.0	62.8
Information in water, sewer, utility bills (n=576)	3.45	22.9	24.5	52.6
Govt. publications (n=581)	3.21	27.4	27.2	45.4
Your local government (n=592)	3.20	27.4	29.2	43.4
Govt. websites (n=529)	3.17	29.7	25.1	45.2
Other				
Billboards (n=585)	2.34	56.9	27.4	15.7

- Respondents were asked to rate the trustworthiness of the sources listed in Table 76 to deliver information on environmental issues. Sources were rotated as each respondent was interviewed. An average score was computed (based on a scale of 1 being untrustworthy to 5 being trustworthy). Categories were collapsed from 5 to 3 where 1 or 2 indicated "untrustworthy" and 4 or 5 indicated "trustworthy."

News articles in local newspapers

- Sixty-one percent of all respondents rated news articles in local newspapers as trustworthy (see Table 76). The average score was 3.68.
- Among Other respondents, female respondents (63.6 percent) were more likely than male respondents (37.1 percent) to rate news articles in local newspapers as trustworthy (see Table 77).

Table 77
News Articles in Local Newspapers
by Selected Demographics

	Group	Percentage responding		
		Untrust-worthy (1-2)	(3)	Trust-worthy (4-5)
Gender				
Female	City	-	-	-
	Other*	14.5	21.8	63.6
Male	City	-	-	-
	Other	20.0	42.9	37.1

Advertising in local newspapers

- Forty percent of all respondents rated advertising in local newspapers as trustworthy. The average score was 3.11.
- Among Whitney respondents, the percentage of respondents who rated advertising in local newspapers as trustworthy decreased as education increased (see Table q36f). Whitney respondents who commuted to another city for work (36.7 percent) were more likely than those who work near the lake (24.5 percent) to rate advertising in local newspapers as untrustworthy.
- Among Other respondents, trustworthiness of advertising in local newspapers decreased as the age of the respondent, education, and income increased, and was higher among female respondents than male respondents (see Table 78).

Table 78
Advertising in Local Newspapers
by Selected Demographics

	Group	Percentage responding		
		Untrust-worthy (1-2)	(3)	Trust-worthy (4-5)
Age of respondent				
18 to 45	City	-	-	-
	Other*	31.6	21.1	47.4
46 to 60	City	-	-	-
	Other	60.0	13.3	26.7
61 or older	City	-	-	-
	Other	25.0	40.0	35.0
Gender				
Female	City	-	-	-
	Other*	27.8	31.5	40.7
Male	City	-	-	-
	Other	54.3	20.0	25.7

* The difference between demographic groups was statistically significant at the p<.05 level.

Table 78
Advertising in Local Newspapers
by Selected Demographics (continued)

Education				
High school or less	City***	26.1	22.5	51.4
	Other**	17.9	35.7	46.4
Some college/technical school	City	31.0	24.1	44.9
	Other	31.3	28.1	40.6
College or more	City	34.7	36.1	29.2
	Other	65.6	17.2	17.2
Income				
$25,000 or less	City	-	-	-
	Other*	9.5	33.3	57.1
$25,001 to $50,000	City	-	-	-
	Other	41.7	25.0	33.3
$50,001 to $75,000	City	-	-	-
	Other	31.6	36.8	31.6
Over $75,000	City	-	-	-
	Other	65.0	15.0	20.0
Work site				
Work near the lake	City*	24.5	36.3	39.2
	Other	-	-	-
Commute to another city	City	36.7	20.4	42.9
	Other	-	-	-

News features on television

- Forty-one percent of all respondents rated news features on television as trustworthy. The average score was 3.20.
- Among Whitney respondents, 47.7 percent of female respondents and 35.8 percent of male respondents rated news features on television as trustworthy (see Table 79).

Table 79
News Features on Television
by Selected Demographics

	Group	Percentage responding		
		Untrust-worthy (1-2)	(3)	Trust-worthy (4-5)
Gender				
Female	City**	19.3	33.0	47.7
	Other	-	-	-
Male	City	30.7	33.5	35.8
	Other	-	-	-

* The difference between demographic groups was statistically significant at the p<.05 level.
** The difference between demographic groups was statistically significant at the p<.01 level.
*** The difference between demographic groups was statistically significant at the p<.001 level.

Advertising on television

- Forty-seven percent of all respondents rated advertising on television as untrustworthy. The average score was 2.58.
- Among Whitney respondents, the percentage of respondents who rated advertising on television as untrustworthy increased as the age of the respondent and income increased (see Table 80).
- Among Other respondents, untrustworthiness of advertising on television was higher among male respondents than female respondents.

Table 80
Advertising on Television
by Selected Demographics

	Group	Percentage responding		
		Untrust-worthy (1-2)	(3)	Trust-worthy (4-5)
Age of respondent				
18 to 45	City**	38.8	29.5	31.7
	Other	-	-	-
46 to 60	City	41.4	38.2	20.4
	Other	-	-	-
61 or older	City	55.0	29.2	15.8
	Other	-	-	-
Gender				
Female	City	-	-	-
	Other**	38.5	42.3	19.2
Male	City	-	-	-
	Other	71.4	25.7	2.9
Income				
$25,000 or less	City**	39.3	36.8	23.9
	Other	-	-	-
$25,001 to $50,000	City	37.0	34.8	28.3
	Other	-	-	-
$50,001 to $75,000	City	52.7	34.1	13.2
	Other	-	-	-
Over $75,000	City	57.4	25.0	17.6
	Other	-	-	-

** The difference between demographic groups was statistically significant at the p<.01 level.

News features on radio

- Thirty-five percent of all respondents rated news features on television as trustworthy. The average score was 3.07.
- Among Other respondents, the percentage of the respondents who rated news features on radio as trustworthy varied with the age of the respondents and was higher among respondents age 46 to 60 (see Table 81).

Table 81
News Features on Radio
by Selected Demographics

	Group	Percentage responding		
		Untrust-worthy (1-2)	(3)	Trust-worthy (4-5)
Age of respondent				
18 to 45	City	-	-	-
	Other*	15.8	63.2	21.1
46 to 60	City	-	-	-
	Other	48.3	44.8	6.9
61 or older	City	-	-	-
	Other	30.8	38.5	30.8

Advertising on radio

- Forty-five percent of all respondents rated advertising on radio as untrustworthy. The average score was 2.64.
- Among Whitney respondents, the percentage of respondents who rated advertising on radio as untrustworthy increased as education and income increased (see Table 82).

Table 82
Advertising on Radio
by Selected Demographics

	Group	Percentage responding		
		Untrust-worthy (1-2)	(3)	Trust-worthy (4-5)
Education				
High school or less	City***	35.3	27.2	37.5
	Other	-	-	-
Some college/technical school	City	42.2	38.3	19.5
	Other	-	-	-
College or more	City	52.8	29.6	17.6
	Other	-	-	-

* The difference between demographic groups was statistically significant at the p<.05 level.
*** The difference between demographic groups was statistically significant at the p<.001 level.

Table 82
Advertising on Radio
by Selected Demographics (continued)

	Group	Percentage responding		
		Untrust-worthy (1-2)	(3)	Trust-worthy (4-5)
Income				
$25,000 or less	City**	36.0	28.0	36.0
	Other	-	-	-
$25,001 to $50,000	City	43.1	33.6	23.4
	Other	-	-	-
$50,001 to $75,000	City	43.8	39.3	16.9
	Other	-	-	-
Over $75,000	City	55.2	30.5	14.3
	Other	-	-	-

County extension agents

- Sixty-three percent of all respondents rated information from county extension agents as trustworthy. The average score was 3.69.
- Among Whitney respondents, trustworthiness of information from county extension agents increased as the age of the respondent increased (see Table 83).

Table 83
County Extension Agents
by Selected Demographics

	Group	Percentage responding		
		Untrust-worthy (1-2)	(3)	Trust-worthy (4-5)
Age of respondent				
18 to 45	City*	16.5	27.2	56.3
	Other	-	-	-
46 to 60	City	21.3	19.3	59.3
	Other	-	-	-
61 or older	City	18.1	13.9	68.1
	Other	-	-	-

* The difference between demographic groups was statistically significant at the p<.05 level.
** The difference between demographic groups was statistically significant at the p<.01 level.

Information in water, sewer and utility bills

- Fifty-three percent of all respondents rated information in their water, sewer and utility bills as trustworthy. The average score was 3.45.
- Among Whitney respondents, the percentage who rated the information in their water, sewer and utility bills as trustworthy decreased as length of residence increased and was higher among female respondents (see Table 84).

Table 84
Information in Water, Sewer, Utility Bills
by Selected Demographics

	Group	Percentage responding		
		Untrust-worthy (1-2)	(3)	Trust-worthy (4-5)
Gender				
Female	City***	15.7	27.5	56.8
	Other	-	-	-
Male	City	31.6	20.8	47.6
	Other	-	-	-
Length of residence				
0 to 5 years	City*	17.5	20.2	62.3
	Other	-	-	-
6 to 10 years	City	22.9	22.9	54.3
	Other	-	-	-
11 to 20 years	City	20.2	27.4	52.4
	Other	-	-	-
21 to 35 years	City	31.9	20.2	47.9
	Other	-	-	-
36 years or more	City	21.8	38.2	40.0
	Other	-	-	-

Government publications

- Forty-five percent of all respondents rated information from government publications as trustworthy. The average score was 3.21.
- There were no statistically significant differences among demographic groups.

Local government

- Forty-three percent of all respondents rated information from their local government as trustworthy. The average score was 3.20.
- Among Whitney respondents, trustworthiness of information from their local government varied with education and employment status (see Table 85).
- Among Other respondents, trustworthiness of information from their local government varied with income.

* The difference between demographic groups was statistically significant at the $p<.05$ level.
*** The difference between demographic groups was statistically significant at the $p<.001$ level.

Table 85
Your Local Government
by Selected Demographics

	Group	Percentage responding		
		Untrust-worthy (1-2)	(3)	Trust-worthy (4-5)
Education				
High school or less	City*	26.4	23.6	50.0
	Other	-	-	-
Some college/technical school	City	31.9	34.4	33.8
	Other	-	-	-
College or more	City	25.2	28.2	46.5
	Other	-	-	-
Employment status				
Employed	City*	25.4	26.4	48.3
	Other	-	-	-
Unemployed/Student/Homemaker	City	22.8	45.6	31.6
	Other	-	-	-
Retired	City	30.4	26.2	43.5
	Other	-	-	-
Income				
$25,000 or less	City	-	-	-
	Other**	33.3	33.3	33.3
$25,001 to $50,000	City	-	-	-
	Other	26.1	13.0	60.9
$50,001 to $75,000	City	-	-	-
	Other	10.5	68.4	21.1
Over $75,000	City	-	-	-
	Other	30.0	15.0	55.0

Government websites

- Forty-five percent of all respondents rated information on government websites as trustworthy. The average score was 3.17.
- There were no statistically significant differences among demographic groups.

Billboards

- Fifty-seven percent of all respondents rated information on billboards as untrustworthy. The average score was 2.34.
- Among Whitney respondents, trustworthiness of information on billboards decreased as education increased (see Table 86).

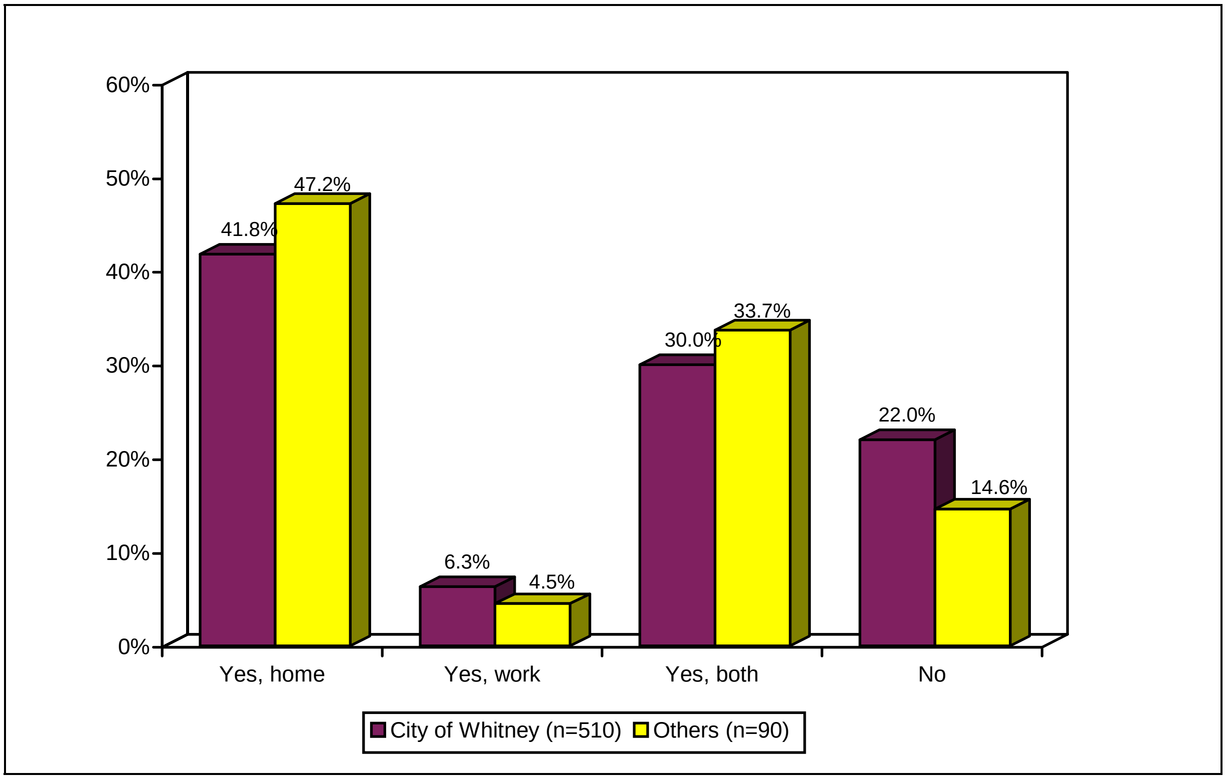
* The difference between demographic groups was statistically significant at the p<.05 level.
** The difference between demographic groups was statistically significant at the p<.01 level.

Table 86
Billboards
by Selected Demographics

	Group	Percentage responding		
		Untrust-worthy (1-2)	(3)	Trust-worthy (4-5)
Education				
High school or less	City*	48.6	26.4	25.0
	Other	-	-	-
Some college/technical school	City	55.8	31.4	12.8
	Other	-	-	-
College or more	City	59.0	27.0	14.0
	Other	-	-	-

* The difference between demographic groups was statistically significant at the p<.05 level.

Figure 19
Access to Internet from Home or Work



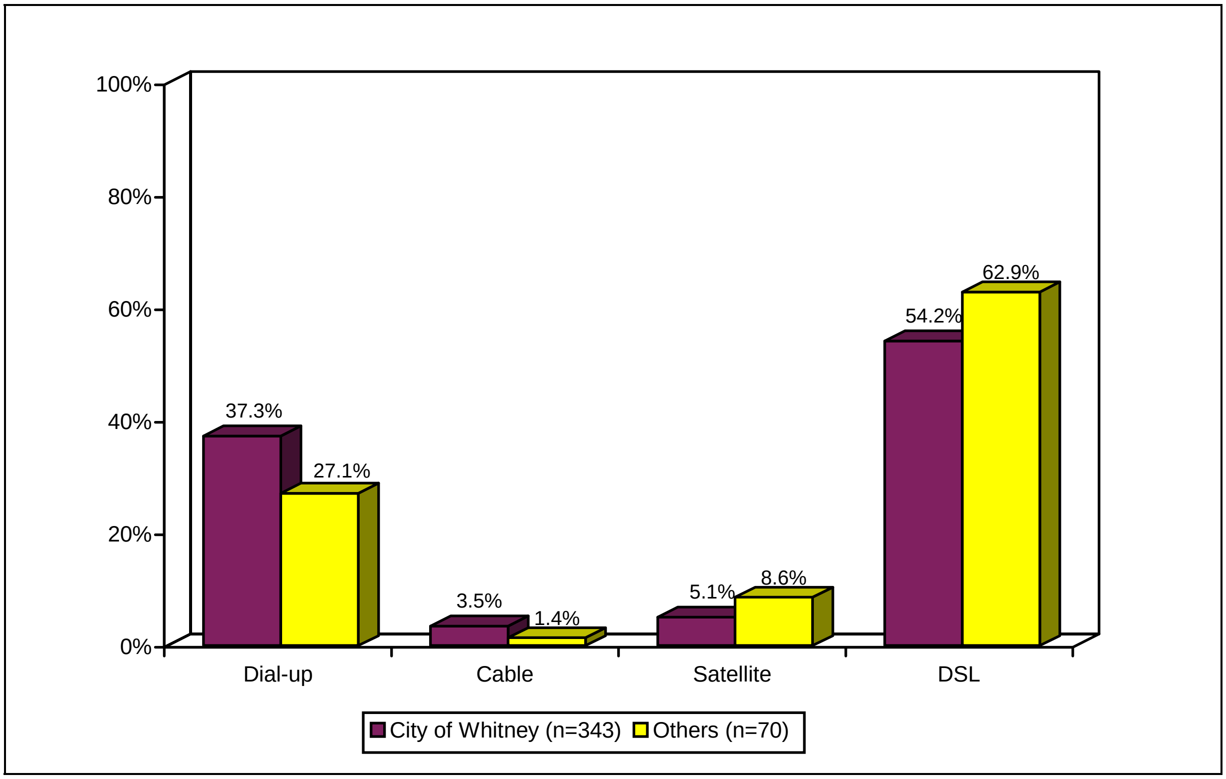
- Respondents were asked if they had Internet access from their home or work place. As shown in Figure 19, 41.8 percent of Whitney respondents and 47.2 percent of Other respondents reported having Internet access at home. Access to the Internet at both home and work was reported by 30.0 percent of Whitney respondents and 33.7 percent of Other respondents.
- Among Whitney respondents, the percentage who had Internet at both home and work decreased as the age of the respondent increased, and increased as education and income increased. Access at both home and work was higher among male respondents and employed respondents (see Table 87).

Table 87
Internet Access
by Selected Demographics

	Group	Percentage responding			
		Yes, home	Yes, work	Yes, both	No
Age of respondent					
18 to 45	City***	22.9	12.4	51.4	13.3
	Other	-	-	-	-
46 to 60	City	33.3	9.8	47.1	9.8
	Other	-	-	-	-
61 or older	City	54.6	1.6	10.8	33.1
	Other	-	-	-	-
Gender					
Female	City**	47.4	7.2	25.8	19.6
	Other	-	-	-	-
Male	City	34.2	5.0	35.6	25.1
	Other	-	-	-	-
Education					
High school or less	City***	40.0	4.1	13.1	42.8
	Other	-	-	-	-
Some college/technical school	City	47.5	10.0	27.5	15.0
	Other	-	-	-	-
College or more	City	38.7	4.9	44.1	12.3
	Other	-	-	-	-
Employment status					
Employed	City***	17.2	13.3	60.1	9.4
	Other	-	-	-	-
Unemployed/Student/Homemaker	City	45.8	3.4	23.7	27.1
	Other	-	-	-	-
Retired	City	61.3	1.3	6.7	30.8
	Other	-	-	-	-
Income					
$25,000 or less	City***	45.0	2.5	8.3	44.2
	Other	-	-	-	-
$25,001 to $50,000	City	45.4	9.9	27.7	17.0
	Other	-	-	-	-
$50,001 to $75,000	City	35.2	8.8	46.2	9.9
	Other	-	-	-	-
Over $75,000	City	38.0	5.6	51.9	4.6
	Other	-	-	-	-

** The difference between demographic groups was statistically significant at the p<.01 level.
*** The difference between demographic groups was statistically significant at the p<.001 level.

Figure 20
Type of Home Internet Access



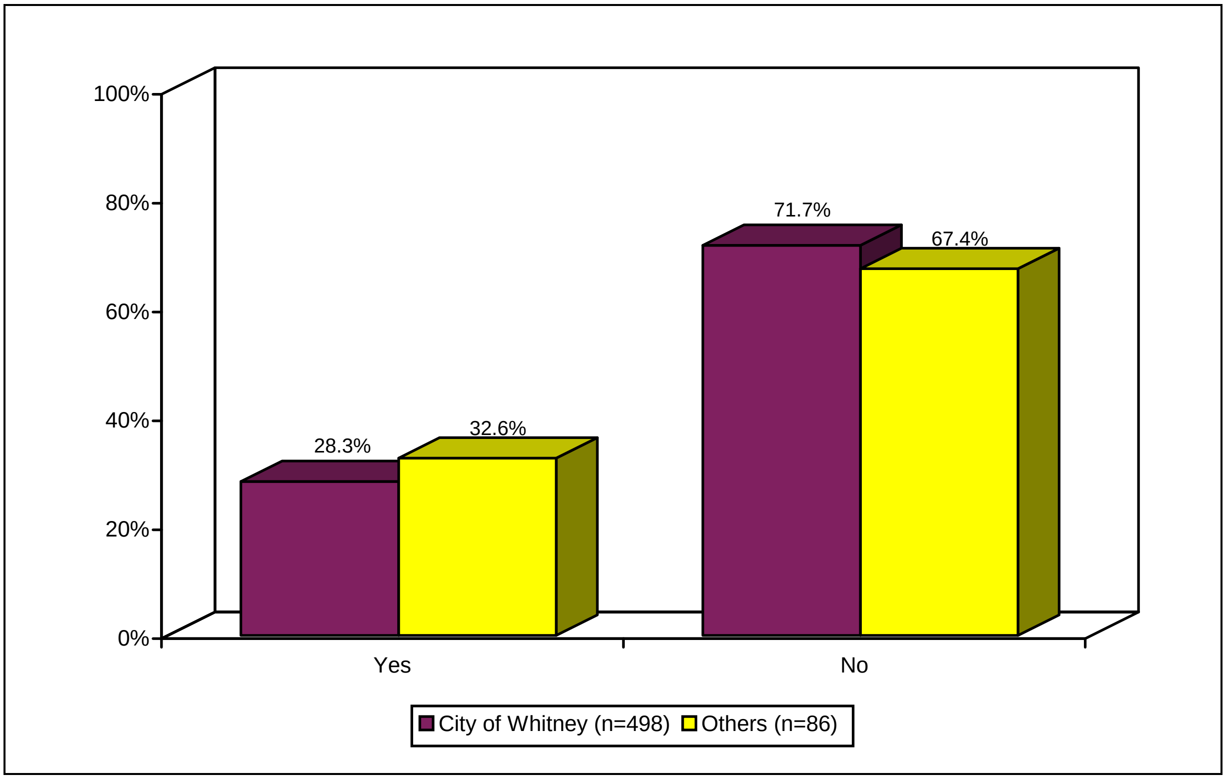
- Respondents who had Internet access at home were asked what type of access they had. As shown in Figure 20, a majority of Whitney (54.2 percent) and Other respondents (62.9 percent) reported using DSL to access the Internet at home.
- Among Whitney respondents, usage of DSL to access the Internet at home decreased as the age of the respondent increased, and was higher among unemployed/student/ homemaker respondents. Retired respondents were more likely to use a dial-up connection than respondents of other employment status (see Table 88).

Table 88
Type of Internet Access
by Selected Demographics

	Group	Percentage responding			
		Dial-up	Cable	Satellite	DSL
Age of respondent					
18 to 45	City*	26.7	5.3	2.7	65.3
	Other	-	-	-	-
46 to 60	City	34.7	2.5	2.5	60.2
	Other	-	-	-	-
61 or older	City	44.3	3.4	8.1	44.3
	Other	-	-	-	-
Employment status					
Employed	City*	33.3	4.7	2.0	60.0
	Other	-	-	-	-
Unemployed/Student/Homemaker	City	29.3	2.4	4.9	63.4
	Other	-	-	-	-
Retired	City	43.9	2.7	8.1	45.3
	Other	-	-	-	-

* The difference between demographic groups was statistically significant at the p<.05 level.

Figure 21
Know the Purpose of the Study



- Finally, all respondents were asked if they were aware or had heard, prior to the interview, that researchers from Baylor were studying Lake Whitney. Twenty-eight percent of Whitney respondents and 32.6 percent of Other respondents answered "yes" (see Figure 21).
- Respondents who answered "yes" were asked if they knew the purpose of the study. Table 89 shows the responses given by these respondents. Forty-six percent of Whitney respondents indicated that the purpose was to use Lake Whitney as a source of drinking water. Fifty percent of Other respondents reported that the purpose was either to study the algae (25.0 percent) or the saltiness of the lake/desalinization (25.0 percent).

Table 89
Know Purpose of Study

	Percentage responding	
	City of Whitney (n=140)	Others (n=28)
Use Lake Whitney as source of drinking water	45.7	14.3
Algae	16.4	25.0
Study water quality	14.3	25.0
Saltiness/desalinization	7.1	0.0
Water conservation	4.3	21.4
Clean up water	3.6	7.1
A city project	2.9	0.0
Educate public about water/environment	2.1	0.0
Commercial project	1.4	3.6
Something about water	1.4	0.0
Building a treatment plant	0.7	3.6

V. CONCLUSIONS

The Lake Whitney Survey 2007 conducted by the Survey Research Center at the University of North Texas was based on interviews with 510 respondents who lived in the City of Whitney and 90 respondents who lived in the cities of Blum, Morgan, Clifton, and Laguna Park about water issues and concerns in the Lake Whitney area. The findings reveal that both City of Whitney respondents and respondents living in other area cities were fairly knowledgeable about the various water issues and concerned about the current environmental conditions pertaining to water quality and availability. In many cases there were no significant differences between the responses of City of Whitney respondents and those of the respondents who lived in the area surrounding Lake Whitney.

Over three-quarters of Whitney and Other respondents reported using water conservation techniques such as usage of 1.5 gallon toilets and low-flow shower heads. Over half reported using xeriscaping or low-water grasses and plants to conserve water. About one-third reported collecting and storing rain water for outside watering. A high percentage of both Whitney (70.4 percent) and Other respondents (76.1 percent) watered their lawn during the summer. Whitney respondents who watered their lawn watered an average 2.24 days per week while Other respondents averaged 2.08 days per week. Approximately one-third of respondents who watered used a sprinkler system. Roughly 40 percent watered by hand. About 60 percent of both Whitney and Other respondents were interested in learning more about water conservation techniques.

Whitney and Other respondents generally agreed about the major or moderate business and local government contributors to water pollution (in descending order of contribution): agricultural use of pesticides and fertilizers, sanitary sewer overflows, waste from agriculture/dairy farms, soil erosion off farm lands, industrial waste, storm water runoff from city streets and parking lots, and soil erosion from construction sites. Major or moderate contributors related to individual citizen activities were: litter and trash, improper disposal of household hazardous waste, improper disposal of automobile oil and antifreeze, use of fertilizers and pesticides for lawns in residences, and not picking up after pets.

The top concern about water issues for Whitney (average score of 7.68 where a score of 10.0 indicates extreme concern) and Other respondents (7.82) was drought or lack of rain. Whitney (6.68) and Other respondents (7.10) were extremely concerned about drinking water quality. Golden algae (Whitney-7.90, Others-8.25) and clean water for fish and wildlife (Whitney-7.70, Others-8.28) were of moderate to extreme concern while the saltiness of the lake (5.64-Whitney, 5.96-Others) was of moderate concern. Both groups (Whitney-6.66; Other-6.96) of respondents expressed concern regarding water pollution. Using the average scores as a guide, Other respondents reported more concern than Whitney respondents on most environmental issues mentioned.

Eighty-six percent of Whitney respondents and 88.9 percent of Other respondents rated the water quality of Lake Whitney area streams, rivers and reservoirs either good or fair. One quarter (24.8 percent-Whitney) or less (19.5 percent-Other) reported that the water quality in their area had improved over the past five years. Both Whitney and Other respondents reported that the state government had the most responsibility for maintaining the water quality in area streams and reservoirs; the federal government was said to have the least amount of responsibility. Over three-quarters of both Whitney and Other respondents indicated that local and county governments should place a high priority on protecting their regional water resources.

Approximately two-thirds of both Whitney (67.8 percent) and Other respondents (69.2 percent) reported support for using Lake Whitney to supply drinking water for the region. Thirty percent of Whitney respondents and 28.0 percent of Other respondents who did not support it gave questionable water quality or water pollution as their reason. About half of Whitney and Other respondents reported that using Lake Whitney as a drinking water source would likely negatively affect lake recreation usage and would increase residential development around the lake. About two-thirds of all respondents indicated it was unlikely that using Lake Whitney as a source of drinking water would improve their quality of life.

When respondents were asked to rank their level of concern about water issues if treated water from Lake Whitney was offered to their household through a local utility company, golden algae was their top concern (7.78-Whitney, 8.07-Others). Following golden algae was cost, pollution, safety of drinking water and saltiness of water. For each issue mentioned, the average score of concern was higher among Other respondents than Whitney respondents. Female respondents expressed more concern than male respondents about these water issues.

The top concern about environmental issues for Whitney (average score of 7.90 where a score of 10.0 indicates extreme concern) was golden algae in Lake Whitney while the top concern for Other respondents (8.28) was clean water for fish and wildlife. Water supplies to meet the future needs of the region was an extreme concern for both Whitney (7.27) and Other respondents (7.81). Both groups (Whitney-7.00; Other-7.20) of respondents expressed concern regarding the taste and/or odor of their drinking water. Using the average scores as a guide, Other respondents reported more concern than Whitney respondents on all water issues mentioned.

While there were similarities, there were differences also between the Whitney and Other respondents. A greater percentage of Whitney respondents reported purchasing their water from a supplier, while a larger percentage of Other respondents reported their supplier got their water from a private well. Other respondents were more likely than Whitney respondents to consider waste from agriculture/dairy farms and soil erosion off farms to be a major or moderate contributor to local water pollution. On the other hand, a larger percentage of Whitney than Other respondents reported that not picking up after pets was a major or moderate contributor to local water pollution.

Newspapers followed by television were respondents' most common sources of information about local issues. Trustworthiness of information sources was higher for county extension agents (average score of 3.69 on a score of 5 indicates trustworthiness), news articles in local newspapers (3.68), and information in water/sewer/utility bills (3.45). Government publications (3.21) and local government (3.20) were moderately trustworthy. Advertising on billboards (2.34), television (2.58), and radio (2.64) were deemed untrustworthy. Forty-two percent of Whitney respondents and 47.2 percent of Other respondents reported having Internet access at home. Access to the Internet at both home and work was reported by 30.0 percent of Whitney respondents and 33.7 percent of Other respondents.

Approximately one-quarter of both Whitney and Other respondents moved to or lived in the Lake Whitney area because of its rural atmosphere or to get out of the city. Aspects of Lake Whitney that were important to respondents' quality of life were (in descending order) wildlife, scenic views, impact on local businesses, lake-related businesses, tourism, swimming, fishing, and boating.

Twenty-eight percent of Whitney respondents and 32.6 percent of Other respondents reported knowing the purpose of this study. Nearly half of those Whitney respondents indicated the study was about using Lake Whitney as a source of drinking water. Fifty percent of the Other respondents said the study was about either algae (25.0 percent) or water quality (25.0 percent).

This survey has several limitations. First, the survey provides a representative sample of households with listed telephone numbers within the Lake Whitney area. The survey does not include households without a listed telephone number or with no telephone. In many surveys, it is assumed that responses among households with listed and unlisted phone numbers would be similar. However, since the Lake Whitney area includes seasonal residences, it is reasonable to assume that many of the unlisted households may, in fact, be seasonal residences without landline telephone service. The survey may therefore under represent respondents living in seasonal housing units. Second, the small number of “Other” respondents make the responses from this segment less rigorous than those of the City segment. Third, while the report describes the findings of the survey, the meaning of those findings and strategies to be followed are left to the primary research team. On the other hand, the report does include enough responses overall to offer a good understanding of public knowledge and sentiment regarding water use issues of residents in the Lake Whitney area.

In conclusion, while two-thirds of both Whitney and Other respondents reported support for using Lake Whitney to supply drinking water for the region, concerns were raised about cost, drought and low lake levels, water pollution, drinking water quality, golden algae, saltiness of the water, and the impact on local wildlife if the lake became a source of drinking water. Two-thirds did not believe that using Lake Whitney as a drinking water source would improve their quality of life.

APPENDIX A: SURVEY INSTRUMENT

2007 Lake Whitney Survey

Hello, my name is _____________ from University of North Texas Survey Research Center. I am not selling anything; we are conducting a survey on area water issues.

S1 INTERVIEWER: IF THE RESPONDENT IDENTIFIES THEMSELVES AS A BUSINESS, ASK:

Is this business also your place of residence (or your home)?
1. YES, RESIDENCE ALSO (CONTINUE)
2. NO, BUSINESS ONLY (TERMINATE INTERVIEW)

I need to speak to someone over the age of 18. We are trying to learn what people know about water issues, and to understand where people are most likely to get information about water quality. Your participation is voluntary. Your responses to our questions will be reported only as percentages so your individual answers will remain confidential. The survey will take about 10 to 15 minutes to complete. This project has been approved by the UNT Institutional Review Board. If you have any questions about the study you may call 800-687-7055.

1. If I ask you to think about water, what is the first thing that comes to your mind?

(DO NOT READ RESPONSES)
1. NEED CLEAN WATER SUPPLY
2. WATER POLLUTION
3. LAKE WHITNEY
4. LAKE WHITNEY HAS A LOW WATER LEVEL
5. OTHER SPECIFIC BODIES OF WATER (LAKES/RIVERS)
6. LACK OF WATER SUPPLY
7. GOVERNMENT PROGRAMS
8. OTHER, SPECIFY
9. NR/DK

2. Do you live in a watershed?

Yes ---1 **[ASK Q3]**
No --2 **[SKIP TO Q4]**
Don't Know ---9 **[SKIP TO Q4]**

3. If yes, can you name your watershed? **[RECORD VERBATIM]**

____

4. Using a scale from 1 to 10 with 1 being no concern and 10 being extremely concerned, what level of concern would you say have about each of the following environmental issues ***in the Lake Whitney area*?**

	No Concern — Extremely Concerned
a. Poor air quality	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9– 10
b. Trash/litter	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9– 10
c. Water pollution	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9– 10
d. Urban sprawl	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9– 10
e. Loss of wildlife habitat	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9– 10
f. Loss of open land to housing or business developments	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9– 10
g. Loss of Trees	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9– 10
h. Drought or lack of rain	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9– 10
i. Drinking water quality	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9– 10
j. Traffic	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9– 10

Landscaping

5. The next set of questions address the ways you maintain the landscape outside around your property. Do you use fertilizers and/or pesticides on your yard, garden, farm or ranch?
   1. Yes
   2. Sometimes
   3. No - SKIP TO Q9
   9. DK/NR

6. How do you get rid of excess lawn, garden or farm chemicals and their containers?
   1. STORE IN THE GARAGE
   2. THROW AWAY IN THE TRASH CAN
   3. POUR INTO THE TOILET OR SINK
   4. POUR OUTSIDE (EX: DRIVEWAY, STORM WATER DRAIN, CURB ETC.)
   5. BRING TO ORGANIZED HAZARDOUS WASTE COLLECTION LOCATIONS
   6. OTHER [SPECIFY]
   9. DK/NR

7. Do you try to apply fertilizers and chemicals on your lawn or around your home just before a rain?
   1. Yes
   2. Sometimes
   3. No - SKIP TO Q9
   9. DK/NR

8. Do you water your lawn during the summer?
   1. YES
   2. NO – (SKIP TO Q12)
   3. DON'T HAVE A LAWN (SKIP TO Q12)
   9. DK/NR

9. Do you have a sprinkler system, water by hand or use another type of sprinkler?
   1. Sprinkler/irrigation system
   2. Water by hand (holding a hose, using a watering can)
   3. Other sprinkler (manual sprinkler that hooks up to a hose, or leaving the hose running by itself)
   9. DK/NR

10. On average, how many days a week do you water your lawn during the summer?
   ___ Days

Waste Water and Water Supply

12. Is your home served by a municipal sewer system or do you have your own septic system?
   1. SEWER SYSTEM
   2. OWN SEPTIC SYSTEM
   3. SHARED SEPTIC SYSTEM
   4. NOT SURE
   9. DK/NR

13. Do you know what happens to the water after it has been treated by the sewage [treatment plant/septic system]? Would you say . . .
   1. Definitely
   2. I think I know
   3. Not sure
   9. DK/NR

14. (ASK IF Q12 EQ 2-3) Do you think water exiting your septic system could be used or should not be used for watering your landscape?
   1. Could be used
   2. Should not be used (SKIP TO Q16)
   9. Don't Know (SKIP TO Q16)

15. Do you use water exiting your septic system to water your landscape?
   1. YES
   2. NO
   9. DK/NR

16. Do you have a private well or do you purchase your water from a supplier?
   1. PRIVATE WELL (SKIP TO Q19)
   2. SHARED WELL (DO NOT PURCHASE WATER) (SKIP TO Q19)
   3. PURCHASE WATER
   9. DK/NR

   17. Do you know where your water supplier gets the water you purchase?
      1. YES
      2. NO (SKIP TO Q19)
      9. NR/DK

18. What is that source? DO NOT READ RESPONSES
    1. LAKE WHITNEY
    2. A WELL
    3. OTHER (SPECIFY)____________________
    9. NR/DK

19. Do you know what storm water runoff is?
    1. Yes - Go to Q20
    2. No - Skip to Q21
    9. DK/NR - Skip to Q21

20. Does your area wastewater treatment plant treat storm water?
    1. Yes
    2. No
    9. DK/NR

21. Some have considered treating the water in Lake Whitney to supply drinking water for the region. Would you support or not support using Lake Whitney to supply drinking water for the region?
    1. Support (SKIP TO Q23)
    2. Not support
    9. DK/NR

Q22. Why would you not support this idea? ___________________________

23. If Lake Whitney were used as a regional source of drinking water, do you think it would very likely, somewhat likely, somewhat unlikely, or very unlikely that it would . .

	Very Likely	Somewhat Likely	Somewhat Unlikely	Very Unlikely	DK/NR
a. negatively affect lake recreation usage	1	2	3	4	9
b. increase residential development around the lake	1	2	3	4	9
c. improve your quality of life	1	2	3	4	9

24. If treated water from Lake Whitney was offered to your household through a local utility company, how concerned would you be about each of the following items? Use a scale of 1 to 10 where 1 is "not concerned" and 10 is "extremely concerned."

	No Concern — Extremely Concerned	DK/NR
1. Safety of drinking the water	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9– 10	9
2. Saltiness of water	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9– 10	9
3. Pollution	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9– 10	9
4. Golden algae	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9– 10	9
5. Cost	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9– 10	9

25. The following questions are not only about drinking water, but water issues in general. Using a scale from 1 to 10 with 1 being no concern and 10 being extremely concerned, what level of concern would you say you have about the following water issues ***in Lake Whitney area?***

	No Concern / Extremely Concerned	DK/NR
a. Personal health concerns about clean drinking water	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9– 10	9
b. Saltiness of the water in Lake Whitney	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9– 10	9
c. Water supplies to meet future needs of the region	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9– 10	9
d. Golden algae in Lake Whitney	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9– 10	9
e. Clean water for fish and wildlife	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9– 10	9
f. Swimming in Lake Whitney	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9– 10	9
g. Eating fish from Lake Whitney	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9– 10	9
h. Taste and/or odor of your drinking water	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9– 10	9

Pollution

26. For the following please tell me how much you feel each is a contributing factor to local water pollution. Would you say …………………… is a major contributor, a moderate contributor, a minor contributor or is not at all a contributor to water pollution in this area?
(ROTATE LIST)

	Major	Moderate	Minor	Not at all	DK/NR
a. Industrial waste	1	2	3	4	9
b. Improper disposal of automobile oil and antifreeze	1	2	3	4	9
c. Agricultural use of pesticides and fertilizers	1	2	3	4	9
d. Use of fertilizers and pesticides for lawns in residences	1	2	3	4	9
e. Improper disposal of household hazardous waste (paints, cleaners, etc.)	1	2	3	4	9
f. Litter and trash	1	2	3	4	9
g. Not picking up after pets	1	2	3	4	9
h. Sanitary sewer overflows	1	2	3	4	9
i. Storm water runoff from city streets and parking lots	1	2	3	4	9
j. Soil erosion from construction sites	1	2	3	4	9
K. Soil erosion off farm lands	1	2	3	4	9
L. Waste from agriculture or dairy farms	1	2	3	4	9

27. In general, do you think that the water quality of the streams, rivers and reservoirs in and around Lake Whitney is : **[READ LIST]**
Excellent--1
Good---2
Fair---3
Poor--4
[DON'T READ] DK/NA/Refused ---9

28. Over the past five years, do you think the quality of water in your area has improved?
Yes-- 1
No--2
[DON'T READ] DK/NA/Refused ---9

Quality of Life

29. What was the main reason you live or moved to the Lake Whitney area?
    1. BORN HERE
    2. RURAL ATMOSPHERE
    3. LOW POPULATION
    4. LAKE WHITNEY
    5. LAKE RECREATION
    6. OTHER (SPECIFY)______________________________
    9. NR/DK

30. Considering your own quality of life, how important are the following aspects of Lake Whitney to you?

	Very Important	Somewhat Important	Somewhat unimportant	Very unimportant	DK/NR
a. Boating	1	2	3	4	9
b. Fishing	1	2	3	4	9
c. Scenic views	1	2	3	4	9
d. Swimming	1	2	3	4	9
e. Wildlife	1	2	3	4	9
f. Tourism	1	2	3	4	9
g. Lake-related businesses	1	2	3	4	9
h. Impact on local businesses	1	2	3	4	9

Information

31. Of the following which would you say has the **MOST** responsibility for maintaining the water quality in our area streams, rivers and reservoirs.
    1. Federal government
    2. State government
    3. County and City governments
    4. Business and industry
    5. Farmers and ranchers
    6. Individuals
    9. DK/NR

32. Now, of the list I just read which would you say has the **SECOND MOST** responsibility for maintaining the water quality in our area streams and reservoirs.
    1. Federal government
    2. State government
    3. County and City governments
    4. Business and industry
    5. Farmers and ranchers
    6. Individuals
    7. NO ONE ELSE (DO NOT READ AS AN OPTION)
    9. DK/NR

33. Of the following which would you say has the **LEAST** responsibility for maintaining the water quality in our area streams and reservoirs?
    1. Federal government
    2. State government
    3. County and City governments
    4. Business and industry
    5. Farmers and ranchers
    6. Individuals
    9. DK/NR

34. Should our local and county governments place a high, medium, low or no priority on protecting Lake Whitney?
    1. High
    2. Medium
    3. Low
    4. No priority
    9. DK/NR

35. What news or information source are you most likely to use to get important information about local issues? I'm going to read seven sources to you. Please tell me which one you are most likely to use to get important information. Which is the next most important? The next most important? Any others? Any others? (CONTINTUE UNTIL NO MORE ARE NAMED)

    [READ AND ROTATE]

    a. Television
    b. Internet
    c. Radio
    d. Newspaper
    e. Magazines
    f. From Friends neighbors or family
    g. Through local schools
    h. Through local churches
    i. Local government cable TV, info inserts in bills, etc.

36. Consider your level of trust in the following sources of information. On a scale of 1 to 5 where 1 is untrustworthy and 5 is trustworthy, how would you rate the following **SOURCES** to deliver information on environmental issues?

[READ AND ROTATE]

a. News articles in local newspapers
b. News features on radio
c. News features on TV
d. Advertising on TV
e. Advertising on radio
f. Advertising in local newspapers
g. Government websites
h. Government publications
i. Billboards
j. Your local government
k. Information in your water, sewer and utility bills
l. County extension agents (Explanation: Do not read unless asked) Each county has a team of educators to assist citizens learn agricultural practices, horticultural techniques and ways to protect the environment run by the TA&M Extension Service.

37. Do you use any of the following water conservation techniques?

	Yes	No	DK/NR
a. Low-flow shower heads	1	2	9
b. 1.5 gallon toilets	1	2	9
c. Collect and store rain water for outside watering	1	2	9
d. use of xeriscaping or low-water grasses and plants	1	2	9

38. Would you be interested in learning more about water conservation techniques?
1. YES
2. NO
9. DK/NR

Now for the last few questions I would like to ask you several things about yourself.

39. Into which of the following age groups do you fall?
1. 18-25
2. 26-35
3. 36-45
4. 46-60
5. 61 and over
9. NR/DK

40. Do you consider yourself to be White, Black, Hispanic, Asian, American Indian or something else?
    1. White
    2. Black
    3. Hispanic/Latino/Latino
    4. Asian
    5. American Indian
    6. Other, specify:
    9. NR/DK

41. What language is spoken **MOST** often in your home?
    1. English
    2. Spanish
    3. Two languages spoken equally
    4. Other (Specify)
    9. NR/DK

42. What is the highest level of education you have completed?
    1. Primary or middle school
    2. High school
    3. Some College or Technical School
    4. College
    5. Masters degree or higher
    9. NR/DK

43. Do you have access to the Internet from your home or work?

    1. YES, HOME (ASK Q43a)
    2. YES, WORK (SKIP Q44)
    3. YES, BOTH (ASK Q43a)
    4. NO (SKIP TO Q44)
    9. NR/DK (SKIP TO Q44)

    43a. What form of Internet access do you use at home, dial-up, DSL, cable or satellite?

    1. DIAL-UP
    2. CABLE
    3. SATELLITE
    4. DSL
    9. NR/DK

44. Are you employed fulltime, part time, presently unemployed, retired, or are you a student, or homemaker?
    1. Full-time
    2. Part-time
    3. Unemployed (SKIP TO 46)
    4. Retired (SKIP TO 46)
    5. Student (SKIP TO 46)
    6. Homemaker (SKIP TO 46)
    9. NR/DK (SKIP TO 46)

    45a. Do you work near the lake or do you commute to another city?

1. Work near the lake (SKIP TO 46)
2. Commute to another city
9. NR/DK (SKIP TO 46)

45b. What city?
Waco
Hillsboro
Dallas
Fort Worth
Other ________________
9. NR/DK

46. Do you live in a city or town, or do you live in the country?

1. City or town (ASK 46a)
2. In the country (ASK 46b)
9. NR/DK

46a. Do you live in a house, mobile home, apartment or condominium?
1. HOUSE
2. MOBILE HOME
3. APARTMENT
4. CONDOMINIUM
5. OTHER __________________
9. NR/DK

SKIP TO Q47

46b. Do you live on a farm or a ranch?
1. FARM
2. RANCH
9. NR/DK

47. Is this residence your primary place where you live or is it a second home?
1. PRIMARY
2. SECOND HOME
3. HALF HERE/HALF SOMEWHERE ELSE
4. OTHER (SPECIFY)___________________
9. NR/DK

48. How long have you lived in the Whitney area?

RECORD # of YEARS--_____ ___

49. I am going to read several different income categories. Without telling me your exact income, into which category did your total household income for the past year fall?
    1. Under $10,000
    2. 10,001-25,000
    3. 25,001-50,000
    4. 50,001-75,000
    5. 75,001-100,000
    6. 100,001-150,000
    7. Over 150,000
    9. DK/NR

50. Prior to this phone call, were you aware or had you heard that researchers from Baylor were studying Lake Whitney?
    1. YES
    2. NO
    9. NR/DK

51. Do you know the purpose of the study?
    1. YES (Specify)
    2. NO
    9. DK/NR

TO ALL: Baylor researchers started a water quality study of Lake Whitney in 2006. Scientists from Baylor have been taking measurements of salt and algae levels to understand how the quality of the water changes over time and at different locations in the lake.

THAT IS ALL OF THE QUESTIONS THAT I HAVE FOR YOU TODAY. THANK YOU VERY MUCH FOR YOUR TIME AND HELP IN THIS STUDY. GOODBYE.

INTERVIEWER: RECORD GENDER OF RESPONDENT

Gender: 1. Male
2. Female

APPENDIX B: OPENENDS

Respondents were asked the first thing that came to their mind when they thought of water in their community or rural area.

City of Whitney respondents

(The number in parentheses is the number of times the exact word or phrase was mentioned.)

<u>Water for drinking (bottled or tap)</u>

A drink
A glass of water
Being thirsty
Bottled water (4)
Buying bottled water
Cool something to drink
Dasani
Drinking it
Drink (9)
Drink and bathe
Drink and moisture.
Drink it or use it
Drink only filtered water, out of the tap it has too much chlorine.
Drink water
Drink, clean, alive
Drinking (34)
Drinking and bathing water
Drinking filtered water
Drinking it (5)
Drinking it and taking a bath
Drinking quality
Drinking water (56)
Drinking water and bathing
Drinking it
Fair drinking water
Fresh drinking water
Good drinking water
I drink it (2)
I need a drink (2)
I used to drink it out of a creek, now I have to buy it in a bottle.
Iced tea
Is it drinkable
Quenching thirst
Safe drinking water
Satisfying my thirst
Something that I drink
Something to drink (2)
Tap water
That I'd like to have it
The water I drink
Thirst (3)
Thirsty (12)
To drink

Water that you drink
Water to drink
We drink it
What we drink
Whether she is thirsty or not
You drink it
You get thirsty
You have to drink it

Need clean water supply

Clear (3)
Fresh water (2)
Got good water
If it’s clean
If it's pure
Not polluted water
Pure water (2)
Pure well water
Purity (4)
Quality (2)
Quality of water (2)
Safe
Safety
Safety with drinking
Supply
The good water we have
Water purity (2)
Water quality

Necessary for life/living

A commodity that folks need to use for agricultural and other needs, cleaning, coking, industrial process
Can't do without it (2)
Essence of life
Essential ingredient to livestock
Essential part of life
Everybody needs it
Good for you
Got to have it
Got to have, there's no doubt about it
Have to have it to live
How dependent we are on it
How much we needed
Important commodity
It is absolutely necessary
It is the basis of life
It’s good for you
It’s good when you want it
It's necessary

It's wet and it's essential to life
Just that I couldn't do without it
Life (6)
Necessity
Necessity for life
Nourishment
Precious commodity
Something you have to have
Survival (2)
Surviving
Thought of it as a precious, vital resource
Water is important
What we need for life
You need it to live
You need it to live off of

Lack of water supply

Better come out of that tap when I turn it on
How much longer we will have the supply of drinking water
I hope we don't run out
It's easy to take for granted, but not when we have a drought
Lack of it
Recent restrictions
Scarcity
Water shortage
We don’t have enough of it

Lake Whitney

Beautiful lake, because I live on a "beautiful lake"

Wet/cool/refreshing

Cool and refreshing
Fresh
I like the sound of it
I like water (2)
It's wet
Just water (2)
Liquid
Refreshing (2)
Something wet
That it's wet.
Water (5)
Wet (6)
Wet blue

Taste (good or bad)

Bad water in Waco

Doesn’t taste as good as it use to it
Good tasting
How it tastes
It stinks
It tastes likes toppers
Taste (6)
Taste of water (2)
That it is getting bad.
The taste
Water taste

Specific bodies of water (lakes/rivers)

A bubbling brook
A lake
Aquifer
Good spring water
Lake
Lake Waco
Lakes
Pond behind my house
Reservoirs
The aquifer where we get it from
The ocean
Watershed

Recreation

Boating
Cool swim
Fishing (4)
Going swimming
Scuba diving
Swimming (4)
Swimming and fishing and drinking
Swimming pool
Swimming, taking a bath

Bathing/cleaning

A good hot bath
Bathing
Bathtub
Clothes
Doing dishes
Shower (3)
Taking a bath
Used to clean
Washing dishes, take a bath, drinking
Washing or drinking
Wet, wash, bathe, drinking

Availability/abundance of water

Abundance
Availability (5)
Availability of it
Demand for it
Plentiful and clear
That I have plenty to suit my needs
Water need

Cost

Cost
Cost of water to water the yard
Expensive
Have to buy it
How expensive its gotten
My bill
Prices and scarcity
The best thing we have that doesn't cost us much money right now
Too expensive
Water bill keeps going up

Supplier/city/service

Hill County water supply
I have good service
Septic tank operations from yard into lake
The faucet
Water comes out of the faucet
Water in my house
Water in the homes
Water scheme
Water tap
Where are future water sources are going to come from
Who is providing it

Rain

Fall out of the sky all night
I grew up on a farm, if you don't get it you're in trouble
Rain (6)

Conservation of water

Conservation
Save it
Smart water use
Wasting water

Water conservation

Chemicals in the water

A lot of times it smells like chlorine
Both the refrigerator and my sink faucet have water filters
How much chlorine is in it
Hydrogen oxygen
It's got chemicals in it

Watering yard/plants

Food
Gardening
Lots of things, water hose
Moisture to keep the ground moving and growing

Health

Health
Health, drinking and bathing
Thyroid/health issues

Well water

My well
Well water
Wells

Water pressure

Water pressure

Water pollution

The dirty water from the sewer lines.

Other

Charity
Convenience
Doesn't like water
E-coli
First
Go to the bathroom
Gratitude
I take it for granted
It ain’t what it use to be
Livelihood
Nothing comes to mind.

Nothing, actually.
Potable water
Use of water
Water pump turns off when it lightnings.

Other respondents

Water for drinking (bottled or tap)

Bottled water (2)
Drinking (4)
Drinking water (10)
I'm thirsty
something to drink (2)
Thirst (2)

Need clean water supply

Fresh and clean
Fresh clear water
Pure
The supply
Water purity

Necessary for life/living

A necessity
Enough to drink
Just can't do without water, we need it for everything
Nourishment
Something you can't live without
Survival (2)
We need it, everything needs it (water)

Lack of water supply

Running out of water
Water restrictions resuming

Wet/cool/refreshing

Beauty

Taste (good or bad)

Taste (4)
Taste of water

Recreation

Fish
Fishing
Swimming

Water skiing

Water pollution

Contamination

Availability/abundance of water

Availability
Plenty of it

Cost

Cost of delivering water
The high price of water

Supplier/city/service

Faucet
Going to Home Depot to get
Water company
Water system
Water that comes out of your faucet

Lake Whitney has a low water level

How far down the lake is

Rain

Rain

Chemicals in the water

Chlorine

Water pressure

Water pressure

Other

Children

Lake Whitney Educational Outreach
DRAFT Final Report

Phase IB

Study Element No. 10b:
Assistance with STEM curricula at the Whitney High School

Prepared for:
USDOE

Prepared by:
Bruce Byars, Baylor University
&
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CRASR

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WHITNEY HIGH SCHOOL

Curtis L. Haley, Principal
Andy Mills, Athletic Director

Sandie Hanks, Asst. Principal
Janis Collins, Counselor
Wendy Wright, Counselor

Date: May 13, 2008

To: STEM Committee

Re: SRD Course Proposal for 2008-2009 School Year

The Scientific Research and Design (SRD) high school science course is designed to accommodate students who perform research in high school under the direction of trained professionals. It is a State approved innovative science course offering a full year credit towards high school graduation. WHS is partnering with Baylor University for the Science, Technology, Engineering, and Mathematics Project. University professors will be working closely with WHS faculty and students in an effort to promote these areas of study for possible career choices (in conjunction with a current Baylor project with Lake Whitney). SRD appears to be the perfect fit for the project that STEM has in mind.

In order to allow adequate time for laboratory and fieldwork requirements for the course curriculum, it seems that a modified block schedule would work best allowing for extra time for student involvement and participation. The Scientific Research and Design class would have to be offered every other day with another higher level course that could include the same students. The teachers that are members of the STEM Committee are T. Williams, B. Pierce, S. Seibel, and M. Coffelt. The SRD class could be offered for a 90 minute block and coincide on the schedule to alternate with Physics, Environmental Systems, AP Biology, and DCP or Horticulture. These courses offer a level of campus diversity that would include a percentage of the at-risk student group.

The assigned time frame for the course would need to be when upper classmen are not involved in athletics or band so they could continue to participate. Perhaps 7th and 8th periods would be ideal, depending upon the other higher level courses that are offered during those periods. (This involves a plan to move the 8th period Varsity Girls athletics period.) 8th period is the last period of the school day; therefore, students would have additional time to complete labs and fieldwork. It is important that the potential SRD students are able to take the other AP/dual credit classes they need for their recommended or distinguished graduation plan and most of these classes are offered in the morning.

The class would be on a modified A/B block schedule. If a student takes SRD during 7th/8th period on MWF , he/she would take either Physics, Environmental Systems, AP Biology, or DCP/Horticulture on TTh. The following week the courses would switch days. The four WHS teachers could divide the SRD class and teaching responsibilities in a way that corresponds to the objectives/goals of the curriculum. Projects for students can either be decided by SRD or by the individual teachers' corresponding course. These are decisions that will be determined by the STEM committee. Further research needs to be conducted on existing programs that offer similar goals and results to aid in establishing curriculum design.

Thank you,

Sandie Hanks, Principal

Scientific Research and Design

The Scientific Research and Design course was designed to accommodate students who perform research in high school under the direction of trained professionals and for the purpose of competing in Science Fairs at the local, regional, state, and national levels. However, this course has grown over the years to also accommodate students enrolled in special programs such as the Texas Pre-freshman Engineering Program or for laboratory time accompanied by an Advanced Placement course. Recently, this course has become a vehicle for innovative or focused study on special topics such as Aerospace, Biotechnology, Forensics, or Visualizations in Space Science courses. It is expected that whatever the course content, students must perform 40% lab time in conjunction with the content. Since this course has three separate PEIMS numbers, it can be taken up to three separate times and used as elective credit.

TEKS for Course:

§121.12. Scientific Research and Design (One Science Credit).

(a) General requirements. The prerequisite for this course is one unit of high school science. To receive credit in science, students must meet the 40% laboratory and fieldwork requirement identified in §74.3(b)(2)(C) of this title (relating to Description of a Required Secondary Curriculum). This course is recommended for students in Grade 11 or 12.

(b) Introduction.

(1) Science is a way of learning about the natural world. Students should know how science has built a vast body of changing and increasing knowledge described by physical, mathematical, and conceptual models, and that science may not answer all questions.

(2) A system is a collection of cycles, structures, and processes that interact. Students should understand a whole in terms of its components and how these components relate to each other and to the whole. All systems have basic properties that can be described in terms of space, time, energy and matter. Change and constancy occur in systems and can be observed and measured as patterns. These patterns help to predict what will happen next and can change over time.

(3) Investigations are used to learn about the natural world through questioning, observing and drawing conclusions. Students should understand that certain types of questions can be answered by investigations, and that conclusions and models built from these investigations change as new observations are made. Models of objects and events are tools for understanding the natural world and can show how systems work. They have limitations and, based on new discoveries, are constantly being changed to more closely reflect the physical world.

(c) Knowledge and skills.

(1) The student conducts laboratory investigations and fieldwork using safe, environmentally appropriate, and ethical practices. The student is expected to:

(A) Demonstrate safe practices during laboratory investigations and fieldwork; and

(B) Make wise choices in the conservation and use of resources and the disposal of materials.

(2) The student identifies scientific methods used during fieldwork and laboratory investigations. The student is expected to:

(A) Plan and implement investigative procedures including asking questions, formulating testable hypotheses, and selecting equipment and technology;

(B) Collect data by observing and measuring in various ways;

(C) Organize, analyze, evaluate, make inferences, and predict trends from data; and

(D) Communicate valid conclusions.

(3) The student uses critical thinking and scientific problem solving to make informed decisions. The student is expected to:

(A) Analyze, review, and critique hypotheses and theories as to their strengths and weaknesses using scientific evidence and information;

(B) Make responsible choices in selecting everyday products and services using scientific information;

(C) Evaluate the impact of research on scientific thought, society, and the environment; and

(D) Gather information about future careers using a variety of sources.

(4) The student knows how to formulate hypotheses to guide experimentation and data collection. The student is expected to:

(A) Perform background research with respect to an investigative problem; and

(B) Examine hypotheses generated to guide a research process, evaluating the merits and feasibility of the hypotheses.

(5) The student knows how to analyze published research. The student is expected to:

(A) Identify the scientific methodology used by a researcher;

(B) Examine a prescribed research design and identify dependent and independent variables;

(C) Evaluate a prescribed research design to determine the purpose for each of the procedures performed; and

(D) Compare the relationship of the hypothesis to the conclusion.

(6) The student knows how to develop and implement investigative designs. The student is expected to:

(A) Interact and collaborate with scientific researchers and/or other members of the scientific community to complete a research project;

(B) Identify and manipulate relevant variables within research situations;

(C) Use a control in an experimental process; and

(D) Design procedures to test hypotheses.

(7) The student knows how to collect, organize, and evaluate qualitative and quantitative data obtained through experimentation. The student is expected to:

(A) Record observations and events as they occur within an investigation;

(B) Acquire, manipulate, and analyze data using equipment and technology;

(C) Construct data tables to organize information collected in an experiment; and

(D) Evaluate data using statistical methods to recognize patterns, trends, and proportional relationships.

(8) The student knows how to synthesize valid conclusions from qualitative and quantitative data. The student is expected to:

(A) Synthesize conclusions supported by research data;

(B) Consider and communicate alternative explanations for observations and results; and

(C) Identify limitations within the research process and provide recommendations for additional research.

(9) The student knows how to communicate conclusions clearly and concisely to an audience of professionals. The student is expected to:

(A) construct charts, tables, and graphs in facilitating data analysis and in communicating experimental results clearly and effectively using technology; and

(B) Suggest alternative explanations from observations or trends evident within the data or from prompts provided by a review panel.

Source: The provisions of this §121.12 adopted to be effective September 1, 1998, 22 TexReg 5014.

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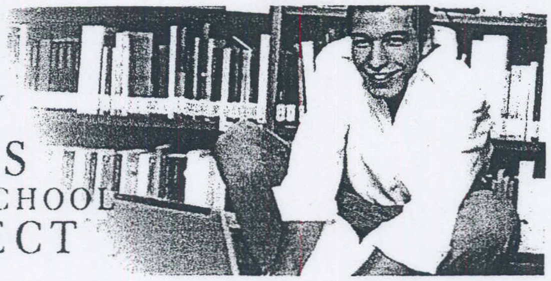
TEXAS HIGH SCHOOL PROJECT



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THSP » Initiatives » T-STEM » T-STEM Network » Weslaco ISD Math & Science Academy

Exemplar: Weslaco ISD Math and Science Academy

Mission & Philosophy | Challenge & History | Strategy | Outcomes | Lessons Learned

of the Project

The Weslaco ISD Science & Math Research Academy is an academic year expansion of the original summer academy that addresses the subjects in the Governor's Cluster category. It is designed to provide a concrete problem-based learning structure throughout the upcoming academic year for our largely Hispanic and economically disadvantaged student population, so that they continue scholarly science, engineering, and mathematics independent research projects with student and teacher mentors. We expect the program to continue to increase the number and quality of projects that compete, place, and continue at regional, state, and international science fairs.

Mission

The exemplar program fits into our school district's newest priority, our High School Redesign Project at our high schools. We have already implemented, and will expand next year, Scientific Research & Design courses at the high school level. These are intended to serve as thematic electives for students in the Health Sciences and Design & Engineering Small Learning Communities, starting in the sophomore year. This exemplar program creatively bridges the gap between middle school and the tenth grade year by providing a structure for students to develop their research skills from a younger age during summers and weekends. The combination of related programs in a carefully planned sequence will highly prepare the participating students for success in undergraduate and graduate science programs, especially research science programs, so that they can be productive members of society who can ultimately increase the number of Hispanics entering STEM professions.

Challenge

This year, we are targeting the current 8th grade students who participated in the program last year, plus a new group of incoming 8th grade students. Each year, we plan to target a new group of students. Our students are almost all Hispanic and are predominantly economically disadvantaged, yet can absolutely and successfully compete with any of their peers statewide based on initial program results at the regional and state science fairs.

Proposed Model for Replication

Replication of this program design and structure at other school districts would be relatively straightforward with the required funding. The expansion of the program described in this proposal provides opportunities for interested visitors to observe the program in action. We welcome and invite visitors to view student research with mentors in the summer and on subsequent Saturdays, as well as attend the fall research symposia where student participants will present formal reports on the progress of their projects and plans for the immediate future. We will utilize our partners at Region One ESC, The University of Texas – Pan American Regional Science Collaborative, Teach For America, Gear-Up, and the Rio Grande Valley Science Association Annual Conference to share best practices and lessons learned.

Expected Outcomes

The long-term objectives of the program include increasing our local population of predominantly Hispanic and economically disadvantaged students actively and successfully engaged in science, mathematics, and engineering research, undergraduate and graduate programs, and professions. Primary measures of program success for students involved in the five-year program include participation and achievement at the regional, state, and international science and engineering fairs; numbers of high school graduates entering college with declared majors or interest in STEM subjects; and numbers of students involved in research opportunities at local research facilities. A broad district-wide objective of the program is to provide a concrete, feasible structure to allow students to develop independent project-based research in middle school that they can then continue throughout high school as they either elect to take Scientific Research & Design classes or are required to do so as thematic electives for those who self-select to be part of the Health Sciences or Design & Engineering Small Learning Communities that are part of our upcoming High School Redesign Project funded in part by Texas High School Project.

Fo Weslaco ISD

Initiative: THSP Exemplar Program

Exemplar Categories:
The Governor's Cluster; Project-Based Learning Category; and Mentoring

Demographics
Total students in district: 16,000
Hispanic: 98%
Caucasian: 1.5%
Asian or African American: .5%
Economically Disadvantaged 87%
LEP: 23%
Bilingual/ESL: 23%

Location
Weslaco ISD is a public school district in Weslaco, Texas located 7 miles north of Mexico. It is located in ESC Region 1 in South Texas along the Texas – Mexico border

 0.25

High School Science Research Intern Partnership

Program Description

The High School Science Research Internship Program is a partnership between the Madison Metropolitan School District (MMSD) and the University of Wisconsin-Madison. Sixteen students from MMSD are partnered with research professors at UW-Madison each summer. The goal of the program is to provide an authentic science research experience for the intern. Each intern develops and researches a question of their own, designs protocols for data collection, and collects data over the course of the summer under the guidance of a professor, degree candidate, postdoctoral candidate or research associate. As the summer ends and during the fall semester, interns write a formal research paper and design a scientific poster. The concluding event of the program is a scientific poster session, which allows the interns to communicate their findings to a larger audience and also to celebrate the completion of their internship with associates from the university, teachers, friends and family.

Program Highlights

Interns will have the opportunity to:

- Participate in science research at the University of Wisconsin-Madison during the summer as a member of a research team
- Design and implement an extensive research project under the supervision of a research scientist
- Earn Credits:
  three quarters of one high school science credit awarded by MMSD
  one credit from UW-Madison awarded and paid by MMSD
  two additional university credits available at student/parent expense
- Learn how to use both high and low tech research tools and technologies
- Meet with other interns and tour their labs during the summer seminars
- Participate in high school research competitions (optional)
- Publish research in a professional journal at the discretion of the professor

Minimum Requirements

- Sophomore or junior status at time of application
- A sincere interest in science and learning science research skills
- Minimum GPA of 3.6
- Availability: a **minimum** of 25 hours per week for 9 weeks
- Attend an informational meeting with a parent/guardian (April)
- Brown bag seminars on campus (June-August)
- Two evening seminars (September and October)
- Complete a formal research paper (September-October)
- Present scientific research poster (November)

Responsibilities

Many people are involved in making the High School Science Research Intern partnership between the University of Wisconsin-Madison and the Madison Metropolitan School District work effectively and meaningfully for all. Some of the responsibilities of those involved are as follows.

High School Interns

- Work in your lab a **minimum** of 25 hours per week for a **minimum** of 9 weeks
- Attend meetings and seminars
- Collect data under the supervision of an assigned mentor
- Periodically meet with the professor/mentor to critique the collected data
- Periodically ask to have the stages of the research paper critiqued
- Complete a formal research paper
- Prepare a scientific poster and present it at the poster session in November
- Stay in contact via email, seminars and phone with the research coordinator

Program Coordinator

- Recruit and select high school students
- Recruit UW faculty to mentor students during the summer
- Register and grade interns for MMSD
- Facilitate strong MMSD/UW partnership
- Communicate with science teachers, students, UW faculty and parents
- Plan and conduct weekly student seminars
- Teach students concept and design of science posters
- Inform student of science research competition opportunities

UW-Professors

- Supervise an intern for a **minimum** of nine, 25 hour weeks
- Critique the drafts of the research paper for scientific accuracy
- Provide direct instruction or assign instruction in safety protocols of the lab
- Provide direct instruction or assign instruction in data collection techniques
- Provide a place and materials for collecting data
- Attend fall poster session - optional

Benefits

High School Interns

- Experience the joys and frustrations of authentic scientific research
- Participate in research at a world class research institution
- Work in laboratories related to their scientific interests
- Form beginning networks with professors and graduate students
- Work collaboratively with more experienced researchers
- Tour labs of fellow interns

UW-Professors and Researchers

- Fulfill the requirements of various granting institutions for outreach
- Form an informal partnership with the school district for future interns
- In depth teaching opportunities for degree and post doctoral candidates
- Opportunity to share their discipline with a highly motivated, well prepared high school junior or senior

For more information, please contact:

Rachel Egan
High School Science Research Intern Program Coordinator

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Updated: January 8, 2008
Editor & Publisher: Paula Srite, psrite@madison.k12.wi.us
Webmaster: webmaster@madison.k12.wi.us

Environmental Inquiry

Authentic Scientific Research for High School Students

- ▶ Home
- For Teachers
- For Students

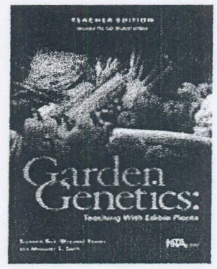
- **Toxicology**
  - Bioassays
  - Risk
- **Ecology**
  - Invasive Species
  - Long-term Research
- **Biodegradation**
  - Composting
  - Bioremediation
  - Wastewater Treatment
- **Watersheds**

- **Publications**
  - Assessing Toxic Risk
  - Invasion Ecology
  - Decay and Renewal
  - Watershed Dynamics

- Peer Review
- Discussion Boards
- Related Links

Welcome to Environmental Inquiry!

Environmental Inquiry (EI) is a collection of ideas and resources to support student projects on a wide range of topics in the environmental sciences.



How can I get started?

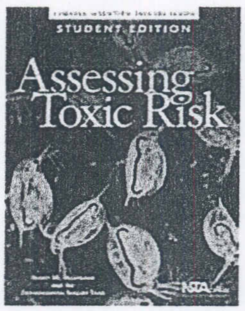
If you're looking for online resources related to one of our books, click on the appropriate book cover below. Otherwise, a good way to start is by browsing through this list of topics for student projects.

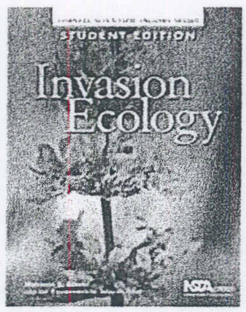
How does EI work?

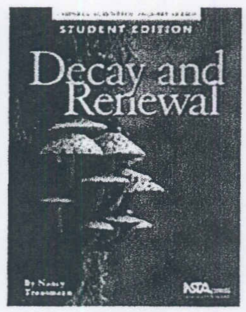
EI includes two levels of inquiry, modeled after professional scientific research. First, students learn specific research protocols. Using these protocols, they conduct interactive research projects. Downloadable forms help students design feasible experiments and then analyze, interpret, and present the results. Discussion boards and an online peer review forum provide opportunities for interaction with fellow students.

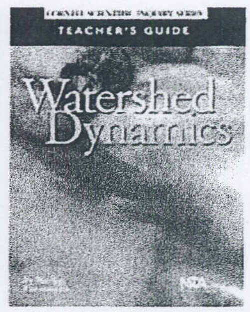
Who can participate?

This EI website is designed for use by any interested high school students and teachers. Our college-level EI website at Penn State University is for undergraduate students and faculty.









Other Environmental Inquiry Publications

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In 2003, EI won an Environmental Quality Award from EPA for Excellence in Environmental Education. More about EI.

EI More about EI CORNELL UNIVERSITY Grant Support NSF

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Lake Whitney Educational Outreach
DRAFT Final Report

Phase IB

Study Element No. 10c:
Development of a Lake Whitney Learning Laboratory Manual

Prepared for:
USDOE

Prepared by:
Bruce Byars
Baylor University Center for Spatial Research

CRASR

Introduction

As a part of a much larger comprehensive evaluation of Lake Whitney water quality by Baylor University's Center for Reservoir and Aquatic Systems Research (CRASR), a tremendous amount of scientific data has been gathered, along with a detailed analysis of the environment. This field guide is designed to provide information to make a trip to Lake Whitney and enjoyable outdoors educational experience. Much of the information presented here is the result of data gathering in the field, as well as from the excellent field trip reference produced by the Baylor University Department of Geology (1974).

This Lake Whitney Learning Laboratory Manual is intended to give an educational experience learning about the environment, while you're actually in the environment. The exercises contained in this manual are designed to be simple, yet informative and are based on the actual work performed by researchers who have studied Lake Whitney. Topics covered include biology, ecology, water quality, geology, engineering and meteorology.

Situated in both Bosque and Hill counties, Lake Whitney is one of the largest reservoirs in the state of Texas with a surface area of 23,500 acres and a volume of 627,000 acre feet of water. The population around the Lake Whitney area varies seasonally and at times can swell to 50,000+. Such flux in population as well as economic development puts an enormous strain on groundwater resources that currently feed the region. Thus, reliable surface water sources should be investigated for development as public water supply.

Physically, Lake Whitney is approximately 25 river miles (= 41 km) in length and averages approximately 40 feet (12 m) in depth. This depth value can be deceiving however, since the lake is constructed in a meandering river valley of the Brazos River, giving it a long-slender profile with a narrow (one mile) average width. The result of this valley construction is a very steep bathymetry that reaches a depth of just over 100 feet (30 m) at the dam (fig. 1).

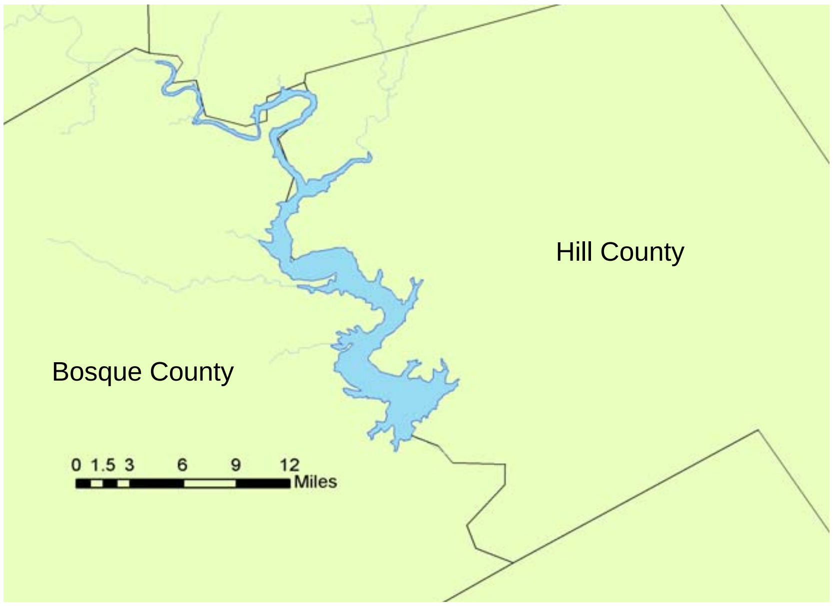


Figure 1 – Lake Whitney, TX is a run-of-the-river reservoir on the Brazos River. It is located between Hill and Bosque Counties, in Central TX.

A wide variety of wildlife can be seen around Lake Whitney, and it is attractive to waterfowl, wading birds, gulls and terns. Rare or unusual birds are in bold type.

Waterfowl
Neotropical cormorant
Pied-billed grebe
Northern shoveler
Hooded merganser
Lesser scaup
Bufflehead
Green-winged teal
Blue-winged teal
Ring-necked duck
Ruddy duck
Mallard
Redhead
Gadwall

Shorebirds
Killdeer
Lesser yellowlegs
Wilson’s snipe
Solitary sandpiper

Wading Birds
Great blue heron
Little blue heron
Tricolored heron
Green heron
Great egret
Snowy egret
Cattle egret

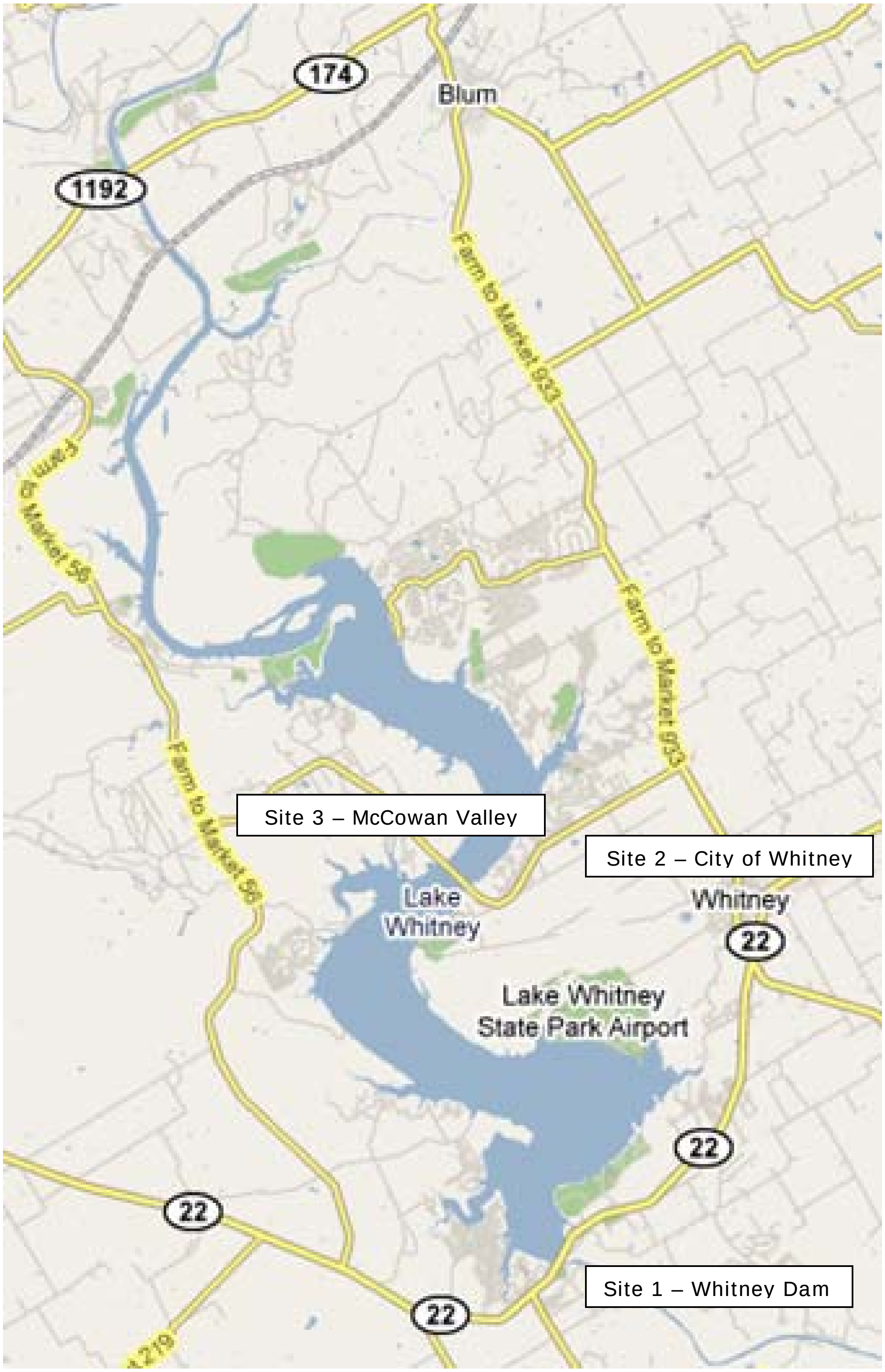
Gulls and Terns
Ring-billed gull
Bonapartes gull
Black tern
Least tern

Other Birds
American crow
Turkey vulture
Black vulture
Crested caracara
Rock pigeon
Mourning dove
Red-winged blackbird
Brewers blackbird
Eastern meadowlark
Scissor-tailed flycatcher
Eastern phoebe
Eastern kingbird
American pipit
Cliff swallow
Savannah sparrow
Wild turkey
Eastern blue jay
Cardinal
Mockingbird
Golden cheek warbler

Apart from the many varieties of birds, raccoon, grey and red fox, armadillo, opossum, and coyote also call the Lake Whitney area home.

In the lake itself, the predominate fish species include:

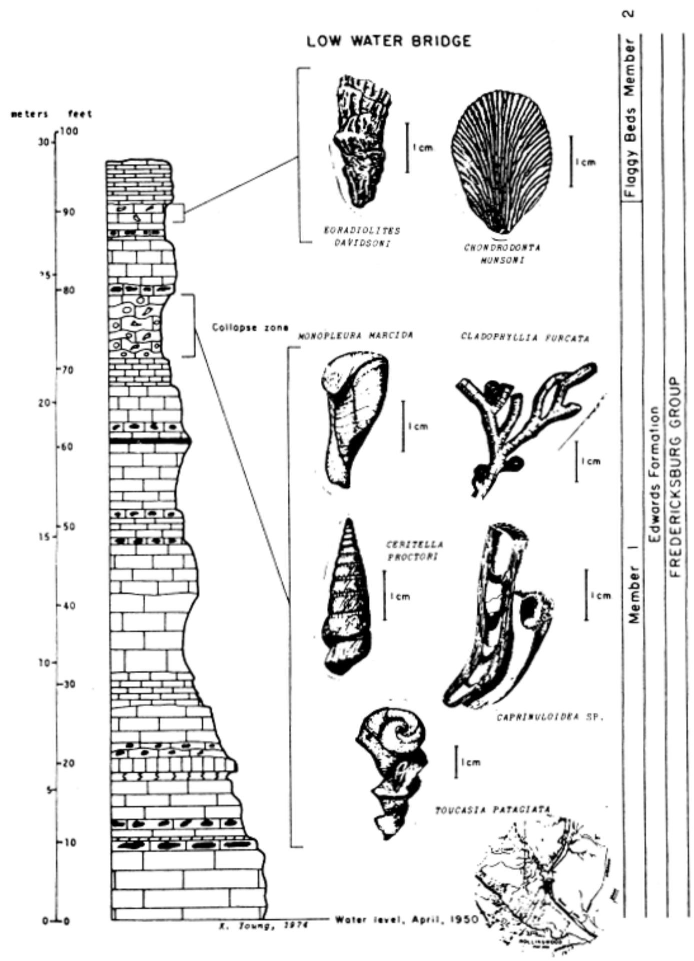
- Striped bass
- White bass
- Smallmouth bass
- Largemouth bass
- Black crappie
- White crappie
- Longnose gar
- Channel catfish
- Blue catfish
- Flathead catfish
- Smallmouth buffalo
- Grass carp
- Freshwater drum
- Sunfish


174
Blum
1192
Farm to Market 933
Farm to Market 56
Site 3 – McCowan Valley
Site 2 – City of Whitney
Lake Whitney
Whitney
22
Lake Whitney State Park Airport
22
22
22
Site 1 – Whitney Dam

Site One – Laguna Park and the Lake Whitney Dam

Laguna Park is the largest community immediately adjacent to Lake Whitney, and owes its existence directly to its proximity to Whitney Lake and Dam. Most of the roughly 500 persons who live here are employed in providing services directly or indirectly related to recreation and the lake. Service stations, restaurants, food stores, and real estate offices are seen along State Highway 22. Other inhabitants are either retired or are only part-time residents who have summer cottages located close to the lake.

The proximity to Lake Whitney makes Laguna Park an excellent example of an area of soaring land values. Once a scrub land with little value, the area has now been subdivided into lots to be sold for fishing cottages and retirement homes. Haphazard building practices encouraged by overzealous land speculators and the lack of building and zoning ordinances are currently the primary problems encountered by residents.



As you descend along the road that leads to the US Army Corps of Engineers road and the dam and powerhouse, you see a vertical section of rocks supporting the dam. Notice the Duck Creek Limestone, a member of the Georgetown Limestone exposed on the left. Edwards Limestone crops out on the cut to the left.

The Whitney Dam is located on the Brazos River 38 miles north of Waco. Its purposes are generation of hydroelectric power, flood control, and recreation. The government owns the entire 190 miles of shore-line and adjacent flood prone areas. Boating, fishing, swimming, diving, camping, and even hunting are all allowed in the area.

The U.S. Army Corps of Engineers started dam construction in May, 1947. Construction was completed in April, 1951, at an estimated cost of $41,795,000 to the taxpayer. Impoundment of water began in December, 1951. Power generation began June 25, 1963 with the marketing agency being Southwestern Power Administration.

This dam is concrete gravity and earthfill type. It stands 584 feet above mean sea level and 159 feet above the Brazos River bed. Its overall length is 17,695 feet, with 1,674 feet constituting the concrete spillway. Both sides of the spillway are flanked by earth embankments of carefully selected soils which are compacted and protected from wave action of the lake by a two foot layer of rock rubble, called rip-rap.

Selection of dam sites is based on both political and geological factors. Because of the intricacies of the political influence, the geological factors will be discussed here. The geological factors can be grouped into two general headings: topography and geomechanics. Topography is a driving influence in the choice of the dam site. The objective in dam construction is to build the smallest dam that will do the job. In an area like this, with many steep bluffs, the problem is choosing bluffs on opposite sides of the lake that are close to each other.

Topography also controls the size and depth of the impoundment basin. Lake Whitney's basin is determined by the shape of the old Brazos River Basin. The Edwards Limestone, which almost surrounds the lake, forms step banks which create a high depth to surface ration in the lake. This is good in semi-arid areas because it reduces evaporation. The Soldier's Bluff and Loafer's Bend area provide a short width to build a dam and a maximum capacity in the valley for a reservoir.

Properties of the underlying rock present no serious problem at Lake Whitney. However, rock properties which might cause problems are the load bearing capacity of the rock, the plasticity and shrink-swell capacity, the permeability of the rock, and the chemical properties of the rock. The Whitney Dam is underlain by the Georgetown Formation, the Edwards Limestone, the Comanche Peak Limestone, and Brazos Terrace alluvium. Members of the Georgetown Formation underlying the dam are the Duck Creek Limestone Member and the Kiamichi Shale Member. The Edwards and Comanche Peak are limestones, but the Comanche Peak also has some small beds of shale. The limestones have high strength support capacities. The Brazos alluvium here is mostly sand. The Brazos Terrace materials are too permeable and lack the support strength needed for the dam's weight. Thus, the terrace was stripped from the site before construction of the dam.

As already noted, the benefits from the dam are power production, flood control, and recreation. The dam complex houses two hydroelectric generators which are used periodically to produce electricity. The low flow of the Brazos River necessitates intermittent use of these generators. Water is stored until a certain level is reached; power is then generated by releasing water through two penstocks. Total value of the electricity produced by the dam averages several million dollars per year.

Behind the dam, the reservoir's flood storage capacity is 1,620,400 acre-feet, large enough to control any flood known to have occurred at the dam site. This dam protects downstream cities such as Waco and College Station from any moderate flood on the Brazos that originates upstream from Lake Whitney. The dam provides incalculable recreation benefits for Central Texans, as well as supporting the local population through tourism.

Recently, planning for the development and use of water resources has become one of the most vital parts of the Corps of Engineers programs. The Corps has moved progressively from the planning of single-unit, single-purpose projects to planning the optimum development of water and related land resources for entire river basins or regions, through multi-unit, multi-purpose, integrated project systems. Some functions of the Federal Water Resources Development include: municipal and industrial water supply; water quality control; and recreation, fish, wildlife conservation.

Whitney Dam serves as a reminder of two different economies you see here: the agrarian Brazos Valley and the commercialized Lake Whitney area. Emphasis has been on what the Brazos Valley is like because it shows what was lost with the Dam's construction. Now, we will observe development resulting from the lake.

Note the Mesquite and Cedar trees to the east side of the dam. Mesquite is particularly common on deep soils and lands with Mesquite typically make up grazing land for cattle. Ironically, it decreases the amount of forage available to cattle by robbing the soil of water. A young Mesquite can easily draw its own weight in water and release it to the atmosphere daily. To grow one pound of Buffalo Grass, or 596 pounds of water to grow one pound of Blue Grama. Since the Mesquite root system is more extensive, it gets the water first, eventually killing the native grasses.

Site Two – City of Whitney on the East Side of Lake Whitney

Whitney, Texas was established in 1879 when the Texas Central Railroad crossed the county. The town was named for Charles Whitney of New York, a stockholder in the railroad. The town is an agricultural market and distribution point whose population grew from 824 in 1940, to 1383 in 1950. The building of Whitney Dam and Reservoir in 1949 changed Whitney into an important spot for fisherman. Although the population of the town varies considerably depending on the season, the permanent population is now approximately 2,000 residents.

The clumps of trees, called Motts, you see standing on the prairie, are characteristic of the Washita Prairie. The Washita Prairie is predominantly a grassland; trees are the exception rather than the rule. Thin soils and a semi-arid climate make it difficult for a tree to grow, but once a tree becomes established, it does its best to get help and make friends with the grasses growing at its base. The tree shades the ground below and drops leaves and seeds. The seeds sprout under the tree and the mott has formed. Because of harsh physical conditions, motts do not spread and change the prairie into a forest. A common mott will contain four to eight trees in the Washita Prairie Motts, providing a beautiful oasis in the short grass prairie.

As you travel, notice the difference between resort development on the west and east side of Lake Whitney. Here it is almost absent and is the result of the underlying geology. The slope away from the lake on the east side is very gradual. The flood control pool margin is therefore away from the power pool level. This results in greater distances to privately owned land which can be developed. In addition, there is a lack of prominent scenic overlook on the east side. The gradual slope also creates shallow hot waters in summer, which makes recreational opportunities much greater.

Soils of the Brazos terraces are easily differentiated by their darker red color and high sand content, distinctively different from the thinner solids on the west side of the lake. The Brazos terrace soils provide evidence of the effects of five soil-forming factors: climate, parent material, topography, organics, and time. Since climate and parent material are nearly equivalent for all terrace levels, topography, organics and time are the prime determinants of soil type. The lowest terrace has the greatest range of soil types. Since these soils are the youngest, their great variety reflects insufficient time for the development of dominant mature soil types. With time, maturation by weathering and erosion will form dominant types as evidenced in the upper terrace levels. The oldest terraces are almost exclusively covered by soils exhibiting mature features of well developed, deep top soil.

Soil maturity controls not only the type of vegetation, but also dictates the design properties of this area. On the lower terrace levels, variety of soils in such a small area comes before any adaptations of the universal engineering parameters as based on only a few scattered tests. Constant on-site testing is necessary prior to any construction. However, on the upper terraces, testing needs be made only on the typical soil for that location.

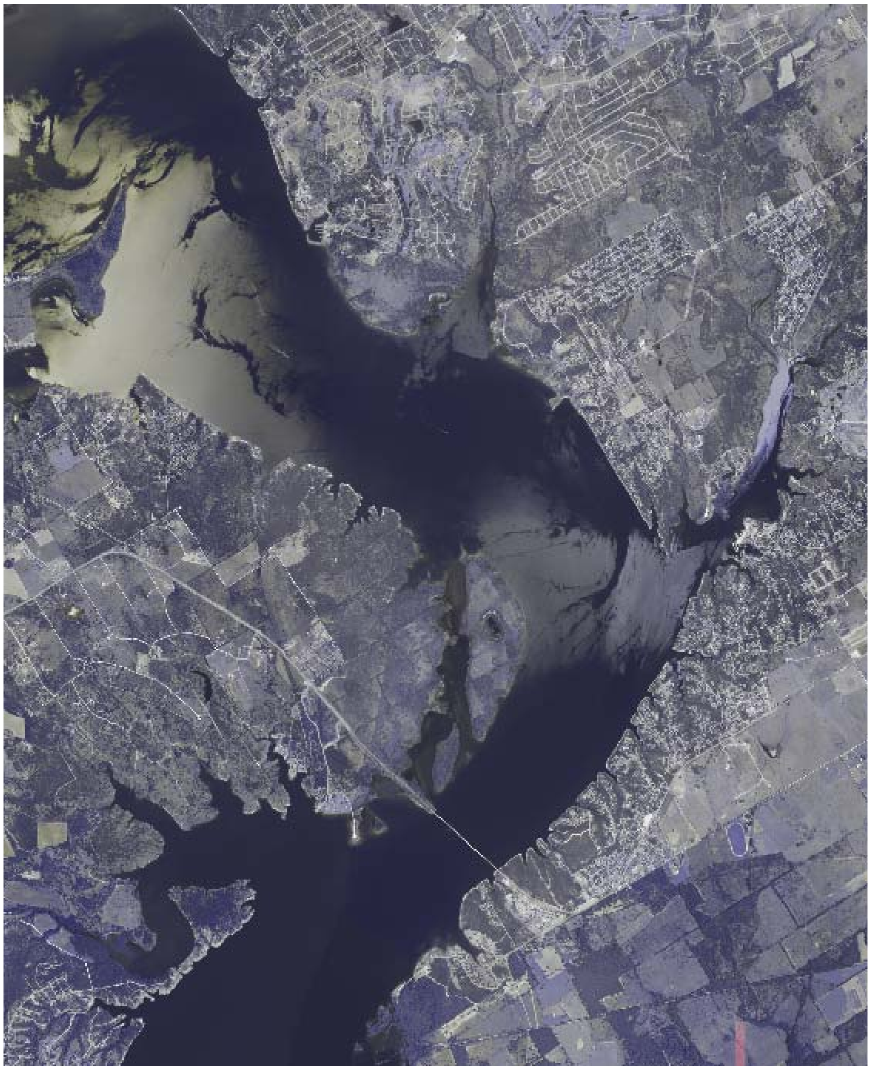
Along the fence lines in the area we see, among other things, Hackberry (Celtis occidentalis) and the Slippery Elm (Ulmus rubra). The Slippery Elm is found throughout the central, eastern, and northeastern United States. Leaves of this elm are harsh and rough. The Hackberry is more abundant and is distinguished by the 3 main veins arising from the leaf base, as compared to the elm's one vein.

Edwards Limestone contains more than 99% calcium carbonate. Due to its massiveness and hardness induced by the high calcium carbonate content, the Edwards Limestone gives rise to this particular topography region of Central Texas. This region is typified by flat-topped hills or mesas, all similar altitude and all capped by Edwards Limestone. The steep concave slopes of the mesas are formed by the softer Comanche Peak Limestone and the valley floors are developed on Walnut Clay.

Typical native vegetation of the Edwards Limestone includes varieties of bluestem and gramas, Texas Wintergrass, buffalo grass and mountain scrub oak or Quercus fusiformis. The latter grows almost exclusively on the Edwards and is never found in abundance on other formations. Vegetation indicating land abuse includes Juniper, sumac, and mesquite (Prosopis glandulsa).

Site Three – McCowan Valley Park

At the McCowan Valley Park, we have an opportunity to view the Lake Whitney and the geologic section on a broader scale than on the previous stops. Let's ask some basic questions: Why are these valleys and hills here, and why does the land look the way it does?



First, look to the west across the lake. The old river channel is marked by the trees, the floodplain of the Brazos River is now flooded by the waters of the lake. The flat floodplain and terrace deposits comprise what was once Steiner Valley.

All of what you see to the east was shaped by the Brazos River. The Brazos Valley is delineated by White Bluff on the east, and Powelldale Mountain on the west. The Brazos River shaped the Valley by erosion and deposition. Meander analysis and study of river competence suggests that in Pleistocene time the Brazos River had 5-9 times more water discharge than today. This stronger river carved steep bluffs like White Bluff in front of you. Migration of the present Brazos River in its valley accounts for deposition of Steiner's Valley. Steiner's Valley was formed predominantly by point bar accretion.

As a river bends, current slows on the inside of the bend, and speeds up on the outside. On the slow inner edge, sands rolling along the river bed stop. On the outside, sediment is picked up and moved downstream, sometimes undercutting the outside bend and causing the bank to collapse into the river. Thus, the inside of the bend moves into the river, and the outside is washed away. A river may migrate back and forth, reworking its sediments and widening its valley. In an area of low relief, this creates a broad alluvial plain; here the Edwards Limestone bluffs confine river migration across the valley.

To the west, isolated hills like the one on which we stand are scattered across flat lands. To the southwest is the escarpment of Edwards Limestone. This area is a northwest extension of the

Lampasas Cut Plain in the Brazos Valley. The Lampasas Cut Plain is a maturely dissected plain with isolated hills formed by erosion of the Edwards Limestone, Comanche Peak Limestone, and Walnut Formation. The Edwards Limestone, which you are standing on, caps the hills and forms vertical cliffs. The nodular Comanche Peak Limestone, which you saw on your way up the hill, forms the steep slopes; the Walnut Formation, which you saw at STOP II, forms the gentle slopes in the valley. These mesas are erosional remnants. Because the Edwards Limestone is of fairly uniform strength, most of these mesas represent interstream areas. The shape of the mesas, called mountains by the locals, may be controlled by distribution of the slightly more resistant rudist bioherms.

Useful References

US Army Corps of Engineers
http://www.swf-wc.usace.army.mil/whitney/

Texas Parks and Wildlife
http://www.tpwd.state.tx.us/fishboat/fish/recreational/lakes/whitney/

Baylor University Center for Reservoir and Aquatic Systems Research
http://www.baylor.edu/CRASR/

The Utility of Lake Whitney as a Potential Drinking Water Source: Engineering Scoping Perspective
DRAFT Final Report

Phase IB

Study Element No. 11:

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CRASR

Table of Contents

Table of Tables

Table of Figures

Abstract

This report focuses on scoping possible engineering methods of decreasing the concentration of salt in Lake Whitney so that it can be used for human consumption. Dissolved solids are very difficult to remove from water, and require either a device which will filter them out, or a system that will dilute the concentration to a level that would be acceptable for simpler purification methods. In our research, we first studied many different ways of accomplishing both of these methods such as the suppression of the source of the salt contamination or the dilution of these sources using water imported from cleaner sources. We were then able to separate our findings into the two most feasible categories: technical solutions and regional solutions. The technical solutions will encompass two forms of desalination, electrodialysis and reverse osmosis, both of which use large amounts of energy to push the contaminated water through fine membranes which filter out impurities. The regional solution will focus specifically on the area around Lake Whitney, using data collected by other resources to determine the best way to reduce the salinity of the river using impoundments. Armed with the information from this report and further investigations, a drinking water solution will be determined for the city of Whitney.

Statement of Purpose

Water salinity can be the source of many problems when a population must use the local water supply found in the environment. Salinity in the water supply can be caused by several different mineral ions: sodium, calcium, magnesium, chlorides, carbonates, sulfates, bi-carbonates, etc. These dissolved solids are harmful when imbibed in large concentrations, and therefore, great engineering effort is necessary to reduce these concentrations to protect the public health.

This report focuses on scoping a possible engineering method for reducing the salinity of Lake Whitney to provide a new and sustainable drinking water source for local residents. The water wells on which the city relies are growing increasingly drier, so other methods of obtaining drinking water must be developed. The local population has turned to the surrounding rivers and reservoirs in the Brazos River Basin for a new source of water. This report will first briefly present several possible solutions for reducing salinity, followed by a detailed examination of the most feasible engineering solutions.

Lake Whitney- Brief Site Description

Whitney, Texas is located within a couple of miles from Lake Whitney Reservoir, the construction of which was completed in December of 1951 by the U.S. Army Corps of Engineers (USACE). Specifically, Lake Whitney is part of the "Three Rivers Region in the Forth Worth District of the USACE.[2]" The lake is part of the Brazos River Basin and currently the supplies water for municipal use, irrigation, and power production. Its water capacity is 379,000 acre-feet[1] and its current outflow (as of early December 2008) is 25 cfs. The main purpose of constructing Lake Whitney was for flood control of the region. As time progressed (in June 1953) the powerhouse was completed to generate hydroelectric power. "The construction cost of the dam was $41,880,000 and the cost of the powerhouse was $2,208,354.[2]" Each year over two million people visit Lake Whitney camping, fishing, boating, and other recreational activities.

[1] *Handbook of Texas Online*, s.v. "," http://www.tshaonline.org/handbook/online/articles/WW/ruw1.html (accessed August 19, 2008).
[2] http://www.swf-wc.usace.army.mil/whitney/

Methods to be Considered

Pollution can be stopped in one of three phases in the contamination process. The pollutants can either be prevented from spreading at the source, removed once they have reached the targeted resource, or the process that creates the pollutants can be abolished all together. The processes contributing to the salinity in the watershed cannot be abolished, leaving only two possible solutions - preventing them from spreading or removal at target sites. Stopping the spread of salinity would be the most beneficial solution to all cities in the watersheds; however, control of underground salt pollution from natural sources would require a comprehensive understanding of the extent and cause of the contamination. The other removal method that was tested involved the smaller scale treatment of water once it had been drawn from the Brazos rather than treatment of the whole body of water. The following sections will discuss several possible engineering solutions, with the most feasible and effective solutions examined in more detail.

Flow Suppression

One technique for the containment of brine sources is flow suppression. The process of flow suppression consists of building a circular containment basin or dike that would capture all of the water that flows from the spring. The weight of the brine detained there would act against the natural artesian flow of the spring, and eventually stop it from producing more water. This technique has been successfully implemented in areas such as the Estelline Springs in the Red River Basin, though it is not believed to be an option for control of brine sources in the Brazos River Basin for several reasons. Most of the springs in the area are very small and issue brine in high concentrations, which quickly evaporate into salt flats. The flow from these springs is very low; surface flow is often only found in areas where several springs are grouped together. Also, most of these springs are located in the floodplain, so during large rain events the dikes would be subject to damage and overflow. Based on these factors, it was determined that other methods of salt pollution control should be investigated.

Impoundments

Impoundments are a common way to disrupt the flow of rivers for water storage and can be used to detain pollutants before they can spread through a system. There are three types of impoundments that could work for the purpose of controlling salt water contamination: total impoundments, low flow impoundments, and diversion impoundments. Total impoundments are very large so that they can be used to completely stop and store all the flow from a stream, including water, brines, and sediments. This method will be discussed further in depth later on in this report. Low flow impoundments are typically used to capture and divert water to a total impoundment when topographical irregularities make a total impoundment impractical. Diversion impoundments were thought to be the most feasible for the Brazos River Basin because the water does not have to be stored, it is simply diverted away and then back into the river downstream from where the water is being used.

Dilution/Desalination

If salt water containment is not a possible method for reducing contamination, then there are two other methods for making contaminated water useable that can be considered: dilution and desalination. Since the Brazos River already contains large amounts of minerals that are diluted by a series of tributaries, additional methods of dilution were considered to lower the salt to fresh water ratio. Unfortunately, this method would involve purchasing water and having it delivered to the river basin, which would be a very expensive endeavor. The other option would be to remove the salt from the system in a process called desalination. This can be done in many different ways, the details of which will be discussed in a later section. This process is feasible and has shown to be effective at providing quality drinking water.

Distribution/Import

Another way to provide water to the people of Whitney would be to import clean water from other sources through pipelines. Neither of these options would affect the quality of the existing water supply, water would simply be redistributed from areas where the need for clean water is not as great. This plan would aim to pipe water that has been designated for use in the lower Basin region to areas in the upper and middle Basin, where the salt pollution is the most severe. The lower Basin could then use water from the Brazos main stem combined with water imported from East Texas. Another source of water that a pipeline could be drawn to would be some of the tributary lakes that exist in the lower Basin. This plan would require extensive changes to the current state water planning and water allocation procedures, and would not be able to ensure clean water for all residents of the Brazos Basin. Additionally, with the increase in population in the Brazos Basin, this solution will only be short-term and temporary.

Tributary Supply

An alternative to piping water from tributaries in the lower Basin would be to create new tributaries that water could be drawn from in the upper-middle Basin. There are four possible locations for lakes along the Brazos tributaries. These tributaries, which include Big Creek, Childress Creek, Paluxy River, and Lampasas River would provide yields equal to the projected use from the three main stem lakes (Possum Kingdom, Granbury, and Whitney). Not only would this save on the cost of importing the water from the lower Basin, but it would also ensure that people in the lower Basin would have all of the fresh water that had originally been allocated for them. This system would most likely be the most sustainable, but also one of the most costly. The cost associated with the construction of a new tributary will be enormous, especially when considering the issue of water rights.

Conclusion

While there are many physical means of decreasing the concentration of salt in Lake Whitney, we believe that these methods are for the most part inferior to other removal methods because of the high cost and extensive construction it would entail. Two other possible methods are investigated in this report: technical solutions to desalinate the water, and salt impoundment dams to sequester the salt water and dilute the potential drinking water. There are two main types of desalinization using membranes: reverse osmosis and electrodialysis, both of which will be detailed in the following two sections.

Regional solutions such as salt impoundments are a means of physically restricting the source of the salt contamination before it reaches the main body of water and pollutes all of the sources downstream. Salt impoundments require large changes to the physical geography of the surrounding environment and while the implications of such a system are largely unknown, our research details the possible outcomes of salt impoundment dams in the Brazos River Valley in a later section.

Technical Solutions

There are two main methods of desalination using technical applications which will be reviewed in this section as potential solutions for Lake Whitney. Reverse osmosis and electrodialysis are both highly effective in providing quality drinking water. The following paragraphs describe in detail the processes and considerations needed for implementing these technologies.

Reverse Osmosis

Reverse osmosis (RO) is an effective way to remove dissolved solids such as salt from surface water. Reverse osmosis is the process of forcing a solvent from a region of high solute concentration through a membrane to a region of low solute concentration by applying a pressure in excess of the osmotic pressure. This treatment process is complex and requires a large amount of energy, making it one of the more expensive options for desalination, yet also the most successful. The following paragraphs describe in detail the engineering processes and consideration associated with reverse osmosis technology. The state of the art desalination plant will be used as an example throughout this section.

Pretreatment

Pretreatment of the feed water is an essential process that is required in all reverse osmosis systems. Pretreatment consists of pH adjustment and addition of an antiscalant to prevent scaling, as well as prefiltration to remove suspended solids and to prevent fouling. Once these phases of pretreatment are complete, the feed water is pressurized with feed pumps, and then sent through the membrane arrays.

Scaling

Scaling occurs when there is an exceptionally high concentration of salt present in the water and as a result, the salts form precipitates. Precipitation can irreversibly damage the membrane, and can decrease the permeability of the newly treated water. Adjusting the pH of the feed water and treating it with an antiscalant are two methods used to prevent the occurrence of scaling. As an example, the desalination plant in El Paso, TX employs both methods during the pretreatment process.

Membrane scaling is a major concern for the potential reverse osmosis plant at Lake Whitney, due to the high levels of salinity and the slightly basic pH present in the lake. In 2006, the average level of pH in Lake Whitney was 7.54, and in 2007, the overall average pH was 7.85. The overall average salinity concentration in Lake Whitney in 2006 was 2.30 grams per liter and in 2007 it was 1.11 grams per liter. The combination of these two factors provides the prime conditions for calcium carbonate precipitation, which is known to cause irreversible damage to the membrane.

pH Adjustment

Adjusting the pH of the feed water can be a means of changing the solubility of the precipitate, and ultimately control scaling. Precipitation of calcium carbonate is common in many feed water sources, specifically the feed water from Lake Whitney, and pretreatment of this compound is required by many reverse osmosis systems to prevent scaling. A pH value of 5.5 to 6.0 is needed to prevent calcium carbonate precipitation (Water Treatment). However, the pH that the feed water is adjusted to may differ depending on the salinity in the feed water. The desalination plant in El Paso adjusts the pH of the feed water to 7.4 during pretreatment (El Paso Water Utilities Power Point). Since the potential for high calcium levels exist in Lake Whitney, the pH will have to be lowered to acidic levels, specifically around 5.5 to 6.0, to prevent calcium carbonate precipitation on the membrane surface. Adjustment of pH is accomplished with the addition of either sulfuric acid or hydrochloric acid, which converts carbonate to bicarbonate and carbonic acid. Carbonate in the form of bicarbonate or carbon dioxide (aq) in water, with a pH range of 5.5 to 6.0, can pass through the membrane without forming a precipitate (Water Treatment 1475). Depending on the concentration of sulfur in the feed water, sulfuric acid may not be used, because it can raise the concentration of sulfate, and may cause the precipitation of sulfate compounds.

Treating feed water with antiscalants

In addition to adjusting the pH of the feed water, the addition of antiscalant chemicals is performed to prevent scaling. The antiscalants cause the feed water to become supersaturated, which prevents crystal growth and formation, and slows the rate that the precipitate forms. Antiscalant dosages range from 2 ppm to 5 ppm (parts per million), (Avista Technologies), depending on the degree of saturation needed. Typical antiscalants used are polyacrylic, polymaleic and polyphosphate compounds. Polyphosphate compounds are not as common, because it may add phosphate to the feed water, which will most likely cause disposal problems in the post-treatment process. Antiscalants interfere with precipitation reactions in the following three ways: threshold inhibition, crystal modification and dispersion. Threshold inhibition is the ability of antiscalants to maintain the supersaturation of the feed water. Crystal modification is the ability of antiscalants to distort or alter crystal shapes, which results in the formation of soft scale that is easily removed. Dispersion is the capability of antiscalants to absorb onto crystals and transmit a high anionic charge, which separates the crystals and creates a barrier to crystal growth. When choosing an antiscalant and the dosage, it is necessary to choose one based on the recommendations of the equipment used in reverse osmosis. Also, the specific degree of saturation that needs to be reached depends on the characteristics of the antiscalant.

Silica, another common mineral found in the feed water, precipitates in an unstructured, shapeless form rather than in a crystalline form. Consequently, antiscalants that prevent crystal growth are unsuccessful in preventing silica precipitation. The presence of metals in the feed water is known to increase silica precipitation and to alter its form, causing it to appear in many different forms. When high concentrations of silica exist in feed water, additional pretreatment methods, such as lime softening, may be necessary to prevent precipitation.

Pre-filtration

Pre-filtration is required during the pretreatment to remove suspended solids and turbidity that may clog or create fouling on the membrane. Akin to membrane scaling, fouling is also a major concern for the future reverse osmosis plant at Lake Whitney, due to the high concentration of chlorophyll (algae) and the turbidity it causes in the lake. In 2006, the average concentration of chlorophyll in Lake Whitney was 9.87 micrograms per liter, and in 2007, the overall average chlorophyll concentration was 28.47 micrograms per liter. The variation between the two averages is most likely because samples were only taken over a time span of three months during 2006; however, in 2007 the samples were taken throughout the entire year. As a result, the average concentration for 2007, 28.47 micrograms per liter, is a more accurate value and should be taken into consideration when designing the future reverse osmosis plant for Lake Whitney. Although there are no water quality standards that directly pertain to chlorophyll concentrations, concentrations above 11 micrograms per liter are characteristic to eutrophic conditions. The turbidity concentrations from both 2006 and 2007 are relatively similar, but have minor variation due to the sampling time periods. In 2006, the average amount of turbidity in the lake was about 5.12 nephelometric turbidity units (NTU), and the overall average turbidity in 2007 was 9.68 NTU. These high concentrations of turbidity far exceed the EPA's drinking water standard of 0.3 NTU. Suspended solids and other particles causing the water to be turbid must be filtered out during the pre-treatment stage of reverse osmosis to prevent the occurrence of fouling and plugging of the membrane, and most importantly to reduce the final turbidity to a level that complies with the drinking water standard. The brownish green color of the lake proves the existence of chlorophyll and therefore turbidity in excessive amounts. Not only are these factors a concern for the design of reverse osmosis plants, but they also create a problem for aquatic life as eutrophication causes oxygen depletion.

A cartridge filter with a 5 micrometer strainer opening is used to remove particulate matter from the feed water before it is pumped through the reverse osmosis membrane (Water Treatment 1437). More advanced filtration methods may be employed if the feed waters contain high amounts of particulate matter, including coagulation, flocculation, granular filtration, sediment filtration or membrane filtration. Disinfection is another method of pre-filtration, however the use of disinfection is not as widely used as the cartridge filter, because various disinfectants are not compatible with some membrane materials, and may result in premature membrane degradation. Pre-filtration is necessary to prevent fouling and is recommended by all reverse osmosis manufacturers.

Particulate fouling

Particulate fouling is the result of suspended inorganic and organic materials, such as microbial constituents and biological debris. Particulate fouling causes plugging and cake formation, which both add resistance to the feed water flow and can affect the performance of the reverse osmosis system. Plugging occurs when particles accumulate and become trapped in the piping and feed channels, and cake formation occurs when particles build up on the membrane surface. Over time, as particulate matter accumulates in the pipes and on the membrane surface, the deposit may harden or age, causing damage to the equipment.

Biological fouling

Biological fouling, often referred to as biofouling, is the accumulation and growth of microorganisms, including algae, on the membrane surface or in the feed channels and pipes. Biological fouling creates many problems in reverse osmosis systems, and can adversely affect the systems performance. It may slow the feed water flow, decrease the solute rejection, pollute the permeate, cause degradation of the membrane material and decrease the membrane life.

Unlike particulate fouling, biological fouling is not prevented by pre-filtration, but rather by maintaining the system by properly flushing the membrane and feed channels with permeate, and applying biocides, such as chlorine, especially when the system is not in use. The membrane material limits the type of biocide that can be used. A limited amount of chlorine is acceptable to use on cellulose acetate membranes, but polyamide membranes require sodium bisulfate, because chlorine may damage polyamide membranes. Both cellulose acetate and polyamide membranes will be described in the "Treatment" section of this report.

Metal oxide fouling

Metal oxide fouling occurs when metals, such as iron and manganese, oxidize, precipitate and foul membrane material when oxidants penetrate the feed water. Iron fouling is typically more common than manganese fouling, and can quickly take place when air enters the feed water. Pretreatment of the feed water to eliminate iron and manganese is usually done by oxidation with chlorine or oxygen. Oxidation is followed by mixing and hydraulic detention time, as well as membrane filtration or granular media filtration, where oxidation and filtration occur simultaneously. In addition to using precaution with biocides, oxidants must be used cautiously to prevent them from touching the membranes because some membrane materials, specifically polyamide membranes, are not oxidant resistant. In addition to the presence of iron and manganese in the anaerobic groundwater (the feed water), hydrogen sulfide is also a common constituent. If air penetrates the feed water, hydrogen sulfide oxidizes to colloidal sulfur, which can irreversibly damage the membrane equipment.

Treatment

After the feed water has completed the pretreatment processes, the water flows to the feed pumps. The high pressure feed pumps supply the pressure that forces that water through a membrane, where it is treated through reverse osmosis (figure 1). The membrane used is semi-permeable and is made of a dense material without pores or empty spaces, which allows the solute to be separated from the feed water. The amount of pressure applied varies between brackish water and seawater. The amount of pressure used to pressurize brackish water ranges from 225 to 375 Ibf/in^2 (1.6 to 2.6 MPa), and the amount of pressure used for seawater ranges from 800 to 1,180 Ibf/in^2 (6 to 8 MPa) (Wikipedia). The semi-permeable membrane that the feed water is forced through separates dissolved solutes from the water and allows the pure solvent, or permeates, to pass through the membrane to the next stage of treatment. The retained solutes, often referred to as concentrate, must also be treated in a post-treatment phase before it is disposed. Reverse osmosis is one of the most common processes used to desalinate water worldwide.

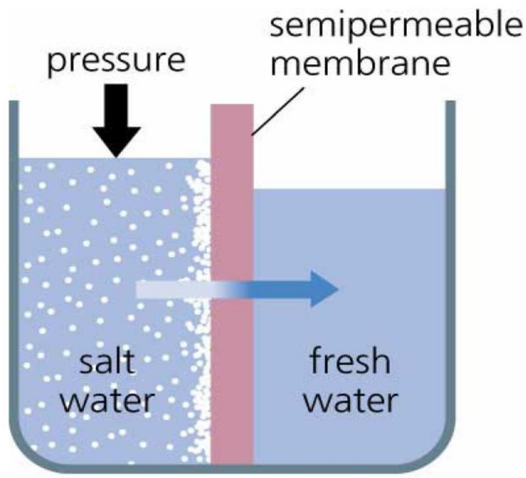

Figure 1. Reverse osmosis process

http://www.ibwc.state.gov/Files/ibwc080907.pdf

Energy consumption

Desalination plants using reverse osmosis require large amounts of energy to operate. This energy-intensive process can be expensive and emit high levels of greenhouse gases into the atmosphere. This is the main reason why desalination plants are looking to use renewable energy sources, such as windmills, solar power or bio-fuels to power their reverse osmosis operations. Using power generated by windmills or other renewable energy sources significantly decreases the amount of energy consumed, and most importantly decreases the overall emissions from the plant. Of the 114 desalination plants in Florida, 33 in California and 39 in Texas, none are currently powered by renewable energy (TWDB). Then again, many desalination plants using reverse osmosis are powered by existing power plants, which also considerably decreases the amount of energy consumed and reduces total operation costs. The largest desalination plant in the world known to be powered from a renewable energy source is the Kwinana Desalination Plant in Perth, Australia. Electricity for the plant comes from an 80MW windmill farm that consists of 48 wind turbines (Water-Technology.net).

A hydroelectric powered dam exists at the south end of Lake Whitney, and it can be used as the main energy source to power the desalination plant. Since hydroelectric power currently exists on site, a power plant will not need to be built. This accessible power source will significantly reduce overall costs and may decrease the amount of energy consumed.

Desalinating brackish groundwater and surface water costs about $1.50 per 1,000 gallons of water, which is significantly less expensive than desalinating brackish seawater, which can cost anywhere from $2.50 to more than $3.00 per 1,000 gallons water (TWDB). The majority of the energy used in a reverse osmosis system is used to pressurize the feed pumps, which force the water through the membrane. More energy is required to pressurize and force water with a greater total dissolved solids (TDS) concentration through the feed pumps, thus increasing energy costs. Desalinating seawater is significantly more expensive than desalinating other brackish waters due to its high TDS concentration.

Most of the 39 desalination facilities in Texas use reverse osmosis to desalinate brackish groundwater and surface water. Other desalination methods used include Electrodialysis Reversal (EDR) and Electrodialysis (ED), which will be reviewed in the next section. The City of Granbury, Dell City, City of Sherman and Oak Trail Shores currently use EDR, and the DEFS Fullerton Gas Plant is the only facility in Texas known to use ED. The Oak Trail Shores and The City of Granbury plan to upgrade their facilities and switch to reverse osmosis (A Desalination Database for Texas). Although Texas does not have any seawater desalination plants, pilot studies are currently being performed in the lower Rio Grande Valley, specifically in the Brownsville PUB and Laguna Madre Water District (TWDB). The Texas Gulf coast provides a vast quantity of seawater that could potentially be desalinated, and since a seawater desalination plant has yet to be built along the Texas coast, it is likely that one will be built in the future (TWDB).

Membrane element configuration

Membranes used in reverse osmosis systems are either spiral-wound configurations or hollow-fine-fiber (HFF) configurations, which are no longer used, and rarely manufactured. Toyobo, a HFF membrane manufacturer in Japan, is currently the only company in the world that makes them (Water Treatment 1440). Although they are still in use in older reverse osmosis systems, the spiral-wound configurations are most commonly used in newer systems.

A spiral-wound membrane will most likely be the membrane configuration of choice for the potential reverse osmosis treatment process at Lake Whitney, because they are more widely manufactured, more efficient than hollow-fine-fiber configurations, and less susceptible to fouling and scaling. Membrane fouling and scaling are a major concern when choosing a membrane configuration, due to the high levels of salinity, turbidity, chlorophyll and the pH of the water.

Spiral-wound modules

Spiral-wound modules are the most efficient type of membrane used for reverse osmosis in desalination plants. Compared to HFF modules, they use half as much pumping energy, and produce high quality permeate with 86 ppm vs. 470 ppm permeate produced by HFF membranes (Butt, Rahman, Baduruthamal). Spiral wound modules are usually 40 inches long and 12 inches in diameter, however, most are 8 inches in diameter (Water Treatment 1438, 1440).

The modules are composed of several membrane envelopes, which are rolled into a cylinder and attached to the permeate collection tube, which runs through the middle of the membrane. Also, rolling the membrane envelopes in a cylinder forms a feed channel called the feed-concentrate channel. Feed water enters this channel at one end of the module, and the concentrate is discharged at the other end, as shown in Figures 2 and 3. The membrane is enclosed between a feed spacer and a permeate carrier spacer, with the active membrane layer face out, and is sealed on three sides, creating an envelope. The open ends of the envelopes are attached to the permeate collection tube. The feed spacers are located between the envelopes and provide a flow path for the feed water, and the permeate carrier spacers are placed inside the envelopes, creating a flow path for permeate.

When in operation, the feed water enters through the feed-concentrate channel, and is exposed to the active layer of the membrane. Some water passes through the membrane, as permeate, and then flows into the permeate collection tube, where it flows to the post-treatment process. The concentrate is discharged on the opposite side of the module where it goes through a different post-treatment process, which enables the concentrate to be disposed properly. These membranes are grouped in arrays, similar to those shown in Figure 4.

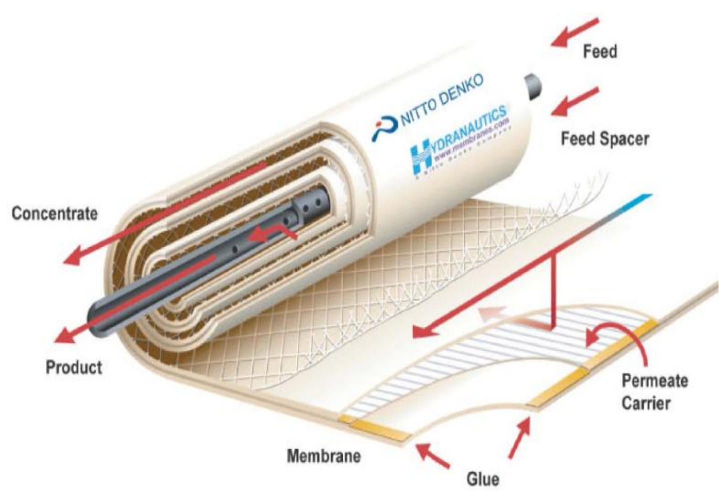

Figure 2. Spiral-wound membrane used in the El Paso, TX desalination plant
http://www.ibwc.state.gov/Files/ibwc080907.pdf

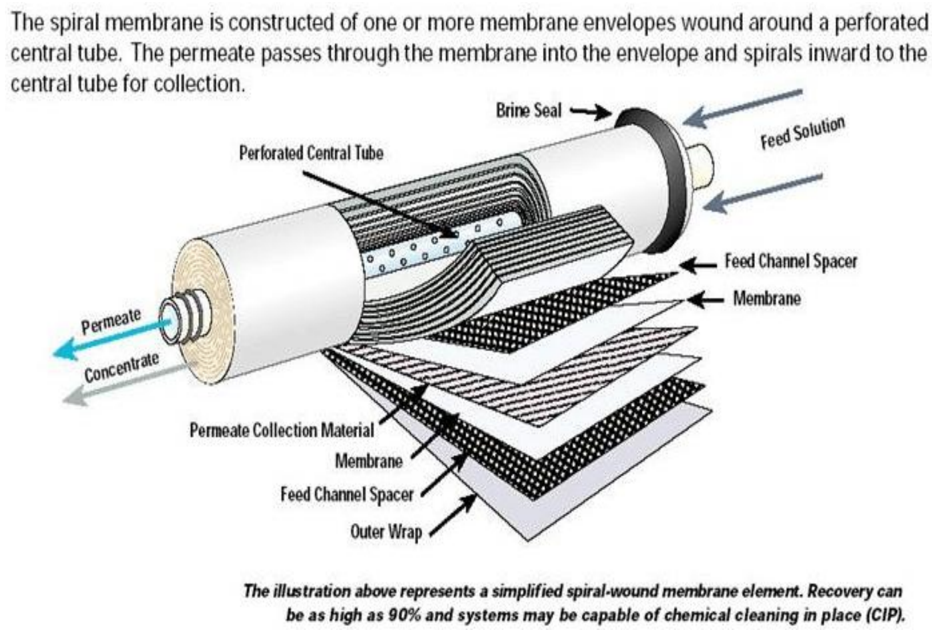

Figure 3. Dr. H20
http://www.doctorh2o.ca/images/HowReverse2.gif

Figure 4. Spiral-wound membrane arrays in the El Paso, TX plant

Membrane Material

The physical and chemical properties of the membrane material can greatly affect membrane performance. Ideal properties of the membrane material are that it should be non biodegradable, physically and chemically stable, chemically resistant, and should not cause clogging or fouling (Water Treatment 1442). However, not all membrane materials have these ideal properties, so it is important to maintain the system by backwashing to prevent clogging and fouling and to utilize antiscalant chemicals that won't destroy the membrane material. The most common materials used on reverse osmosis membranes are cellulosic derivatives and polyamide derivatives.

Cellulose acetate membranes

Cellulose acetate membranes are asymmetric, which means that they are chemically homogeneous, but physically heterogeneous. The hydrophilic properties of cellulose acetate help to prevent fouling on the membrane surface and they help maintain a high flux. Although some properties of cellulose acetate membranes are ideal, many of its other properties are not ideal. In cases where the pH of the feed water is below 3 or above 8 and the temperature of the feed water is above 30°C, the cellulose acetate material is not tolerant to these conditions and may hydrolyze (Water Treatment 1442). The average pH of the water in Lake Whitney is consistently around 7, and is only lowered to values between 5.5 and 6.0 during pre-treatment, thus the potential for the membrane material to hydrolyze will not be a major concern. In addition, if the membrane comes into contact with free chlorine concentrations greater than 1 mg/L, the membrane may begin to degrade, depending on how long it was in contact with the membrane and the concentration of the chlorine (Water Treatment 1442). The type of membrane material that would work best with conditions of the water in Lake Whitney would be the cellulose acetate membrane. As stated before, fouling and scaling are major concerns, and both the membrane configuration and the membrane material must be least vulnerable to these factors.

Polyamide membranes

The polyamide membranes have the advantage of being more stable in a pH range of 3 to 11 and most are resistant to bacterial degradation (Water Treatment 1442). However, polyamide membranes are not as hydrophilic as cellulose acetate membranes, are more vulnerable to fouling and have no tolerance for any concentration of free chlorine. If excess chlorine is present in the feed water and comes in contact with the membrane, rapid deterioration will occur as a result. Many pre-treatment processes require dechlorination of the feed water to prevent the occurrence of membrane degredation. Dechlorination can be achieved by adding activated carbon, sodium bisulfate or sulfur dioxide to the feed water (Water Treatment 1443). Many reverse osmosis systems have sensors that monitor the feed water and shut down the RO system if damaging oxidants, such as chlorine, are present. Although manufacturers of polyamide membranes claim that they are more ideal than cellulose acetate membranes, cellulose acetate membranes will be more ideal for the future reverse osmosis plant at Lake Whitney, because they are specifically designed to prevent fouling on the membrane. Also, cellulose acetate membranes are designed to tolerate low concentrations of chlorine, unlike polyamide membranes, which begin to nearly instantly deteriorate when it comes into contact with chlorine.

Post-Treatment

The post-treatment process in reverse osmosis can be broken down into two separate processes: the post-treatment of the permeate, or the treated water, and the post-treatment and disposal of the concentrate, the waste.

Post-Treatment of the Permeate

The reverse osmosis process produces permeate that generally requires post-treatment. Post-treatment includes adjusting the alkalinity and pH, removing dissolved gases and disinfection. The water produced in the pre-treatment phase, prior to the reverse osmosis process, has an acidic pH, low hardness, and low alkalinity, which all cause the water to become corrosive to the piping. These conditions are unfavorable and must be removed in a post-treatment phase. In addition to the low levels of pH, hardness and alkalinity, hydrogen sulfide (a dissolved gas) is often present in the feed water and must be removed in post-treatment. Hydrogen sulfide is a compound that is not removed during the RO process, and it causes the treated water to have a strong, undesirable odor.

Permeate Stability

The main process in the post-treatment stage reverse osmosis is to increase the stability of the permeate, which simultaneously reduces the corrosivity. In the pre-treatment stage the permeate is acidified with antiscalants to control scaling, which lowers the pH to acidic levels. Adding antiscalants also converts the alkalinity to carbonic acid in the permeate, greatly reducing the alkalinity levels in the water. To adjust the pH and alkalinity to acceptable levels, caustic soda is often added to the water. The El Paso Desalination Plant adds caustic soda to restore pH levels to 7.5 (El Paso Water Utilities Power Point). The addition of caustic soda does not reduce the corrosivity of the water, so therefore additional measures must be taken when using caustic soda. Adding a base containing calcium is often preferred over caustic soda, because it improves the stability (reduces the corrosivity) of the permeate by adding hardness ions, in addition to adjusting the pH and alkalinity to tolerable levels. Another method used for producing stable water with acceptable levels of pH, alkalinity and hardness, is to blend the permeate with a stream of properly treated raw water. When blending water, the disinfection byproduct (DBP) concentration in the raw water, as well as the probability for DBP formation to occur in the finished water must be evaluated before choosing the blending option. The post treatment process for Lake Whitney's permeate will have to consist of either adding a base or blending it with treated water to restore the pH back to an acceptable level of 7 or slightly above and reduce the corrosivity of the water.

Disinfection

Disinfection of the permeate is the last step in the post-treatment process before the permeate is distributed municipally. Disinfection is necessary to eliminate any bacteria that may have bypassed the reverse osmosis process into the treated water. Ultraviolet radiation, chlorination and chloramination (chlorine and ammonia) are all methods of disinfection, however chlorination is the most commonly used.

Disposal of the Concentrate

In the United States, half of the desalination plants discharge to surface water, a third discharges to a municipal sewer and 10 percent discharges by deep-well injection (Water Treatment 1495). In addition to these three disposal methods, the use of evaporation ponds is another alternative method used to dispose of concentrate. The desalination plant in El Paso, TX uses deep-well injection to dispose of their concentrate, because it is significantly less expensive than the other disposal options (Archuleta). In Texas, the deep-well injection process, as well as the other methods, requires a permit from the Texas Commission on Environmental Quality (TCEQ) (Archuleta). Before the deep-well injection process can be approved by the TCEQ, the geologic and hydrologic conditions of the area must be studied. The TCEQ requires drilling test holes, completing geophysical and seismic work and taking water samples at the site before it can be approved.

Discharging the concentrate to surface water or a municipal sewer would not be suitable due to the high salinity concentrations already present in the lake. The current salinity concentration of 1.11 g/L exceeds the EPA's drinking water standard for salinity of 0.5 g/L. The high salinity concentration in the concentrate has toxic characteristics and may diminish plant life, as well as have harmful effects on human and animal health if consumed. In addition to discharging to surface waters or a municipal sewer, deep-well injection is also not a suitable disposal method because it poses a risk of potentially contaminating the groundwater. Groundwater is currently the main drinking water source for Whitney, Texas, and residents may be hesitant due to the possibility of groundwater contamination. Consequently, evaporation ponds will most likely be the disposal method employed, since it does not create a risk of potentially contaminating either groundwater or surface water sources.

Factors affecting concentrate disposal

Volume, salinity/toxicity and regulations are all factors that may affect concentrate disposal methods. The waste stream volume from reverse osmosis systems can range from 15 to 50% of the feed stream volume, as compared to other water treatment processes, such as wastewater and drinking water treatments, which have waste steam volumes of less than 5% of the feed stream (Water Treatment Principles and Design 1496). The waste stream specifically from reverse osmosis systems used for desalination, has high salinity levels and chemicals used to prevent scaling and fouling, which causes the water to be toxic to humans, plants and animals if discharged onto surface waters. This will be a major concern for the concentrate produced from desalinating the water from Lake Whitney, due to the high levels of salinity already present in the lake, as well as the addition of chemicals to prevent scaling and fouling. Although the salinity and total dissolved solids (TDS) concentration can be harmful to humans, plants and animals, it is not classified as "hazardous." Laws including the Clean Water Act (CWA), the Safe Drinking Water Act (SDWA) and National Primary Drinking Water Regulations, established by the EPA, list priority water pollutants, and specify the maximum allowable concentration of contaminants in water. The maximum concentration of TDS in drinking water is 500 mg/L, and any concentration greater than 500 mg/L could be potentially harmful (EPA). The CWA authorizes the National Pollutant Discharge Elimination System (NPDES), which is a permit program that regulates point sources, such as pipes, where polluted water is discharged into surface waters. This system specifies that not only can this waste be dangerous in drinking water, but it can also contaminate surface waters, causing them to be unsafe for fishing, swimming and other water activities.

Electrodialysis

Electrodialysis is an electrochemical separation technique used for ionic solutions. Electrodialysis has some advantages over reverse osmosis in terms of requiring a lower level of water pretreatment process, reduced membrane replacement frequency and lower energy costs. However, this method of desalinization is hindered by the inadequate membrane materials and membrane quality available.

Electrodialysis (ED) is an electromembrane process in which ions are transported through ion permeable membranes from one solution to another under a given current/influence of a potential gradient. Commonly this method of desalinization is used in industry to make potable water from brackish water and remove metals from wastewater. Since Lake Whitney is concerned with separating the high salt concentration from the water that is currently making the water too saline for consumption, electrodialysis is a possible solution. The following paragraph describes the processes involved in electrodialysis.

Pretreatment

With a high turbidity and chlorophyll content, a pretreatment such as filtration is necessary to have a useable feed. Scaling, the precipitation and deposition of solids, would need to be prevented before the actual electrodialysis takes places because lead elements of the removal are the most susceptible to the scaling and fouling and when a layer of scale forms it helps to exponentially create more scaling. Calcium carbonates present in the water create a large scaling possibility for the membranes. Pretreatment options include the addition of acids to ensure that the carbonates will not scale on the membrane; this will also lower the pH. In addition, chemically induced flocculation, microfiltration and ultrafiltration can be utilized to remove particulates and bacteria along with organics (EET Crop). Pretreatment for ED is done to reduce the resistances of concentration polarization and ohmic polarization, to avoid scale forming by salt deposit, to remove from supply water the materials of a colloidal nature which would otherwise deposit on the diaphragms, and to raise the density of actual current (while increasing the amount of product and decreasing the specific consumptions of energy and chemical reactants).

The Electrodialysis Stack

The Electrodialysis stack is where the desalinization takes place. The stack is made up of alternating anion and cation membranes separated by proprietary spacers or gaskets which are then separated in between an anode and a cathode. The spacers consist of a fabric that is sealed and filled with electrolytes. The varying membranes never touch due to the spacer fabric. There is an electrical potential difference across these positively and negatively charged membranes which causes the selective transport of ions from one solution to another. The membranes are stacked within two electrode-end blocks, which also house the inlets, outlets and the electrical connections. The whole stack unit is then held together by a steel frame as is shown in Figure 5 (Ameridia).

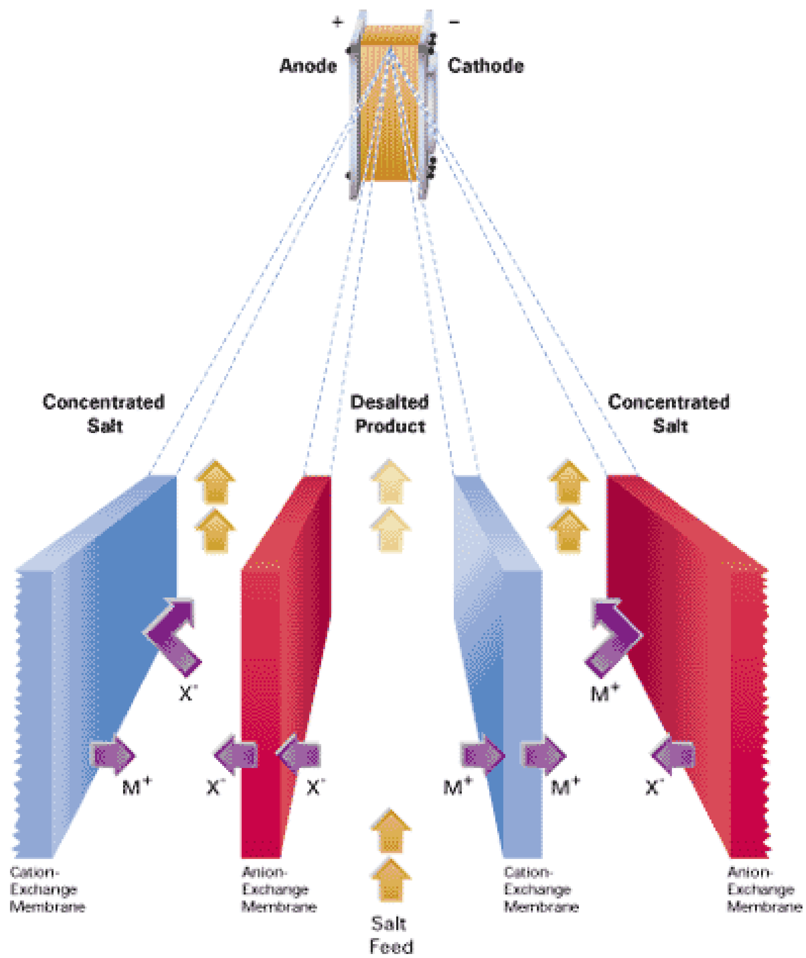

Figure 5. Schematic of Electrodialysis Stack

http://www.ameridia.com/html/elep.html

Membranes

Regardless of which type of membrane the stack is comprised of, the membranes are composed of 60-70% ion-exchange resins. As a result, the membranes are solid, strong, hydrated electrolytes. Membranes for this process last about 10 years before they need to be replaced. Cleaning the membranes prolongs the life of the membrane and improves the quality of the output. Generally cation membranes last longer than anion membranes because anion membranes are more susceptible to oxidation (Water Reuse 507).

Separation

The solution that is being treated is fed into the electrodialysis cell and then a direct current (DC) voltage, generated by batteries, thermocouples, solar cells, and/or commutator-type electric machines is applied. With the electrical charge flowing in one direction, the anions and cations are passed through exchange membranes in which anions and cations are only permeable to anion exchange membranes or cation exchange membranes, respectively. The membrane properties determine whether an ion is allowed to pass through or is rejected. One cycle through the stack is usually not enough to treat the water fully so the water has to travel several times through the stack (Polymerchemie Altmeier).

There are several different ways that electrodialysis can be done in order to fill the multiple cycle requirement. These processes include batch desalination/batch-recirculation, continuous mode and feed and bleed. The details of these processes are summarized in the table below.

	Process	**Advantages**	**Disadvantages**
Batch Desalination/Batch-Recirculation Process	A fixed volume of the feed solution is cycled through the stack until the required amount of salt is removed	• Varying salinity/temperature do not affect quality or optimum velocity of the production rate • Simplest process	• High power consumption • Requires recirculation reservoirs and a lot of piping • Density varies through membranes • Membranes do not operate at equilibrium
Continuous Mode	Fresh feed enters the unit and final product flows out simultaneously with no recycling necessary	• Greater degree of demineralization due to parallel stacks • Minimum power requirements • No recirculation reservoir • Minimum piping	• Increased membrane sensitivity due to varying salinity/temperature • Control of the feed velocities • Gives a final diluate beyond the range of modular units
Feed and Bleed	Continuously blends a portion of the product stream with the feed solution	• Always a continuous product that can accept feed water • Membranes always at equilibrium • Minimum current density	• High power consumption • High cost due to sophisticated process controls • Only applicable to large-scale systems

In light of the data retrieved from the lake, the batch desalinization/batch recirculation process would be best suited to Lake Whitney. The salinity levels within the lake fluctuate from month to month, from year to year, and also from location to location. Temperature also fluctuates throughout the lake and seasons, as can be seen from the 2006-2007 year data the temperature can range from 32.11°C (August 2006) to 7.01°C (January 2007). The final outcomes of all these different modes of the electrodialysis process are the diluate and the concentrate stream. The desalted stream can be used as drinking water where the concentrate stream is comparable to salt brine. Depictions of the processes are presented below in Figures 6 and 7:

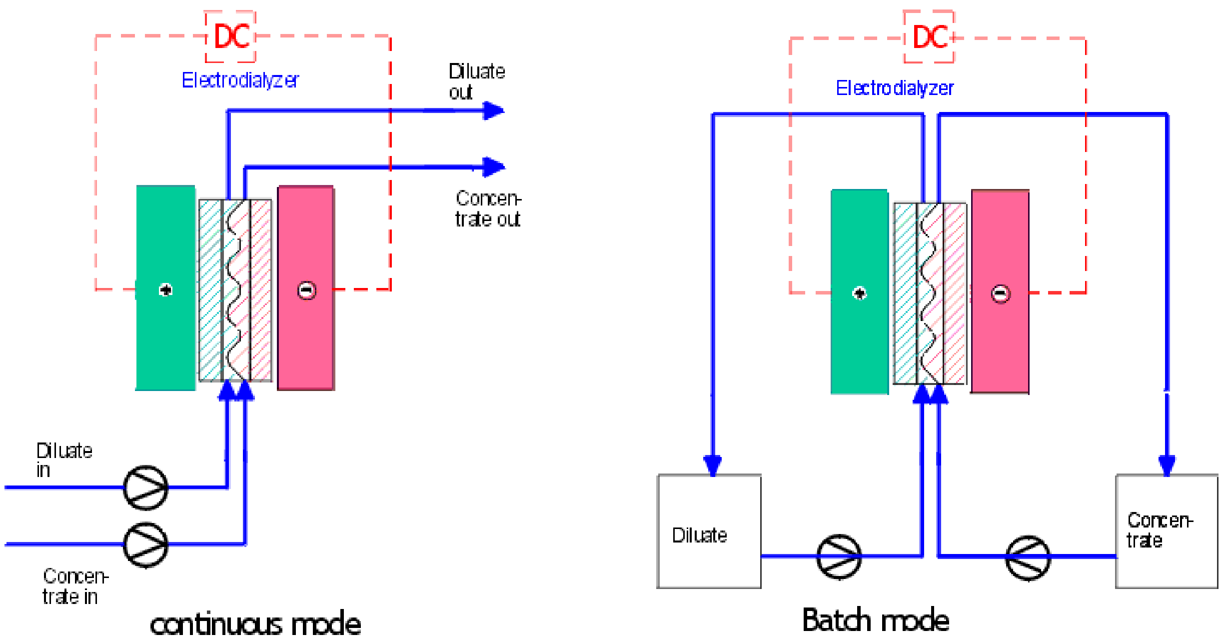

Figure 6. Continuous Mode and Batch Mode Electrodialysis Circuits

www.pca-gmbh.com/appli/ed.htm

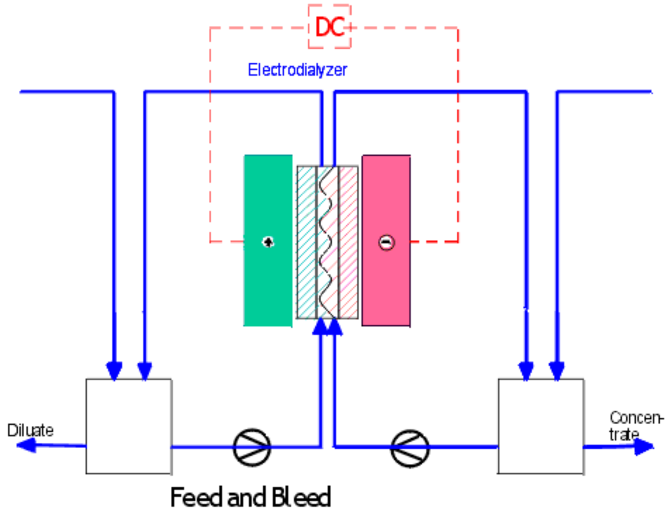

Figure 7. Feed and Bleed Electrodialysis Circuit
www.pca-gmbh.com/appli/ed.htm

System Performance

Throughout the electrodialysis process there is a depletion of ions in certain regions of the chamber. Consequently the electrical resistance increases, which is directly correlated to the salinity limit of the final diluate product. This resistance can be overcome by increasing the temperature of the system. Build-up of solids, due to ions precipitating as a result of a change in pH, over the membrane surface also increases resistance and can cause fouling but within Lake Whitney there is not a large change in pH annually, which is necessary for this to occur (Water Reuse 342). The yearly highs are in the pH range of 8 and the annual lows are in the range of 7. Thus ion precipitation should not occur due to a change in pH, ensuring the membranes are kept clean and efficiently working.

Fouling

Chemical precipitation of the salts with low solubility and organic matter can clog the membrane. Calcium carbonate concentrations within the lake, found in deposits along the sides of the lake would cause precipitation on the membrane, thus fouling the membrane and possibly altering the effectiveness of the electrodialysis membranes. Clean-in-place systems can circulate hydrochloric acid solution to reduce mineral scale and also circulate sodium chloride solution to balance pH and remove organic materials (Water Reuse 356). Also, pulsed electric fields have shown no fouling in the same scenarios in which DC voltage showed fouling.

Energy Consumption

The minimum work necessary for an electrodialysis system is approximately 5.26kWh/m^3. With work requirement from 5.26kWh/m^3 to 6.6kWh/m^3 the approximate cost of the water would be \$1.05/m^3. With greater system optimization, researchers have noted that the energy required could go as low as 5 kWh/m^3 (Turek).

Applications

Desalination of brackish water is the main use of electrodialysis. Electrodialysis systems can range from supplying individual homes to entire communities, such as is the case for Lake Whitney. This process is most effective with salt concentrations of 10,000 ppm and below. This method for salt removal also works best when the total dissolved solids (TDS) are less than 10 g/L (Water Reuse 467).

Advantages Compared to Reverse Osmosis

Significantly higher brine concentration can be achieved through a properly configured electrodialysis than by reverse osmosis. Scaling (i.e., precipitation of insoluble di- or multivalent salts such as calcium sulfate) is less severe in electrodialysis than in reverse osmosis since monovalent ions are typically transported through the ion exchange membranes faster than multivalent ions, resulting in a brine less concentrated in the multivalent ions and so having less scaling potential. In contrast to reverse osmosis, electrodialysis becomes more costly than reverse osmosis when extremely low salt concentrations in the product are required. Since there are fewer ions in the solution, ion transport and energy efficiency greatly decline. Therefore with electrodialysis large membranes are needed for low concentrations of feed solutions.

Advantages	Disadvantages
Electrodialysis	
• Minimal pretreatment may be required (cartridge filtration is recommended) • Operates at a low pressure • Process is much quieter because high pressure pumps are not required • Antiscalant is not required • Membrane life expectancy is longer because foulants are removed continuously during the reversal process • Requires less maintenance than RO due to reversal process	• Limited to 50 percent salt rejection for a single membrane stack (stage) • Requires larger footprint to produce similar quantity and quality of water if multiple staging is used • Electrical safety requirements • Less experience for wastewater demineralization in the U.S. • Not as effective at removing microorganisms and many anthropogenic organic contaminants
Reverse osmosis	
• RO membranes provide a barrier to microorganisms and many anthropogenic organic contaminants (for the treated portion of the water produced) • More demonstrated experience for wastewater demineralization • RO membranes can remove more than 90 percent of TDS • Source water blending will reduce size of systems • Flexibility to provide higher quality water, if desired	• Requires high pressure to achieve high salt rejection • Requires pretreatment processes to minimize scaling and fouling • Requires chemical addition for MF & RO fouling control • More routine maintenance may be required to maintain performance

[a]Adapted from Adham et al. (2004).

Conclusion

Overall, both reverse osmosis and electrodialysis are viable options for desalinating Lake Whitney's brackish water and transforming it into a major drinking water source for Whitney and surrounding cities. The pH, salinity, chlorophyll concentration and turbidity are key factors in determining whether reverse osmosis or electrodialysis can be used to desalinate the brackish water in Lake Whitney. Based on the current data for these four factors, it is necessary for the reverse osmosis and electrodialysis systems to be designed with consideration of how the pH, salinity, chlorophyll and turbidity might impact the effectiveness of the system. Lowering the pH by adding either sulfuric acid or hydrochloric acid to the brackish feed water is crucial during both pre-treatment and post-treatment stages. Also, salinity, chlorophyll concentrations and turbidity are important factors when choosing the type of membrane, as well as the material on the membrane surface, because they all have the potential to cause scaling, fouling and ultimately membrane degradation. Although samples have been taken of contaminants that will affect the design of the future reverse osmosis system, additional data that further examines factors such as algae blooms, metal concentrations and energy consumption of the hydroelectric dam on site will better assist in the design of the plant.

Regional Solutions

While technical solutions would serve well to supply drinking water to the town of Whitney, a larger, more regional solution would be needed to affect a larger range of communities. Physical restrictions such as dams are a means of reducing the concentration of salt in Lake Whitney that would allow a larger area to benefit from the cleaner water. This section will detail the requirements for creating a damming system on the Brazos River that would achieve this goal.

Salt Impoundment Dams

Our hypothesis is that salt impoundment dams placed at the boundaries of several highly saline tributaries upstream from Lake Whitney would filter out much of the salt load entering the lake. Once the lake's tributaries have been dammed, a salt load should accumulate at the dam site, and the remaining water input into Lake Whitney from the tributaries that have not been dammed should be more diluted and thus far less saline than the water was originally.

To test the efficacy of this theory, we use salinity data from the U.S. Geological Survey (USGS) and examine a report by the U.S. Army Corps of Engineers (USACE) that previously considered damming three of the most saline tributaries into Lake Whitney and analyzed various regulating parameters to determine the most effective method of reducing salt load in the lower regions of the Brazos River Basin. Subsequently, we will analyze their results as well as consider salinity projections presented by salinity modeling techniques (i.e. WRAP-SALT).

Data on the Brazos River Basin

Figure 8 below shows a map of the rivers and tributaries in the Brazos River Basin that the US Geological Survey tested for salinity over a span of several years. Lake Whitney is represented by site location number 15. The proposed salt dams that will be discussed later in this report are located in the upper region of the Brazos River Basin.

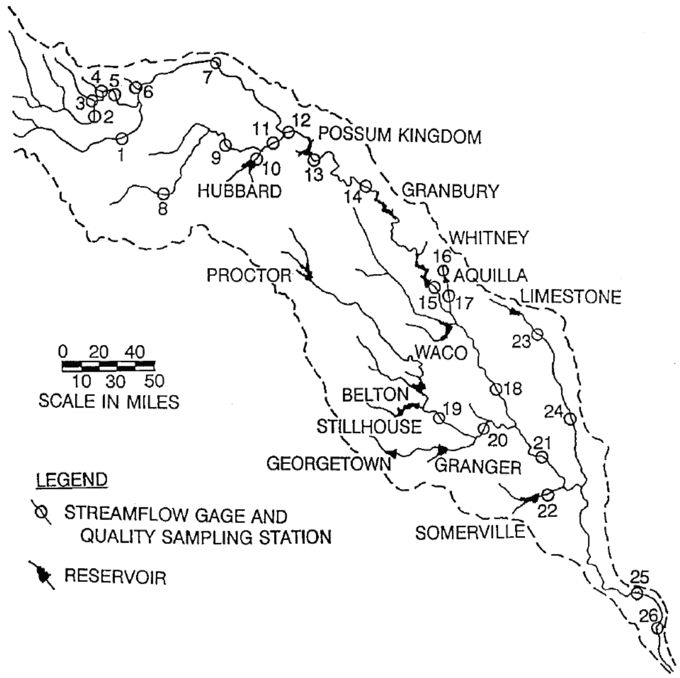

Figure 8. Map of Sampling Stations in the Brazos River Basin used by the USGS

The U.S. Public Health Service has established standards for drinking water, recommending chloride concentrations in municipal water supplies to be below 250 ppm. TDS, the measure of total dissolved solids including any number of mineral ion pollutants including chloride and sulfate, is recommended to be below 500 ppm. TDS is widely accepted as an indicator of water quality and is a common parameter used in determining the palatability of water supplies. According to the USACE in the mid-1970s, the concentration of sulfate at the mouth of the Brazos River was just below 250 ppm, which according to the U.S. Public Health Service is the lowest palatable concentration. As you travel up the Brazos River closer to the water sources that we will be investigating, the salinity concentrations are even higher due to the lack of water outflow and dilution which occurs at the river mouth near the gulf. (USACE 66-75).

As shown in Figure 8 above, the upper Brazos River has three main branches, the Salt Fork (stations 2 & 5), the Double Mountain Fork (station 1), and the Clear Fork (stations 8, 9, & 11). The Salt Fork has been determined to be too saline for any municipal use and contributes the most natural salt in the Brazos River system compared to any other tributary (USACE 80). The Double Mountain Fork is not as saline as the Salt Fork but still has salinity concentrations high enough to be ruled out for possible municipal or industrial uses. The Clear Fork is the least saline in comparison to the Salt Fork and Double Mountain Fork, but at times still exceeds the acceptable salinity constraints due to increased brine from oil production (USACE 80). These branches/tributaries are major contributors to the salt concentration of the entire Brazos River Basin, and with Lake Whitney being the largest lake within the basin (~2,000,000 acre-feet of storage) it has the "potential to fulfill about 1,600,000 acre-feat of the annual 2020 requirements (USACE 90)." Therefore, by pinpointing and regulating these highly saline tributaries within the upper branches of the basin, salinity concentrations then can be decreased in the lower portions of the basin. This overall effect is desirable since Lake Whitney is a part of this lower system of the Brazos River Basin.

Data was compiled on Lake Whitney (specifically TDS, chloride, and sulfate) in order to better understand the salt loads and concentrations within the Brazos River Basin. Much of the data was acquired via the National Water Data Storage and Retrieval System, which is maintained by the USGS. Multiple sampling stations, including a station at Lake Whitney, were placed through the river system in order to acquire monthly salinity statistics over several years. Total dissolved solids, discharge, chloride, and sulfate loads were measured in terms of tons/day and cubic feet/second (cfs), while concentration units are in mg/L. Concentration, discharge, and load are related by the equation: concentration = load/discharge.

Figure 9 shows that over the period of 1964-1986 the mean discharge of Lake Whitney was 1,230 cfs. For the same period of record, sulfate, TDS, chloride, and loads were 3,075, 1,134, and 591 tons/day, and mean concentrations of sulfate, TDS, chloride, and where 178, 928, and 342 mg/l correspondingly (Figure 10-12).

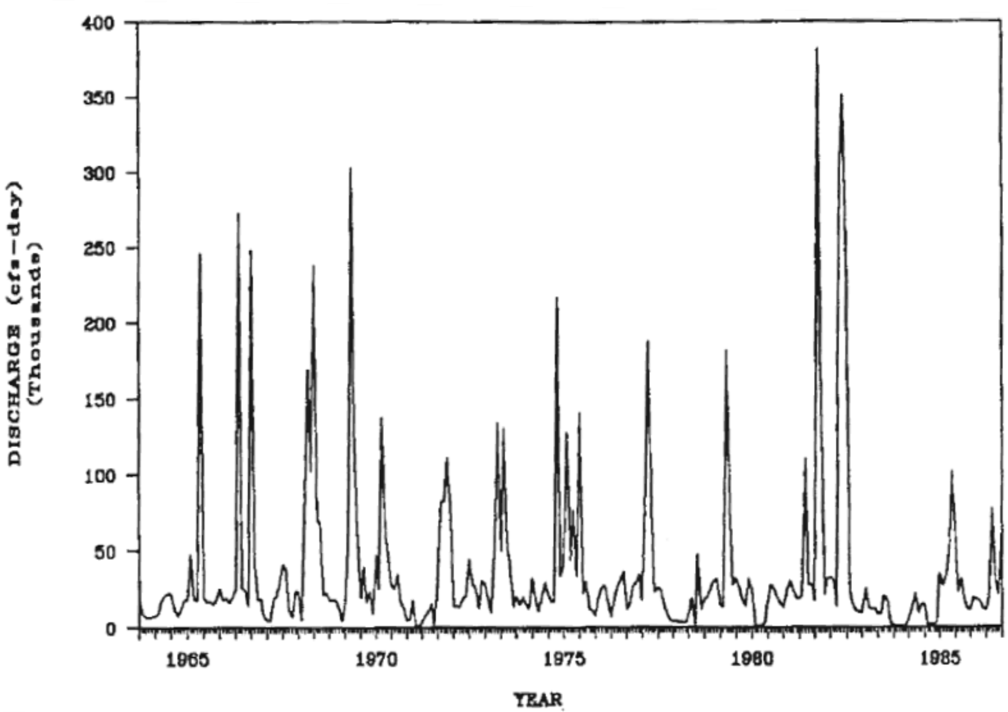

Figure 9. Discharge Hydrograph, Whitney Gage (Station 15)

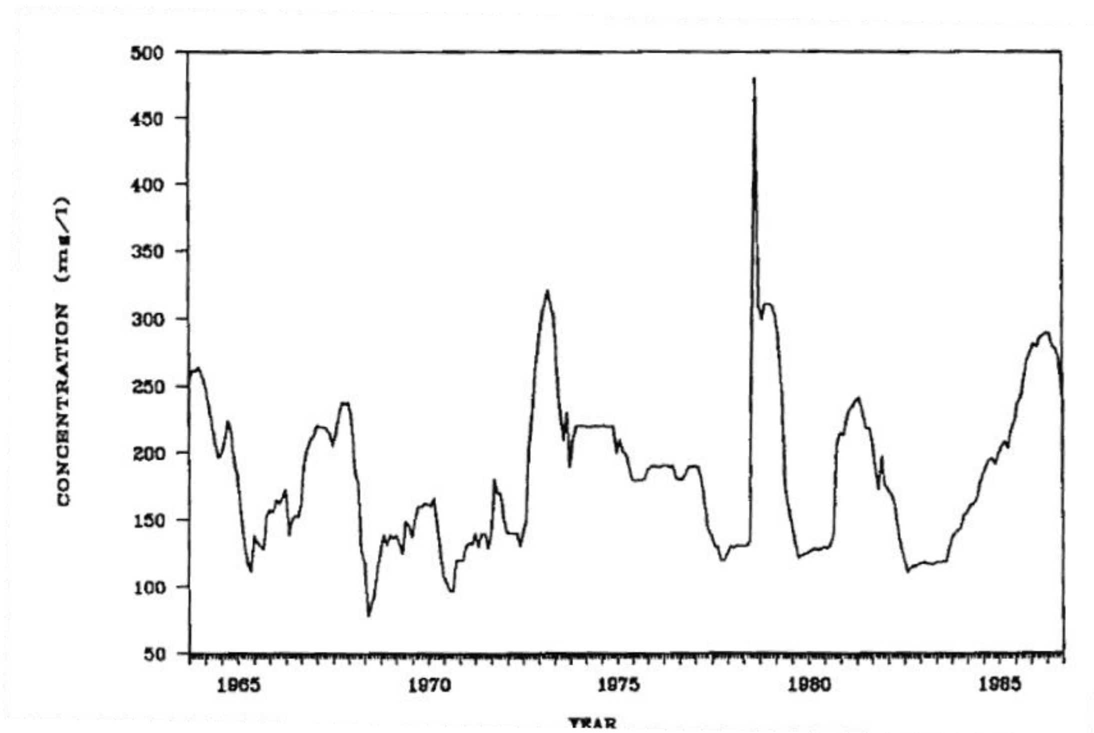

Figure 10. Sulfate Concentration Versus Time, Whitney Gage (Station 15) (TWRI 33)

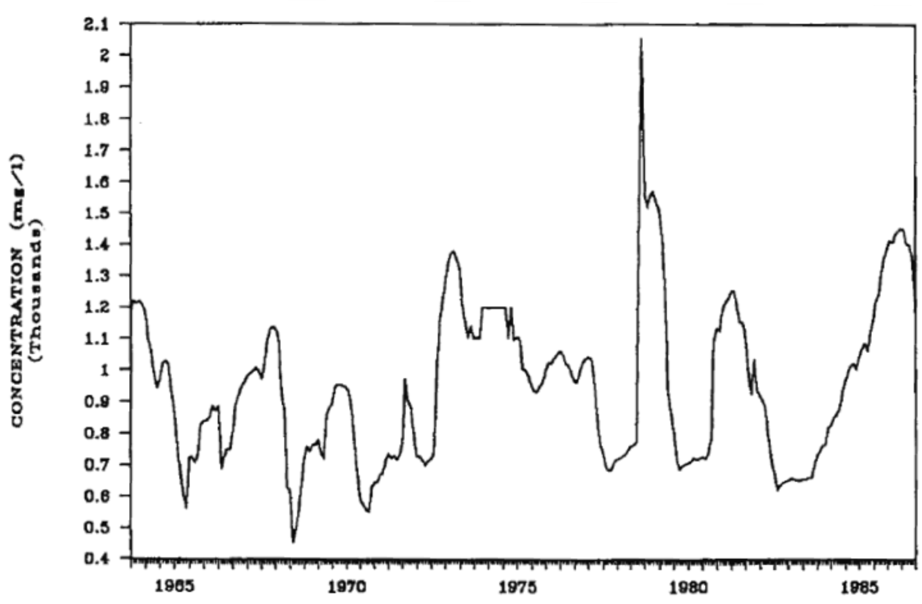

Figure 11. TDS Concentration versus Time, Whitney Gage (Station 15) (TWRI 32)

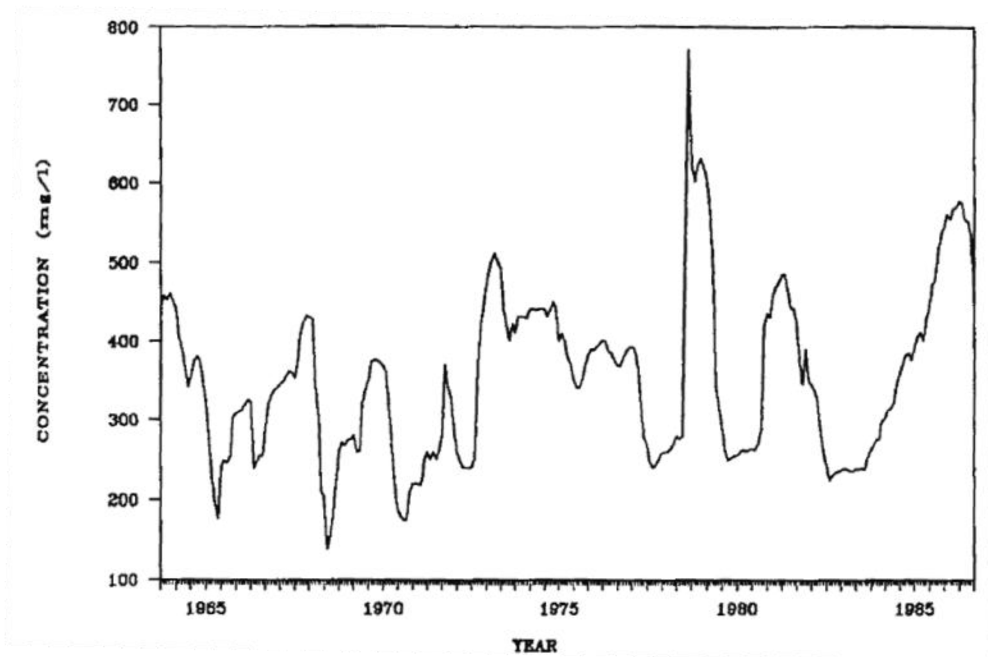

Figure 12. Chloride Concentration versus Time, Whitney Gage (Station 15) (TWRI 32)

The entire range of data (which includes years prior to 1964) is presented in annual averages of TDS, chloride, and sulfate in Figure 13. Annual Average Concentrations, Whitney Gage (Station 15) (TWRI 39)
13.

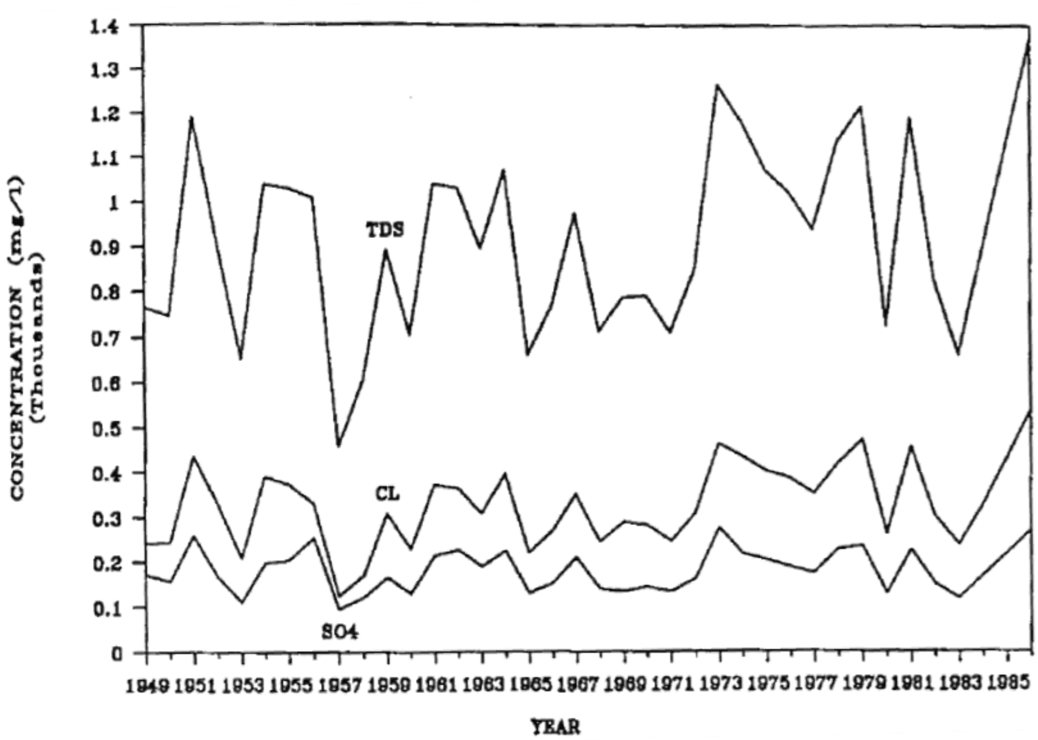

Figure 13. Annual Average Concentrations, Whitney Gage (Station 15) (TWRI 39)

Concentration duration curves were also computed with the available data for the period of 1964-1986 (Table 1- Table 3), and a composite data is shown in Table 4.

Table 1. Concentration-Duration Curves for Total Dissolved Solids (TWRI)

Percent Equalled or Exceeded	Seymour Gage (mg/l)	Possum Kingdom Gage (mg/l)	Whitney Gage (mg/l)	College Station Gage (mg/l)	Richmond Gage (mg/l)
0.01	15,400	2,810	2,050	1,360	978
0.05	15,400	2,810	2,050	1,360	978
0.1	15,400	2,810	2,050	1,360	978
0.2	15,400	2,810	2,050	1,360	978
0.5	15,000	2,800	1,580	1,260	910
1	14,500	2,710	1,560	1,040	902
2	13,700	2,540	1,520	1,010	845
5	12,700	2,420	1,400	870	701
10	11,900	2,290	1,250	763	635
15	11,000	2,190	1,210	704	601
20	10,500	2,090	1,170	659	566
30	8,530	1,890	1,070	596	498
40	7,320	1,780	1,000	557	426
50	6,220	1,620	945	505	382
60	5,270	1,510	864	448	346
70	4,320	1,420	750	412	317
80	3,320	1,350	723	370	264
85	2,800	1,300	699	339	250
90	2,420	1,130	666	313	235
95	1,870	948	639	270	218
98	1,400	739	567	238	198
99	1,290	583	552	231	169
99.5	1,190	508	487	228	164
99.8	817	500	476	225	161
99.9	774	495	472	223	160
99.95	742	492	469	221	159
99.99	692	486	464	218	157
100	618	475	456	212	153

Table 2. Concentration-Duration Curves for Chloride (TWRI 33)

Percent Equalled or Exceeded	Seymour Gage (mg/l)	Possum Kingdom Gage (mg/l)	Whitney Gage (mg/l)	College Station Gage (mg/l)	Richmond Gage (mg/l)
0.01	7,740	1,100	771	512	355
0.05	7,740	1,100	771	512	355
0.1	7,740	1,100	771	512	355
0.2	7,740	1,100	771	512	355
0.5	7,270	1,100	637	370	340
1	6,850	1,100	625	364	328
2	6,530	1,000	612	353	290
5	6,110	989	551	288	213
10	5,760	949	484	250	192
15	5,270	892	451	220	176
20	4,850	844	437	198	162
30	3,810	756	400	173	135
40	3,240	706	376	154	108
50	2,610	652	350	134	93
60	2,210	594	316	113	80
70	1,690	562	270	91	67
80	1,290	522	256	79	55
85	1,080	503	247	69	49
90	851	447	236	60	43
95	647	362	218	41	36
98	455	282	176	35	34
99	339	223	169	32	33
99.5	297	195	156	30	32
99.8	271	192	148	28	31
99.9	256	190	146	27	31
99.95	244	189	145	26	30
99.99	224	187	143	24	30
100	190	183	139	20	28

Table 3. Concentration-Duration Curves for Sulfate (TWRI 34)

Percent Equalled or Exceeded	Seymour Gage (mg/l)	Possum Kingdom Gage (mg/l)	Whitney Gage (mg/l)	College Station Gage (mg/l)	Richmond Gage (mg/l)
0.01	2,220	582	481	262	185
0.05	2,220	582	481	262	185
0.1	2,220	582	481	262	185
0.2	2,220	582	481	262	185
0.5	2,090	582	325	239	172
1	2,040	574	317	213	166
2	2,010	547	313	191	157
5	1,910	501	291	170	124
10	1,800	481	267	143	113
15	1,720	459	237	133	105
20	1,640	436	228	121	98
30	1,400	396	214	109	86
40	1,300	364	195	100	73
50	1,160	328	181	90	64
60	986	309	160	80	58
70	854	289	141	72	51
80	686	273	132	62	45
85	604	258	127	57	40
90	539	219	122	51	37
95	367	180	116	41	33
98	281	147	103	39	29
99	224	118	93	38	27
99.5	145	99	83	38	25
99.8	137	98	80	37	25
99.9	132	97	79	37	25
99.95	128	97	79	37	25
99.99	122	96	79	36	24
100	112	94	78	35	24

Other tools used include linear regression analysis and slope change by observation of accumulated mass plots in order to distinguish any overall variations or trends in the salinity data. Arithmetic averages of monthly TDS and chloride concentrations were computed and shown in Figure 14. Arithmetic Average of Monthly TDS Concentrations (TWRI 45)
14 and Figure 15.

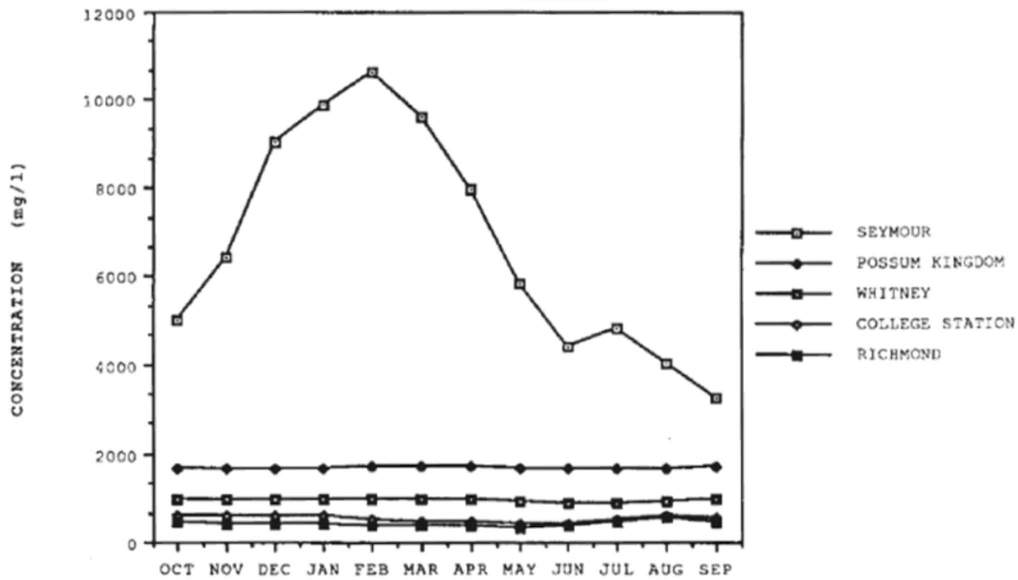

Figure 14. Arithmetic Average of Monthly TDS Concentrations (TWRI 45)

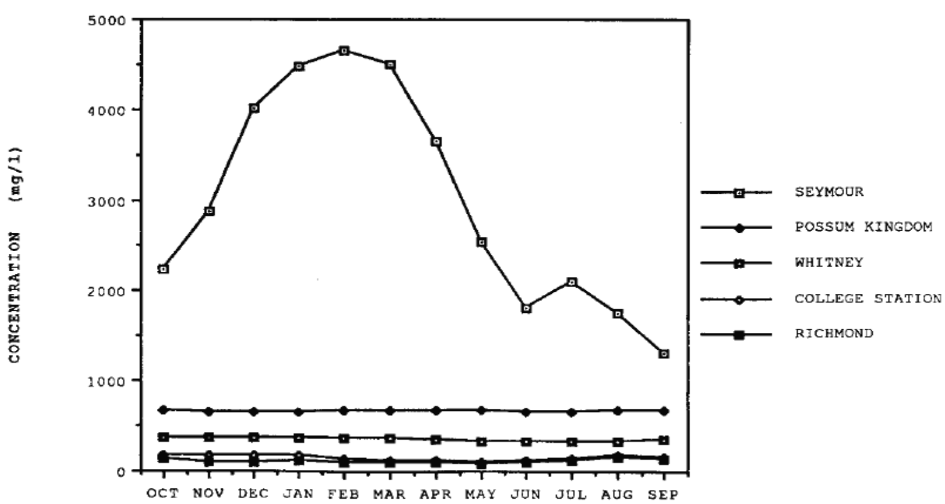

Figure 3.32 Arithmetic Average of Monthly Chloride Concentrations

Figure 15. Arithmetic Average of Monthly Chloride Concentrations (TWRI 45)

Some gage points showed seasonal concentration variations, specifically the Seymour gage, but Lake Whitney's salinity data depicted a minimal amount of fluctuation. The entire salinity data set also shows no major trends and demonstrates mostly random variance; suggesting that salinity levels in this area are very unpredictable.

As stated in the Texas Water Resources Institute Report and implied in the opening statement of this report, major changes have occurred in the past decades that have contributed to the rise in salinity concentrations and the increased loads of the Brazos River system and Lake Whitney. Man-made projects such as reservoirs, oil fields, and water supply use (municipal, industrial, and agricultural) have been a major factor in the increase in salinity levels. The need for a feasible solution to decrease the salinity in Lake Whitney in order to meet regulations for its use as a drinking water supply led to the ideas proposed in the USACE report on salt control impoundments.

Table 4. Mean Discharges, Loads, and Concentrations for Comparable Time Periods

Study Station Number	Abbreviated Station Name	Tributary	Years of Record	Mean Discharge (cfs)	Load (tons/day) TDS	Load (tons/day) Cl	Load (tons/day) SO4	Concentration (mg/l) TDS	Concentration (mg/l) Cl	Concentration (mg/l) SO4
1	Aspermont	Double Mountain Fork	1964-86	126	580	153	209	1,540	416	548
2	Peacock	Salt Fork	1965-86	40	684	339	81	5,782	2,830	698
3	Jayton	Croton Creek	1964-86	13	225	93	53	6,391	2,541	1,591
4	Aspermont	Salt Croton Creek	1969-77	4	676	425	33	56,923	32,856	2,273
5	Aspermont	Salt Fork	1964-82	60	1,660	1,094	219	12,407	6,066	1,235
6	Knox City	North Croton Creek	1966-86	17	211	80	58	4,723	1,786	1,323
7	Seymour	Main Stem	1964-86	269	2,601	1,074	504	3,591	1,482	696
13	Possum Kingdom	Main Stem	1964-86	686	2,795	111	571	1,512	601	309
15	Whitney	Main Stem	1964-86	1,230	3,075	1,134	591	928	342	178
20	Cameron	Little River	1964-86	1,481	1,024	123	119	256	31	30
21	College Station	Main Stem	1964-83	4,529	5,348	1,368	938	438	112	77
25	Richmond	Main Stem	1964-86	6,868	6,267	1,466	1,030	339	79	56

Engineering Solution-Salt Impoundment

Three major studies were reviewed to compile information on the feasibility of the use of salt impoundments in the Brazos River Valley area. These studies were performed by the United States Army Corps of Engineers (USACE), the Texas Water Resources Institute (TWRI), and the Texas Commission of Environmental Quality to provide data on the current state of the Brazos River and its tributaries and what may be done to improve the quality of water. Our analysis of their data and report that are pertinent to city of Whitney will be presented in the following sections.

United States Army Corps of Engineers (USACE)

Salt impoundments can be used to control or interrupt stream patterns for the betterment of the resource pool, ultimately controlling salt water pollution. Different impoundments were investigated for possible implementation. “One type, called total impoundments, is designed to stop all flow on a stream including the 100-year flood” (USACE 106). The problem with total impoundments is that they have to be very large to hold all water, brine, and sediments that will be permanently stored (USACE 106). Low flow impoundments “include low dams with inflatable weirs to detain stream flow for pumpage to a total impoundment site” (USACE 106). The final type of impoundment that was evaluated was diversion impoundments, which “stop all fresh flow from passing downstream similar to the total impoundment, but the water would be routed across stream divides to reenter the Brazos River” (USACE 106). Installing salt impoundments is preferable to other methods of reducing salinity, such as dilution, pipeline transfer, desalination, storage in nuclear cavities, sealing salt springs, and deep well injection, because of their limited impact on the ecosystem and minimal reduction of flow. Alternatives, such as moving stored brine water, could have adverse effects on the new storage area and uses (USACE 273-275).

There were six plans for positioning salt impoundments in the Brazos River Basin analyzed by the U.S. Army Corps of Engineers in the 1970s. A comparative analysis was performed in order to identify the best plan for decreasing salinity levels. The six possible plans that the USACE analyzed were as follows:

Plan 1 consists of nine impoundments throughout the upper region of the Brazos River Basin; these impoundments are small to moderate in size. The impoundments would focus on highly saline water outflows of the McDonald Creek, Verbena Canyon, Red Mud Creek, Salt Creek of the Salt Fork, Salt Creek of the Double Mountain Fork, Croton Creek, Salt Croton Creek, Stinking Creek, and North Croton Creek.

Plan 1A is a derivative of Plan 1, and it is focused on additional water quality improvements by adding a diversion tunnel from Croton Creek to North Croton Creek, which is in the Brazos River. It consists of “five total impoundment reservoirs, four low-flow dams, one fresh water diversion dam, and one fresh water supply reservoir” (USACE 228).

Plan 2 has more diversion capacity. It “consists of four total impoundment reservoirs, two low-flow dams, and three fresh water diversion dams” (USACE 228).

Plan 2A was a combination of “four total impoundment reservoirs, two low-flow dams, and two fresh water diversion dams” (USACE 233).

Plan 3 focused on providing maximum salt control as well as maximum diversion capabilities. It has “three total impoundment reservoirs, one low-flow dam, and three fresh water diversion dams” (USACE 234).

Plan 3A was comprised of three impoundment reservoirs, one low-flow dam, and two fresh water diversion dams.

Plan 4 had five impoundment reservoirs, one of them for fresh water supply, and two low-flow dams.

Plan 4A was a combination of four impoundment reservoirs without the low-flow dams or fresh-water reservoirs. This plan consisted of sites 10, 14, 19, and 20.

Plan 4B focused on maximum salt control with the least expenditure and minimizing adverse effects on the environment. It contains all the impoundment sites of 4A except for site 20.

Plan 5 had four impoundment reservoirs, one of which is a fresh-water reservoir, and one low-flow dam. Water held in the low-flow dam is pumped out to the Salt Fork.

Plan 6 had three impoundment reservoirs, no low-flow dams, and no fresh water diversion dams. This plan represents the lower bounds of salinity control.

The USACE determined that while plan 4B had less quality improvement than plan 4A, the recommended solution would be 4B due the degree of balance between desalination, environmental impacts, and ultimately the cost of implementation. The following is a more in depth report on each element of what plan 4B entails.

Dam site 10 is on Croton Lake (site 3 from Figure 8) and would be the second largest impoundment in the plan. The location would be in northwestern Stonewall and northeastern Kent Counties. The impoundment would be limited to an elevation of approximately 1793 ft. Water at dam site 10 would have to pumped at an 11 cfs rate to Kiowa Peak Lake and the average water level would be at elevation 1760 ft with an approximate pool size 1/3 as large as the limited elevation of 1793 ft. The maximum length is projected to be 10 miles and a width of 3000 feet (USACE 122).

Dam site 14 is on Dove Lake (4) and is the smallest of the three impoundments. The location would be in the northwestern corner of Stonewall and the southwestern corner of King Counties. Dam site 14 is significant because its primary purpose is to control the largest salt input of the polluting tributaries. In addition, site 14 would control/collect the salt pollution associated with Salt Croton Creek flows which could then be pumped into the Kiowa peak impoundment. Site 14 is equipped for large water flows (adequate for the 100-year flood) but does not have the capability to accumulate storage due to a storage threshold at elevation 1700 ft. In order to keep water levels under this maximum elevation, water must be pumped at a rate of 18 cfs. (USACE 125)

Dam site 19 is on Kiowa Peak Lake (6) and it would be the largest impoundment in the recommended solution (plan 4B) and would accumulate much larger salt volumes than the other sites. Much of the water would be lost over time due to evaporation and the remaining brine would be stored at the site. The primary purpose of site 19 would be for salt regulation of North Croton Creek as well as control of Croton and Salt Croton Creek. “Flows from 265 square miles of North Croton Creek drainage along with pumpage from Croton Lake and Dove Lake would be impounded behind 148 feet high embankment that stretches 18,360 feet across the valley of North Croton Creek in northern Stonewall and southern King Counties" (USACE 125). The length of the lake would be 25 miles at a maximum elevation of 1583 and the width would range to about 3 miles. The total volume after 100 years is projected to be approximately 17,000 acre-feet. Dam site 19 is classified as a total impoundment site opposed to a low flow impoundment such as dam site 10 and 14.

Once the plan was determined, more in-depth analysis was done to show the projected salt improvement between the 1970s salinity data and the 2020 projections. The following Figures 9-11 show the effects that plan 4B would have on the salinity projections for Lake Whitney in 2020. These projections are based on the salinity data accumulated prior to 1977 and do not include the updated data that was presented earlier. The parameters of focus are TDS, sulfate, and chloride.

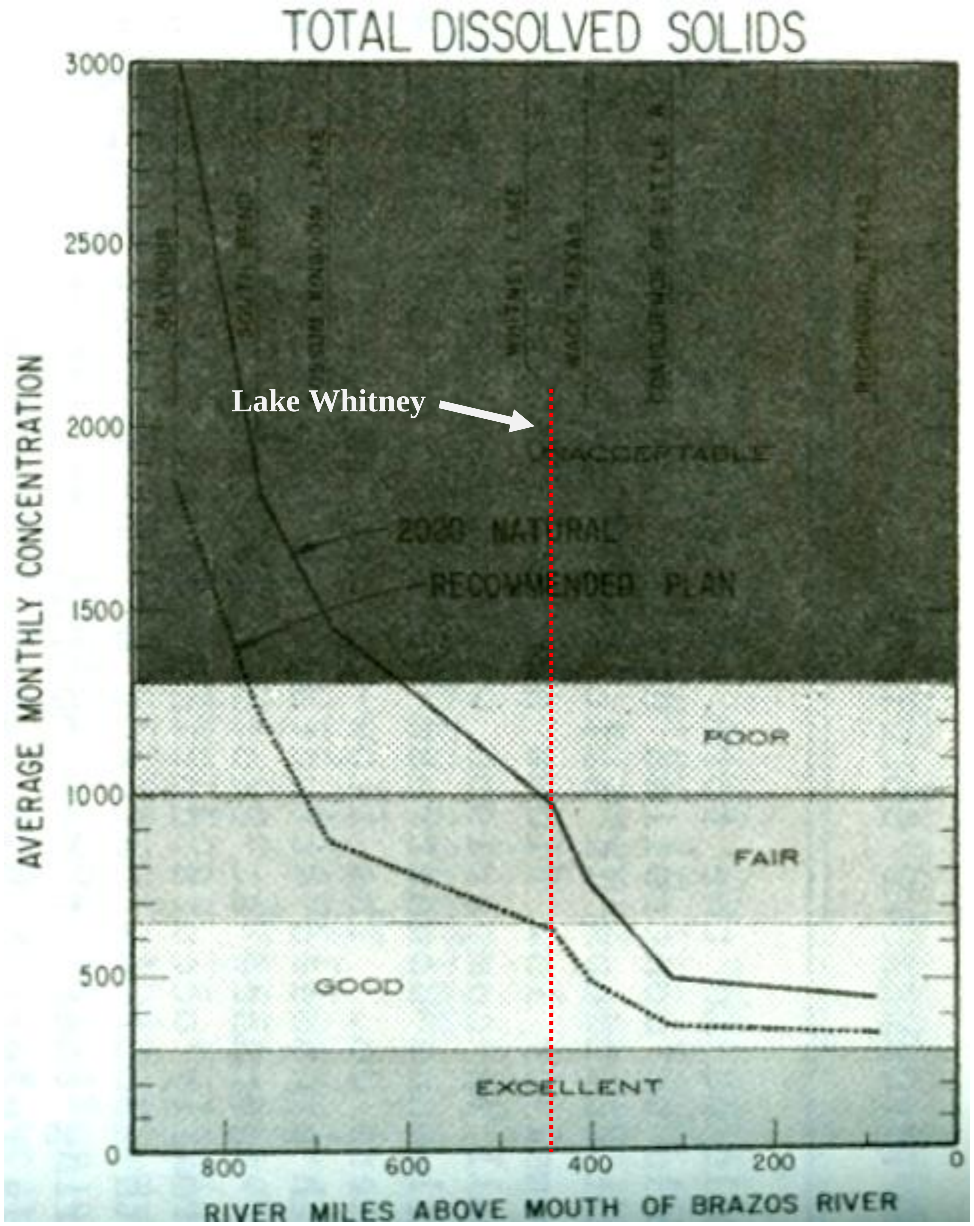

Figure 16. 2020 Natural and Plan 4B TDS projections

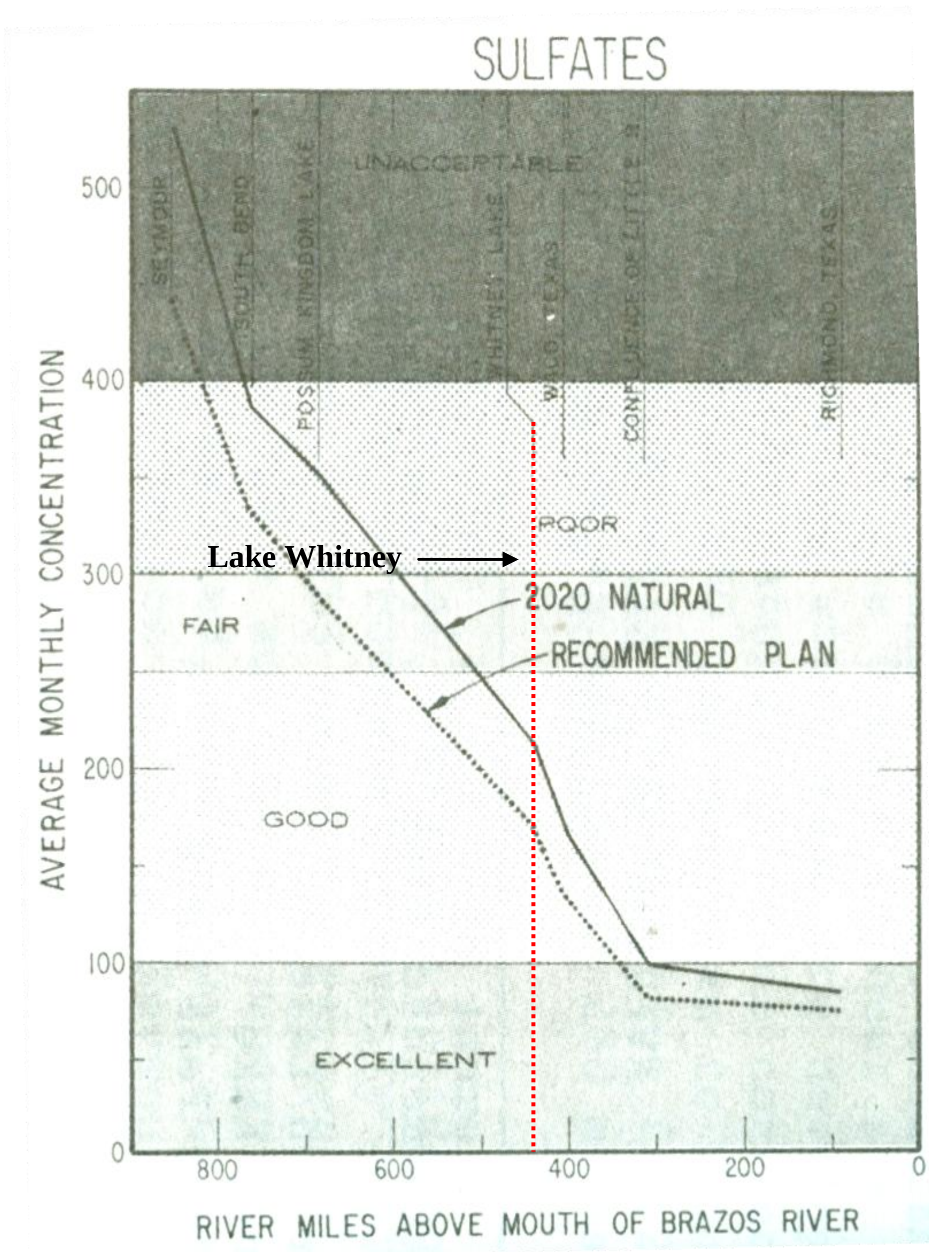

Figure 17. 2020 Natural and Plan 4B Sulfate projections

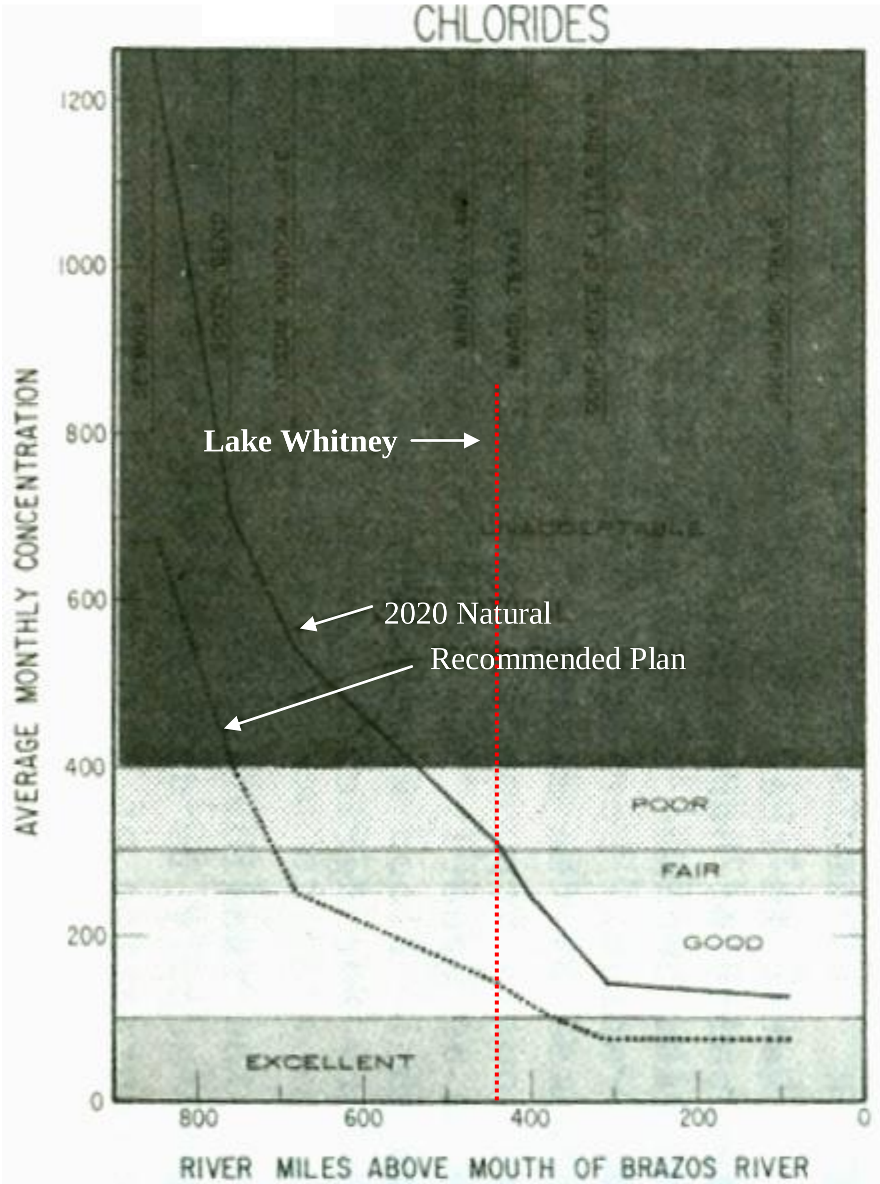

Figure 18. 2020 Natural and Plan 4B Chloride projections

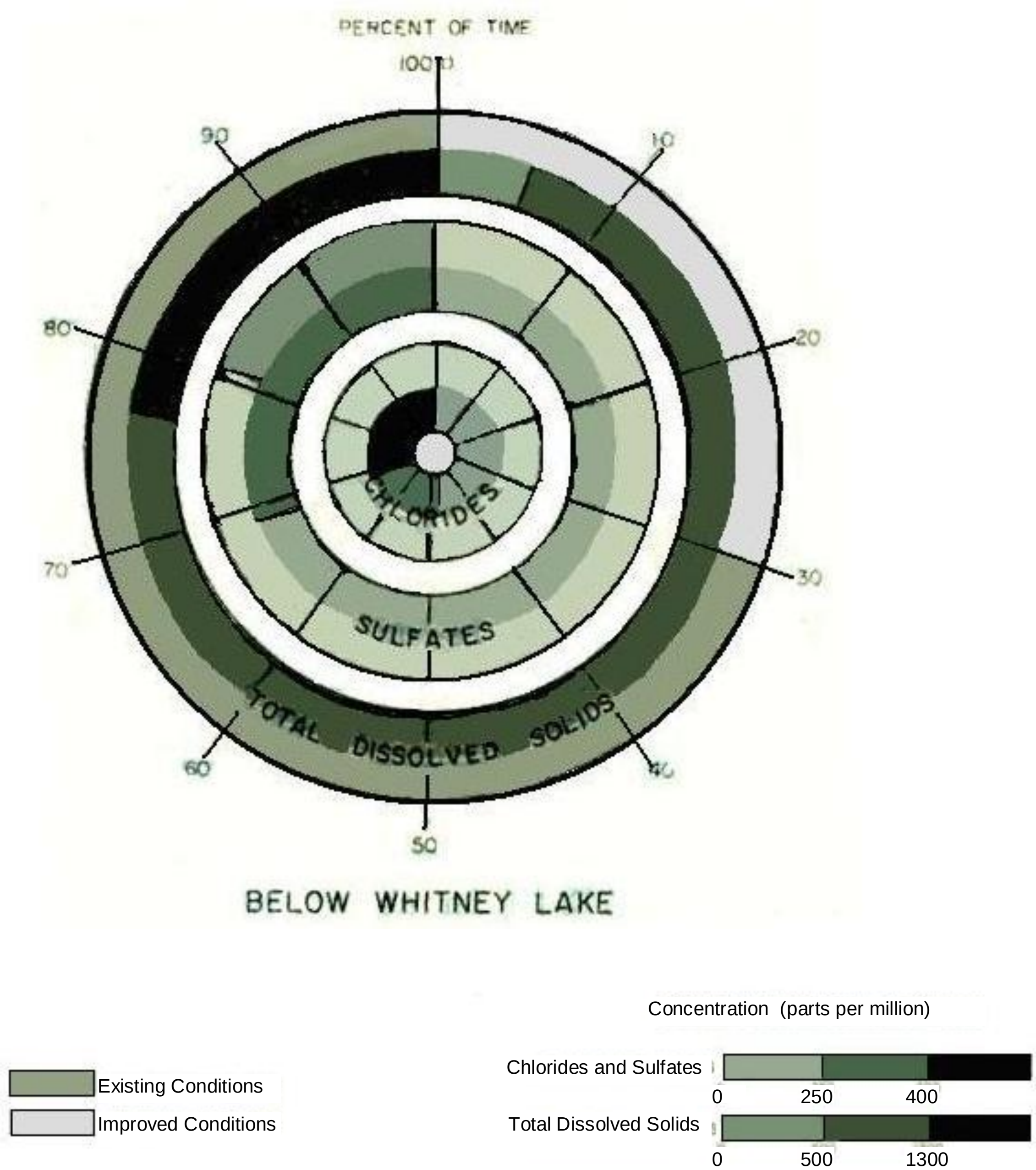

Figure 19. 2020 Quality Improvement Chart

The USACE reccomended plan 4B would decrease salinity levels throught the Brazos River Basin which includes our location of study. Figure 9 shows that Lake Whitney's TDS conentrations are slightly under 1 g/L for the 2020 projections, and the current data shows similar concentration levels. If plan 4B is implemented then the average monthy TDS concentrations would decrease by an estimated 30%. Similar improved results are also shown in both the chloride and sulfate projections. Figure 19 shows the quality improvement from the recomended solution based on percentage and time base. As shown, approximatley 76% of the time TDS would be below 1300 mg/L but under plan 4B the 2020 projections would be under 1300 mg/L TDS 100% of the time. Both sulfate and chloride concentations would also be less than the indicated upper bounds (which represent"poor" quality) for 2020 salinity projections. Pertaining to drinking water standards (for 2020 projections): without the reccomended plan chlorides would be ≤ 250 ppm 47% of the time, sulfates would be ≤ 250 ppm 67% of the time, and TDS would ≤ 500 ppm 6% of the time. Conversely with the reccomended plan chlorides, sulfates, and TDS would be within the reccomended drinking water standards 100%, 80%, and 30% of the time. Table 5 shows the maximum and median concetntrations for Lake Whitney in order to more accuatetly grasp the bounds and improvements that plan 4B exhibits. Comparing the change between both alternatives for median TDS, median sulfate, and median chloride yields approximatley a 33% , 21%, and 55% improvement for 2020 projections. Thereofore it is apparent that the proposed plan would drastically improve the salinity pollution compared to no regulation at all.

Table 5. Maximum and Median concentrations for Lake Whitney (2020 projections)

Concentration Characteristic	**Without** the Reccomended Plan	**With** Plan 4B
	(ppm)	(ppm)
Maximum Chloride	565	250
Median Chloride	275	125
Maximum Sulfate	365	290
Median Sulfate	190	150
Maximum TDS	1575	950
Median TDS	880	590

Texas Water Resources Institute

As mentioned above, the US Army Core of Engineers proposed multiple plans for decreasing the salinity levels of the Brazos River Basin. The plans consisted of building dams to stop the flow of saline water into lower parts of the Brazos River systems. Three tributaries in the upper basin were identified as highly saline sources: Croton Creek, Salt Croton Creek, and North Croton Creek. TWRI incorporated the data accumulated by the USACE and the 1980's data set presented above to give further projections on the salt water pollution of the Brazos River system. TWRI focused on two of the impoundment plans. Plan 1 proposed the construction of salt impoundments at Croton Lake, Dove Lake, and Kiowa Peak Lake which correspond to points 3, 4, and 6 on the map below (Figure 20. Map of the Upper Brazos River Basin
20). Plan 1 is the same as plan 4B mentioned above in the USACE report, and points 3,4, and 6 correspond to dam sites 10, 14, and 19 from the USACE report. Plan 2 proposed the construction of only Dove Lake and Kiowa Peak Lake. All saline lakes would be connected by a pipeline to transport any excess water to Kiowa Peak Lake to reduce overflow. In addition, it is important to note that the following analysis assumes that the salt impoundments proposed for both plans completely removes all salt loads and ceases discharge of the salts into Lake Whitney.

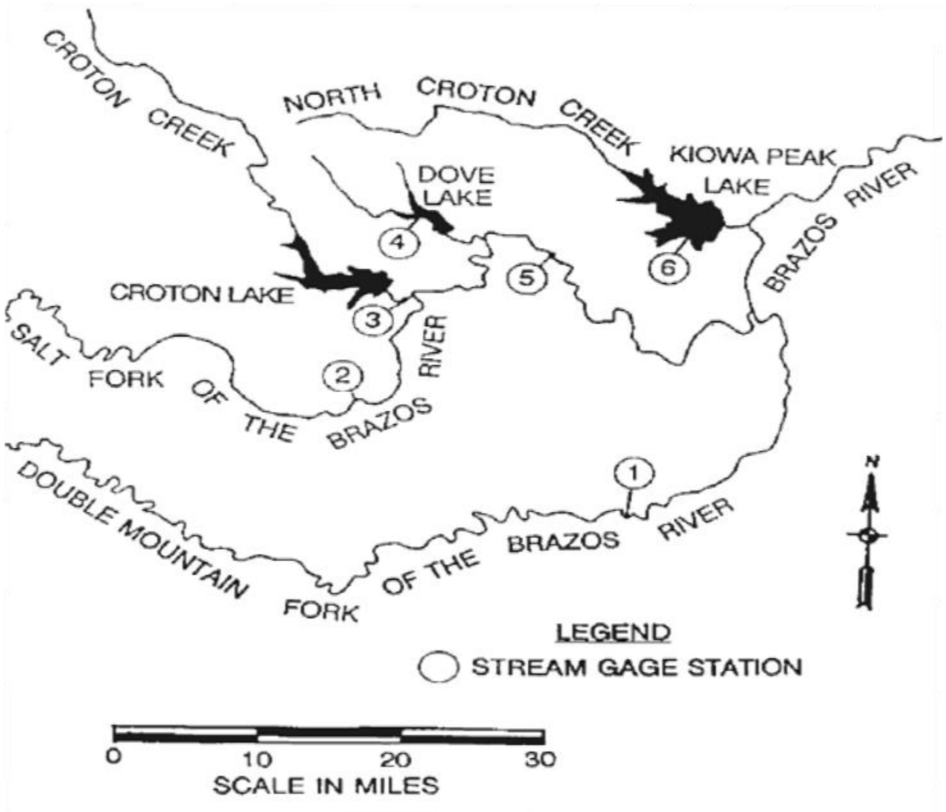

Figure 20. Map of the Upper Brazos River Basin

Mean salinity data was tabulated for the two periods of record 1964-1986 (Table 6) and 1969-1977 (Table 7). The significance of Table 6 and Table 7 is the mean discharge, loads, and concentrations for the two proposed plans designated as stations 3,4,6 (plan 1) and stations 4,6 (plan 2). Mean discharges and concentrations for the plans' proposed salt impoundments were also determined as a percentage of downstream salinity contributions. Table 8 shows that stations 3, 4, and 6 which are part of plan 1 respectively contribute 2.18%, 31%, 42.38%, and 20.25% of discharge, TDS, chloride, and sulfate for Lake Whitney. Table 9 shows that stations 4 and 6 proposed by plan 2 contribute 1.25%, 25.01%, 36.55%, and 10.99% of discharge, TDS, chloride, and sulfate for Lake Whitney.

Table 6. Mean Discharges, Loads, and Concentrations for 1964-1986 (TWRI 54)

Station	Discharge	Load (tons/day)			Concentration (mg/l)		
	(cfs)	TDS	Cl	SO_4	TDS	Cl	SO_4
2	40	684	339	81	5,782	2,830	698
3	13	225	93	53	6,536	2,690	1,558
4	5	676	425	53	54,560	34,356	2,634
5	62	1,660	1,094	219	9,999	6,589	1,321
6	17	211	80	58	4,719	1,801	1,301
7	269	2,601	1,074	504	3,591	1,482	696
13	686	2,795	1,111	571	1,512	601	309
15	1,230	3,075	1,134	591	928	342	178
21	4,529	5,348	1,365	938	438	112	77
25	6,868	6,267	1,466	1,030	339	79	56
3,4,6	34	1,112	599	144	12,145	6,539	1,573
4,6	21	887	506	91	15,534	8,865	1,590

Table 7. Mean Discharges, Loads, and Concentrations for 1969-1977 (TWRI 54)

Station	Discharge (cfs)	Load (tons/day) TDS	Load Cl	Load SO_4	Concentration (mg/l) TDS	Concentration Cl	Concentration SO_4
2	41	594	289	80	5,378	2,614	722
3	12	200	72	59	6,034	2,185	1,783
4	4	673	388	27	56,923	32,856	2,273
5	63	1,548	775	179	9,088	4,547	1,051
6	11	163	62	43	5,397	2,070	1,427
7	251	2,693	1,073	520	3,982	1,586	769
13	608	3,029	1,214	625	1,849	741	381
15	1,285	3,339	1,234	637	964	356	184
21	4,760	5,631	1,413	967	439	110	75
25	7,828	7,181	1,632	1,130	340	77	54
3,4,6	28	1,035	523	129	13,793	6,969	1,717
4,6	16	835	451	70	19,906	10,739	1,665

Table 8. 1969-77 Mean Discharges and Loads for Stations 3, 4, and 6 (Plan 1) as a Percentage of Downstream Stations (TWRI 55)

Downstream Station	Sta 3, 4 & 6 Discharge	Stations 3,4 & 6 Loads TDS	Cl	SO_4
7	11.16%	38.43%	48.74%	24.81%
13	4.61%	34.17%	43.08%	20.64%
15	2.18%	31.00%	42.38%	20.25%
21	0.59%	18.38%	37.01%	13.34%
25	0.36%	14.41%	32.05%	11.42%

Table 9. 1969-77 Mean Discharges and Loads for Stations 4 and 6 (Plan 2) as a Percentage of Downstream Stations (TWRI 55)

Downstream Station	Sta 4 & 6 Discharge	Stations 4 & 6 Loads TDS	Cl	SO_4
7	6.37%	31.01%	42.03%	13.46%
13	2.63%	27.57%	37.15%	11.20%
15	1.25%	25.01%	36.55%	10.99%
21	0.34%	14.83%	31.92%	7.24%
25	0.20%	11.63%	27.63%	6.19%

The Statistical Analysis of Time Series (STATS) was used to model and compute the changes in the salinity levels of the various gage locations if the salt impoundment dams were constructed. Figures 21-23 represent Lake Whitney's concentration-duration curves for mean TDS, chloride, and sulfate. Given a TDS, chloride, or sulfate concentration, the percentage of time that the specified concentration would be exceeded is given a line graph format. TDS, chloride, and sulfate concentration-duration curves were the lowest for plan 1, while both plan 1 and plan 2 were significantly less with no dams at all. Plan 1 (plan 4B) showed concentration-durations of 90% for TDS, chloride, and sulfate concentrations of approximately 500 mg/l, 140 mg/l, and 100 mg/l. More notably, the percentages of exceeding the current EPA standards of TDS, chloride, and sulfate of 500 mg/l, 250 mg/l, and 250 mg/l are approximately 85%, 20%, and 5%. These estimations can be made by following the y-axis' of Figures 21-23 to the regulated concentrations and then correlating them with the x-axis duration percentage. The results presented show that the performance of plan 1 for 1980's data is parallel to the USACE's 2020 projected results for plan 4B even though the USACE used less current data on Lake Whitney. Again, the data concluded that the salinity will be dramatically reduced, but levels of reductions to satisfy current drinking water standards at all time is of debate.

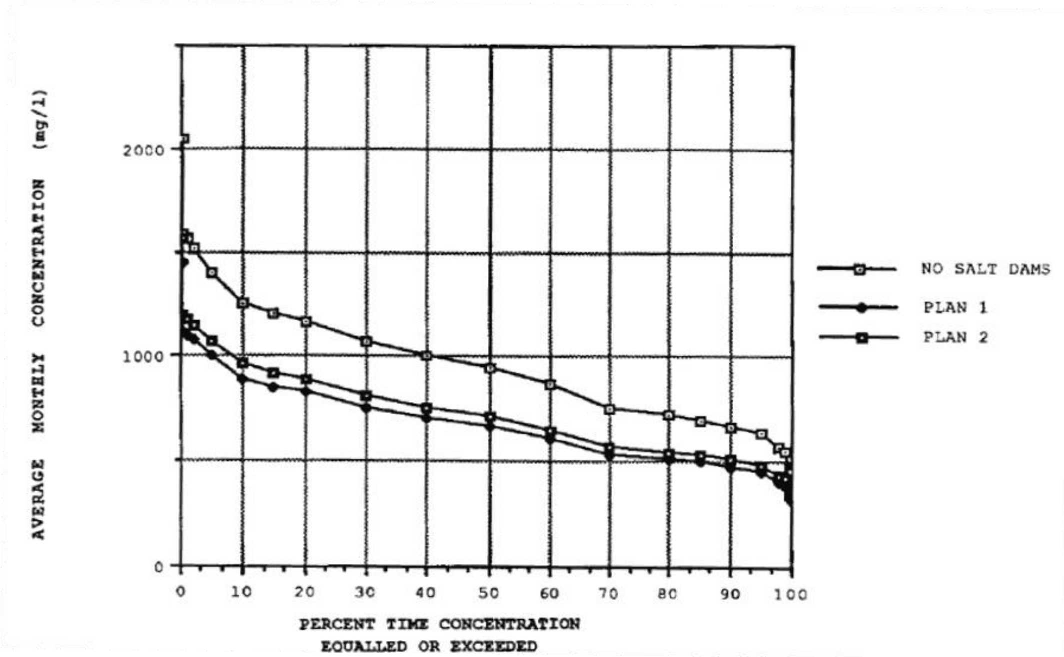

Figure 21. TDS Concentration-Duration Curves for Whitney Gage (Station 15)

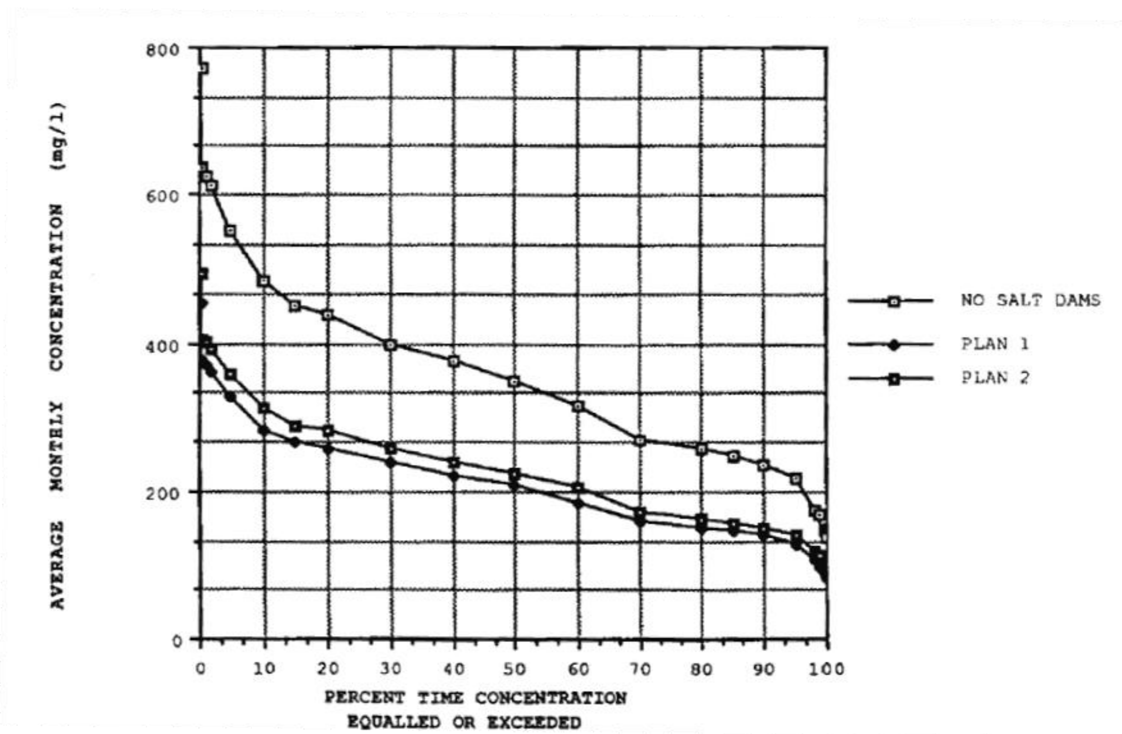

Figure 22. Chloride Concentration-Duration Curves for Whitney Gage (Station 15)

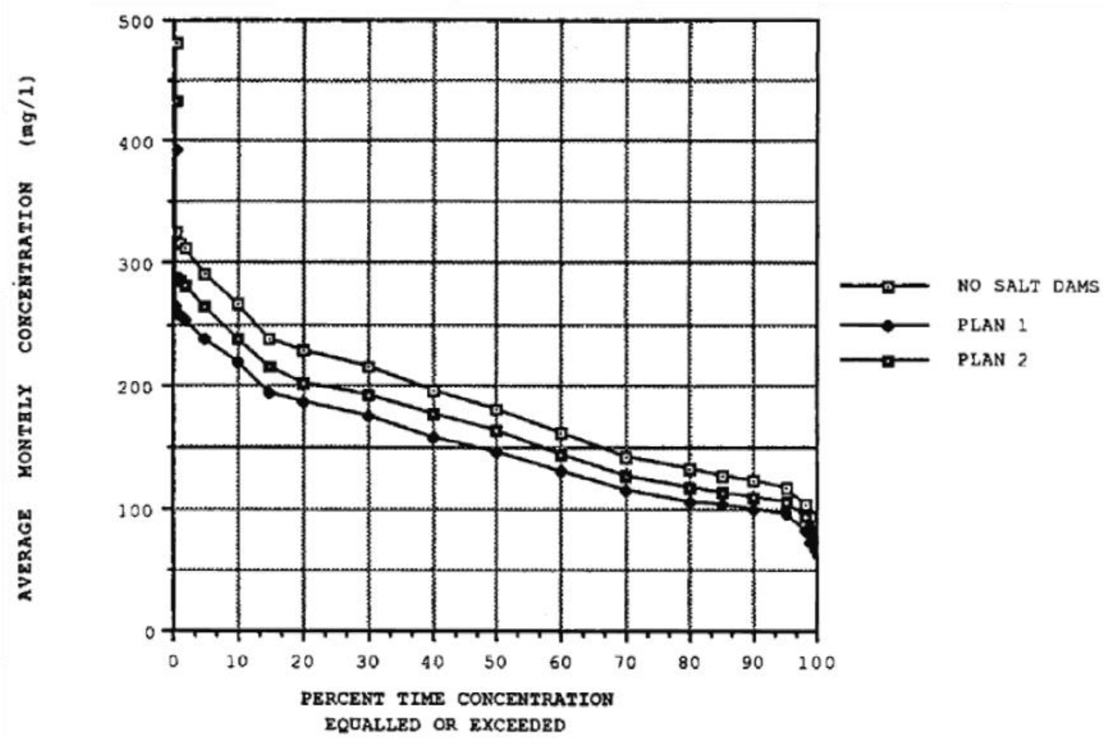

Figure 23. Sulfate Concentration-Duration Curves for Whitney Gage (Station 15)

WRAP-SALT Salinity Analysis

The Water Rights Analysis Package (WRAP) is a model used by the Texas Commission of Environmental Quality to gauge water statistics and availabilities for the river systems. While the generalized model focuses on availabilities, it lacks water quality measurements such as salinity. The thesis by Ganesh Krishnamurthy pinpoints the development of the WRAP-SALT model and its application of salinity considerations for the Brazos River Basin. The following is a synthesis of the WRAP-SALT model and its pertinence to Lake Whitney's salinity analysis.

The WRAP-SALT model addresses the issue of salt pollution in river basin systems. The model operation uses a "naturalized salt load input file and writes an additional output file with salinity related simulation results" (Krishna 41). The WRAP-SALT model incorporates different combinations of water allocation while taking into account reservoir system operating policies and other salinity control systems. Multiple balancing equations are used to accurately determine the output of the river system; an example is the equation for reservoir storage volumes which uses beginning storage volumes, diversion shortages and targets, evaporation, stream-flow depletions, and ending storage volumes to calculate approximated values. Each cycle of the analysis is performed over monthly hydrological cycles. The WRAP-SALT model process consists of three major components: 1) water volume inputs, 2) water quality and concentration data, and 3) program tabulations that summarize the output simulations. The third component of the WRAP-SALT simulation model includes a TABLES programs that outputs tables for regulated flows, reservoir storage, and frequency volumes which all include volumes, loads, and concentrations. In addition the output includes "reliability tables that reflect constraints on salt concentrations" (Krishna 41). The latter output is of the most importance when focusing on the salinity requirements of Lake Whitney since our main purpose is to explore the possibility of salt impoundments as a possible approach to decreasing salt loads and concentrations.

Table 10 shows the WRAP-SALT frequency analyses for Lake Whitney with the impoundment dams. TDS, chloride, and sulfate concentrations were computed for corresponding frequencies of time equaled or exceeded. Maximum, mean, and standard deviations were also computed for each water quality parameter. Finally, the percentage-time concentrations were graphed in comparison to the original data without the included dams in Figures 17-19. The simulated results presented by the WRAP-SALT model are based on a combination of salt data from Wurbs and Ganze (shown in the above reports in "Data on Brazos River Basin" and in the TWRI section) as well as the Brazos WAM datasets that extend from January 1940 to December 1997. Therefore the WRAP-SALT model uses the most updated and homogeneous data set while being one of the most recent 21st century models.

Table 10. Frequency Analyses for Lake Whitney with proposed Salt Impoundments

Percent Time Equalled or Exceeded	TDS (mg/l)	Cl (mg/l)	SO4 (mg/l)
10%	1449.0	532.0	395.0
25%	1139.0	456.0	319.0
40%	1023.0	440.0	301.0
50%	978.0	430.0	293.0
60%	947.0	423.0	284.0
75%	893.0	414.0	272.0
90%	819.0	399.0	256.0
95%	780.0	389.0	239.0
98%	746.0	379.0	249.0
99%	712.0	370.0	231.0
100%	602.0	351.0	201.0
Mean	1054.0	455.0	304.0
Standard Deviation	256.0	84.0	50.0
Maximum	1927.0	793.0	468.0

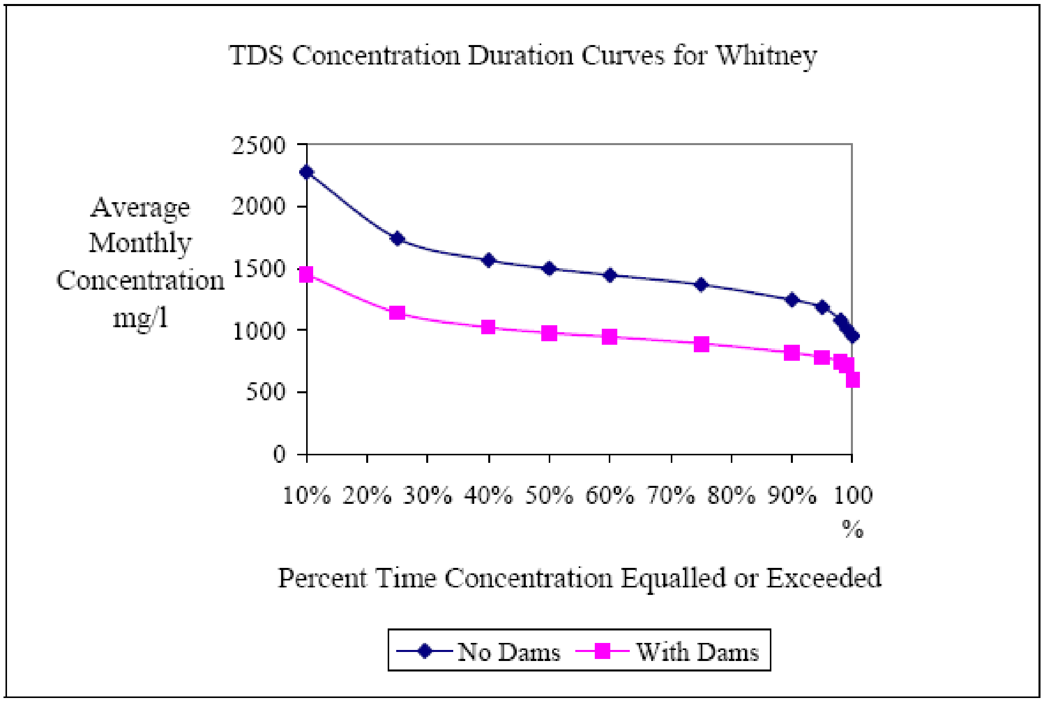

Figure 24. Lake Whitney TDS Frequency Analysis Graphs with and without Salt Impoundments

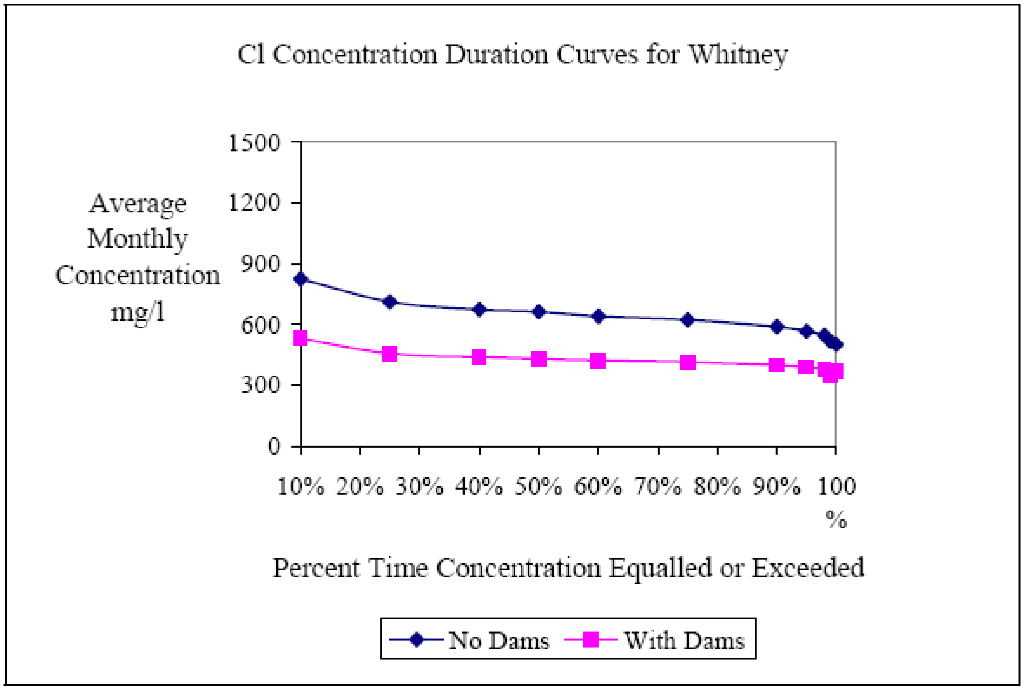

Figure 25. Lake Whitney Chloride Frequency Analysis Graphs with and without Salt Impoundments

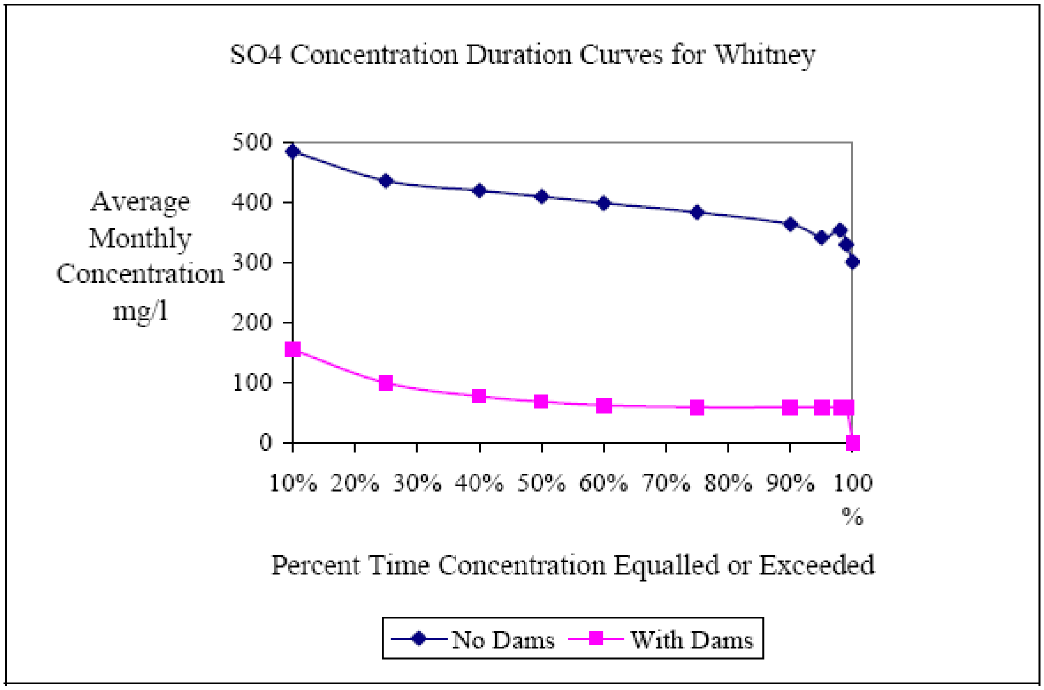

Figure 26. Lake Whitney Sulfate Frequency Analysis Graphs with and without Salt Impoundments

Table 11. Lake Whitney Reliabilities with Salt Impoundments and Salinity Constraints

Constituent	Concentration mg/l	Reliability (%)	
		Volume	Period
TDS	500	0.00	0.00
	1000	58.26	57.04
	1500	91.14	90.06
	max	98.85	99.20
Cl	250	0.00	0.00
	500	98.85	99.20
	750	98.85	99.20
	max	98.85	99.20
SO4	250	6.69	5.89
	500	98.85	99.20
	750	98.85	99.20
	max	98.85	99.20

As is shown in Table 10, for a 25% frequency at Whitney Gage the TDS, chloride, and sulfate concentrations were 1139 mg/l, 456 mg/l, and 319 mg/l; therefore, with the salt impoundment dams those salinity constraints would be exceeded 25% of the time. The lower bound at which 100% frequency would be exceeded is when TDS, chloride, and sulfate concentrations are at 602 mg/l, 351 mg/l, and 50 mg/l.

It is also important to notice the shift in average monthly concentrations between no salt impoundments and with salt impoundments in the following graphs; the TDS, chloride, and sulfate concentrations are much lower across the entire spectrum of percentages of time exceeded. For a 10% exceeded frequency, the average month TDS concentration shifts from greater than the 2000 mg/l threshold for no impoundments to slightly below 1500 mg/l with impoundments. Consequently, for the same 10% frequency average monthly chloride concentration thresholds decrease approximately 30% while sulfate concentrations decrease approximately 60%. These concentration duration results show that the impoundment dams will allow better salinity management while lower TDS, chloride, and sulfate restrictions can be imposed to still maintain the same frequency exceedance characteristics that are shown without the impoundments. The only problem is that the mean concentration values sill remained quite higher than the recommended EPA restrictions for drinking water.

Reliabilities with the impoundments were also calculated with the recent salinity data. The period and volume reliabilities were calculated with the same equations as given in the RESSALT analysis section. Period and volume reliabilities for WRAP-SALT are 0% for both TDS and chloride while sulfate is 5.89% and 6.69% for current EPA salinity regulations of: 500 mg/l TDS, 250 mg/l chloride, and 250 mg/l sulfate. This indicates that with the current updated 1990's salinity data the impoundment structures would not have made a big enough improvement with the current EPA standards. Therefore, if period and volume reliabilities are to remain within a good limit (ie. above 90%) then the standards for TDS, chloride, and sulfate would have to be elevated to 1500 mg/l, 500 mg/l, and 500 mg/l accordingly.

Conclusions

There are three major components of this report that incorporate the hypothetical construction the three salt impoundments on the upper tributaries of the Brazos River: 1) the USACE's account of Whitney salinity data up to the 1970's to determine 2020 salinity predictions, 2) the Texas Water Resources Institute's account of 1980's salinity data to determine current concentration duration relationships, 3) and the WRAP-SALT simulation model that uses 1990's salinity data to determine current concentration durations and reliabilities. Even though not all data sets are homogeneous, these three components still give a good indication of the capabilities and detriments that salt impoundments could have on the Lake Whitney's natural salt pollution. Ultimately, the viability of undertaking such a project can be assessed for the current year based on updated inputs such economics and policy.

The synthesized data for Lake Whitney's impacts of the salt impoundments can be summarized in the following, based on current salinity regulations by the EPA (500 mg/l TDS and 250 mg/l for chloride and sulfate) for sustainable drinking water sources. Concentration duration analysis of TWRI salinity data up to the 1980's yielded ~85%, ~20%, and ~5% probabilities of being exceeded for TDS, chloride, and sulfate. WRAP-SALT concentration duration projections based on salinity data up to the late 1990's yielded 100%, 100%, and 98% probabilities of being exceeded for TDS, chloride, and sulfate. Conversely, year 2020 projections for concentration durations based on salinity data accumulated by the USACE up to the 1970's was noted as70%, 30%, and 20% probabilities of being exceeded for TDS, chloride, and sulfate. These slight discrepancies in concentration duration analysis are expected due to the volatility associated with predicting salinity characteristics over a long period of time opposed to have direct measured data.

After collecting and analyzing the data presented above, TWRI in conjunction with the USACE concluded that salt impoundments were not economically viable and, therefore, that no salt dams be built. Their findings were as follows. First, the question of water rights and contracts must be resolved before the city of Whitney could use the lake's water supply legally. Second, the effects of salt impoundment damming upstream would be felt only minimally at Lake Whitney due to dilution by flows from low salinity tributaries and reservoirs downstream from the main salinity pollution. Third, using water from other rivers in the Brazos River Basin and other basins would be more cost-effective than using water from the Brazos River itself. Fourth, if salt impoundment dams were implemented, there would be a modest increase in irrigation for agriculture upstream in the basin. Fifth, the salt dams could serve a dual purpose of preventing minor flooding. Sixth, salt impoundment dams could create some added recreational activities to the region. Seventh, although the salt dams would cause land losses as water levels rise, these areas lost to the water could become a migration area for wildlife. Eighth, if the dams were implemented, the benefit-cost ratio would be less than 1.0 using 1983 prices and interest rates. A more updated evaluation would be beneficial due to fluctuations in cost benefit analysis based on the economic time.

The given results within this case study show a considerable decrease in salinity by implementing the proposed salt impoundments, especially in comparison to the current salinity state of Lake Whitney without the effects of any impoundments. The final impoundment results would not completely put Lake Whitney within a salinity range of current EPA standards, but the sustainable results and residual effects it would have on the entire Brazos River Basin would be immense. It should also be noted that these results are based on modeling efforts with prediction tools, in which the exact precision of the concentration levels cannot be confused with factual data. These modeling results give us a guideline on the possible ranges of the salinity concentration, but natural variations in the lake as well as local developments would significantly change the environment. The combination of the desirable findings indicated in the previous paragraph, the preferable reliability simulations based on flow rate, the projected large decrease in salinity loads within Whitney and many other reservoirs within the Brazos River Basin, the favorable concentration duration probabilities (specifically chloride and sulfate concentrations), and the possibility of better forecasted cost benefit analysis based on future federal support all make this method of salinity reduction of Lake Whitney a feasible solution.

Summary

This report investigated two possible types of solutions to the problem of high salt concentration in Lake Whitney: those of a technical application and physical means of regional reconstruction. Although both options have the potential of providing clean drinking water to the city of Whitney, there are many factors (cost-benefit analysis, environmental impact, etc.) that must be taken into consideration before implementing either solution. In terms of technical applications, the methods of electrodialysis and reverse osmosis were compared to determine which would be more suitable for our purposes. Both options require a large amount of energy to produce purified water, but should be able to produce high quality water on the larger scale that would be necessary for this project. Before such a system could be constructed, more information must be gathered such as the availability of a power source that would be able to provide enough power to run the system, as well as possible options for the disposal of the harmful waste this system creates. The regional solution of salt water impoundments would help to decrease the concentration of salt in Lake Whitney, and would provide clean, easily accessible water for a larger number of communities along the Brazos River. Aside from the great cost, other logistical information must be investigated such as a more detailed analysis of the quality of water in each of the tributaries to ensure that the impoundments would in fact have the effect of decreasing the salinity of the main body of water, and the potential environmental impact of building dams on multiple tributaries along the Brazos River. Our research has shown that both of these systems could be options for the Lake Whitney area, but more data is needed in order to make an informed decision on which solution would be most suitable.

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